Volume 1

Green Cities, Clean Waters (CSO LTCP Update) Advisory Committee
Invitation Packet

September 26, 2007

Re: Invitation to Join PWD's Green Cities – Clean Waters Advisory Committee

Dear Potential Committee Member:

The Philadelphia Water Department (PWD) is beginning a two year process to update its Combined Sewer Overflow Long Term Control Plan (CSOLTCP). To assist us with the development of strategies, public information and outreach materials regarding this plan, we are convening a public advisory committee to guide and provide input about the program and the communication strategies that will be developed to ensure successful public participation. We are hoping that you are interested in joining this committee, as the perspective that you will provide, as a representative of your organization and/or neighborhood, will be invaluable.

You are invited to participate in the first advisory committee meeting, scheduled for Tuesday, November 13, 10 a.m. to 12 p.m., at the Fairmount Water Works Interpretive Center. This meeting will focus on providing advisory committee members with a background on PWD's approach to meeting the requirements (and our own goals for our region's rivers and streams) of the National CSO Policy, a general assessment of the City's combined sewer system, and a timeline for future meetings and meeting topics. We expect that the advisory committee will meet twice a year over a two year period (although advisory committee members would certainly be welcome at all CSO Long Term Control Plan Update (LTCPU) public meetings).

I have enclosed two backgrounders – one on the LTCP and one on the LTCPU - to give you a sense of the program and the elements we will be striving to share with the public. I have also enclosed the directions to the Fairmount Water Works Interpretive Center.

Please give me a call at 215-685-4944 or e-mail me at joanne.dahme@phila.gov with questions and to confirm your attendance at the first advisory committee meeting. We look forward to working with you to make this an exciting public process.

Sincerely yours,

JOANNE DAHME
Watersheds Programs Manager

(Turn Over)

THE FAIRMOUNT WATER WORKS INTERPRETIVE CENTER

We're looking forward to your visit To the Fairmount Water Works Interpretive Center!

640 Waterworks Drive   Philadelphia Pennsylvania 19130
Fairmount Water Works Delaware Watershed Address: 02040202

Information & Reservations: 215-685-0723
Contributions: Ed Grusheski, 215-685-6110

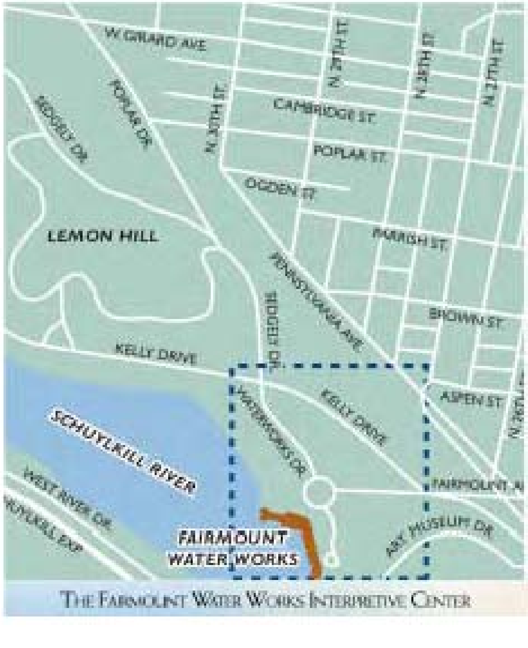
Facilities: The FWWIC is an ideal site for workshops, lectures, seminars, conferences and some private events. The entire site is Americans with Disabilities Act accessible.

Directions from the West (From I-76)

1. Take the SPRING GARDEN STREET/HAVERFORD EXIT   0.2 Miles
2. Turn Left on SPRING GARDEN STREET   0.3 Miles
3. Continue on W RIVER DRIVE   0.0 Miles
4. Continue on BENJAMIN FRANKLIN PARKWAY   0.1 Miles
5. Bear Left on EAKINS OVAL   0.1 Miles
6. Bear Left on BENJAMIN FRANKLIN PARKWAY   0.2 Miles
7. Bear Right towards KELLY DRIVE   0.1 Miles
8. Turn Left at light on WATERWORKS DRIVE   0.3 Miles

From The East (From I-95)

1. I-95 South to Philadelphia VINE STREET EXPRESSWAY
2. Exit on to NORTH BROAD STREET   0.5 Miles
3. Turn Right onto VINE STREET   3.6 Miles
4. Bear Left on BENJAMIN FRANKLIN PARKWAY   0.2 Miles
5. Bear Left on EAKINS OVAL   0.1 Miles
6. Bear Left on BENJAMIN FRANKLIN PARKWAY   0.2 Miles
7. Bear Right towards KELLY DRIVE   0.1 Miles
8. Turn Left at light on WATERWORKS DRIVE   0.3 Miles



THE CSO LONG TERM CONTROL PLAN

GREEN CITIES
CLEAN WATERS

History and Background

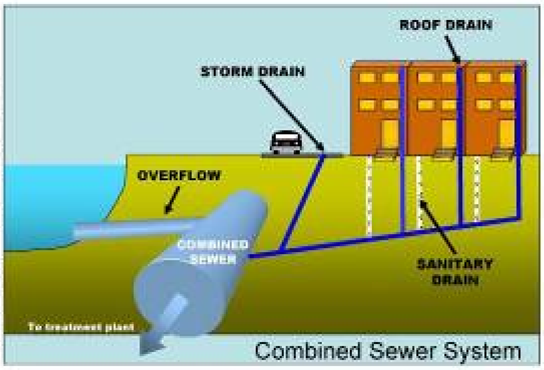
The City of Philadelphia

INTRODUCTION

Philadelphia is fortunate to have an abundance of creeks, open space, parkland and beautiful rivers. The Schuylkill and Delaware Rivers are not only scenic; they are the drinking water source for Philadelphia residents. These waterways, however, suffer from pollution from various sources, both within and outside the City limits. One such pollution source: Combined Sewer Overflows (CSOs)*.

What are Combined Sewers Overflows?

A combined sewer system is a wastewater collection system owned by a municipality which transports wastewater* from homes, businesses and industry, stormwater* from the approximately 75,000 storm drains on our streets and property roof leaders through a single-pipe system to a Water Pollution Control Plant (WPCP).



Combined Sewer System

During dry weather conditions (when it is not raining) and during very small storm events, combined sewers* can adequately transport this mixture of sanitary wastewater and stormwater to one of the City's three WPCPs for treatment.

Under heavier rainfall conditions, however, the flow in combined sewers may exceed the capacity of the pipe or treatment facility. As a result, a portion of the wastewater and stormwater may be diverted directly to a nearby stream or river so as to prevent the flooding of homes and streets. This is what is known as a Combined Sewer Overflow (CSO). During heavy rainfalls or sudden snowmelts, Philadelphia may experience these overflows in various locations throughout the City from any of its 164 permitted combined sewer outfalls. These overflows may exceed water quality standards (WQS)*, threaten aquatic life and habitat, and impair the use and enjoyment of the water body.

The definitions of words with an asterisk* can be found in the glossary at the end of this publication.

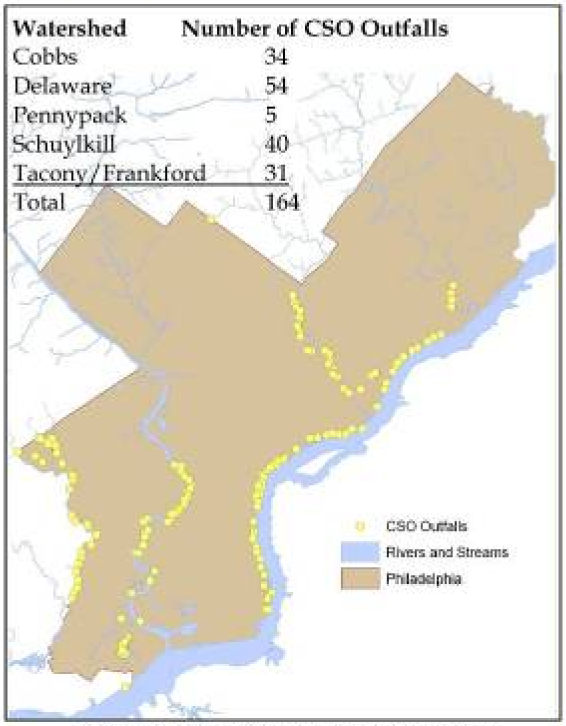
For more information, please visit us at www.phillyriverinfo.org

GREEN CITIES
CLEAN WATERS

THE CSO LONG TERM CONTROL PLAN

History and Background

Fact Sheet #1



Watershed	Number of CSO Outfalls
Cobbs	34
Delaware	54
Pennypack	5
Schuylkill	40
Tacony/Frankford	31
Total	164

CSO outfalls in the City of Philadelphia

What is the Combined Sewer Overflow Program?

The fundamental goal of the Philadelphia Water Department's (PWD) combined sewer overflow program is to improve and preserve the water environment in the Philadelphia area and to fulfill the PWD's obligations under the Clean Water Act and the Pennsylvania Clean Streams Law by implementing technically viable, cost-effective improvements and operational changes.

The PWD's strategy to attain these goals has three primary phases: aggressive implementation of a comprehensive program for Nine Minimum Controls (NMCs); planning, design and construction of numerous capital projects that would further enhance system performance and reduce CSO volume and frequency; and a commitment of significant dollars for services and resources toward comprehensive watershed based planning and analyses that would identify additional priority actions to further improve water quality in Philadelphia area water bodies.

These three phases successively provide comprehensive programs that follow the direction of the EPA CSO Policy and its guidance documents and are consistent with the requirements of the Clean Water Act. The NMCs and the capital improvement program have resulted in implementation of the highest level of cost-effective, technology-based improvements. They have provided a substantial reduction in CSO volume and frequency and a significantly greater percentage of combined sewer flow transported and treated at the PWD's three wastewater treatment plants.

Combined Sewer Overflow at Crescentville in Philadelphia

Nine Minimum Controls (NMCs) System "Tune-Up"

In the first phase of the PWD's CSO strategy, and in compliance with its National Pollutant Discharge Elimination System (NPDES)* permits, the PWD submitted to the Pennsylvania Department of Environmental Protection (PADEP) on September 27, 1995, CSO Documentation: Implementation of Nine Minimum Controls (NMCs).

The NMCs are low-cost actions or measures that can reduce CSO discharges and their effect on receiving waters*, do not require significant engineering studies or major construction, and can be implemented in a relatively short time frame. This program ensures that our existing sewer system is operating to the best of its ability, providing a "tune-up" to the existing infrastructure.

To provide information needed for the development of the NMCs program, the PWD instituted a $6.5 million project to upgrade its comprehensive system flow monitoring network. This program provides information necessary to identify and eliminate dry weather overflows, monitor system performance and operation, and configure and calibrate computer hydraulic models needed to develop the NMCs and long-term CSO control plans.

Extensive data from the PWD's Geographic Information System (GIS), flow monitoring system, the U.S. Army Corps of Engineer's Storage, Treatment, Overflow, Runoff Model (STORM), and the EXTRAN and RUNOFF blocks of the U.S. EPA Stormwater Management Model (SWMM) were used to support each phase of the CSO program. These tools were developed to support concept engineering through implementation and post-construction monitoring. The monitoring system, models, and GIS have and will serve as the basis for planning improvements and enhancing operation of the sewerage system over the long-term.

For more details on the NMCs, please visit the U.S.EPA on-line at: http://cfpub.epa.gov/npdes/home.cfm?program_id=5.

Capital Projects
Design and Build New Combined Sewer System Components

The second phase of the PWD's CSO strategy had been focused on technology-based capital improvements to the City's sewerage system that have and will further increase its ability to store and treat combined sewer flow, reduce inflow to the system, eliminate flooding due to system surcharging, decrease CSO volumes and improve receiving water quality. The recommended capital improvement program is the result of a detailed analysis of a broad range of technology-based control alternatives. The capital improvement plan encompasses the three major areas of the City that are affected by CSOs: the Northeast, Southeast and Southwest drainage districts. Capital projects were selected by the PWD to provide significant CSO load reduction.

The total estimated cost of the selected capital improvement projects is in excess of $48 million. However, to date, current expenditures and estimates of future estimates bring this number to over $100 million. Hydraulic and hydrologic model simulations indicate that annual CSO volumes will be reduced by over two billion gallons system-wide in a typical hydrologic (average rainfall) year, upon completion of all these projects.

These significant, technology-based projects may not, in and of themselves, bring receiving waters into compliance with all water quality standards. Additional management plans, actions and projects needed to attain water quality standards will be defined through the process of watershed planning, as discussed below. However, these projects will not only reduce overall loadings, but will hopefully encourage other point* and non-point source* dischargers to implement similar technologies, over and above what their current permit mandates, while the development of a comprehensive watershed management plan proceeds.

For more details on the capital projects, please view the 2006 CSO Annual Report on-line at: http://www.phillyriverinfo.org.

Watershed Management & Watershed Partnerships - Integrated, Regional Watershed Planning & Implementation

The third component of the City's CSO strategy involves a substantial commitment by the City to conduct watershed planning to identify long term improvements throughout the watershed, including possibly additional CSO controls that will result in further improvements in water quality, and ultimately, the attainment of water quality standards. The need for this watershed initiative is rooted in the fact that insufficient physical, chemical and biological information currently exists on the nature and causes of water quality impairments, sources of pollution, and appropriate remedial measures. In addition, Philadelphia is downstream, meaning that the headwaters, some tributaries, and upper segments of our rivers and streams reside in municipalities north of Philadelphia. We do not always know the source, nor can we control stormwater runoff* or other pollutants* flowing into our streams above the city's boundaries. This creates a unique challenge in our goal to attain water quality standards, especially with respect to the effects of wet weather discharges and receiving water dynamics.

These watershed realities have led to a broader, national recognition of the need for regional, watershed-based planning and management to properly define water quality standards and goals. Therefore, the PWD has adopted a holistic approach – a watershed management approach to control pollution to rivers and streams. This approach evaluates the impacts of both point and non-point pollution sources and aims to find regional, watershed solutions to restore water quality. Because watersheds are defined by natural features and do not adhere to political boundaries, the PWD believes that watershed management is the most practical and effective way to manage pollution and improve water quality. Through PWD's watershed management plans, water quality impairments are identified and addressed via comprehensive watershed based planning, stream water quality analysis, baseline water quality monitoring and the assessment of watershed-wide pollutants. Consequently, the major sources of the impairments are explored, modeled, and defined to understand how to attain regulatory water quality standards and establish programs that will continue to monitor and ensure permanent improvements in water quality.

> A watershed refers to the land that drains stormwater (rain or melting snow) to a specific body of water, such as a river or stream.

The PWD forms partnerships with its suburban neighbors, businesses and industries, community and non-profit groups and all other watershed stakeholders to evaluate our regional watersheds and to develop an effective watershed management plan. To be successful, watershed management plans must be adopted and implemented by all participating stakeholders and their constituents.

To date, the PWD has initiated the formation of watershed partnerships in all of the City's watersheds. The combined sewer watersheds include the Darby-Cobbs Watershed Partnership, Tookany/Tacony – Frankford Watershed Partnership and Pennypack Watershed Partnership, while the separate sewer watersheds include the Poquessing Watershed Partnership and the Wissahickon Watershed Partnership. The Schuylkill Watershed is represented by the Schuylkill Action Network (SAN), a partnership of the City of Philadelphia, federal and state agencies, and local watershed groups protecting the drinking water supply in the Schuylkill River watershed. This fall, the remaining watershed partnership will be formed - the Delaware Direct Watershed Partnership.

Tacony Creek

*Glossary**

Combined Sewer Overflow (CSO)

A mixture of wastewater and runoff found in combined sewers during rainfall or snowmelt events that spills to the environment untreated. CSOs enter the environment either directly or through a storm sewer, as the result of the capacities of the interceptor sewers and/or treatment plants being exceeded.

Combined Sewer System (CSS)

A wastewater collection and treatment system where domestic and industrial wastewater is combined with storm runoff. Although such a system does provide treatment of stormwater, in practice, the systems may not be able to handle major storm flows.

Indirect Discharge

The introduction of pollutants into a municipal sewage treatment system fro any non-domestic source (i.e., any industrial or commercial facility) regulated under Section 307(b), (c), or (d) of the CWA.

Industrial Sources

Non-municipal, or industrial sources, often generate wastewater that is discharged to surface waters. The types of wastewaters generated at a facility depend on the specific activities undertaken at a particular site, and may include manufacturing or process wastewaters, cooling waters, sanitary wastewater, and stormwater runoff.

National Pollutant Discharge Elimination System (NPDES)

A provision of the Clean Water Act which prohibits discharge of pollutants into waters of the United States unless a special permit is issued by EPA, a state, or, where delegated, a tribal government on an Indian reservation.

Glossary continued

Non-Point Source

Diffuse pollution sources (ie, without a single point of origin or not introduced into a receiving stream from a specific outlet). The pollutants are generally carried off the land by storm water. Common nonpoint sources are agriculture, forestry, urban, mining, construction, dams, channels, land disposal, saltwater intrusion, and city streets.

Point Source

Any discernible, confined, and discrete conveyance, including but not limited to, any pipe, ditch, channel, tunnel, conduit, well, discrete fissure, container, rolling stock concentrated animal feeding operation (CAFO), landfill leachate collection system, vessel or other floating craft from which pollutants are or may be discharged. This term does not include return flows from irrigated agriculture or agricultural stormwater runoff.

Pollutant

Dredged spoil, solid waste, incinerator residue, filter backwash, sewage, garbage, sewage sludge, munitions, chemical wastes, biological materials, radioactive materials (except those regulated under the Atomic Energy Act of 1954, as amended (42 U.S.C. 2011 et seq.)), heat, wrecked or discarded equipment, rock, sand, cellar dirt, and industrial, municipal, and agricultural waste discharged into water [40 CFR 122.2].

Receiving Waters

All distinct bodies of water that receive runoff or wastewater discharges, such as streams, rivers, ponds, lakes, and estuaries. The "Water of the United States" as defined in 40 CFR 122.2 into which the regulated stormwater discharges.

Runoff

Water from precipitation or irrigation that flows over the ground and into bodies of water. It can contribute to soil erosion and carry harmful pollutants.

Sanitary Sewer

A pipe or conduit (sewer) intended to carry wastewater or water-borne wastes from homes, businesses, and industries to the POTW.

Sanitary Sewer Overflow (SSO)

Untreated or partially treated sewage overflows from a sanitary sewer collection system.

Stormwater

Water that accumulates on land as a result of storms, and can include runoff from urban areas such as roads and roofs.

Stormwater Discharge-Related Activities

Activities that cause, contribute to, or result in stormwater point source pollutant discharges, including excavation, site development, grading, and other surface disturbance activities; and measures to control stormwater, including the siting, construction, and operation of BMPs to control, reduce, or prevent stormwater pollution.

Wastewater

The spent or used water from a home, community, farm, or industry that contains dissolved or suspended matter. Water Pollution: The presence in water of enough harmful or objectionable material to damage the water's quality.

Water Quality Standards

State-adopted and EPA-approved ambient standards for water bodies. The standards prescribe the use of the water body and establish the water quality criteria that must be met to protect designated uses.

THE CSO LONG TERM CONTROL PLAN *UPDATE*

Clean Water Benefits and the Balanced Approach

GREEN CITIES
CLEAN WATERS

The City of Philadelphia

INTRODUCTION

The Philadelphia Water Department (PWD) wants to transform Philadelphia's urban landscape into a vibrant, green community where people want to live and work. By merging the vision of a "green city" with "clean water" we can benefit not only our watershed environment, but the region's economic health, quality of life and sustainability.

The PWD is well suited to the development and implementation of a watershed approach to Combined Sewer Overflow (CSO) control. The PWD owns and operates the City's sanitary sewers, storm sewers, combined sewers and wastewater treatment plants. In cooperation with the Philadelphia City Planning Commission, the PWD regulates stormwater management during the construction and post-construction phases of most development and redevelopment projects.

In 2007, the PWD began to revaluate its CSO Long Term Control Plan (LTCP) and capital improvements program to integrate additional projects that reduce CSO frequency and volume. The CSO Long Term Control Plan Update (LTCPU) involves the development of additional management alternatives to ensure capture and treatment of sanitary sewer system flows and the reduction of discharges from CSOs, building on the experience and progress gained from the implementation of our original CSO LTCP.

Benefits of Clean Water

The resources, amenities and socioeconomic impacts that result from the watershed management approach are endless. A "Green Cities - Clean Water" strategy will stimulate tourism, recreation, and riverfront development, along with the resulting economic benefits and jobs. Cleaner rivers create increased civic pride in the riverfront area, higher property values, and greater potential for valuable riverfront projects.


An exciting day of fishing at the annual Philly Fun Fishing Fest!


Paddlers take to their boats for the Schuylkill Regatta.

The definitions of words with an asterisk* can be found in the glossary at the end of this publication.


For more information, please visit us at www.phillyriverinfo.org

GREEN CITIES
CLEAN WATERS

THE LONG TERM CONTROL PLAN *UPDATE*

Clean Water Benefits and the Balanced Approach

Fact Sheet #2

CSO Long Term Control Plan Update (CSO LTCPU)

Philadelphia's CSO LTCPU seeks to achieve the regulatory requirements of the National CSO Control Policy through a comprehensive watershed-based approach. The Long Term Control Planning Guidance set forth by the U.S. EPA supports the implementation of a comprehensive watershed management approach and recognizes that the major advantage in using such an approach is that it identifies multiple solutions (land-water-infrastructure based) that are cost effective measures which result in site specific improvements to problems caused by the impacts of CSO and non-CSO sources of pollution on water quality.

The CSO Long Term Control
Plan Update
Falls under the
"Green Cities - Clean Waters"
Program.

The National CSO Control Policy

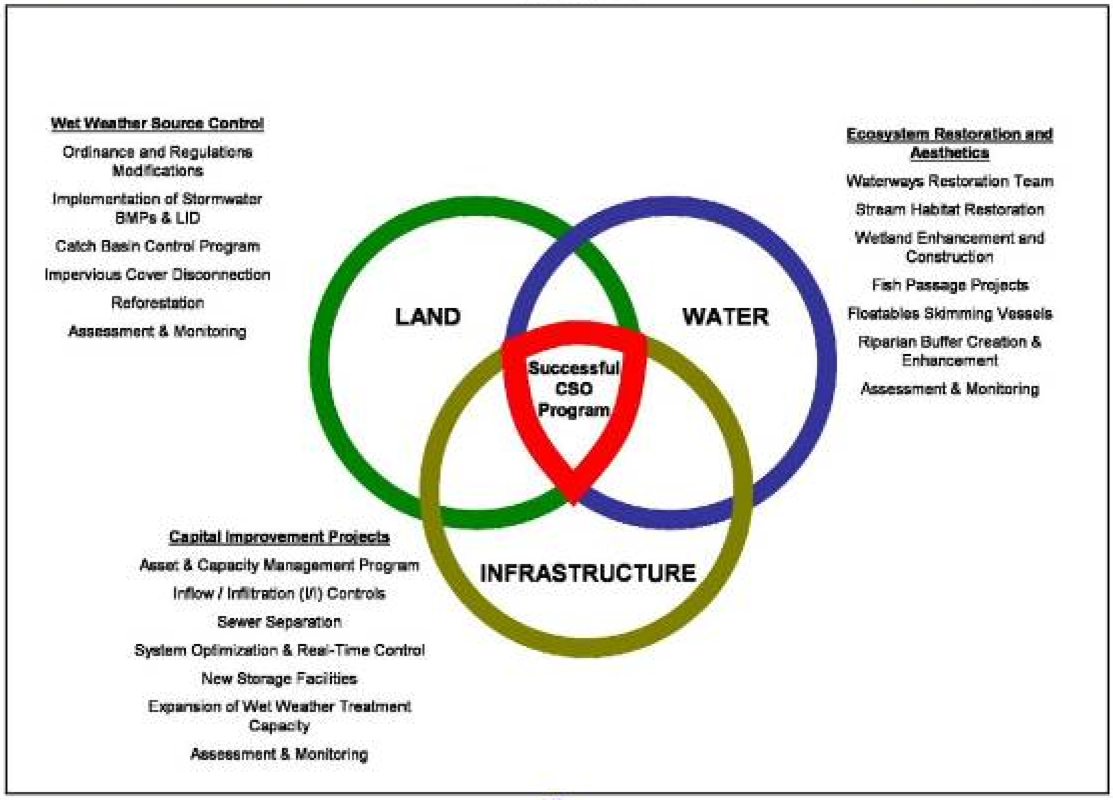
The National CSO Control Policy requires that the CSO LTCPU consist of the following nine elements:

- Characterization, monitoring, and modeling of the combined sewer system as the basis for selection and design of effective CSO controls
- A public participation process that actively involves the affected public in the decision-making to select long-term CSO controls
- Consideration of sensitive areas as the highest priority for controlling overflows
- Operational plan revisions to include agreed-upon long-term CSO controls
- Evaluation of alternatives that will enable the permittee, in consultation with the National Pollutant Discharge Elimination System (NPDES)* permitting authority, Water Quality Standards (WQS)* authority, and the public, to select CSO controls that will meet the Clean Water Act (CWA)* requirements
- Cost/performance considerations to demonstrate the relationships among a comprehensive set of reasonable control strategies
- Maximization of treatment at the existing wastewater treatment plant for wet weather flows
- An implementation schedule for CSO controls
- A post-construction compliance monitoring program adequate to verify compliance with water quality-based CWA requirements and to achieve the effectiveness of CSO controls.

A Successful CSO Program: The Balanced "Land-Water Infrastructure" Approach

The Philadelphia Water Department is committed to a balanced "land-water-infrastructure" approach to achieve its watershed management and CSO control goals. This method includes infrastructure-based approaches where appropriate, but also includes a range of land-based stormwater management techniques and the physical reconstruction of aquatic habitats, where appropriate.

The ultimate goal of PWD's approach is to restore and protect our rivers and streams including the floodplains, riparian buffers, stream channels, streambeds, wildlife, vegetation and other biomarkers that define a



healthy stream ecosystem that have been degraded as a result of urbanization within the City of Philadelphia and in the surrounding counties, while achieving full regulatory compliance in a cost-effective manner. The "Land-Water-Infrastructure" approach is made up of the following three programs, all of which enable the PWD to accomplish its goals under the CSO LTCPU.

LAND:
Wet Weather Source Control

The Wet Weather Source Control program promotes the use of Low Impact Development (LID)* and other structural and non-structural controls to reduce CSO volume through evaporation*, transpiration*, infiltration* and detained release* to the combined sewer system for treatment. The goal of our LID program, unlike past practices, is to keep stormwater runoff out of our sewer systems. One way that PWD is meeting its goals for this program is through the enactment of our recent stormwater management regulations for new development and redevelopment, established in 2006. These regulations focus on restoring a more natural balance between stormwater runoff and infiltration by requiring the capture of the first one inch of rainfall, reducing pollutant loads through infiltration and/or detention and controlling runoff rates at levels that minimize stream bank erosion. Site designers can ensure the level of stormwater management performance required through the use of a variety of land-based practices that mimic the natural environment, (e.g., redirecting runoff from impervious surfaces* to green areas, bioretention*, subsurface storage* and infiltration, green roofs, swales*, and tree canopy).

GREEN CITIES
CLEAN WATERS

THE LONG TERM CONTROL PLAN *UPDATE*

Clean Water Benefits and the Balanced Approach

Fact Sheet #2

Our planned Low Impact Development (LID) programs will include:

- Large-scale implementation of green, attractive measures to manage stormwater at the source on public land and streets to reduce demands on sewer infrastructure
- Requirements and incentives for green, attractive measures to manage stormwater at the source on private land and streets to reduce demands on sewer infrastructure
- A large-scale street tree program to improve appearance and manage stormwater at the source on City streets
- Incentives to preserve open space for use for stormwater management at the source

Infiltration garden at Buckman Heights in Portland, Oregon

Green roof at The Fencing Academy of Philadelphia

Naturalized stormwater detention basin at Black Rock in Upper Providence Township

Porous parking lot at Johnson & Johnson Pharmaceutical Research and Development campus

Rain Garden at Wissahickon Creek installed as part of the Valley Green Environmental Restoration program

A rain barrel installed at a Philadelphia residence

WATER:
Ecosystem Restoration and Aesthetics

The Ecosystem Restoration and Aesthetics program focuses on projects that contribute to the improvement of the aesthetic and ecological integrity of CSO receiving waters.

Such watershed-based approaches include stream bed and bank stabilization and reconstruction, aquatic habitat creation, plunge pool removal, improvement of fish passage, and floodplain reconnection. Restoring designated uses and ultimately removing streams from the state's list of impaired waters will require the restoration of the functions of a healthy aquatic ecosystem. These functions may be impossible to restore without restoration of the physical channel and the habitat required to support them.

PWD is designing and implementing projects that will restore and/or create stream and wetland habitat through programs that focus on stream habitat restoration, wetland enhancement and construction, fish passage projects and riparian buffer creation and enhancement.

Cobbs Creek at Marshall Road

Before

The creek at Marshall Road suffered from severely eroded banks (*triangle*) and exposed infrastructure (*star*).

In Progress

After

The natural design of the creek and healthy riparian buffer provides many benefits, including improved habitat for aquatic animals.

INFRASTRUCTURE:
Capital Improvement Projects

The Capital Improvement Projects program continues to build CSO capital improvement projects that were planned during the previous CSO permit cycle in addition to new projects to continue to increase the capture and treatment of combined sewage.

These construction projects include traditional storage, conveyance, and treatment measures within the combined sewer collection and treatment system, (e.g., the installation of inflatable dams, underground sewage storage tanks, and storm relief sewers.) Similar in-system construction will continue to be considered along with land-based and water-based measures, and they may be identified as the most cost-effective and feasible solutions in some situations.

However, if used alone, infrastructure-based measures can not address the root causes of impairment in urban streams. For example, the Cobbs Creek and Tookany/Tacony-Frankford Integrated Watershed Management Plans conclude that while some water quality problems exist, the primary causes of impairment in these streams are modified flow patterns and habitat degradation resulting from the urban development of our once natural watersheds. Controlling volume and quality of stormwater runoff is key for restoring the ecosystems of our streams. The Pennsylvania Department of Environmental Protection's (PADEP) integrated impairment listings agree with these findings.

Infrastructure-based measures are typically focused on removing loads of specific pollutants in our piping systems rather than restoring natural flow conditions and habitat. Controlling stormwater runoff (before it enters the sewer system) through rain gardens, tree infiltration trenches, bioswales* and other land-based practices that recreate the natural environment, is essential for achieving healthy streams. It is for this reason that PWD's strategies include a well defined evaluation of infrastructure solutions combined with LID.

From a story in the Philadelphia *Inquirer's* "Today" Magazine, January 29, 1961. *Research credit Adam Levine.*

Additional examples of our capital improvements program include the Real Time Control Center, Water Pollution Control Plant (WPCP) Wet Weather Treatment Maximization, In-Line System Storage Projects, an Asset & Capacity Management Program, Inflow/Infiltration (I/I) Controls, Sewer Separation, and New Storage Facilities.

Additional Watershed Projects

The PWD integrated and adaptive approach has the added benefit of meeting other stakeholder water resources needs more universally. These programs and projects include: River Conservation Plans, the Watershed Information Center, Integrated Water Use Status Networks, Interpretive Signage, Interpretive Centers, Basin-Specific Stormwater Management Plans (Act 167*) and Sewage Facility Planning. For more information on the CSO LTCP, please visit: http://www.phillyriverinfo.org

The encapsulation of Mills Creek in 1883. *Research credit Adam Levine.*

*Glossary**

Act 167

The Pennsylvania Stormwater Act 167 of 1978 says that each county must prepare a stormwater management plan for each of its designated watersheds in consultation with the municipalities located within the boundaries of the watershed.

Bioretention

A vegetated depression located on the site that is designed to collect, store and infiltrate runoff. Typically includes a mix of amended soils and vegetation.

Detention System

Temporary storage of stormwater to control the rate of release, allow for infiltration and provide treatment.

Evaporation

A change of liquid to vapor form.

Impermeable

Not easily penetrated. The property of a material or soil that does not allow, or allows only with great difficulty, the movement or passage of water.

Impervious Surface

Those surfaces in the landscape that can not infiltrate rainfall, such as rooftops, pavement, sidewalks, driveways and compacted earth. Lawns with underlying soils compacted by heavy machinery are considered impervious.

Infiltration

The penetration of water through the ground surface into sub-surface soil or the penetration of water from the soil allowing for the recharge of our groundwater table and the baseflow of streams.

Low Impact Development (LID)

A design strategy with the goal of maintaining or replicating the pre-development hydrologic regime through the use of design techniques that mimic the natural environment.

National Pollutant Discharge Elimination System (NPDES)

A provision of the Clean Water Act which prohibits discharge of pollutants into waters of the United States unless a special permit is issued by EPA, a state, or, where delegated, a tribal government on an Indian reservation.

Pervious or Permeable Surfaces

Soil or other material that allows infiltration or passage of water or other liquids.

Subsurface Storage

Retaining or detaining water underground. Stored water can be released at a later time into natural waterways to reduce peak storm flows, or allowed to slowly infiltrate to recharge groundwater.

Swale / Bioswale

Open, vegetated drainage channel designed to detain, treat and/or infiltrate stormwater.

Transpiration

The process by which water vapor is lost to the atmosphere from living plants.

Water Quality Standards (WQS)

State-adopted and EPA-approved ambient standards for water bodies. The standards prescribe the use of the water body and establish the water quality criteria that must be met to protect designated uses.

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Clean Water Act (CWA)

Introduction to the Clean Water Act as given by the EPA

The Clean Water Act (CWA) is the cornerstone of surface water quality protection in the United States. (The Act does not deal directly with ground water nor with water quantity issues.) The statute employs a variety of regulatory and nonregulatory tools to sharply reduce direct pollutant discharges into waterways, finance municipal wastewater treatment facilities, and manage polluted runoff. These tools are employed to achieve the broader goal of restoring and maintaining the chemical, physical, and biological integrity of the nation's waters so that they can support "the protection and propagation of fish, shellfish, and wildlife and recreation in and on the water."

For many years following the passage of CWA in 1972, EPA, states, and Indian tribes focused mainly on the chemical aspects of the "integrity" goal. During the last decade, however, more attention has been given to physical and biological integrity. Also, in the early decades of the Act's implementation, efforts focused on regulating discharges from traditional "point source" facilities, such as municipal sewage plants and industrial facilities, with little attention paid to runoff from streets, construction sites, farms, and other "wet-weather" sources.

Starting in the late 1980s, efforts to address polluted runoff have increased significantly. For "nonpoint" runoff, voluntary programs, including cost-sharing with landowners are the key tool. For "wet weather point sources" like urban storm sewer systems and construction sites, a regulatory approach is being employed.

Evolution of CWA programs over the last decade has also included something of a shift from a program-by-program, source-by-source, pollutant-by-pollutant approach to more holistic watershed-based strategies. Under the watershed approach equal emphasis is placed on protecting healthy waters and restoring impaired ones. A full array of issues are addressed, not just those subject to CWA regulatory authority. Involvement of stakeholder groups in the development and implementation of strategies for achieving and maintaining state water quality and other environmental goals is another hallmark of this approach.

For more information, please visit us at www.phillyriverinfo.org

Advisory Committee Meeting #1

Philadelphia PWD Water Department

CSOLTCPU Advisory Committee
November 13, 2007

Agenda

1. Welcome & Introductions

2. Purpose of the Advisory Committee
    - topics the committee will be covering over the next two years
    - timeline for committee work
    - public outreach projects

3. Presentation on CSO Policy and PWD's Approach

4. Questions on Presentation

5. Presentation on PWD outreach projects/materials

6. Recommendations for public outreach

7. Next Steps
    - Public Meeting
    - Interest in subcommittee work

Philadelphia
PWD
Water Department

PWD CSOLTCPU Public Advisory Committee
Meeting #1
November 13, 2007

Please Sign In

Name	Organization	Email
Thu Tran	Community Legal Services Inc.	ttran@clsphila.org
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Christine Knapp	PennFuture / Next Great City	Knapp@pennfuture.org
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Sarah Thorp	DRCC	smthorp@drcc-phila.org
Joseph Syrnick	SRDC	joseph.syrnick@srdc.net

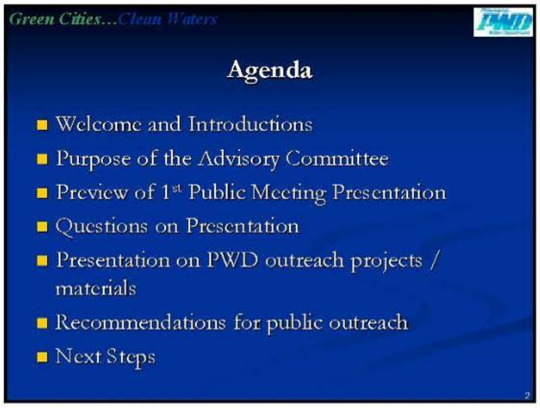
LTCPU Steering Committee Public Outreach Presentation Comments – 11/13/07

- Too much technical jargon – **Starr**
- Why does this matter to the public – **Mann**
- Slide 7 Wow (graphic with the location of 164 outfalls) – **RobbGrecco**
- Start with photos not technical stuff – **Starr**
- From the civic group side, Who will fix my problems, I don't care about the regulatory issues, talk more about the personal impacts of overflows (basement) – **Simpkins**
- Talk first about what the problems are, then go into the solutions – **Thorp**
- What is the regulatory process – who approves, EPA, who lobbies, how can each 'hood get more money – **Tran**
- Show this as an investment to our City – Get them to care – **Starr**
- Show Cost-effectiveness – **Mann**
- City incentives for green roofs on private property – **Mann**
- LTCPU – had 10 yrs to study, these are the investments made, it's an ongoing process, now it's time for a mix of solutions – **Blaustein**
- Give them clear alternatives for the future – **Blaustein**
- Adaptive Management Approach – **Neukrug**
- Tell them what we have done and what we are doing. We are standing at a fork in the road now. Tell them the story of the choices. Give them the problem and two alternative solutions. Focus on the stuff we have done. – **Starr**
- Remember the anger from affected citizens (flooding). We are walking a fine line with the citizens. Make the story clear. Cut the # of slides in half or third – **Knapp**
- SFR vs CSO – big difference of what we are on the hook to solve in the LTCPU – **Smullen**
- Show a few slides discussing SFR, but clearly state that this is not what we are talking about in the rest of the presentation., acknowledge the seriousness of the flooding issue – **Starr**
- What are the long term health risks, what are you doing about public notification – **Mann**
- Put signs up high like they did in Pittsburgh – **Blaustein**
- Do dogs drink the water? – **Neukrug**

Green Cities…Clean Waters

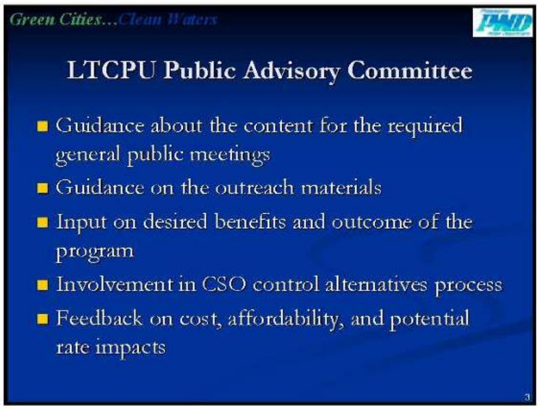
Long Term Control Plan Update

Public Advisory Committee Meeting #1
November 13th, 2007



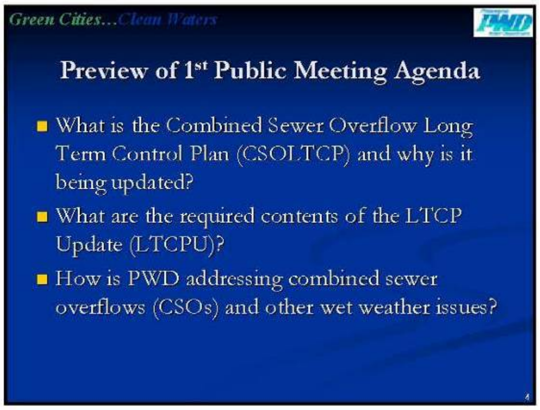
Agenda

- Welcome and Introductions
- Purpose of the Advisory Committee
- Preview of 1st Public Meeting Presentation
- Questions on Presentation
- Presentation on PWD outreach projects / materials
- Recommendations for public outreach
- Next Steps



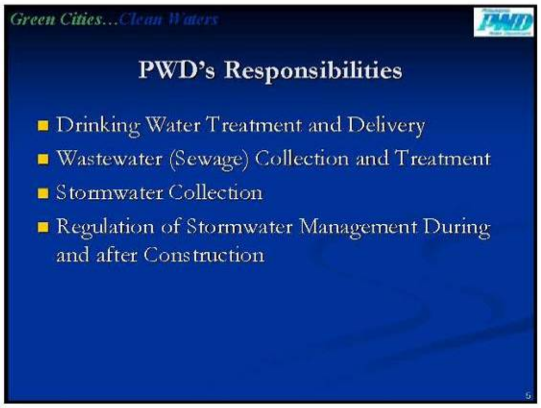
LTCPU Public Advisory Committee

- Guidance about the content for the required general public meetings
- Guidance on the outreach materials
- Input on desired benefits and outcome of the program
- Involvement in CSO control alternatives process
- Feedback on cost, affordability, and potential rate impacts



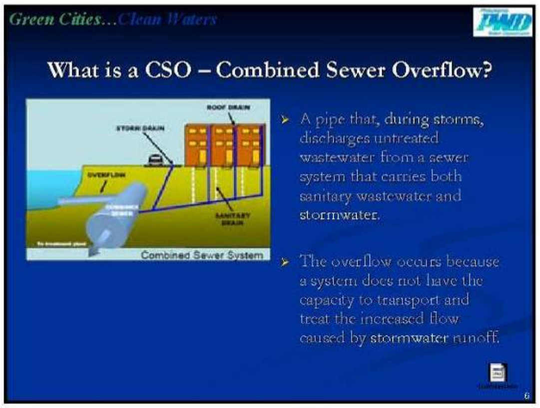
Preview of 1st Public Meeting Agenda

- What is the Combined Sewer Overflow Long Term Control Plan (CSOLTCP) and why is it being updated?
- What are the required contents of the LTCP Update (LTCPU)?
- How is PWD addressing combined sewer overflows (CSOs) and other wet weather issues?



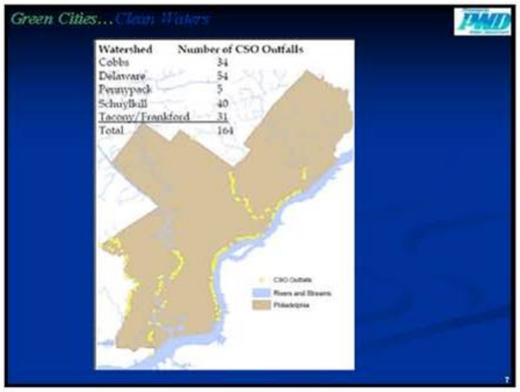
PWD's Responsibilities

- Drinking Water Treatment and Delivery
- Wastewater (Sewage) Collection and Treatment
- Stormwater Collection
- Regulation of Stormwater Management During and after Construction

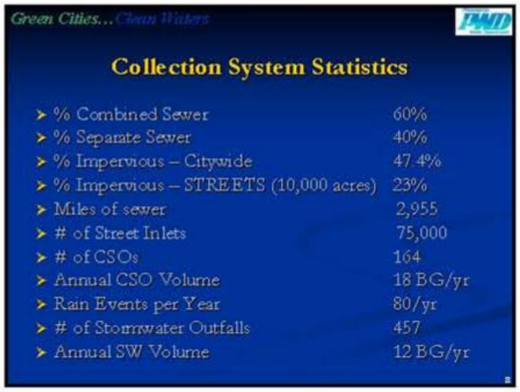


What is a CSO – Combined Sewer Overflow?

- A pipe that, during storms, discharges untreated wastewater from a sewer system that carries both sanitary wastewater and stormwater.
- The overflow occurs because a system does not have the capacity to transport and treat the increased flow caused by stormwater runoff.

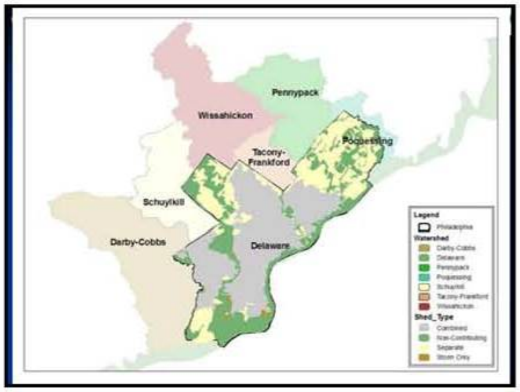


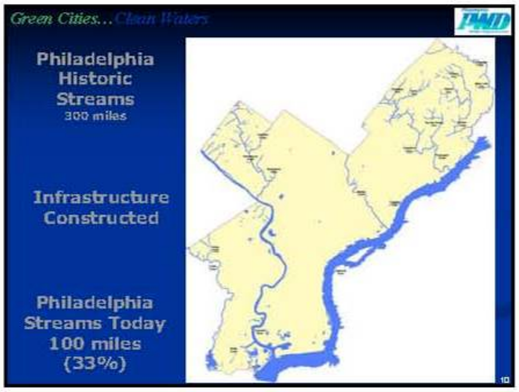
Watershed	Number of CSO Outfalls
Cobbs	34
Delaware	54
Pennypack	5
Schuylkill	40
Tacony/Frankford	31
Total	164



Collection System Statistics

% Combined Sewer	60%
% Separate Sewer	40%
% Impervious – Citywide	47.4%
% Impervious – STREETS (10,000 acres)	23%
Miles of sewer	2,955
# of Street Inlets	75,000
# of CSOs	164
Annual CSO Volume	18 BG/yr
Rain Events per Year	80/yr
# of Stormwater Outfalls	457
Annual SW Volume	12 BG/yr

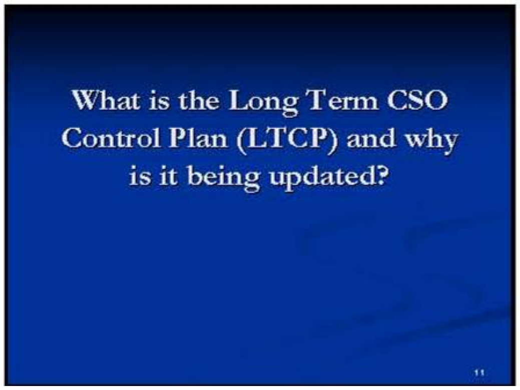




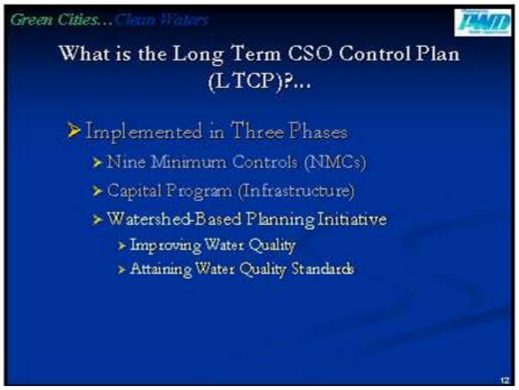
Philadelphia Historic Streams
300 miles

Infrastructure Constructed

Philadelphia Streams Today
100 miles
(33%)

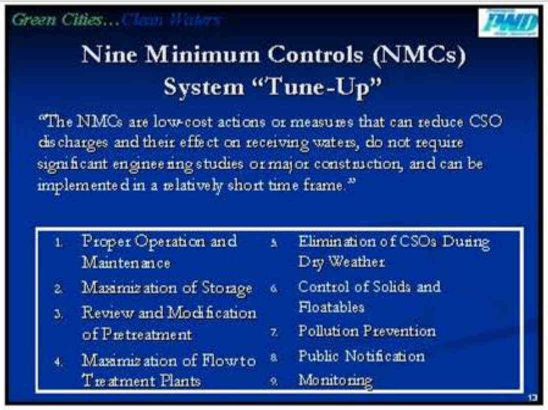


What is the Long Term CSO Control Plan (LTCP) and why is it being updated?



What is the Long Term CSO Control Plan (LTCP)?…

- Implemented in Three Phases
  - Nine Minimum Controls (NMCs)
  - Capital Program (Infrastructure)
  - Watershed-Based Planning Initiative
    - Improving Water Quality
    - Attaining Water Quality Standards

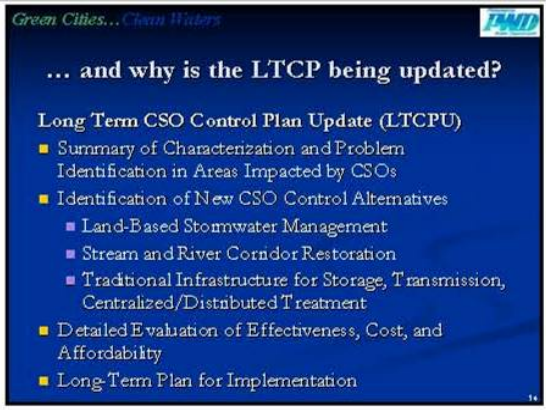


Green Cities…Clean Waters

Nine Minimum Controls (NMCs) System "Tune-Up"

"The NMCs are low-cost actions or measures that can reduce CSO discharges and their effect on receiving waters, do not require significant engineering studies or major construction, and can be implemented in a relatively short time frame."

1. Proper Operation and Maintenance
2. Maximization of Storage
3. Review and Modification of Pretreatment
4. Maximization of Flow to Treatment Plants
5. Elimination of CSOs During Dry Weather
6. Control of Solids and Floatables
7. Pollution Prevention
8. Public Notification
9. Monitoring

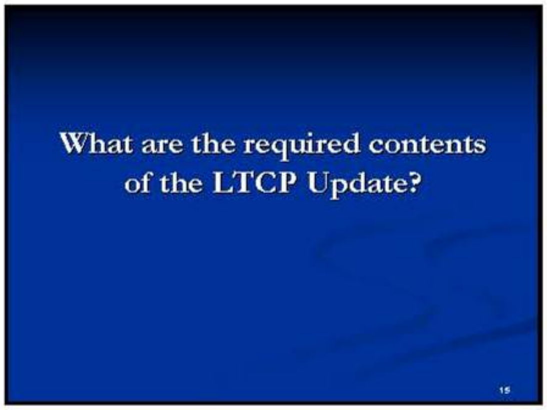


Green Cities…Clean Waters

… and why is the LTCP being updated?

Long Term CSO Control Plan Update (LTCPU)

- Summary of Characterization and Problem Identification in Areas Impacted by CSOs
- Identification of New CSO Control Alternatives
  - Land-Based Stormwater Management
  - Stream and River Corridor Restoration
  - Traditional Infrastructure for Storage, Transmission, Centralized/Distributed Treatment
- Detailed Evaluation of Effectiveness, Cost, and Affordability
- Long-Term Plan for Implementation



What are the required contents of the LTCP Update?

Green Cities…Clean Waters

Regulatory Framework: Clean Water Act and National CSO Control Policy

- Nine Minimum Controls
- Long Term CSO Control Plan
  - System Characterization
  - Public Participation
  - Consideration of Sensitive Areas
  - Evaluation of Alternatives
  - Cost/Performance Consideration
  - Operational Plan
  - Maximizing Treatment at Existing Plants
  - Implementation Schedule
  - Post-Construction Compliance Monitoring Program
  - Water Quality Standards Review

Today's Meeting

Green Cities…Clean Waters

Watershed and Water Body Characterization

Living Resources
Designated Uses
Regulatory Compliance

Stakeholder Goals
Quality of Life

Dry Weather Water Quality and Aesthetics
Stream and Stream Corridor Living Resources
Wet Weather Water Quality and Quantity

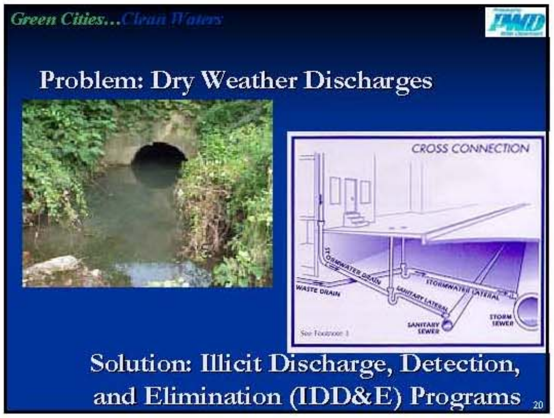
Green Cities…Clean Waters

Target A – Dry Weather Water Quality and Aesthetics

- Streams need to look good, be accessible, and become an amenity to the community
- Stream water quality during dry weather (about 60-65% of the time) should improve

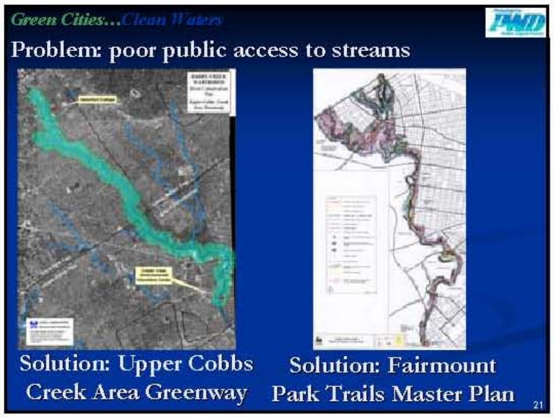
Problem: Dumping and Trash

Solution: Waterways Restoration Team - removing trash



Problem: Dry Weather Discharges

Solution: Illicit Discharge, Detection, and Elimination (IDD&E) Programs



Problem: poor public access to streams

Solution: Upper Cobbs Creek Area Greenway

Solution: Fairmount Park Trails Master Plan

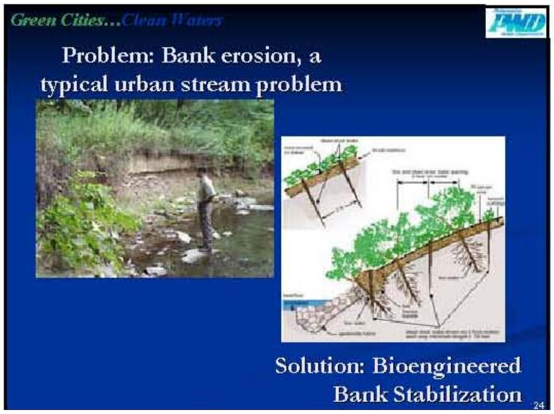
Problem: Can we increase resident awareness?

Solution: Public Education

Solution: Active Community Stewardship

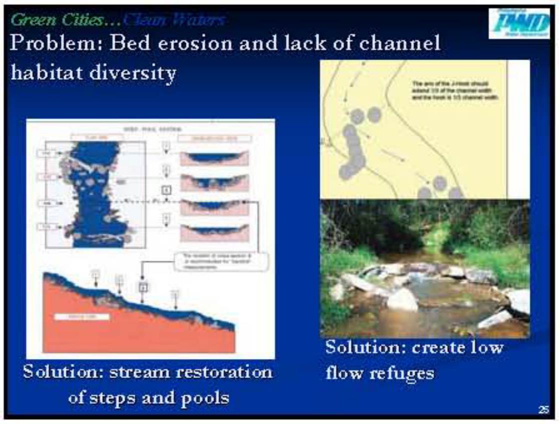
Target B – Healthy Living Resources

- Focus on improved aquatic habitat and healthy fish populations
- Stream restoration (bank, channel, riparian, corridor)
- Fish passage (fish ladders, dam modification)



Problem: Bank erosion, a typical urban stream problem

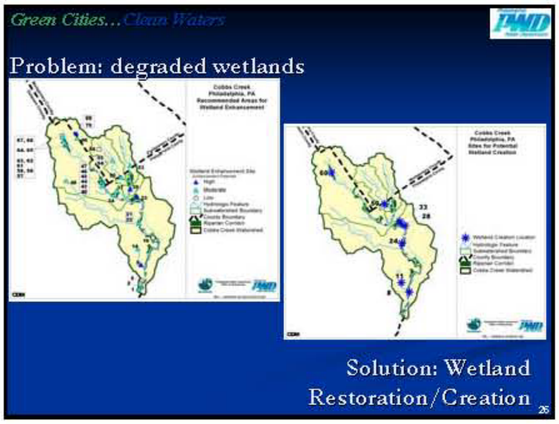
Solution: Bioengineered Bank Stabilization



Problem: Bed erosion and lack of channel habitat diversity

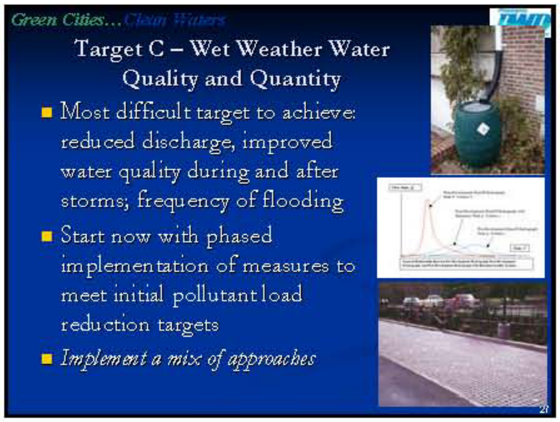
Solution: stream restoration of steps and pools

Solution: create low flow refuges



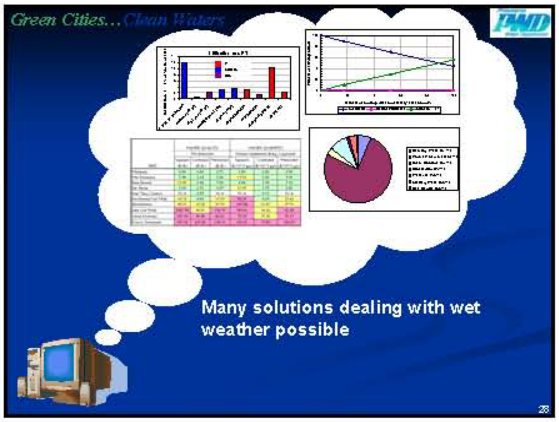
Problem: degraded wetlands

Solution: Wetland Restoration/Creation

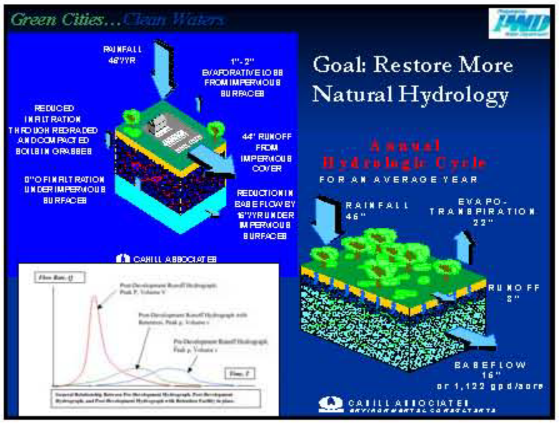


Target C – Wet Weather Water Quality and Quantity

- Most difficult target to achieve: reduced discharge, improved water quality during and after storms; frequency of flooding
- Start now with phased implementation of measures to meet initial pollutant load reduction targets
- *Implement a mix of approaches*



Many solutions dealing with wet weather possible

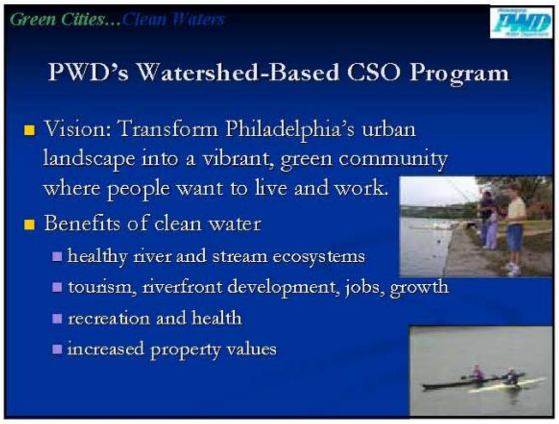


Goal: Restore More Natural Hydrology

How is PWD addressing combined sewer overflows (CSOs) and other wet weather issues?

The Old Approach – Big Tanks and Tunnels

- Are we going to build on yesterday's mistakes?
- Is this approach sustainable?
- Can we reach our environmental goals?
- Can we get a better value for limited $$$?



PWD's Watershed-Based CSO Program

- Vision: Transform Philadelphia's urban landscape into a vibrant, green community where people want to live and work.
- Benefits of clean water
  - healthy river and stream ecosystems
  - tourism, riverfront development, jobs, growth
  - recreation and health
  - increased property values

Watershed-Based CSO Program

Streambank and Habitat Restoration
Constructed Wetlands
Baseflow Augmentation
Floatables Skimming Vessels
Stream Cleanup Teams
Assessment & Monitoring

Low-Impact Development and Re-Development
Stormwater BMPs
Regional Stormwater Facilities
Riparian Buffer Creation & Enhancement
Reforestation
Green Building Technology
Water Conservation
Assessment & Monitoring

New Storage Facilities
New Treatment Capacity
Real-Time Control
Sewer Separation
Inflow / Infiltration Controls
Catch Basin Controls
In-line Netting
Swirl Concentrators
Assessment and Monitoring

INFRA

- Asset & Capacity Management Program
- Inflow / Infiltration (I/I) Controls
- Sewer Separation
- System Optimization & Real-Time Control
- New Treatment Capacity
- New Storage Facilities

Tank - Venice Island

WPCP Wet Weather Capacity Expansion

Thermal Imaging Studies

Sewer/Stream Separation - USACE Mill Creek Feasibility Study

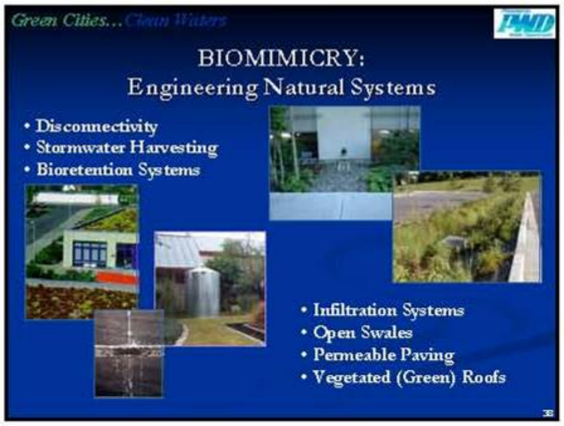
In-System Storage

Infrastructure Summary

- Necessary part of CSO mitigation
- These projects are a large part of PWD's Capital Program
- Innovative
- But…
  addresses only a small part of the environmental goal

LAND

- Implementation of Stormwater BMPs
- Low Impact Development & Redevelopment (LID)
- Catch Basin Control Program
- Impervious Cover Disconnection
- Reforestation
- Green Building Technology & Water Conservation
- New Stormwater Management Regulations



BIOMIMICRY: Engineering Natural Systems

- **Disconnectivity**
- **Stormwater Harvesting**
- **Bioretention Systems**

- **Infiltration Systems**
- **Open Swales**
- **Permeable Paving**
- **Vegetated (Green) Roofs**

Low Impact Development Program

Stomwater Detention (ex. Vacant Land Management)

Green Streets

Infiltration Trenches & Basins

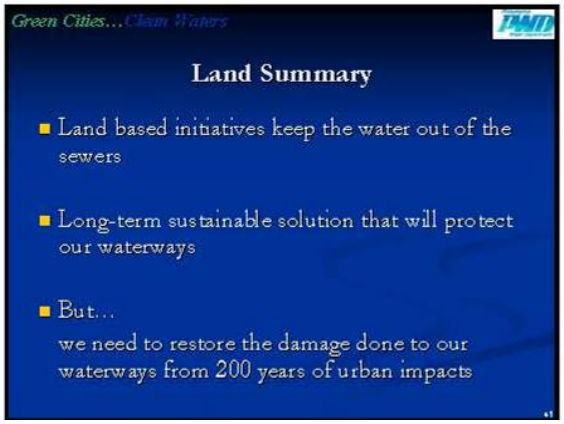
Bioretention (ex Rain Garden)

Permeable Paving

New SW Regulations

Green Roofs

Cisterns & Rain Barrels



Land Summary

- Land based initiatives keep the water out of the sewers
- Long-term sustainable solution that will protect our waterways
- But…

  we need to restore the damage done to our waterways from 200 years of urban impacts

WATER

- Waterways Restoration Team
- Stream Habitat Restoration
- Constructed Wetlands
- Fish Passage Projects
- Floatables Skimming Vessels
- Riparian Buffer Creation & Enhancement

Green Cities... Clean Waters

Waterways Restoration Team

Fluvial Geomorphology & Stream Restoration

Riparian Buffer Enhancements

Wetlands

Green Cities... Clean Waters

Fish Passage

Scrap Yard Task Force

Floatables Skimming Vessel

Information/ Interpretive Centers

Green Cities... Clean Waters

New Visions: Our roadmaps for Change

Green Plan NTI River City

Green Cities... Clean Waters

Future Meeting Topics

- Meeting #2 – CSO Control Options – Low Impact Development (green infrastructure) and Capital Improvements; What Other Cities Are Doing; Prototype Examples
- Meeting #3 – Alternatives Analysis and Affordability
- Meeting #4 – Review of Draft Plan

Green Cities... Clean Waters

Today's Agenda

- Welcome and Introductions
- Purpose of the Advisory Committee
- Preview of 1st Public Meeting Presentation
- Questions on Presentation
- Presentation on PWD outreach projects / materials
- Recommendations for public outreach
- Next Steps

Green Cities... Clean Waters

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The fundamental goal of the Philadelphia Water Department's (PWD) combined sewer overflow program is to improve and preserve the water environment in the Philadelphia area and to fulfill the PWD's obligations under the Clean Water Act and the Pennsylvania Clean Streams Law by implementing technically viable, cost-effective improvements and operational changes.

Today's Agenda

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Advisory Committee Meeting #2

CSOLTCPU Advisory Committee
February 20, 2008

Agenda

1. Welcome & Introductions

2. Preview of Updated Public Meeting Presentation

3. Philly RiverCast

4. Questions and Answers

Sign In	CSO LTCP Advisory Committee Meeting #2	February 20, 2008
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David Burke	daburke@state.pa.us	PA-DEP
Dwayne Myers	myersrd@cdm.com	CDM/PWD
Bill Cesanak	cesanakwe@cdm.com	CDM/PWD

Comments for February 20th Meeting

1. Take out the acronyms- don't say "CSO," say Combined sewer overflow – Sarah R.G.
2. CSO vs Separate – make the colors different. (H2O for stormwater- blue & poop brown, then combine colors)
3. Take time on CSO vs. Separate diagrams, BUT ALSO VERY IMPORTANT to point out NPS pollution with CSO effect. + pros and cons of each
4. Fix diameter of CSO & separate into 2 pipes where it comes out of house – Burke
5. After Green vs. Gray go back to sewer diagram and add green and show H2O coming out -Burke
6. Old Maps → New maps = Good (we should still treasure & preserve what we still have & bring back what is lost – Burke
7. Stream Natural vs. Urban → Different isn't visible in photos because you can't see development in 2nd pair; show aerial?
8. 4" Rain vs. 3" → impact? → MAJOR STORM! 4" over 3 hours vs. 4" over 24 hours…explain clear difference & emphasize impact – Sarah R.G.

- Average storm is ½ in – Melanie
- Snow comparison?

9. "Piping" is creek- EXPLAIN that burying creek and creek runs through pipe
10. How to get involved → go to very end again x2 & Add "next steps"- why you want to get involved & why are they here?
11. What can they do?

- Good Practices- rain barrel, explain why these practices are beneficial.

12. Vision of what their street can look like – list things like plant trees, rain barrels, you can do it, grass… etc.
13. Role of public? Do you like the idea of spending $ on green stuff? & gray stuff? Mix?
14. Additional Tables? Recycling Table, Anti Litter Campaign?
15. Stream Restoration & other green > cut out 1-2 i.e. keep Portland and Chicago.
16. Don't use toxic, use "unsanitary" & "filthy" in history section!

1. Darby Cobbs

- 34 outfalls
- 2004 wmp completed

2. Schuylkill

- 40 overflows
- Sewer water as t.s. & sewer Water Protect. Plan- completed in 2006

3. Tookany/Tacony-Frankford

- 31 in TF section
- WMP completed 2007

4. Pennypack

- Only 5 CSOs
- WMP started in 07. To be completed in 2008

5. Delaware

-54 in DE Direct
- started RCP last year
6. Poquessing
- 0 outfalls, served by separate sewer system RCP complete last year & wmp to start this fall

Imagine a
Philadelphia like
this…

(Refer to the Public Meeting Series # 1 of this volume for complete set of slides.)

Advisory Committee Meeting #3

Philadelphia Water Department

CSOLTCPU Advisory Committee
October 8, 2008

Agenda

1. Welcome & Introductions

2. Water Quality Characterization, Problem Analysis & Goals for Our Watersheds

3. Combined Sewer Overflow (CSO)Cast

4. Questions and Answers on presentation

5. Preview of "Green Cities, Clean Waters" Art Exhibit

Philadelphia
PWD
Water Department

PWD CSOLTCPU Public Advisory Committee
Meeting #3
October 8, 2008

Please Sign In

Name	Organization	Email
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Laura Rozumalski	PWD	laura.rozumalski@phila.gov

CSO LTCPU Advisory Board Meeting Comments 10.08.2008

Intro Presentation

- What do we want from the public?
- Targeting the public: what is the cost to them and how will it benefit them and their children
- Explain what PWD does and how this is an additional but necessary part of their role as a water utility provider
- Emphasize recreation, quality of life, increase in property value in using green infrastructure
- Contrast green and gray more explicitly
- Big investment in infrastructure is necessary, but how do we do this?
- Slide 30- call out features or what is being shown

Characterization Presentation

- Maps- provide landmarks, parks, streets, neighborhood names for reference
- Redo Tookany/Tacony- Frankford map
- Slide 4- take out or switch with previous
- Emphasize recreation
- Connect public actions to their effect (e.g. what pour down the drain, flush the toilet- goes into sewer system)
- Homeowner Stormwater Management Manual could be referred to
- Mark green streets slides with call outs to different features

Green Cities, Clean Waters

Combined
Sewer Overflow
Long-term Control
Plan Update

Philadelphia
PWD
Water Department

(Refer to the Public Meeting Series # 2 of this volume for complete set of slides.)

Advisory Committee Meeting #4

CSO LTCPU Adv. Committee Mtg. 4/9/09

FAIRMOUNT WATER WORKS INTERPRETIVE CENTER

VISITOR SIGN-IN SHEET

~~DATE~~ Affiliation	NAME + e-mail	~~PURPOSE FOR VISIT~~	~~TIME IN~~
PWD Consultant	Tiffany Ledesma Groll, ledesmagrolltd@cdm.com		
FAIRMOUNT PARK	JOAN BLAUSTEIN JOAN.BLAUSTEIN@PHILA.GOV		
TTF	SARAH ROBBGRIECO sarah@ttfwatershed.org		
TTF	Katie Donnelly katie@ttfwatershed.org		
PWD Consultant	Marosa Bolette [illegible] BolettaMP@cdm.com		
PWD Drexel coop	Ralph Hernandez rch39@drexel.edu		
PennFuture	Rachel Vassar vassar@pennfuture.org		
NL Clean & Green	Lara Kelly trash@nlna.org		

CSO Advisory Meeting 4-9-09

Slide Target C- Change RT Control to Inflatable dam
Slide Cost vs Benefit- Phrase it down
Slide RTB – make it plural
    Take out RTB and add a text saying it is underground
Slide green homes – make sure its local plants
Slide Green public facilities – Change green walls to living walls
Slide green programs – make components readable
Slide Enhanced Aquatic life – Show that it is a fish ladder
Slide Alternatives – Take out TTF CSO…
    Take out TBL
    Add pics, take out legends, Bigger Pipe instead of increased transmission
Slide Survey – Take out notes and acronyms
Slide CSO – take out CSO, spell it out
Slide Benefit – Text centered, bullets fixed, animation needs to be faster.

-City spend Billions, how does the public wants us to spend the money?
-Gray before and after photos with green before and after photos
-Explain all elements
-Pics of green components before the green program slide so the public will know what they are.
-Picture of Street overflowing
-Should we be biased towards green since were incorporating both green and gray?
-Add incentives for going green
- Fix all animations and layouts

Adv. Ct. Meeting Comments 4/9/09

-Too technical, remove "Satellite", "Transmission", "DO" or explain what it means – **Lara**
-Make it simpler – **Rachel**
-RTB slide, spell it out on 2nd slide – **Sarah**
-No acronyms at all – **Katie**
-Too much impervious language, explain it at the beginning – **Sarah**
-3 Alternatives, explain what the headings mean and how they differ – **Sarah**
-Green, Bigger pipe, mini treatment plant – **Marc**
-More neutral but discuss green benefits better –**Marc**
-List more green benefits – **Marc**
-More construction, detail so the public knows – **Rachel**
-Green Streets, components of each – **Katie**
-Explain green components thru pics – **Joan B**
-Explain how each components impact stormwater management – **Joan B.**
-Insert Stormwater slides, impervious vs pervious, stormwater runoff slides – **Joan B.**
-What is a CSO? Spell it out. – **Lara**
-Summarize slide: Cost vs Benefit, green vs gray – **Sarah**
-Overview 30 mins. New topic 2nd presentation; advertize as such – **Rachel**
-how do you want the city to tell us what you think? Be upfront. – **Marissa**
-Explain what other cities have done in our position. This is new so we need public input. – **Marissa**
-Show partnerships and others are green, so what is the additional value? – **Rachel**
-More biased go green – **Rachel**
-history of CSO slides, why not there now? – **Rachel**

Green Cities, Clean Waters

The Combined Sewer Overflow Long Term Control Plan Update

Philadelphia
PWD
Water Department

(Refer to the Public Meeting Series # 3 of this volume for complete set of slides.)

Advisory Committee Meeting #5

Philadelphia
PWD
Water Department

CSO LTCP Update Advisory Committee Meeting
August 5, 2009

Please Sign In

Name	Organization	Email
DENNIS R. WINTERS	SIERRA CLUB	dennis.winters@verizon.net
Rachel Vassar	PennFuture	vassar@pennfuture.org
Lisa Simon	SimonPR/PWD	lsimon@simonpr.com
JOAN BLAUSTEIN	FAIRMOUNT PARK	JOAN.BLAUSTEIN@PHILA.GOV
Marc Cammerata	PWD - OOW	marc.cammarata@phila.gov
DAVID BURKE	PA DEP	daburke@state.pa.us
Maggie Allio	PWDconsl -OOW	allioml@cdm.com
PAUL RACETTE	PA ENV. COUNCIL	PRACETTE@PECPA.ORG
Khiet Luong	PA Env. Council	kluong@pecpa.org
Patrick Starr	PA Env Council	pstarr@pecpa.org
Joanne Dahme	PWD	joanne.dahme@phila.gov
Tiffany Ledesma Groll	Consultant to PWD	ledesmagrolltd@phila.gov

Green Cities, Clean Waters Advisory Committee Meeting

August 5, 2009

The purpose of the meeting was to review the draft summary report CSO LTCP Update and to discuss how to improve outreach on the CSO LTCP Update upcoming final round of meetings.

Key comments made on draft summary report CSO LTCPU:

- "This plan is a marvelous illustration of a real world watershed approach and we plan to use it as a model for watershed planning for counties and municipalities across Pennsylvania." – Patrick Star, PEC
- "This plan addresses social justice and equity issues" [that other CSO programs do not]- Patrick Star
- "This plan really builds on the first LTCP in 1997 that laid the groundwork for the watershed approach." - David Burke, DEP
- "Biggest Public Works Project in the foreseeable future." - Joan Blaustein, Fairmount Park
- "Fairmount Park will be planting 300,000 trees to meet the GreenWorks Challenge. Their primary purpose is to improve water quality and reduce stormwater runoff." Joan
- "The Green Program allows Philadelphia residents to see what they are paying for" – Unknown

Brainstorming results on increasing public participation at final round of public meetings:

- Give away water ice
- Write Op-ed in Inquirer
- Get Inquirer to write articles
- Conduct press briefing to draw environmental bloggers
- Have ANS Urban Sustainability Forum contact promote through listserv

Public Meetings
Notifications & Media Coverage

Philadelphia
PWD
Water Department

GREEN CITIES, CLEAN WATERS PROGRAM:

COMBINED SEWER OVERFLOW LONG-TERM CONTROL PLAN PUBLIC MEETINGS

Please join the Philadelphia Water Department (PWD) for a series of public meetings on our Combined Sewer Overflow Long-Term Control Plan Update entitled "Green Cities, Clean Waters".

Learn about the City's combined sewer system, and PWD's proposed strategies for significantly reducing combined sewer overflows to our rivers and streams. Give us your feedback on these strategies that are designed to combine 'gray' solutions, such as underground infrastructure and 'green' solutions such as tree infiltration trenches.

1ST MEETING

WHEN: Wednesday, April 2 from 5:45 – 7:45 p.m.

WHERE: Port Richmond Library
(2987 Almond Street, Philadelphia, 19134)

2ND MEETING

WHEN: Thursday, April 10 from 6:00 – 8:00 p.m.

WHERE: Fels Community Center
(2407 S. Broad Street, Philadelphia, 19148)

3RD MEETING

WHEN: Thursday, April 24 from 6:00 – 8:00 p.m.

WHERE: School of the Future
(4021 Parkside Avenue, Philadelphia, 19104)

Learn how you can help protect our local sources of drinking water and help Philadelphia Go Green!

For more information, please contact Tiffany Ledesma

Philadelphia
PWD
Water Department

GREEN CITIES, CLEAN WATERS PROGRAM: COMBINED SEWER OVERFLOW LONG-TERM CONTROL PLAN PUBLIC MEETING

Please join the Philadelphia Water Department (PWD) for a public meeting on our Combined Sewer Overflow Long-Term Control Plan Update entitled: "Green Cities, Clean Waters"

This meeting is a follow-up to the previous round of meetings held last spring.

At this meeting, PWD will present the problems of the creeks and rivers, the sources of pollution and the vision behind the goals that will help transform the City.

Give us your feedback on these strategies and let your voice be heard!

WHEN: Thursday, October 23 from 5:30 – 7:30 p.m.
WHERE: Fairmount Water Works Interpretive Center
640 Waterworks Drive, Philadelphia, 19130
(behind the Philadelphia Museum of Art)

Learn how you can help protect our local sources of drinking water and help Philadelphia Go Green!

For more information, please contact Tiffany Ledesma Groll at (215) 499-3756 or visit www.phillyriverinfo.org.

Water Department

GREEN CITIES, CLEAN WATERS PROGRAM:

HEAR ABOUT THE CITY'S PLANS TO REDUCE POLLUTION AND PROTECT YOUR DRINKING WATER!

Please join the Philadelphia Water Department (PWD) for two public meetings on the Combined Sewer Overflow Long-Term Control Plan Update entitled: "Green Cities, Clean Waters"

- Hear about the vision for a greener, cleaner Philadelphia and how it affects your community;
- Find out how you can help protect your drinking water;
- Provide feedback on your future!

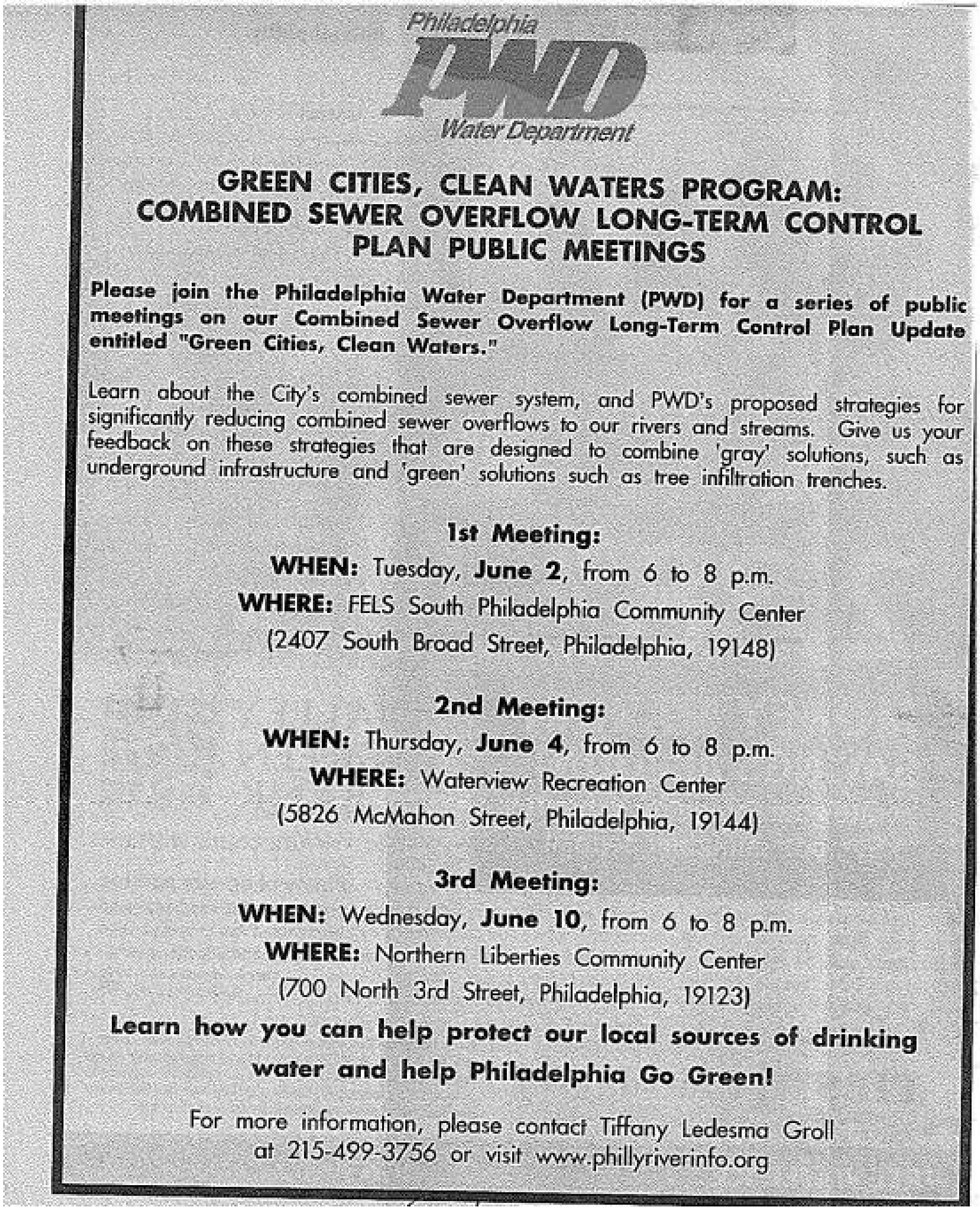
At the public meetings on December 4 and 10, PWD will review the sources of pollution that affect the creeks and rivers in your communities, and present its plan to transform Philadelphia into a green oasis!

Join us to hear the vision and strategies, and let your voice be heard!

1st Meeting:
WHEN: Thursday, December 4 from 5:30 – 7:30 p.m.
WHERE: Cobbs Creek Community Environmental Education Center
(700 Cobbs Creek Parkway, Philadelphia 19143)

2nd Meeting:
WHEN: Wednesday, December 10 from 6:00 – 8:00 p.m.
WHERE: Center in the Park
(5818 Germantown Avenue, Philadelphia, 19144)

For more information, please contact Tiffany Ledesma Groll at (215) 499-3756 or visit www.phillyriverinfo.org.



Philadelphia
PWD
Water Department

GREEN CITIES, CLEAN WATERS PROGRAM: COMBINED SEWER OVERFLOW LONG-TERM CONTROL PLAN PUBLIC MEETINGS

Please join the Philadelphia Water Department (PWD) for a series of public meetings on our Combined Sewer Overflow Long-Term Control Plan Update entitled "Green Cities, Clean Waters."

Learn about the City's combined sewer system, and PWD's proposed strategies for significantly reducing combined sewer overflows to our rivers and streams. Give us your feedback on these strategies that are designed to combine 'gray' solutions, such as underground infrastructure and 'green' solutions such as tree infiltration trenches.

1st Meeting:

WHEN: Tuesday, **June 2**, from 6 to 8 p.m.
WHERE: FELS South Philadelphia Community Center
(2407 South Broad Street, Philadelphia, 19148)

2nd Meeting:

WHEN: Thursday, **June 4**, from 6 to 8 p.m.
WHERE: Waterview Recreation Center
(5826 McMahon Street, Philadelphia, 19144)

3rd Meeting:

WHEN: Wednesday, **June 10**, from 6 to 8 p.m.
WHERE: Northern Liberties Community Center
(700 North 3rd Street, Philadelphia, 19123)

Learn how you can help protect our local sources of drinking water and help Philadelphia Go Green!

For more information, please contact Tiffany Ledesma Groll at 215-499-3756 or visit www.phillyriverinfo.org

Mount Airy Independent

8/13/09

Community Calendar

GREEN CITIES, CLEAN WATERS

Free Library, Central Branch, 1901 Vine St. "Green Cities, Clean Waters" exhibit offers ideas on improving drinking water, greening neighborhoods. Free. Through August 21. Monday-Thursday 9 a.m. – 9 p.m., Friday 9 a.m. – 6 p.m. Info: 215-499-3756.

Mount Airy Independent

8/13/09

Give Your Views on Water Issues

Philadelphia's waterways supply essential drinking water and destinations to play, fish, relax and reconnect. That's why the Philadelphia Water Department is submitting a 20-year plan to the Environmental Protection Agency that outlines how to improve our waters and green our city. Citizens are strongly encouraged to attend a public meeting and provide important feedback to City planners.

Meetings will be held from 6 to 8 pm throughout the City. Water ice will be provided to attendees.

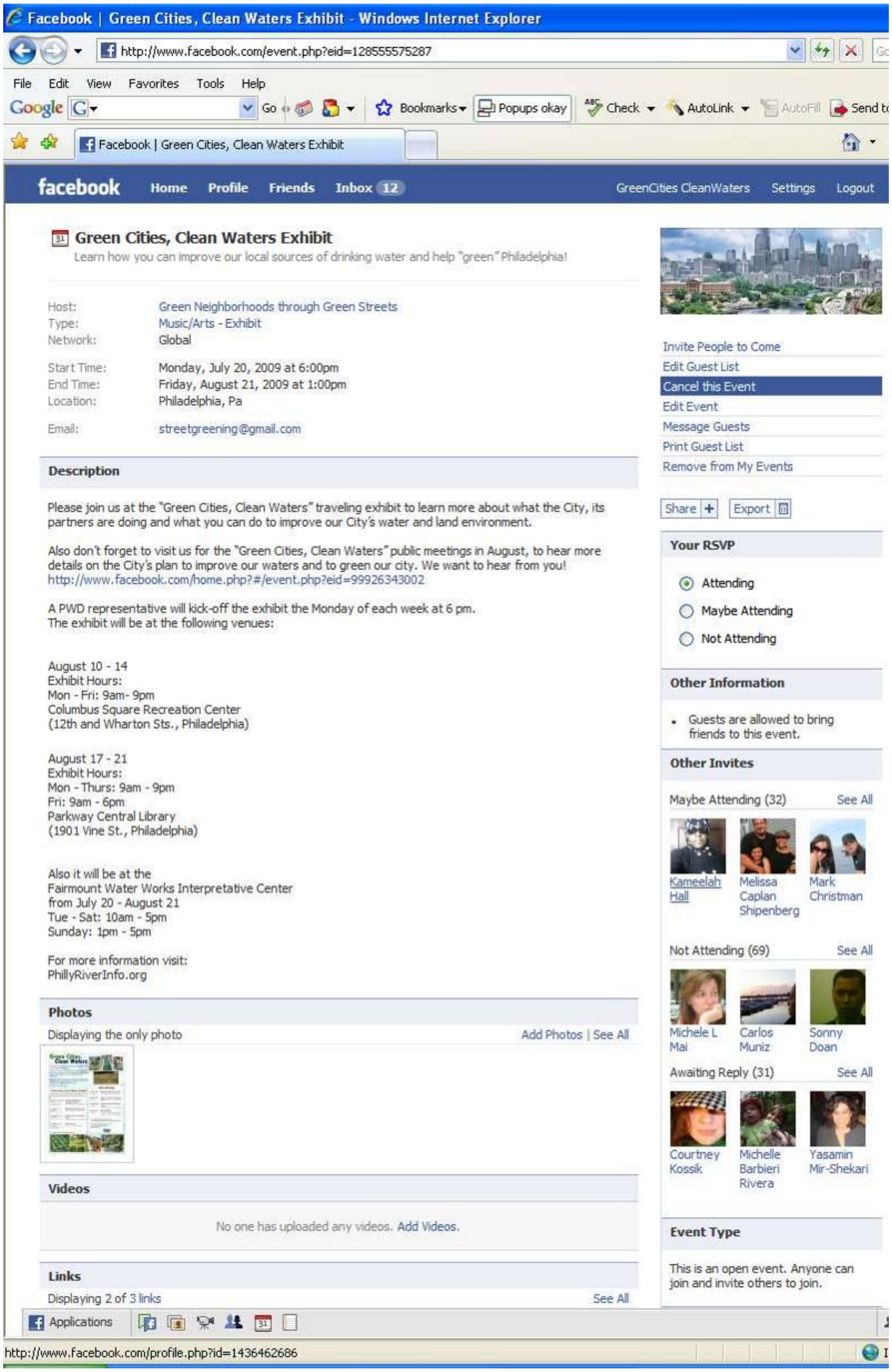
In the Northwest, the meeting will take place August 18 at Waterview Recreation Center, 5826 McMahon Street.

Other meetings will be held August 19 at the Northern Liberties Community Center, 700 North 3rd Street; August 20 at Columbus Square Recreation Center, 12th and Wharton streets; and August 25 at Mercy Hospital, 54th and Cedar streets, 7th Floor Chapel Conference Room

The Green Cities, Clean Waters program commits $1.6 billion over 20 years to capture 80 percent of the sewage and storm water that flows into the Schuylkill and Delaware Rivers and the Tacony and Cobbs creeks. A major part of the solution focuses on greening our streets, schools and public facilities.

"The program is designed to make our waterways cherished and thriving destinations, and lay the groundwork for revitalizing Philadelphia in areas of public health, recreation, housing and neighborhood values," says Joanne Dahme, Public Affairs Manager for PWD. "But we need citizens to tell us what they think before we present to the EPA on September 1."

For more information, visit www.PHILLYRIVERINFO.org/CSOLTCPU or call 215-499-3756.



Green Cities, Clean Waters Exhibit

Learn how you can improve our local sources of drinking water and help "green" Philadelphia!

Host: Green Neighborhoods through Green Streets
Type: Music/Arts - Exhibit
Network: Global

Start Time: Monday, July 20, 2009 at 6:00pm
End Time: Friday, August 21, 2009 at 1:00pm
Location: Philadelphia, Pa

Email: streetgreening@gmail.com

Description

Please join us at the "Green Cities, Clean Waters" traveling exhibit to learn more about what the City, its partners are doing and what you can do to improve our City's water and land environment.

Also don't forget to visit us for the "Green Cities, Clean Waters" public meetings in August, to hear more details on the City's plan to improve our waters and to green our city. We want to hear from you!
http://www.facebook.com/home.php?#/event.php?eid=99926343002

A PWD representative will kick-off the exhibit the Monday of each week at 6 pm.
The exhibit will be at the following venues:

August 10 - 14
Exhibit Hours:
Mon - Fri: 9am- 9pm
Columbus Square Recreation Center
(12th and Wharton Sts., Philadelphia)

August 17 - 21
Exhibit Hours:
Mon - Thurs: 9am - 9pm
Fri: 9am - 6pm
Parkway Central Library
(1901 Vine St., Philadelphia)

Also it will be at the
Fairmount Water Works Interpretative Center
from July 20 - August 21
Tue - Sat: 10am - 5pm
Sunday: 1pm - 5pm

For more information visit:
PhillyRiverInfo.org

Photos

Displaying the only photo — Add Photos | See All

Videos

No one has uploaded any videos. Add Videos.

Links

Displaying 2 of 3 links — See All

Your RSVP

● Attending
○ Maybe Attending
○ Not Attending

Other Information

- Guests are allowed to bring friends to this event.

Other Invites

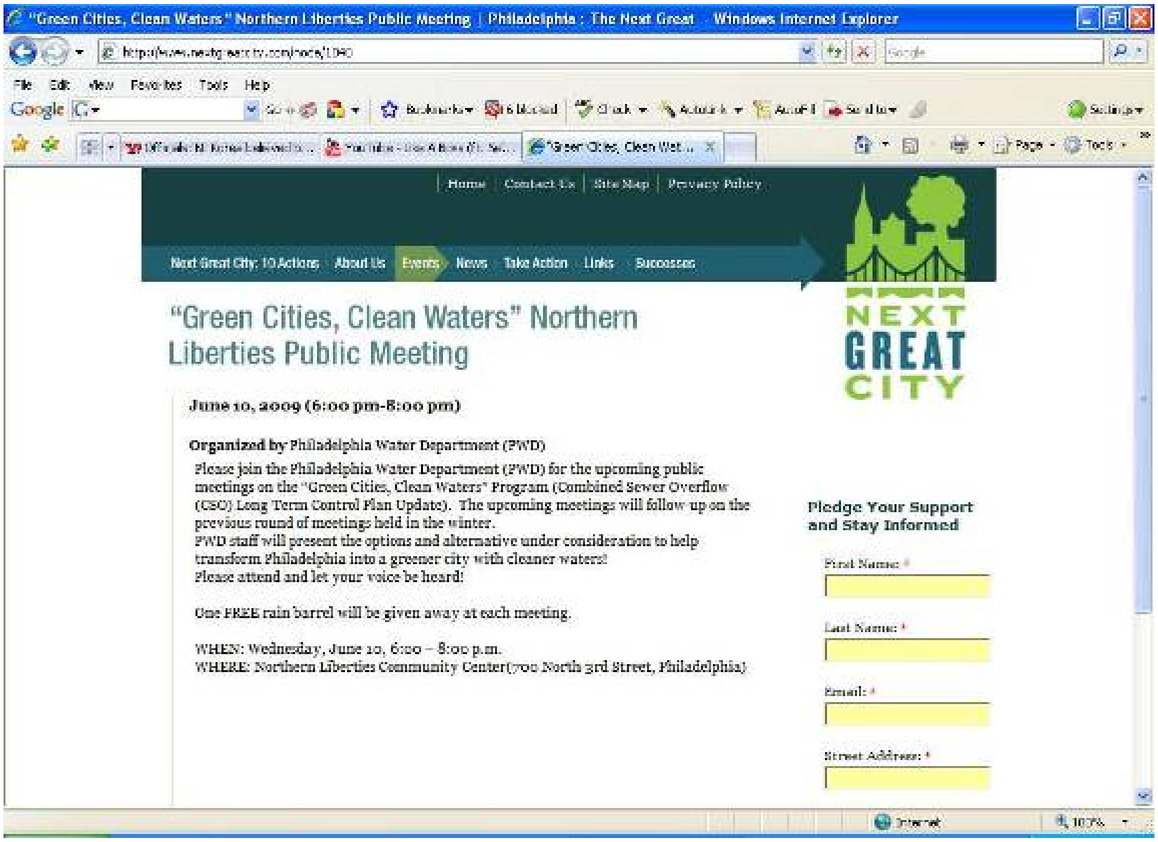
Maybe Attending (32) — See All
Kameelah Hall
Melissa Caplan Shipenberg
Mark Christman

Not Attending (69) — See All
Michele L Mai
Carlos Muniz
Sonny Doan

Awaiting Reply (31) — See All
Courtney Kossik
Michelle Barbieri Rivera
Yasamin Mir-Shekari

Event Type

This is an open event. Anyone can join and invite others to join.



"Green Cities, Clean Waters" Northern Liberties Public Meeting

June 10, 2009 (6:00 pm-8:00 pm)

Organized by Philadelphia Water Department (PWD)

Please join the Philadelphia Water Department (PWD) for the upcoming public meetings on the "Green Cities, Clean Waters" Program (Combined Sewer Overflow (CSO) Long Term Control Plan Update). The upcoming meetings will follow up on the previous round of meetings held in the winter.
PWD staff will present the options and alternative under consideration to help transform Philadelphia into a greener city with cleaner waters!
Please attend and let your voice be heard!

One FREE rain barrel will be given away at each meeting.

WHEN: Wednesday, June 10, 6:00 – 8:00 p.m.
WHERE: Northern Liberties Community Center(700 North 3rd Street, Philadelphia)

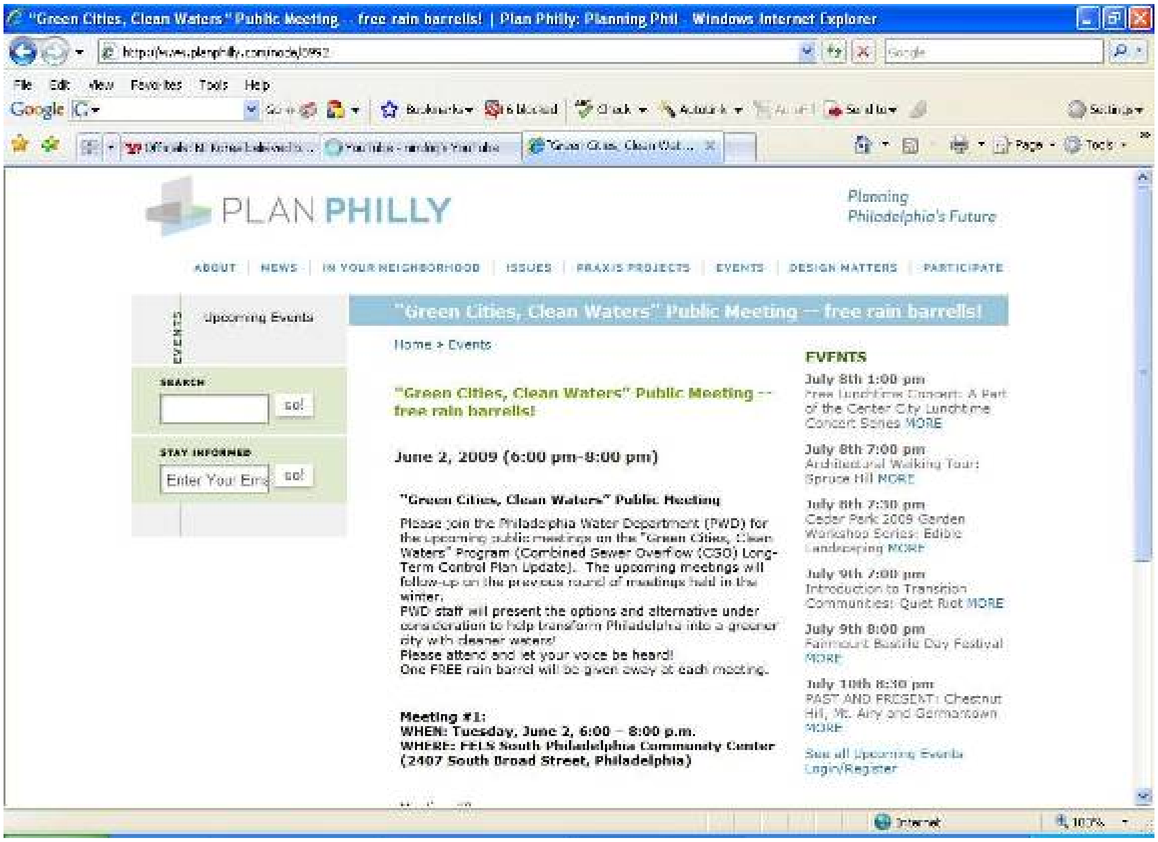
Pledge Your Support and Stay Informed

First Name: *

Last Name: *

Email: *

Street Address: *



"Green Cities, Clean Waters" Public Meeting -- free rain barrells!

Home > Events

"Green Cities, Clean Waters" Public Meeting -- free rain barrells!

June 2, 2009 (6:00 pm-8:00 pm)

"Green Cities, Clean Waters" Public Meeting

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PWD staff will present the options and alternative under consideration to help transform Philadelphia into a greener city with cleaner waters!
Please attend and let your voice be heard!
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Meeting #1:
WHEN: Tuesday, June 2, 6:00 – 8:00 p.m.
WHERE: FELS South Philadelphia Community Center (2407 South Broad Street, Philadelphia)

EVENTS

July 8th 1:00 pm
Free Lunchtime Concert: A Part of the Center City Lunchtime Concert Series MORE

July 8th 7:00 pm
Architectural Walking Tour: Spruce Hill MORE

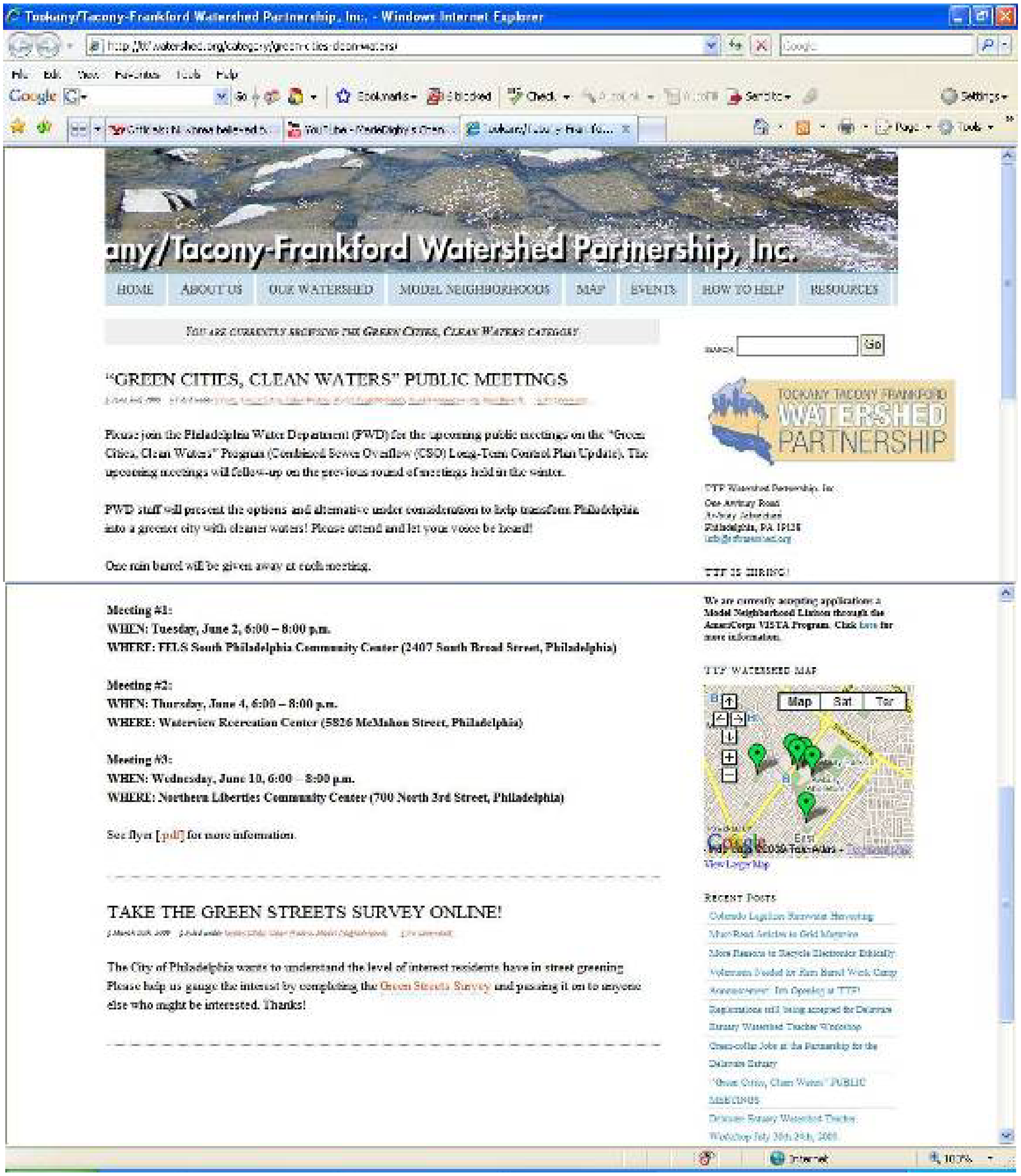
July 8th 7:30 pm
Cedar Park 2009 Garden Workshop Series: Edible Landscaping MORE

July 9th 7:00 pm
Introduction to Transition Communities: Quiet Riot MORE

July 9th 8:00 pm
Fairmount Bastille Day Festival MORE

July 10th 6:30 pm
PAST AND PRESENT: Chestnut Hill, Mt. Airy and Germantown MORE

See all Upcoming Events
Login/Register



any/Tacony-Frankford Watershed Partnership, Inc.

HOME | ABOUT US | OUR WATERSHED | MODEL NEIGHBORHOODS | MAP | EVENTS | HOW TO HELP | RESOURCES

You are currently browsing the Green Cities, Clean Waters category

"GREEN CITIES, CLEAN WATERS" PUBLIC MEETINGS

[illegible]

Please join the Philadelphia Water Department (PWD) for the upcoming public meetings on the "Green Cities, Clean Waters" Program (Combined Sewer Overflow (CSO) Long-Term Control Plan Update). The upcoming meetings will follow-up on the previous round of meetings held in the winter.

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WHERE: FELS South Philadelphia Community Center (2407 South Broad Street, Philadelphia)

Meeting #2:
WHEN: Thursday, June 4, 6:00 – 8:00 p.m.
WHERE: Waterview Recreation Center (5826 McMahon Street, Philadelphia)

Meeting #3:
WHEN: Wednesday, June 10, 6:00 – 8:00 p.m.
WHERE: Northern Liberties Community Center (700 North 3rd Street, Philadelphia)

See flyer [pdf] for more information.

TAKE THE GREEN STREETS SURVEY ONLINE!

March [illegible], 2009 | Filed under [illegible]

The City of Philadelphia wants to understand the level of interest residents have in street greening. Please help us gauge the interest by completing the Green Streets Survey and passing it on to anyone else who might be interested. Thanks!

SEARCH ☐ Go

TOOKANY TACONY FRANKFORD WATERSHED PARTNERSHIP

TTF Watershed Partnership, Inc
One Awbury Road
Awbury Arboretum
Philadelphia, PA 19138
info@ttfwatershed.org

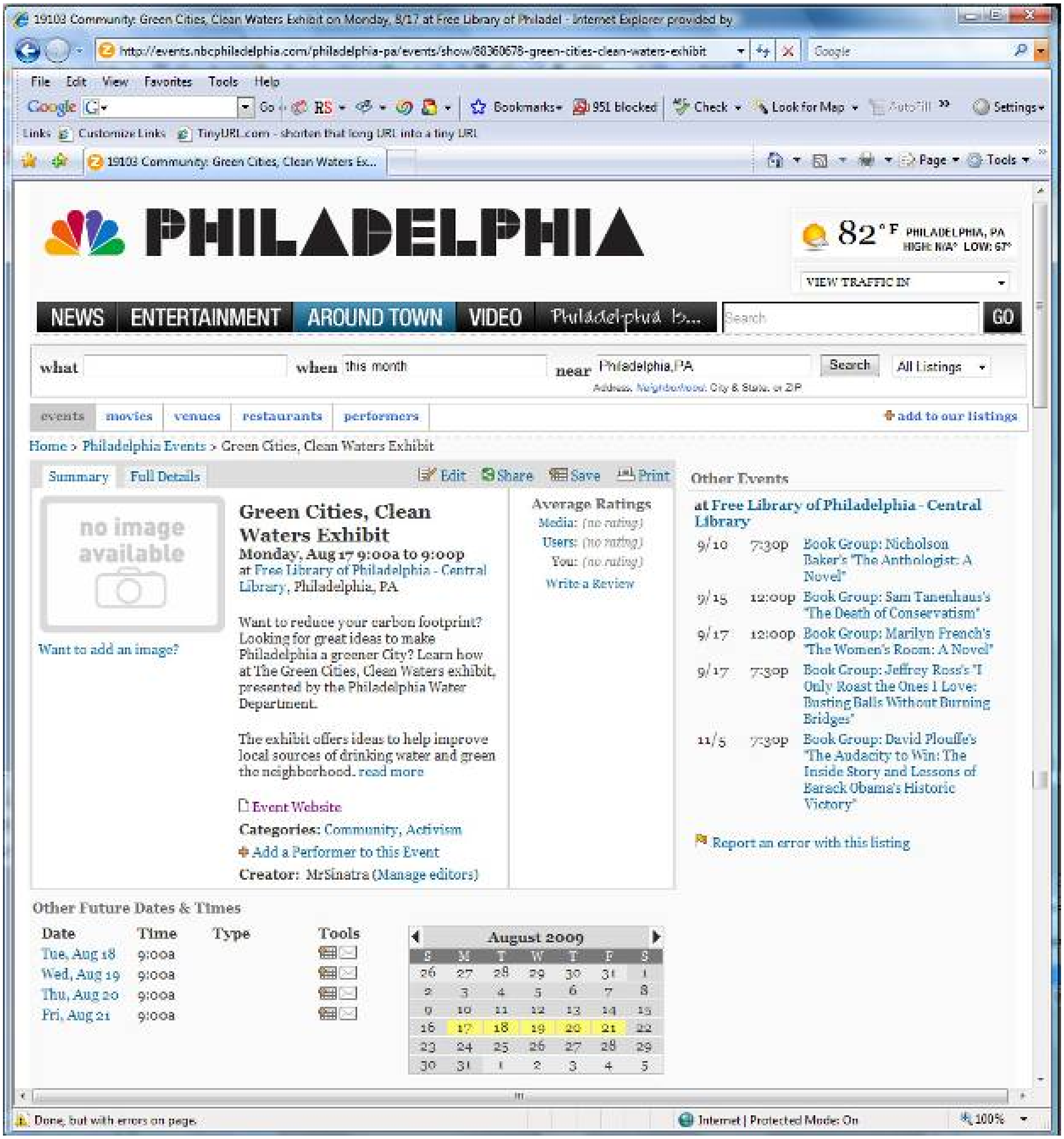
TTF IS HIRING!

We are currently accepting applications a **Model Neighborhood Liaison through the AmeriCorps VISTA Program.** Click here for more information.

TTF WATERSHED MAP

RECENT POSTS

- Colorado Legalizes Rainwater Harvesting
- Main Road Article in Grid Magazine
- More Reasons to Recycle Electronics Ethically
- Volunteers Needed for Rain Barrel Work Camp
- Announcement: Job Opening at TTF!
- Registrations still being accepted for Delaware Estuary Watershed Teacher Workshop
- Green-collar Jobs at the Partnership for the Delaware Estuary
- "Green Cities, Clean Waters" PUBLIC MEETINGS
- Delaware Estuary Watershed Teacher Workshop July 20th-24th, 2009



Home > Philadelphia Events > Green Cities, Clean Waters Exhibit

Want to add an image?

Green Cities, Clean Waters Exhibit

Monday, Aug 17 9:00a to 9:00p
at Free Library of Philadelphia - Central Library, Philadelphia, PA

Want to reduce your carbon footprint? Looking for great ideas to make Philadelphia a greener City? Learn how at The Green Cities, Clean Waters exhibit, presented by the Philadelphia Water Department.

The exhibit offers ideas to help improve local sources of drinking water and green the neighborhood. read more

Event Website

Categories: Community, Activism

Add a Performer to this Event

Creator: MrSinatra (Manage editors)

Average Ratings
Media: *(no rating)*
Users: *(no rating)*
You: *(no rating)*
Write a Review

Other Events

at Free Library of Philadelphia - Central Library

9/10	7:30p	Book Group: Nicholson Baker's "The Anthologist: A Novel"
9/15	12:00p	Book Group: Sam Tanenhaus's "The Death of Conservatism"
9/17	12:00p	Book Group: Marilyn French's "The Women's Room: A Novel"
9/17	7:30p	Book Group: Jeffrey Ross's "I Only Roast the Ones I Love: Busting Balls Without Burning Bridges"
11/5	7:30p	Book Group: David Plouffe's "The Audacity to Win: The Inside Story and Lessons of Barack Obama's Historic Victory"

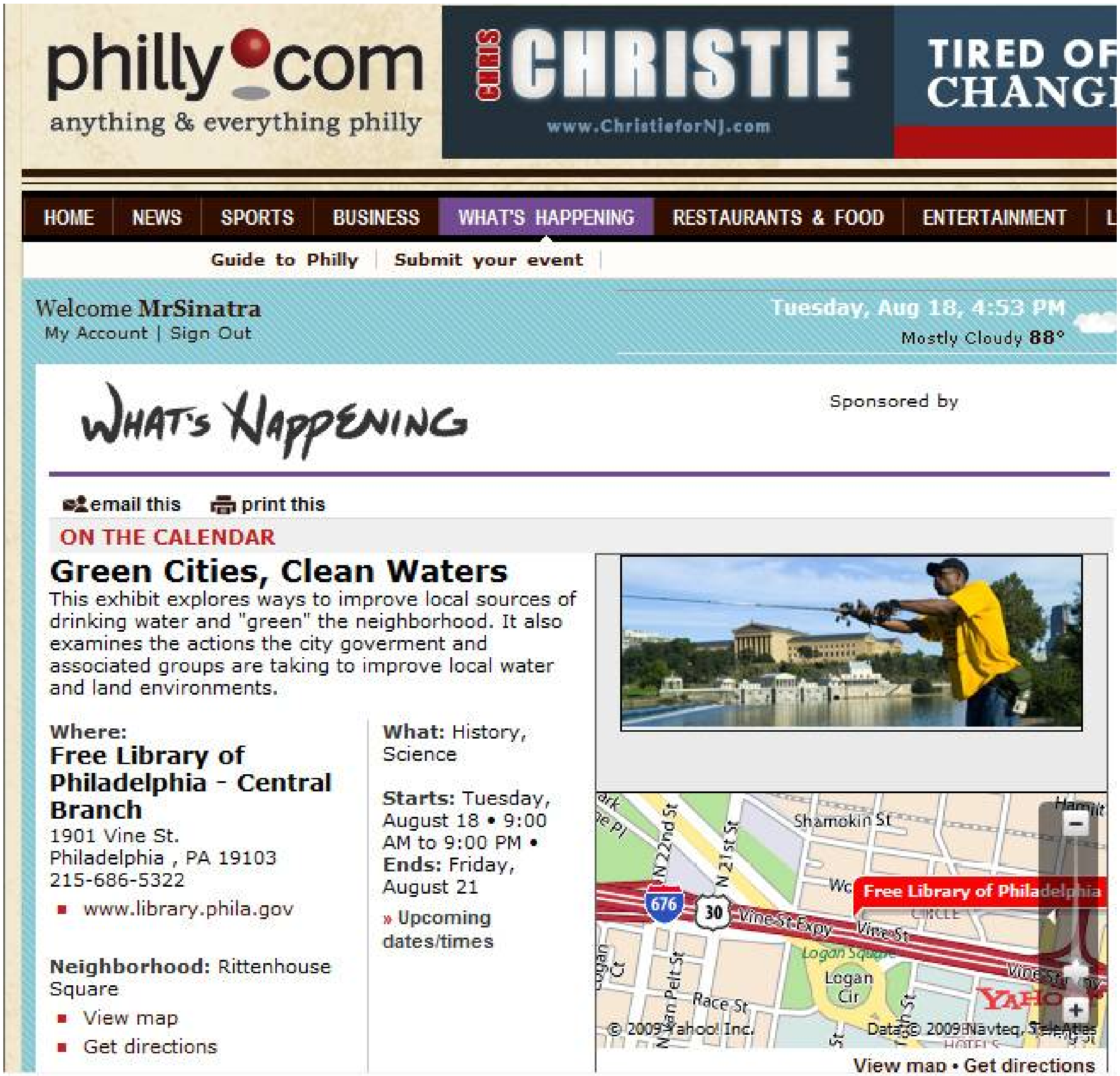
Report an error with this listing

Other Future Dates & Times

Date	Time	Type	Tools
Tue, Aug 18	9:00a		
Wed, Aug 19	9:00a		
Thu, Aug 20	9:00a		
Fri, Aug 21	9:00a		

August 2009

S	M	T	W	T	F	S
26	27	28	29	30	31	1
2	3	4	5	6	7	8
9	10	11	12	13	14	15
16	17	18	19	20	21	22
23	24	25	26	27	28	29
30	31	1	2	3	4	5



Welcome **MrSinatra**
My Account | Sign Out

Tuesday, Aug 18, 4:53 PM
Mostly Cloudy **88°**

WHAT'S HAPPENING

Sponsored by

ON THE CALENDAR

Green Cities, Clean Waters

This exhibit explores ways to improve local sources of drinking water and "green" the neighborhood. It also examines the actions the city goverment and associated groups are taking to improve local water and land environments.

Where:
Free Library of Philadelphia - Central Branch
1901 Vine St.
Philadelphia , PA 19103
215-686-5322

- www.library.phila.gov

Neighborhood: Rittenhouse Square

- View map
- Get directions

What: History, Science

Starts: Tuesday, August 18 • 9:00 AM to 9:00 PM • **Ends:** Friday, August 21

» Upcoming dates/times

Philly.com

SoPhReview

Name South Philly Review
Location South Philadelphia, PA
Web http://www.southp...
Bio The Review is a weekly community newspaper that serves the South Philadelphia area with news, sports, features, columns and more.

65 following 137 followers

Tweets 51

Favorites

Actions
block SoPhReview

Following

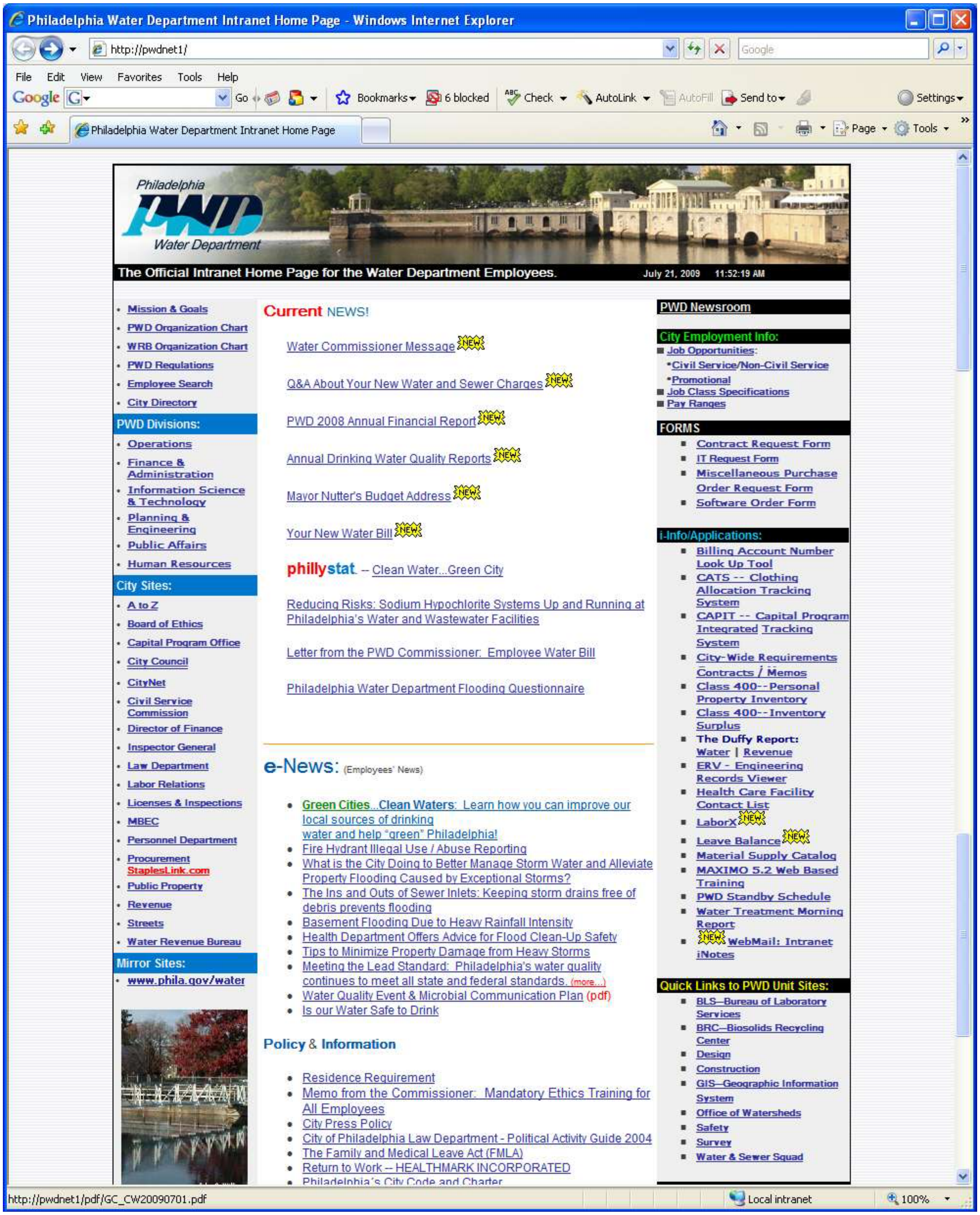
PWD “Green Cities, Clean Waters" exhibit 6 p.m. through Aug 14. Columbus Square Rec Center, 12th and Wharton streets. http://bit.ly/1155UC.
about 2 hours ago from bit.ly

The South Street Headhouse District's S.O.S. Movie Series w/ “Beethoven” 8 p.m. tonight. Second and Lombard streets. http://bit.ly/kVmVJ.
about 3 hours ago from bit.ly

Fox29 John Atwater's photos are in “Artist of the Month” series 6-8 p.m. Aug. 11 JimmyStyle, 1820 E. Passyunk Ave. http://bit.ly/17uDRv.
about 23 hours ago from bit.ly

Health Commissioner Donald F. Schwarz issued an Excessive Heat Watch for Philadelphia today.
10:54 AM Aug 11th from web

Twitter.com



The Official Intranet Home Page for the Water Department Employees. July 21, 2009 11:52:19 AM

- Mission & Goals
- PWD Organization Chart
- WRB Organization Chart
- PWD Regulations
- Employee Search
- City Directory

PWD Divisions:

- Operations
- Finance & Administration
- Information Science & Technology
- Planning & Engineering
- Public Affairs
- Human Resources

City Sites:

- A to Z
- Board of Ethics
- Capital Program Office
- City Council
- CityNet
- Civil Service Commission
- Director of Finance
- Inspector General
- Law Department
- Labor Relations
- Licenses & Inspections
- MBEC
- Personnel Department
- Procurement StaplesLink.com
- Public Property
- Revenue
- Streets
- Water Revenue Bureau

Mirror Sites:

- www.phila.gov/water

Current NEWS!

Water Commissioner Message NEW

Q&A About Your New Water and Sewer Charges NEW

PWD 2008 Annual Financial Report NEW

Annual Drinking Water Quality Reports NEW

Mayor Nutter's Budget Address NEW

Your New Water Bill NEW

phillystat -- Clean Water...Green City

Reducing Risks: Sodium Hypochlorite Systems Up and Running at Philadelphia's Water and Wastewater Facilities

Letter from the PWD Commissioner: Employee Water Bill

Philadelphia Water Department Flooding Questionnaire

e-News: (Employees' News)

- Green Cities...Clean Waters: Learn how you can improve our local sources of drinking water and help "green" Philadelphia!
- Fire Hydrant Illegal Use / Abuse Reporting
- What is the City Doing to Better Manage Storm Water and Alleviate Property Flooding Caused by Exceptional Storms?
- The Ins and Outs of Sewer Inlets: Keeping storm drains free of debris prevents flooding
- Basement Flooding Due to Heavy Rainfall Intensity
- Health Department Offers Advice for Flood Clean-Up Safety
- Tips to Minimize Property Damage from Heavy Storms
- Meeting the Lead Standard: Philadelphia's water quality continues to meet all state and federal standards. (more...)
- Water Quality Event & Microbial Communication Plan (pdf)
- Is our Water Safe to Drink

Policy & Information

- Residence Requirement
- Memo from the Commissioner: Mandatory Ethics Training for All Employees
- City Press Policy
- City of Philadelphia Law Department - Political Activity Guide 2004
- The Family and Medical Leave Act (FMLA)
- Return to Work -- HEALTHMARK INCORPORATED
- Philadelphia's City Code and Charter

PWD Newsroom

City Employment Info:

- Job Opportunities:
  - Civil Service/Non-Civil Service
  - Promotional
- Job Class Specifications
- Pay Ranges

FORMS

- Contract Request Form
- IT Request Form
- Miscellaneous Purchase Order Request Form
- Software Order Form

i-Info/Applications:

- Billing Account Number Look Up Tool
- CATS -- Clothing Allocation Tracking System
- CAPIT -- Capital Program Integrated Tracking System
- City-Wide Requirements Contracts / Memos
- Class 400--Personal Property Inventory
- Class 400--Inventory Surplus
- The Duffy Report: Water | Revenue
- ERV - Engineering Records Viewer
- Health Care Facility Contact List
- LaborX NEW
- Leave Balance NEW
- Material Supply Catalog
- MAXIMO 5.2 Web Based Training
- PWD Standby Schedule
- Water Treatment Morning Report
- NEW WebMail: Intranet iNotes

Quick Links to PWD Unit Sites:

- BLS--Bureau of Laboratory Services
- BRC--Biosolids Recycling Center
- Design
- Construction
- GIS--Geographic Information System
- Office of Watersheds
- Safety
- Survey
- Water & Sewer Squad

http://pwdnet1/pdf/GC_CW20090701.pdf

Green Cities, Clean Waters

Public Meeting

Please join the Philadelphia Water Department (PWD) for a public meeting on the Green Cities, Clean Waters Program (Combined Sewer Overflow (CSO) Long Term Control Plan Update).

Meeting Locations and Times

Thursday, December 4th - 5:30-7:30 p.m.
Cobbs Creek Community Environmental Education Center
(700 Cobb Creek Parkway, Philadelphia)
Wednesday, December 10th - 6:00-8:00 p.m.
Center in the Park
(5818 Germantown Avenue, Philadelphia)

These meetings are a follow-up to the previous round of meetings held last spring. PWD will present the problems of the creeks and rivers, the sources of pollution and the vision behind the goals that will help transform Philadelphia into a greener city with cleaner waters.

Give us your feedback on these strategies
and let your voice be heard!

Contact Tiffany Ledesma Groll at:
ledesmagrollta@cdm.com or (215) 499-3756 with questions

PUBLIC MEETINGS

GREEN CITIES, CLEAN WATERS

Please join the Philadelphia Water Department (PWD) for a series of public meetings on our Combined Sewer Overflow Long-Term Control Plan Update, entitled "Green Cities, Clean Waters."

Learn about the City's combined sewer system, and PWD's proposed strategies for reducing combined sewer overflows to our rivers and streams. Give us your feedback on these strategies that are designed to combine 'gray' solutions, such as underground tunnels, and 'green' solutions, such as rain gardens and tree trenches.

PUBLIC MEETINGS

1st Meeting:	2nd Meeting:	3rd Meeting:
WHEN: Tuesday, June 2, 2009 6:00 – 8:00 p.m.	**WHEN:** Thursday, June 4, 2009 6:00 – 8:00 p.m.	**WHEN:** Wednesday, June 10, 2009 6:00 – 8:00 p.m.
WHERE: FELS South Philadelphia Community Center (2407 South Broad Street, Philadelphia)	**WHERE:** Waterview Recreation Center (5826 McMahon Street, Philadelphia)	**WHERE:** Northern Liberties Community Center (700 North 3rd Street, Philadelphia)

Rain Barrel Drawing: We will give away 1 *FREE* rain barrel at each public meeting!

Learn how you can help protect our local sources of drinking water and help Philadelphia Go Green!

For more information, please visit
www.phillyriverinfo.org
or contact Tiffany Ledesma Groll at LedesmaGrollTD@cdm.com or (215) 499-3756

Philadelphia PWD Water Department

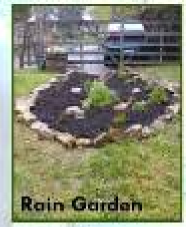
Green Cities, Clean Waters

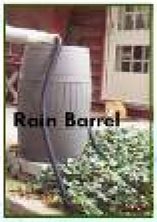
Learn how you can improve our local sources of drinking water and help "green" Philadelphia!

Please join us at the "Green Cities, Clean Waters" exhibit to learn more about what the City and its partners are doing (and what *you* can do) to improve our City's water and land environment.

Also, don't forget to visit us for the "Green Cities, Clean Waters" *public meetings* in August, to hear more details on the City's plan to improve our waters and to green our city.

We want to hear from you!





Green Cities, Clean Waters Exhibits

A Philadelphia Water Department representative will kick-off the exhibit the Monday of each week at 6 pm.

July 27 - 31 Exhibit Hours Mon, Wed: 12pm - 8pm Tue, Thurs: 10pm - 5pm Fri: 10pm - 5pm	**Free Library West Philadelphia Branch** (40th and Walnut Sts., Philadelphia)
July 21 - August 21 Exhibit Hours Tue - Sat: 10am - 5pm Sunday: 1pm - 5pm	**Fairmount Water Works Interpretive Center*** (640 Waterworks Dr., Philadelphia)
August 3 - 7 Exhibit Hours Mon - Fri: 7am - 9pm	**Waterview Recreation Center** (5826 McMahon St., Philadelphia)
August 10 - 14 Exhibit Hours Mon - Fri: 9am - 9pm	**Columbus Square Recreation Center** (12th and Wharton Sts., Philadelphia)
August 17 - 21 Exhibit Hours Mon - Thurs: 9am - 9pm Fri: 9am - 6pm	**Central Library** (1901 Vine St., Philadelphia)

* A speaker will not be available at this site.

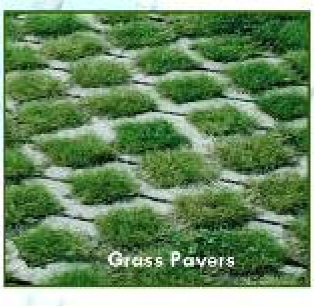
Public Meetings

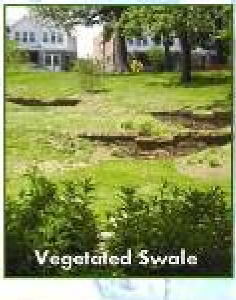
August 18 6 - 8 pm	**Waterview Recreation Center** (5826 McMahon St., Philadelphia)
August 19 6 - 8 pm	**Northern Liberties Community Center** (700 N 3rd St., Philadelphia)
August 20 6 - 8 pm	**Columbus Square Recreation Center** (12th and Wharton Sts., Philadelphia)
August 25 6 - 8 pm	**Mercy Hospital** 7th Floor Chapel Conference Room (54th and Cedar Sts., Philadelphia)

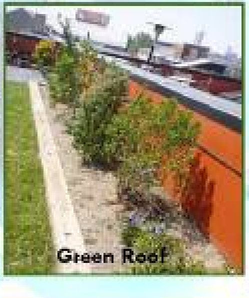
For more information, please visit:
www.PHILLYRIVERINFO.org/CSOLTCPU

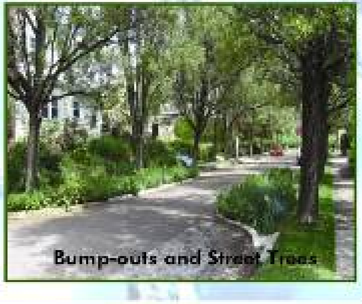
Or contact Tiffany Ledesma Groll:
LedesmagrollTD@cdm.com
(215) 499-3756

Philadelphia PWD Water Department









South Philly review

NEWS – JUN 11, 2009

Let it seep in

by Amanda Snyder

Three local areas are already part of The Water Department's long-term plan to prevent sewers from overflowing and to make the city greener. More learned how to become part of the mix last week.

Marc Cammarata, manager of watershed planning and engineering for the Philadelphia Water Department, presented the long-term plan to lessen combined sewer overflow in the city (Staff Photo by Greg Bezanis).

Public Meetings, Series #1

Philadelphia
PWD
Water Department

PWD CSOLTCPU Public Meeting #1
Port Richmond Library
Wednesday, April 2 from 5:45 – 7:45 p.m.

Please Sign In

Name	Organization	Email
Melanie Garrow	PWD	melanie.garrow@phila.gov
Diane Wilcox	New Kensington CDC	dwilcox@nkcdc.org
Joe McNulty	"	jmcnulty@nkcdc.org
Elizabeth K. Brown	Delaware Riverkeeper Network	elizabeth@delawareriverkeeper.org
Andrew Sinclair	PA DEP	asinclair@state.pa.us
Stephen Maakestad	Hatch Mott MacDonald	stephen.maakestad@hatchmott.com
William Plymouth	PWD	Belmont water treatment plant
Ted Lahm	Resident	
Joanne Dahme	PWD	joanne.dahme@phila.gov
Dwayne Myers	CDM	myersrd@cdm.com

Start **1101 Market St**
Philadelphia, PA 19107
End **2987 Almond St**
Philadelphia, PA 19134
Travel **4.1 mi – about 11 mins**

1101 Market St
Philadelphia, PA 19107
Drive: 4.1 mi – about 11 mins

	1. Head **east** on **Market St** toward **N 11th St**	0.5 mi 2 mins
←	2. Turn **left** at **N 5th St**	0.2 mi 1 min
→	3. Slight **right** to stay on **N 5th St**	397 ft
→	4. Turn **right** at **Race St**	0.3 mi 1 min
←	5. Merge onto **I-95 N** via the ramp on the **left** to **Trenton/NE Phila**	1.2 mi 2 mins
	6. Take exit **23** toward **Girard Ave/Lehigh Ave**	0.3 mi 1 min
	7. Merge onto **N Delaware Ave**	0.3 mi 1 min
	8. Continue on **Richmond St**	0.9 mi 2 mins
←	9. Turn **left** at **E Ann St**	0.2 mi 1 min
→	10. Turn **right** at **Almond St**	269 ft

2987 Almond St
Philadelphia, PA 19134

These directions are for planning purposes only. You may find that construction projects, traffic, or other events may cause road conditions to differ from the map results.

Map data ©2008 NAVTEQ™, Sanborn

Overview

Start

End

Map data ©2008 NAVTEQ™, Sanborn

PWD CSOLTCPU Public Meeting #1
Port Richmond Library
Wednesday, April 2 from 5:45 – 7:45 p.m.

Comments/Questions paraphrased:
Unknown asked: Is the I & Ramona project already installed.
Joanne Dahme responded that the project is currently in design and will go out to bid this summer.

Unknown asked: Are you going to have to have a storage tank or diversion system for every one of the 164 outfalls?
Joanne Dahme responded that we will be looking at the drainage area to each outfall to find the most cost-effective solution.

Unknown asked: Why were people in the NE so upset about the proposed tank?
Joanne Dahme responded that we should have done more outreach to explain the tank. Joanne also explained current solution.

Unknown asked: Cost comparison between Holy Family tank and new pipe solution?
Joanne Dahme responded that implementation costs were comparable; maintenance may be easier for piping solution.

Unknown asked: Are we (PWD) in talks with PENNDOT about SW for Girard interchange work?
Joanne Dahme explained our talks with PENNDOT and how we expect them to adhere to our SW regulations.

Unknown asked: With marshlands that filter SW, do they ever get clogged?
Joanne Dahme explained periodic cleaning of sedimentation fore bay.

Unknown asked: Why do we allow garbage disposals in Philly?
Joanne Dahme explained that it is part of the plumbing code. Explained that we need outreach to help people understand how their garbage disposal affects sewer system. Conversation ensued on cities that change/prohibit garbage disposals.

Unknown asked: Are grey water systems illegal in Philly?
Joanne Dahme explained meeting with L & I to allow downspout disconnects where applicable with permission from PWD. Joanne explained rain barrel program.

Unknown commented: It seems like you are going to do as much green as possible and then moving to gray.

Unknown asked: Does the National Policy require Green Projects?
Joanne Dahme responded that EPA put out a paper that recognized the green approach.

Unknown commented: Recommendation to bring in political science people to help PWD interact with the public.

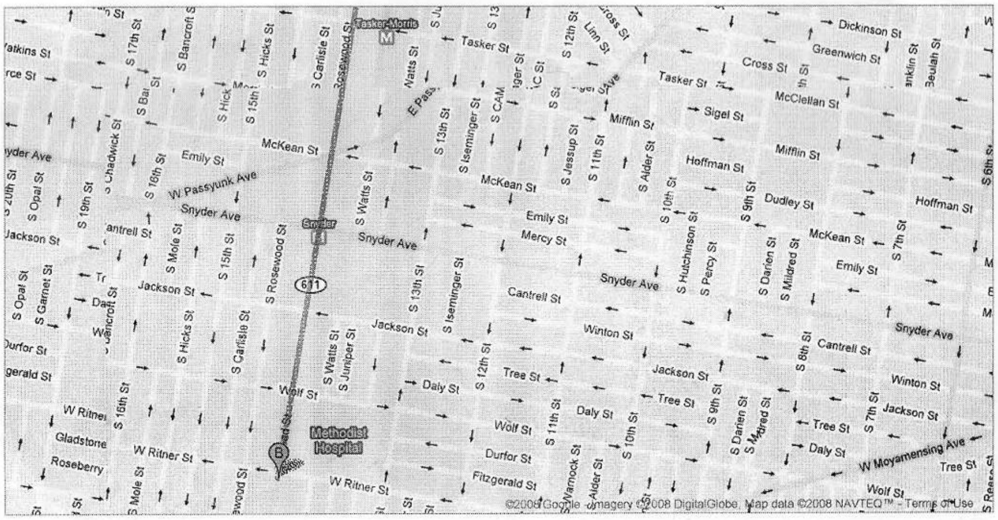
Philadelphia
PWD
Water Department

PWD CSOLTCPU Public Meeting #2
Fels Community Center
Thursday, April 10 from 6:00 – 8:00 p.m.

Please Sign In

Name	Organization	Email
Megan Malloy	FWWIC	megan.malloy@gmail.com
HARRY LASPEE	RESIDENT/PENNONI ASSOC	hlaspee@pennoni.com
TIFFANY LEDESMA	GROLL Consultant w/PWD	ledesmagrolltd@cdm.com
Laura Rozumalski	PWD	laura.rozumalski@pwd.gov
Jim Smullen	CDM	SMULLENJT@CDM.COM
Marc Cammarata	PWD-OOW	marc.cammarata@phila.gov

Google Maps



☐ Avoid highways

1101 Market St
Philadelphia, PA 19107
Drive: 2.7 mi – about 10 mins

1. Head **east** on **Market St** toward **N 11th St** 0.1 mi
2. Turn **right** at **S 10th St** 0.2 mi
3. Turn **right** at **Sansom St** 0.4 mi
4. Turn **left** at **S Broad St/PA-611** 2.1 mi

2407 S Broad St
Philadelphia, PA 19148

Harry / Meg
Lespee / Malloy

PWD CSOLTCPU Public Meeting #1
FELS Center
Thursday, April 10 from 6:00 – 8:00 p.m.

Comments/Questions

Name:

Meg Malloy

Comment/Question:

"I do like the strategy."

Think its key – ex: that you show

☆ Makes it real. gives a pt in real life +

brings it home – makes it personal

I wish more people could see the photos

how bout @ FMAIC

Name:

Harry Lespee

Comment/Question:

– "Yeah I think its a great idea"

Takes a while to get the world out to the public. They are busy

– compared to the recycling program. Took a while to take hold

– Rain barrels

Partnering w/ community groups + associations help build momentum → leads to individual action

Name:

Harry Lespee

Comment/Question:

Do you keep track of how many rain barrels are ~~deploy~~e out there.

Name:

Meg Malloy

Comment/Question:

For these projects do you analyze, study, model the benefits.

Nice to show/refer to sites that show effectiveness

Green Roofs - IN PHILA
17!

①
"I like the strategy"
↳ Meg

② "I think it takes a while to get the word out to public b/c people are busy w/ their lives." (Yes - exhibit ~~this~~ at FWWIC)
↳ Penoni

"It may also be economics b/c people may not be able to afford to buy rain gardens, so work w/ communities/ associations - groups"
↳ Penoni

③ Examples are key
↳ i.e. Penn Alexander
Meg's ↳ Specifics w/ locations - that ~~it~~ hits home. People realize what's there.
(Yes - Nice to do more BMP tour)

④ - Do you monitor how many rain barrels you've distributed? - Penoni (Yes)

⑤ "W/ some of these projects, can you calculate the impact that results from projects?" - Meg
(Yes - w/ Infrastructure projects)
+ w/ green
harder to quantify but works!
look @ Porous Pavement

⑥ SW

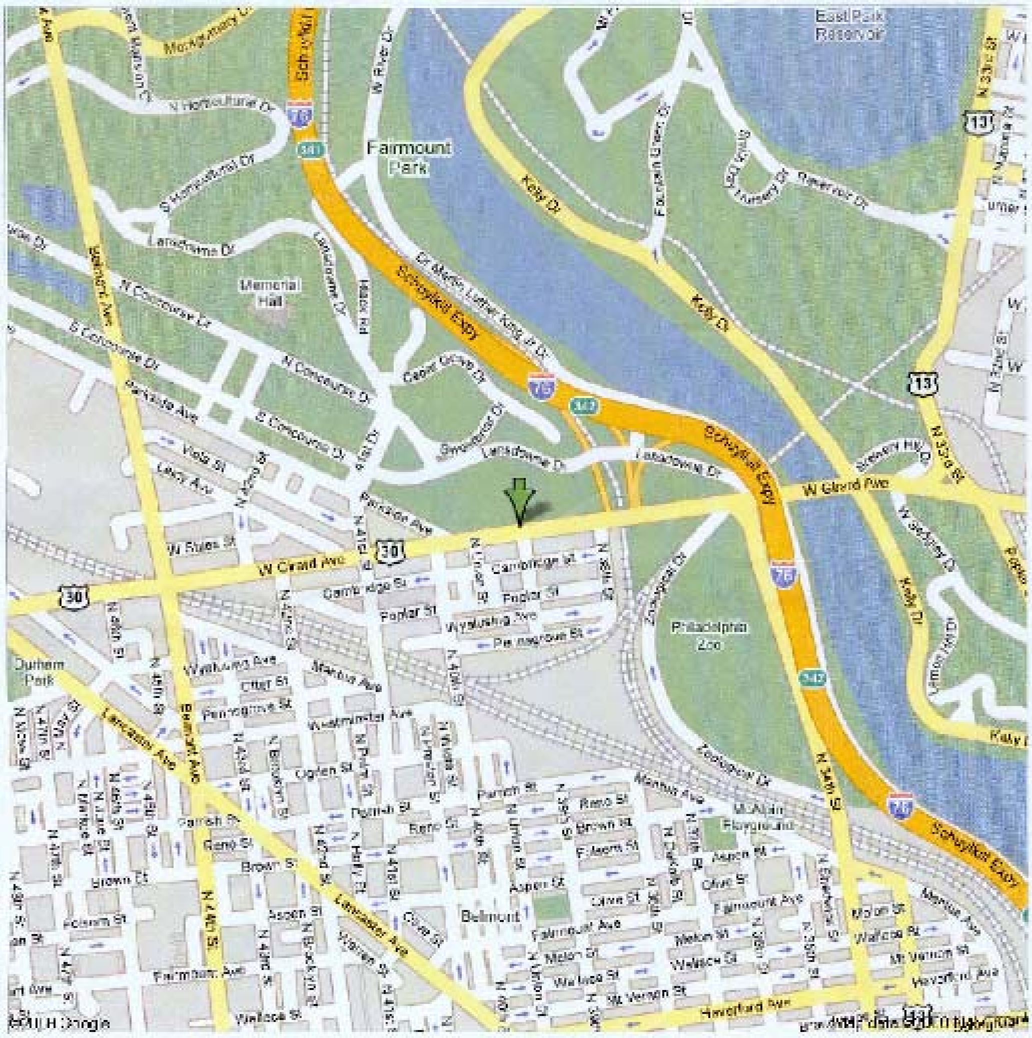
Philadelphia PWD Water Department

PWD CSOLTCPU Public Meeting #1
School of the Future
Thursday, April 24 from 6:00 – 8:00 p.m.

Please Sign In

Name	Organization	Email
Leonard Simmons	Water Dept	
DAVID BURKE	PADEP	dburke@state.pa.us
Marc Cammarata	PWD - OOW	marc.cammarata@phila.gov
Melanie Garrow	PWD - OOW	melanie.garrow@phila.gov
TIFFANY LEDESMA	PWD-OOW	[illegible]
SARAH CORBISIERO	TTF	sarah@ttfwatershed tledesmagrolitd@cdm.com
EDWARD CHOW	CENTER IN THE PARK SEC	chflood@aol.com
Johnnie M. Henderson	CIP SEC	jhenderson@centerinthepark.org
Carrie Lewis	CIP SEC	
FRED LEWIS	CIP / SEC	FLEWIS@CENTERINTHEPARK.ORG
Daryl Tripp	" "	Trippdary1@yahoo.com
Marcel A. Hannah	[illegible]	[illegible]
Tony Federici	Resident / URS	antonio_federici@urscorp.com
CALVIN DAVENGER	PHILA. INT. AIRPORT	CALVIN.DAVENGER@PHL.ORG
DARCEL D. DAVENGER	School District of Phila.	dddavenger@AOL.COM
Andrew Goodman	PennPraxis	agoodman@design.upenn.edu
JAMES G. BRADLEY	PWD	JAMES.G.BRADLEY@Phila.gov
DAVID M.EL	PWD FOX ST.	David.McBride@phila.gov
Jim Smullen	CDM	SMULLENJT@CDM.COM
JS		

Address **4021 Parkside Ave**
Philadelphia, PA 19104



PWD CSOLTCPU Public Meeting #1
School of Future
Thursday, April 24 from 6:00 – 8:00 p.m.

Comments/Questions

Name: CALVIN DAVINGER

Comment/Question:
Do you have Capital project designs now? SPECIFICALLY WETLAND PROJECT;
Marc said YES! → Columbus Square
Mill Creek Tree Trench, Mill Creek Porous Pavement,
" " Outdoor Rain Garden

Name: MRS. DAVINGER

Comment/Question:
How do you keep weeds down (with all of the green stuff) ?
We work w/ partners to help us maintain the sites, such as community groups, BUT PWD will also work O+M into place + it's not as intensive as one thinks → minimal maintenance.

Imagine a Philadelphia like this…

Image credit: PENN Praxis

Image credit: PENN Praxis

Image credit: PENN Praxis

NN Praxis

Your School

Image credit: GreenPlan Philadelphia

Your School

Image credit: GreenPlan Philadelphia

Your Home

Image credit: GreenPlan Philadelphia

Your Home

Your Neighborhood

Your Neighborhood

Image credit: PENN Praxis

Your Neighborhood

Image credit: PENN Praxis

Your Streets

Image credit: GreenPlan Philadelphia

Your Streets

Image credit: GreenPlan Philadelphia

Your Streets

Image credit: PENN Praxis

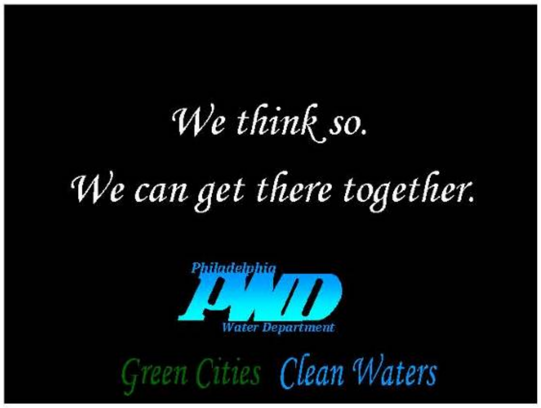
Your Philadelphia

Green Cities Clean Waters

Image credit: PENN Praxis

Could this be the
Philadelphia of the
future?

Green Cities Clean Waters



We think so.

We can get there together.

Philadelphia PWD Water Department

Green Cities Clean Waters

Combined Sewer Overflow Long Term Control Plan Update

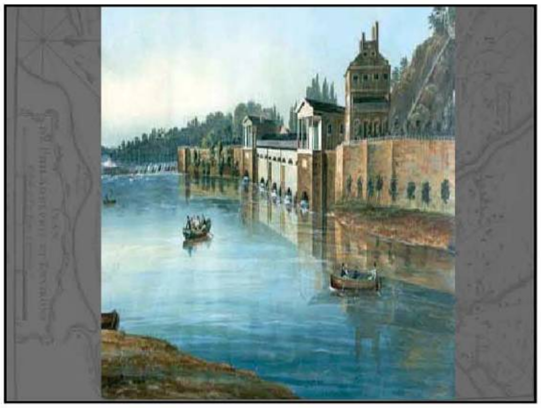
Green Cities Clean Waters

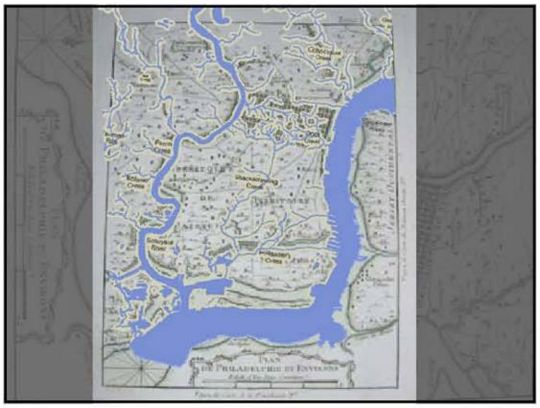
Presentation Overview

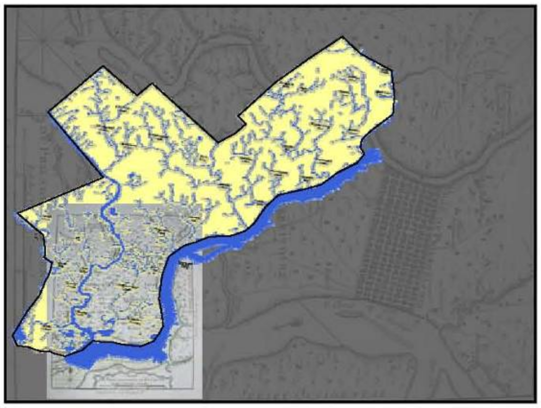
I. Philly Underground
- The history and current status of Philadelphia's creeks and sewers

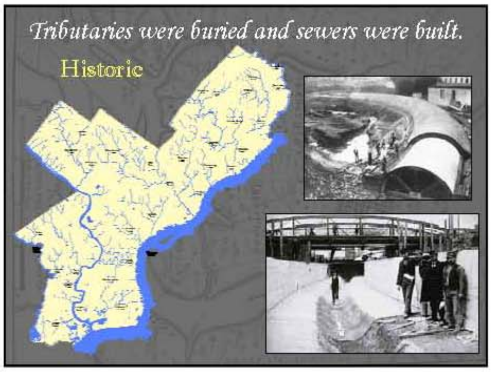
II. Cleaning up our water
- The combined sewer overflow long term control plan

III. Securing clean water for the future
- *Updating* the combined sewer overflow long term control plan



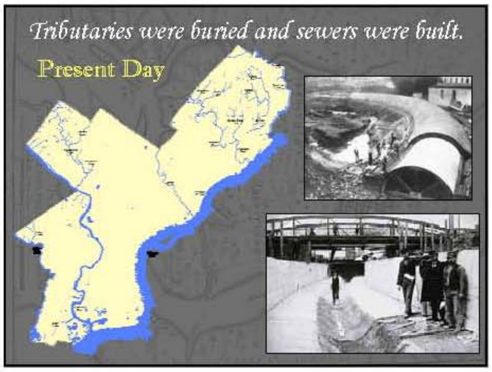






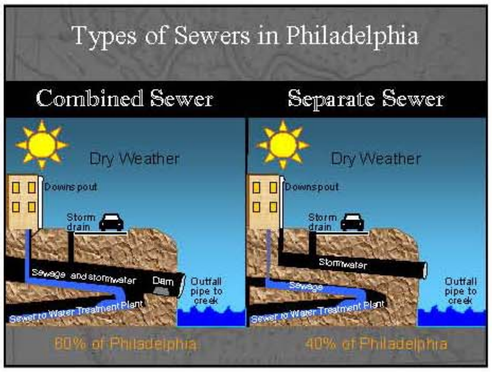
Tributaries were buried and sewers were built.

Historic



Tributaries were buried and sewers were built.

Present Day

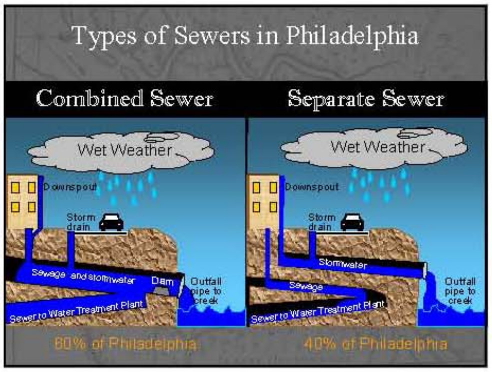


Types of Sewers in Philadelphia

Combined Sewer | **Separate Sewer**

60% of Philadelphia

40% of Philadelphia



Types of Sewers in Philadelphia

Combined Sewer | **Separate Sewer**

60% of Philadelphia

40% of Philadelphia

Stormwater

'Natural' Area

Plants and trees work to absorb stormwater

Stormwater is absorbed into the ground

'Urban' area

Water hits impervious surface and runs off

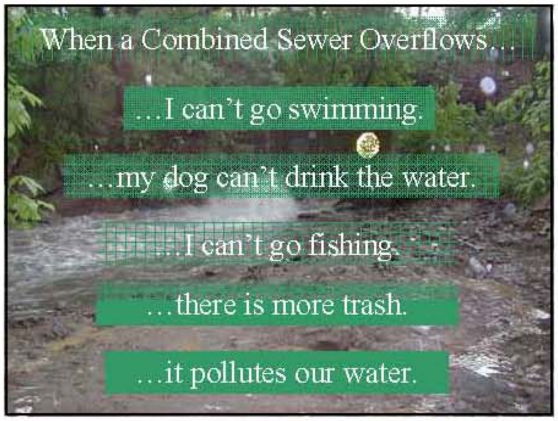
Roofs, streets, parking lots, etc.

Runoff goes into the sewers

4” rain in three hours “Natural” watershed

4” rain in 24 hours “Urban” watershed

Stormwater causes combined sewers to overflow.



When a Combined Sewer Overflows…

…I can’t go swimming.

…my dog can’t drink the water.

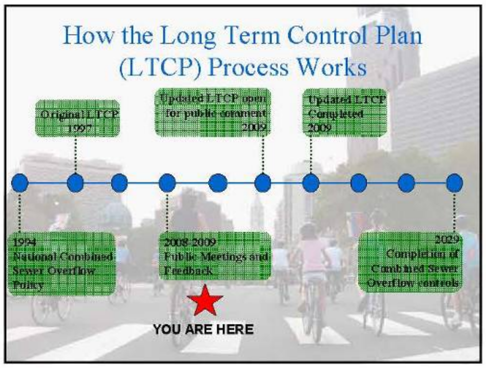
…I can’t go fishing.

…there is more trash.

…it pollutes our water.

National Combined Sewer Overflow Control Policy

Every city with Combined Sewer Overflows must create a Long Term Control Plan to clean up the water.



How the Long Term Control Plan (LTCP) Process Works

Original LTCP 1997

Updated LTCP open for public comment 2009

Updated LTCP Completed 2009

1994 National Combined Sewer Overflow Policy

2008-2009 Public Meetings and Feedback

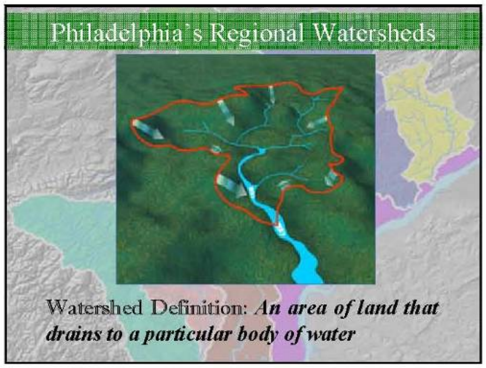
2029 Completion of Combined Sewer Overflow controls

YOU ARE HERE

You Can be Involved in Many Ways!

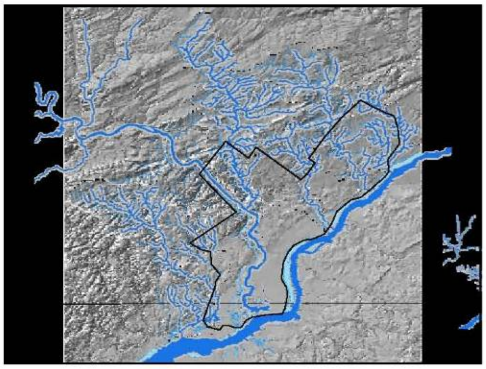
- ✓ Attending meetings of the Advisory Committee.
- ✓ Attending public meetings.
- ✓ Signing up to receive updates.
- ✓ Visit our website at www.csosrock.gov.
- ✓ Contributing feedback to the designers' plan.
- ✓ Advocating for the implementation of the plan.

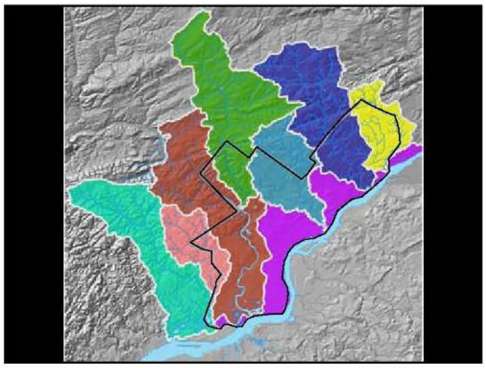
YOU ARE HERE

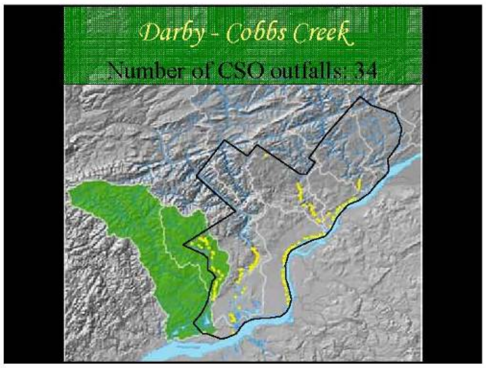


Philadelphia's Regional Watersheds

Watershed Definition: ***An area of land that drains to a particular body of water***

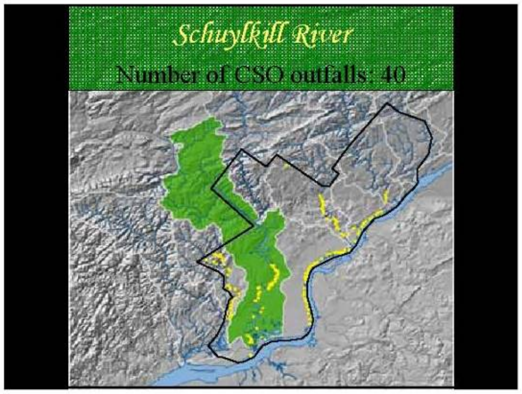






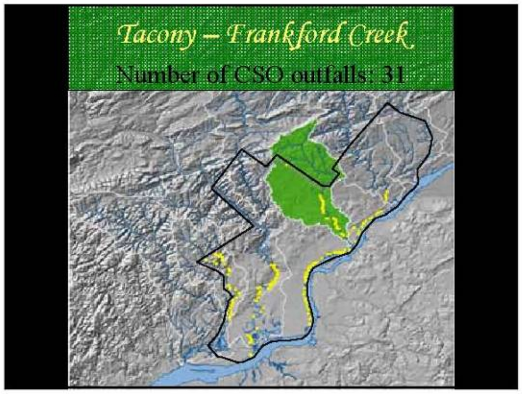
Darby - Cobbs Creek

Number of CSO outfalls: 34



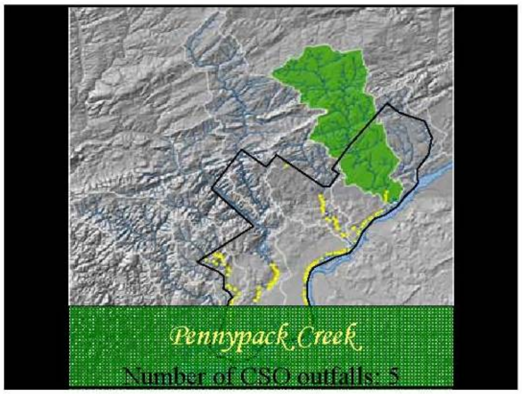
Schuylkill River

Number of CSO outfalls: 40



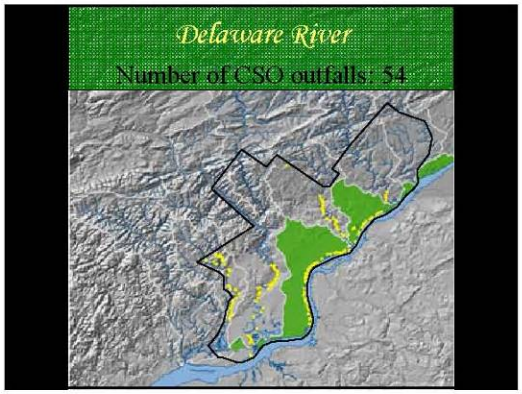
Tacony – Frankford Creek

Number of CSO outfalls: 31



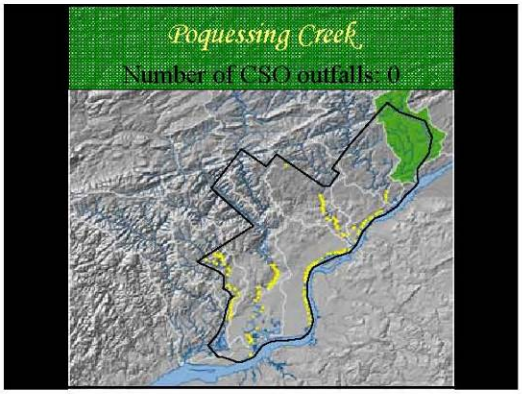
Pennypack Creek

Number of CSO outfalls: 5



Delaware River

Number of CSO outfalls: 54



Poquessing Creek

Number of CSO outfalls: 0

Wissahickon Creek

Number of CSO outfalls: 0

The Long Term Control Plan (LTCP)

Nine Minimum Controls

Capital Projects

Integrated Watershed Management Plans

Watershed Partnership Programs

Stream Restoration

Teacher Training

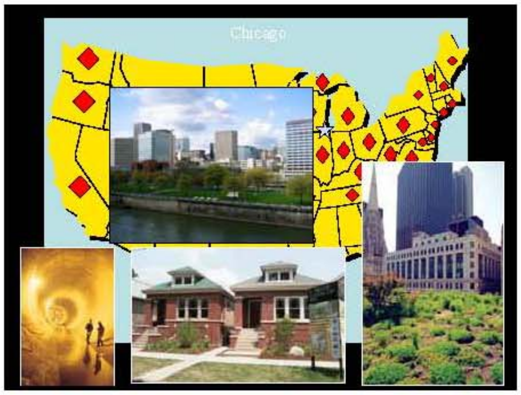
Homeowner Stormwater Management

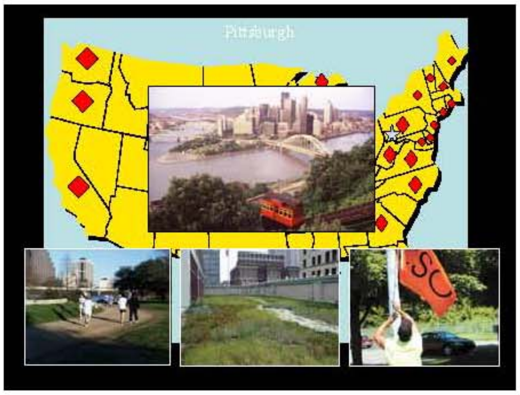
Tree Planting

Portland

Seattle

Milwaukee


Chicago


Pittsburgh


Philadelphia

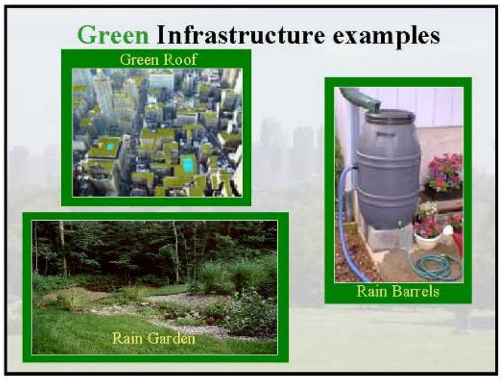

Gray Infrastructure Solutions **Green**


Green

"Green" is the use of natural and man-made technology to mimic nature's ability to deal with stormwater.

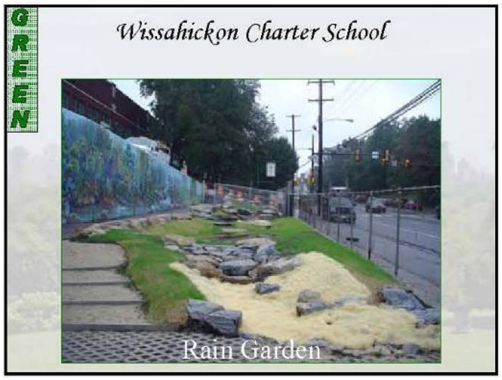

4" rain in three hours "Natural" watershed

4" rain in 24 hours "Urban" watershed



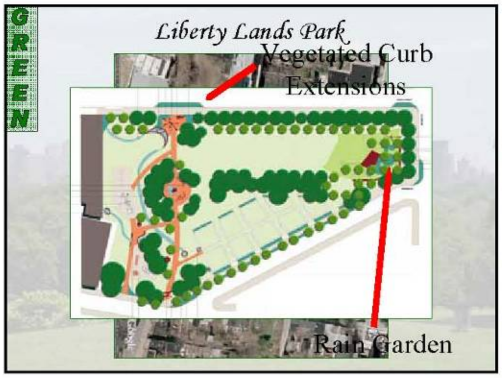
Green Infrastructure examples

Green Infrastructure examples

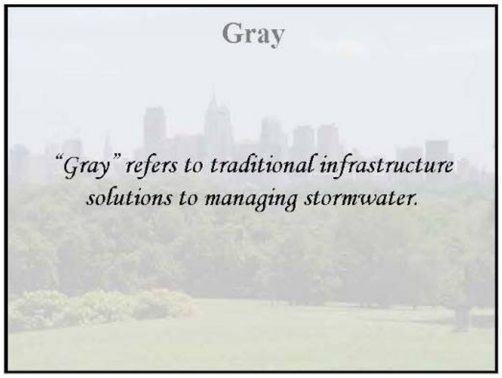


Wissahickon Charter School

Penn Alexander School

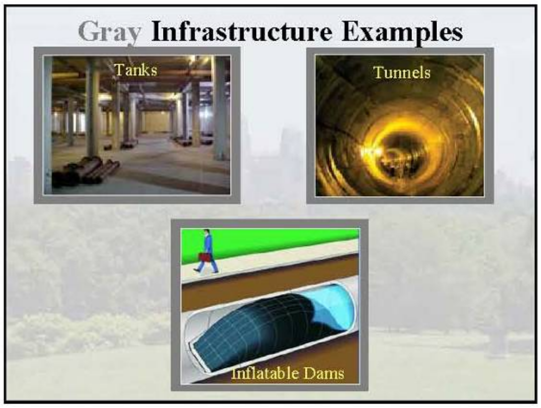


Liberty Lands Park

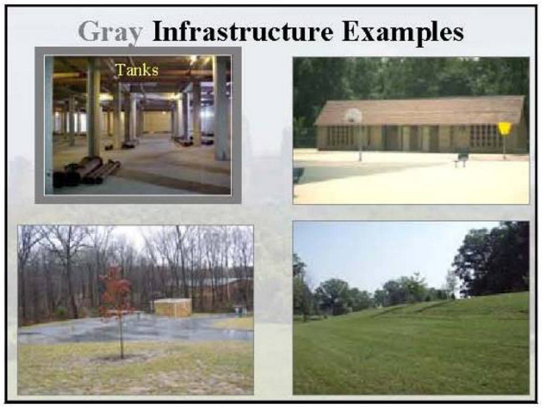


Gray

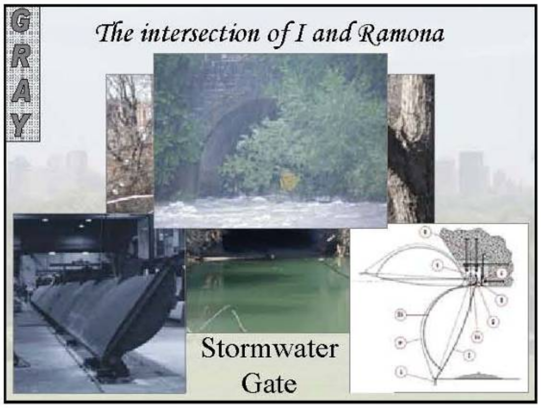
"Gray" refers to traditional infrastructure solutions to managing stormwater.



Gray Infrastructure Examples

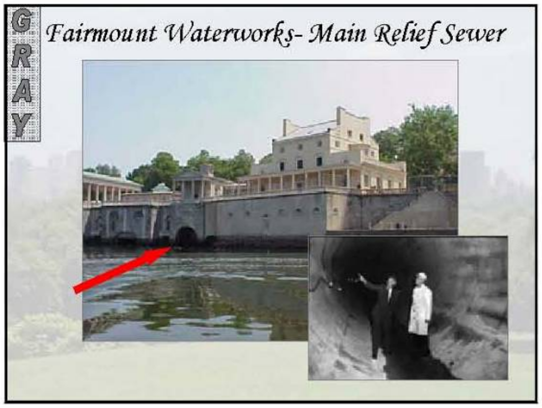


Gray Infrastructure Examples

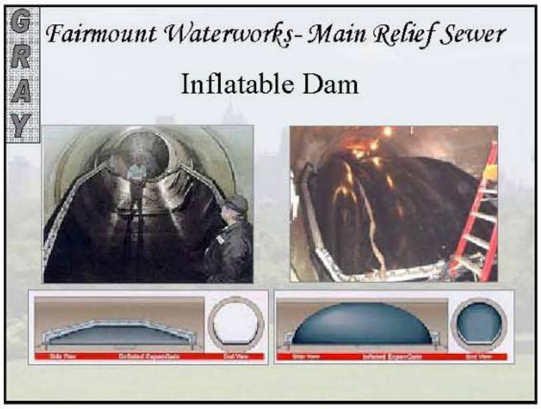


The intersection of I and Ramona

Stormwater Gate



Fairmount Waterworks- Main Relief Sewer



Fairmount Waterworks- Main Relief Sewer

Inflatable Dam

Balance

Updating the
Combined Sewer Overflow
Long Term Control Plan
will utilize green and gray technology.

Good Timing

Currently, many initiatives around Philadelphia share the same 'green' goals.

Rain Garden

Image credit: GreenPlan Philadelphia

Porous Asphalt

Image credit: GreenPlan Philadelphia


Underground Storage Tank

Image credit: GreenPlan Philadelphia


Vegetated Curb Extensions

Image credit: GreenPlan Philadelphia


Green Roofs

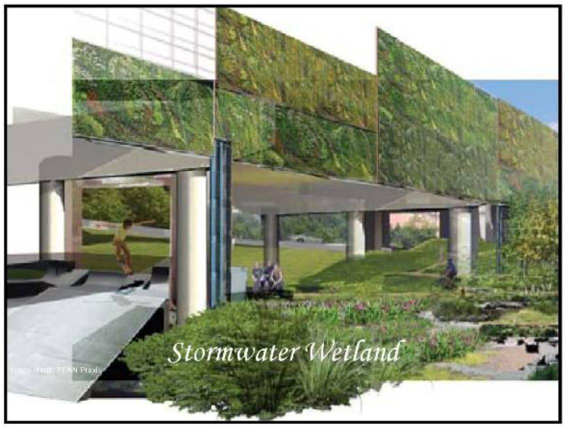


Image credit: TERN Praxis

From now

From now to the future,

we are committed to creating a
greener Philadelphia.

This has been a presentation
of the

Combined Sewer Overflow
Long Term Control Plan
Update

Green Cities Clean Waters

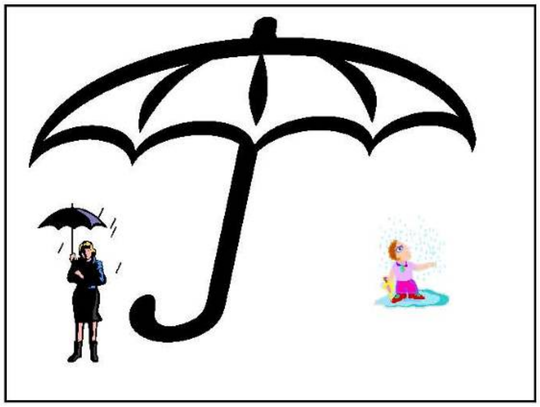
Philadelphia
PWD
Water Department

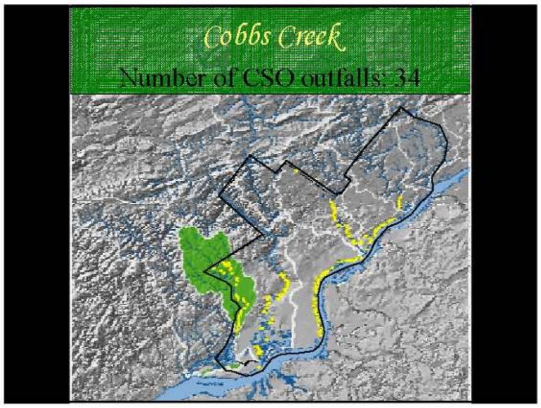
Thank you for participating.

COMBINED SEWER OVERFLOW

LONG TERM CONTROL PLAN

UPDATE

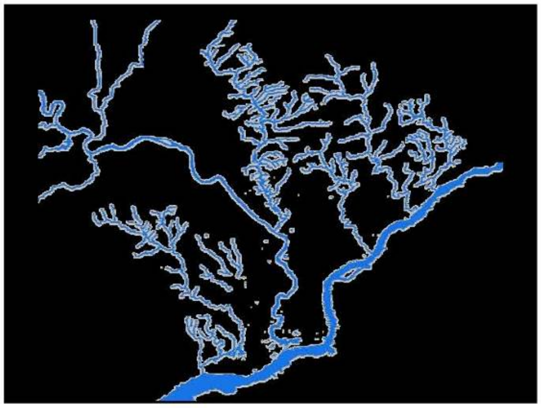


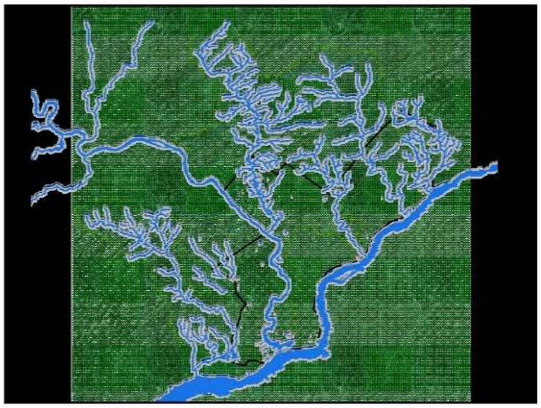


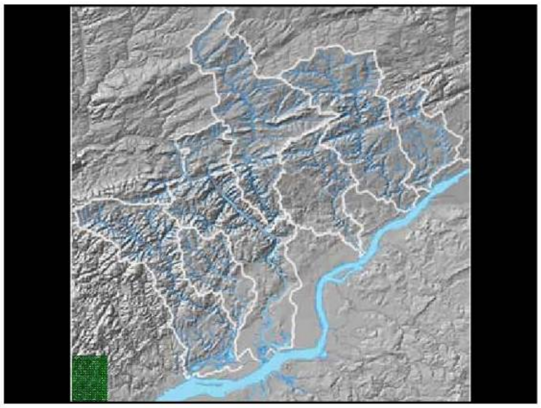
Cobbs Creek

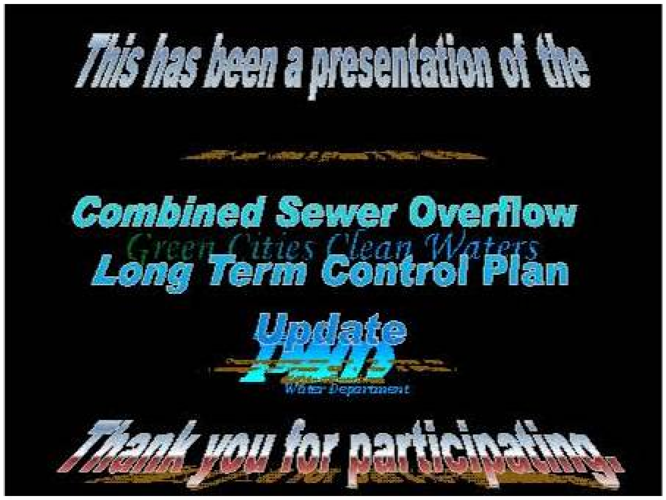
Number of CSO outfalls: 34

National Combined Sewer Overflow Control Policy = Every city with Combined Sewer Overflows must create a Long Term Control Plan to clean up the water.








This has been a presentation of the

Combined Sewer Overflow
Green Cities Clean Waters
Long Term Control Plan
Update

Water Department

Thank you for participating.

Public Meetings, Series #2

Philadelphia
Water Department

CSO LTCPU
Public Meeting
October 23, 2008

Agenda

1. Welcome & Introductions

2. Water Quality Characterization, Problem Analysis & Goals for Our Watersheds

3. Questions and Answers

PWD CSOLTCPU Public Meeting #2
Fairmount Water Works Interpretive Center
Thursday, October 23, 2008 from 5:30 – 7:30 p.m.

Comments/Questions
Name:

Comment/Question:
__How is PWD going to provide incentives for residential/ commercial properties to encourage greening?

Name:

Comment/Question:
__Have you (PWD) had any dialogue with the larger parcels that will be affected by the rate reallocation?

Comments/Questions
Name:

Comment/Question:
CSOcast; is it showing whether an overflow is occuring or is it measuring volume?

Name:

Comment/Question:
__Gray infrastructure- how will you model/size?

Comments/Questions
Name:

Comment/Question:
Are there tidal influences on the drinking water intake on the Delaware?

PWD CSOLTCPU
Public Meeting
Dec. 4, 2008

THANK YOU FOR VISITING
CCCEEC AND FOR SIGNING
THE VISITORS' REGISTER.

VISITORS' REGISTER

Sigh In Sheet

2008

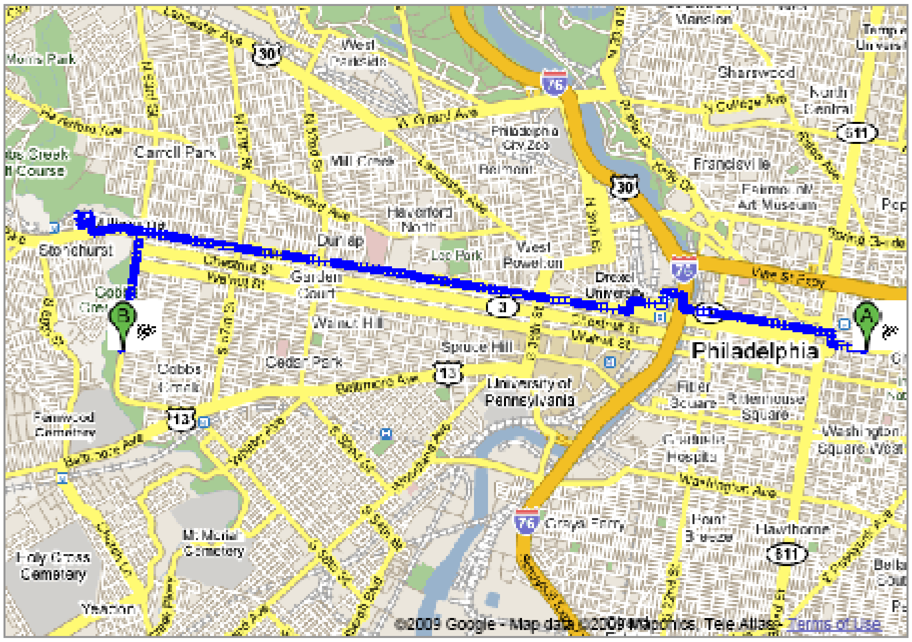
DATE	NAME & ADDRESS	E-MAIL ADDRESS	ORGANIZATION/BUSINESS	TELEPHONE
12-4-08	5421 Kingsessing Ave Russell Coleman		PWD - Flow Control	685-2057
12 4	Trish Fries Wissahickon Env Center	patricia fries @phila.gov	Fairmount Park	685 9285
12-4	Megan Sgarlat Wiss. Env. Center, Fairmount Park	megan.sgarlat@ phila.gov	Fairmount Park	685.9285
12-4	Stephanie Hoffer Fairmount Park, PEC	stephanie.hoffer @phila.gov	Fairmount Park	685.0429
12-4	Delano Pope PWD FOX ST FLOW Control		PWD Flow Cont	685-2057
12-4	Obi Hardin	obi.hardin @yahoo.com	Flow Control	685-2057
12-4	Jason Brady Sierra Club	jason.brady@ sierraclub.org	Sierra Club	215-558-3310
12-4	DEBBIE CARR FPC			215 683- 0214
12-4	Roberta Turner 330 [illegible] St Bucks Co	robertaturner@ hotmail.com	cell	[illegible]
12-4	Herb Skillcross 19125 1305 E. Susquehanna [illegible]	herbskillcross@ comcast.net	Fishtown Neighbors Assn	215- 423 2045
12-4	TIM BURKETT 2081 CLIPPER PK RD BALTIMORE, MD 21211	tburkett@ biohabitats.com	BIOHABITATS INC	410-554- 0156

THANK YOU FOR VISITING
CCCEEC AND FOR SIGNING
THE VISITORS' REGISTER.

VISITORS' REGISTER

2008

DATE	NAME & ADDRESS	E-MAIL ADDRESS	ORGANIZATION/BUSINESS	TELEPHONE
12/4/08	Iliyaas Muhammad 4000 Market St Philadelphia PA 19123	imuhammad@thepartnershipcdc.org	The Partnership CDC	215 662 1616 [illegible] 27
12/4/08	Khet Luong 20 Bud Ave, Upper Darby PA 19082	kluong@pecpa.org	PA Env. Council	215 592 7020 X107
" "	Tiffany Ledesma Groll	ledesmagrolltd@cdm.com	Consultant to PWD	215-499-3756


West Parkside
Carroll Park
Mill Creek
Philadelphia City Zoo
Belmont
Haverford North
Sharswood
North Central
Francisville
Fairmount Art Museum
Dunlap
Lee Park
West Powelton
Drexel University
Stonehurst
Garden Court
Walnut Hill
Spruce Hill
Cedar Park
Cobbs Creek
University of Pennsylvania
Philadelphia
Fitler Square
Rittenhouse Square
Washington Square West
Graduate Hospital
Fernwood Cemetery
Mt Moriah Cemetery
Holy Cross Cemetery
Grays Ferry
Point Breeze
Hawthorne
Yeadon
Chestnut St
Walnut St
Baltimore Ave
Lancaster Ave
Haverford Ave
Girard Ave
Vine St Expy
Washington Ave
A
B
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PWD CSOLTCPU Public Meeting #2
Cobbs Creek Community Environmental Education Center
Thursday, December 4, 2008 from 5:30 – 7:30 p.m.

Comments/Questions

Name: Trish
"Gray infrastructure stores H_2O in tank instead of going to creek?"

Comment/Question: Joanne
Yes.

Name: Debbie Carr
"Where will there be sidewalk planters?"

Comment/Question: Joanne
1st one @ Columbus Sq., but in the future we would like to see it at all parks, city properties + others such places.

Comments/Questions

Name:

Trish

Comment/Question:

Trish Do you have literature on the success of S. grove & the treatment wetland?

Joann - yes, mainly on Total Suspended solids. It has reduced significantly so far

Name:

[redacted] Roberta Turner

Comment/Question:

What is the longevity of porous asphalt? Any models?

Joann Morris Arb. has had theirs for over 17 years & there is minimal maintenance.

Comments/Questions

Last wmn

Name:
Roberta Turner

Comment/Question:
SW Regs. are only <u>in</u> the City?

Yes, but other muni's are doing Similar programs - some even more stringent

Name: Mr. Shallcross
What is baseflow?

Comment/Question:
Marc. The amt. of water in the Stream on non-rainy days. It's not possible to replenish base flow with water not infiltrating land.

Comments/Questions

Name:
Khiet

Comment/Question:
Why catfish in pic?

Marc - B/c fish need DO, so represents importance of DO in creeks.

Name:
Roberta Turner

Comment/Question:
Any difference in bacteria from Suburbs (Montgo Co) vs. in City?
Yes, some time can be worse in suburbs...That's why we need to work with upstream neighbors through partnerships.

⑤

Comments/Questions

Name:

[illegible]

Comment/Question:
Where is the fish ladder in the photo?
Flat Rock.

Will the Fairmount fish ladder have a photographic monitor?
Yes. It will stream to FWWIC.

Name:
Jason Brady

Comment/Question: Marc –
are other cities developing plans? Are we behind?
Yes, we're behind but it's a good thing. B/c others are under consent decree, so we learn from their mistakes & develop a plan that can try to get us under a consent decree.

⑥

Comments/Questions

Name:
~~[illegible]~~ Tim Burkett

Comment/Question:
Matt ~~[illegible]~~ Phila. has a very comprehensive program, ~~[illegible]~~ [illegible] Other cities are doing programs, but not leading with green + filling in with gray.

Name:
Jason Brady

Comment/Question:
What's the price tag? Over how long?

Rough numbers - $2½-$5 Billion over 20 yrs - 30 yrs.

Comments/Questions

Name:
Mr. Shallcross

Comment/Question:
What is the tunnel system?

Marc: Pipes that are 30ft. in diameter
+ 200ft. below the ground.
Will we build tunnels?
Marc: Yes, we will have to build some.

Name:
Tim Burkett

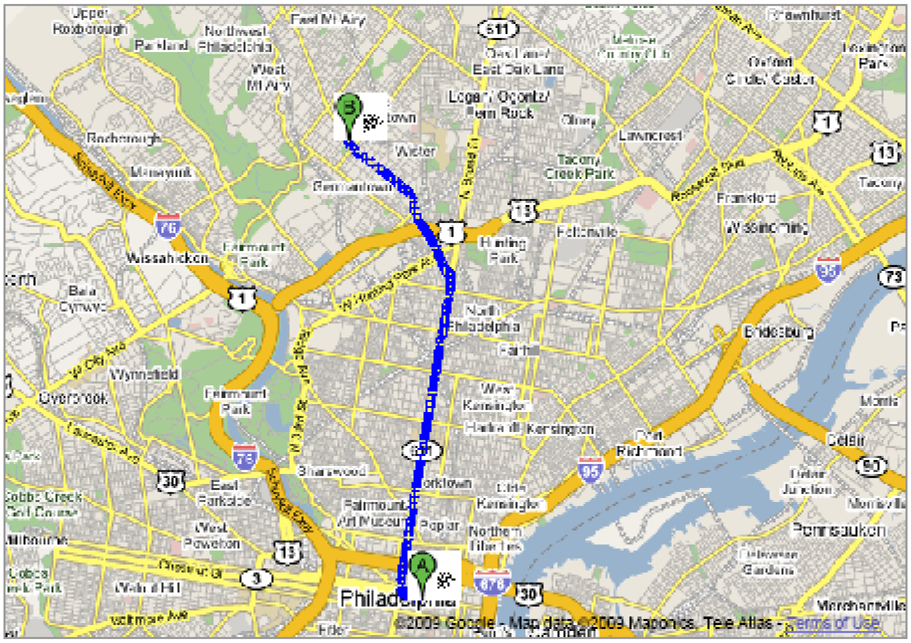
Comment/Question:
What is the degree of imperviousness?
In Cobbs?
56% City-wide

CSO LTCPU
Public Meeting
December 10, 2008

Agenda

1. Welcome & Introductions
2. Water Quality Characterization, Problem Analysis & Goals for Our Watersheds
3. Questions and Answers

Google Maps


Upper Roxborough
Parkland
Northwest Philadelphia
East Mt Airy
West Mt Airy
511
Cedarbrook
East Oak Lane
Melrose Country Club
Oxford Circle/ Castor
Lexington Park
Logan/ Ogontz/ Fern Rock
Olney
Lawncrest
1
13
Tacony
Roxborough
Manayunk
Germantown
Wister
N Broad St
Tacony Creek Park
Frankford
Wissinoming
Schuylkill Expy
76
Wissahickon
Fairmount Park
1
13
Feltonville
Hunting Park
95
73
Bala Cynwyd
W Hunting Park Av
North Philadelphia
Bridesburg
W City Ave
Wynnefield
Fairhill
Overbrook
Fairmount Park
West Kensington
Harrowgate
Kensington
Port Richmond
Cobbs Creek Golf Course
Lancaster Ave
30
East Parkside
76
Strawberry
Yorktown
Kensington
Delair Junction
Morrisville
90
Pennsauken
West Powelton
Fairmount Art Museum
Poplar
Northern Liberties
Millbourne
13
Chestnut St
3
Walnut Hill
Philadelphia
676
30
Delaware Gardens
Merchantville
Cobbs Creek Park
Baltimore Ave
Elder
Camden
A
B
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Philadelphia PWD Water Department

PWD CSOLTCPU
Public Meeting
December 10, 2008

Please Sign In

Name	Organization	Email
GREATER PHILADELPHIA WATERSHED ALLIANCE Charles Parsons, President 215-843-0749		
SARAH ROBBGRIECO	TTF	sarah@ttfwatershed.org
Kate Zaichan	Clean Air Council	katezcai kzaickan@cleanair.org
Chris Nicholson		chnichol@verizon.net
PETER KURTZ	FPC	PETER.KURTZ@Phila.gov
FRED MAURER	RTCD	215 329 8842
Ellen McClure	Biohabitats	emcclure@biohabitats.com
HAL KRIEGER	Manayunk Watershed	HAROLDKRIEGER@VERIZON.NET
EDDIE BATTLE	EDDIE R. BATTLE ASSOC.	MARSHBATTLE@AOL.COM
FRED LEWIS	CIP/SEC	FLEWIS@CENTERINTHEPARK.ORG
David Schogel	CIP/SEC	davidschogel@yahoo.com
EDWARD CHIN	CIP/SEC	chfied@aol.com
REV CHRISTER William	CBWC Ch.	215-849-8021
Spencer Selenck		215-849-5481
Bridget Chadwick	Cheltenham EAC	215 887-3564 chadwick@voicenet.com
CATHERINE BROWN	GCCB	215-685 3514 cathy.brown@phila.gov
BRIANA BROWN	GCCB	
JOHNNIE HENDERSON	CIP/SEC	JHENDERSON@CENTERINTHEPARK.ORG
Margaret Bowerman	BD	margaretB@voicenet.com
gerry Kaufman	Awbury Arboretum	
Tiffany Ledesma Groll	PWD Consultant	

PWD CSOLTCPU Public Meeting
Center in the Park
Thursday, December 10, 2008
6:00 – 8:00 p.m.

Comments/Questions

Name: Kate Zaidan (Clean Air Council Rep.)
Will the presentation be on-line?

Comment/Question:
Joanne (PWD): Yes – phillyriverinfo.org

Name:
Peter Kurtz (Fairmont Park Commission)

Comment/Question:
Joanne (PWD): The dams are designed to prevent back-ups ???
They capture minimum amt. of rainfall. We have realtime control (computers) that know when to blow dams (inflatable) up + deflate, so they control the flow going out.

②

Comments/Questions

Name: Hal Krieger (Frnds of Monoshe)

Is the Kelly Drive Flood Relief Project a dam (in-storage) project?

Comment/Question:

Joanne (PWD): Yes. (Technical Explanation provided by Marc Cammarata)

Name: Eddie Battle (Eddie R. Battle Assoc.)

Comment/Question:

What other cities have gray projects?

Joanne (PWD): Many – Portland, Baltimore,... a lot of the older cities.

③

Comments/Questions Rev. Williams:

Name: [redacted]

Comment/Question: There is alot of digging Underground in the city. Why not do more modern projects, like watrfall-type (on surface)?

Joanne (PWD) Yes, We would like to do as much on the surface as possible. You are right on! I'll present some of these projects now = Green Approach.

Name: Rev. Williams:

[redacted]

Comment/Question:

How do you pick out sites for projects? My community would love to see a green project in our area - on Chew Ave.?

Joanne: We will work with communities soon on the greening projects, we're just not there yet. like a sidewalk planter

We will work with the Communities through the TTF Watershed Partnership.

Comments/Questions

Name:
Jerry Kaufield (Awbury Arb.)

Comment/Question:
Can you tell us how the sidewalk infiltration project works?

Joanne (PWD): (Detailed technical) explanation followed.

Name: Rev. Williams
~~Spencer Schenk~~

Comment/Question:
What do you consider an Emergency?

Joanne (PWD): These projects aren't for sites handling Emergencies. They are planning initiatives & opportunities, not Emergencies.

Spencer: What if you have flooding Emergency on your property (at storm street drain)?

We need to know about these issues immediately. Report them, so that we can address them.

Comments/Questions Margaret

Student that attends Springside School

Name: Cliveden Park "That is pretty"!

Comment/Question:

~~Spencer~~ Rev. Williams:
Along the expressway, ~~near~~ ~~[illegible]~~ (Queen Ln.) ... Are you doing anything to catch the stormwater Runoff on Park site?

Joanne: Yes, We're looking into a project to better manage the Stormwater there.

Name:

Gerry: What does it mean to get

Comment/Question: the neighborhood involved?

Joanne: Having TTF Watershed Partnership (Sarah Robb Greco) set up now ~~[illegible]~~ enables us to work + coordinate with the Communities.

Charles Parsons: Why are City Water Customers forced to pay for stormwater?

Joanne: We have a 3,000 mile collection system. We have a user fee. ~~[illegible]~~ ~~[illegible]~~

⑥

Comments/Questions

Name: Rev. Williams:

~~[illegible]~~

Comment/Question:

Whatever we do to survive, ~~we need~~ will require the support of the community. Why can't we Start with the community 1st ~ to develop the partnership? We want ~~it~~ a green project at a train station, not a park?

Joanne: That's where we want to go. Before, with pipes only, it wasn't ~~[illegible]~~ benefiting communities. Now, we're designing with communities in mind.

Name:

Comment/Question:

We're gearing up to do more grass roots projects in the very near future

?

Jo: PWD is funded solely thru water + sewer bills. We only collect enough to operate - not to make profit.

We need to sit down with other agencies to work together, like the GreenPlan brought people together.

Comments/Questions

Name:
Charles:

Comment/Question:
The stormwater permit doesn't belong to PWD, but to the City.

Joanne: The PWD is the designated agency. We hold the permit, as a utility.

Name:
Catherine Brown: How can we engage average family? How ~~get~~ them to relate to green projects?

Comment/Question:
Education should be simpler. You shouldn't have to have a degree to understand these problems.

People need to relate the everyday benefit to these projects.

Joanne: Yes, that's why we have Sarah (TTF Partnership) + we want to figure out how to get more people/communities to these meetings + getting involved. →

Catherine : There should be projects that kids have to take on to get involved in those projects.

Marc: One of the major programs that may address this issue is the Green Schools Program. Look at the student, here, that pointed out the rain garden on her school property (in the PowerPoint). That is the result of a demonstration project.

springside Student : Teachers at my school teach through watershed model, taking us to stream to learn about fish + insects, etc.

Charles : ~~The water customers are~~ PWD should go back to just taking care of the basic watr responsibilities,

Marc : When you turn your faucet on, does watr come out?

9

Comments/Questions

Name: Bridget Chadwick:

I live in Cheltenham. I think

Comment/Question: We should work/develop partnerships with DVRPC – transportation projects ~~to widen the streets~~. b/c they are impacting our environment with the widening of streets, etc. Not goo

Marc: Since our projects have multiple benefits, we will have to partner with the multiple agencies.

Name:

Comment/Question:

Charles: How much does PWD spend on cleaning storm drains? Why can't Streets do this?

Marc: We (PWD) own the infrastructure

Rev. Williams: We want (my community) ~~wants~~ greening projects in ~~o~~ my (15-block radius) community. How do we do it?

Marc: Contact Councilman + Work w/ TTF Partnership

Rev. Williams:

~~Spencer~~: Who are the stakeholders?

Marc.: Everyone - Business leaders, landholders, municipal reps, etc.

Bridget: Make a list of shovel ready projects, Like Breaking up channelized stream so

Green Cities, Clean Waters

Combined
Sewer Overflow
Long-term Control
Plan Update

Philadelphia
PWD
Water Department

Green Cities ….

- Unite the City with its water environment
- Create a green legacy for future generations
- Incorporate a balance between ecology, economics and equity

…Clean Waters

Imagine a
Philadelphia like
this…

Image credit: PENN Praxis

Image credit: PENN Praxis

Image credit: PENN Praxis

Your School

Image credit: GreenPlan Philadelphia

Your Street

Image credit: GreenPlan Philadelphia

Image credit: PENN Praxis

Could this be the Philadelphia of the future?

We think so.

We can get there together.

Green Cities

Clean Waters

Philadelphia Water Department

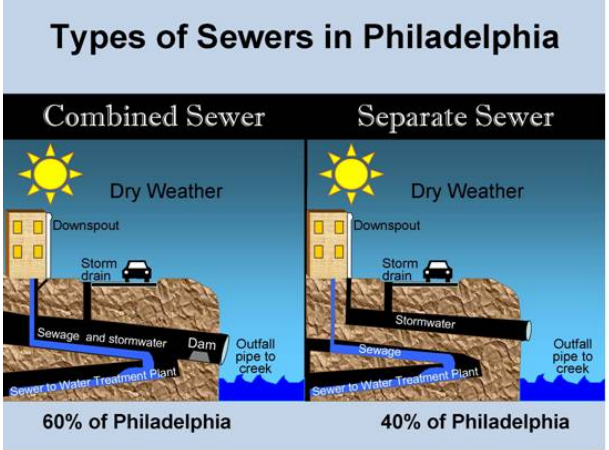
Natural vs. Urban Stormwater Drainage

Stormwater infiltrates into the ground

Plants and trees work to absorb stormwater

Water hits impervious surface and runs off roofs, streets, parking lots etc.

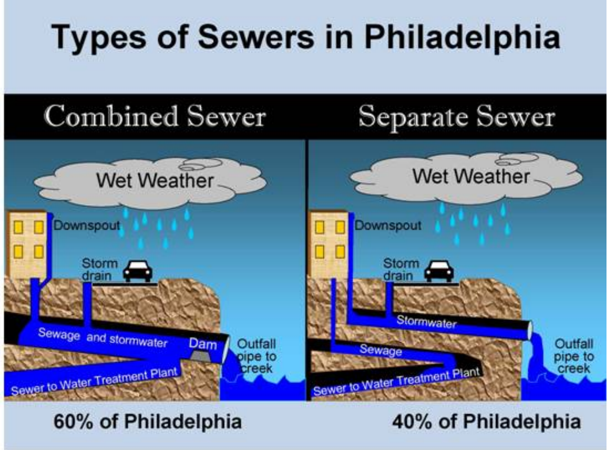
Runoff goes into the sewers



Types of Sewers in Philadelphia

60% of Philadelphia

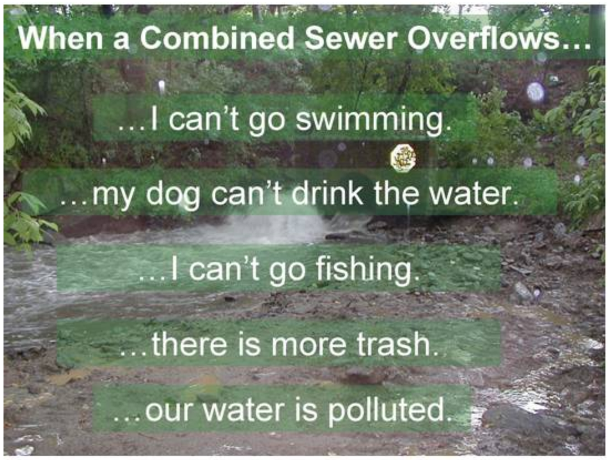
40% of Philadelphia



Types of Sewers in Philadelphia

60% of Philadelphia

40% of Philadelphia



When a Combined Sewer Overflows…

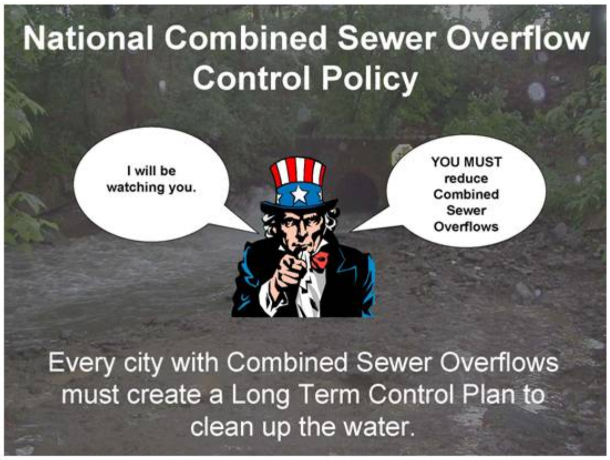
…I can't go swimming.

…my dog can't drink the water.

…I can't go fishing.

…there is more trash.

…our water is polluted.



National Combined Sewer Overflow Control Policy

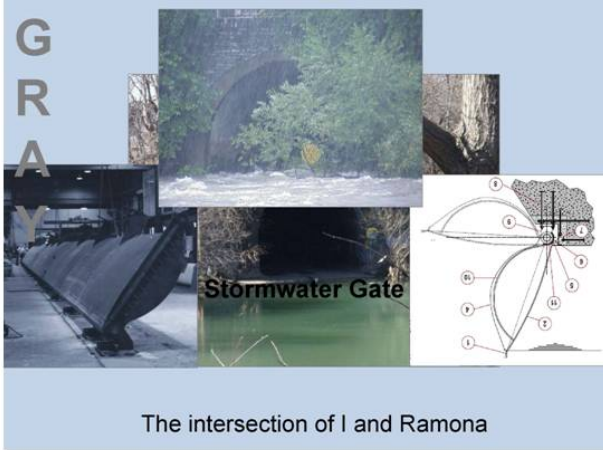
Every city with Combined Sewer Overflows must create a Long Term Control Plan to clean up the water.

GRAY and GREEN

The GRAY Approach

Refers to traditional infrastructure solutions to managing stormwater

G
R
A
Y



G
R
A
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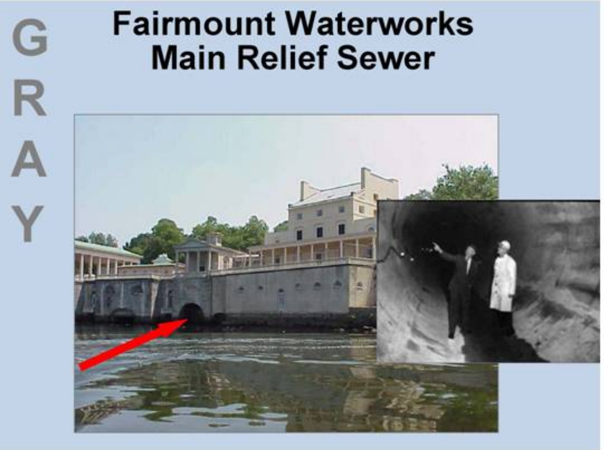
The intersection of I and Ramona



G
R
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Fairmount Waterworks Main Relief Sewer

G
R
A
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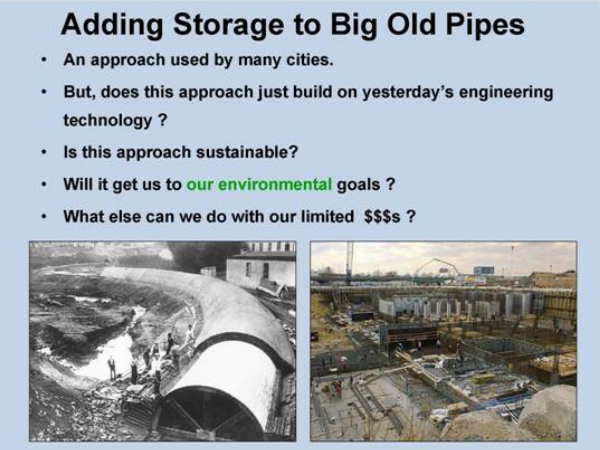
Fairmount Waterworks Main Relief Sewer

Inflatable Dam



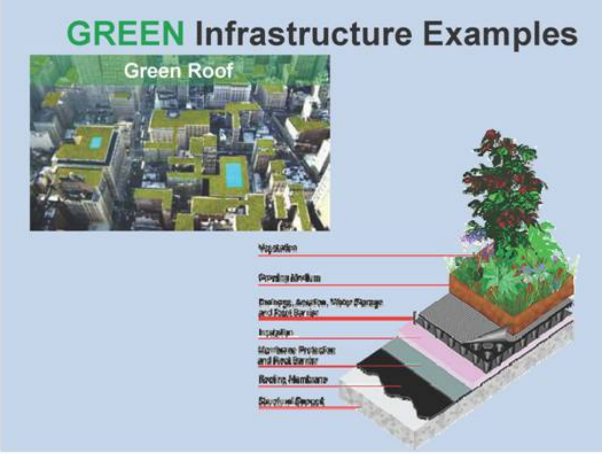
Adding Storage to Big Old Pipes

- An approach used by many cities.
- But, does this approach just build on yesterday's engineering technology ?
- Is this approach sustainable?
- Will it get us to our environmental goals ?
- What else can we do with our limited $$$s ?

The GREEN Approach

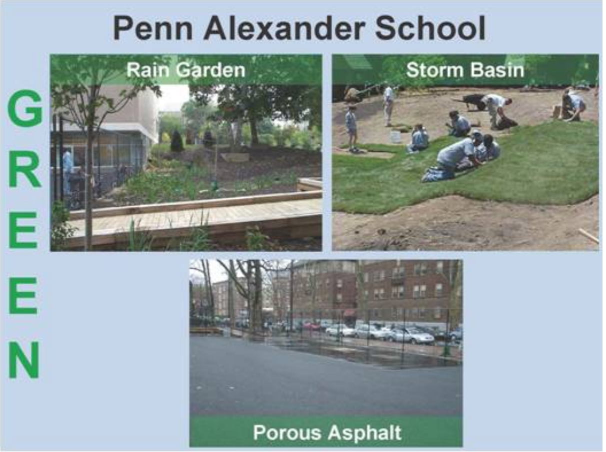
Refers to green infrastructure solutions to managing stormwater

GREEN Infrastructure Examples



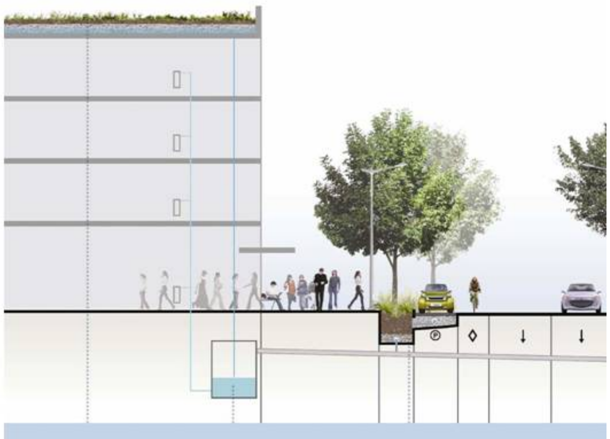
GREEN Infrastructure Examples

Wissahickon Charter School



Penn Alexander School

Liberty Lands Park



GRAY GREEN

Balance

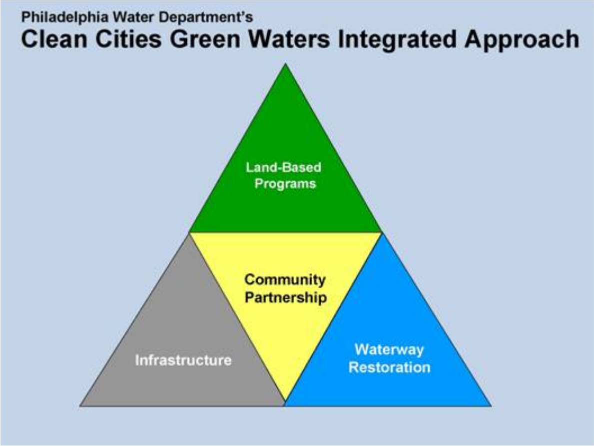
Updating the
Combined Sewer Overflow
Long Term Control Plan
will utilize **GREEN** and **GRAY**
technology.

Good Timing

Currently, many initiatives around Philadelphia share the same 'green' goals.

Mayor's Priorities

- Public Safety: Safest largest city in the country
- Education: Country's premier education city
- Jobs & Economic Development: Grows as a green city
- **Healthy & Sustainable Communities: Philly neighborhoods vibrant and livable**
- Ethics: Philly demonstrates highest standards for ethics and accountability
- Customer Service and a High Performing Government: Philly becomes a national customer service leader



Philadelphia Water Department's

Clean Cities Green Waters Integrated Approach

Community Partnerships

The primary goals of community partnership efforts include:

- Implementation projects in upstream communities
- Coordination of stormwater regulations
- Increased visibility of PWD efforts
- Stronger public stewardship
- More public education and awareness
- Strengthened political and public support for projects

Infrastructure

PWD will continue to evaluate, and where appropriate, design and implement gray infrastructure projects, such as:

- Expanding wastewater treatment capacity
- Creating new storage capacity using tanks and tunnels
- Adding floatables control through outfall netting
- Installing street catch basin controls and cleaning
- Integrating time control, inflatable dams, etc.

Waterways Restoration

PWD is implementing a waterways restoration program including:

- Restoration of stream channels and riparian habitat
- Creation or restoration of wetlands
- Elimination of impediments to fish migration
- Stream maintenance and cleanup
- Floatables control using skimming vessels

Land-based Programs

This program includes a wide variety of measures requiring or encouraging distributed storage, infiltration, and evapo-transpiration of stormwater to ease the burden on existing infrastructure, including:

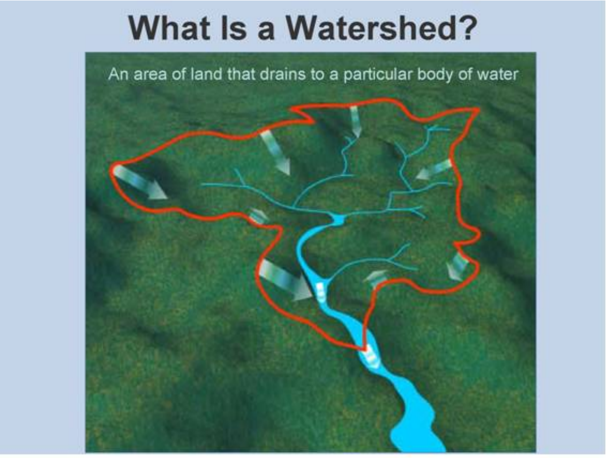
- New stormwater management regulations
- Use of low impact development
- Parcel-based stormwater billing

Together we can achieve a brighter tomorrow

Why Are We Here?

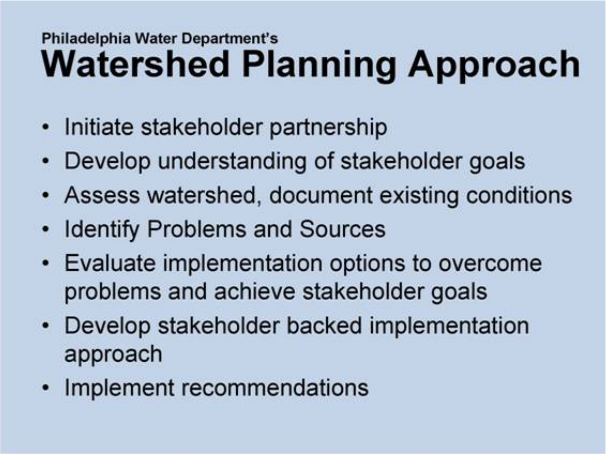
Why Are We Here?

- To gain an understanding of existing watershed problems and conditions
- To explore how the Long Term Control Plan addresses these problems and helps us realize our vision



What Is a Watershed?

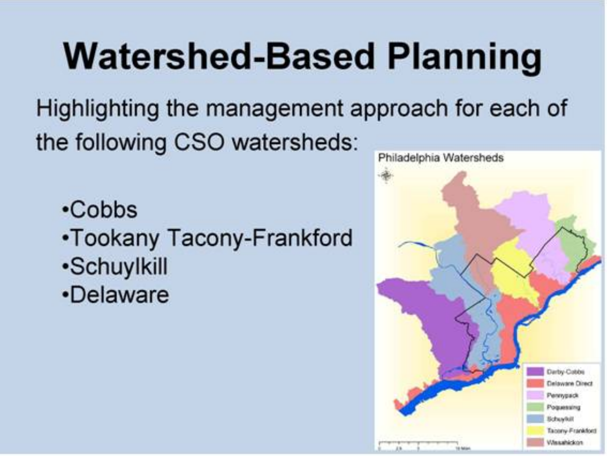
An area of land that drains to a particular body of water



Philadelphia Water Department's

Watershed Planning Approach

- Initiate stakeholder partnership
- Develop understanding of stakeholder goals
- Assess watershed, document existing conditions
- Identify Problems and Sources
- Evaluate implementation options to overcome problems and achieve stakeholder goals
- Develop stakeholder backed implementation approach
- Implement recommendations



Watershed-Based Planning

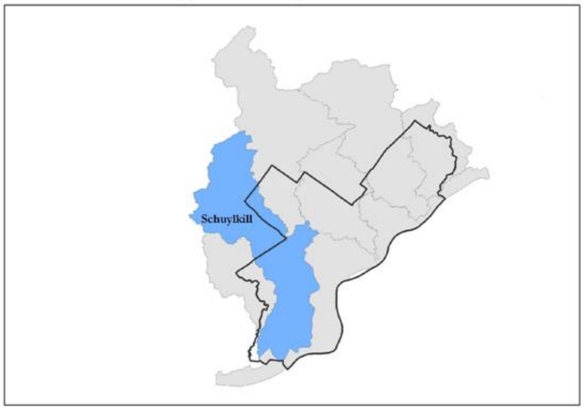
Highlighting the management approach for each of the following CSO watersheds:

•Cobbs
•Tookany Tacony-Frankford
•Schuylkill
•Delaware

Philadelphia's Regional Watersheds

Philadelphia's Regional Watersheds

Philadelphia's Regional Watersheds



Philadelphia's Regional Watersheds

PWD's Watershed Partnerships

Watershed	Partnership Active Since	Plan
Darby-Cobbs	1999	IWMP Completed 2004; Implementation underway
Tookany/Tacony-Frankford	2000	RCP completed 2004; IWMP completed 2005; Implementation underway
Schuylkill (Schuylkill Action Network)	2004	Source Water Protection Plan completed 2004; RCP completed 2001
Delaware (Direct)	2007	RCP Underway (2008); Implementation plan to follow

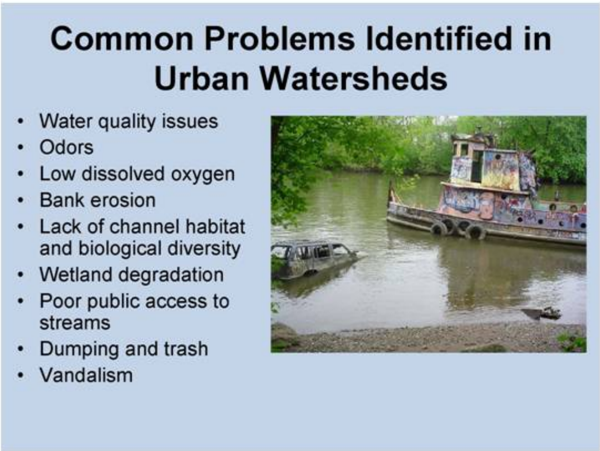
Characterization of Existing Conditions

PWD implements a detailed monitoring program in each planning shed including:

Chemical

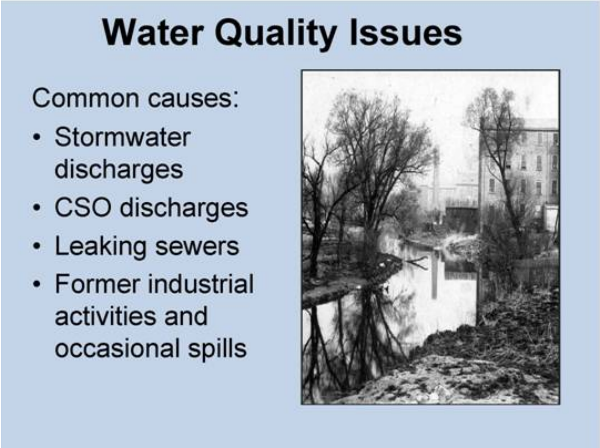
Biological

Physical



Common Problems Identified in Urban Watersheds

- Water quality issues
- Odors
- Low dissolved oxygen
- Bank erosion
- Lack of channel habitat and biological diversity
- Wetland degradation
- Poor public access to streams
- Dumping and trash
- Vandalism



Water Quality Issues

Common causes:

- Stormwater discharges
- CSO discharges
- Leaking sewers
- Former industrial activities and occasional spills

Odors

Common causes

- Cross-connections in separate sewered areas
- Leaking sewers along stream
- CSOs during storms

Low Dissolved Oxygen

Common causes/sources:

- Oxygen demanding substances
- Leaking sanitary sewers
- CSOs
- Stormwater runoff
- Lack of streamside shade
- Over-widened channels
- Loss of baseflow
- Excessive invasive plant growth

http://www.waterencyclopedia.com/images/wsel_01_img0017.jpg

Bank Erosion

Common causes:

- Lack of stormwater management upstream
- High impervious cover in watershed

Lack of Channel Habitat and Biological Diversity

Common causes:

- Lack of stormwater management upstream
- High impervious cover in watershed
- Alterations to stream channel (channelization)

Degraded Wetlands

Common causes:

- Land development
- Uncontrolled Stormwater

Poor Public Access to Streams

Common causes:

- Residential development up to stream edge
- Lack of public paths

Dumping and Trash

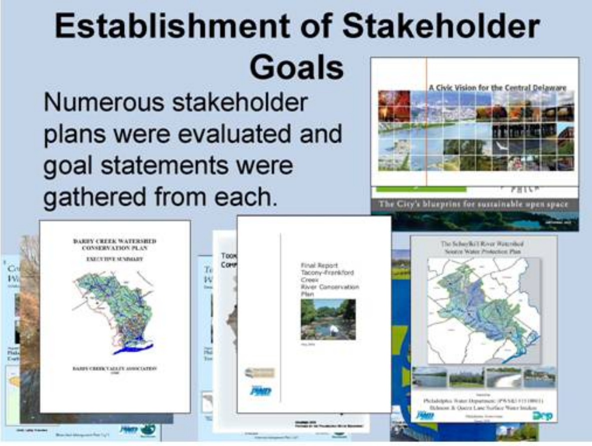
Common causes:

- Litter carried by storm flows
- Illegal dumping at vehicle access points

Vandalism

Common causes:

- Poor lighting
- Lack of public visibility and engagement
- Lack of patrolling

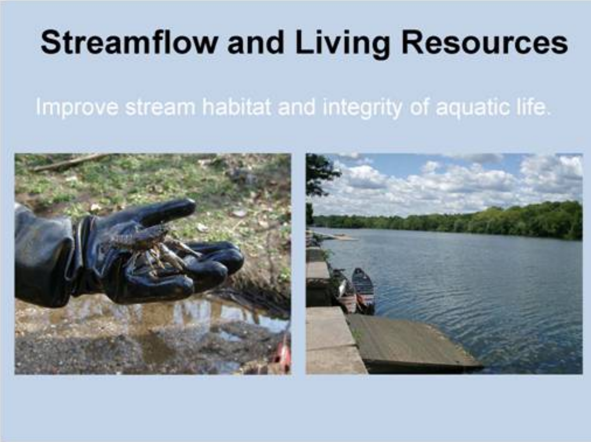


Establishment of Stakeholder Goals

Numerous stakeholder plans were evaluated and goal statements were gathered from each.

The Philadelphia Water Department's "Umbrella" Stakeholder Goals

1. Streamflow and Living Resources
2. Instream Flow Conditions
3. Water Quality and Pollutant Loads
4. Stream Corridors
5. Flooding
6. Quality of Life
7. Stewardship, Communication, and Coordination
8. Recreation



Streamflow and Living Resources

Improve stream habitat and integrity of aquatic life.

Instream Flow Conditions

Reduce the impact of urbanized flow on living resources.

Water Quality and Pollutant Loads

Improve dry and wet weather stream quality to reduce the effects on public health and aquatic life.

Stream Corridors

Protect and restore stream corridors, buffers, floodplains, and natural habitats including wetlands.

Flooding

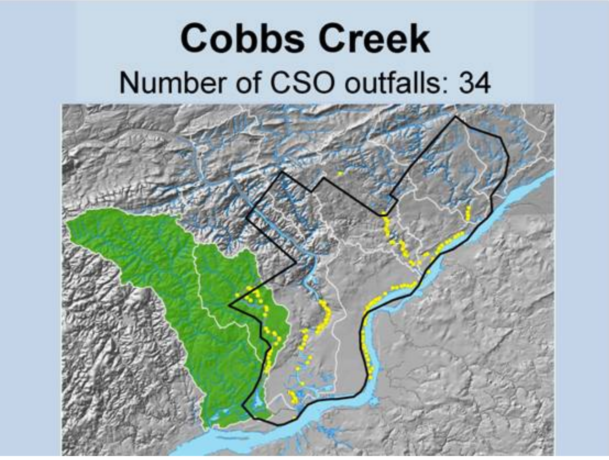
Identify flood prone areas and decrease flooding.

Quality of Life

Enhance community environmental quality of life

Stewardship Communication and Coordination

Foster community stewardship and improve inter-governmental, state, local, and stakeholder cooperation and coordination on a watershed basis.



Cobbs Creek

Number of CSO outfalls: 34

What issues have emerged in this watershed?

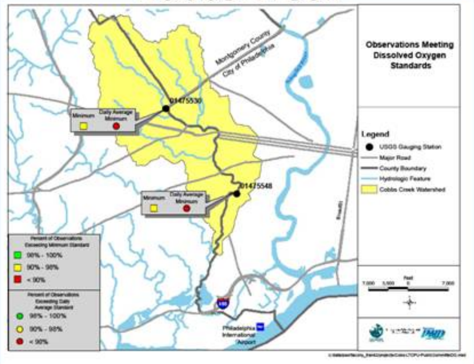
Vandalism

Dumping in and around the creek

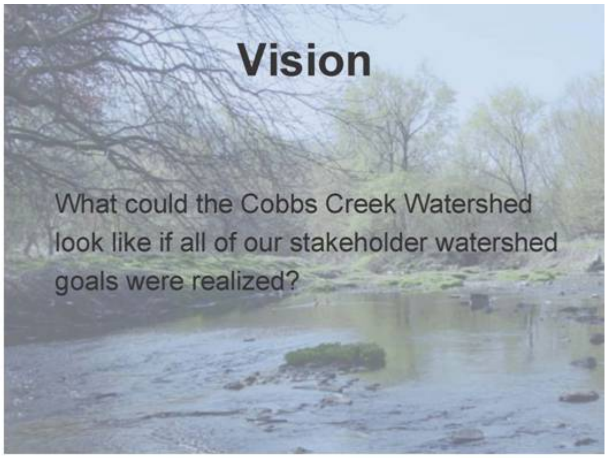
Erosion

Bacteria in Cobbs Creek

Dissolved Oxygen Levels in the Cobbs Creek



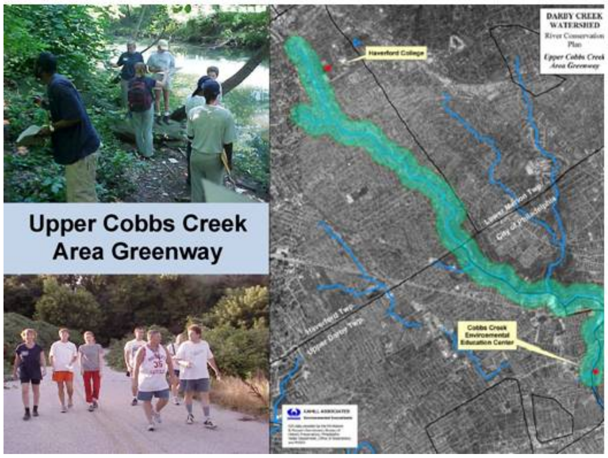
Cobbs Creek Streambank Restoration



Vision

What could the Cobbs Creek Watershed look like if all of our stakeholder watershed goals were realized?

Waterways Restoration Team



Upper Cobbs Creek Area Greenway

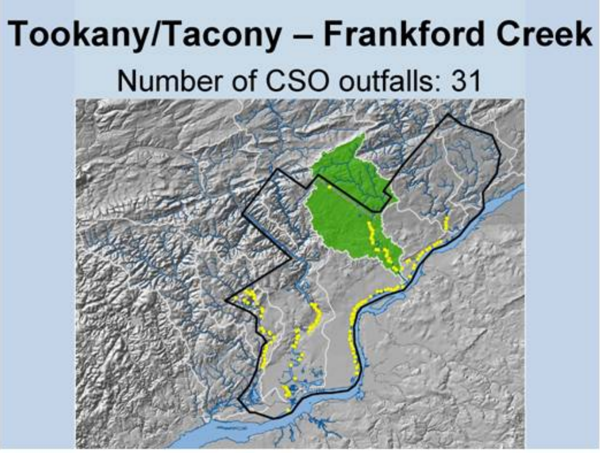
Active Community Stewardship

Wetland Restoration/Creation

Before

After

During



Tookany/Tacony – Frankford Creek

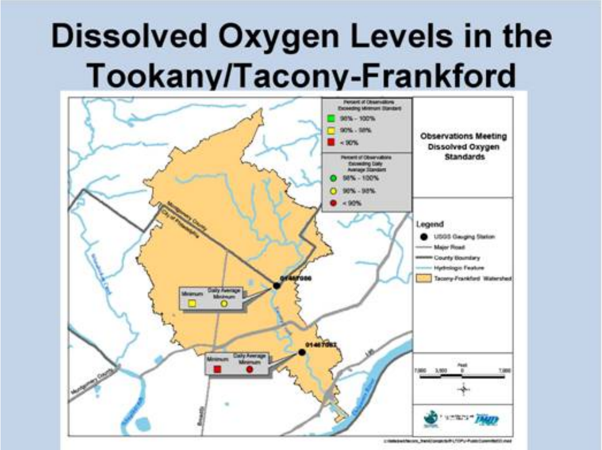
Number of CSO outfalls: 31

What issues have emerged in the TTF watershed?

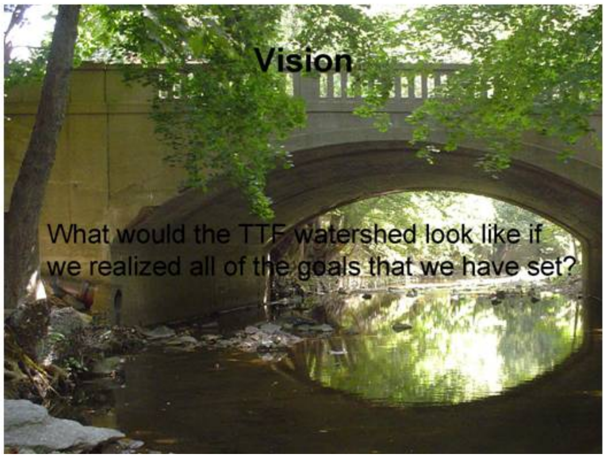
Stream Channelization

Litter and dumping

Exposed Infrastructure



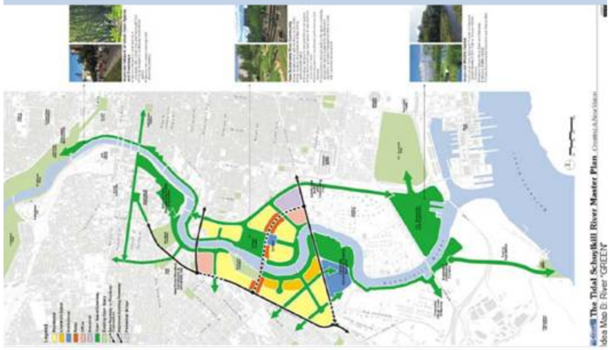
Dissolved Oxygen Levels in the Tookany/Tacony-Frankford



Vision

What would the TTF watershed look like if we realized all of the goals that we have set?

Schuylkill River Trail Links



Triathlons

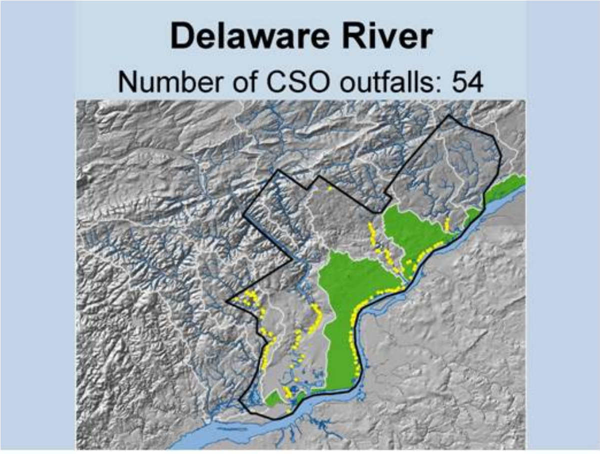
Rowing and Boating

Resurgence of aquatic life!


FWWIC Fish Ladder - River Otter Still Photos
March 20, 2005

Schuylkill River Fish Ladder

Fishing



Delaware River

Number of CSO outfalls: 54

What issues have emerged in this watershed?

Riverfront land uses make public access difficult

Dumping and trash

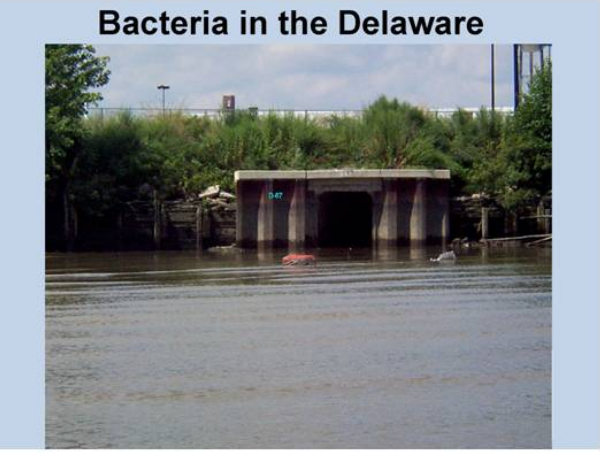
Spills and Water Quality Incidents

The Athos I

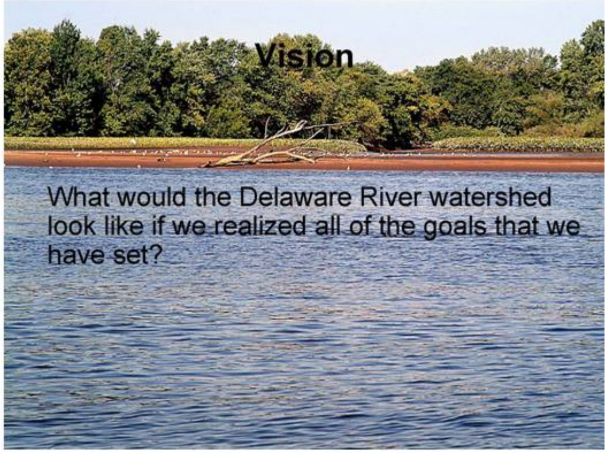
Oil Spill on the Delaware River

Information for the Public

Presented by the University of Delaware Sea Grant Program



Bacteria in the Delaware



Vision

What would the Delaware River watershed look like if we realized all of the goals that we have set?

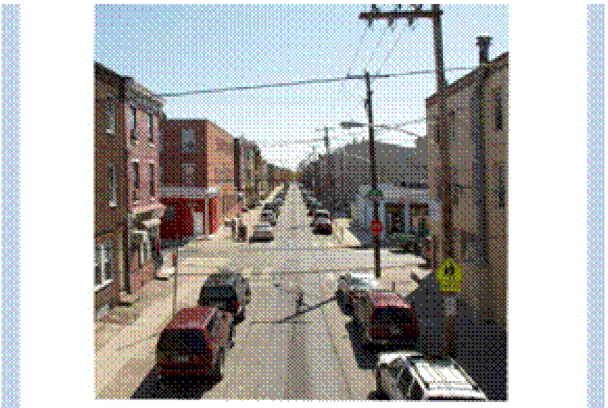
image credit: PENN Praxis

image credit: PENN Praxis

Next Steps

So – How do we get there?

- Visions have been outlined by various stakeholder groups
- We believe implementation of the LTCP with respect to the visions outlined by stakeholders and coupled with adequate support will enable the realization and execution of these visions.



Green Streets

Green Streets

Green Streets

Green Streets

Green Streets

Public Meeting Series #3

Philadelphia PWD Water Department

PWD CSOLTCPU
Public Meeting
Tuesday, June 2, 2009
FELS Center

Please Sign In

Name	Organization	Email
Amanda Snyder	South Philly Review	asnyder@southphillyreview.com
Henrietta Martin		
Andrew Clothier	ASCM	
Rose Rafferty	Block Captain	
Stephanie Odell	LoMo Civic Association	stephodell@gmail.com
Susan Gould	LoMo Civic Assoc.	gouldsue@yahoo.com
Heidi Tengel	"	heidetengel@hotmail.com

PWD CSOLTCPU Public Meeting, Series #3
FELS Center
Tuesday, June 2, 2009
6:00 – 8:00 p.m.

Comments/Questions

Name:

Audience Member

Comment/Question:

I like what is being proposed. But what if a street already has trees, will PWD remove the trees or build infiltration pits beneath the trees? Can this be done?

No. PWD will not remove any trees. We love trees. If a block already has a full set of trees, we'll look at other green street tools, e.g., bumpouts, that we can apply to manage the stormwater.

Name:

Audience Member

Comment/Question:

Who is paying for this?

PWD's Capital budget is funding the design and implementation of both the green and the gray, traditional projects. But it ultimately comes back to being paid by our ratepayers, our water/sewer customers. That's why it's so important to have public feedback

Comments/Questions

Name:

Audience Member

Comment/Question:

I live on Albion Street which is a very small street. Can you green a street like mine?

Small streets are certainly more challenging than wider streets, but we are still fine tuning designs that may be a better fit for streets like yours. When homeowners install a rain barrel or a flow through planter, this can help make the street a green one.

Name:

Audience Member

Comment/Question:

When this happens, how are we training the designers and contractors to build these properly and to maintain them in the future?

PWD has been designing and building stormwater demonstration projects for the past 10 years with many public and private partners, so we've gained a lot of experience. But we are still learning and we have consultants working with us to help us refine our current designs and to help us develop guidelines for long term maintenance and operation of these systems. We see green infrastructure as providing green economy jobs.

Comments/Questions

Name: Audience Member

Comment/Question:

I live on a block where nobody wanted trees. So I bought a large planter and placed it on my sidewalk. Suddenly, all my neighbors saw how nice it looks and that it stopped people from parking on the sidewalk. Now a lot of my neighbors have tem. Sometimes, people just need to see how things looks and work first to accept and want them.

Yes! That's why we are doing model neighborhood projects. Social Marketing!

Name:

____

Comment/Question:

____

____

____

____

____

____

PWD CSOLTCPU
Public Meeting
June 4, 2009
Waterview Recreation Center

Please Sign In

Name	Organization	Email
Maryann Hefferty	EPA R3	hefferty.maryann@epa.gov
MEGAN SGARLAT	FAIRMOUNT PARK	megan.sgarlat@phila.gov
Steve Monheim	Neighbor	monheims@[illegible]
Brian Winters	"	brianwinters_3@msn.com
LISA MAIORANO	KSNAC	lisadmail@gmail.com
[illegible]	CDNC Inc	
Michael Ingram	Ingram Plumbing	MIKESR@Ingrams[illegible].com
Michael Wilcox		mcwilcox@yahoo.com
Shambara Johnson		Shambara330@msn.com

①

PWD CSOLTCPU Public Meeting, Series #3
Waterview Recreation Center
Thursday, June 4, 2009
6:00 – 8:00 p.m.

Comments/Questions

Name:
Rev. Williams

Comment/Question:
PWD did a very good job restoring the creek near Adams Ave. & Rising Sun intersection.

Name:
Michael Wilcox ([illegible])

Comment/Question:
Can you tell us about Porous asphalt?

PWD: Yes, I will explain it & show you because we have a demonstration of it right outside of the building.

Comments/Questions

Name:
Rev. Williams

Comment/Question:
Could you separate sw runoff and sanitary at the end of the pipe?

PWD: You can't do it at the end of pipe. It must be at the source, unless you build a tunnel.

Name:
Rev. Williams

Comment/Question:
How does green roof work, in terms of plants surviving?

PWD: Green roofs use sedums, which are ideal for green roofs.

Comments/Questions

Name:

Rev. Williams

Comment/Question:

Is the City incorporating green design in all current bumpouts.

PWD: We're in the process of trying to convince them, (storm wtr) but we need the residents to go to City + express they want it to be green.

Name:

Brian Williams (gray)

Comment/Question:

How do you deal with mosquitoes?

PWD: Mosquitos ~~[illegible]~~ only like stagnant water. Green infrastructure ~~[illegible]~~ is designed ~~[illegible]~~ to move water ~~[illegible]~~, therefore ~~water is always moving~~ mosquitoes aren't a problem.

Michael Wilcox (Green)

Parking lot for church I work with is having problems with green b/c it is taking a long time & it is too expensive.

↳ PWD: We have to change the system (to speed it up?)

We can speak to congregations, about the greening benefits.

Green is Michael (Biz Card

9

Comments/Questions

Name:
Rev. Williams

Comment/Question:
Can you create long sidewalk planters along entire block?
PWD: Yes, you can put multiple ones in.

Name: Lisa

Comment/Question:
~~Explain~~ Do you put tree pits or actual trenches in for tree trenches?

→ PWD: Actual trenches are below ground.

⑤

Comments/Questions

Name: Lisa

girl line?

Comment/Question: What do trees do to sidewalks?

PWD: Broken laterals invite trees, not vice versa. Also If you plant trees properly, then you won't have problem.

Name: Rev. Williams

Comment/Question: I tried the new system for my roof where you paint the roof gray + now runoff just shoots right off.

PWD: That is the negative impact that roofs have.

⑥

Comments/Questions

Name:

Brian Williams gray

Comment/Question:

Kids can drown in buckets of water. Are rain barrels safe?

PWD - Yes, they have tops on top to protect children from getting inside.

Name:

Rev. Williams

Comment/Question:

Do we have to cut grasses on sidewalk?

PWD: No, we want to use native plants, so there is less maintenance.

⑦

Comments/Questions

Name:
Lisa

Comment/Question:
Are there incentive for developers to do green infrastructure?

PWD: Yes, new regs. require that they manage 1st inch of runoff, if site is going to be disturbed and is larger than 15,000 ft.^{2}

Name:
Michael Wilcox

Comment/Question:
I'm a registered plumber. I'm concerned about contamination, esp rain barrel. What are the negatives? Maybe have sticker on rain barrel that says not safe to drink water?

PWD: Contamination in SW is same at source, as at the end of pipe.

~~Maybe adding~~ Adding sticker warning is a great idea!

Rev. Williams

If I have rain barrel + move
out + new owner has problem
w/ rain barrel. Am I liable?

PWD: No!

Lisa

Since city corridors already developed,
how become green?

PWD: Convert vacant lands to urban
farms or other greening.
As streets get redeveloped, add green.
give businesses incentives.
give homes incentives.
Need to tackle in steps ~ in
pockets & areas that need redeveloping.

Rev. Williams

Wouldn't City save $ by building green, instead of paying alot for cement?

PWD - Yes, In future, we hope it will be a requirement to do green, but right now it's not cost-effective for the Streets Dept.

Rev. Williams

Why not green 30th st station? It's blight + an eyesore.

PWD - It's not cost effective at this moment for them, possibly.
We need to create the incentive for ~~the~~ property owners to do this like in the way we will bill large commercial + Industrial properties (billed based on size of property + amt. of impervious)

~~Rev. [illegible]~~

Rev. Williams

Is there such thing as too many trees on ~~a~~ block?

PWD - Yes. You need to have appropriate spacing, so roots don't overlap, etc.

Rev. Williams

Who owns the sidewalks?

PWD = You do!

Philadelphia
PWD
Water Department

PWD CSOLTCPU
Public Meeting
June 10, 2009
Northern Liberties Community Center

Please Sign In

Name	Organization	Email
Allison Graham	EPA Region3	graham.allison@epa.gov
Paul Gansky	NLNA	pgansky@aol.com
Sari judd	NLNA	
VIVEK ANANTHAN	VIS.	VIVEKA@JUNO.COM
KEN MITCHELL	NLNA	BANDAMAKER@YAHOO.com
Brady Russell	Clean Water Action	brussell@cleanwater.org
Erika Goldberg	NLNA	bgoldewag@verizon.net
Scott Willy	NLNA	willingham.scott@epa.gov
PAUL MAIELLO	KSNK GREENING	MAIELLO7@VERIZON.NET
Lara Kelly	NLNA	larakelly@comcast.net
Iva Richards	NLNA	ibr1007@verizon.net
Khiet Luong	P.E.C.	kluong@pecpa.org

PWD CSOLTCPU
Public Meeting
June 10, 2009
Northern Liberties Community Center

Please Sign In

Name	Organization	Email
Ty Patton		multiplex77@aol.com
Ronald Nord		~~[illegible]~~
		NORDR@aol.com

PWD CSOLTCPU Public Meeting, Series #3
Northern Liberties Community Center
Thursday, June 10, 2009
6:00 – 8:00 p.m.

Comments/Questions

Name:

Erika

Comment/Question:

We have a new rain garden in our park ~ a mini - version of a wetland!
Marc - Yes!

Name:

Comment/Question:

Is street higher than sidewalk where bioswales are present?
Yes, in order to direct stormwater to the vegetation

Comments/Questions

Name:

Aberdee

Comment/Question:

Are there contractors that can do porous pavement?

PWD: Yes, there are. You can find them on-line. We need the demand to be there, so that the costs decrease + contractors want to do it.

Name:

Aberdee

Comment/Question:

How much stormwater runoff will you remove thru greening?

PWD: The 1^{st} inch of rain fall (at the very least).

③

Comments/Questions

Name:

Comment/Question:

Is it common to measure temperature thru the green projects?

Green will create more cooling than blacktop at sometimes we consider temperature differentials, depending on the project.

Name:

Comment/Question:

Do you have information on what the neighbor think, re: vegetation?

[illegible] At Saylor Grove Wetland, residents love it!

Comments/Questions

Name:
Attendee

Comment/Question:
Do native plants stay?
With control, after first two seasons,
yes + they keep invasives out.

Name:
Attendee

Comment/Question:
How does school sign up for greening?
Phila. School Dist. is a private entity +
PWD can only financially support public ~~projects~~
properties, but PWD can support
private schools with other support (e.g. grant funds
+/or license agreements/ownership rights.)

⑤

Comments/Questions

Name:
Attendee

Comment/Question:
Has anyone on city-council taken this on as a city issue (green)?
The Mayor! We are [illegible] following his green plan

Name:
Attendee

Comment/Question:
Can you green rec. center?
Yes!

⑥

Comments/Questions

Name:

Comment/Question:

Will new SW regs affect homeowners?

NO!

Only industry/commercial + huge property owners.

However, bills go down when these impacted properties start putting in green (they will get credit)!

Name:

Comment/Question:

Is there a way to incentivize residential credit?

Right now, no, but working w/ PennFuture, So that resident gets credit if put Rain barrels, etc. in.

(57)

Comments/Questions

Name:

Comment/Question:

Can we green playground + (next to Akwd) REC Center?
Yes, We have to create a demand for it!

Name:

Comment/Question:

Is general street tree planting a component?
Yes, but current tree pits are not designed to manage SW runoff. But we will pay $ to enhance tree pits.

Green Cities, Clean Waters

Summer, 2009

CSO-Control Approach Survey

The Philadelphia Water Department (PWD) believes that the best way to spend its customers' dollars to decrease Combined Sewer Overflows (CSOs) is through an approach that largely focuses on a green solution that captures stormwater on land through more natural practices, with some traditional "gray" solutions, such as new pipes and tanks to fill in the gaps where green practices can't capture the volume that we are targeting.

- Generally, do you like this strategy?

- Generally, what do you like about this strategy?

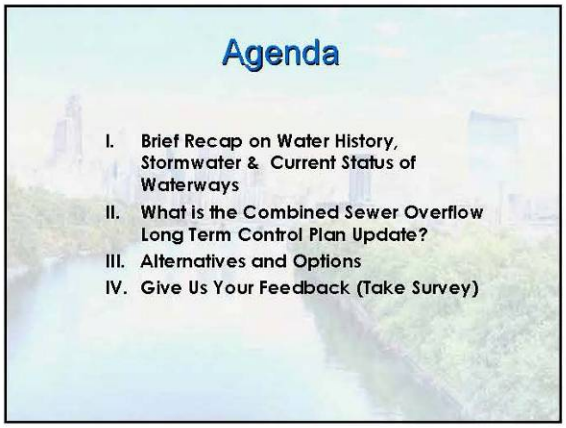
- Generally, what concerns do you have about this strategy?

- What additional information do you think would be helpful?

Green Cities, Clean Waters

The Combined Sewer Overflow Long Term Control Plan Update

Philadelphia PWD Water Department



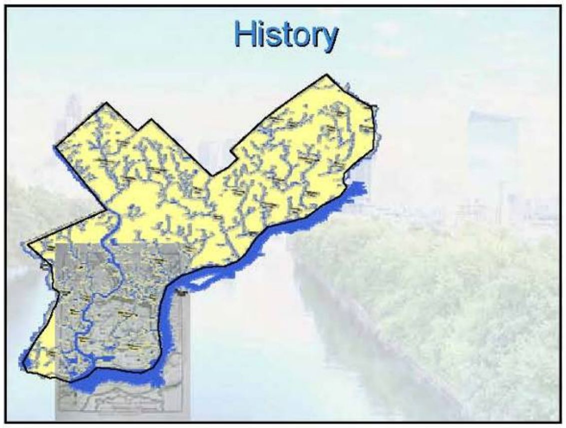
Agenda

- I. Brief Recap on Water History, Stormwater & Current Status of Waterways
- II. What is the Combined Sewer Overflow Long Term Control Plan Update?
- III. Alternatives and Options
- IV. Give Us Your Feedback (Take Survey)

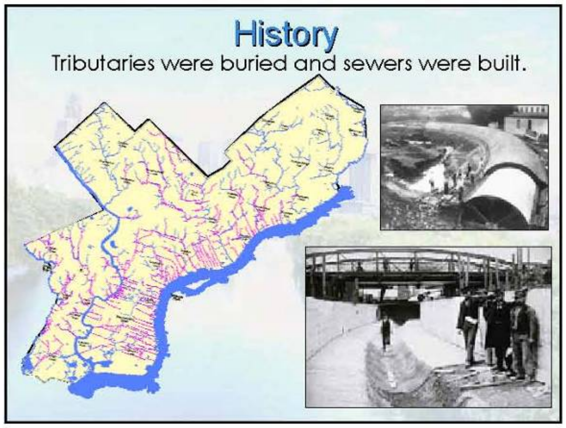
Vision

- We want a beautiful, green city with clean waters.

Image credit: PENN Praxis

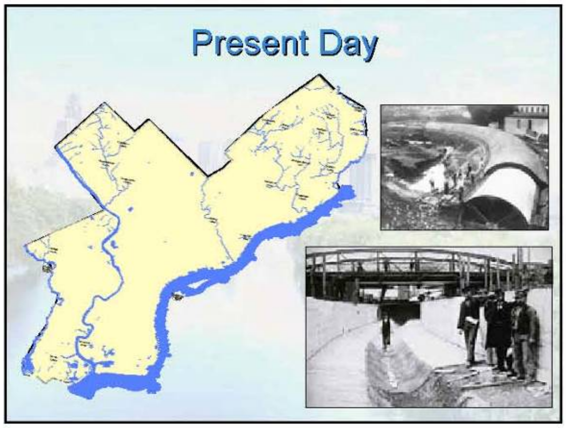


History

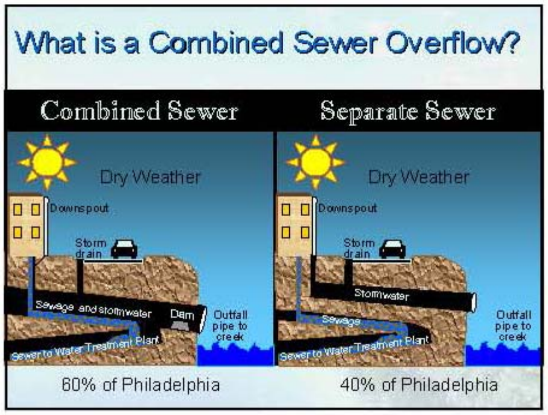


History

Tributaries were buried and sewers were built.



Present Day



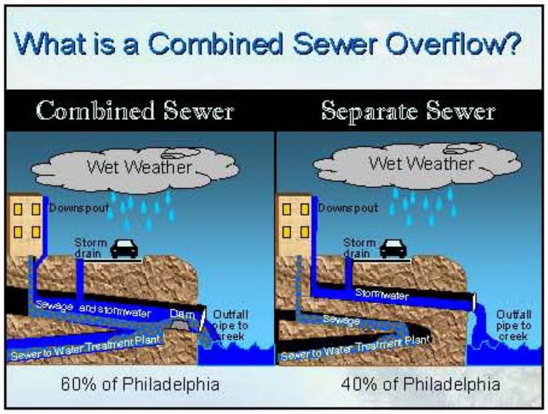
What is a Combined Sewer Overflow?

Combined Sewer

Separate Sewer

60% of Philadelphia

40% of Philadelphia



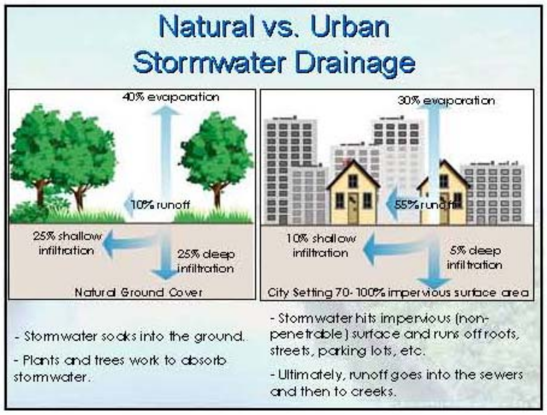
What is a Combined Sewer Overflow?

Combined Sewer

Separate Sewer

60% of Philadelphia

40% of Philadelphia



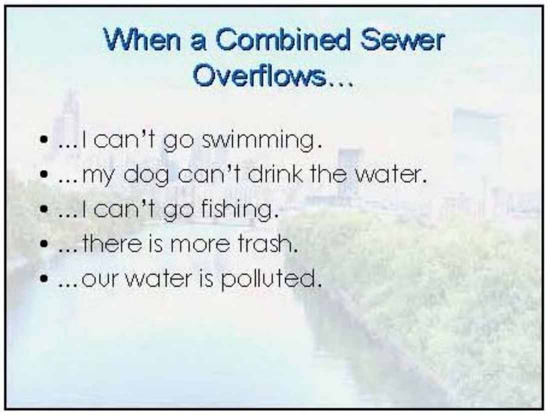
Natural vs. Urban Stormwater Drainage

- Stormwater soaks into the ground.

- Plants and trees work to absorb stormwater.

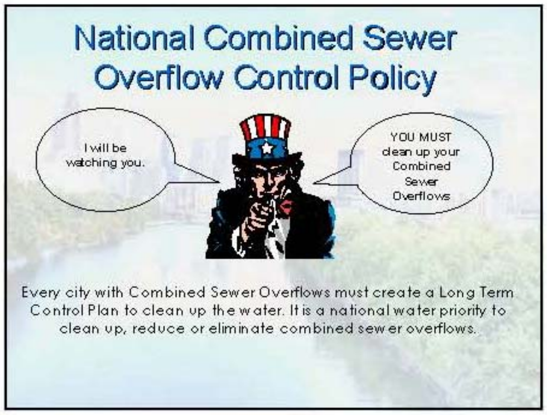
- Stormwater hits impervious (non-penetrable) surface and runs off roofs, streets, parking lots, etc.

- Ultimately, runoff goes into the sewers and then to creeks.



When a Combined Sewer Overflows…

- …I can't go swimming.
- …my dog can't drink the water.
- …I can't go fishing.
- …there is more trash.
- …our water is polluted.



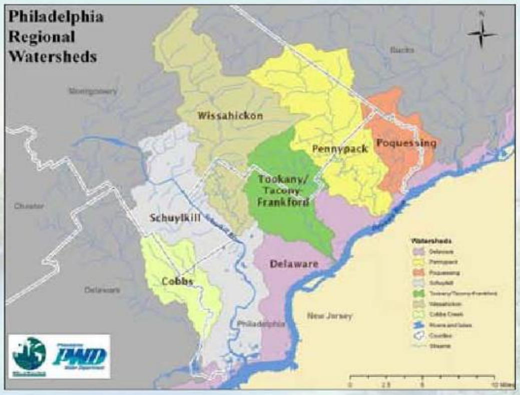
National Combined Sewer Overflow Control Policy

Every city with Combined Sewer Overflows must create a Long Term Control Plan to clean up the water. It is a national water priority to clean up, reduce or eliminate combined sewer overflows.

It's not just a Philly Problem

Philadelphia's Watershed Approach

Watershed: An area of land that drains stormwater to a common body of water



Implementation Approach

- PWD has developed "**Implementation Targets**" as means to measure progress and sustain stakeholder support through the Combined Sewer Overflow Plan over the span of 20 -30 years.
  - **Target A:** Dry Weather Water Quality and Aesthetics
  - **Target B:** Healthy Living Resources
  - **Target C: Wet Weather Water Quality**

Target A: Dry Weather Water Quality and Aesthetics

Target B: Healthy Living Resources

Boulders and plants added to provide refuge for fish and bugs

Concrete box channel remains

Target C: Wet Weather Quality

- **Requires lengthy timeline**
  - Heavily relies on Combined Sewer Overflow and Low Impact Development teams
- **Building both Green and Gray Infrastructures**
  - Inflatable Dam, Combined Sewer Overflow gates, etc.
  - Best Management Practices
    - All of our Green Program Elements
- **Adaptive Management**

Cost vs. Benefit

The Water Department is expecting to spend billions of dollars over 20 – 30 years to reduce the number of Combined Sewer Overflows that occur each year.

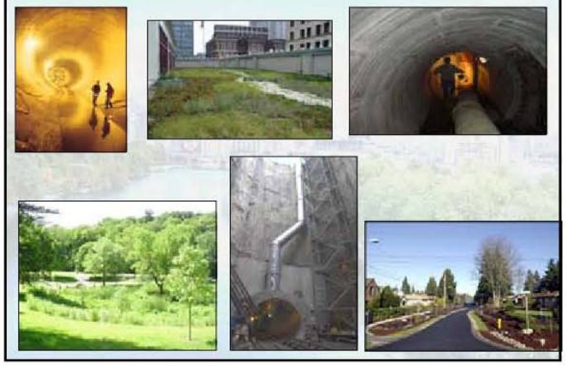
There is a level of benefit (and cost) associated with every dollar spent on building green and gray infrastructure.

PWD is working to determine a cost effective solution to improve and restore the quality of our waterways and to reduce the number of annual overflows.

What can we afford that works best?

The most cost effective & beneficial method will be the **Green Infrastructure** approach with some traditional "gray" solutions to fill in the gaps where green practices can't capture the volume that we are targeting.

Gray Infrastructure Solutions Green



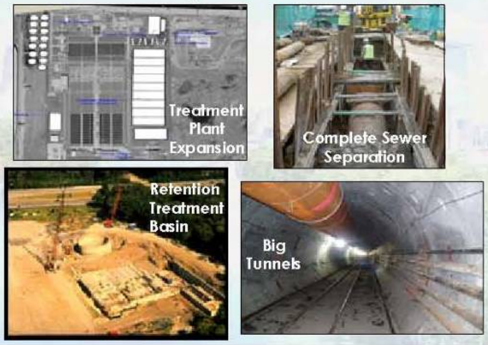
Gray – What is it?

"Gray" refers to traditional infrastructure solutions to manage stormwater.

4 Options

- Complete Sewer Separation
- Expand Treatment Facilities
- Big Tunnels/More Storage
- Retention Treatment Basins

Gray Options

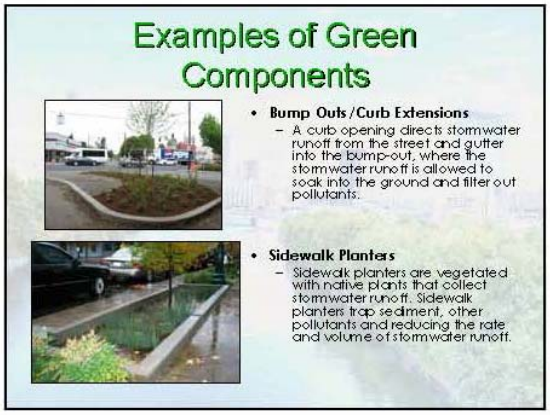


Green – What is it?

- "Green" is the use of natural and man-made technology to mimic nature's ability to deal with stormwater.
- Treats stormwater as a resource
- 10 Green Elements in our Green Program

Examples of Green Components

- **Green Roofs**
  - A green roof is a roof that is partially or completely covered with vegetation to manage stormwater runoff.
- **Porous Pavement**
  - This porous surface replaces traditional pavement, allowing stromwater runoff to infiltrate directly into the soil and receive water quality treatment.



Examples of Green Components

- **Bump Outs/Curb Extensions**
  - A curb opening directs stormwater runoff from the street and gutter into the bump-out, where the stormwater runoff is allowed to soak into the ground and filter out pollutants.
- **Sidewalk Planters**
  - Sidewalk planters are vegetated with native plants that collect stormwater runoff. Sidewalk planters trap sediment, other pollutants and reducing the rate and volume of stormwater runoff.

Examples of Green Components

- **Grass Pavers**
  - Grass pavers are porous surfaces with open areas designed to allow grass to grow within the open slots.
- **Flow-through Planters**
  - Flow-through planters are vegetated boxes with a small reservoir that receive runoff through rain drains or curb cuts.

Examples of Green Components

- **Living Wall**
  - A living wall is a vertical arrangement of plants and other vegetation.
- **Rain Barrel**
  - A Rain barrel collects and stores stormwater runoff from downspouts.

Examples of Green Components

- **Tree Trenches**
  - The trees and soil in the tree trench provide the important function of filtering out common stormwater runoff pollutants and absorbing stormwater runoff
- **Vegetated Swales**
  - Swales are designed to trap suspended solids and to reduce the flow and velocity of stormwater runoff.

Green Program

Green Streets

Components of a Green Street could include:

-Curb Openings
-Sidewalk Planters
- Street Trees
- More Landscaping
-Curb Extensions/Bump Outs
-Porous Pavement

Green Program

Green Homes

Components of a Green Home could include:

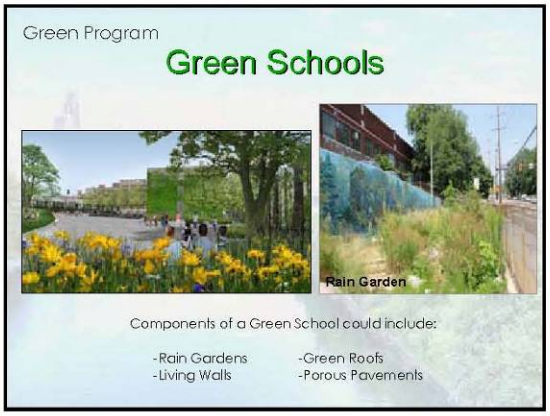
-Rain Barrels
-Rain Gardens
-Flow-through Planters
-Green Roofs
-Native Plants
-Energy Efficient Practices & Appliances

Green Program

Green Parking

Components of Green Parking could include:

- Porous Pavements
-Vegetated Swales
- Pavers



Green Program

Green Schools

Components of a Green School could include:

-Rain Gardens
-Living Walls
-Green Roofs
-Porous Pavements

Green Program

Green Public Facilities

Components can include:

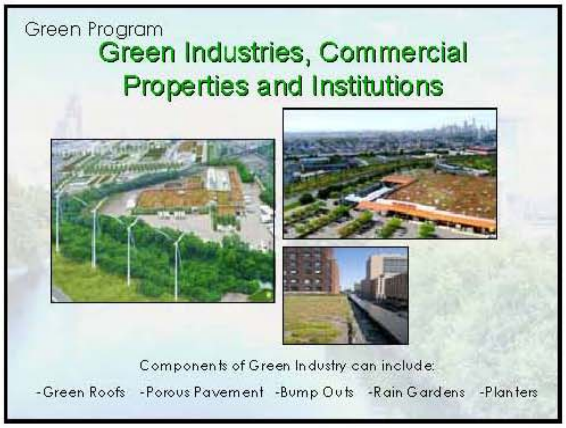
- Living Wall
- Street trees
- Rain Gardens
- Green Roofs
- Porous Pavements
- Sidewalk Planters

Green Program

Public Open Spaces

Components can include:

- Rain Gardens
-Porous Pavements
- Tree Trenches
- Vegetative Swales



Green Program

Green Industries, Commercial Properties and Institutions

Components of Green Industry can include:

-Green Roofs -Porous Pavement -Bump Outs -Rain Gardens -Planters

Green & Gray Infrastructure Costs

- **Dollars**
  - Both strategies cost money to implement.
- **Construction**
  - Both strategies require construction and the disruptions that come with it.

Green & Gray Infrastructure Costs

- **Traffic**
  - Both strategies may cause traffic (during construction).
- **Energy**
  - Both strategies consume energy.

Benefits

Gray	Green
Reduced Combined Sewer Overflows	Reduced Combined Sewer Overflows
Improved Water Quality	Improved Water Quality
More Jobs	More Jobs (Green Jobs)
	Better Air Quality & Health Benefits
	Cooling
	Reduced Heat Stress
	Reduced Carbon Footprint
	Energy Savings
	Increased Recreation
	Enhanced Aquatic Life & Terrestrial Life
	Improved Aesthetics
	Higher Property Values

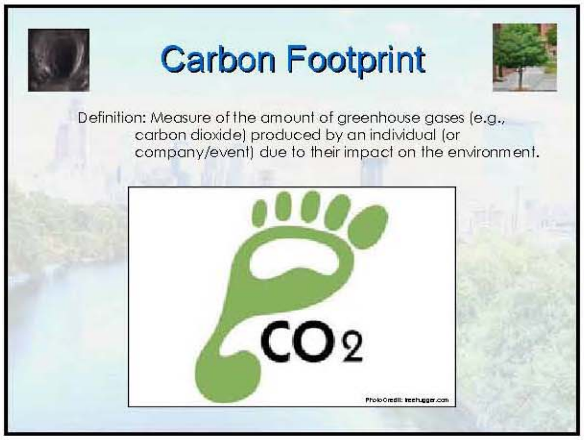
Reduced CSOs/ Improved Water Quality

Both strategies are designed to clean up, reduce or eliminate combined sewer overflows and therefore, improve water quality.

Increased Job Creation

Green technology creates more local green jobs over time compared to gray infrastructure, where big companies are hired to do the work on a short-term basis.

Air Quality & Health Benefits



Carbon Footprint

Definition: Measure of the amount of greenhouse gases (e.g., carbon dioxide) produced by an individual (or company/event) due to their impact on the environment.

Photo Credit: treehugger.com

Increased Recreation

Green parks coupled with clean water increases recreational opportunities and promotes a city of Brotherly Love.

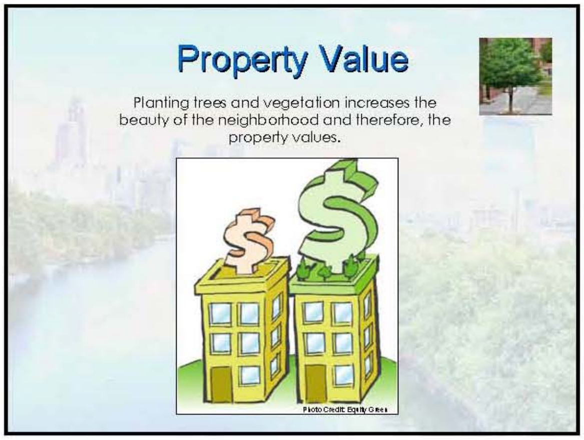
Enhanced Aquatic Life & Terrestrial Life

Improve stream habitat and integrity of aquatic and terrestrial life.

Fish Ladder

Fishing Fest

Aesthetics



Property Value

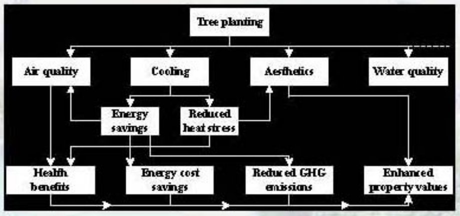
Planting trees and vegetation increases the beauty of the neighborhood and therefore, the property values.

Photo Credit: Equity Green

Economic/Environmental/Social Benefits

- Costs
- Ecological Benefits
- Recreation
- Heat Stress Mortality
- Energy Savings
- Air Quality
- Carbon Footprint
- Aesthetics
- Jobs
- Property Value

How Benefits are Linked



Alternatives Evaluation

- **Qualitative Factors Considered**
  - Public Support
  - Location
  - Construction Feasibility
  - Complexity and Difficulty of Solution
- **Maximize benefits to society – Triple Bottom Line**
- **Minimize Cost to PWD and its Customers**
- **Financing and Affordability**
- **All alternatives must meet goals**

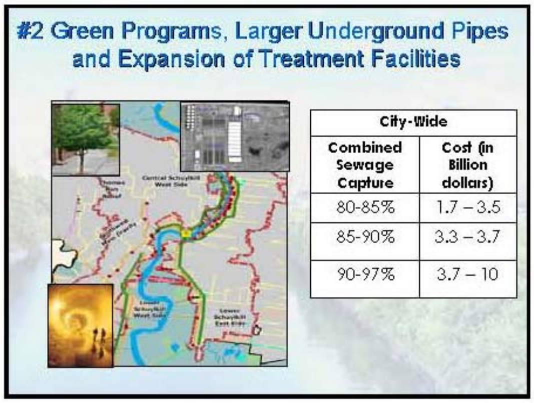
The alternatives considered to help us reach the ultimate goal of reducing CSOs…

Alternatives Evaluated

1. **Big Tunnels**
2. **Green Programs, Larger Pipes and Expansion of Treatment Facilities**
3. Green Programs, Increased Transmission , Expansion of Treatment Facilities and Retention Treatment Basins
4. **All Green**
5. Green with Smaller-Scale Gray
6. Plant Expansion, Satellite Treatment (Ballasted Floc)
7. Plant Expansion, Satellite Treatment (Swirl/Vortex)
8. Retention Treatment Basins

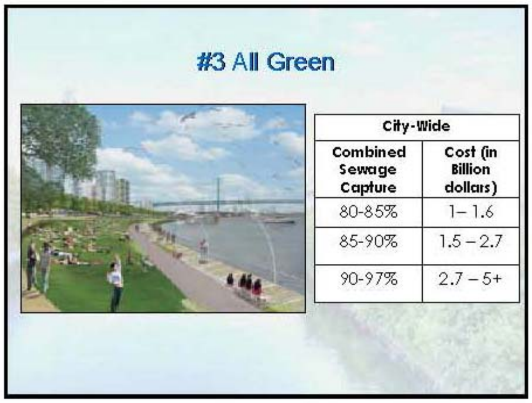
#1: Big Underground Tunnels

City-Wide	
Combined Sewage Capture	Cost (in Billion dollars)
80-85%	N/A
85-90%	N/A
90-97%	3.2 – 10



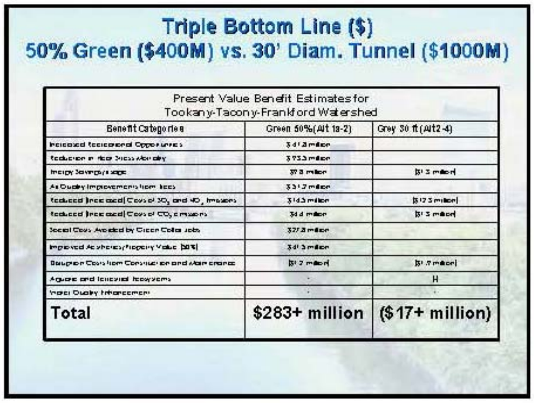
#2 Green Programs, Larger Underground Pipes and Expansion of Treatment Facilities

City-Wide	
Combined Sewage Capture	Cost (in Billion dollars)
80-85%	1.7 – 3.5
85-90%	3.3 – 3.7
90-97%	3.7 – 10



#3 All Green

City-Wide	
Combined Sewage Capture	Cost (in Billion dollars)
80-85%	1– 1.6
85-90%	1.5 – 2.7
90-97%	2.7 – 5+



Triple Bottom Line ($)
50% Green ($400M) vs. 30' Diam. Tunnel ($1000M)

Present Value Benefit Estimates for Tookany-Tacony-Frankford Watershed		
Benefit Categories	Green 50%(Alt 1a-2)	Grey 30 ft (Alt2-4)
Increased Recreational Opportunities	$41.8 million	
Reduction in Heat Stress Mortality	$93.3 million	
Energy Savings/Usage	$7.8 million	($1.3 million)
Air Quality Improvements from Trees	$31.7 million	
Reduced (Increased) Costs of SO_2 and NO_x Emissions	$14.3 million	($12.3 million)
Reduced (Increased) Costs of CO_2 Emissions	$4.4 million	($1.3 million)
Social Costs Avoided by Green Collar Jobs	$27.8 million	
Improved Aesthetics/Property Value (50%)	$41.3 million	
Disruption Costs from Construction and Maintenance	($1.2 million)	($1.7 million)
Aquatic and Terrestrial Ecosystems	-	H
Water Quality Enhancement	-	-
Total	**$283+ million**	**($17+ million)**

Thank you!

WHAT DO YOU THINK?

Please fill out the survey.

We want to hear from you!

Model Neighborhoods

(Sample petitions, educational materials, walk announcements,
street design layouts and sample photo simulation sets)

Green Streets/Model Neighborhood Petition

I, Mike Ritzius, as the representative for the 1200 block of Ellsworth Street, submit this petition as evidence that nearly 100 percent of the residents on my block want to find out more about becoming one of the City's Green Streets (which can include trees with planters, curb bumpouts, above ground planters, and other street features that better manage rainwater runoff and improve the beauty of our block).

#	Name	Address
1	Mike + Marisa Ritzius	Ellsworth St #1215
2	Jackie & Don Gusic	1222 Ellsworth Street Phila PA 19147
3		1200
4	Vacant	1201 - Vacant lot
5		1202
6	Vacant	1203 - Vacant lot
7	Heather Brennan	1204
8	Bridget Fitzpatrick	1205 - 13
9		1206
10		1207 Vacant
11	Dorothea Staron	1208
12	[illegible] Nocella	1209
13		1210
14	Rachel Kratzer	1211
15		1212
16		1213
17	Rachel A. Hildebrandt	1214
18		1216
19	Jocelyn Butler	1217
20		1218
21	John [illegible]	1219
22		1220 ELLSWORTH ST. PHILA, PA 19147
23		1221
24		1223
25		1224
26	MONICA ZALESKI	1225

Philadelphia PWD Water Department

Green Streets/Model Neighborhood Petition

I, Virginia Cofield, as the representative for the 3100 block of Marston Street, submit this petition as evidence that nearly 100 percent of the residents on my block want to see their street become one of the City's Green Streets (which can include trees with planters, curb bumpouts, above ground planters, and other street features that better manage rainwater runoff and improve the beauty of our block).

#	Name	Address
1	Virginia L. Cofield	3151 North Marston Street
2	Mrs. Susie Robinson	3155 North Marston Street
3	Cheryl Spencer	3128 N. Marston St.
4	Karen Little	3119 N MARSTON ST.
5	Gladys E. [illegible]	3104 N. Marston St.
6	Denise Abney	2914 W. Allegheny Ave
7	Darnell Rodgers	3159 N. Marston St
8	Devarc Chappell	3159 N. Marston St
9	Hafeez Brown	3156 N. Marston
10	Timothy Randolph	3113 N Marston St
11	Jeannie [illegible]	3146 N. Marston St.
12	David Carmichael	3143 Marston St
13	[illegible]	3125 N Marston
14	Tina Willis	3132 N Marston St
15	Patricia Green	3123 N. Marston
16	Tanya FRISBY	3109 N. MARSTON ST.
17	Timmy Green	3116 Marston St
18	Deneen Wright	3102 N Marsten St.
19		3108 N. Marston St
20	Nate Avery	3120 N MARTON ST
21	Melvin Collins	3126 MARSTON St.
22	Mrs Annie Scott	3140 N Marston St
23	[redacted]	[redacted]
24	[redacted]	[redacted]
25	Alberta M[illegible]	3135 N. Marston St
26	Levin Bishop	3119 N Marston ST.
27	Paul A. [illegible]	3131 N. MARSTON ST

Philadelphia
PWD
Water Department

Green Streets/Model Neighborhood Petition

I, [illegible], as the representative for the 3100 block of PENNOCK St, submit this petition as evidence that nearly 100 percent of the residents on my block want to see their street become one of the City's Green Streets (which can include trees with planters, curb bumpouts, above ground planters, and other street features that better manage rainwater runoff and improve the beauty of our block).

#	Name	Address
1	Ida Brown	3152 N Pennock st
2	Alphonso Graves	3155 N. Pennock St
3	Roxanne Whaley	3156 N. Pennock ST
4	Ebony & Dee DAVIS	3154 N Pennock ST
5	Terry Merriweather	3159 N PENNOCK. St
6	Sheila Merriweather	3148 N Pennock, St
7	Hugh Allen	3147 N. Pennock St.
8	Andrew Hostetter	3151 N. Pennock St
9	[illegible]	3133 N. Pennock St
10	M Clarke	3135 N. Pennock St
11	[illegible] Lukes	3121 N PENNOCK St
12	Patrice Luker	3124 N. Pennock St
13	E. A. [illegible]	3137 N. Pennock ST
14	Earline Young	3153 N. PENNOCK St
15	[illegible]	3101 Pennock Phila. Pa. 19132
16	Shirley Smith	3106 Pennock St Phila PA 19132
17	Julia Adams	3100 Pennock St Phila. Pa. 19132
18	John Bennett	3116 Pennock St. Phila, Pa. 19132
19	Melissa Thomas	3127 Pennock ST Phila 19132
20	Hattie Herndon	3119 pennock st phila pa, 19132
21	Mamie Taylor	3157 Pennock St. phila. Pa. 1932
22	Barbara Miller	3139 n Pennock st Phila. pa 19132
23	Denise Whittaker	3149 N. Pennock St Phila PA 19132
24	Litefia Marrow	3128 N. Pennock St. Phila, PA 19132
25		
26		
27		

Green Streets/Model Neighborhood Petition

I, Andrew Kerber as the representative for the 2500 block of Grays Ferry Avenue, submit this petition as evidence that nearly 100 percent of the residents on my block want to find out more about becoming one of the City's Green Streets (which can include trees with planters, curb bumpouts, above ground planters, and other street features that better manage rainwater runoff and improve the beauty of our block).

#	Name	Address
1	Andw Kerber	2534 Grays Ferry Ave
2	[illegible]	2527 Grays Ferry Ave.
3	[illegible]	2527 GRAYSFERRY AVE
4	Mildred J Himes	2521 Grays Ferry Ave
5	[illegible]	2519 Grays Ferry Ave
6	[illegible]	2519 Grays Ferry Ave.
7	[illegible]	2519 Grays Ferry Ave
8	Beverly Higgins	2527 Grays Ferry Ave.
9	JAMES CAMPBELL	2531 GRAYS FERRY AVE
10	Madeleine Gates	2515 Grays Ferry Ave
11	Joe Whitley	2536 Grays Ferry Ave.
12	[illegible]	2523 Graysferry ave.
13	[illegible]	2526 Grays Ferry Ave.
14	Tommie Hill	2527 GRAYS FERRY Ave
15	Joyce [illegible]	2522 Carpenters St
16	[illegible]	2526 Grays Ferry Ave
17	John McHugh	2529 Grays Ferry Ave
18	[illegible]	2546 Gray Ferry Ave
19	Roosevelt Logan	2513 Graysferry Ave.
20		
21		
22		
23		
24		
25		
26		

Model Neighborhood

Three Typical Stormwater Management Projects

Street Tree Plantings

Street trees provide shade, improve air quality, reduce stormwater runoff, absorb noise and beautify neighborhoods. From a stormwater management perspective, trees can reduce stormwater runoff by capturing rainfall on leaves and branches. Trees can be planted in special ways to capture the flow of water from the street and sidewalk letting it soak to the soil around the tree roots, and filtering pollutants from the runoff. Other tree benefits include, improved property values and crime reduction.

Sidewalk Planters

Sidewalk planters (or rain gardens) are shallow depressions in the sidewalk, vegetated with native plants that collect stormwater runoff from the adjacent street and sidewalk, filter pollutants from the runoff and allow the runoff to soak into the ground. Stormwater runoff from the street is directed to the planter through a curb opening. Stormwater that is not absorbed by the plants and the soil overflows back out to the street and the existing storm inlet or directly into the sewer system through a pipe. Sidewalk planters/rain gardens help protect our waterways by trapping sediment, fertilizer, oil, pet waste and other pollutants and reducing the rate and volume of the stormwater runoff.

Vegetated Curb Bump Outs

Vegetated curb bump-outs are located along the curb line of the street, where the curb is bumped out into the existing parking lane of the street. A curb opening directs stormwater runoff from the street and gutter into the bump-out. The bump-out is slightly depressed and vegetated with native plants to allow stormwater runoff to pond, soak into the ground and become filtered by the plants before overflowing to the existing storm inlet. In addition to managing stormwater runoff and improving water quality, bump-outs may also slow down traffic and create safer pedestrian crossings.

WHY A MODEL NEIGHBORHOOD ?

Philadelphia Water Department (PWD) is working on a new and exciting green initiative with its partners, Fairmount Park, Citizens for Pennsylvania's Future (PennFuture), the Next Great City coalition, Pennsylvania Horticultural Society and local community groups.

Model Neighborhoods is an initiative to transform the neighborhoods of Philadelphia into model green communities that manage stormwater in innovative ways. These neighborhoods will showcase green infrastructure elements, such as street trees trenches, sidewalk planters, and bump outs/curb extensions (see middle panel for definitions). These projects help clean stormwater runoff, help slow it down and help it soak back into the ground, reducing the amount of stormwater that would otherwise travel through underground pipes to our streams and rivers.

Beyond stormwater benefits, green infrastructure projects beautify neighborhoods, improve air quality, reduce the City's temperature (urban heat island effect), and create safer, healthier communities.

HOW TO NOMINATE YOUR BLOCK?

1. Contact your local neighborhood group or civic organization to notify them of your interest. Civic partners play a key role in *Model Neighborhoods.*
2. Fill out the Green Street Petition and obtain signatures from the residents on your block.
3. Submit the petition to the Philadelphia Water Department so that your block can be considered.

* The first four blocks that sign up in each neighborhood will be considered for a green street. Others may be considered at a later date.

See contact information on the reverse side for materials.

MODEL NEIGHBORHOOD ELEMENTS

Examples of green infrastructure elements that you may see on your street, block and on other public properties:

Street Trees Trenches

Street trees trenches capture the flow of stormwater from the street and sidewalk, letting it soak into the soil. They provide shade, improve air quality, absorb noise and beautify neighborhoods.

Sidewalk Planters

Stormwater runoff from the street is directed to the planter through a curb opening. Sidewalk planters help protect our waterways by trapping pollutants and reducing stormwater runoff.

Bump Outs/Curb Extensions

A curb opening allows stormwater runoff from the street and gutter into the curb extensions, where the stormwater runoff soaks into the ground and filters out pollutants.

Rain Barrels

Rain barrels are storage containers that collect and store stormwater runoff from the downspouts.

Rain Gardens

Rain gardens are shallow depressions in the land, vegetated with native plants that filter stormwater runoff.

Porous Pavement

Porous pavement allows stormwater runoff to soak right through it, while providing the same structural support as traditional pavement.

WHERE ARE THE CURRENT MODEL NEIGHBORHOODS?

Location	*Civic Partner*
Passyunk Square	Passyunk Civic Association
Awbury/Cliveden	Tookany/Tacony-Frankford (TTF)Watershed Partnership
Northern Liberties	Northern Liberties Neighborhood Association
Pennsport	Pennsport Civic Association
New Kensington/ Fishtown	New Kensington CDC
Point Breeze	South Philadelphia Homes, Inc./ Newbold/Redevelopment Au-
North Philadelphia	Asociación Puertorriqueños en Marcha (APM)
Manayunk	Manayunk Development Corp/ Roxborough CDC
East Falls	East Falls Development Corporation

LEARN MORE ABOUT MODEL NEIGHBORHOODS THROUGH THESE PROGRAMS

- **Fairmount Park's Street Tree Walks**
- **Philadelphia Water Department's Dock Street Tour, Cohocksink Tour and Wingohocking Tour**

For more details on the above events and other future events, in addition to more information on *Model Neighborhoods*, visit:

www.PHILLYWATERSHEDS.org
Facebook Group: *Green Neighborhoods through Green Streets*

WHAT CAN HOMEOWNERS DO?

Examples of projects that homeowners can do on their properties to better manage stormwater runoff:

- Plant a tree.
- Install a rain barrel.
- Plant a rain garden.
- Install a planter (container garden).

Project Sponsors:

FREQUENTLY ASKED QUESTIONS (FAQS)

Q. Who funds *Model Neighborhoods*?

A. Primarily Philadelphia Water Department (PWD), with support from other city agencies and local nonprofit groups.

Q. Are projects on private properties considered for funding?

A. No. PWD can only implement projects in public right of ways (i.e. streets and sidewalks), however, PWD may provide technical support to private property owners. In fact, PWD is interested in evaluating residential properties in Philadelphia for rain gardens (where appropriate) and flow-through planters. Please contact us, if you are interested.

Q. Who will maintain the *Model Neighborhoods* green infrastructure projects?

A. PWD. However, PWD will rely on residents to do minor maintenance, such as litter removal and sweeping leaves.

Q. Where can the general public purchase porous asphalt?

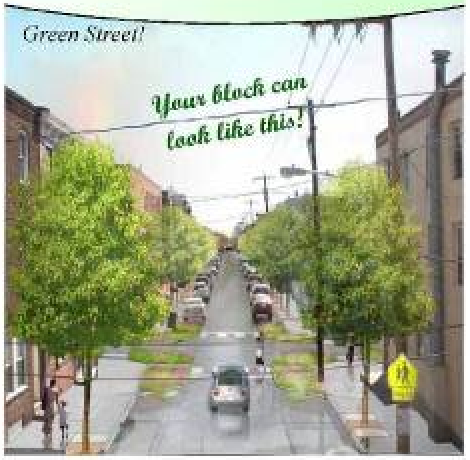
A. Porous asphalt is only cost-effective in larger batches. PWD recommends that you contact a contractor that you would hire to install a traditional driveway and ask this contractor if he/she is willing to work with porous materials.

For more information, contact:

Tiffany Ledesma Groll
Office of Watersheds
Philadelphia Water Department
1101 Market St. 4th Floor
Philadelphia, PA 19107
Phone: 215-499-3756
Fax: 215-685-6043
E-mail: **ledesmagrolltd@cdm.com**

Existing Street

Green Cities, Clean Waters
MODEL NEIGHBORHOODS



Green Street!

MODEL NEIGHBORHOODS
NORTHERN LIBERTIES

Green Cities,
Clean Waters

Tree Walk on Your Block

Saturday, May 30, 2009
10am—11:30am

Meet at
Liberty Lands
900 Block of N. 3rd Street

Have you ever wondered why some urban neighborhoods are so charming? It's often because of **street trees!** Join us for this fun tree walk and discover why many of Philadelphia's urban neighborhoods are going **GREEN** with trees! Learn tricks for identifying trees and see how Fairmount Park selects ideal trees for an urban environment. Look at the benefits trees provide--the temperature is always several degrees cooler under the shade of a tree! Learn about proper placement, selection, and care, and who to call when you have questions. *All welcome. Free. No registration necessary. For information call* **215.685.9285**.

Discover the opportunities offered by the Philadelphia Water Department and Fairmount Park to make your community a Model Neighborhood. For additional information, visit **www.phillywatersheds.org**.

Green Cities, Clean Waters
MODEL NEIGHBORHOODS

Philadelphia PWD Water Department
Fairmount Park
PennFUTURE

Discover how a green neighborhood could be ***YOURS!***

MODEL NEIGHBORHOODS
PASSYUNK SQUARE

Green Cities,
Clean Waters

Tree Walk on Your Block

Saturday, May 16, 2009
Noon

at
PASSYUNK SQUARE
SPRING FESTIVAL
Capitolo Park
9th & Federal Streets

Have you ever wondered why some urban neighborhoods are so charming? It's often because of street trees! Join us for this fun tree walk and discover why many of Philadelphia's urban neighborhoods are going GREEN with trees! Learn tricks for identifying trees and see how Fairmount Park selects ideal trees for an urban environment. Look at the benefits trees provide--the temperature is always several degrees cooler under the shade of a tree! Learn about proper placement, selection, and care, and who to call when you have questions. *All welcome. Free. No registration necessary. For information call* ***215.685.0470.***

Discover the opportunities offered by the Philadelphia Water Department and Fairmount Park to make your community a Model Neighborhood. For additional information, visit **www.phillywatersheds.org.**

Passyunk Square Civic Association

Discover how a green neighborhood could be YOURS!

MODEL NEIGHBORHOODS
AWBURY/CLIVEDEN

Green Cities,
Clean Waters

Tree Walk on Your Block

Saturday, June 13, 2009
10am—11:30am

Meet at
6211 Chew Avenue, Philadelphia, PA
(between Belfield Avenue and Tulpehocken Street)

Have you ever wondered why some urban neighborhoods are so charming? It's often because of street trees! Join us for this fun tree walk and discover why many of Philadelphia's urban neighborhoods are going GREEN with trees! Learn tricks for identifying trees and see how Fairmount Park selects ideal trees for an urban environment. Learn how to choose trees that won't interfere with sidewalks or power lines. Discover the benefits trees provide --the temperature is always several degrees cooler under the shade of a tree! And trees increase property values and improve the quality of air around them!

Learn about proper placement, selection, and care, and who to call when you have questions. *All welcome. Free. No registration necessary. For information call 215.685.9285.*

Discover the opportunities offered by the Philadelphia Water Department and Fairmount Park to make your community a Model Neighborhood. For additional information, visit **www.phillywatersheds.org**.

Green Cities, Clean Waters
MODEL NEIGHBORHOODS

Discover how a green neighborhood could be YOURS!

History

In 1682, William Penn made a treaty with the local Native American tribes under the sheltering branches of the "Treaty Elm" which stood at what is now Penn Treaty Park. Penn's vision for the city would eventually grow up around that site and include parks, gardens, open spaces and trees.

Now, more than 325 years later, Penn would be proud of his vision. There are more than 125,000 street trees in the 21st Century version of his "greene countrie towne," and they are the responsibility of Fairmount Park.

Green Cities, Clean Waters
MODEL NEIGHBORHOODS

Philadelphia Street Tree Management Division

Telephone: 215.685.4362 or 215.685.4363
Fax: 215.685.4364
Email us at: fpc.streettree.info@phila.gov

Hours of Operation:

7AM-3:30PM; Monday-Friday, Year Round (except City holidays).

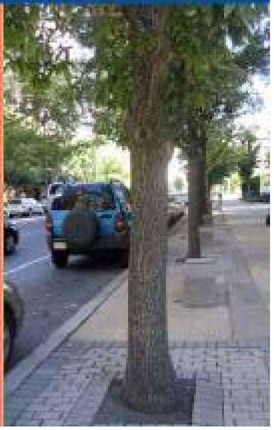
Visit www.fairmountpark.org and click on Street Tree for detailed information or to obtain a Tree Maintenance Citizen Service Request form.

Call 911 for emergencies (fallen tree or limb is blocking a street, damaged a house, car or utility line) after normal business hours.

Fairmount Park
PHILADELPHIA'S PARK SYSTEM

PHILADELPHIA Street Trees

WWW.FAIRMOUNTPARK.ORG



What is a "Street Tree?"

Street trees are located in the strip of land between sidewalks and curbs – or in planting sites cut into sidewalks next to a curb. They range from newly planted maple trees to the mighty oak trees planted in the 1920's. Philadelphia street trees are important to our environment, they shade and beautify our neighborhoods, absorb noise, filter pollution and improve property values while keeping William Penn's vision alive.

Street trees don't have an easy life. They have to endure pests and diseases, air pollution, summer droughts and salt contamination from melting ice and snow. Damage occurs from cars, animals, bicycle chains and by advertisements stapled or nailed to their trunks.

Like any living thing, street trees need care and Fairmount Park has the authority over street trees in the City of Philadelphia. Please contact us before planting, removing, pruning or any other work on Philadelphia street trees.

A periodic visual inspection of your street trees will help keep them healthy. Examine your tree for the presence of:

- pests and insects
- stunted growth
- dead branches
- tree rot
- cavities in the trunk or branches

How You Can Help

At the request of Philadelphia property owners, Fairmount Park's Street Tree Management Division will inspect street trees and, if conditions warrant, have the tree pruned or removed for safety reasons at no cost to the homeowner.

Fairmount Park arborists will also inspect your location to determine whether it is appropriate for a new street tree. If so, the proper tree species for the site will be selected by the arborist.

Property owners are permitted to hire tree contractors* (qualified arborists) to perform work on street trees adjacent to their property. This work can include planting, pruning, minor root pruning (required for plumbing and/or masonry work), pesticide spraying, fertilization and tree removal. Contractors must apply for a permit from the Fairmount Park Street Tree Management Division prior to performing work on any street tree in Philadelphia.

* Homeowners can obtain a list of qualified tree contractors by contacting the Philadelphia Street Tree Management Division.

When street trees are no longer able to provide shade and beauty, they provide benefits to Philadelphia citizens through our organic recycling program. Free wood chips, firewood and compost are available at the Fairmount Park Recycling Center near Ford Road & Chamounix Drive in West Fairmount Park and at Park District recycling yards in Northeast, Northwest and South Philadelphia. Contact 215.683.0200 for locations.

Tree Tenders

In 1993, Fairmount Park partnered with The Pennsylvania Horticultural Society to launch the Tree Tenders project to teach general tree care skills to organized community groups and Philadelphia residents. Today, there are over 1,900 Tree Tenders from 150 different neighborhoods.

Learn how you can be a Tree Tender by visiting http://www.pennsylvaniahorticulturalsociety.org/phlgreen/tree-training.html.

Sidewalk Trees
& House Sewer Laterals

Homeowners often engage in a type of "chicken or the egg" discussion concerning the roots of their sidewalk trees and the effect of these roots on their sewer lateral – the pipe that connects the home's wastewater drainage system to the sewer in the street. You may have heard a neighbor claim that the roots of the tree in front of their house broke through their lateral pipe, causing the pipe to eventually block up so that problem-free flushing became a fond memory.

Tree roots can find their way into a sewer lateral, but normally that occurs only after the lateral has begun to deteriorate as a result of age, settlement or other factors. Most of a tree's root system is concentrated in the **top 12 – 24 inches of soil** directly beneath the concrete sidewalk. A home's sewer lateral, beneath the sidewalk slab, is an average of **six to seven feet below ground,** providing a buffer of soil and fill between the lateral and the tree.

The **brown pipe** connecting the house to the sewer in the street is the house sewer lateral. The **blue pipe** connecting the house to the street is the house water service. Note that the sewer lateral is approximately six feet below the sidewalk and that the roots of the tree are approximately two feet below the sidewalk.

When roots are adventurous enough to find their way to the lateral, it is usually a result of a crack or open joint in the pipe that allows water to escape into the surrounding soil, attracting stray tree roots.

Following are a few additional facts to set your mind at ease when contemplating your own sidewalk tree:

- **House laterals** in Philadelphia are made from **cast iron.** Pipes of this material usually last 60 – 70 years. This is based upon average Philadelphia weather (its freeze and thaw cycles), urban loads in streets (cars and trucks), the nature of sidewalk/street fill and electrical currents in the ground. Older homes, built prior to World War II, may have had terra cotta lateral pipes, which are more prone to cracking and breaking.
- **Sidewalk trees** in the City are approved by the Fairmount Park Commission to ensure that only trees that are suitable to urban environments (trees that can withstand urban challenges such as pollution and sidewalks & streets that are filled with infrastructure) are planted along city streets.
- Plumbers have the ability to **check the condition of house laterals** without digging up the pipe if they need to look for blockages caused by roots or other materials. In addition, commercially available products exist that can be poured into your toilet and flushed into your pipe, destroying any roots that may have found their way into the pipe via a crack.

Trees are Good for your House and the Environment

- A 2005 Study by the University of Pennsylvania found that trees translated into **higher property values.** The study found, for example, that planting a tree within 50 feet of a house increased its sale price by nine percent.
- Trees provide a **cooling shade** to a home in the hot summer months, decreasing the amount of energy required to cool a home and the related electric bills. Tree lined blocks can actually decrease local temperatures.
- Trees naturally **clean the air** of pollutants and create a neighborhood **noise buffer.**
- Trees improve **stormwater management,** reducing the amount of polluted stormwater runoff that normally would go directly into storm drains. The **leaves** of trees capture rain drops before they hit the ground, evaporating some of this rain water and sending it back into the air. **Tree roots** allow rainwater to filter back into the soil, recharging the often thirsty earth.

Your House Lateral and You

Property owners are responsible for the care and maintenance of their house lateral, from the point it leaves the property to its connection into the city sewer in the street. PWD has a Homeowner's Emergency Loan Program (HELP) in place to assist residents with the cost of repairing a broken sewer lateral (the average replacement cost is $3,000). If you receive a notice from PWD about a broken lateral or water service, call the number on the notice – 215-685-xxxx. For water or sewer emergencies, or for general information, call PWD's hotline at 215-685-6300.

Green Cities, Clean Waters
MODEL NEIGHBORHOODS

for STAFF ONLY

Street Trees in Philadelphia

Background Information

What are some of the benefits of street trees?
Street trees provide shade from the hot rays of the sun. The temperature is always several degrees cooler under the shade of a tree! Trees muffle noise from traffic and construction, help filter dust and pollution particles from the air (the air is actually cleaner and healthier beneath and around trees!), help reduce flooding from storm water runoff, and provide habitat for wildlife. Trees give beauty and charm to neighborhoods, can increase property values by 10-15%, and can encourage local businesses.

Who owns the street trees?
The City of Philadelphia

What is a street tree?
A street tree is a tree located between the sidewalk and the curb. A tree growing in your yard is not a street tree even though its branches might be hanging over into the sidewalk or street. The Park will go out to the site to determine if it's a street tree or not.

Who is responsible for street trees?
Fairmount Park manages all street trees (as well as park trees) in the City of Philadelphia and is responsible for planting, pruning and removing street trees. Most of this work is done by arborists overseen by the Park. The Park has a separate contract for each of these three services: one for planting, a second for pruning, and a third for removal.

Who do I call to get a street tree planted?
Call Fairmount Park's *Street Tree Management Division* at **215 685-4363** or send an email to **fpc.streettree.info@phila.gov** .

How long does it take to get a street tree planted?
The wait to get your street tree planted can be one year, depending on resources. The Park plants street trees in spring and fall. Spring planting begins mid-March; fall planting begins at the end of October. The planting schedule depends on weather conditions and when the vendor can get trees. (Fairmount Park just received their 2006 **and** 2007 street tree budget in one lump and will be planting these trees in fall 2007 and spring 2008.)

Who chooses the street tree?
The resident can request a particular species, but the Park arborist who visits the site makes the final determination. There are many factors that go into choosing a street tree: the Park chooses a variety of species so that they don't create a monoculture and looks at the surroundings--are there overhead wires, telephone poles, driveways?--all of which determine what the species will be and whether the species should be large, medium, small or columnar. Check out the City of Philadelphia's recommended street tree list at www.fairmountpark.org/RecommendedTreeList.asp

Planting the street tree
A large hole, called a tree pit, is dug for the new street tree. The minimum tree pit size is 3'x3' and depends on the site conditions. After the tree is planted, the contractor mulches the tree pit area, stakes the new tree, and waters it.

What can residents do to help care for their street tree?
Residents should **water** their street trees with 15-20 gallons of water each week. One of the biggest stresses on newly planted street trees is not getting enough water. Residents can also remove weeds from the tree pit and should not plant anything (other than the tree) in the tree pit. Weeds, flowers and ground cover compete for water, nutrients and root space and can put stress on your street tree. Residents can help by being careful with car doors and bikes, which can damage the protective bark. To do anything more to your street trees, such as major pruning or removing, you must obtain a permit. Contact Fairmount Park when you observe a problem. The Pennsylvania Horticultural Society (PHS) has a program called "Tree Tenders" that provides 9 hours of training on tree biology, urban stresses, tree identification, basic pruning, root care, tree planting, and community organizing. For more information about the Tree Tenders program, call PHS at (215) 988-8844 or check out their website at www.pennsylvaniahorticulturalsociety.org.

Who do I call when there is a problem?
To report a problem with your street tree, call Fairmount Park's *Street Tree Management Division* at **215 685-4363** or send an email to **fpc.streettree.info@phila.gov** If it is after normal working hours, leave a voice mail message. The Park will send someone out within 7-10 working days to look at it. Hours are 7:00 am – 3:30 pm Monday through Friday except City holidays.

If it is an **emergency**, **call 911**. Examples of emergencies are a tree or branch falls and is blocking access to the sidewalk or street; a tree or branch falls on your roof. Someone from the Park will be dispatched through radio.

Will the Park remove a tree I don't like?
No. The Park does not take down trees because people don't like them. There has to be a valid problem for the Park to remove it. Having to rake up fallen leaves, seeds and other fruits is not considered a valid problem.

What if the tree is breaking up my sidewalk?
If a street tree is breaking up the sidewalk, the Park will come out to look at it. The Park will make a decision on a case-by-case basis according to the condition of the tree and what's going on around it. Often the solution is for the property owner to replace the paving.

Will the Park take care of a problem with a tree in my yard?
No. The Park is not responsible for trees growing in yards. Trees growing in the yard are the resident's responsibility.

What about trees growing in alleyways?
The City only responds to emergencies with trees in alleyways. Emergencies would include a tree or branch that falls and blocks the alleyway, falls on your roof, or damages your property. For emergencies with trees in your alleyway, call **215 683-0222**. The work on alleyway trees is paid for through the Mayor's Neighborhood Transformation Initiative (NTI) program and is performed by Fairmount Park arborists under the supervision of Gus Jardell.

What about trees growing through cracks in the sidewalk?
Trees growing through a crack are not street trees. Any tree growing through a crack should be pulled out. The resident can do this.

What are some of the stresses on street trees?
The biggest stress on new trees is not getting enough water. Cuts and gashes in the protective bark caused from car doors, lawn mowers, weed wackers, bicycles, and carving initials allow insects and disease to enter and can weaken and kill the tree. Insects and disease can also enter when branches get broken or torn off from climbing on trees. Salt used to melt ice on sidewalks and roads can try the leaves and roots (although the Park tries to choose salt-tolerant trees), dog feces (dog feces are high in acidity and nitrates which are harm ful to trees), pollution, harmful insects and disease.

Where does the money come from for street trees?
Money for street tree planting, care and removal comes from a variety of sources :

- Planting money comes from the Park's capital budget.
- Pruning and removal money comes from the Park's operating budget and the Managing Director's operating budget.
- City Council members have their own "discretionary" money and will sometimes allot some of this money for street trees. For example Janie Blackwell recently put money aside to do tree removals in her council district.

Tell me more about Fairmount Park's *Street Tree Management Division*
The Park's Street Tree Management Division is located at Boelson Cottage on West River Drive . The division has a total of 9 Park staff: this includes five tree inspectors who are in the field each day, two arborists, one word processing operator, and a manager (Fran Piller) who oversees the division. For management purposes, the Street Tree Management Division divides the city into 5 districts. East Park's district is district 1.

Contact Information
Fairmount Park
Street Tree Management Division
Hours: 7:00 am – 3:30 pm Monday through Friday except City holidays.
215 685-4363
fpc.streettree.info@phila.gov
www.fairmountpark.org/StreetTreeIntro.asp
For alleyway trees only, call 215 683-0222

Prepared by Debbie Carr
Revised 1-7-08

Street Trees
for
Model Neighborhoods

Small Trees (mature height under 30')

Trident Maple	Acer buergeranum
Amur Maple	Acer ginnala
Paperbark Maple	Acer griseum
Serviceberry	Amelanchier x grandiflora
American Hornbeam	Carpinus caroliniana
American Red Bud	Cercis Canadensis
Carolina Silverbell	Halesia carolina
Chinese Fringetree	Chionanthus retusus (tree form)
Fringetree	Chionanthus virginicus (tree form)
Flowering Dogwood	Cornus florida
Thornless Cockspur Hawthorn	Crataegus crusgalli var. inermis
Winter King Green Hawthorn	Crataegus viridis 'Winter King'
Mt. Fuji Cherry	Prunus serrulata 'Shirotae'
Autumn Flowering Cherry	Prunus subhirtilla 'Autumnalis'
Rosy Cloud Cherry	Prunus subhirtilla 'Rosy Cloud'
Dream Catcher Cherry	Prunus incisa x campanulata 'Dream Catcher'
Okame Cherry	Prunus x 'Okame'
Crapemyrtle	Lagerstroemia indica (tree form)
Japanese Tree Lilac	Syringa reticulata 'Ivory Silk'
Japanese Tree Lilac	Syringa reticulata 'Summer Snow'

Medium Trees (mature height 30' to 40')

Sargent Cherry	Prunus sargentii

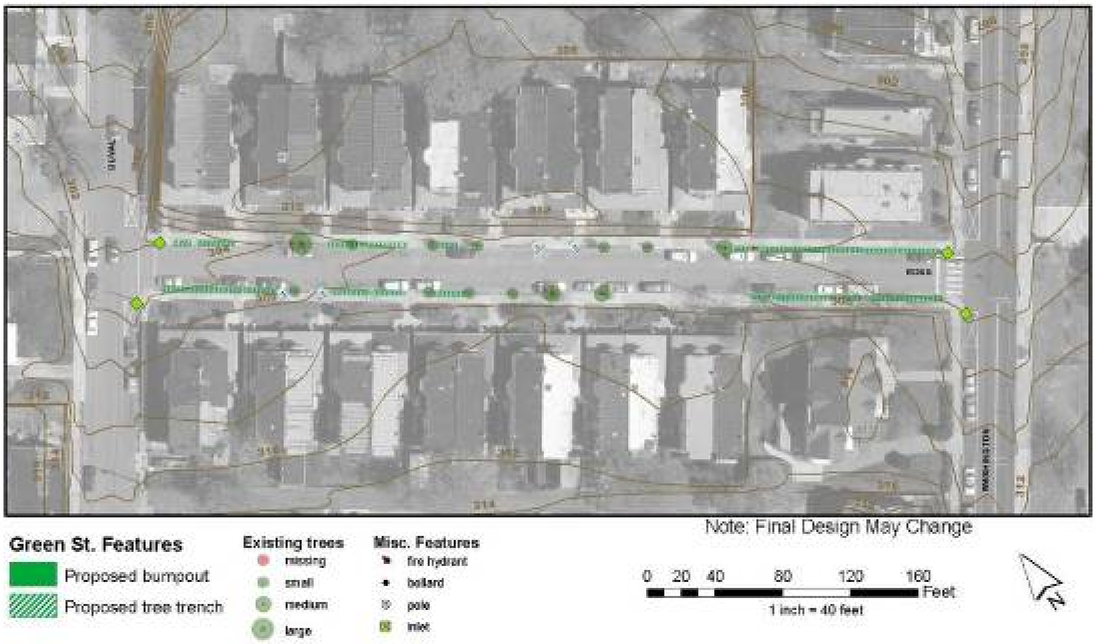
Trees for Narrow Streets

Fastigiate Red Maple	Acer rubrum 'Armstrong'
Bowhall Maple	Acer rubrum 'Bowhall'
Goldspire Maple	Acer saccharum 'Goldspire'
Columnar European Hornbeam	Carpinus betulus 'Columnaris'
Columnar Sargent Cherry	Prunus sargentii 'Spire'

Green Cities, Clean Waters
MODEL NEIGHBORHOODS

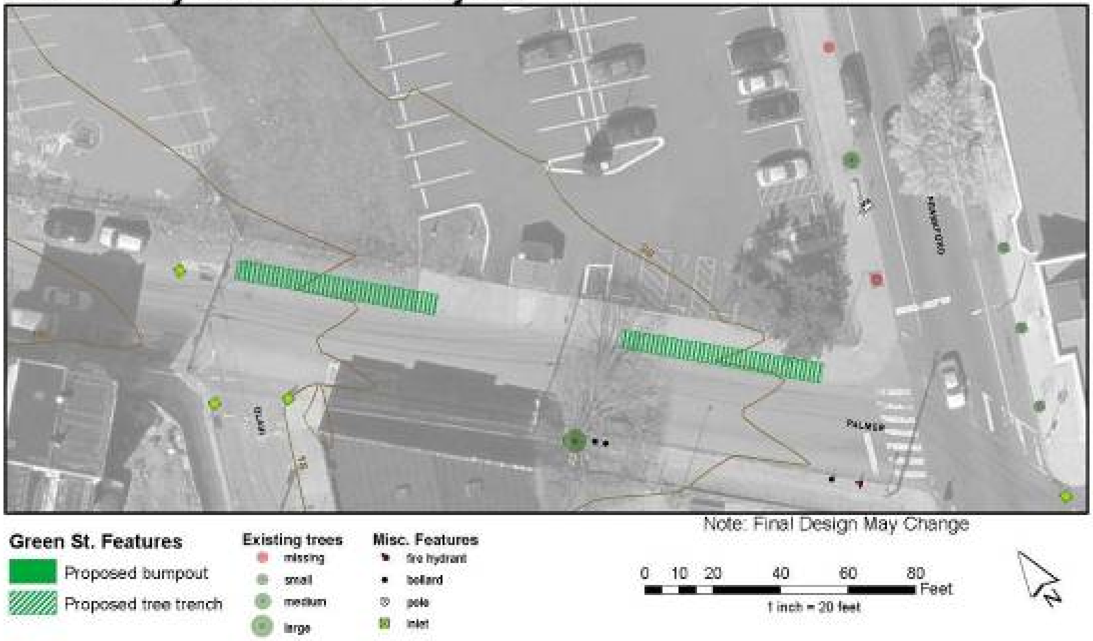
6300 Block Ross St. Preliminary Green Street Layout

July 2009



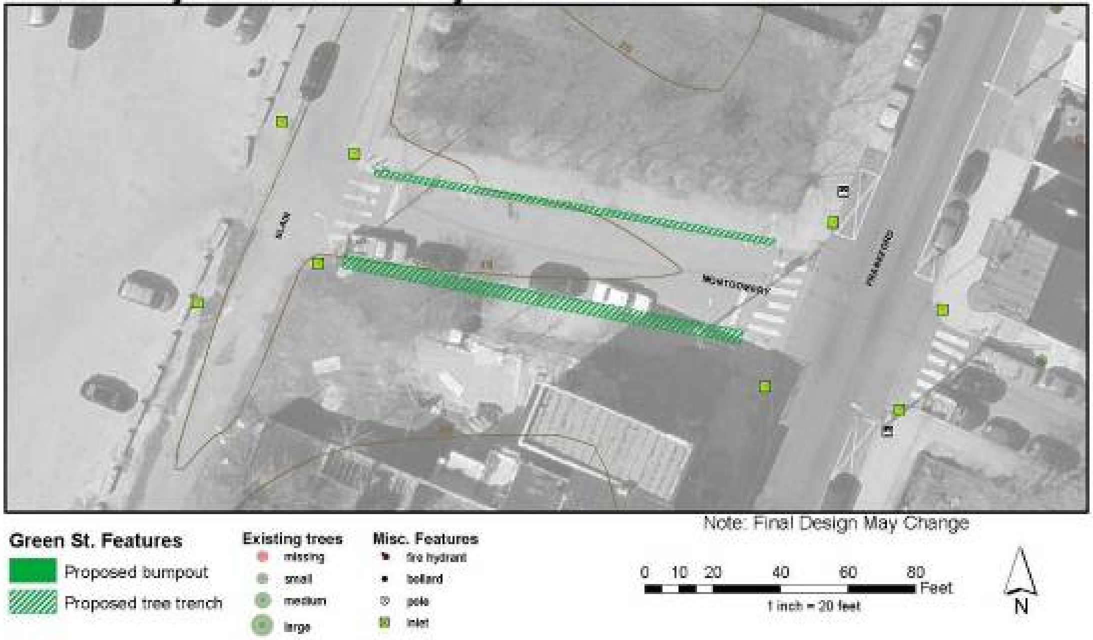
1 - 10 Block East Palmer St. Preliminary Green Street Layout

July 2009



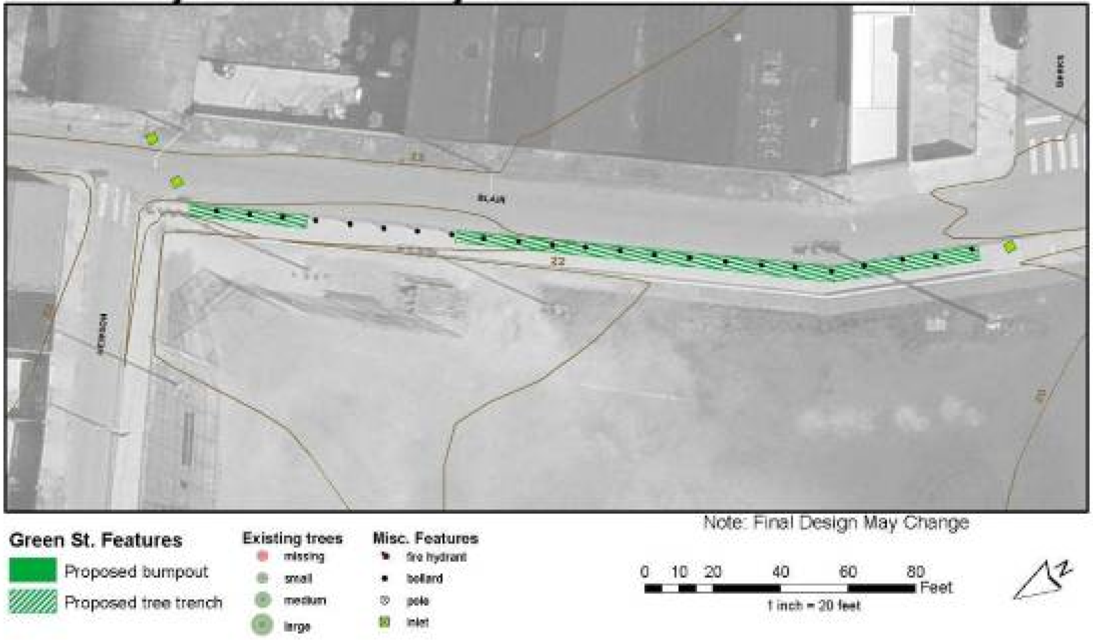
1 - 10 Block East Montgomery Ave.
Preliminary Green Street Layout

Philadelphia PWD Water Department
July 2009



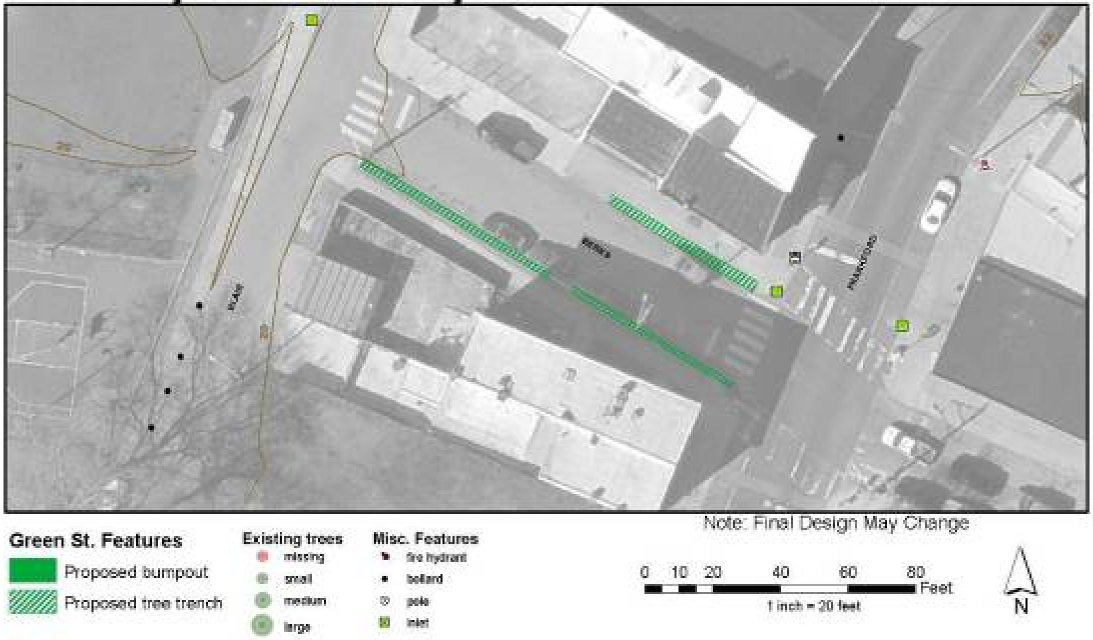
1800 Block Blair St.
Preliminary Green Street Layout

Philadelphia PWD Water Department
July 2009



1675 - 1700 Block East Berks St. Preliminary Green Street Layout

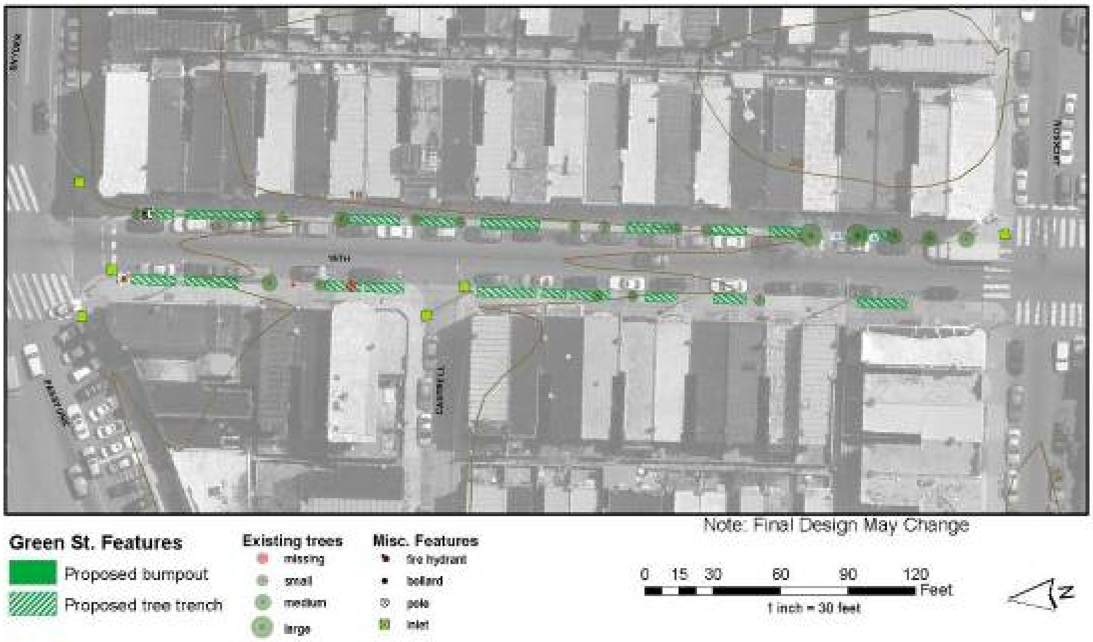
July 2009



Note: Final Design May Change

2100 Block South 16th St. Preliminary Green Street Layout

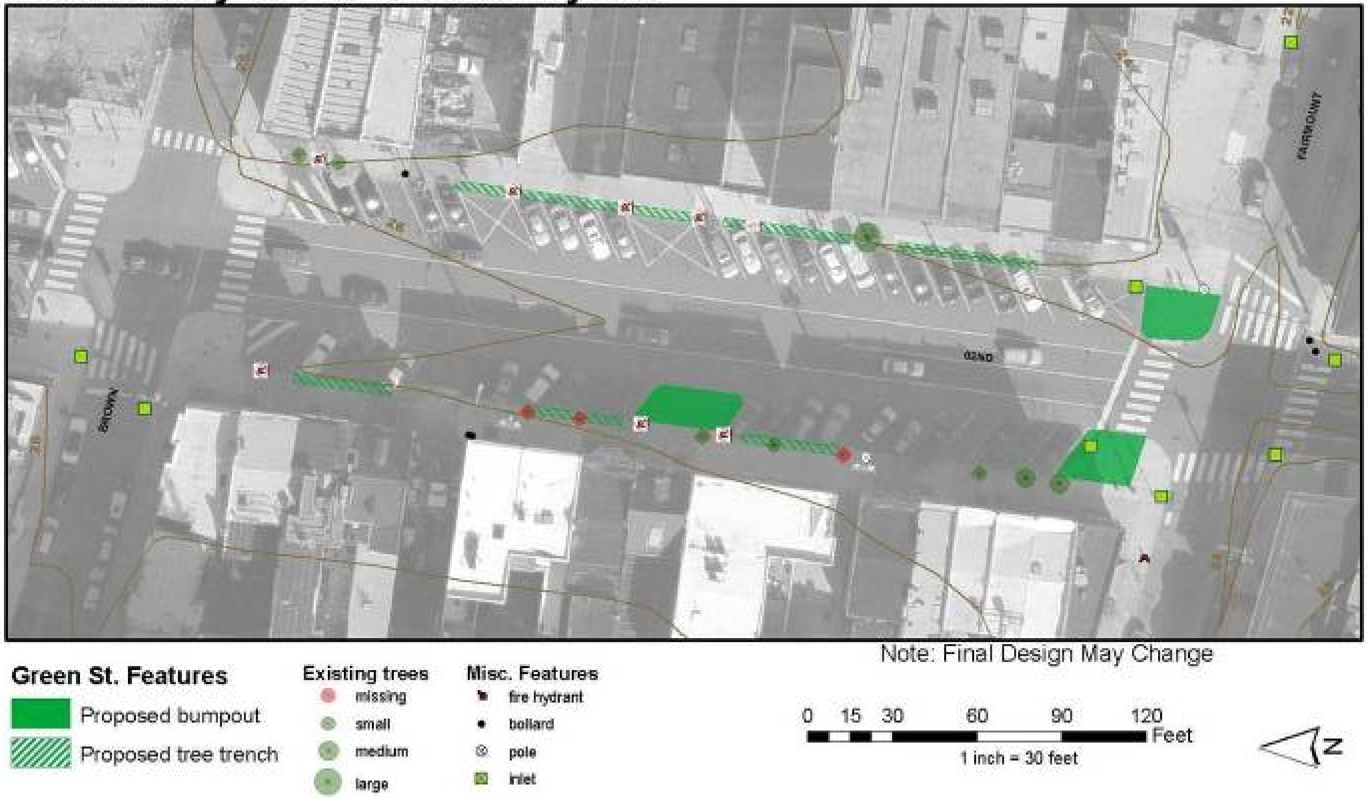
July 2009



Note: Final Design May Change

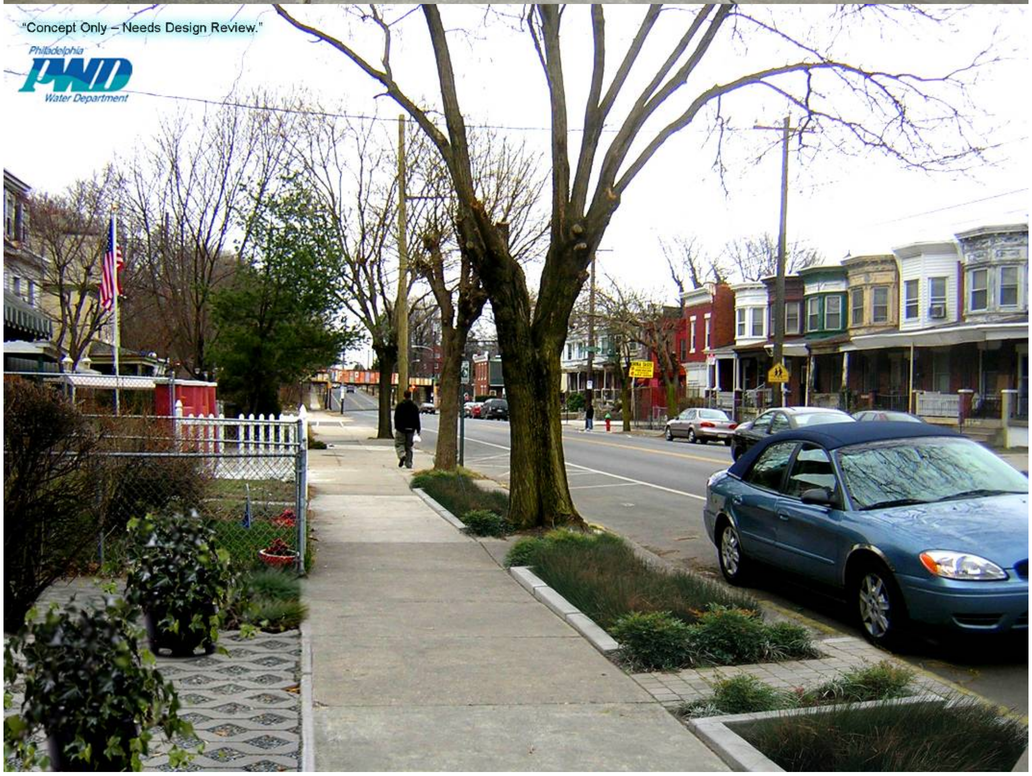
700 Block North 2nd St.
Preliminary Green Street Layout

Philadelphia Water Department
July 2009

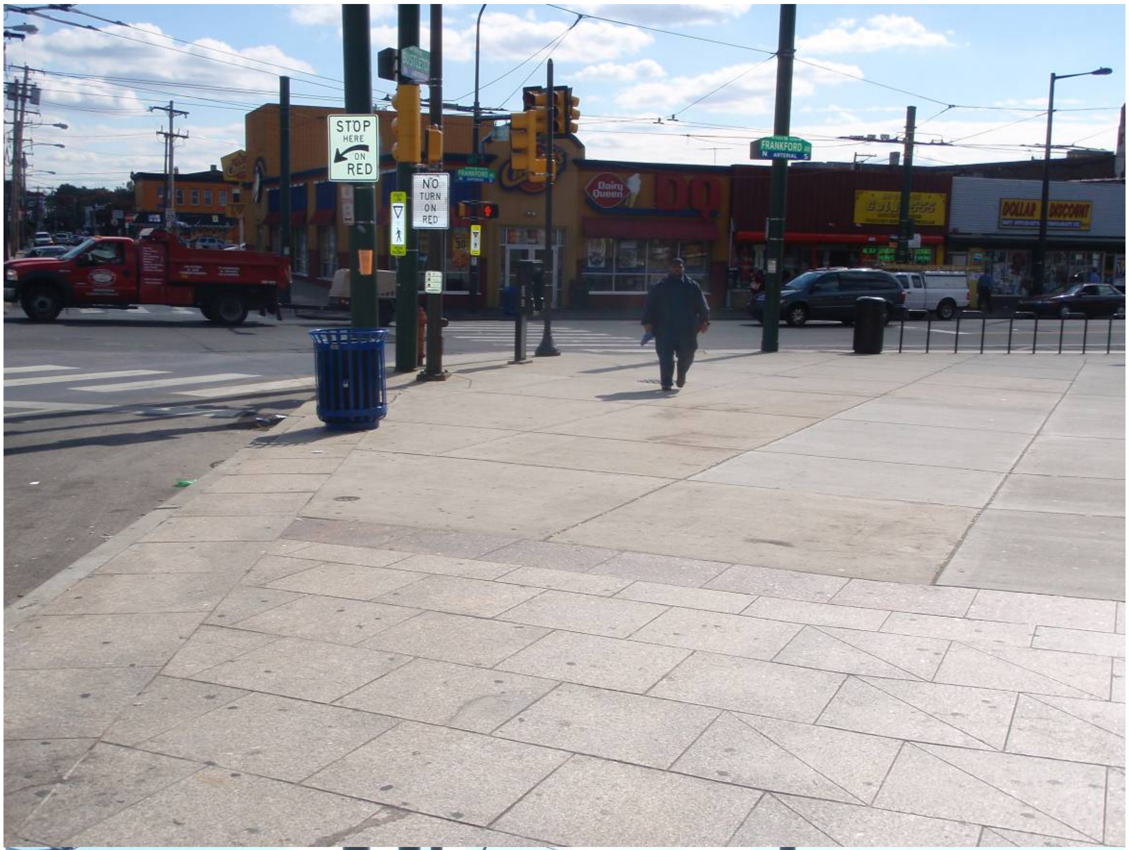


Note: Final Design May Change

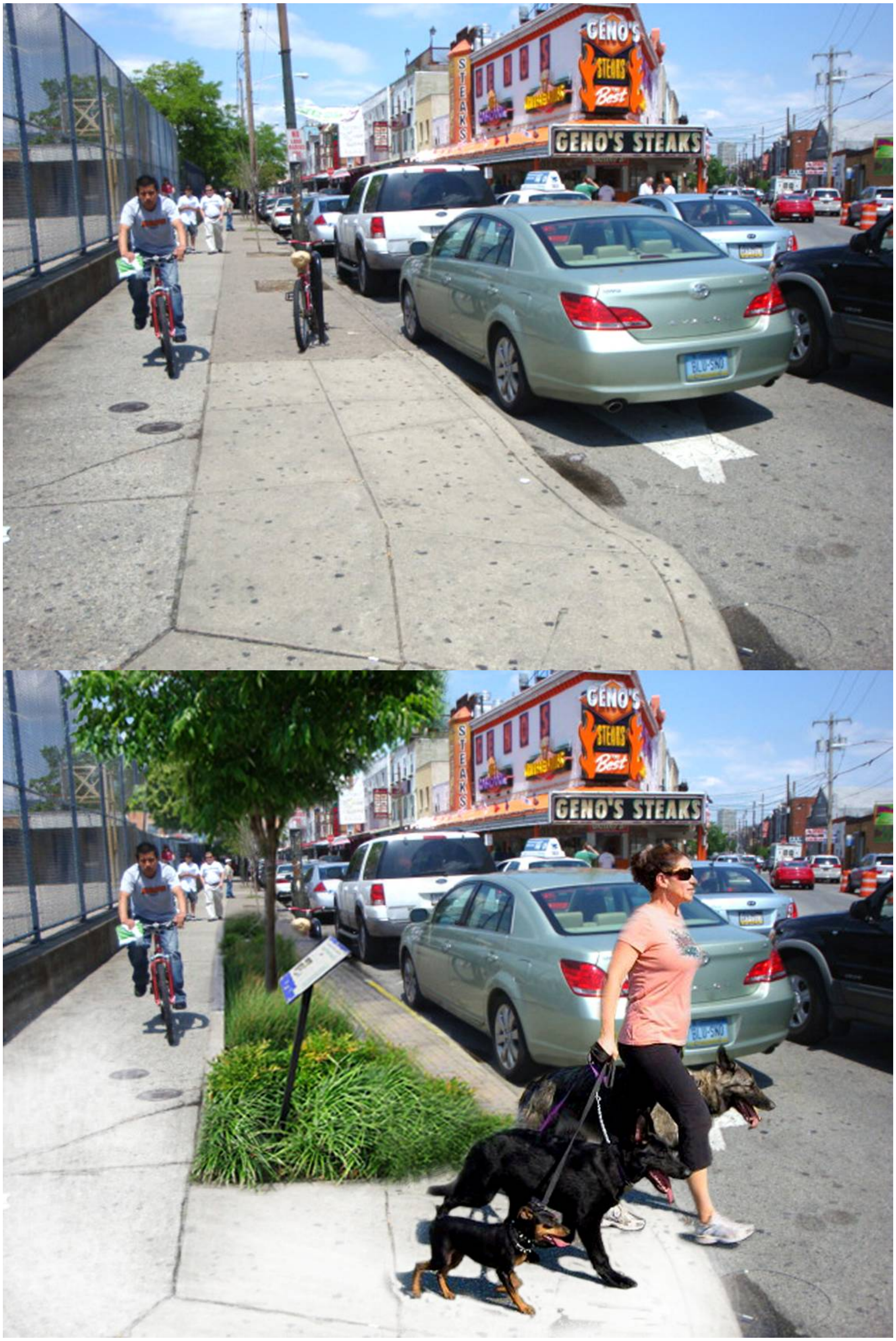
Photo Simulation
Before and After pictures


"Concept Only – Needs Design Review."
Philadelphia
PWD
Water Department


Philadelphia
PWD
Water Department
Concept Only - Needs Design Review


STOP HERE ON RED
NO TURN ON RED
FRANKFORD
N ARTERIAL
Dairy Queen
DQ
DOLLAR DISCOUNT


STOP HERE ON RED
NO TURN ON RED
FRANKFORD
N ARTERIAL
Dairy Queen
DQ
DISCOUNT


GENO'S
STEAKS
Best
STEAKS
GENO'S STEAKS

Green Neighborhoods through Green Streets Survey

Green Neighborhoods through Green Streets

The Philadelphia Water Department (PWD) would like to green our neighborhoods to better manage stormwater (rain or melting snow) runoff before it enters storm drains. This would consequently improve our quality of life. The City would like to help by planting trees, and by using other green techniques.

We appreciate your feedback on green streets. This survey will only take about 7 minutes. Time permitting please complete the entire survey of 12 questions.

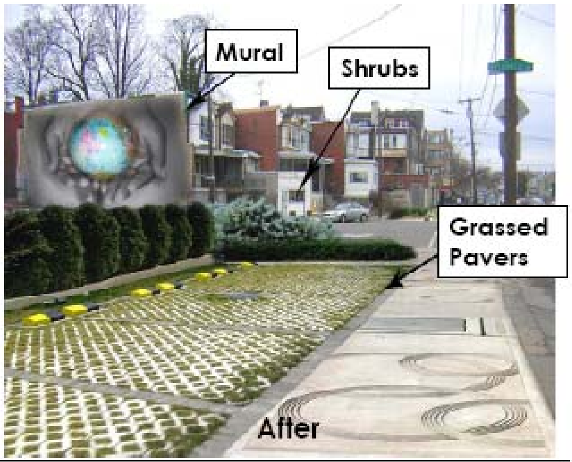
1) After viewing each set of images below, are you in favor of greening in your neighborhood?

☐ Yes

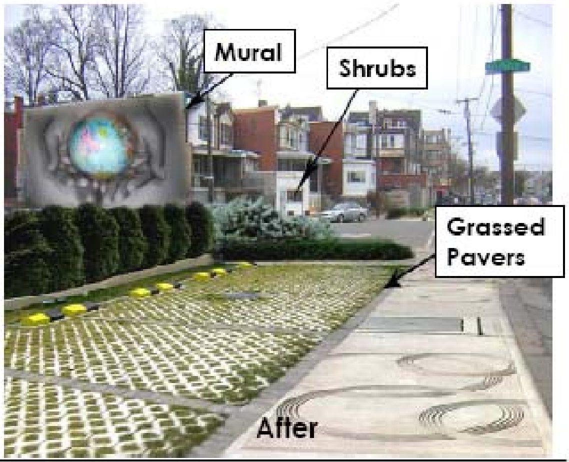
☐ No

a) What do you like about the images?

b) What don't you like about the images?



2) In your own words, please describe a "Green Street."



2) In your own words, please describe a "Green Street."

3) Using trees and plants as examples of green street features, what actions would you be willing to take to green your neighborhood? Please check all that apply.

☐ Ask for more trees/plants for your street

☐ Plant a tree/garden

☐ Maintain a tree/garden (pruning, removing litter, etc.)

☐ Advocate for more trees/plants

☐ Participate in a public meeting

☐ Educate your neighbors about trees/gardens

☐ Provide feedback

☐ Other (please specify)

4) Of the following issues, which THREE are most important to you?

☐ Safety – e.g. Traffic calming

☐ Health – e.g. Less asthma

☐ Environment – e.g. Cleaner water

☐ Streets – e.g. In safe condition

☐ Parks and playgrounds – e.g. In good condition

☐ Less or no trash and litter

☐ Less or no vandalism

☐ Leaving the world a better place for our children (the next generation)

5) If the nearby riverfront was cleaner, safer and more accessible, which recreational activities would you participate in? (Choose all that apply.)

☐ Walking/Hiking/Jogging
☐ Boating/Canoeing/Kayaking
☐ Resting/Viewing/Hanging Out
☐ Biking
☐ Birding
☐ Fishing
☐ Picnics
☐ Photography
☐ Other (please specify)

6) A: Where does the water in your neighborhood go when it rains?

☐ Nearest water treatment plant
☐ Nearest creeks and/or rivers
☐ I don't know

B: What do you call this water?

☐ Rainwater
☐ Runoff
☐ Stormwater
☐ Other (please name)__________

8) A: Are you familiar with the term watershed?

☐ Yes
☐ No

B: What watershed do you live in?

(include an "I don't know" option aside from all the watersheds)

9) Do you have any additional comments?

10) Gender

☐ Male

☐ Female

11) Age

☐ Under 18

☐ 18-25

☐ 26-34

☐ 35-45

☐ 46-54

☐ 55-64

☐ Over 64

12) Race/Ethnic Background

☐ White or Caucasian

☐ Black or African-American

☐ Latino/Hispanic

☐ Alaska Native or Native American

☐ Asian/Pacific American

☐ Prefer not to answer

☐ Other (please specify)

13) What is your zip code?

14) What is your block address (ex. 1100 Market St.)?

Thank you for taking this survey! If you would like to learn more about Philadelphia's waterways and watersheds, visit www.phillyriverinfo.org.

Start showing your support for green streets today! Forward the link to this survey to your friends and colleagues in Philadelphia.

Green Neighborhoods through Green Streets

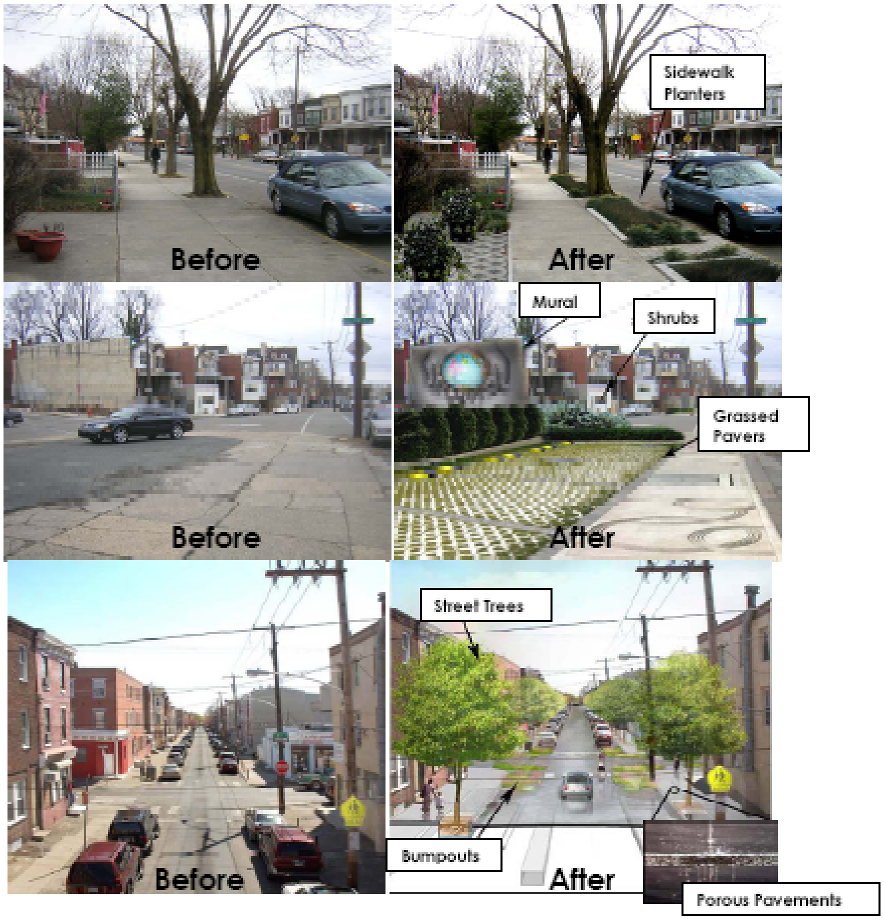
The Philadelphia Water Department (PWD) would like to green our neighborhoods to better manage stormwater (rain or melting snow) runoff before it enters storm drains. This would consequently improve our quality of life. The City would like to help by planting trees, and by using other green techniques.

<u>**We appreciate your feedback on green streets. This survey will only take less than 5 minutes.**</u>

1. After viewing each set of images below, are you in favor of greening in your neighborhood?
☐ Yes
☐ No

a) What do you like about the images?

b) What don't you like about the images?



Turn Over →

2. Using trees and plants as examples of green street features, what actions would you be willing to take to green your neighborhood? Please circle or check all that apply.

- ☐ Ask for more trees/plants for your street
- ☐ Plant a tree/garden
- ☐ Maintain a tree/garden (pruning, removing litter, etc.)
- ☐ Advocate for more trees/plants
- ☐ Participate in a public meeting
- ☐ Educate your neighbors about trees/gardens
- ☐ Provide Feedback to the Philadelphia Water Dept.

3. In your own words, please describe a "Green Street."

4. Do you have any additional comments?

5. Your Zip Code:

____

6. What is your block address (ex.1100 Market Street)?

____

Thank you for taking this survey. If you wish to learn more about green streets, please provide your contact information (name, email, phone and/or address) in the space below so that we can update you on meetings and activities. You can also check us out online at www.phillyriverinfo.org

Total number of responses: 438(online) + 297(hardcopy) = **735**

What do you like about the images?		
Responses	**Total**	%
1) I love greening	150	22.3
2) Beautiful, Attractive, etc...	100	14.9
3) I want more Trees	91	13.5
4) Safer, Friendlier, Welcoming Atmosphere	91	13.5
5) Plants and Vegetation	75	11.1
6) Environment friendly	58	8.6
7) Health and Cleanliness	54	8.0

Description:

1) They are in favor of greening.
2) Greening makes the block look aesthetically pleasing.
3) They want more trees.
4) Greening makes them feel safe in their block and creates a sense of pride in their neighborhood.
5) They want more gardens, planters, flowers and grass.
6) Greening improves air quality and takes care of runoffs.
7) Greening provides shade, cools the warm air and makes the block cleaner.

Overall: 92% responded positively (698/735)

What do you dislike (potential concerns)?		
Responses	**Total**	%
1) Nothing	226	34.7
2) Maintenance problems	148	22.7
3) Trash and Leaves	63	9.7
4) Root Damages	47	6.5
5) Before pictures	42	5.5
6) Financial costs/ taxes	29	4.1
7) Narrow Sidewalk	24	3.1

1) They like everything about greening
2) Who will prune, water and cut the trees and plants?
3) Trash and pet waste will accumulate near trees and bumpouts. Foliage is also a problem.
4) Tree roots damages sidewalk, pipes and home foundations.
5) They dislike the "before pictures."
6) Where is the money for the project and upkeep coming from? Are taxes going to rise?
7) Trees and plants might get vandalized.

Overall: 60% have potential concerns regarding greening

Describe a green street		
Responses	**Total**	%
1) A street with substantial plant life	167	25.7
2) Clean, safe and friendly neighborhood	99	15.3
3) All about greening	76	11.7
4) Deals with runoff issues	64	9.9
5) None	56	8.6
6) a street that is properly maintained	47	7.2
7) environment-friendly street	46	7.1

1) Explained a green street as having trees, plants, vegetation, garden, etc...
2) Aside from having some or none of number 1, they mentioned the positive effect it has on the morale, health and cleanliness of the neighborhood.
3) They mentioned a little bit of everything. I just decided to group them all together.
4) Aside from having some or none of number 1, they specifically mentioned that it helps deal with flooding, runoff, etc...
5) No comment
6) Aside from having some or none of number 1, they mentioned that it needs to be maintained either by the neighbors or by the city.
7) Aside from having some or none of number 1, Green helps the environment (more oxygen, cooler, etc...)

2) What are you willing to do?

	total	%
Ask for more trees/plants for your street	575	79.42
Plant a tree/garden	533	73.62
Maintain a tree/garden	516	71.27
Advocate for more trees/plants	432	59.67
Participate in a public meeting	428	59.12
Educate your neighbors	400	55.25
Provide Feedback	429	59.25
None	24	3.31

Rec Activities

	total	%
Walking/ hiking/ jogging	407	93.14
Resting/ Viewing/ Hanging out	356	81.46
Picnics	332	75.97
Biking Boating/ Canoeing/ Kayaking	242	55.38
Photography	180	41.19
Fishing	82	18.76
other	61	13.96

Important Issues

	total	%
Environment	316	72.31
Trash	254	58.12
Parks	164	37.53
Children	157	35.93
Health	153	35.01
Safety	129	29.52
Streets	98	22.43
Vandalism	85	19.45
Biking	3	0.69
Walking/hiking/jogging	2	0.46

Where does the water go when it rains?

	total	%
Nearest creeks and/or rivers	198	45.31
I do not know	170	38.90
Nearest water treatment plant	69	15.79

What do you call this water?

	total	%
Runoff	223	50.45
Stormwater	135	30.54
Rainwater	69	15.61
Other	15	3.39

Are you familiar with the term watershed?

	total	%
Y	269	85.13
N	47	14.87

Which watershed do you live in?

	total	%
Delaware	120	27.46
I don't know	104	23.80
Schuylkill	103	23.57
Wissahickon	44	10.07
Tacony/Frankford	27	6.18
Pennypack	24	5.49
Darby/Cobbs	15	3.43
Poquessing	9	2.06

Gender

	total	%
Female	272	62.24
Male	165	37.76

Age

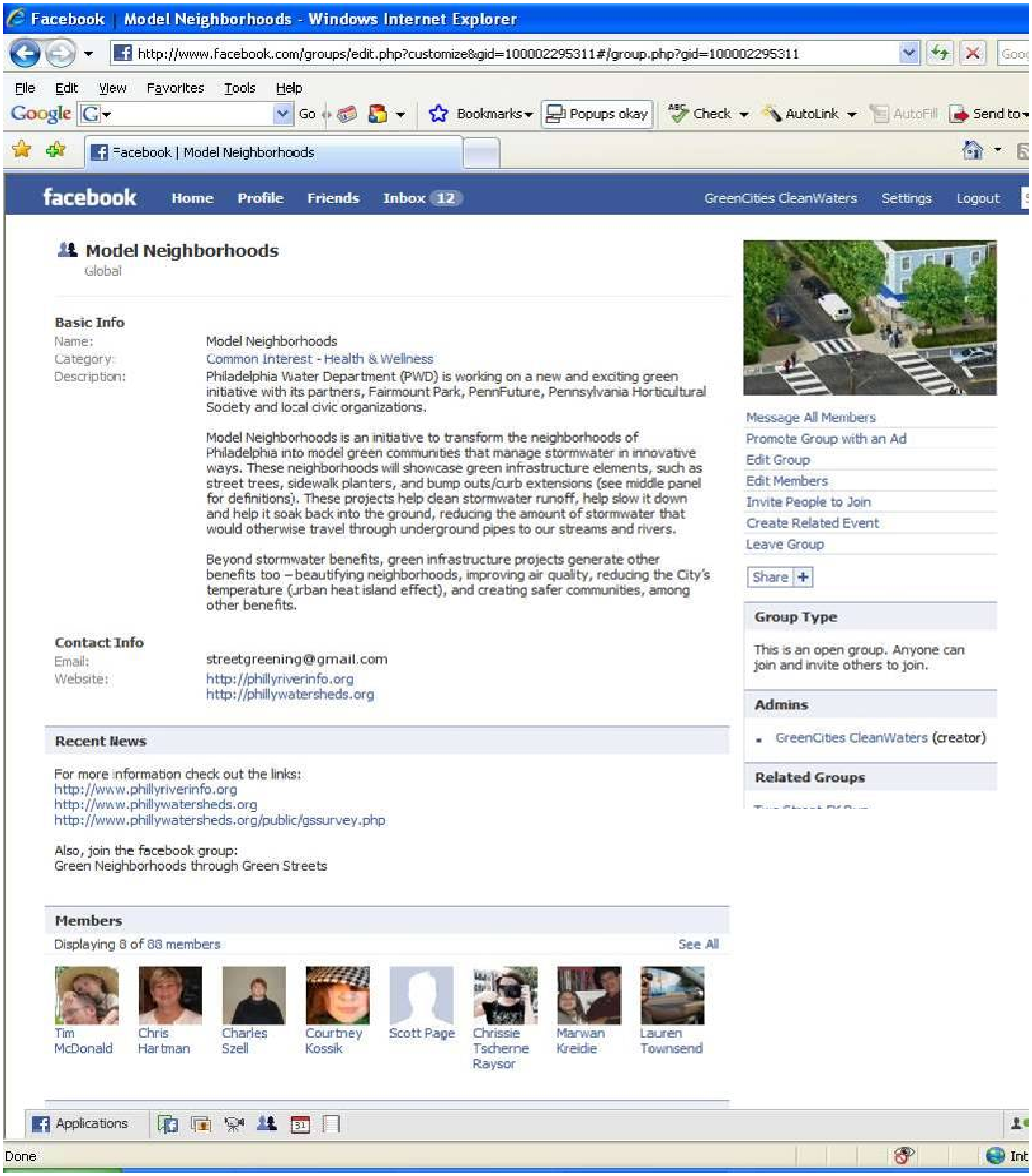
	total	%
26-34	142	33.26
35-45	128	29.98
55-64	53	12.41
18-25	35	8.20
46-54	40	9.37
over 64	24	5.62
under 18	5	1.17

Race/Ethnic Background

	total	%
White/Caucasian	366	83.75
Black or African American	21	4.81
Other	11	2.52
Prefer not to answer	15	3.43
Asian/Pacific American	16	3.66
Latino/Hispanic	8	1.83

zipcode	total	%
19147	81	11.60
19130	53	7.59
19123	49	7.02
19125	40	5.73
19146	36	5.16
19104	27	3.87
19132	27	3.87
19143	26	3.72
19119	25	3.58
19148	25	3.58
19144	20	2.87
19107	19	2.72
19129	18	2.58
19128	16	2.29
19138	15	2.15
19139	15	2.15
19145	14	2.01
19103	12	1.72
19111	12	1.72
19121	11	1.58
19122	11	1.58
19120	10	1.43
19140	10	1.43
19141	10	1.43
19131	7	1.00
19134	7	1.00
19151	7	1.00
19106	6	0.86
19115	6	0.86
19133	6	0.86
19136	6	0.86
19114	4	0.57
19137	4	0.57
19149	4	0.57
19152	4	0.57
19154	4	0.57
19010	3	0.43
19050	3	0.43
19083	3	0.43
19102	3	0.43
19118	3	0.43
19124	3	0.43
19126	3	0.43
19127	3	0.43
19135	3	0.43
19142	3	0.43
19116	2	0.29
19150	2	0.29
19153	2	0.29
19460	2	0.29
19466	2	0.29
19002	1	0.14
19020	1	0.14
19023	1	0.14
19026	1	0.14
19038	1	0.14
19044	1	0.14
19046	1	0.14
19082	1	0.14
19157	1	0.14
19422	1	0.14
19426	1	0.14

Facebook



Model Neighborhoods

Global

Basic Info

Name:	Model Neighborhoods
Category:	Common Interest - Health & Wellness
Description:	Philadelphia Water Department (PWD) is working on a new and exciting green initiative with its partners, Fairmount Park, PennFuture, Pennsylvania Horticultural Society and local civic organizations.

Model Neighborhoods is an initiative to transform the neighborhoods of Philadelphia into model green communities that manage stormwater in innovative ways. These neighborhoods will showcase green infrastructure elements, such as street trees, sidewalk planters, and bump outs/curb extensions (see middle panel for definitions). These projects help clean stormwater runoff, help slow it down and help it soak back into the ground, reducing the amount of stormwater that would otherwise travel through underground pipes to our streams and rivers.

Beyond stormwater benefits, green infrastructure projects generate other benefits too – beautifying neighborhoods, improving air quality, reducing the City's temperature (urban heat island effect), and creating safer communities, among other benefits.

Contact Info

Email:	streetgreening@gmail.com
Website:	http://phillyriverinfo.org http://phillywatersheds.org

Recent News

For more information check out the links:
http://www.phillyriverinfo.org
http://www.phillywatersheds.org
http://www.phillywatersheds.org/public/gssurvey.php

Also, join the facebook group:
Green Neighborhoods through Green Streets

Members

Displaying 8 of 88 members See All

Tim McDonald, Chris Hartman, Charles Szell, Courtney Kossik, Scott Page, Chrissie Tscherne Raysor, Marwan Kreidie, Lauren Townsend

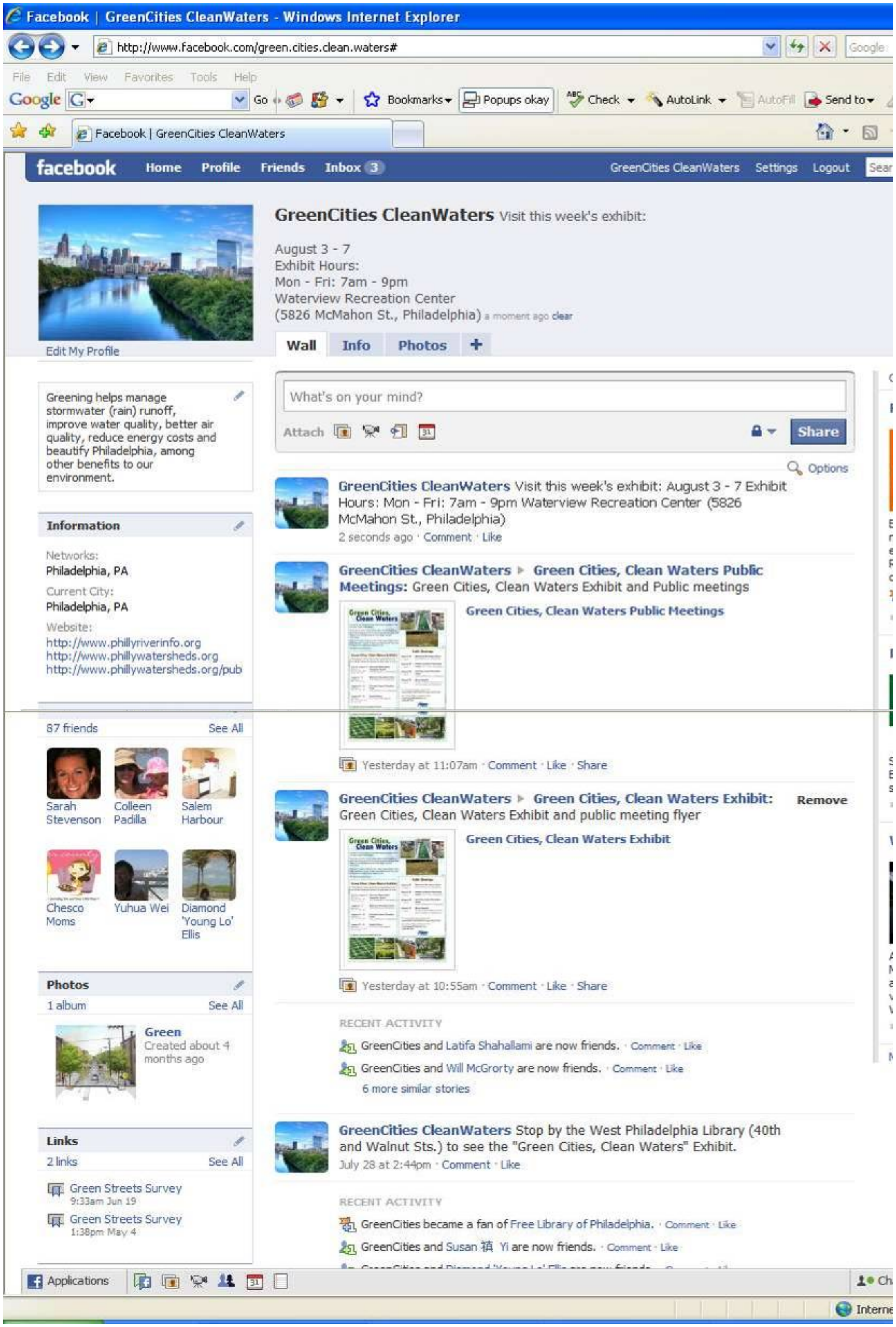
Group Type

This is an open group. Anyone can join and invite others to join.

Admins

- GreenCities CleanWaters (creator)

Related Groups



GreenCities CleanWaters Visit this week's exhibit:

August 3 - 7
Exhibit Hours:
Mon - Fri: 7am - 9pm
Waterview Recreation Center
(5826 McMahon St., Philadelphia) a moment ago clear

Greening helps manage stormwater (rain) runoff, improve water quality, better air quality, reduce energy costs and beautify Philadelphia, among other benefits to our environment.

Information

Networks:
Philadelphia, PA

Current City:
Philadelphia, PA

Website:
http://www.phillyriverinfo.org
http://www.phillywatersheds.org
http://www.phillywatersheds.org/pub

87 friends See All

Sarah Stevenson
Colleen Padilla
Salem Harbour
Chesco Moms
Yuhua Wei
Diamond 'Young Lo' Ellis

Photos
1 album See All

Green
Created about 4 months ago

Links
2 links See All

Green Streets Survey
9:33am Jun 19

Green Streets Survey
1:38pm May 4

GreenCities CleanWaters Visit this week's exhibit: August 3 - 7 Exhibit Hours: Mon - Fri: 7am - 9pm Waterview Recreation Center (5826 McMahon St., Philadelphia)
2 seconds ago · Comment · Like

GreenCities CleanWaters ▸ Green Cities, Clean Waters Public Meetings: Green Cities, Clean Waters Exhibit and Public meetings

Green Cities, Clean Waters Public Meetings

Yesterday at 11:07am · Comment · Like · Share

GreenCities CleanWaters ▸ Green Cities, Clean Waters Exhibit: Green Cities, Clean Waters Exhibit and public meeting flyer **Remove**

Green Cities, Clean Waters Exhibit

Yesterday at 10:55am · Comment · Like · Share

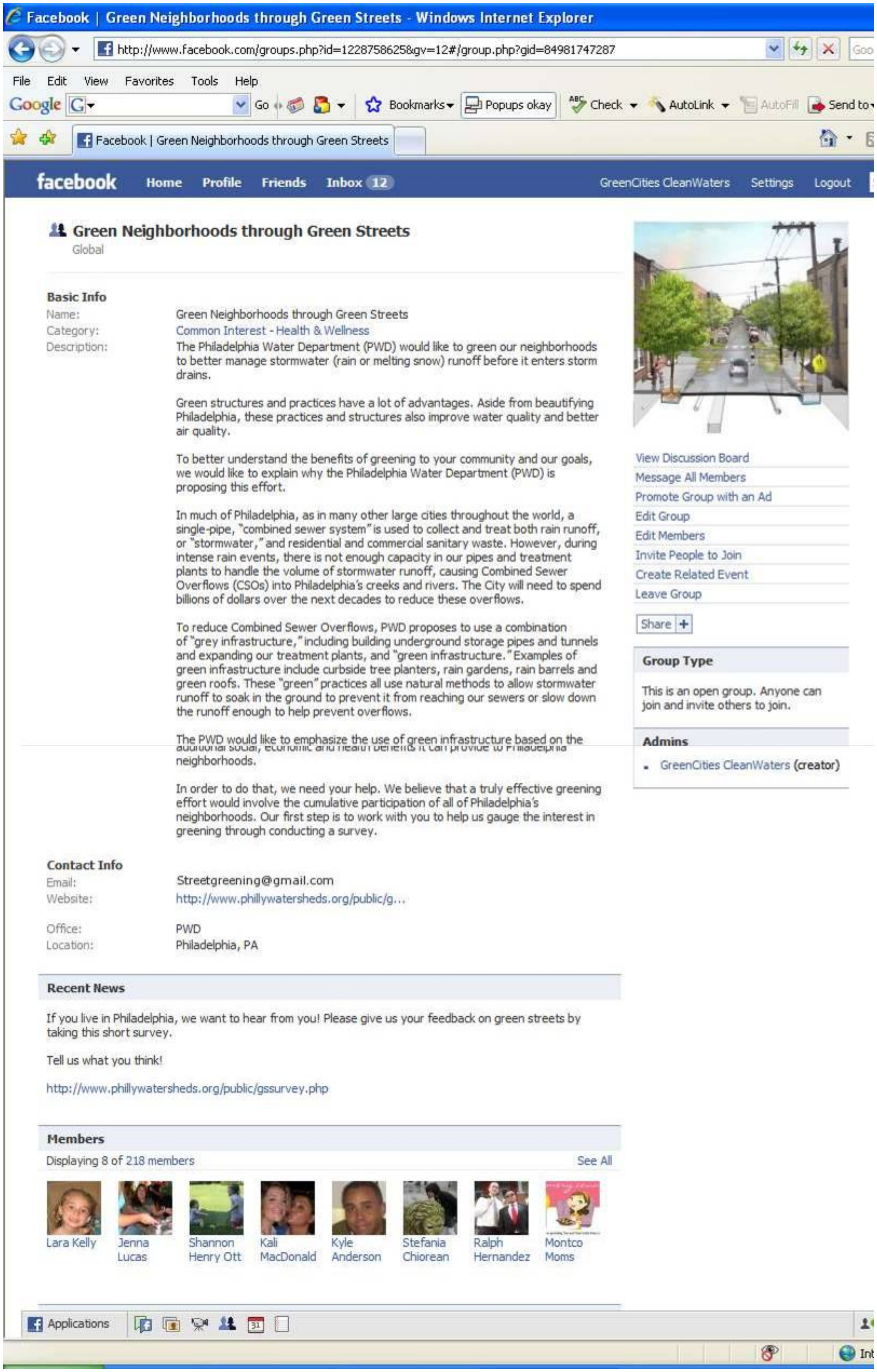
RECENT ACTIVITY

GreenCities and Latifa Shahallami are now friends. · Comment · Like
GreenCities and Will McGrorty are now friends. · Comment · Like
6 more similar stories

GreenCities CleanWaters Stop by the West Philadelphia Library (40th and Walnut Sts.) to see the "Green Cities, Clean Waters" Exhibit.
July 28 at 2:44pm · Comment · Like

RECENT ACTIVITY

GreenCities became a fan of Free Library of Philadelphia. · Comment · Like
GreenCities and Susan 禎 Yi are now friends. · Comment · Like



Green Neighborhoods through Green Streets

Global

Basic Info

Name: Green Neighborhoods through Green Streets

Category: Common Interest - Health & Wellness

Description: The Philadelphia Water Department (PWD) would like to green our neighborhoods to better manage stormwater (rain or melting snow) runoff before it enters storm drains.

Green structures and practices have a lot of advantages. Aside from beautifying Philadelphia, these practices and structures also improve water quality and better air quality.

To better understand the benefits of greening to your community and our goals, we would like to explain why the Philadelphia Water Department (PWD) is proposing this effort.

In much of Philadelphia, as in many other large cities throughout the world, a single-pipe, "combined sewer system" is used to collect and treat both rain runoff, or "stormwater," and residential and commercial sanitary waste. However, during intense rain events, there is not enough capacity in our pipes and treatment plants to handle the volume of stormwater runoff, causing Combined Sewer Overflows (CSOs) into Philadelphia's creeks and rivers. The City will need to spend billions of dollars over the next decades to reduce these overflows.

To reduce Combined Sewer Overflows, PWD proposes to use a combination of "grey infrastructure," including building underground storage pipes and tunnels and expanding our treatment plants, and "green infrastructure." Examples of green infrastructure include curbside tree planters, rain gardens, rain barrels and green roofs. These "green" practices all use natural methods to allow stormwater runoff to soak in the ground to prevent it from reaching our sewers or slow down the runoff enough to help prevent overflows.

The PWD would like to emphasize the use of green infrastructure based on the additional social, economic and health benefits it can provide to Philadelphia neighborhoods.

In order to do that, we need your help. We believe that a truly effective greening effort would involve the cumulative participation of all of Philadelphia's neighborhoods. Our first step is to work with you to help us gauge the interest in greening through conducting a survey.

Contact Info

Email: Streetgreening@gmail.com

Website: http://www.phillywatersheds.org/public/g...

Office: PWD

Location: Philadelphia, PA

Group Type

This is an open group. Anyone can join and invite others to join.

Admins

- GreenCities CleanWaters (creator)

Recent News

If you live in Philadelphia, we want to hear from you! Please give us your feedback on green streets by taking this short survey.

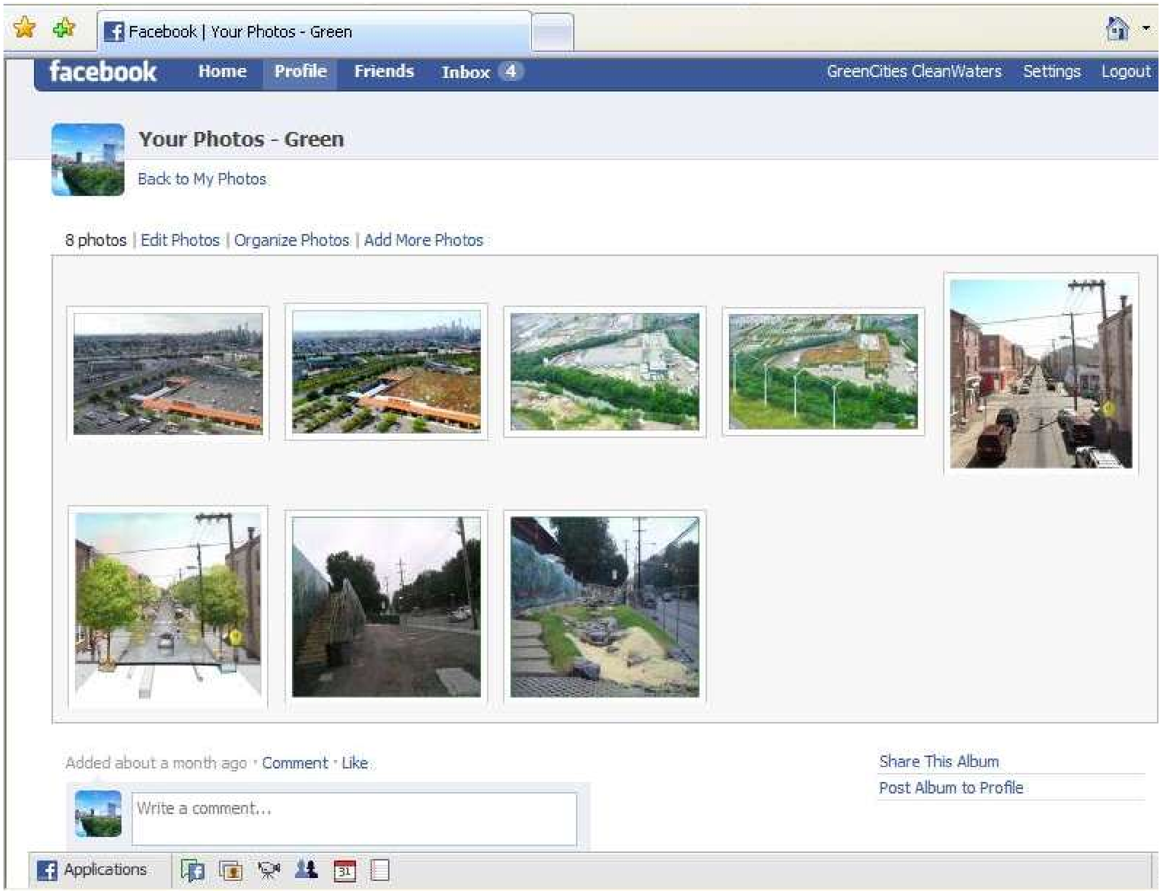
Tell us what you think!

http://www.phillywatersheds.org/public/gssurvey.php

Members

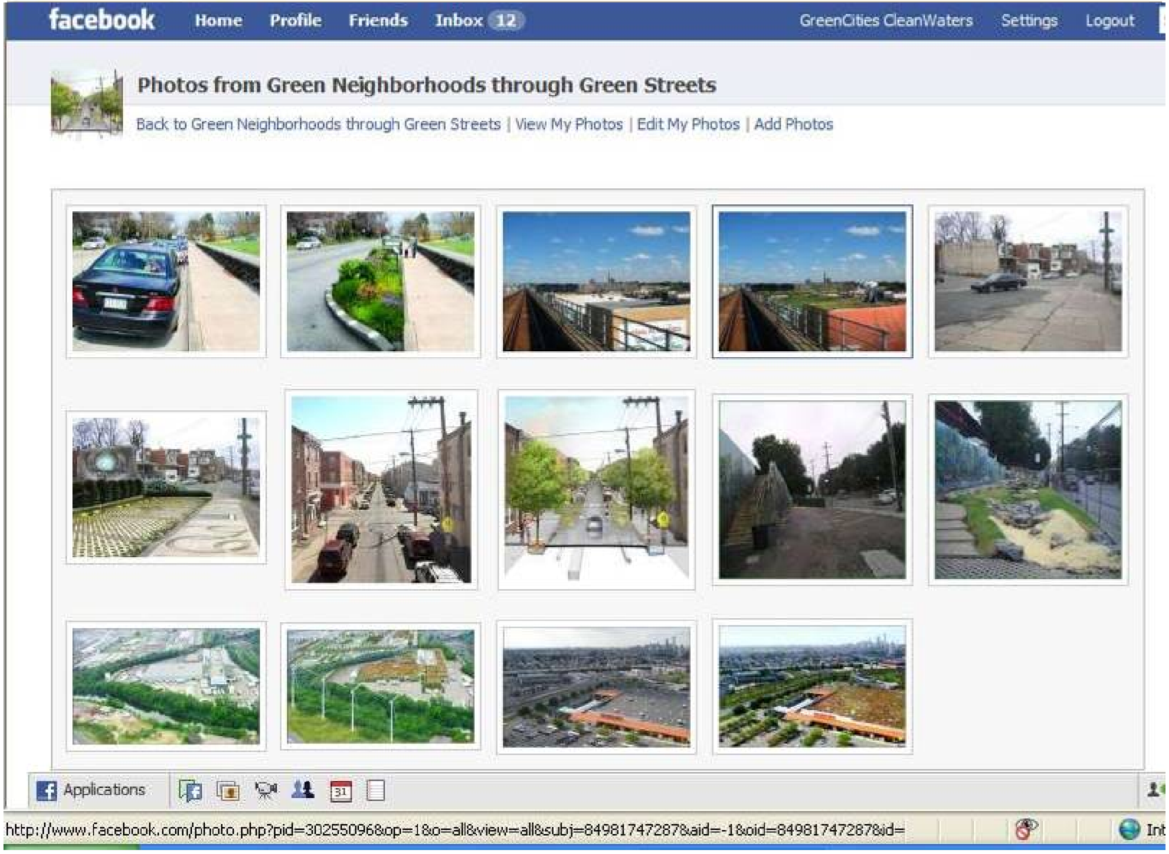
Displaying 8 of 218 members

Lara Kelly
Jenna Lucas
Shannon Henry Ott
Kali MacDonald
Kyle Anderson
Stefania Chiorean
Ralph Hernandez
Montco Moms



Your Photos - Green

Added about a month ago



Photos from Green Neighborhoods through Green Streets

http://www.facebook.com/photo.php?pid=30255096&op=1&o=all&view=all&subj=84981747287&aid=-1&oid=84981747287&id=

Information Fair Materials

THE CSO LONG TERM CONTROL PLAN

GREEN CITIES
CLEAN WATERS

History and Background

The City of Philadelphia

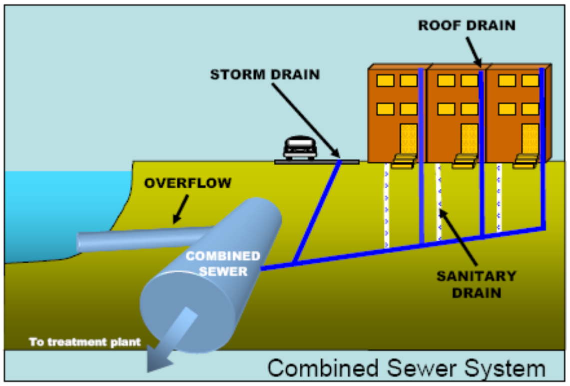
Philadelphia
PWD
Water Department

INTRODUCTION

Philadelphia is fortunate to have an abundance of creeks, open space, parkland and beautiful rivers. The Schuylkill and Delaware Rivers are not only scenic; they are the drinking water source for Philadelphia residents. These waterways, however, suffer from pollution from various sources, both within and outside the City limits. One such pollution source: Combined Sewer Overflows (CSOs).*

What are Combined Sewers Overflows?

A combined sewer system is a wastewater collection system owned by a municipality which transports wastewater* from homes, businesses and industry, stormwater* from the approximately 75,000 storm drains on our streets and property roof leaders through a single-pipe system to a Water Pollution Control Plant (WPCP).



During dry weather conditions (when it is not raining) and during very small storm events, combined sewers* can adequately transport this mixture of sanitary

to a nearby stream or river so as to prevent the flooding of homes and streets. This is what is known as a Combined Sewer Overflow (CSO).

Real-Time Control - Tacony Creek Park Storage

Infrastructure Project

Tacony-Frankford Watershed

Contact: Marc Cammarata
215.685.4948
marc.cammarata@phila.gov

Status: Concept Design

Partners:

Philadelphia Water Department

Real-Time Control - Tacony Creek Park Storage...

CSO outfall T14, a very large sewer (21' by 24'), discharges into the Tacony Creek during periods of moderate to heavier rainfall. T14 has a volume of approximately 10 million gallons and to use as much of this storage as possible, a control structure is needed in the sewer. Installation of a crest gate is proposed in order to retain flow within the sewer. This gate will reduce CSO discharges to the creek by utilizing the relief sewer for in-system storage. This control technology provides an additional margin of protection against dry weather overflows while still maintaining flood protection for upstream communities. The crest gate retains the stored flow in the relief sewer and a new connector pipe drains the stored flow to an existing nearby interceptor.

Benefits:

- The Tacony Creek will realize a consistent average annual reduction of

Waterways Restoration Team

Restoration Project

Multiple Watersheds

Contact: Joanne Dahme
215.685.4944
joanne.dahme@phila.gov

Status: Monitoring

Partners:

Fairmount Park Commission (FPC)

Philadelphia Water Department

Waterways Restoration Team...

The Philadelphia Water Department has instituted a Waterways Restoration Team (WRT), a crew dedicated to removing large trash, cars, shopping carts, and other dumped debris from the 100 miles of stream systems that define our City's neighborhoods. This crew is also restoring eroded streambanks and streambeds around outfall pipes and in tributaries as a part of PWD's goal to restore our streams while meeting Clean Water Act permit requirements. The Waterways Restoration Team is working in partnership with the Fairmount Park Commission staff and the various Friends of the Parks groups to maximize resources and the positive impacts to our communities.

Benefits:

Real-Time Control - Main Relief Sewer Storage

Infrastructure Project

Schuylkill Watershed

Contact: Marc Cammarata
215.685.4948
marc.cammarata@phila.gov

Status: Monitoring

Partners:

Philadelphia Water Department

Real-Time Control - Main Relief Sewer Storage...

The Main Relief Sewer, a set of five sewers which provide flood relief to combined sewer areas in all of PWD's drainage districts, discharges to the Schuylkill River at Fairmount Park. Prior to this project, CSO was released into the river at the Main Relief Sewer outfalls. An inflatable dam was installed in the Main Relief sewer (13.5' by 13.5') with a potential storage volume of 6.2 million. This dam will reduce CSO discharges to the creek by utilizing the sewer for in-system storage. The inflatable dam retains the stored flow in the sewer and a new connecting sewer drains the stored flow to a nearby interceptor. The dam became fully operational in Fall 2006.

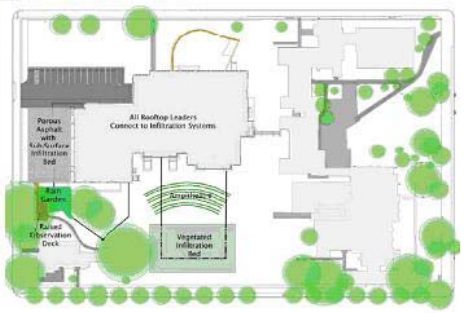
Benefits:

•The installation of the inflatable dam results in significant reductions in CSO

Penn Alexander School

Stormwater BMP Project

Multiple Watersheds



Contact: Amy Leib
215.685.6035
amy.leib@phila.gov

Status: Monitoring

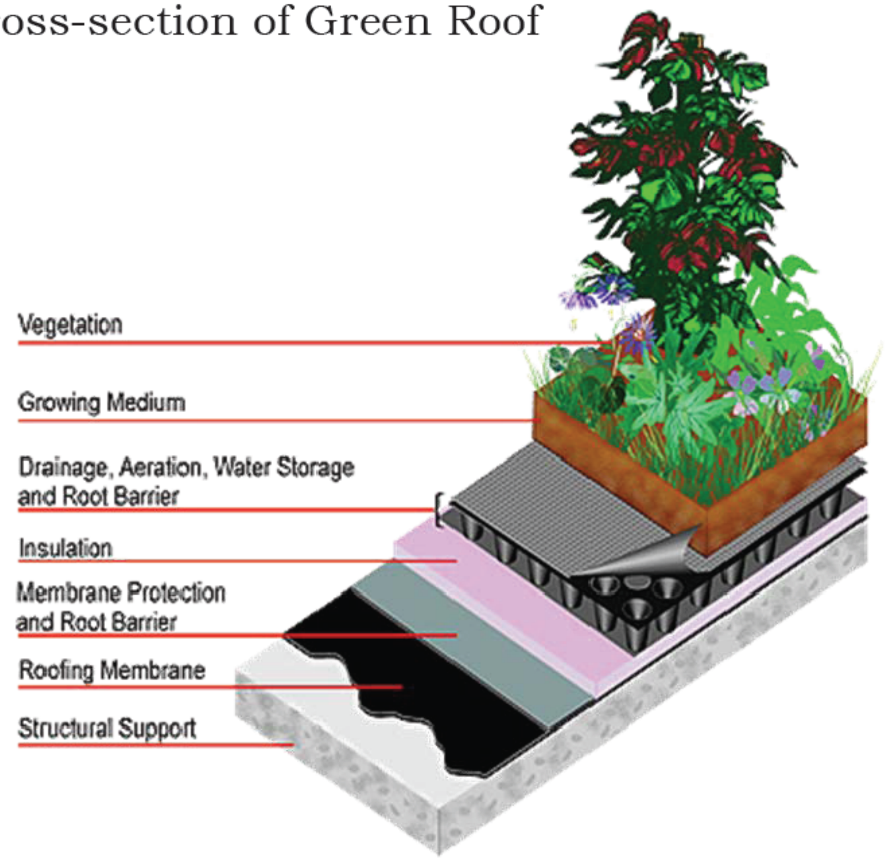
Partners:

- Pennsylvania Department of Environmental Protection (PADEP)
- University of Pennsylvania (UPENN)
- Philadelphia School District (PSD)

Penn Alexander School...

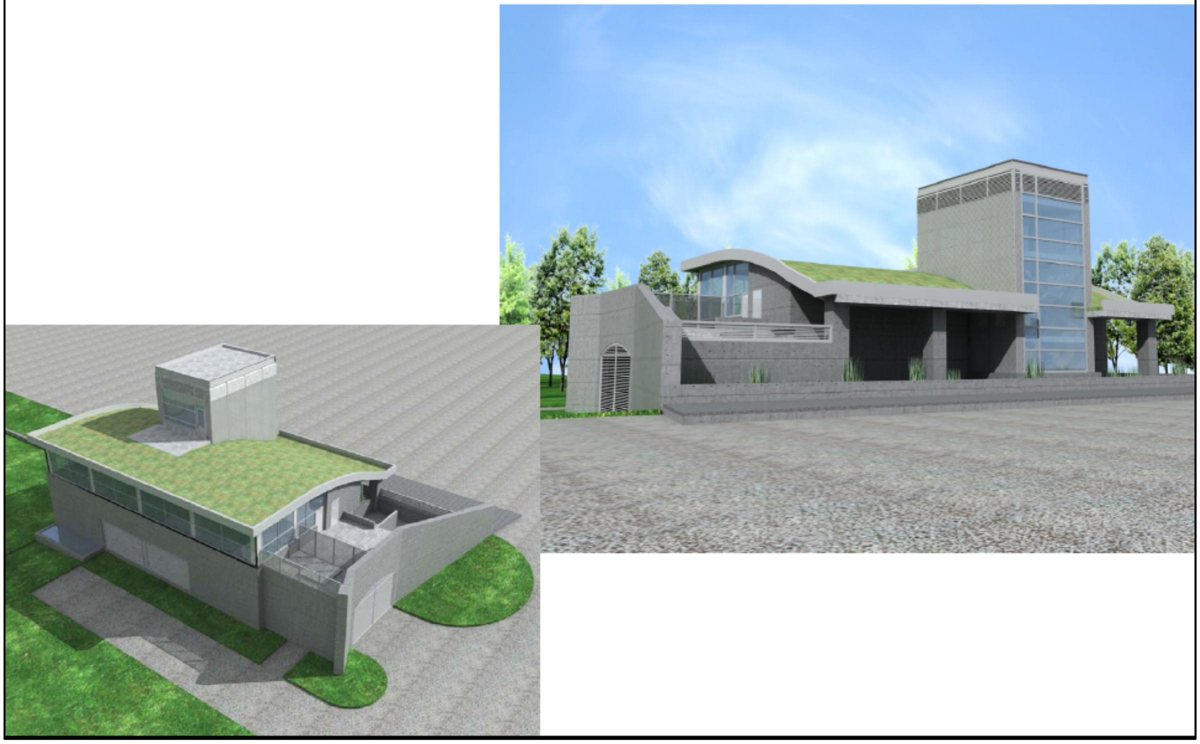
The University of Pennsylvania and the School District of Philadelphia, working in partnership with the Philadelphia Water Department Office of Watersheds, implemented an innovative storm water management project on the site of Alexander Elementary School in West Philadelphia. The school site posed significant challenges in terms of stormwater retention and soil erosion and offered significant opportunities to provide environmental education and environmental diversity to the community. Major components of the project include rooftop collection, an underground infiltration bed, porous pavement play yard, and a rain garden.

Benefits:



Cross-section of Green Roof

Venice Island Pumping Station with Green Roof

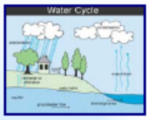


Mill Creek Playground Basketball Courts

The basketball courts at Mill Creek Playground have been built with a special type of pavement that allows rain and melted snow to pass right through it instead of running off into the sewer system. This surface is called "porous pavement." Below the pavement is a layer of stone where water is stored until it is all absorbed into the ground below. Porous pavement is best suited for parking lots, walkways, or play courts.

Effects of Stormwater

Stormwater is precipitation. In an urban environment, stormwater flows over concrete and pavement, rather than percolating through soil into ground water, like it would in a natural environment.



RAIN BARRELS

A rain barrel is a device that collects water from the downspouts which lead from the roof of a building to the ground

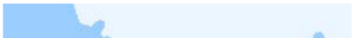
By storing rain water, there is a decreased impact of stormwater

Uses for Rain Barrel Water

- Watering the lawn
- Watering garden plants and flowers
- Filling a bird bath
- Washing gardening containers and tools

Stream Restoration of Cobbs Creek at Marshall Road

Restoration Project **Darby-Cobbs Watershed**

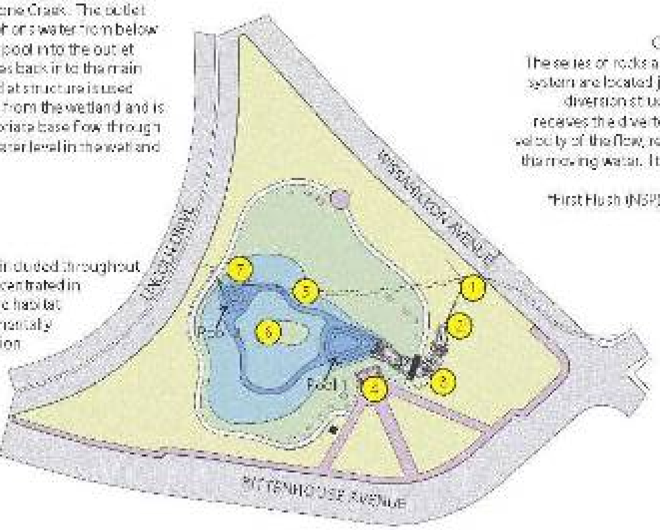


SAYLOR GROVE
STORMWATER WETLAND
& ITS STORMWATER MANAGEMENT FEATURES

Final Outlet/ Stormwater Diversion Chamber #2
This is the final outlet structure. It diverts the flow back into the original storm sewer after treatment before it enters the Monoshone Creek. The outlet has an 8" storm pipe that siphons water from below the surface of the collecting pool into the outlet structure. The outlet then ties back in to the main 48" stormwater line. The outlet structure is used to regulate flow discharging from the wetland and is used to maintain the appropriate base flow through the wetland system. If the water level in the wetland goes above 2 feet, it will spill into the outlet structure.
*Stream Bank Erosion, Stream Restoration

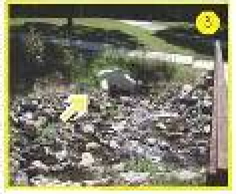
Island/Wetland Meadow
Plants, shrubs, and trees are included throughout the site, but are heavily concentrated in this area to provide a diverse habitat community in this environmentally sensitive zone. The vegetation also filters and removes pollutants from the water, slows down the velocity of the flow, and increases the uptake of water.
*Native Species, Removal of Pollution by Plants, Indicators of Water Quality (Aquatic Organisms)

Permanent Pool (Pool #1),
Channels, Collecting Pool (Pool #2)
The permanent pool is located at the base of the cascade. It removes the majority of the fine particulate matter in the stormwater wetland. The collecting pool is a smaller version of the permanent pool. It is located directly across – on the other side of the wetland where the outlet structure is located. The surrounding channels reduce the velocity of the flow.
*Water Quality Sampling



Stormwater Diversion Chamber #1:
A 48" storm sewer carries the stormwater runoff from this region and connects to a diversion chamber, which intercepts the stormwater flow and directs it to the weir (cascade) for treatment. This structure also acts as a settling chamber where it captures the metals, hydrocarbons and/or other pollutants found in the sediment carried by stormwater runoff, before it enters the wetland. If the two manholes at this site were to be removed, you could view the encapsulated stream flowing right below you into the park.
*Watersheds, Nonpoint Source Pollution (NSP), Stormwater Runoff, Cross Connections/Illicit Discharges

Cascade (Energy Dissipator System):
The series of rocks and pools that make up the cascade system are located just downstream of the stormwater diversion structure outlet (Image 3). The cascade receives the diverted stormwater and slows down the velocity of the flow, reducing the energy associated with the moving water. It also removes coarse sediment and aerates the water.
*First Flush (NSP), Water Quality and Water Quantity Issues, Energy Dissipation



Stormwater Diversion Chamber #2 Outlet:
Stormwater runoff from the Rittenhouse Avenue side of the Park is diverted into the Park as well. The outlet for this diversion chamber is also visible at the cascade. Refer to Site #1 for a description of the chamber.
*Stream Daylighting

Scenic Overlook/Site of Old Fountain:
Surface stormwater runoff from the surrounding parkland on this side of the site drains to the fountain area. There are two drains that release runoff into the wetland underneath this structure.
*Surface Stormwater Runoff

*Indicates Possible Educational Discussion Topics

BACKGROUND

Stormwater Runoff Impacts

The Monoshone Creek flows alongside Lincoln Drive, just across from Saylor Grove, through Historic RittenhouseTown. The majority of the Monoshone Creek now exists in storm sewer pipes. The creek and its tributaries were encapsulated over a century ago to allow for development of the Germantown community. When development occurs, the natural features of a landscape, such as vegetation and soil, are replaced with hard surfaces, such as pavement and buildings. These hard surfaces prevent stormwater from soaking back into the earth during a rainstorm. As a result, stormwater flows across these impenetrable surfaces, picking up all of the pollutants in its path such as oil, pesticides, fertilizers, or anything else that will float and/or dissolve in stormwater. These pollutants can be transported either directly over land into nearby water bodies or into storm drains which are connected to storm sewer pipes that discharge to streams and creeks. Polluted stormwater not only impacts the water quality of streams, but when the runoff rushes out of the stormwater pipes in great volumes and at high velocities, the form and shape of the streams also become jeopardized. Among many impacts that result from such conditions, the stream beds become scoured, erosion is accelerated, aquatic habitats are damaged, and stream banks become unstable. Stormwater is a water quantity and water quality issue, as we have seen in the Monoshone Creek.

Drinking Water Impacts

The Monoshone Creek and its surrounding sub-shed (smaller scale watershed) are located within the Philadelphia Water Department's (PWD) highest priority zone for source water (drinking water) protection — the Queen Lane and Belmont intakes. The Monoshone is a tributary to the Wissahickon Creek, which empties into the Schuylkill River, near the drinking water intake for Philadelphia's Queen Lane Water Treatment Plant. Because 24% of Philadelphia's drinking water comes from Queen Lane, the health of the entire Wissahickon Creek Watershed, including the Monoshone Creek, is critical to all who live and work in Philadelphia.

In Conclusion

At Saylor Grove, the stormwater treatment wetland will help detain (temporarily hold back) and treat the stormwater which was originally piped directly to the Monoshone Creek. This project will help reduce the quantity of stormwater entering the Monoshone at any given time and help improve the quality of the stormwater runoff as well. The Philadelphia Water Department would like to see every stream mile in the City of Philadelphia meet its designated use as a fishable and "swimmable" stream. This project is an exemplary demonstration of how the City and its partners are reaching this goal together.

SITE FACTS

- Saylor Grove Park is approximately 3.2 acres. The Saylor Grove Wetland makes up about one-third to one acre of the park.
- Saylor Grove Wetland drains approximately 156 acres of stormwater runoff from Germantown. The wetland is designed to drain the stormwater within 24 hours.
- Saylor Grove Wetland will filter a significant portion of the estimated 70 million gallons of stormwater per year.
- The wetland will remove approximately 13 tons of total suspended solids from the Monoshone Creek.
- The first 0.7 inches of every rainfall event will be sent to and treated at the wetland. According to the long-term historical record of the airport's rainfall data, 70% of all storms make up 0.7 inches or less of rainfall.
- The wetland will improve flow variability of the Monoshone Creek.
- The wetland will increase biodiversity (vegetation and animals).
- Approximately 3,000 trees, shrubs, and herbaceous plugs have been planted.

For more information on the stormwater management features, refer to the inside of this document.

Saylor Grove Stormwater Treatment Wetland Tour Guide

Stormwater Management Practices Demonstration Site

Spring 2006

Welcome to the Saylor Grove Stormwater Treatment Wetland! The Philadelphia Water Department (PWD), the Fairmount Park Commission (FPC), and its many partners like to dream big in their shared mission to protect and improve the environment. Fortunately for the Germantown section of Philadelphia, the dreaming (and hard work!) has transformed Fairmount Park's parcel of parkland — Saylor Grove — into one of Philadelphia's first stormwater treatment wetlands. The one-acre wetland, constructed in the fall of 2005, helps to slow down stormwater runoff and filter polluted stormwater from approximately 156 acres of Germantown before it enters the Monoshone Creek. A significant portion of this estimated 70 million gallons of urban stormwater runoff will be treated naturally every year! Saylor Grove not only boasts a stormwater treatment wetland, but also a new educational trail, interpretive signage, historic memorials and sculptures previously located in the park and a renovated, beautified space for all visitors to enjoy.

Why a Wetland?

Wetlands clean stormwater, replenish groundwater, reduce flooding risks, and provide habitats for wildlife. The Saylor Grove Stormwater Treatment Wetland is a highly visible project in the historic Wissahickon Watershed and was selected as a demonstration to illustrate how wetlands can successfully treat stormwater in an urban environment. In demonstrating the success of this project, we hope that similar wetland projects will be replicated throughout the City and in neighboring communities to improve water quality and to help bring back healthy streams and creeks throughout the region.

Philadelphia PWD Water Department

Office of Watersheds

CENTER IN THE PARK

Fairmount Park

Prepared for the Center in the Park (Senior Environment Corps)
by the Office of Watersheds, Philadelphia Water Department

CONSTRUCTION & SPECS

The R. E. Roy is a 39-ft, front-end loader, single hull, shallow draft, debris skimming vessel. It is powered by a main diesel engine, Caterpillar Model 3056 205 hp and a four-blade, magnesium bronzed propeller. The vessel is also equipped with a 122-gallon fuel tank, a 150 gpm, 100 psi Water Canon system, and a 5.6 yd^3 hydraulically controlled, grated bucket. Its construction began in June, 2004 and the vessel was delivered in March, 2005

THE DEDICATION

The dedication took place on July, 16, 2005 where the R. E. Roy was officially commissioned. The skimming vessel is named for Richard E. Roy, a former Water Commissioner who gave more than 30 years of gracious service to the City of Philadelphia and the Philadelphia Water Dept.

PARTNERS

Pennsylvania Coastal Zone Management Program

Partnership for the Delaware Estuary Inc.

Philadelphia PWD Water Department

Office of Watersheds

Philadelphia Water Department
Office of Watersheds
Aramark Tower – 4th Floor
1101 Market Street
Philadelphia, PA 19107

Philadelphia PWD Water Department

The R. E. Roy

Floatable Skimming Vessel

Commissioned July, 2005

HISTORY AND BACKGROUND

The Philadelphia Water Department Office of Watershed's (PWD OOW) vision is to unite the city with its waterways, creating a green legacy for future generations while incorporating a balance between ecology, economics and equity. PWD's Combined Sewer Overflow Long-Term Control Plan (PWD CSO LTCP), completed in 1997, highlights the need to improve public awareness of an individual's contribution to coastal aesthetics, notably in the Delaware and Schuylkill Rivers, and to improve water quality and aesthetics of surrounding parks and recreational areas. As such, the plan recommends the use of a floatables skimming vessel to remove debris from targeted reaches of the Delaware and Schuylkill Rivers. Similar waterfront enhancement programs have been very successful in New York City, Passaic Valley, NJ, Baltimore, MD, and Washington D.C.

WHY THE NEED FOR THE VESSEL?

The Schuylkill and Delaware Rivers are both undergoing a renaissance of development, ranging from hotel and entertainment centers and new housing, to the restoration of museums, greenways, gardens, and open space. The floatable skimming vessel enables the Philadelphia Water Department to monitor and remove floatables that accrue on the City of Philadelphia's waterways. In addition, it demonstrates to our citizens the value that the City of Philadelphia places on its waterways

HOW IT WORKS!

The front-end loader design allows the skimmer to utilize a grated bucket to lift floatables from the water surface into an on-board hold. The vessel collects debris in the bucket through two means. As the vessel drives through a mat of debris, the debris enters the bucket and is held by the grates as water passes through the grates. In addition, the vessel is designed to create a strong suction current that draws water through the vessel hull and the grated bucket, thus, drawing floatables into the bucket. The grated bucket is capable of holding over 3 yd^3 of material. Once the vessel returns to the dock, a crane lifts the grated bucket from the deck for disposal. The R. E. Roy is scheduled to be operated through PWD's Flow Control Unit five days per week from March through November each year, with December to February allotted for annual maintenance.

PROJECT BENEFITS

- Address water quality by collecting trash of a wide variety – identified through the qualitative assessment.
- Directly affect the interface of land and water by educating the public about where to put trash and better managing non-point source pollution in river.
- Improve and expand public access to coastal zone by drawing people to cleaner and more aesthetically pleasing rivers and providing a cleaner tourist destination point.
- Manage and protect coastal natural, historic, cultural or recreational resources.
- Provide a regional model that can serve as an example for similar projects that will address watershed management that directly impacts the Delaware Estuary by serving as a key implementation project in the abatement of trash as a result of non-point and point source pollution.

CONTACTS

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CSO Program Manager
Philadelphia Water Dept.
Office of Watersheds

Lance Butler (215) 685-4947
Aquatic Biologist, Supervisor
Philadelphia Water Dept.
Office of Watersheds

A Homeowner's Guide to Stormwater Management

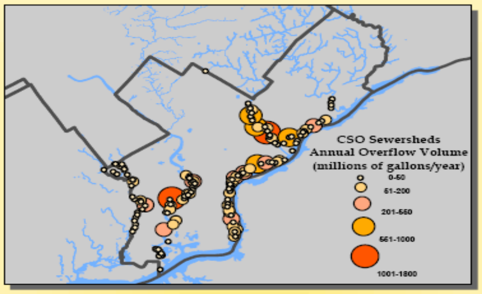
You can make a difference!

Learn what you can do on your property and in your community to improve the health of your watershed.

Prepared by: Office of Watersheds
Philadelphia Water Department
Volume 1 • January 2006

Top 10 Most Wanted CSOs

These 10 outfalls account for 8.3 billion gallons
of combined sewer overflow every year,
59% of the estimated annual overflow volume in Philadelphia.




#1
FFRFG (R18)

1765 MG/yr, Frankford Creek
Castor Avenue & Hunting Park
Frankford High Level Relief Sewer


#2
S50

1552 MG/yr, Schuylkill River
43rd Street east of Woodland Avenue
Mill Creek, 20' x 20' outfall


#3
T14

998 MG/yr, Tacony Creek
I Street and Ramona Street
21' x 24' outfall


#4
D25

895MG/yr, Delaware River
Somerset Street east of Richmond Street
Twin outfall 12' diameter


#5
F21

808 MG/yr, Frankford Creek
Wakling Street northwest of Creek Basin
Twin outfall 10.5' x 9.5'


#6
T8

681MG/yr, Tacony Creek
Ashdale Street west of Tacony Creek
12.5' outfall

#7
C17

522 MG/yr, Cobbs Creek
Beaumont Street and Cobbs Creek
12' x 11.5' outfall


#8
D5

416 MG/yr, Delaware River
Magee Street southeast of Milnor Street
Twin outfall 11' x 9'

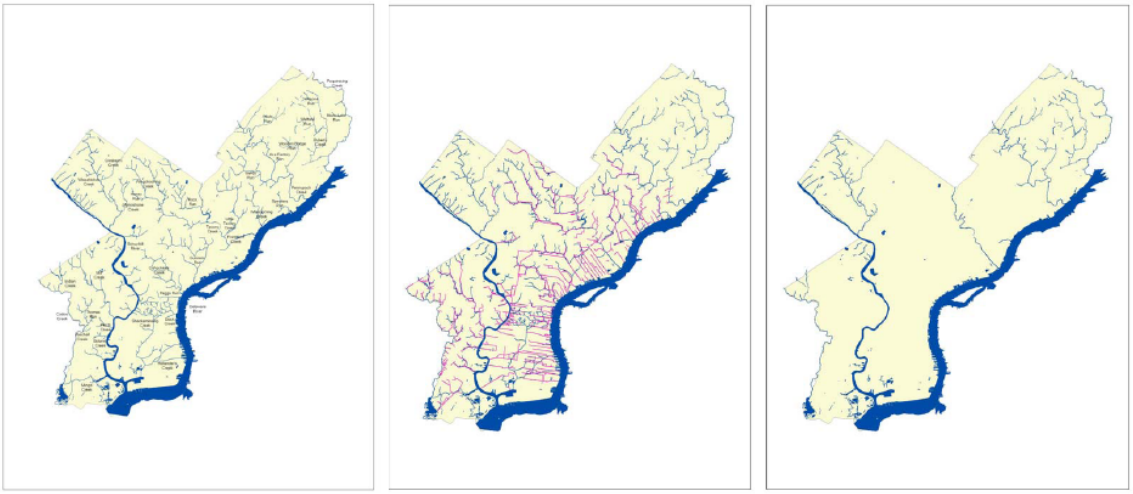

#9
S45

365 MG/yr
Schuylkill River
67th Street east of P&R railroad


#10
D45

307 MG/yr, Delaware River
Laurel Street and Delaware Avenue
14.5' x 16' outfall

PHILADELPHIA'S CHANGED LANDSCAPE



PHILADELPHIA'S HISTORIC STREAMS

THE PIPING OF SOME HISTORIC STREAMS

PHILADELPHIA'S REMAINING STREAMS

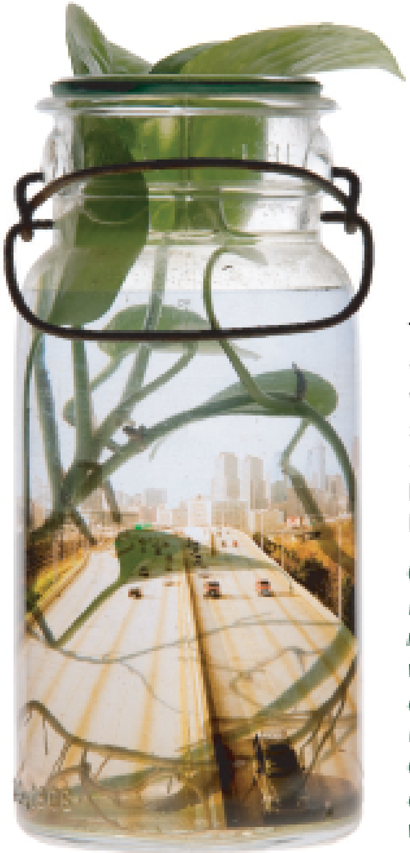
Bill Kelly Artwork & Exhibit Materials
(Interpretation of *Green Cities, Clean Waters*)


What PWD & Partners Are Accomplishing
Springside School
Green Infrastructure Design Elements:
1. Rain Garden
Green Infrastructure Benefits at Springside School:
2. Disconnected Downspouts & Art Sculptures
Partners
PWD
Waterview Recreation Center
Green Infrastructure Design Elements:
Project Benefits
Partners
PWD
Cliveden Park


Green Cities, Clean Waters
Philadelphia Water Department's Combined Sewer Overflow Long Term Control Plan
Green Cities, Clean Waters

WORLD
CLEAN WATERS
H2O
Where has that water been?
Where hasn't it been?

The Philadelphia Water Department's
Fairmount Water Works Interpretive Center
Presents:



Bill Kelly

Interpreting the Green Cities, Clean Waters Vision

The Philadelphia Water Department's (PWD) "Green Cities, Clean Waters" program seeks to implement a comprehensive watershed management approach that identifies multiple solutions (land, water, and infrastructure-based) to improve and preserve the City's water environment, to create a green legacy for future generations and to incorporate a balance between ecology, economics and equity.

Our daily interaction with water provides a prime example of humans' ecological relationship with the planet – it is one of the most common yet vital interactions we have with the natural world everyday. Art, with its appeal to the senses, imagination, and intellect, provides a unique approach to explore this relationship between society and water. The jars featured in this exhibit, filled with water and teeming with life and imagery, are a reminder of how intertwined we are both locally and globally with the finite amount of water that exists on this planet.

- Bill Kelly

Please join us at the Fairmount Water Works Interpretive Center, as artist, Bill Kelly, displays an artistic interpretation of Philadelphia's "Green Cities, Clean Waters" program.

Exhibit Opens September 25th, 2008
Reception: Thursday | October 16, 2008 | 5:30pm - 7:30pm
RSVPs welcomed by October 14, 2008: 215.685.0723

Fairmount Water Works Interpretive Center
640 Waterworks Drive, Philadelphia, PA 19130
For Directions: www.fairmountwaterworks.org

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Wednesday, Oct 22, 1:28 PM

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TEXT SIZE: A A A A
☐Email this post | Back to Blog home

WEDNESDAY, OCTOBER 15, 2008

Water meets art meets water

Bill Kelly's jar art

Bill Kelly thinks about water a lot.

As an artist, he's looked at how people interact with the wilder world, and he's recently focused on water as "one of the most common but easily overlooked interactions we have with nature everyday, and one reason why it presents an ideal lens through which to explore the larger story of society's reliance upon the natural world."

He's recently finished a series of "jar art" - filled with water, plants and images - tal "remind how we are intertwined both locally and globally with the finite amount of water that exists on this planet."

A public reception is being held Thursday from 5:30 to 7:30 p.m. at the Fairmount Water Works Interpretive Center.

The exhibit will remain open through Nov. 22.

The exhibit is part of the Philadelphia Water Department's "Green Cities, Clean Waters" program.

Kelly studied photography at the Art Institute of Philadelphia and has a master's degree in fine arts from Goddard College in Vermont.

He reports in a prepared statement that after this, "I can never again nonchalantly drive over a local river, turn on my tap, or dump something down the drain without thinking of the many ways I may be impacting - and am in turn affected by - the local water cycle."

Posted by Sandy Bauers @ 9:43 PM Permalink | 2 comments

SAVE AND SHARE

Comments

Sign in to post a comment

Posted by **eryanphoto** 10:55 AM, 10/22/2008 Sign in to report abuse

I would like to see more of Bill Kelly's jar art. Does he have a website or book of his jar art?

Posted by **Professor Smartypants, PhD** 11:58 AM, 10/22/2008 Sign in to report abuse

Pretty.

ABOUT SANDY BAUERS

Sandy Bauers is the environment reporter for the Philadelphia Inquirer, where she has worked for more than 20 years as a reporter and editor. She lives in northern Chester County with her husband, two cats, a large vegetable garden and a flock of pet chickens.

GreenSpace - her column about how to reduce your carbon footprint in everyday life - appears every other Monday in Health & Science.

BLOG ROLL

- The green living campaign of the Pa. Dept. of Conservation and Natural Resources
- Green Guide
- emagazine.com
- Environmental news and commentary from grist.org
- Green Living from

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FWWIC The Fairmount Water Works Interpretive Center
The Delaware River Basin's Watershed Education Center

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Calendar of Events
About the Water Works ▸
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Green Cities, Clean Water Exhibition

"Green Cities, Clean Water," the new exhibit at the Interpretive Center combines photography, art and stormwater management practices. A team from the Office of Watersheds created the exhibit to raise awareness of its long-range plan to transform Philadelphia into a city celebrated for its clean and beautiful rivers and streams.


Bill Kelly with one of his "jars."

Known officially as the Combined Sewer Overflow Long-term Control Plan, The Philadelphia Water Department's CSOLTCP seeks to implement a comprehensive watershed management approach that identifies multiple solutions (land, water, and infrastructure-based) to improve and preserve the City's water environment, to create a green legacy for future generations and to incorporate a balance between ecology, economics and equity.

Office of Watersheds Director Joanne Dahme predicts that the Green Cities, Clean Water project will take 20 years and many millions of dollars. "Our goal is to reduce stormwater runoff as much as possible by capturing it on the surface, through gardens, green roofs, permeable building materials and other green technologies that minimize runoff. Green technology will allow us to replace today's system with smaller pipes and fewer storage tanks. And we'll keep our rivers and streams cleaner and more beautiful." For more information go to: phillyriverinfo.org

Meanwhile, the Office of Watersheds has completed several demonstration projects and offers suggestions homeowners can put into practice to reduce runoff on their properties. The exhibit juxtaposed successful public programs with small projects, such as rain barrel collection systems, wild flower meadows and permeable paving materials.

Click here to see the environmental projects underway at Springside School.

Water Department project designer Tiffany Ledesma Groll invited environmental photographer Bill Kelly to create artwork to complement the Green Cities, Clean Water exhibit. Bill brings his perspective as an individual living in urban environments and interacting with the "wild" world on a daily basis. He uses jars filled with water, photographs, and plant life to demonstrate both the finite amount of water in our world and its ubiquity in our cities and lives.

"While jars are often used to preserve, in this context the addition of a living organism suggests that what needs preservation is not a static entity which can be bottled and stored, but rather it is the purity of the natural cycle of water that must be allowed to run its course," Bill explained. "As we witness the plants make their home in a surreal aquatic environment, we are reminded of water's life-sustaining gifts to both humanity and all that grows alongside us. This work is a tribute to the miracle and challenge of making our home in what was originally dubbed a city between two rivers."

To see a slide show of Kelly's work, click here. Copies of his photos and his actual jars are available at the Fairmount Water Works Interpretive Center. A portion of the sale price will benefit the Interpretive Center.

Green Cities, Clean Waters: with Artist and Educator Bill Kelly
FAIRMOUNT WATER WORKS INTERPRETIVE CENTER

THURSDAY, OCTOBER 16, 2008
05:30 PM TO 07:30 PM

Please Print

NAME	PHONE	E-MAIL	Check Here To Be Added To Our E-mail List
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45. Heather Rutledge	2155720622	eastmanheather@hotmail.com	
46. [illegible]	570 704 9094		
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48. Mr + Mrs Andrew Sherman	215-685-4008		
49. BRIAN PARKER			
50. Michael [illegible]			
51. Jonalyn Larson	267-257-4720	MKeaganPhoto@gmail.com	
52. Tom TAGGART		Thomas.TAggart@phila.gov	
53. Beth [illegible]	—		RM
54. GREG BERGEN			
55. LAUREN ROSENTHAL	267-230-2846	juicenart@gmail.com	

Kirsten Knoblauch 215 531-2490

✓ beth nixon

→

Green Cities, Clean Waters: with Artist and Educator Bill Kelly

FAIRMOUNT WATER WORKS INTERPRETIVE CENTER

THURSDAY, OCTOBER 16, 2008
05:30 PM TO 07:30 PM

NAME (Please Print)	**PHONE**	**E-MAIL**
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4. ANDREW SHERMAN ②		
5. ALICE WRIGHT ②	484-250-5818	
6. MARY ELLEN McCARTY ④	685-6246	
7. STEPHANIE CHIOREAN ⑤	814-883-1909	
8. MR. AMIN RAMLI 19		
9. LAURA WATT ② [illegible]	215-880-3003	
10. 27		
11. DR. & MRS. BONE ②		
12. SUSAN BECKETT ①	267-269-7545	
13.		
14.		
15.		

Green Cities, Clean Waters: with Artist and Educator Bill Kelly
FAIRMOUNT WATER WORKS INTERPRETIVE CENTER

THURSDAY, OCTOBER 16, 2008
05:30 PM TO 07:30 PM

NAME (Please Print)	**PHONE**	**E-MAIL**
✓ 46. BOB MYERS	610-662-3784	Bob@myers-media.com. * Place on mailing List
47. ERICA IRWIN	"	(PERSONALLY KNOW ARTIST KELLY)
48. DONALD GRISHAM	267-253-7462 TELE ✓m.	
worked on project 49. TIFFANY LEDESMA GROLL (3)	215-620-9055	ON MAILING LIST Husband of [illegible]
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Green Cities, Clean Waters: with Artist and Educator Bill Kelly

FAIRMOUNT WATER WORKS INTERPRETIVE CENTER

THURSDAY, OCTOBER 16, 2008
05:30 PM TO 07:30 PM

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	31.	ADRIENNE STALEIC	215 717 6122	astalek@uarts.edu	✓
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	33.	doug franklin	215 732 5067	dougalfranklin@gmail	
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	36.	Melanie Garrow	215-685-6036		
	37.	Jonine + Wallpoge	215.848.7514		
	38.	Bob Walker			
✓	39.	Martine Fournier		M_Fournier22@hotmail.com	✓
	40.	Jacob mitas	—	jacobpablomitas@hotmail.	
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✓	42.	SUE fitzpatrick		Suefitz1@comcast.net	✓
		Joshua morris		[illegible]	

15

Green Cities, Clean Waters: with Artist and Educator Bill Kelly

FAIRMOUNT WATER WORKS INTERPRETIVE CENTER

THURSDAY, OCTOBER 16, 2008
05:30 PM TO 07:30 PM

Please Print

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✓ 19. Anna Cascio	215 233 3484	mcascio9@comcast.net	✓
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23. Tom Groll	215-620-9994	tgroll28@hotmail.com	
24. Todd Murray	610 764-6156	tmphoto915 e yahoo.com	
25. Joann Dahm	215-685-4411	joann.dahm@phila.gov	
26. Debby + Alan Dion		ddion@verizon.net	
27. Jo Owen	610 [illegible] 4409		
28. Lisa Simon	215 545 470 ~~720~~	lsimon@simonpca	

Green Cities, Clean Waters: with Artist and Educator Bill Kelly

FAIRMOUNT WATER WORKS INTERPRETIVE CENTER

THURSDAY, OCTOBER 16, 2008
05:30 PM TO 07:30 PM

17
15
16
16
13
77

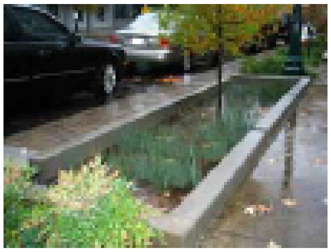
Please Print Maureen O'Rourke 484.437.1645 maureenorourke@antonelli.edu

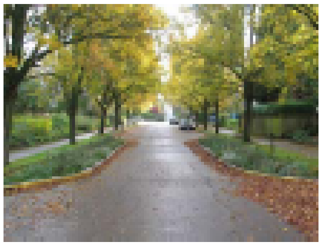
		NAME	PHONE	E-MAIL	Check Here To Be Added To Our E-mail List
✓	1.	Lucia Mettler	215-869-5414	lucia.mettler@gmail.com	✓
✓	2.	Lynn Amarnick	215 802-0097	LAMARNICK@comcast.net	✓
✓	3.	Bonnie Kornstein		bkornstein@comcast.net	✓
✓	4.	Ellen Rosenberg	215-470-9195	ELLENOTR@COMCAST.net	—
	5.	Jené Copeland			
✓	6.	Bob Van Ess	610 344 0700	bvaness@vanguarddirect.com	—
✓	7.	David Thompson		dthompson@simonpr.com	✓
	8.	Kelly Anderson		kellyanderson@phila.gov	
✓*	9.	Michelle Lutz		Mlutz@lutheransettlement.org	✓
	10.	Lila & Jill	215 307 6061	lstvempfis@hotmail.com	
	11.	Stephanie Chiorean	8148851909	stephanie.chiorean@phila.gov	
	12.	Megan Molloy			
✓	13.	Joanne Pinto		cottagefolks@msn.com	✓
	14.	Diane & Bob Rounds	235-9788		

GREENING OUR STREETS

2008

URBAN WATERSHEDS
REVITALIZATION CONFERENCE





Date: Friday, October 31, 2008

Time: 8:30 a.m.— 3:30 p.m.

Location: Community College of Philadelphia

Fee: $20

Register Today: http://www.stormwaterbmp.org/conference
watersheds@pennhort.org
215-988-8772

Overview

We plan to explore what constitutes a green street, present the vision that is guiding the movement toward green streets, and provide insight into how our region can move forward by turning the vision into a reality. We will explore how to improve stormwater management on public right-of-ways, while also beautifying communities, providing economic incentives, and creating other environmental benefits and amenities. The conference will focus on demonstration projects and case studies in Philadelphia and in the nearby suburbs, as well as the work and experience of regional and national design and engineering experts.

Brought to you by: Philadelphia Water Department, Pennsylvania Horticultural Society, American Water Resources Association, Pennsylvania Environmental Council, Montgomery County Conservation District, Temple University, Villanova University, Philadelphia University, Drexel University, & Community College of Philadelphia.

2007
URBAN WATERSHEDS REVITALIZATION CONFERENCE

Please reserve **Thursday, May 3,** from **8:30 a.m. to 3:00 p.m.** for the third annual Urban Watersheds Revitalization Conference at Philadelphia University (School House Ln. & Henry Ave.) in Philadelphia.

The conference will target the urban (or mostly developed) watershed communities of south-east Pennsylvania, including the City of Philadelphia and the surrounding suburbs. The event will feature two panel discussions, a poster session and an awards ceremony for the winning projects of the Stormwater Best Management Practices (BMPs) Recognition Program. The first panel discussion will cover the theme of stormwater management regulations and requirements. The second panel discussion will be the response from the design community on the realities of implementing these regulations and requirements. The subjects addressed in the panel discussion may include the perceptions, realities and responses to the state model stormwater ordinance, National Pollutant Discharge Elimination System (NPDES) requirements, flood control minimization, stormwater rate structure reallocation, retrofit funding mechanisms and other programs and initiatives that aim to demonstrate the environmental, economic and social benefits that arise through sustainable watershed management.

FOR MORE INFORMATION

For more information and to register for the conference, please visit: **www.stormwaterbmp.org/conference**. This event is FREE, so sign up soon!

Also, please visit the Stormwater BMP Recognition Program website and nominate a local project at: www.stormwaterbmp.org.

SPONSORS

Philadelphia PWD Water Department

Villanova Urban Stormwater Partnership

conserving natural resources *for our future*

Office of Watersheds

AMERICAN WATER RESOURCES ASSOCIATION
Community, Conservation, Connections

PHILADELPHIA UNIVERSITY

From: Sarah RobbGrieco [mailto:sarah@ttfwatershed.org]
Sent: Tuesday, November 04, 2008 1:12 PM
To: Ledesma Groll, Tiffany; Khiet Luong
Subject: Re: Help with CSO LTCPU Public Meetings

Hi Tiffany,

The conference was fantastic for me. One of the best I've been to since I started with TTF. In particular, the panel with Joy and Gina and the PWD and Streets Dept staff was incredibly useful. I learned so much from hearing all their points of view. You guys really did a great job with the entire day.

Let's talk more.

Sarah

Sarah RobbGrieco
Executive Director
Tookany/Tacony-Frankford Watershed Partnership, Inc.
One Awbury Road
Awbury Arboretum
Philadelphia, PA 19138
phone: 215.208.1613
email: sarah@ttfwatershed.org
web: ttfwatershed.org

Robert Allen/MDO/Phila

10/31/2008 04:26 PM

To Howard Neukrug/PWD/Phila@Phila, Glen Abrams/PWD/Phila@Phila, Joanne Dahme/PWD/Phila@Phila

cc

Subject Greening Our Streets

Just a quick note to congratulate you all on a great conference! It's gratifying to see the City coming together on these issues thanks to your leadership.

From: Dan Meier [mailto:dmeier@duffnet.com]
Sent: Tuesday, November 04, 2008 1:12 PM
To: Ledesma Groll, Tiffany
Subject: RE: Duffield presentation

No problem. The conference was one of the best I've been to in 25 years. Such a wide cross-section of people but all of us focused on the same city-improving agenda. Thanks for including us and thanks for your efforts in making it happen.

Dan Meier, P.E.
Duffield Associates
211 N. 13th Street, Suite 704
Philadelphia, PA 19107
(215) 545-7295
(215) 875-7356 fax

Backgrounders

(View Advisory Committee Invitation Packet for complete versions of first two backgrounders)

THE CSO LONG TERM CONTROL PLAN *UPDATE*

GREEN CITIES
CLEAN WATERS

Current Status
of Our Waterways
The City of Philadelphia

Philadelphia PWD Water Department

Introduction

The Philadelphia Water Department (PWD) is charged with ensuring optional compliance with the City's federal Clean Water Act (CWA) permit. In doing so, PWD is striving to define a stormwater management program that protects and enhances our region's waterways by managing stormwater in a way that significantly reduces the need for infrastructure (pipes). PWD believes that money spent on stormwater management and the attainment of CWA goals should also represent money spent to improve the natural resources of the City and to enhance the community. In 2007, PWD began to reevaluate its Combined Sewer Overflow (CSO) Long Term Control Plan (LTCP) and capital improvements program to integrate additional projects that will reduce CSO frequency and volume. The CSO Long Term Control Plan Update (LTCPU) involves the development of additional management alternatives to ensure capture and treatment of combined sewer system flows and the reduction of discharges from CSOs by building on the experience and progress gained from the implementation of our original CSO LTCP.

The US EPA's Guidance for Long Term Control Plan Development outlines a number of specific tasks for municipalities to undertake while developing their own LTCP, including what is called a "System Characterization." A system characterization includes a detailed assessment of current conditions of the combined sewer system and receiving waters. To accomplish this task, PWD initiated a detailed monitoring program that includes chemical, biological and physical assessments to characterize the current state of the watershed and identify existing problems and their sources. PWD characterized both CSO and non-CSO sources of pollution within each watershed, in order to better understand all causes of water quality impairment. Technical Memorandums, Reports, Plans and Documents for each of our watersheds are available on the City's Watershed Information Center website at www.phillyriverinfo.org

This fact sheet includes a summary of existing conditions for the Cobbs, Tookany/Tacony-Frankford, Schuylkill and Delaware Watersheds; potential solutions for addressing problems identified through the System Characterization will be presented in a forthcoming fact sheet – winter 2009.

PWD's Monitoring and Assessment Programs for System Characterization:

PWD's monitoring and assessment program includes the collection and organization of both existing and new data on surface water hydrology and quality, wastewater collection and treatment, stormwater control, land use, stream habitat and biological conditions, and historic and cultural resources in order to gain an understanding of what data already exists and where there may be gaps worth filling. Data are collected from various agencies and organizations in a variety of forms, ranging from reports to databases and Geographic Information System (GIS) files. To supplement existing data, PWD's Office of Watersheds (OOW) conducted an extensive sampling and monitoring program to characterize the conditions of each watershed.

Schuylkill and Delaware Rivers. The Delaware River Basin Commission (DRBC) and PWD have collected water quality data from sampling locations within the Delaware and Schuylkill Rivers. Additionally, the U.S. Geological Survey (USGS) had recorded historic baseline water quality data that can now be compared with the data collected by DRBC. This comparison allows for a more comprehensive analysis of water quality and the impacts of urbanization over the past 10 years.

Cobbs and Tookany/Tacony-Frankford Creeks. A Comprehensive Characterization Report (CCR) has been developed for both the Cobbs and Tookany/Tacony-Frankford Watersheds. CCRs form the scientific basis for the creation of an Integrated Watershed Management Plan. A CCR includes physical, chemical and biological assessments of a watershed and incorporates land use, geology, soils, hydrology, water quality, ecology, and pollutant loads related information about a watershed. PWD carried out a comprehensive sampling and monitoring program in the Darby-Cobbs watershed between 1999 and 2002 and in the Tookany/Tacony-Frankford between 2002 and 2004.

The definitions of words with an asterisk* can be found in the glossary at the end of this publication.

For more information, please visit us at www.phillyriverinfo.org

Watershed Planning Process

PWD's Integrated Watershed Management Planning (IWMP) process is based on a carefully developed approach to meeting the challenges of watershed management in an urban setting. PWD developed their concept of regional watershed management planning recognizing that, as the downstream most entity in each of the watersheds leading to the City of Philadelphia, they could not make sustainable improvements to the waterways without support from upstream partners. The planning process also incorporates the best of existing municipal and conservation planning efforts (including River Conservation Plans, Open Space Plans, municipal Comprehensive Plans, etc.) as well as regulatory requirements and stakeholder goals. Its focus is on attaining priority environmental goals in a phased approach, making use of the consolidated goals of the numerous existing programs that directly or indirectly require watershed planning. These plans are built upon a solid, scientific foundation composed of water quality monitoring (wet and dry weather), macroinvertebrate and fish bioassessments, physical stream surveys (FGM) and computer simulated modeling programs for stormwater flows and pollutant loading.

An integrated watershed management plan is a long-term road map designed to achieve healthy communities and restore natural resources. An integrated plan embraces the laws designed to save our streams, preserve the streams' ecology, and enhance the parkland and riparian buffers that shelter these streams. The plan will also reach out to include the best of municipal and conservation planning efforts, which strive to ensure that growth within the watershed occurs with particular attention to the impacts on the environment. Most importantly, the plan will incorporate the goals of a diversity of people who live, work, and dream in all areas of the watershed.

Watershed Partnerships:
Stakeholder support is critical to the success of a regional planning initiative. A diversity of stakeholder perspectives must be involved with the development of each stage in the planning process in order to ensure that the plan is representative of stakeholder interests. This stakeholder buy-in is most critical to ensuring ultimate implementation of the plan. Recognizing this, PWD has helped to develop stakeholder watershed partnerships for each watershed that drains to the City of Philadelphia.
The ultimate goal is to cultivate a partnership committed to implementing the plan once completed.

Characterization of Existing Conditions in Philadelphia's Watersheds

Philadelphia, which is being called "The Next Great City," faces new and exciting challenges in every aspect of city planning. Having to restore the natural resources of the waterways, as well as prevent further damage to the creeks and rivers is a tall order for such a rapidly growing and constantly changing City, but Philadelphia is embracing this challenge and leading the way with its integrated watershed management planning approach.

Philadelphia's urban watersheds suffer from many problems within the City limits. Many of these problems stem from the highly urbanized settings surrounding the waterways and have a direct correlation to the actions of the public and land management practices in the region.

During wet weather (when it is raining), our consequences on the environment are evident when bacteria (from human waste and other sources) ends up in our waterways through both combined and stormwater outfalls. This type of problem creates an environment which is not conducive to swimming, nor to any other form of primary contact with the water.

An additional problem in our waterways includes fluctuations in dissolved oxygen (oxygen in the water) levels, which have been observed in all of our urban creeks. These changes can adversely affect the health of the fish in our streams.

Furthermore, very high flows are common in our streams during larger storm events. During these events, the streamside vegetation along the creek banks begin to disappear, leading to erosion of the stream banks contributing to additional sediment in the water and habitat loss. High volume streamflows erode the stream banks and stream bottoms, and in many locations, this results in exposed PWD sewer infrastructure.

PWD and its partners are working hard to reverse the adverse impacts on our streams. As such, stream restoration projects, outreach to large property owners and the implementation of a variety of innovative stormwater management practices, such as green roof installations, are only a few examples of the steps that we are taking, as a City, towards the ultimate goal of transforming Philadelphia into a leading "green city" with "clean waters."

Cobbs Creek

Cobbs Creek drains approximately 23 miles over portions of 10 municipalities and the City of Philadelphia, ultimately discharging into the Darby Creek. The designated uses for the non-tidal suburban portion of Cobbs Creek include all the state-wide uses including: Migratory Fishes, Warm Water Fishes, Potable Water Supply, Industrial Water Supply, Livestock, Water Supply, Wildlife Water Supply, Irrigation, Boating, Fishing, Water Contact Sports, Aesthetics, plus the addition of Migratory Fishes (25 PA§ 93.9e).

Completed Plans and Watershed Assessments

A number of assessments and planning initiatives have been completed within this watershed area, each illuminating problems, potential problem sources as well as recommended solutions. PWD carried out a comprehensive sampling and monitoring program in the Darby-Cobbs Watershed between 1999 and 2002. PWD's sampling revealed some *good news* – very few (only five) of the Pennsylvania State Water Quality Criteria revealed exceedances of in dry weather conditions and thirteen during wet weather conditions. A total of 29 criteria were used to test these parameters. Also, during the biological assessment — 44 different species of fish were identified. And, as the Integrated Watershed Management Plan is implemented in this watershed, these numbers will only improve!

Among those evaluated by the CSO LTCPU process are:

- Cobbs Creek Wetland Assessment – 2000 and 2006
- Darby-Cobbs Comprehensive Characterization Report – 2004
- Geomorphologic Survey – Level II for Cobbs Creek – 2003
- Streamside Infrastructure Assessment – 2002
- Cobbs Creek Integrated Watershed Management Plan – 2004
- Darby-Cobbs River Conservation Plan – 2005
- The Darby-Cobbs Act 167 Stormwater Management Plan – 2005

Partnerships

In 1999, the Philadelphia Water Department initiated the Darby-Cobbs Watershed Partnership in an effort to engage residents, businesses, and government, as neighbors and stewards of the watershed. Since then, the Partnership has been active in developing a vision for the watershed and guiding and supporting subsequent planning activities within the watershed.

The mission as established by the Darby-Cobbs Watershed Partnership is *"To improve the environmental health and safe enjoyment of the Darby-Cobbs watershed by sharing resources through cooperation of the residents and other stakeholders in the watershed. The goals of the initiative are to protect, enhance, and restore the beneficial uses of the Darby-Cobbs waterways and riparian areas."*

Current Conditions	
Erosion, Sediment Accumulation, Flow Variety	• Stream bank erosion • Storm discharges • Channel modification • Hydromodification and combined sewer overflow
Wetlands	• 43 wetlands have been identified within the watershed (many impaired) • 10 wetland creation/enhancement opportunities have been identified • Invasive Species programs in place
Healthy Riparian Habitat	• Water diverted from land to waterways • Land Development/encroachment • Invasive Species Programs in place • Streamside tree plantings underway
In-stream Habitat and Biological Impairment	• Over-widening/Erosion • Loss of natural curves/Habitat alteration • Loss of floodplain • Loss of stream/floodplain connection • Loss/degradation of aquatic habitat • Severe water flow fluctuations • Point and non-point source (NPS) pollution from urban development
Sewer Odors	• Suspected sewer leaks during dry weather • Cross-connected sewer lines • CSOs*
Trash and Dumping	• Trash from stormwater discharge • Deliberate disposal of debris in the creeks • Careless behavior
Water Quality Concerns	• Sediment** • Bacteria*** • Dissolved Oxygen****

*Combined Sewer Overflow (CSO) number in Cobbs Creek: 34

**Sediment—symptom of erosion and habitat loss caused by high flows

***Bacteria—levels are higher during and soon after wet weather when CSO's and stormwater outfalls are discharging to the stream

****Dissolved Oxygen— Stormwater and CSO discharges, treated discharges, septic systems, lack of shade, invasive plant growth, natural sources, plunge pools and other poorly mixed areas

Tookany/Tacony-Frankford Creek

The Tookany/Tacony-Frankford (TTF) Watershed drains 29 square miles of Philadelphia and Montgomery County. The creek is referred to as the Tookany Creek until it enters Philadelphia at Cheltenham Avenue; then as the Tacony Creek until the confluence with the historic Wingohocking Creek in Juniata Park; and finally the section of the stream from Juniata Park to the Delaware River is referred to as the Frankford Creek. Municipalities within this watershed drainage area include Cheltenham Township, Abington Township, Jenkintown Borough, Rockledge Borough, Springfield Township and the City of Philadelphia.

Completed Plans and Watershed Assessments

A number of assessments and planning initiatives have been completed within this watershed area, each illuminating problems, potential sources as well as recommended solutions. From 2000 through 2004, PWD has collected water quality data for sampling locations in the Tookany/Tacony-Frankford Watershed. Sample results were compared to relevant PA DEP general water quality criteria to provide an initial impression of which parameters might need further investigation. Applicable relevant standards include water uses to support a potable water supply, recreation and fish consumption, human health, and aquatic life to support warm water fishes. PWD's sampling revealed some *good news* – very few (only nine) of the Pennsylvania State Water Quality Criteria revealed exceedances of in dry weather conditions and eighteen during wet weather conditions. A total of 46 criteria were used to test these parameters. Also, during the biological assessment — 17 different species of fish were identified. And, as the Integrated Watershed Management Plan is implemented in this watershed, these numbers will only improve!

Among those evaluated by LTCPU process are:

- TTF Creek Wetland Assessment – 2006
- Fluvial Geomorphologic Assessment of the TTF – 2006
- TTF Streamside infrastructure Assessment – 2005
- TTF Integrated watershed Management Plan – 2006
- Tacony-Frankford River Conservation Plan – 2005
- The TTF Act 167 Stormwater Management Plan – 2008

Partnerships

TTF Partnership is a consortium of proactive environmental groups, community groups, municipalities, government agencies, businesses, residents, and other watershed stakeholders who have an interest in improving their watershed.

The goals of the partnership are to protect, enhance, and restore the beneficial uses of the waterways and riparian areas. Through watershed management we can mitigate the adverse physical, biological, and chemical impacts of land uses as surface and ground waters are transported throughout the watershed to the waterways.

The mission of the TTF Partnership is *"To increase public understanding of the importance of a clean and healthy watershed; to instill a sense of appreciation and stewardship among residents for the natural environment; and to improve and enhance our parks, streams, and surrounding communities in the Tookany/Tacony-Frankford watershed.*

Current Conditions	
Erosion, Sediment Accumulation, Flow Variety	Stream bank erosion Storm discharges Channel modification Hydromodification and combined sewer overflow
Wetlands	24 wetlands have been identified within the watershed (many impaired) 26 wetland enhancement opportunities have been identified Invasive Species programs in place
Healthy Riparian Habitat	Water diverted from land to waterways Land Development/encroachment Invasive Species Programs in place Streamside tree plantings underway
In-stream Habitat and Biological Impairment	Over-widening/Erosion Loss of natural curves/Habitat alteration Loss of floodplain Loss of stream/floodplain connection Loss/degradation of aquatic habitat Severe water flow fluctuations Point and non-point source (NPS) pollution from urban development
Sewer Odors	Suspected sewer leaks during dry weather Cross-connected sewer lines CSOs*
Trash and Dumping	Trash from stormwater discharge Deliberate disposal of debris in the creeks Careless behavior
Water Quality Concerns	Sediment** Bacteria*** Dissolved Oxygen****

*Combined Sewer Overflow (CSO) number in TTF Creek: 31

**Sediment—symptom of erosion and habitat loss caused by high flows

***Bacteria—levels are higher during and soon after wet weather when CSO's and stormwater outfalls are discharging to the stream

****Dissolved Oxygen— Stormwater and CSO discharges, treated discharges, septic systems, lack of shade, invasive plant growth, natural sources, plunge pools and other poorly mixed areas

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Among those evaluated by LTCPU process are:
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- Fluvial Geomorphologic Assessment of the TTF – 2006
- TTF Streamside infrastructure Assessment – 2005
- TTF Integrated watershed Management Plan – 2006
- Tacony-Frankford River Conservation Plan – 2005
- The TTF Act 167 Stormwater Management Plan – 2008

Partnerships

TTF Partnership is a consortium of proactive environmental groups, community groups, municipalities, government agencies, businesses, residents, and other watershed stakeholders who have an interest in improving their watershed.

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The mission of the TTF Partnership is *"To increase public understanding of the importance of a clean and healthy watershed; to instill a sense of appreciation and stewardship among residents for the natural environment; and to improve and enhance our parks, streams, and surrounding communities in the Tookany/Tacony-Frankford watershed.*

Current Conditions	
Erosion, Sediment Accumulation, Flow Variety	• Stream bank erosion • Storm discharges • Channel modification • Hydromodification and combined sewer overflow
Wetlands	• 24 wetlands have been identified within the watershed (many impaired) • 26 wetland enhancement opportunities have been identified • Invasive Species programs in place
Healthy Riparian Habitat	• Water diverted from land to waterways • Land Development/encroachment • Invasive Species Programs in place • Streamside tree plantings underway
In-stream Habitat and Biological Impairment	• Over-widening/Erosion • Loss of natural curves/Habitat alteration • Loss of floodplain • Loss of stream/floodplain connection • Loss/degradation of aquatic habitat • Severe water flow fluctuations • Point and non-point source (NPS) pollution from urban development
Sewer Odors	• Suspected sewer leaks during dry weather • Cross-connected sewer lines • CSOs*
Trash and Dumping	• Trash from stormwater discharge • Deliberate disposal of debris in the creeks • Careless behavior
Water Quality Concerns	• Sediment** • Bacteria*** • Dissolved Oxygen****

*Combined Sewer Overflow (CSO) number in TTF Creek: 31

**Sediment—symptom of erosion and habitat loss caused by high flows

***Bacteria—levels are higher during and soon after wet weather when CSO's and stormwater outfalls are discharging to the stream

****Dissolved Oxygen— Stormwater and CSO discharges, treated discharges, septic systems, lack of shade, invasive plant growth, natural sources, plunge pools and other poorly mixed areas

Delaware River

(Delaware Direct)

The Delaware Direct Watershed, located entirely in Philadelphia and draining approximately 84 square miles, is highly urbanized and discharges directly to the Delaware River. As an urban watershed, this area has rich complexities and multiple dimensions-diverse land use and communities, Center City, a formerly industrial Delaware waterfront, and a mix of neighborhoods and communities, reflecting a wide range of stakeholders, concerns and interests. Yet, there are many planning projects underway, many people gathering around the river and many groundbreaking events and projects taking place at this very moment in Philadelphia. As a result, the plans and teams behind these projects are aiding in the reconnection of the people and the City of Philadelphia to its waterway, making the streams and parks in our communities valuable assets to our citizens and joining PWD and partners in our protection efforts.

Completed Plans and Watershed Assessments

A number of assessments and planning initiatives have been completed within this watershed area, each illuminating problems, potential sources as well as recommended solutions. Dissolved Oxygen levels have increased significantly over the last three decades, enabling shad to more freely though the tidal zone of the Delaware River and into the freshwater zone in Philadelphia, as they make their way to the Fairmount Fish Ladder in the Schuylkill River. Where the shad were once limited by a lack of oxygen, they are returning to migrate up the Delaware River - a valuable indicator of improving environmental conditions!

Among those evaluated by the CSO LTCPU process are:

- Delaware Direct River Conservation Plan—2009
- Delaware River Source Water Protection Plan—2007
- Delaware Estuary Program's State of the Estuary Report—2008
- GreenPlan Philadelphia – 2008
- North Delaware Riverfront Master Plan – 2001
- Central Delaware Riverfront Planning Process – 2008
- Northern Liberties Waterfront Plan – 2007
- Philadelphia Navy Yard Master Plan
- Delaware River Basin Commission Boat Run Data
- USGS Gage Stations

Partnerships

The Delaware Direct Watershed Partnership was formed in 2007 to support the River Conservation Planning process for the Delaware Direct River Conservation Plan. A myriad of stakeholders are involved– non-profits, state and local government, in addition to community representatives.

Current Conditions	
Erosion, Sediment Accumulation, Flow Variety	•Stream bank erosion •Storm discharges •Channel modification •Hydromodification and combined sewer overflow
Wetlands	•Several wetland creation/enhancement opportunities have been identified
Healthy Riparian Habitat	•Water diverted from land to waterways •Land Development/encroachment •Invasive Species Programs in place •Streamside tree plantings underway
In-stream Habitat and Biological Impairment	•Loss of flood plain •Loss of stream/floodplain connection •Loss/degradation of aquatic habitat •Point and non-point source (NPS) pollution from urban development
Sewer Odors	•Suspected sewer leaks during dry weather •Cross-connected sewer lines •CSOs*
Trash and Dumping	•Trash from stormwater discharge •Deliberate disposal of debris in the creeks •Careless behavior
Water Quality Concerns	•Sediment** •Bacteria*** •Dissolved Oxygen****

*Combined Sewer Overflow (CSO) number in Delaware River: 54

**Sediment—symptom of erosion and habitat loss caused by high flows

***Bacteria—levels are higher during and soon after wet weather when CSO's and stormwater outfalls are discharging to the stream

****Dissolved Oxygen— Stormwater and CSO discharges, treated discharges, septic systems, lack of shade, invasive plant growth, natural sources, plunge pools and other poorly mixed areas

Philadelphia Water Department

Internet Resources

PhillyRiverInfo

http://www.phillyriverinfo.org/

On this website, you will find general information on Philadelphia's watersheds as well as upcoming watershed-related events. Check this site often to find out what is going on in your watershed!

Green Cities, Clean Waters (LTCPU)

http://www.phillyriverinfo.org/csoltcpu/

An offshoot of PhillyRiverInfo, this websites focuses on the Green Cities, Clean Waters Program (Combined Sewer Overflow Long Term Control Plan Update). Here you can read about details of the plan and learn about the basics of a combined sewer system.

CSOCast

http://www.phillywatersheds.org/csocast/

NEW! This website is PWD's latest effort to show the overflow status of the City's 164 Combined Sewer Outfalls. CSO Cast indicates whether CSOs are occurring or are suspected to have occurred within the last 24 hours. It is updated twice daily with information from PWD's extensive sewer monitoring network.

RiverCast

http://www.phillyrivercast.org/

The Philly RiverCast is a forecast of water quality that predicts potential levels of pathogens in the Schuylkill River between Flat Rock Dam and Fairmount Dam (i.e., between Manayunk and Boathouse Row). Visit this site to find out the daily RiverCast prediction and to learn more about water quality.

Rain Barrel Program

http://www.phillywatersheds.org/rainbarrel/)

The Philadelphia Water Department is providing rain barrels to residents of Philadelphia's watersheds free of charge, in order to promote the reduction of stormwater flows to our sewer system and creeks. To receive a rain barrel, you must attend a rain barrel workshop to be educated on the installation and use of the rain barrel. Rain barrel workshops are held in locations around the city throughout the year. Check this website to see when a workshop is being held in your watershed.

Philadelphia PWD Water Department

THE CSO LONG TERM CONTROL PLAN *UPDATE*

GREEN CITIES
CLEAN WATERS

Clean Water Benefits and the Balanced Approach

The City of Philadelphia

Combined Sewer Overflow (CSO)

A wastewater collection system that transports wastewater from homes, businesses, industry, and stormwater from storm drains on our city streets through a single-pipe system to a Water Pollution Control Plant. Under heavy rainfall conditions the flow in the combined sewers may exceed the capacity of the pipe or treatment facility. As a result, a portion of the wastewater and stormwater may be diverted directly to a nearby stream or river to prevent the flooding of homes and streets.

National Pollutant Discharge Elimination System (NPDES)

A provision of the Clean Water Act which prohibits discharge of pollutants into waters of the United States unless a special permit is issued by EPA, a state, or, where delegated, a tribal government on an Indian reservation.

Non-Point Source

Diffuse pollution sources (i.e., without a single point of origin or not introduced into a receiving stream from a specific outlet). The pollutants are generally carried off the land by stormwater. In Philadelphia, examples include stream bank erosion and construction.

Point Source

A stationary location or fixed facility from which pollutants are discharged; any single identifiable source of pollution; e.g. a pipe, ditch, ship, ore pit, factory smokestack. Municipal sewer systems are regulated as point sources.

Pollutant

Generally, any substance introduced into the environment that adversely affects the usefulness of a resource of the health of humans, animals, or ecosystems.

Receiving Waters

A river, lake, ocean, stream or other watercourse into which wastewater or treated effluent is discharged.

Runoff

That part of precipitation, snow melt, or irrigation water that runs off the land into streams or other surface-water.

Sanitary Sewer

Underground pipes that carry only domestic or industrial waste, not storm water.

Sanitary Sewer Overflow (SSO)

Untreated or partially treated sewage overflows from a sanitary sewer collection system.
Definition from Philadelphia Water Department

Stormwater

The water that runs off surfaces such as rooftops, paved streets, highways and parking lots. It can also come from hard grassy surfaces like lawns, play fields, and from graveled roads and parking lots. *Definition from King County, Water and Land Resources Division.*

Wastewater

The spent or used water from a home, community, farm, or industry that contains dissolved or suspended matter.

Water Pollution

The presence in water of enough harmful or objectionable material to damage the water's quality.

Water Quality Standards (WQS)

Water quality standards are provisions of state or federal law which consist of a designated use or uses for the waters of the United States, water quality criteria to protect the most sensitive uses for such waters, and an antidegradation policy and implementation procedures to protect water quality. Water quality standards are established to protect the public health or welfare, enhance the quality of water and serve the purposes of the CWA.

For more information, please visit us at www.phillyriverinfo.org

Bill Stuffers & WaterWheels

Philadelphia PWD Water Department

WATER Wheel

Protecting Your Environment / 2008

CSO: Public Notification Means You're in the Know

Stormwater Best Management Practices Awards

What is a WATERSHED?

A watershed is the land surrounding a system of rivers (or streams or creeks), or a particular river, that, when it rains, sheds the runoff into that waterway. Everything you do impacts your watershed. Runoff from garden fertilizers, hazardous substances like used motor oil, and trash dumped into one area of a river bank can pollute water many miles downstream. Protecting and preserving our watersheds helps protect our water resources.

The watersheds that drain directly to Philadelphia are: Darby Cobbs Watershed, Schuylkill Watershed, Wissahickon Watershed, Delaware Watershed, Pennypack Watershed, Tookany/Tacony-Frankford Watershed and Poquessing Watershed.

Combined Sewer Overflow (CSO) Public Notification Signage Program

What is a Combined Sewer Overflow (CSO)?

A combined sewer system transports sanitary wastewater (from homes, businesses and industry), stormwater from the storm drains on our streets and stormwater from property downspouts through a single-pipe to a Water Pollution Control Plant (treatment plant).

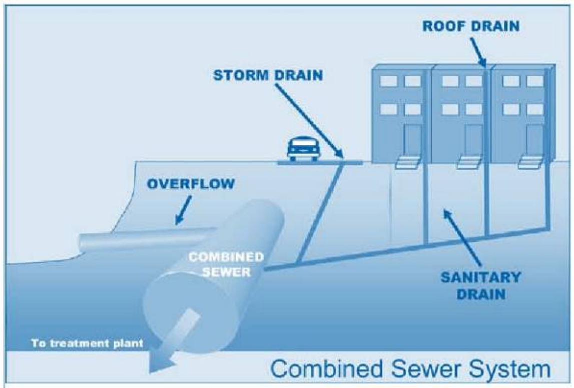
Under heavier rainfall conditions, however, the flow in combined sewers may exceed the capacity of the pipe or treatment facility. As a result, a portion of the wastewater and stormwater may be sent directly to a nearby stream or river to prevent the flooding of homes and streets. This is what is known as a Combined Sewer Overflow.

During heavy rainfalls or sudden snowmelts, Philadelphia may experience these overflows in various locations throughout the City. These overflows may exceed water quality standards, threaten aquatic life and its habitat, and impair the use and enjoyment of the water body.

What is the goal of the Combined Sewer Overflow (CSO) Public Notification Program?

The goal of the Philadelphia Water Department's (PWD) CSO program is to improve and preserve the water environment in the Philadelphia area.

The goal of the CSO Public Notification Program is to educate the public on CSOs using a variety of methods that will reach different segments of the population. One method that we are implementing is the CSO Public Notification Signage Program. This program informs the public of the potential hazards of primary contact with creeks and rivers during combined sewer overflow events.



Combined Sewer System

What is the goal of the Signage Program?

PWD is striving to educate citizens about water quality conditions in our rivers and streams during and after a rain storm.

In 2005, PWD initiated its pilot signage program and installed signs at stream and river locations with good public access. The goal of the pilot program is to gauge the effectiveness of signage as compared to other public outreach efforts. PWD is concerned about primary contact with the water (skin contact) in CSO areas during or immediately after a rain event. The signs warn the public to avoid fishing, use of PWCs (Personal Water Crafts, such as jet-skis or wave runners), wading and particularly swimming. CSOs contain bacteria and pathogens that could make someone sick if they swallow water or eat fish that have come in contact with CSOs. The public should not go in the water, near the CSOs, for 48 hours after a heavy rain event.

The signs are in English and Spanish. PWD recognizes that there are many native-Spanish speakers that use our parks and waterways for recreation, as well as other non-English native speakers.

The signs also include the Philadelphia Water Department Hotline – 215-685-6300. PWD should be contacted if there is flow coming from the outfall during dry weather (when it is not raining).

Frequently Asked Questions (FAQs)

Can I swim in the water near a CSO?

Swimming and bathing are not permitted in the City's rivers and streams due to risks of drowning, injury from submerged objects, strong currents, and other hazards. An additional risk to the public is ingesting tainted water from an overflow as untreated sewage contains bacteria. Women of child-bearing age, children, the elderly, and persons with compromised immune systems are at an even higher risk of getting sick.

Is it safe for my dog to drink the water near a CSO?

PWD recommends that your dog not drink the water after a rainstorm. Despite their superior sense of smell, dogs are known to get "up close and personal" with things that might seem gross to you, or stop to take a drink out of a muddy puddle. If this really concerns you, consider carrying plenty of drinking water and a "packable" drinking bowl for your dog. Dogs that are offered plenty of water in this manner may be less likely to drink out of the creek.

Can I eat the fish?

The Pennsylvania Fish and Boat Commission and Pennsylvania Department of Environmental Protection have jointly issued a statewide "blanket" consumption advisory recommending no more than one meal (up to 8oz) per week of recreationally caught fish, including hatchery-raised stocked trout.

Mercury and PCBs can be harmful to humans, and all fish, whether wild-caught or farm-raised, will contain some level of these contaminants. Women of child-bearing age, children, elderly, and persons with compromised immune systems may wish to limit their consumption of fish. If you still plan to consume the fish, please follow the cooking and cleaning directions for eating skinned and trimmed fish. These instructions, along with other information, may be found at http://www.depweb.state.pa.us.

Stormwater Best Management Practices (BMP) Recognition Program

On May 3, 2007, the Stormwater Best Management Practices (BMP) Recognition Program announced the exemplary and innovative stormwater management projects that were recognized for helping to transform the health of our watersheds in the region. The event took place at the third annual Urban Watersheds Revitalization Conference, held at the Kanbar Center at Philadelphia University.

The Stormwater BMP Recognition Program is sponsored by the Philadelphia Water Department, American Water Resources Association (AWRA), Montgomery County Conservation District, Villanova University, and the Department of Environmental Protection (Coastal Zone Management).

Please visit the website for more information and to submit an application: http://www.stormwaterBMP.org.

2007 Stormwater Best Management Practices (BMP) Recognition Program Recipients

Andropogon Associates & Friends of Wissahickon
Valley Green Environmental Restoration Program
Type of Project: Rain Garden

Gilmore & Associates
Chatham Financial Corporate Headquarters
Type of Projects: Retention Basin/ Wet-Pond & Native Species Landscape Restoration (Meadows)

Johnson & Johnson
Pharmaceutical Research and Development Spring House Road Property
Type of Projects: Porous Asphalt Parking Lot, Underground Infiltration Beds, and Bioretention Swales

Lower Merion Environmental Advisory Council
Riverbend Environmental Education Center
Type of Projects: Porous Pavement Parking Lot and Vegetative Swale

Lower Merion Township
Aqua America Headquarters
Type of Project: Bioretention Parking Lot

Lower Providence Township
Type of Project: Naturalized Stormwater Basin

Pennoni Associates, Inc.
3925 Walnut Street Mixed Use Facility
Type of Project: Green Roof

Upper Darby Township & Cahill Associates
Second Ward Park
Type of Project: Stormwater Retrofit - Porous Pavement Basketball Courts, Bioretention, and Tree Trench

Upper Perkiomen High School (UPHS)
UPHS Stormwater BMPs
Type of Project: Wet-Pond and Vegetated Swales

Upper Providence Township
Black Rock
Type of Project: Naturalized Basin

Warrington Environmental Advisory Committee
Igoe, Porter, Wellings Memorial Field
Type of Project: Rain Garden

Wissahickon Valley Watershed Association
Sandy Run
Type of Project: Wetland Restoration

Wissahickon Charter School
Harmony Garden
Type of Project: Infiltration Basin

Roofscapes, Inc.
Lifetime Achievement Award
Philadelphia Fencing Academy
Type of Project: Green Roof

Philadelphia PWD Water Department

WATER Wheel

Waterways Issue / 2009

Green Cities – Clean Waters

Tookany/Tacony-Frankford Creek

Protecting and Preserving Our Waterways

The Philadelphia Water Department (PWD) is always working to protect your water resources. This includes managing the stormwater that comes with heavy rain or snow falls. We are working on ways to control stormwater that also help our waterways. Our plan to do this is called a "Long Term Control Plan," or LTCP.

Part of our plan includes studying at our combined sewer system and the rivers and streams. This means we now know how our system is working, and where we can make changes to help it work better.

What is a Combined Sewer Overflow (CSO)?

A combined sewer system brings wastewater from homes, businesses and industry, and stormwater from the storm drains on our streets through a single-pipe system to a Water Pollution Control Plant (treatment plant).

Under heavier rainfall conditions, the flow in combined sewers may be more than the pipe or treatment plant can handle. This means that some of the wastewater and stormwater may flow directly to a nearby stream or river to prevent the flooding of homes and streets. This is what is known as a Combined Sewer Overflow.

What is a Watershed?

A watershed is the land surrounding a system of rivers (or streams or creeks), or a particular river, that, when it rains, sheds the runoff into that waterway.

Everything you do impacts your watershed. Runoff from garden fertilizers, hazardous substances like used motor oil, and trash dumped into one area of a river bank, can pollute water many miles downstream. Protecting and preserving our watersheds helps protect our water resources.

The watersheds that drain directly to Philadelphia are: Darby Cobbs Watershed, Schuylkill Watershed, Wissahickon Watershed, Delaware Watershed, Pennypack Watershed, Tookany/Tacony-Frankford Watershed and Poquessing Watershed.

Green City – Clean Water

We want to make Philadelphia's urban landscape into a vibrant, green community where people want to live and work.

Philadelphia can be a green city with clean water -- and benefit economically at the same time. We can help our watershed as well as our region's economic health, quality of life and sustainability.

PWD has the knowledge and experience for creating and managing a watershed approach to Combined Sewer Overflow (CSO) control. We own and operate the City's sanitary sewers, storm sewers, combined sewers and wastewater treatment plants. We work in cooperation with the Philadelphia City Planning Commission to help local builders and developers include stormwater management in many of their projects.

In 2007, PWD began to review its CSO Long Term Control Plan (LTCP) and capital improvements program. We want to make sure our capital improvement projects control CSOs.

For our CSO Long Term Control Plan Update (LTCPU), we have developed new ways to handle sanitary sewer system flows. We have also been successful in reducing CSOs.

Over the past few years, we have gathered thousands of facts about the Schuylkill and Delaware Rivers, as well as the Cobbs and Tookany/Tacony-Frankford Creeks. We have information about their water quality, aquatic wildlife, history, land use, cultural resources, and more.

Watersheds and Waterways

We work with many local partners, including educational and environmental groups, township and other governments, and volunteer organizations. These partnerships are very important in the work we do to protect our waterways. The partnerships work together to write a plan to improve the water resources in each watershed.

Using a watershed approach means we look at more than just Philadelphia's city boundaries. Rivers and streams don't stop at those boundaries, so we don't either.

Some waterways are already damaged – erosion, trash-dumping, and neglect can mean polluted water or even further erosion. We are working to clean up damaged waterways. This will protect the land nearby, and let us enjoy recreational activities on or near the waterways.

Philadelphia PWD Water Department

WATER Wheel

The Tookany/Tacony-Frankford Creek Plan

Looking at The Tookany/Tacony-Frankford Watershed

The Tookany/Tacony-Frankford Creek Watershed is in Philadelphia and Montgomery counties, and is 29 square miles in size. From 2000 to 2004, PWD collected water data for the watershed to look at the health of the water and the land.

We then compared our findings with 46 standards set by the Pennsylvania Department of Environmental Protection. These standards tell us if the water can be used for drinking, and recreational uses, and if the water is clean enough for human health and aquatic life.

Our results were positive, but we did find some areas where we want to improve, and we developed our Watershed Management Plan.

Some of the issues we are now working on include: stream bank erosion, loss of floodplain, pollution from urban development, suspected sewer leaks, and trash and debris dumping.

We have identified the wetlands that need help the most, and developed a list of 26 projects to improve the health of these areas. We are also planting trees to help control erosion, and removing some invasive plants and aquatic life that harm our natural wildlife.

Glossary

Here are definitions of some of the terms we use when talking about water.

Sanitary Sewer

Underground pipes that carry only domestic or industrial waste, not stormwater. *Definition from the U.S. Environmental Protection Agency (EPA).*

Sanitary Sewer Overflow (SSO)

Untreated or partially treated sewage overflows from a sanitary sewer collection system. *Definition from Philadelphia Water Department.*

Stormwater

The water that runs off surfaces such as rooftops, paved streets, highways and parking lots. It can also come from hard, grassy surfaces like lawns, play fields, and from graveled roads and parking lots. *Definition from King County, Water and Land Resources Division.*

Wastewater

The spent or used water from a home, community, farm, or industry that contains dissolved or suspended matter. *Definition from EPA.*

Water Pollution

The presence in water of enough harmful or objectionable material to damage the water's quality. *Definition from EPA.*

Other Resources

PhillyRiverInfo
http://www.phillyriverinfo.org/
On this website, you will find general information on Philadelphia's watersheds. Check this site to find out what is going on in your watershed!

Green Cities, Clean Waters (LTCPU)
http://www.phillyriverinfo.org/csoltcpu/
This websites focuses on the Green Cities, Clean Waters Program (Combined Sewer Overflow Long Term Control Plan Update). Read about details of the plan and learn about the basics of a combined sewer system.

CSOCast
http://www.phillywatersheds.org/csocast/
This website shows the overflow status of the City's 164 Combined Sewer Outfalls. It is updated twice daily.

RiverCast
http://www.phillyrivercast.org/
This is a forecast of water quality that predicts potential levels of pathogens in the Schuylkill River between Manayunk and Boathouse Row. Visit this site to find out the daily RiverCast prediction.

Rain Barrel Program
http://www.phillywatersheds.org/rainbarrel/
PWD is providing rain barrels to residents of Philadelphia's watersheds free of charge. To receive a rain barrel, you must attend a rain barrel workshop. Check this website to see the schedule.

Philadelphia **PWD** Water Department

The Combined Sewer Overflow Program: A Long Term Control Plan For Our Rivers

Introduction

Philadelphia is blessed with an abundance of creeks, open space, park land and beautiful rivers. The Schuylkill and Delaware Rivers are not only scenic; they are the drinking water source for Philadelphia residents. These waterways, however, suffer from pollution from various sources, both within and outside of the City limits. One such pollution source: Combined Sewer Overflows (CSOs).

What are Combined Sewer Overflows?

A combined sewer system is a wastewater collection system which transports sanitary wastewater (from homes, businesses and industry), stormwater from the storm drains on our streets (approximately 75,000 of them) and stormwater from property rain leaders - through a single-pipe system to a Water Pollution Control Plant (WPCP).

During dry weather conditions (when it is not raining) and during very small storm events, combined sewers can adequately transport this mixture of sanitary wastewater and stormwater to one of the City's three water pollution control plants for treatment.

Under heavier rainfall conditions, however, the flow in combined sewers may exceed the capacity of the pipe or treatment facility. As a result, a portion of the wastewater and stormwater may be diverted directly to a nearby stream or river to prevent the flooding of homes and streets. This is what is known as a Combined Sewer Overflow.

During heavy rainfalls or sudden snowmelts, Philadelphia may experience these overflows in various locations throughout the City from any of its 164 permitted combined sewer outfalls. These overflows may exceed water quality standards (WQS), threaten aquatic life and its habitat, and impair the use and enjoyment of the water body.

What is the Goal of PWD's Combined Sewer Overflow Program?

The goal of the Philadelphia Water Department's (PWD) combined sewer overflow program is to improve and preserve the water environment in the Philadelphia area and implement technically viable, cost-effective improvements and operational changes. PWD has taken a three-pronged approach:

1. Nine Minimum Controls (NMC) – System "Tune-Up"

The first component of the PWD CSO strategy involves the Nine Minimum Controls (NMCs). The NMCs are low-cost actions or measures that can reduce CSO discharges and their effect on receiving waters, do not require significant engineering studies or major construction, and can be implemented in a relatively short time frame. This program ensures that our existing sewer system is operating to the best of its ability, providing a "tune-up" to the existing infrastructure.

For more details on the NMCs, please visit the U.S.EPA on-line at: http://cfpub.epa.gov/npdes/home.cfm?program_id=5.

2. Capital Projects – Design and Build New Combined Sewer System Components

The second component of the PWD CSO strategy involves technology-based capital improvements to the City's sewer system. This program requires significant engineering, design and construction to improve the performance of the combined sewer system. This program has and will continue to increase the capacity of the City's combined sewer system, reduce infiltration into the system, decrease the volume of overflows and improve stream water quality.

A watershed refers to the land that drains stormwater (rain or melting snow) to a specific body of water, such as a river or stream.

3. Watershed Management and Watershed Partnerships

The watershed approach evaluates the impacts of both point and non-point pollution sources and aims to find regional, watershed solutions to restore water quality. Because watersheds are defined by natural features and do not adhere to political boundaries, PWD believes that watershed management is the most practical and effective way to manage pollution and improve water quality.

The PWD forms partnerships with its suburban neighbors, businesses and industries, community and non-profit groups and other stakeholders to evaluate the region's watersheds and to develop an effective watershed management plan. To be successful, watershed management plans must be adopted and implemented by all participating stakeholders and their constituents.

To date, PWD has initiated the formation of watershed partnerships in all of the City's watersheds. The combined sewer watersheds include the Darby-Cobbs Watershed Partnership, Tookany/Tacony – Frankford Watershed Partnership and Pennypack Watershed Partnership, while the separate sewer watersheds include the Poquessing Watershed Partnership and the Wissahickon Watershed Partnership. The Schuylkill Watershed is represented by the Schuylkill Action Network (SAN), a partnership of the City of Philadelphia, federal and state agencies, and local watershed groups protecting the drinking water supply in the Schuylkill River Watershed. This fall, the Delaware Direct Watershed Partnership will be formed.

If you are interested in joining a partnership or for further information on the PWD watershed management planning projects, visit: http://www.phillyriverinfo.org.

Green Cities – Clean Waters: Combined Sewer Overflow Long Term Control Plan Update

Crescentville CSO

The CSO Long Term Control Plan Update is also known as the "Green Cities – Clean Waters Program."

Introduction

In 2007, PWD began to reevaluate its combined sewer overflow program and capital improvements program to integrate additional projects that reduce CSO frequency and volume. As a result, the CSO Long Term Control Plan Update (LTCPU) was created. It involves the development of management alternatives that ensure capture and treatment of sanitary sewer system flows and CSO reductions.

PWD is committed to a balanced "Land-Water-Infrastructure" approach to achieve its watershed management and CSO control goals. This method includes infrastructure-based approaches, where appropriate, but also includes a range of land-based stormwater management techniques and the physical reconstruction of aquatic habitats, where appropriate.

The "Land-Water-Infrastructure" approach is made up of three programs:

LAND: Wet Weather Source Control

The Wet Weather Source Control program promotes the use of Low Impact Development (LID) and other structural and non-structural controls to reduce CSO volume through evaporation, transpiration, infiltration and detained release to the combined system for treatment, such as an extensive street tree program, green roofs and rain gardens. This program also requires post-construction stormwater controls on land development and redevelopment in the combined sewer area to achieve CSO reductions.

WATER: Ecosystem Restoration and Aesthetics

The Ecosystem Restoration and Aesthetics program focuses on projects that contribute to the improvement of the aesthetic and ecological integrity of CSO receiving waters. Such water-based approaches include stream bed and bank stabilization and reconstruction, aquatic habitat creation, plunge pool removal, improvement of fish passage, and floodplain reconnection.

INFRASTRUCTURE: Capital Improvement Projects

The Capital Improvement Projects program continues to implement CSO capital improvement projects that were planned during the previous combined sewer overflow program in addition to new projects to increase the capture and treatment of combined sewage. Examples of such projects include the work of the Waterways Restoration Team, Stream Habitat Restoration, Wetland Enhancement and Construction, Fish Passage Projects and Riparian Buffer Creation and Enhancement.

GLOSSARY

Runoff refers to water from rain or melting snow or irrigation that flows over the ground and into the nearest body of water. It can contribute to soil erosion and carry harmful pollutants.

Point source pollution refers to any discernible, confined, and discrete conveyance, such as a pipe, tunnel or ditch, from which pollutants are or may be discharged.

Nonpoint source (NPS) pollution, unlike pollution from industrial and sewage treatment plants, comes from many diffuse sources. NPS pollution is caused by rainfall or snowmelt moving over and through the ground. As the runoff moves, it picks up and carries away natural and human-made pollutants, such as lawn fertilizers, oil and dog waste, finally depositing them into the nearby creeks and rivers.

Receiving Waters: All distinct bodies of water that receive runoff or wastewater discharges, such as streams, rivers, ponds, lakes, and estuaries.

Water Quality Standards (WQS) are state-adopted and EPA-approved standards for water bodies. The standards prescribe the use of the water body and establish the water quality criteria that must be met to protect designated uses.

Philadelphia PWD Water Department

annual Drinking Water Quality Report

This report is being mailed to you as a requirement of the federal Safe Drinking Water Act. NOTE: Industrial and commercial customers, including hospitals, medical centers, and health clinics, please forward this report to your Environmental Compliance Manager.

Philadelphia's water is safe and healthy to drink for most people. For people with special health concerns, please see the information on page two.

Philadelphia Water Department
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PWD is an active and proud member of:

- American Water Resources Association
- American Water Works Association
- American Water Works Association Research Foundation
- Partnership for Safe Water
- American Public Works Association
- Association of Metropolitan Water Agencies
- National Association of Clean Water Agencies
- Water Environment Federation
- Water Environment Research Foundation

PWD's Public Water System Identification #PA1510001

This report is available online at http://www.phila.gov/water

The Philadelphia Water Department

The Philadelphia Water Department (PWD) is pleased to present our annual Water Quality Report. This report, published in April 2008, includes water quality information for the 2007 calendar year.

The good news is – your tap water is top quality. Our Water Quality Report provides our customers with a summary of where Philadelphia's drinking water comes from, how it is treated and the results of water quality monitoring performed by us on a daily basis.

The U.S. Environmental Protection Agency (EPA) requires all water utilities to produce and distribute water quality reports on an annual basis.

We have consistently performed better than all drinking water standards developed by the EPA to protect public health.

How do we do this? We use proven treatment practices at our water treatment plants and we participate in groundbreaking research while keeping water rates among the lowest in the region.

Para obtener una copia del informe en Español sobre los resultados más recientes de la calidad del agua publicado por el Departamento de Agua de Philadelphia, llame al 215-685-6300.

People With Special Health Concerns

Some people may be more vulnerable to contaminants in drinking water than the general population. Immuno-compromised persons, such as persons with cancer undergoing chemotherapy, persons who have undergone organ transplants, people with HIV/AIDS and other immune system disorders, some elderly and infants can be particularly at risk from infections. These people should seek advice about drinking water from their health care providers.

Environmental Protection Agency/Centers for Disease Control (CDC) guidelines on appropriate means to lessen the risk of infection by Cryptosporidium and other microbial contaminants are available from the Safe Drinking Water Hotline: 800-426-4791.

Our standards are the highest: our drinking water consistently performs better than all drinking water standards developed by the EPA to protect public health.

Where does Philadelphia's drinking water come from?

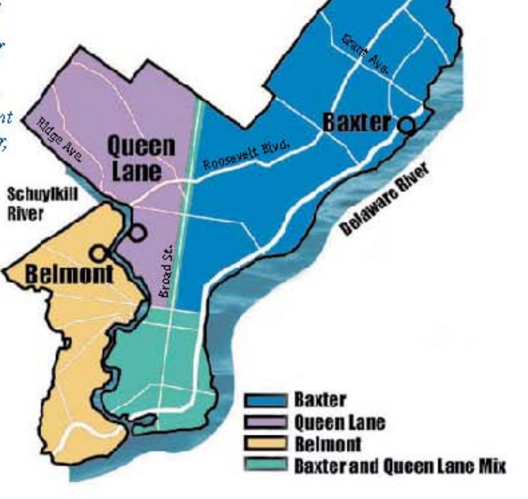
Philadelphia is located in the Delaware River Watershed, which begins in New York State and extends 330 miles south to the mouth of the Delaware Bay. The Schuylkill River is part of the Delaware River Watershed.

Map Courtesy of the Delaware River Basin Commission. Delaware River Basin Commission Map Collection.

The water that we treat comes from the Schuylkill and Delaware rivers. Rivers are surface water supplies. Philadelphia does not use groundwater. Each river contributes approximately one-half of the City's overall supply. We produce approximately 256 million gallons of high-quality drinking water for our customers on a daily basis.

PWD has three water treatment plants that process untreated river water. The Queen Lane Plant is located in East Falls and its water comes from the Schuylkill River. Its intake is located along Kelly Drive. The Belmont Plant is located in Wynnefield and its water also comes from the Schuylkill River. Its intake is located along Martin Luther King, Jr. Drive (formerly West River Drive). The Baxter Plant is located in Torresdale and its water comes from the Delaware River. Its intake is located at the plant on the Delaware River.

Depending on where you live, you receive drinking water from one of the city's three water treatment plants– Baxter, Belmont, or Queen Lane.



Safeguarding the water you drink.

At their sources, the Delaware and Schuylkill Rivers are generally clean rivers. But as the rivers flow downstream, they pick up contaminants from many sources – stormwater runoff washes pollutants on the land into the rivers, and communities and industries discharge used water back into the rivers. Today, the City enjoys watersheds that are cleaner and healthier than they have been in well over a century. Although we have seen a dramatic improvement in the water quality of the City's two major rivers since the passage of the federal Clean Water Act in the early 1970s, there is still more work that needs to be done to protect our drinking water sources from pollution.

In order to ensure that tap water is safe to drink, the Environmental Protection Agency has regulations that limit the amount of certain contaminants in water provided by water suppliers. The Food and Drug Administration establishes limits for contaminants in bottled water that must provide the same protection for public health.

Drinking water, including bottled water, may reasonably be expected to contain at least small amounts of some contaminants. The presence of contaminants does not necessarily indicate that water poses a health risk. More information about contaminants and potential health effects can be obtained by calling the Environmental Protection Agency's Safe Drinking Water Hotline (800-426-4791) or from their website (http://www.epa.gov/safewater).

How do drinking water sources become polluted?

Across the nation, sources of drinking water (both tap water and bottled water) include rivers, lakes, streams, ponds, reservoirs, springs and wells. As water (such as rain and melting snow) travels over the surface of the land or through the ground, it dissolves naturally-occurring minerals and, in some cases, radioactive material, and can pick up substances resulting from the presence of animals or from human activity.

Contaminants that may be present in source water include:

- Microbial contaminants, such as viruses and bacteria, which may come from sewage treatment plants, septic systems, agricultural livestock operations and wildlife.

- Inorganic contaminants, such as salts and metals, which can be naturally-occurring or result from urban stormwater runoff, industrial or domestic wastewater discharges, oil and gas production, mining or farming.

- Pesticides and herbicides, which may come from a variety of sources such as agriculture, urban stormwater runoff and residential uses.

- Organic chemical contaminants, including synthetic and volatile organic chemicals, which are byproducts of industrial processes and petroleum production. They can also come from gas stations, urban stormwater runoff (from streets and parking lots) and septic systems.

- Radioactive contaminants, which can be naturally-occurring or be the result of oil and gas production and mining activities.

Why is chlorine used to disinfect the drinking water?

State and federal laws require the disinfection of all public water supplies. EPA and health agencies recognize that using chlorine is the most effective way to protect public health from disease-causing organisms that can be found in rivers and streams. However, chlorine can chemically react with natural materials in rivers to form disinfection byproducts, such as trihalomethanes.

We have been adjusting our treatment process over the years to reduce this chemical reaction. But we also ensure that the treated water that is distributed through the City's water mains to your homes has a "chlorine residual." This residual continues to protect your water against bacteria and other organisms on its journey to your home tap.

We now use sodium hypochlorite, a safer form of chlorine similar to household bleach, to disinfect the water at our treatment plants.

What do we look for?

Under Primary and Secondary Safe Drinking Water Regulations, EPA and Pennsylvania DEP require drinking water utilities to monitor about 100 regulatory parameters. These regulatory parameters are defined with their maximum contaminant level (MCL) and maximum contaminant level goal (MCLG) under federal rules such as: Total Coliform Rule, Surface Water Treatment Rule, Disinfectants and Disinfection Byproducts Rule, Lead and Copper Rule, Radionuclides Rule. We monitored for the regulatory parameters listed below. Tables on page 8 and page 9 summarize monitoring results for parameters found at detectable levels. Please see a glossary of terms and abbreviations on page 9.

Inorganic Chemicals:

Antimony, arsenic, barium, beryllium, cadmium, chromium, copper, cyanide free, fluoride, lead, mercury, nitrate, nitrite, selenium, and thallium.

Synthetic Organic Chemicals:

Alachlor, atrazine, benzo(a)pyrene, carbofuran, chlordane, dibromochloropropane, di(2-ethylhexyl) adipate, di(2 ethylhexyl) phthalate, endothall, ethylene dibromide, hexachlorocyclopentadiene, lindane, methoxychlor, oxamyl, pentachlorophenol, picloram, and simazine.

Volatile Organic Chemicals:

Benzene, carbon tetrachloride, o-dichlorobenzene, p-dichlorobenzene, 1,2-dichloroethane, 1-1 dichloroethylene, cis-1,2-dichloroethylene, trans-1,2-dichloroethylene, dichloromethane, 1,2-dichloropropane, ethylbenzene, monochlorobenzene, styrene, tetrachloroethylene, toluene, 1,2,4-trichlorobenzene, 1,1,1-trichloroethane, 1,1,2-trichloroethane, trichloroethylene, and total xylenes.

Appealing to Your Senses

We also test for aluminum, chloride, color, iron, manganese, pH, sulfate, total dissolved solids, and zinc to ensure that tap water meets all water quality taste and odor guidelines so that your water looks, tastes, and smells the way it should.

Additional Testing

We periodically test for the following contaminants, even though the Pennsylvania Department of Environmental Protection (PADEP) does not require us to do so: nitrite, asbestos, dalapon, dinoseb, dioxin, diquat, endrin, glyphosate, hexachlorobenzene, 2,4-D, PCBs, toxaphene, 2,4,5-TP, heptachlor, heptachlor epoxide, and vinyl chloride. No significant levels of any of the above contaminants have been found in Philadelphia's drinking water.

Lead in drinking water

It is important to minimize the intake of lead from dust inhalation, food, and water. Children are particularly susceptible to the health effects of lead poisoning. Lead is most commonly found in dust, paint and contaminated soil. To a lesser extent, lead can also occur in tap water. Components of plumbing may have lead in them. You may be surprised to learn that brass fixtures, valves and faucets contain lead. Many homes still have leaded solder that was once used to join copper pipe together. Some homes in Philadelphia still have lead service lines and, when disturbed, these lines can contribute to lead in tap water. It is the homeowner's responsibility to maintain, repair and replace the service lines.

Our primary role in helping you minimize your intake of lead is to reduce the corrosive effects of tap water on materials that contain lead. Water is corrosive and encourages the dissolving of lead from these materials. The Philadelphia Water Department has a permit with PADEP for operating under optimized corrosion control. Under this permit, we maintain the pH of water between 6.8 and 7.8. We also maintain the amount of the corrosion inhibitor, zinc orthophosphate, at greater than 0.12 mg/L (0.12 ppm) as phosphorus. These conditions minimize lead leaching from plumbing materials.

Currently, every three years the Philadelphia Water Department tests for tap water lead at more than 50 representative taps of vulnerable homes in the city. We do this according to the requirement of the EPA's Lead and Copper Rule. The testing results are used to determine if our corrosion control treatment technique is working, so that water has minimum potential for lead to leach from plumbing materials. So far, our test results show that our treatment techniques keep lead levels to a minimum.

However, this could change in any year because Philadelphia is required to meet other regulations for tap water quality. Sometimes these water quality changes can affect the corrosion potential of the water. If such a change were to occur, the Philadelphia Water Department would notify its customers of the change while it works to return to minimum corrosion conditions again. Water utilities all over the country are in the same position as Philadelphia, trying to balance all of the regulatory requirements and changes at one time so that their customers receive the best quality water possible. We are committed to reducing the corrosive effects of plumbing and lead levels in water. Additional information is available from the Environmental Protection Agency's Safe Drinking Water Hotline at 800-426-4791.

Research and Monitoring:

Cryptosporidium and Giardia

Cryptosporidium and *Giardia* are microscopic organisms found in surface water throughout the U.S. In 2007, we conducted 36 tests on our treated drinking water. None of the samples were positive for *Giardia* or *Cryptosporidium*.

When ingested, *Cryptosporidium* and *Giardia* can result in diarrhea, fever, nausea and abdominal cramps. However, these are also symptoms of many intestinal diseases caused by bacteria, viruses or parasites. Most healthy individuals can overcome such illnesses within a few weeks. However, immuno-compromised people are at a greater risk of developing a life-threatening illness. We encourage immuno-compromised individuals to consult their doctor regarding appropriate precautions to take to avoid infection. *Cryptosporidium* and *Giardia* must be ingested to cause disease, and it may be spread through means other than drinking water.

The Philadelphia Water Department is one of the nation's leaders in *Cryptosporidium* research and was one of the first utilities in the U.S. to monitor for the organism. We are also working closely with the Philadelphia Department of Public Health to ensure that our tap water is free of pathogens that can be found in rivers. In addition to routinely monitoring for *Cryptosporidium*, we are involved in an innovative project with Lehigh University to identify the sources of *Cryptosporidium* in our watersheds. As part of the project, we collect water samples upstream of our drinking water intakes. We isolate the *Cryptosporidium* oocysts, and conduct DNA analyses to determine whether the oocysts originate from human sources or from other species such as dogs, cats, deer, geese, cows, horses, etc. By identifying the sources of *Cryptosporidium* in the watershed, we are taking a proactive approach in improving the river water quality.

Pharmaceuticals in Drinking Water

Since 2004, the Philadelphia Water Department has participated in national research and monitoring of pharmaceuticals in drinking water. The technology to detect pharmaceuticals in water is very recent and only a few laboratories in the nation have this capability. The Philadelphia Water Department has been working with them.

Nationwide, pharmaceuticals get into drinking water because people now take more pharmaceuticals than ever, both prescription and over the counter. Only a small portion of these pharmaceuticals is absorbed in the body. The rest is passed through the body, eventually making its way into our nations's rivers and streams which are our drinking water sources. The levels we have found are in extremely low concentrations. For example, a person would need to drink eight glasses of water a day for more than 40,000 years to obtain the equivalent of a single child's dose (80 mg) of Tylenol. There is currently no indication that such extremely low concentrations pose any public health risk. The Philadelphia Water Department will continue to stay abreast of this issue to ensure the safety of our drinking water and the protection of our watersheds.

You can help keep unused pharmaceuticals out of the water supply by paying attention to how you dispose of unused medications. Look for take-back programs that may be established near you, either through pharmacies, or through household hazardous waste collection programs. For more information, please visit: www.phila.gov/water/Pharmaceuticals_in_D.html.

Partnership for Safe Water

Employees of the Philadelphia Water Department's three water treatment plants have earned six consecutive Director's Awards for maintaining an elite status in the Partnership for Safe Water. This award is presented to utilities across the country which meet or go beyond the water quality goals established by the Partnership for Safe Water.

Dating back to 1996, the Philadelphia Water Department was one of the first utilities to join this unique partnership between the drinking water industry and the EPA to make voluntary improvements in the nation's drinking water quality. This program was designed to be much more rigorous than the requirements of State and federal laws.

The turbidity of Philadelphia's water is 80 percent less than the maximum amount allowed by State and federal regulations, and it is 40 percent less than the Partnership's voluntary goal of 0.1 ntu.

The Partnership for Safe Water established a turbidity goal of less than 0.10 ntu (at all times tested). Today, all three of our water treatment plants continue to lower their ntu levels, achieving a total annual average of 0.06 ntu.

Through our participation in this program, we have surveyed our treatment plants, treatment processes, operating and maintenance procedures, and management oversight practices to learn how we can improve our water system. We have already made many of the improvements, and we will continue to apply others. These improvements have helped to enhance our water system's ability to prevent *Cryptosporidium, Giardia,* and other microbial contaminants from entering the water we treat.

drinking water treatment

Philadelphia PWD Water Department

How Do We Treat the Water So That You May Drink It?

Like the majority of water utilities in the U.S., we use a multi-step treatment process at all three of our drinking water treatment plants. This Water Treatment Process diagram provides a brief description of drinking water treatment in Philadelphia.

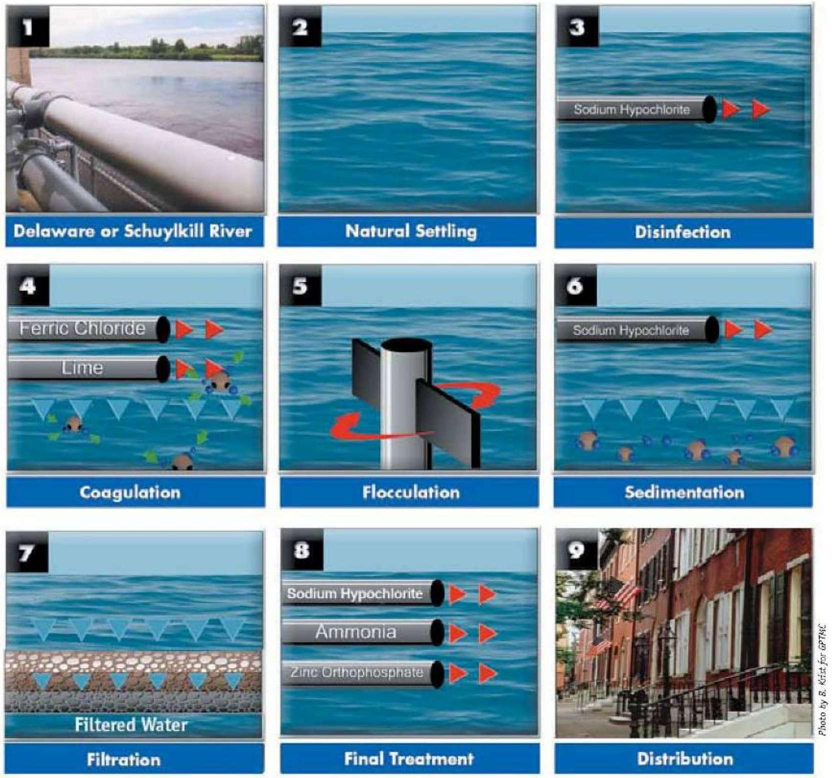


Photo by B. Krist for GPTMC

1. The River
The source of the water is from either the Delaware or Schuylkill River.

2. Natural Settling
After it has been pumped from the river, water is stored in reservoirs or basins for about 24 hours, to allow sediments to settle.

3. Disinfection
Sodium hypochlorite, a chemical compound containing chlorine, is added to kill disease-causing organisms.

4. Coagulation
The river water is "coagulated." Chemicals are added to the water to cause smaller particles in water to join together. This makes them heavier so that they will settle to the bottom of the basin.

5. Flocculation
The water is mixed gently to make sure the added chemicals are well blended and react with all of the smaller particles. The particles combine to form "floc" which settle to the bottom of the basin.

6. Sedimentation
The newly joined particles or "floc" settle by gravity and are removed from the bottom of the mixing tanks. More sodium hypochlorite may be added.

7. Filtration
The water flows by gravity through filters of sand and crushed coal, which remove very small particles that might never settle by gravity.

8. Final Treatment
Fluoride is added to help prevent tooth decay. Zinc orthophosphate is added to minimize rusting of metal pipes by the water. More sodium hypochlorite may be added. Ammonia is added to reduce the flavor of chlorine and to help the sodium hypochlorite to persist in the water while it travels through the water main system, or to remain active in the water all the way to our customers' faucets.

9. Distribution
The treated water is distributed through nearly 3,300 miles of water mains to 480,000 households in Philadelphia.

2007 DRINKING WATER QUALITY

METALS - *Tested at Customers' Taps - Testing is done every 3 years. Most recent tests were done in 2005.*

	EPA's Action Level for representative sampling of customer homes	Ideal Goal (EPA's MCLG)	90% of PWD customers' homes were less than	No. of homes considered to have elevated levels	Source
Lead	90% of homes must test less than 15 ppb	0	9 ppb	9 out of 107	Corrosion of household plumbing
Copper	90% of homes must test less than 1.3 ppm	1.3 ppm	0.3 ppm	0	Corrosion of household plumbing

DISINFECTION BYPRODUCTS IN TAP WATER

	Highest Level Allowed (EPA MCL) One Year Average	Baxter WTP One Year Average	Belmont WTP One Year Average	Queen Lane WTP One Year Average	Source
Total Trihalomethanes (TTHMs)	80 ppb	36 ppb Range of individual test results: 12 - 70 ppb	45 ppb Range of individual test results: 12 - 82 ppb	46 ppb Range of individual test results: 15 - 82 ppb	Byproduct of drinking water chlorination
Total Haloacetic Acids (THAAs)	60 ppb	31 ppb Range of individual test results: 19 - 47 ppb	28 ppb Range of individual test results: 12 - 59 ppb	26 ppb Range of individual test results: 13 - 45 ppb	Byproduct of drinking water chlorination

TOTAL ORGANIC CARBON (Ratio of Removal Achieved Divided by Removal Required)

Treatment Technique One Year Average	Baxter WTP One Year Average	Belmont WTP One Year Average	Queen Lane WTP One Year Average	Source
Must be greater than or equal to 1	1.38	1.50	1.61	Naturally present in the environment.

BACTERIA IN TAP WATER

NOTE: One of the samples with Total Coliforms tested positive for E. coli.

	Level Allowed (EPA's MCL)	Ideal Goal (EPA's MCLG)	Highest Monthly Results	Source
Total Coliform Bacteria	Presence of coliform bacteria in 5% or less of more than 360 monthly samples	0	Highest % of positive samples: 0.22%	Naturally present in the environment.

OTHER CHEMICALS IN TAP WATER – PWD monitors annually although we are only required to report every nine years

	Highest Level Allowed (EPA's MCL)	Ideal Goal (EPA's MCLG)	Highest Result	Range of Test Results for the Year	Source
Nitrate	10 ppm	10 ppm	4.9 ppm	0.75 - 4.9 ppm	Fertilizer runoff, sewage
Barium	2 ppm	2 ppm	0.04 ppm	0.03 - 0.04 ppm	Metal refineries or natural deposits
Cyanide	0.2 ppm	0.2 ppm	0.06 ppm	0.05 - 0.06 ppm	Discharge from steel/metals, plastics and fertilizer factories

CLARITY CHARACTERISTICS – Tested at Water Treatment Plants

Turbidity (measure of clarity)	Baxter WTP	Belmont WTP	Queen Lane WTP	Source
Treatment Technique Requirement	95% of samples must be at or below 0.30 ntu	95% of samples must be at or below 0.30 ntu	95% of samples must be at or below 0.30 ntu	Soil runoff, river sediment
Highest Single Value for the year	0.085 ntu	0.098 ntu	0.093 ntu	Soil runoff, river sediment

NOTE: PWD achieved turbidity limits 100% at all times tested.

		Baxter WTP	Belmont WTP	Queen Lane WTP
Hardness (as Calcium Carbonate)	Annual Average *parts per million or grains per gallon*	86 ppm or 5 gpg	156 ppm or 9 gpg	153 ppm or 9 gpg
	Annual Minimum *parts per million or grains per gallon*	60 ppm or 4 gpg	120 ppm or 7 gpg	66 ppm or 4 gpg
	Annual Maximum *parts per million or grains per gallon*	99 ppm or 6 gpg	202 ppm or 12 gpg	217 ppm or 13 gpg
Alkalinity (as Calcium Carbonate)	Annual Average	40 ppm	69 ppm	67 ppm
	Annual Minimum	22 ppm	44 ppm	44 ppm
	Annual Maximum	60 ppm	108 ppm	95 ppm

SODIUM IN TAP WATER

Chemical	Baxter WTP One Year Average	Belmont WTP One Year Average	Queen Lane WTP One Year Average
Sodium	19 ppm or 4 mg per 8 oz. glass of water Range of individual test results: 14 - 28 ppm or 3 - 7 mg per 8 oz. glass of water	40 ppm or 9 mg per 8 oz. glass of water Range of individual test results: 25 - 61 ppm or 6 - 15 mg per 8 oz. glass of water	36 ppm or 9 mg per 8 oz. glass of water Range of individual test results: 17 - 53 ppm or 4 - 13 mg per 8 oz. glass of water

NOTE: We conducted monitoring for sodium throughout the year, although federal regulations do not require it.

TOTAL CHLORINE RESIDUAL – over 400 samples collected throughout the city every month

Total Chlorine in Tap Water	EPA Maximum Residual Disinfectant Level	One Year Average	Range of Highest Levels Detected at Taps
Chloramine	4.0 ppm	1.64 ppm	2.48 - 2.88 ppm

RADIOACTIVE CONTAMINANTS

Radioactive Contaminants	Highest Level Allowed (EPA's MCL)	Ideal Goal (EPA's MCLG)	Highest Result	Range of Test Results for the Year	Source
Alpha	15 pCi/L	none	3.7 pCi/L	0 - 3.7	Erosion of natural deposits of certain radioactive minerals.
Combined Radium 226 & 228	5 pCi/L	none	3.2 pCi/L	0 - 3.2	Erosion of natural deposits of certain radioactive minerals.

During the period of 2005, we conducted initial monitoring for a revised radionuclides regulation. We performed quarterly analysis of water treatment plant effluents for gross alpha, radium 226, radium 228, and uranium. Three out of twelve samples had detectable levels of radium 228, and one out of twelve samples had a detectable level of gross alpha. All detected values were below one-half of the MCL. Radium 226 and uranium were not detected in our water.

VOLATILE AND SYNTHETIC ORGANIC CHEMICALS (VOC and SOC)

Chemical	Highest Level Allowed (EPA's MCL)	Ideal Goal (EPA's MCLG)	Highest Result	Range of Test Results	Source
Atrazine	3 ppb	3 ppb	0.06 ppb	0.0 - 0.06 ppb	Runoff from herbicide used on row crops.
Simazine	4 ppb	4 ppb	0.12 ppb	0.0 - 0.12 ppb	Runoff from herbicide used on row crops.
Carbofuran	40 ppb	40 ppb	2.0 ppb	0.0 - 2.0 ppb	Leaching of soil fumigant used on rice and alfalfa.
Dichloromethane	5 ppb	0 ppb	0.6 ppb	0.0 - 0.6 ppb	Discharge from drug and chemical factories.

Listed on pages eight and nine are our Drinking Water Quality Results for 2007. All results are better than the recommended federal levels designed to protect public health. We are pleased to report that we did not have any drinking water violations for 2007. In keeping with our long-standing unblemished record, we continue to be free of violations since the Safe Drinking Water Act was implemented in 1974.

By reporting these results in the tables above, we are meeting a requirement of the EPA. Please see the glossary for definitions of abbreviations used in the tables.

Some contaminants may pose a health risk at certain levels. Others, such as turbidity, have no health effects. For information about potential risks, please visit our website (http://www.phila.gov/water), or call us at 215-685-6300. We will be happy to mail them to you.

GLOSSARY

Action Level: The concentration of a contaminant which, if exceeded, triggers treatment or other requirements that a water system must follow. The action level is not based on one sample; instead, it is based on many samples.

Alkalinity: A measure of the water's ability to resist changes in the pH level and a good indicator of overall water quality. Although there is no health risk from alkalinity, we monitor it to check our treatment process.

E. coli (Escherichia coli): A type of coliform bacteria that are associated with human and animal fecal waste.

GPG – Grains Per Gallon: A unit of water hardness. One grain per gallon is equal to 17.1 parts per million.

MCL - Maximum Contaminant Level: The highest level of a contaminant that is allowed in drinking water. MCLs are set as close to the MCLGs as feasible using the best available treatment technology.

MCLG - Maximum Contaminant Level Goal: The level of a contaminant in drinking water below which there is no known or expected risk to health. MCLGs allow for a margin of safety.

mg/L - Milligrams per liter: One milligram per liter is equal to one part per million.

ntu - nephelometric turbidity units: Turbidity is measured with an instrument called a nephelometer. Measurements are given in nephelometric turbidity units.

pCi/L - Picocuries per liter (a measure of radioactivity).

ppb - part per billion: One part per billion is equivalent to one green apple in a barrel with 999,999,999 red apples.

ppm - part per million: One part per million is equivalent to one green apple in a barrel with 999,999 red apples.

SOC – Synthetic Organic Chemical: Organic compounds, such as pesticides and herbicides, that are commercially made.

Total Coliform: Coliforms are bacteria that are naturally present in the environment and are used as an indicator that other potentially harmful bacteria may be present.

THAAs -Total Haloacetic Acids: A group of chemicals called disinfection byproducts, which form during chlorination.

TOC - Total Organic Carbons: A measure of the carbon content of organic matter. The measure provides an indication of how much organic material in the water could potentially react with chlorine to form THAAs and TTHMs.

TTHMs - Total Trihalomethanes: A group of chemicals called disinfection byproducts, which form during chlorination. TTHMs form when natural organic matter in the rivers, such as leaves and algae, decompose and combine chemically with the chlorine added for disinfection. Levels of TTHMs vary seasonally.

Treatment Technique: A required process intended to reduce the level of a contaminant in drinking water.

Turbidity: A measure of the clarity of water related to its particle content. Turbidity serves as an indicator for the effectiveness of the water treatment process. Low turbidity measurements, such as ours, show how we remove particles that cannot be seen by the human eye.

VOC – Volatile Organic Chemical: Organic compounds that include gases and volatile liquids.

WTP: Water Treatment Plant

How do we protect our water supplies from pollution?

We carefully safeguard our urban water supply through a variety of initiatives focused on protecting and improving the quality of our rivers and streams. We conduct research into new and emerging issues in water quality science, implement projects to directly enhance and improve water quality, operate and maintain an early warning system to alert our treatment plants of oil spills and other in-stream events that could impact our water supply, partner with other organizations and agencies throughout our watersheds that are also committed to improving source water quality, and continuously monitor the quality and health of our rivers and streams.

Plans Underway to Protect our Rivers and Streams

During the past several years, we completed Source Water Assessments and Protection Plans for the Delaware and Schuylkill rivers. The Source Water Assessments were completed between 1999 and 2002 and identified the major water quality concerns for the Schuylkill and Delaware rivers. The Schuylkill and Delaware River Protection Plans, completed between 2005 and 2007, took the results of the assessments and developed strategies for addressing the water quality challenges identified in the assessments. We are also involved in research to understand the impact of climate change and global warming on the water supply and conduct experimental research to understand the impact of small concentrations of everyday products, such as caffeine and pharmaceuticals, on the water environment.

For information about the quality of our region's rivers and streams, call the Pennsylvania Department of Environmental Protection at 484-250-5900 or check their website (http://www.dep.state.pa.us).

Schuylkill Action Network (SAN)

In 2004, the Schuylkill Action Network received a grant from the Environmental Protection Agency to fund projects which were identified during the Schuylkill River Source Water Assessment. This grant was one of only 13 awarded nationally that year.

Land use has a major influence on how the quality of our rivers and streams are impacted by stormwater runoff. Some lands, such as forested land or land surrounding high quality streams and reservoirs, are particularly important for drinking water protection. In 2006 and 2007, the SAN Watershed Land Protection Collaborative mapped and prioritized land in the Schuylkill Watershed based on the importance of the land for drinking water protection, and the likelihood of that land being developed. A strategy was then developed to share the results of the prioritization with land use planning and zoning agencies throughout the watershed to make sure future land use decisions consider the impacts of such decisions on drinking water supply.

Schuylkill and Delaware River Source Water Protection Plans

The Schuylkill and Delaware River Source Water Protection Plans provide a comprehensive framework for implementing a watershed-wide effort to improve source water quality. The Plans prioritize real and potential sources of contamination to Philadelphia's raw water supply, and outlines several approaches to reducing them.

One major component of the Schuylkill Plan, completed in 2005, is a build-out scenario of the Schuylkill River Watershed that looks at the possible impacts of significant development in the watershed on source water quality. Under current zoning, low-density housing could increase drastically as agricultural and forested lands are developed. This scenario helped us to see the importance of land preservation for source water protection, and has led to the development of a tool which prioritized land for protection based on its importance for preserving or improving water quality.

The Delaware River Plan, completed in 2007, brought to the forefront the need for the ongoing protection of our Baxter drinking water intake from salt intrusion from the Delaware Bay. To date, we have had ample protection from salt intrusion due to the large quantity of fresh water coming down the Delaware River. Now with the new Flexible Flow Management Plan, which was enacted for the Delaware River in October of 2007, we need to conduct extensive modeling of this plan. Along with project changes in flow characteristics from global warming, climate change, sea level rise, and population changes, this plan will make sure we continue to provide adequate protection of Baxter's intake from salt intrusion well into the future.

SAN FACTS & FIGURES

SAN Mission:
Protecting and restoring the Schuylkill River as a premiere regional:
- Drinking water source
- Recreational resource
- Natural habitat for fish and wildlife

122: Number of SAN organizations in 2007

SAN Members
- Citizens
- Universities
- Water suppliers
- Non-profits
- Funders
- Corporations
- Federal, state and local governments

Major Pollution Threats to Schuylkill River
- Agriculture
- Abandoned mine drainage
- Urban and suburban stormwater runoff
- Faulty sewer systems

The SAN provides:
- Central coordination of restoration and protection efforts for the entire Schuylkill River
- Consensus-based plans for the watershed built on sound science, data, and stakeholder input

$1.15 million: EPA Targeted Watershed Program Grant Award (2005-2009)
- 50 projects reducing the impact of agriculture, abandoned mine drainage (AMD), and stormwater on the quality of the Schuylkill River.

Agriculture: SAN Agriculture Projects are designed to treat excessive loadings of nutrients and contaminiated stormwater runoff. As of 2007:
- 32,000 feet of streambank fencing has been installed
- 6,000 feet of streambank plantings have been completed
- 15 Conservation Plans accomplished

Abandoned Mine Drainage: The upper watershed is impacted by polluted water seeping from abandoned coal mines that discharge iron, manganese, and aluminum to the Schuylkill River. To date:
- 5 AMD projects have been implemented, treating 21 million gallons per day of contaminated flow

Stormwater:
- Ranked all detention basins in the Wissahickon Creek watershed for the potential to be modified to enhance groundwater recharge and water quality treatment of stormwater runoff

Providing Early Warning Protection

Since 2004, we have led the development and implementation of the Early Warning System for the Schuylkill and lower Delaware Rivers. This system is an integrated communication and water quality monitoring network that supports the identification, notification and analysis of source water quality events such as chemical spills and other potential hazards.

The system's goal is to provide advance warning of potential source water contamination to water suppliers. Funded in part by a $775,000 grant from the Pennsylvania Department of Environmental Protection, the system provides water suppliers on both rivers with essential information to make critical treatment and pumping decisions in response to spills and accidents that can have a detrimental impact on the rivers. The Schuylkill and Delaware system is comprised of a partnership of water suppliers, industries with water intakes, and government agencies. The system also includes a web-based centralized database for water quality and event information, a telephone notification system, and a network of real–time water quality monitors located throughout the two watersheds.

Delaware Valley Early Warning System serves
- Over 3 million people
- Philadelphia, Camden and Trenton Metro areas
- 12 water utilities, 23 water treatment plants in Pennsylvania
- 5 water utilities, 5 water treatment plants in New Jersey

Since the system was fully deployed in January of 2005, 100 events have been entered into the system, ranging from a 100-million-gallon fly-ash spill on the Delaware and a cyanide discharge in the Wissahickon Creek, to flood warnings and sewage discharges. In each of these cases, the improved awareness, communication, and coordination provided by the system was valuable to our response.

RiverCast

More than 100,000 people use the Schuylkill River at Fairmount Dam ("boathouse row") for recreational activities every year. The amount and scope of river use seem to increase annually. As recreation increases, so does public concern about river water quality. In response to this concern, we developed RiverCast: the first and only bacteria forecasting system in the United States created for recreational activities. Similar to a weather forecast, RiverCast is an internet-based system that provides the public with hourly updates of expected concentrations of fecal coliform bacteria in the Schuylkill River.

RiverCast uses a color rating system to indicate bacteria levels. Each color rating is linked with guidelines for recreational activity (see below). The bacteria ranges used to determine the color ratings, along with the below activity guidelines, are based on draft EPA regulations for recreational waters.

GREEN

Bacteria	Types of Activities	RiverCast
Low level	**jet skiing, kayaking swimming, sculling**	**recommendation: suitable**

YELLOW

Bacteria	Types of Activities	RiverCast
Level elevated	**jet skiing, kayaking swimming, sculling**	**recommendation: may not be suitable**

RED

Bacteria	Types of Activities	RiverCast
Level high	**jet skiing, kayaking swimming, sculling**	**recommendation: not suitable**

The website has been visited over 100,000 times and has been used for the planning of major water recreational events such as triathlons and regattas. Visit RiverCast at www.phillyrivercast.org.

Source Water Assessments

The Pennsylvania Department of Environmental Protection has been conducting assessments of all potentially significant sources of contamination to all public drinking water sources. The Philadelphia Water Department has prepared assessments to support local and State efforts to protect the quality of Philadelphia's drinking water sources.

Funded in part by a grant from the Pennsylvania Department of Environmental Protection, we partnered with Aqua America (formerly Philadelphia Suburban Water Company) and the Pennsylvania American Water Company to perform a source water assessment of water intakes along the Schuylkill and its tributaries.

The assessment detailed major issues within the watershed that threaten the quality of the drinking water supply. The river is a major source of drinking water for the public served by these three water utilities. In addition, the Philadelphia Water Department conducted an assessment for seven surface water intakes along the tidal section of the Delaware River.

This summary is for water supply areas for the Philadelphia Water Department's Baxter, Belmont, and Queen Lane water treatment plants. It assesses the raw (untreated river) water only.

For water quality information on our treated "tap" water, please see the charts on pages 8 and 9 of this report.

If you would like to receive a copy of the source water assessment summaries, or would like to know how to get involved in protecting your water supply or watershed, please call the Philadelphia Water Department at 215-685-6300, visit our website at www.phila.gov/ water, or see Table 2 on page 14.

Baxter Water Treatment Plant

This plant, located in the Torresdale section of Philadelphia, provides treated water that comes from the Delaware River. Through the Delaware River Protection Plan, we revisited the findings of our source water assessment report and identified population growth and land cover change in the Delaware River watershed; as well as the impact of sea level rise, global warming, and changes in flow management on the vulnerability of our Baxter intake to salt intrusion; as the activities of greatest concern for our water supply on the Delaware.

Historically, we have developed and maintained emergency response plans to address transportation accidents and spills along the Delaware River that could potentially impact the water supply, since it is a working river with barges, railroads, and many other transportation activities on or adjacent to it. We now have an automated early warning system which has greatly enhanced our emergency preparedness and response. Through our award-winning Source Water Protection Program, we also work with upstream partners such as watershed organizations, regulatory agencies, planning commissions, municipalities, and water suppliers to prevent declines in water quality throughout the entire 13,000 square-mile watershed to keep our water supply as clean as possible. Our Delaware River Protection Plan outlines our many strategies for protecting and enhancing the quality of the Delaware River as a source of drinking water for future generations.

Belmont and Queen Lane Water Treatment Plants

These plants provide treated water that comes from the Schuylkill River in Fairmount Park. Through a source water assessment report, the State drinking water program has found that our water supply is potentially most susceptible to challenges caused by discharges of treated and untreated sewage upstream, polluted runoff from urban areas and agricultural lands, transportation accidents and spills, and abandoned mine drainage. Most of these potential sources are located watershed-wide, but abandoned mine drainage originates over 100 miles upriver near the source of the Schuylkill River in Schuylkill County. Much closer to Philadelphia, the Wissahickon Creek requires special protection from potential sources of pollution due to its impact on source water quality at the Queen Lane intake.

Historically, we have developed and maintained emergency response plans to address accidents and spills that could potentially impact the water supply. We now have an automated early warning system which has greatly enhanced our emergency preparedness and response. Through our award-winning Source Water Protection Program, we also work with upstream partners such as watershed organizations, regulatory agencies, planning commissions, municipalities, and water suppliers to prevent declines in water quality throughout the entire 2,000 square-mile watershed to keep our water supply as clean as possible. Our Schuylkill River Protection Plan outlines our many strategies for protecting and enhancing the quality of the Schuylkill River as a source of drinking water for future generations.

We welcome your ideas and opinions

We participate in nearly 200 public and community events a year, including presentations made at schools, ongoing educational programs, and other environmental celebrations.

We offer ways for individuals, families, students, seniors, community groups and others to participate in learning about protecting water.

We greatly benefit from our citizens advisory council, which has been working with us over the last few years to improve our communications with our customers. Citizens representing business and industry, education, environmental advocacy, senior citizens, regulatory agencies, and civic and community groups have assisted us in developing public information about a variety of topics, including drinking water quality and stormwater pollution prevention.

Interested citizens are welcome to attend our Water Quality Education Citizens Advisory Council meetings. Call our Hotline at 215-685-6300 to confirm the meeting dates, times and locations.

Getting Involved

If you would like to help protect your water supply or watershed, please call the Philadelphia Water Department at 215-685-6300, visit our website at www.phila.gov/water, or see Table 2 on page 14.

How to contact us

You can write to us at:
Philadelphia Water Department
ARAMark Tower
1101 Market Street, 3rd Floor
Philadelphia, PA 19107-2994

You can call our Customer Information Hotline at 215-685-6300.

Explore Water in Our World at the Fairmount Water Works Interpretive Center!

Our Fairmount Water Works Interpretive Center is where the water environment comes alive! The Fairmount Water Works stopped pumping water in 1909, but it now has an exciting new life housing the Interpretive Center's exhibits and theater. Activity abounds in the galleries, on the deck, and by the river as school children, families, and other visitors explore the water right outside our window.

Our exhibits and programs serve the entire Philadelphia region; the Interpretive Center has been recognized by the Pennsylvania Department of Environmental Protection as the Delaware River Basin's official Watershed Education Center.

Did you know that you can drink the same water that dinosaurs drank? Come to our Interpretive Center where you can pilot a helicopter up the Delaware River, make it rain, peak inside a 48-inch water main, visit Pollutionopolis, and more! Our adult programs include lectures and seminars from nationally and internationally known scientists and writers. We offer something for everyone.

The Interpretive Center is located at 640 Water Works Drive, below the Art Museum. Our hours are Tuesday through Saturday, 10:00 am to 5:00 pm, and Sunday from 1:00 pm to 5:00 pm. We are closed on Mondays and city holidays. Admission is free. The Center is ADA accessible. To schedule classroom tours, check out the Center's Saturday Family Programs and other environmental education events at the Center, visit our website: www.fairmountwaterworks.org.

Interesting facts about Philadelphia's water

Hardness

Hardness defines the quantity of minerals such as calcium and magnesium in water. These minerals react with soap to form insoluble precipitates and can affect common household chores such as cooking and washing. Philadelphia's water is considered "medium" hard. Hardness also affects other water qualities such as its corrosiveness, with naturally soft water being more corrosive.

Cloudy Water

Aeration is the process which takes place when the water flowing from your tap into your glass appears cloudy. This temporary condition is a result of dissolved air being released from the water and being temporarily suspended in the water in your glass. This most commonly happens in the winter time when the cold water in the water mains is warmed up quickly in household plumbing, thereby encouraging the dissolved air to come out of the water.

Temperature

The temperature of both the Schuylkill and Delaware rivers varies seasonally from approximately 32° to 82° F. The Water Department does not treat the water for temperature.

Clean water begins and ends with you

Always recycle or dispose of unwanted household hazardous wastes properly. Don't pour motor oil, antifreeze or other toxic materials down storm drains. Water that enters our storm drains often flows directly to our local streams and rivers. So, don't pollute! Recycle these household hazardous materials safely and help protect our waterways. Also, don't flush paint thinners, insect sprays, herbicides and other harmful chemicals down the sink. Contact the Streets Department to get a schedule of their Household Hazardous Materials Drop-off Events where you can dispose of these materials safely without polluting your drinking water supply.

TABLE 1: Who to Call to Report Various Situations

Situation	Who To Call	Phone
Dead Fish	Fish & Boat Commission Fish & Boat Waterways Officer PADEP	717-626-0228 717-587-0414 484-250-5900
Illegal Dumping & Related Pollution Activities	PADEP Phila. Environmental Police Unit	484-250-5900 215-686-3082
Sewage Spills	PADEP PWD	484-250-5900 215-685-6300
Oil & Gas Spills/	PADEP	484-250-5900

Important telephone numbers and Internet addresses

Philadelphia Water Department
215-685-6300
http://www.phila.gov/water

Philadelphia Streets Department
215-686-5560
http://www.phila.gov/streets

U.S. Environmental Protection Agency (Safe Drinking Water Hotline)
800-426-4791
http://www.epa.gov/safewater

Schuylkill River Source Water Assessment
http://www.phillyriverinfo.org

Schuylkill Action Network
http://www.schuylkillactionnetwork.org

Philadelphia river and watershed information
http://www.phillyriverinfo.org

RiverCast
http://www.phillyrivercast.org

Fairmount Water Works Interpretive Center
215-685-0723
http://www.fairmountwaterworks.org

TABLE 2 – Places To Go To Get Involved In Protecting Your Local Streams, Rivers, and Water Supply

Organization	Activity Types	Phone Number	Website Address
Friends of the Pennypack	A, C, E, P, T	215-934-PARK	http://balford.com/fopp
Friends of the Wissahickon	A, C, E, P, T	215-247-0417	http://www.fow.org
Friends of Fox Chase Farms	A, C, E, P	215-728-7900	http://www.foxchasefarm.org
Friends of the Tacony Creek Park	A, C, E, P, T	215-745-8903	http://friendsoftaconycreekpark.org
Friends of the Manayunk Canal	A, C, E, P, T	215-483-9238	http://www.manayunkcanal.org
Schuylkill Environmental Education Center	A, B, C, E, P, T	215-482-7300	http://www.schuylkillcenter.org
Partnership for the Delaware Estuary	A, B, C, E, P, S,T	1-800-445-4935	http://www.delawareestuary.org
Environmental Alliance for Senior Involvement	A, C, E, P, T	703-241-4927	http://www.easi.org
Philadelphia Canoe Club	R, F, T	215-487-9674	http://www.philacanoe.org
Friends of Fairmount Fish Ladder	F	215-683-0217	email: epac99@aol.com
Cobbs Creek Environmental Education Center	A, C, E, P, T	215-685-1900	http://www.cobbscreek.org
Wissahickon Restoration Volunteers	A, C, E, P, T	215-951-0330 x2101	http://wissahickon.patrails.org
Wissahickon Valley Watershed Association	A, C, E, P, T	215-646-8866	http://www.wvwa.org
Lower Merion Conservancy	A, C, E, P, T	610-645-9030	http://www.lmconservancy.org
Philadelphia Water Department Water Quality Education Citizens Advisory Committee	A, E	215-685-6300	http://www.phila.gov/water
Schuylkill Banks	B,E,L	215-222-6030 x103	http://www.schuylkillbanks.org

ACTIVITY TYPES

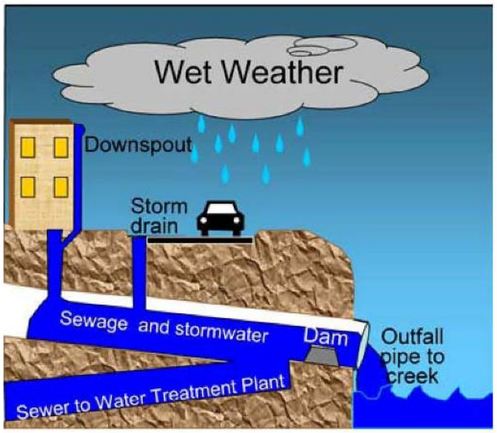
A:	Environmental activism
B:	Business related protection and education activities
C:	Clean-up of trash and litter
E:	Environmental education
F:	Fishing or fish recreation activities
L:	Land conservation and management
P:	Planting trees and streambank repair/ protection
R:	Rowing, canoeing, and related boating activities
S:	Storm drain marking
T:	Water quality testing

Philadelphia PWD Water Department

WATER Wheel

“Green Cities — Clean Waters Program”

Green Cities/2008



What is a Combined Sewer Overflow (CSO)?

A combined sewer system transports sewage (from homes, businesses and industry), stormwater from the storm drains on our streets and stormwater from property rain leaders through a single underground pipe to a Water Pollution Control Plant (treatment plant).

Under heavier rainfall conditions, however, the flow of the sewage and stormwater in combined sewers may exceed the capacity of the pipe or treatment facility. As a result, a portion of the sewage and stormwater may be sent directly to a nearby stream or river to prevent the flooding of homes and streets. This is what is known as a Combined Sewer Overflow.

The Vision for Our Creeks & Our City

Imagine a Philadelphia where you can walk along any creek in the City and find yourself surrounded by wildflowers under a shady canopy, listening to birds chirp, watching butterflies and dragonflies flutter by and where you can rest and fish peacefully in clean waters. This is the vision the Philadelphia Water Department (PWD) has for the future of Philadelphia – for a greener city with cleaner waters.

PWD believes that this vision can become a reality through PWD’s “Green Cities-Clean Waters Program.” This program is also referred to as the Combined Sewer Overflow (CSO) Long Term Control Plan. It is a plan that will help us reduce combined sewer overflows and clean up our waters – the plan that will help us transform Philadelphia into a more desirable place to live, work and play.

The Warning on Our Creeks

Combined Sewer Overflows (CSOs) are not just a Philadelphia problem. They are an old problem in cities throughout the country, where combined sewer outfalls are present. CSOs discharge a mix of sewage and stormwater during rainstorms, resulting in swimming and fishing advisories and habitat destruction. Therefore, it is important that the public avoid contact with the waters in our creeks and rivers during and immediately following rain events.

The History behind Those Pipes

Philadelphia was once a city of water (see Map 1 on the next page) – where hundreds of creeks flowed through the city. It was because of these creeks and rivers that industry flourished. However, as Philadelphia grew, so did the pollution. Waste from slaughterhouses, used dye, trash and sewage – all were discharged to our rivers and creeks. It was standard practice in the 18th and 19th centuries to use creeks as sewers.

At one point, the creeks and rivers were so filthy that they became a health hazard. Thousands of Philadelphians died from disease. The creeks also became an obstacle to development. Eventually, they were driven underground, their streambeds replaced with the sewers that now contain them. By the late nineteenth century, many of the creeks had disappeared – the map of the city’s surface streams was disturbingly blank (see Map 2 on the next page).

(continued on next page)

Philadelphia PWD Water Department

WATER Wheel

"Green Cities—Clean Waters"

(continued from previous page)

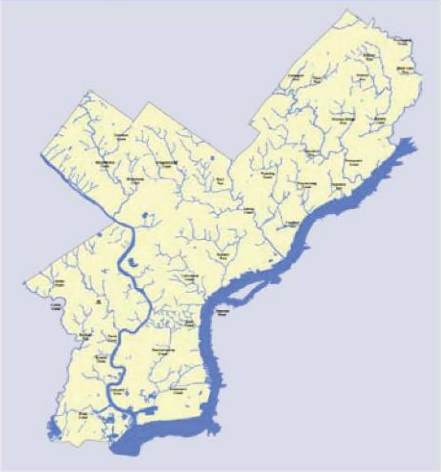
However, by the twentieth century, City leaders realized the benefits of preserving our remaining streams and creating watershed parks (East and West Parks, Wissahickon, Cobbs, Tacony, Pennyack). But for many of those streams, it was too late.

In addition, the 1972 Clean Water Act required utilities to significantly reduce pollution from its treatment facilities, combined sewers and storms. As a result, the creeks and rivers in the City are cleaner now than they have been in half a century.

Over the next 20 years, we will build upon this progress, implementing a mix of new infrastructure, green land practices, stream restoration and community involvement. Through the "Green Cities-Clean Waters Program," and with your support, we will transform Philadelphia into a place where all want to live, work and play. The creeks will become a place where we can find respite in the City; where we can walk amongst wildflowers, listen to the songs of birds, and fish in clean waters again.

For more information and to learn how you can help support the Green Cities-Clean Waters Program, please visit our website: http://www.phillyriverinfo.org.

Map 1: Historic Streams



Map 2: Today's Streams

Clip out and fold this information and carry it in your wallet, so you can report flows.

No Swimming at Any Time in Philadelphia Creeks.
Sewers May Overflow.
During and immediately after rain, polluted water may flow from pipes.

To protect your health, do not come in contact with rivers and streams during and immediately after rain events.

For information on how to protect our waterways, visit: www.phillyriverinfo.org.

Please report flows from pipes during dry weather to PWD's hotline: 215-685-6300.

Philadelphia Water Department (PWD)

Cortelo, doblelo y guardelo en tu billetero, para que puedes reporter desbordamientos.

No Nades en Ningun Tiempo en las Quebradas de Filadelfia. Puede Ocurrir Desbordamiento de Aguas Negras.

Durante e imediatamente después de llover, las aguas contaminadas pueden fluir por tubería.

Para proteger su salud, evite el contacto con ríos y quebradas durante e imediatamente después de llover.

Para información sobre como proteger nuestros cuerpos de agua visite: www.phillyriverinfo.org.

Favor de reportar cualquier desbordamiento (durante tiempos secos) a la línea directa de PWD: 215-685-6300.

Philadelphia Water Department (PWD)

Faith-Based Initiatives

Philadelphia
PWD
Water Department

June 17, 2009

Reverend Luis Cortés
Nueva Esperanza
4261 North 5th Street
Philadelphia, PA 19140

Dear Reverend Cortés,

Peace and blessings to you and Nueva Esperanza!

As the Associate Director of the Mayor's Office for Faith Based Initiatives and the Director of the Philadelphia Water Department's Office of Watersheds, we are pleased to inform you that we feel encouraged by all of the recent city initiatives to foster neighborhood stewardship of our environment. Just this month, the Mayor released GreenWorks Philadelphia, his vision for making Philadelphia the most sustainable city in the country by 2015. As people of faith know, a sustainable city is a safe and beautiful city.

The Mayor's Office for Faith Based Initiatives has been working with the Philadelphia Water Department to consider activities that will compliment the neighborhood and fulfill important environmental objectives that would serve the municipal, economic, health and spiritual needs of the City's residents. In the spirit of hope and community, we are writing to request a one hour meeting with you to begin a dialogue with Nueva Esperanza towards establishing a partnership to beautify and green the surrounding neighborhoods.

Here are a few ideas for how we might be able to work together:

- City beautification (clean-ups, planting gardens, greening sidewalks and streets)
- Establishing living memorials (commemorative trees and gardens)
- Surveying worshipers' attitudes about green streets

For more detailed background information, we have attached a separate fact sheet. Also, please feel free to contact Mr. Gerald Bright, Aquatic Biologist, with the Philadelphia Water Department – 267-339-1826. Mr. Bright will follow up with you on our behalf to schedule a meeting. Thank you for your consideration to partner with us.

Sincerely,

Minister Malcolm T. Byrd
Associate Director
Mayor's Office of Faith-Based Initiatives

Sincerely,

Howard Neukrug
Director, Office of Watersheds
Philadelphia Water Department

Faith Community Greening Partnership Facts

The Philadelphia Water Department (PWD), in partnership with the Mayor's Office of Faith-Based Initiatives (MOFI), is beginning dialogues and partnerships with Philadelphia's religious institutions, faith- inspired organizations, and neighborhoods towards further beautifying and greening of city neighborhoods through the planting of more vegetation on sidewalks and streets.

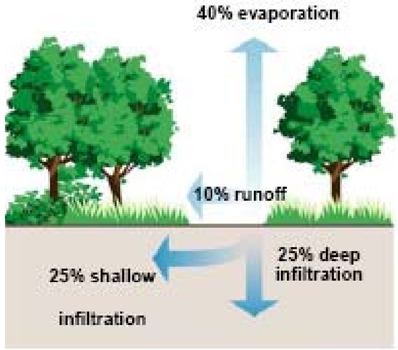
Below are illustrations of pre- and post-development conditions, the City's combined sewer system and examples of grey and green infrastructure. The federal government mandates that the City manage its stormwater runoff in order to minimize impacts to local streams. PWD wants to use as much green (vegetation) as possible to minimize this runoff. Greening will reduce combined sewer overflows, while beautifying communities, and improving air quality, in addition to providing other benefits to Philadelphia and its residents.

MOFI and PWD believe that faith leaders and their congregations understand that stewardship of our land and water is both a civic responsibility and a spiritual obligation.

We would like to gauge the interest of local congregations in greening, through conducting an environmental awareness survey. PWD will provide the surveys, background materials and staff to distribute the surveys and answer questions. Additionally, we can collaborate on formulating the message about this effort to specific congregations.

For more information, visit www.phillyriverinfo.org or contact Gerald W. Bright, Aquatic Biologist and Project Liaison, at 267-339-1826 or Gerald.Bright@phila.gov.

Pre-development



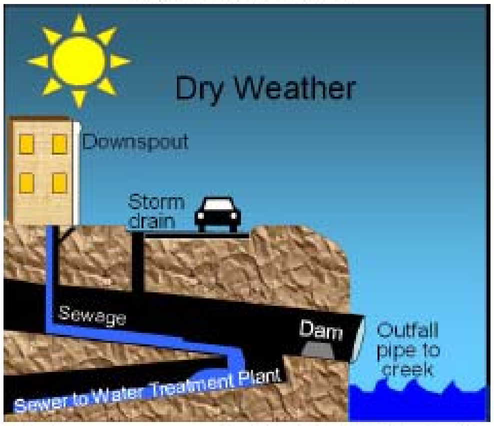
Prior to development, vegetation (trees and plants) enables stormwater (rain or melting snow) to soak into the ground, replenish groundwater and foster tree and plant growth, thereby supporting healthy living streams and rivers.

Post-development

As a city develops, we replace vegetation with built surfaces, such as rooftops, streets, and parking lots, causing stormwater to run off of these impenetrable surfaces, traveling to the nearest storm drains, which connect to underground sewer pipes.

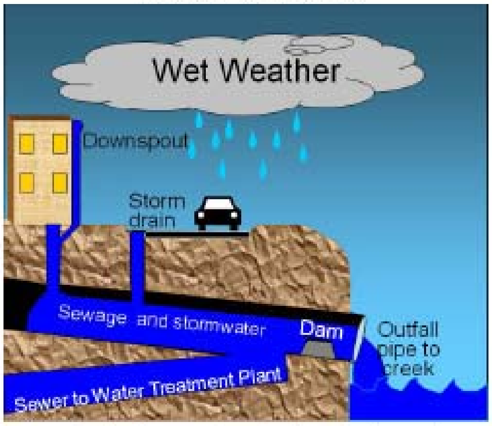
Faith Community Greening Partnership Facts

Combined Sewer System



We built sewer systems to collect the rainfall that flowed off of these built surfaces and to divert it away from our neighborhoods. In much of Philadelphia, as in many other large cities throughout the world, a single-pipe, "combined sewer system," is used to collect and treat both rain runoff, or "stormwater," and residential and commercial sanitary waste.

Combined Sewer System

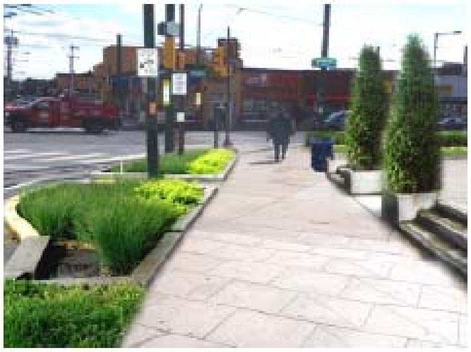


However, during intense rain events, there is not enough capacity in our pipes and treatment plants to handle the volume of stormwater runoff, causing Combined Sewer Overflows (CSOs) into Philadelphia's creeks and rivers.

Grey Infrastructure

To reduce CSOs, PWD proposes to use a combination of "grey infrastructure," including building underground storage pipes and tunnels and expanding our treatment plants, and "green infrastructure."

Green Infrastructure



Examples of "green infrastructure," include curbside tree planters, rain gardens, rain barrels and green roofs. These "green" practices all use natural methods to allow stormwater runoff to soak in the ground to prevent it from reaching our sewers and/or to slow down the runoff enough to help prevent CSOs. Green streets are safe streets that clean and beautiful our city.

Supplemental Documentation
Volume 2

Triple Bottom Line Analysis

Updated: September 1, 2009

PWD "GREEN CITY – CLEAN WATER" PROGRAM
Summary of Triple Bottom Line Analysis

Introduction

The vision outlined in "Greenworks Philadelphia" sets an ambitious agenda to transform Philadelphia into the "greenest city in America", taking advantage of Philadelphia's considerable assets such as walkable neighborhoods and mass transit, and reversing years of population and infrastructure decline. This will take a transformation in the way city agencies work together, and will need to align city government, non-governmental organizations and residents in a joint effort towards achieving a common goal of a more livable, sustainable city that reduces its energy needs, improves the economic condition of its citizens, and manages its natural resources to the greatest extent possible.

PWD's "Green City – Clean Water" program integrates management of Philadelphia's watersheds into this larger context. It is designed to provide many benefits beyond the reduction of combined sewer overflows, so that every dollar spent provides a maximum return in benefits to the public and the environment. To fully understand the economic, environmental, and social benefits of the program, PWD has undertaken a Triple Bottom Line analysis. The results of this analysis are summarized below.

Green Infrastructure and How it Works

Green stormwater infrastructure, as defined by PWD, includes a range of soil-water-plant systems that intercept stormwater, infiltrate a fraction of it into the ground, evaporate a portion of it into the air, and in some cases release a portion of it slowly back into the sewer system where it can ultimately be treated at a wastewater treatment plant. Examples include bioretention planters in sidewalks and parking lots, roof leaders that run off into lawns, green roofs, and rain gardens. These practices manage rain where it falls in a way similar to a natural system such as a forest or a meadow. An important concept used throughout this document is the concept of "greened area". The greened area in a watershed is the percentage of urban land area "served" by green stormwater infrastructure. This area includes the area of the stormwater facility itself, plus the area draining to it.

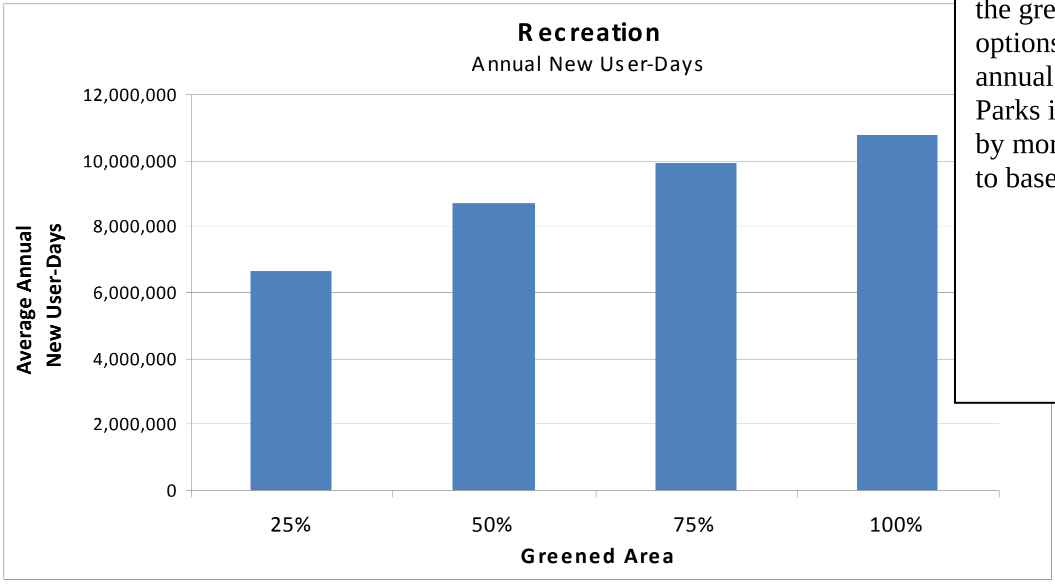
PWD's definition of green infrastructure also includes restoration of physical habitats in stream channels, along stream corridors, and on riverfronts. These practices are important to the larger approach because without them, the damage done to ecosystems by two centuries of urbanization will not be undone. Restoration of stream habitats and riverfronts can also be combined with efforts to improve public access and amenities along the water corridors.

Green Infrastructure Enhances Recreation and Restores Ecosystems

Green Infrastructure Enhances Recreation

Throughout the Fairmount Park system, residents enjoy recreation along Philadelphia's stream corridors and waterfronts, but some areas do not live up to their full potential. Improved access, appearance, and opportunities in these areas will make them more desirable destinations for the public. Recreation also will be more desirable along newly greened neighborhood streets and public places.

At full implementation of the green infrastructure options, the number of annual visits to Fairmount Parks is expected to increase by more than 6% compared to baseline conditions.



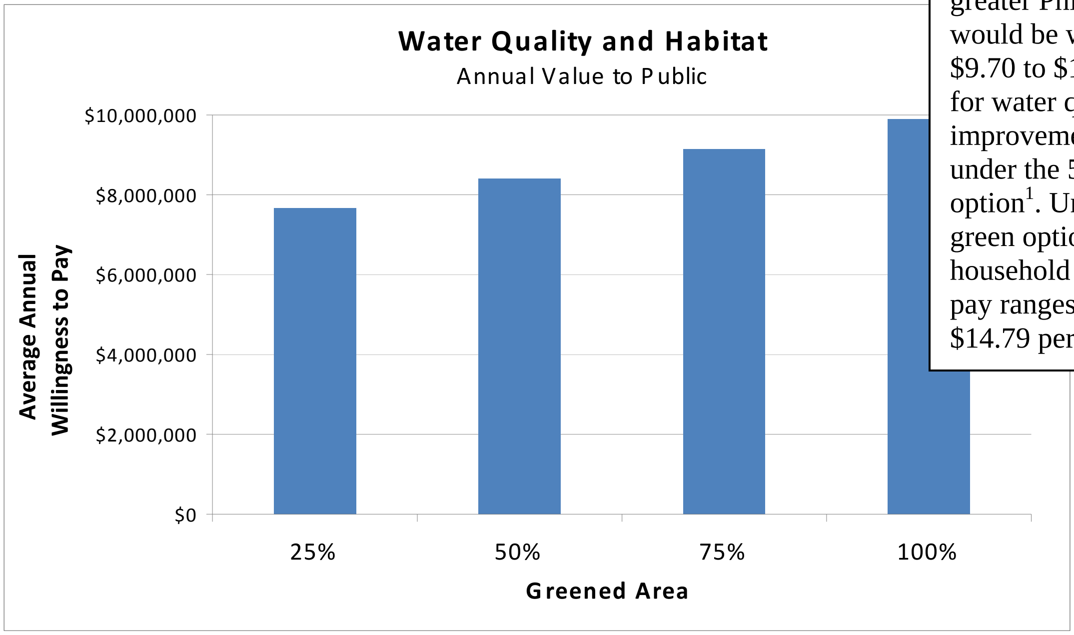
<u>Recreation: Methods and Sources</u>
The team established a baseline for the number of visitors to Philadelphia's parks today, based on reports prepared for the Philadelphia Parks Alliance and the Fairmount Park Commission, and input from park staff. With improvements to underused areas along stream corridors and riverfronts, the team estimated that these areas could be brought up to a level of use more similar to the park system as a whole. Recreation along newly greened streets and public places was linked to the area greened in each watershed. Environmental economists are able to estimate monetary values for recreation activities using "direct use" values from the academic literature and government agencies. These values estimate what a typical user pays or would be willing to pay to take part in that activity. For this study, the team was able to draw upon Philadelphia-specific direct-use values for different recreational activities, as published in a report prepared by the Trust for Public Lands (2008): *How Much Value Does the City of Philadelphia Receive from its Park and Recreation System?*.

Selected References: Trust for Public Lands, 2008; Tidal Schuykill River Master Plan, 2003

Green Infrastructure Restores Ecosystems

Green infrastructure improves ecosystems in two ways. First, by restoring a water cycle more similar to a natural watershed, green infrastructure allows rain to soak into the ground and return to streams slowly. This provides a natural water quality filter and limits erosion of stream channels caused by high flows, both of which benefit aquatic species. Second, PWD's green infrastructure approach includes physical restoration of stream channels and streamside lands, including wetlands, to restore habitat needed for healthy ecosystems.

Households within the greater Philadelphia region would be willing to pay \$9.70 to \$15.54 per year for water quality improvements expected under the 50% green option[1]. Under the 25% green option, estimated household willingness-to-pay ranges from \$8.89 to \$14.79 per year.



<u>Ecosystem Restoration: Methods and Sources</u>
Water quality and ecosystem health are difficult to value economically. However, human beings clearly value clean water and healthy ecosystems both for themselves and for future generations. Environmental economists refer to this as a "nonuse" or "nonmarket" value and have a number of tools for estimating these values in monetary terms. For this study, these values were monetized based on a large body of academic literature where households were surveyed to determine how much they would be willing to pay to improve water quality or habitat by a defined amount. Values also were derived from a large body of literature on the economic value of wetlands.

Selected References: Van Houtven et al., 2007; Woodward and Wui, 2001; Borisova-Kidder, 2006

1

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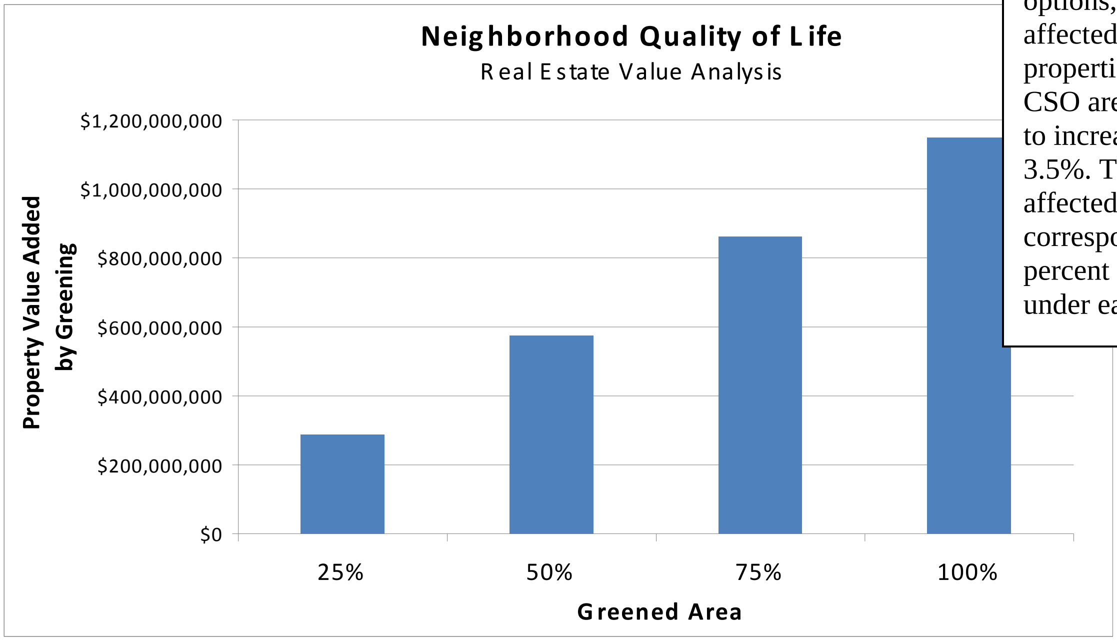
[1] Analysis assumes households outside of Philadelphia County, but within the greater Philadelphia metropolitan area, would be willing to pay for water quality improvements in the Schuylkill and Delaware Rivers due to the regional importance of these rivers. This assumption is based on the findings of several studies demonstrating a willingness-to-pay for improved resources despite the respondent's physical distance from the resource.

Green Infrastructure Improves Neighborhoods

Green Infrastructure Improves Community Quality of Life

Trees and parks are an important part of the recipe that together can make an urban neighborhood into an inviting, exciting place to live, work and play. Residents clearly recognize and value this quality of life effect of urban vegetation, and yet it is difficult to assign it an economic value. One way to estimate a value is to study property values in areas that are close to parks and greenery.

Under the various green options, the values of affected residential properties within PWD's CSO area are expected to increase by about 3.5%. The number of affected properties corresponds to the percent of greened area under each option.



<u>Quality of Life: Methods and Sources</u>

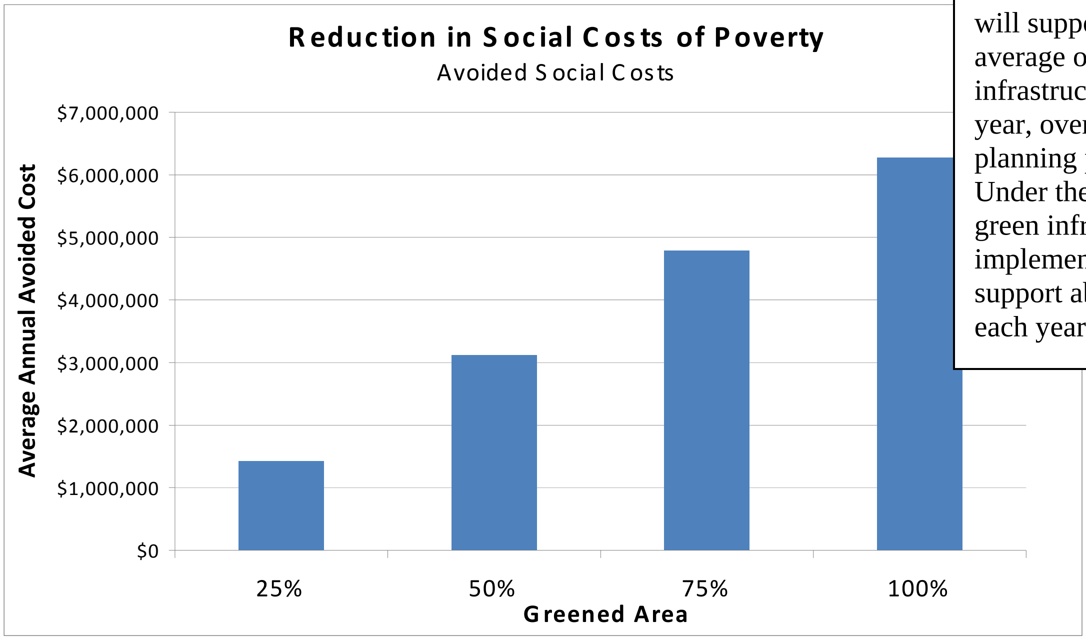
There is a rich body of academic literature showing that property values are higher when trees and other vegetation are present in urban neighborhoods, including some Philadelphia-specific studies. The study team combined estimates from this literature, data on current Philadelphia home values, and proposed increases in "greened area" to estimate these benefits under the greened area CSO options.

It is important to note that the study team evaluated increases in the value of residential properties only. However, commercial, industrial and institutional property values would also likely increase.

Selected References: Braden and Johnston, 2003; Shultz and Schmitz, 2008; Wachter and Wong, 2006

Green Infrastructure Jobs Reduce the Social Cost of Poverty

Governments at all levels incur significant costs in coping with poverty, and Philadelphia is no exception. Green infrastructure creates jobs which require no prior experience and are therefore suitable for individuals who might be otherwise unemployed and living in poverty. These new jobs create a benefit to society in reduced poverty-related costs, in addition to the wages paid to the individual workers. The stabilizing and transforming effects of green infrastructure in neighborhoods further reinforce and support the benefits of providing employment to a population that is outside the labor force. Green infrastructure is not by itself the solution to poverty, but it is a valuable tool in the toolbox of poverty reduction.



The 50% green option will support an average of 380 green infrastructure jobs per year, over the 40-year planning period. Under the 25% option, green infrastructure implementation will support about 170 jobs each year.

<u>Poverty Reduction: Methods and Sources</u>

Based on a number of local and national studies, economists have estimated that the cost of poverty related outlays in Philadelphia divided by the number of adults living in poverty ranges from about $15,000 to $45,000 per year. These studies are based on estimates of spending by all levels of government on assistance programs and avoidable crime and health impacts (e.g. it costs $30,000 per year to keep a person in jail in Philadelphia). Many of the study estimates include documented increased costs of seemingly unrelated city services due to poverty. Some of the lower estimates of total social cost are missing a number of these cost elements, thus, the higher estimates seem more plausible.

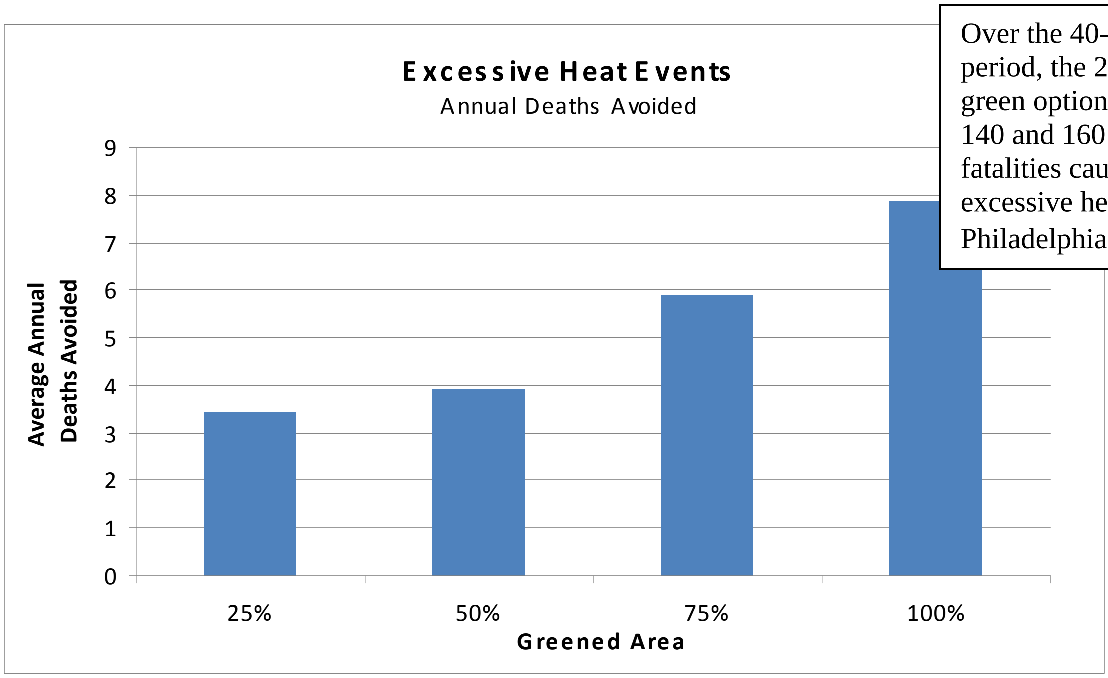
Based on these various studies, This study assumes an avoided social cost of $10,000 per new green infrastructure job created. This study also assumes that three-quarters of these new jobs would require no experience and thus provide the benefits of hiring unemployed adults living in poverty, and reducing poverty expenditures.

Selected References: Schwartz, 1993; Summers and Jakubowski 1996; Pack, 1998; Oppenheim and MacGregor, 2006; Holzer et. al., 2007; Glaster et. al. 2007; Laurie et. al. 2008

Green Infrastructure Improves Public Health

Green Infrastructure Reduces Effects of Excessive Heat

Heat waves are a fixture of summers in Philadelphia, including some severe enough that they have resulted in over 100 premature deaths (for example, the summer of 1993). These events may be more frequent and severe in the future due to climate change. Green infrastructure (for example, trees, green roofs, and bioretention sidewalks) reduces the severity of extreme heat events in three ways - by creating shade, by reducing the amount of heat absorbing pavement and rooftops, and by emitting water vapor – all of which cool hot air. This cooling effect will be sufficient to actually reduce heat stress-related fatalities in the city during extreme heat wave events.



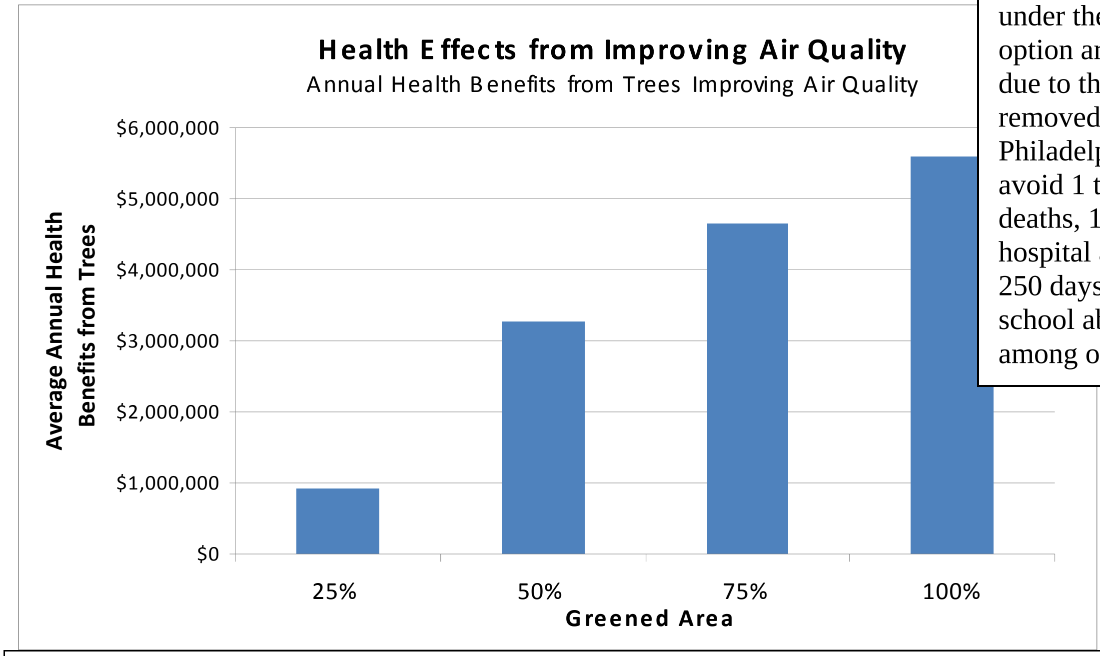
Over the 40-year planning period, the 25% and 50% green options will result in 140 and 160 fewer fatalities caused by excessive heats events in Philadelphia, respectively.

<u>Excessive Heat: Methods and Sources</u>
Extreme heat events in Philadelphia have been studied extensively by the Philadelphia Health Department, the federal Centers for Disease Control, the U.S. Environmental Protection Agency (USEPA) and others. The study team used results of several of these studies that quantified the reduction in temperature that results from significant increases in urban vegetated acreage. The study team incorporated these results into the city's existing methodology for quantifying excess heat mortality to evaluate human deaths avoided under the different green CSO options. The value of avoided heat-related deaths was then monetized based on standard methods routinely used by U.S. EPA in regulatory impact assessments..

Selected References: CDC, 1994; Hudischewskyj et al., 2001; Kalkstein and Sheridan, 2003

Green Infrastructure Improves Air Quality

Like many major cities in the United States, EPA currently classifies the Philadelphia metropolitan area as exceeding federal air quality standards for both ozone (smog) and fine particles (soot). Known health impacts of these air pollutants include premature death, hospitalization for respiratory diseases, heart attacks, and lost work and school days. Green infrastructure will improve Philadelphia's air quality in two ways – by reducing emissions of pollutants (such as SO_2) and by removing ozone and particulates from the air. Reductions in energy and vehicle use will reduce emissions of pollutants. Once in the air, some ozone and particles are taken into the leaves of trees as they "breathe." Leaves also trap additional fine particulates, which then wash off in the rain or fall with the autumn leaf drop.



When the trees planted under the 50% green option are fully grown, due to the air pollution removed by trees, Philadelphia County will avoid 1 to 2 premature deaths, 1 heart attack, 3 hospital admissions and 250 days of work loss or school absence each year, among other health effects.

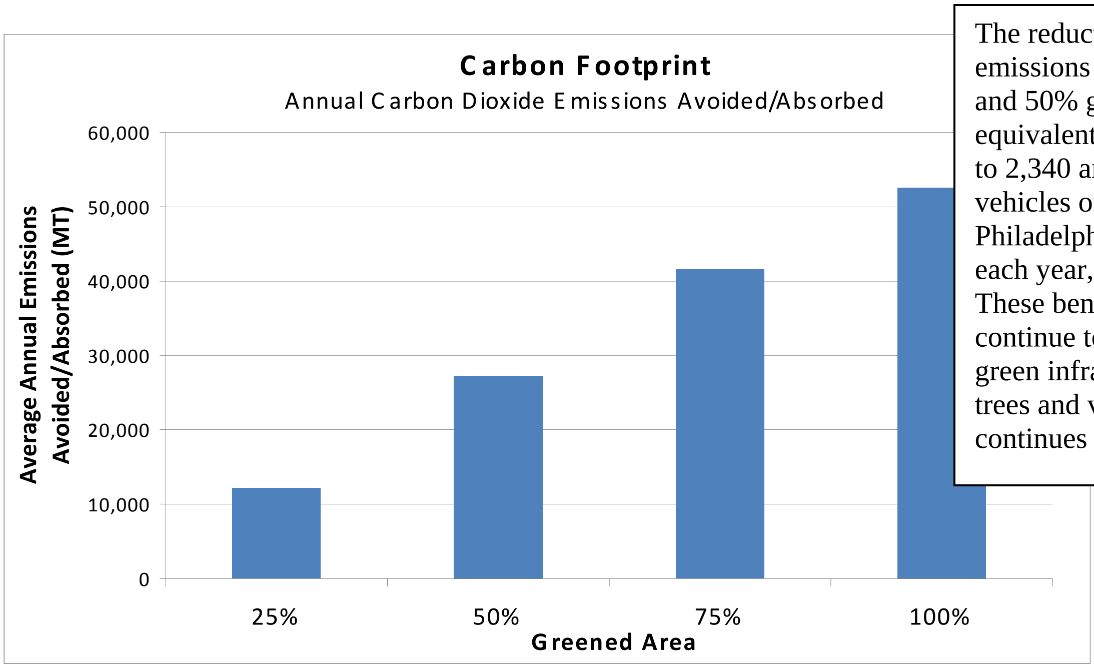
Air Quality: Methods and Sources

The U.S. Forest Service estimated air concentration removal rates associated with the urban forest in Philadelphia. The study team combined these pollutant removal rates with the projected number of new trees under the various green infrastructure scenarios. The study team then used BenMAP, USEPA's air quality benefits model, to estimate corresponding health impacts using current and projected Philadelphia air quality levels . USEPA also provides the standard methods used to value the economic impact of these avoided health effects. Additional air pollution related impacts associated with changes in emissions from energy production and vehicles are discussed in more detail in the energy and carbon section.

Selected References: USDA, 2007; U.S. EPA, 2008a; U.S. EPA, 2008b

Green Infrastructure Saves Energy and Offsets Climate Change

Green infrastructure reduces energy use, fuel use, and carbon emissions in two ways. First, the cooling effects of trees and plants shade and insulate buildings from wide temperature swings, decreasing the energy needed for heating and cooling. Second, rain is managed where it falls in systems of soil and plants, reducing the energy needed for traditional systems to store, pipe, and treat it. Growing trees also act as carbon “sinks”, absorbing carbon dioxide from the air and incorporating it into their branches and trunks.



The reduction in carbon emissions under the 25% and 50% green options, is equivalent to taking close to 2,340 and 5,250 vehicles off of Philadelphia roadways each year, respectively. These benefits will continue to accrue as the green infrastructure (e.g. trees and vegetation) continues to grow.

Energy and Climate Change: Methods and Sources

The team estimated energy savings, pollutant emission reductions, and carbon emission reductions from trees and plants using a study published by the U.S. Forest Service. Emissions related to energy production in Pennsylvania are published by the Energy Information Administration. The cost of carbon emissions to society is an area of active debate, but in the study the team used an estimate provided by the Intergovernmental Panel on Climate Change. Estimates of carbon emissions and sinks also considered construction, traffic delays caused by construction, and the manufacturing and transport of concrete.

Selected References: EIA, 2007; IPCC, 2007; USDA, 2007

Selected References (Please see the full report for a complete list of citations.)

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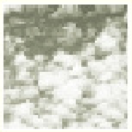

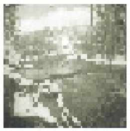

A Triple Bottom Line Assessment of Traditional and Green Infrastructure Options for Controlling CSO Events in Philadelphia's Watersheds
Final Report

Prepared for:

Howard M. Neukrug, Director, Office of Watersheds,
City of Philadelphia Water Department
under contract to Camp Dresser and McKee

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August 24, 2009
SC11737

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Executive Summary

Objectives

The City of Philadelphia Water Department (PWD) is considering a wide array of options for controlling Combined Sewer Overflow (CSO) events in its four relevant watershed areas. The options range from traditional infrastructure-based approaches (e.g., storage tunnels) to more innovative “green infrastructure” approaches based largely on Low Impact Development (LID) elements (e.g., tree planting, permeable pavement, green roofs).

PWD is especially interested in gaining a more complete understanding of the Triple Bottom Line (TBL) implications of the green and traditional infrastructure approaches in terms of their respective ability to provide environmental, social, public health, and other values. Accordingly, this report provides a TBL-oriented benefit-cost assessment of the CSO control alternatives under consideration by PWD. The focus here is on the benefits and external costs of the alternatives. Ultimately, the TBL benefit results from this report, and the engineering cost information from Camp, Dresser and McKee (CDM), will be combined to provide insights as to the estimated net benefits of the alternatives.

Key Findings

The key finding of this TBL assessment is that the LID-based green infrastructure approaches provide a wide array of important environmental and social benefits to the community, and that these benefits are not generally provided by the more traditional alternatives. Tables S.1 and S.2 provide a summary of the numeric findings for two of the CSO control options under consideration: the 50% LID, or green infrastructure option [meaning runoff from 50% of impervious surface in the City of Philadelphia (the City) is managed through green infrastructure], and the 30’ Tunnel option (a system of storage tunnels with an effective diameter of 30 ft, serving all watersheds). These options were chosen to demonstrate the difference in net benefits between green and traditional infrastructure. The reporting of these results is not intended to indicate that a final PWD decision will be based on these two alternatives.

The results shown below reflect benefits (and external costs) accrued over the 40-year study period (from 2010 to 2049). Table S.1 describes the outcomes in terms of the physical outcomes obtained, and the second table provides the estimated monetary value for these outcomes, in present value terms.

Table S.1. City-wide natural unit benefits of key CSO options: Cumulative through 2049[a]

Benefit categories	50% LID option	30' Tunnel option[b]
Additional creekside recreational user days	247,524,281	
Additional non-creekside recreational user days	101,738,547	
Reduction in number of heat-related fatalities	196	
Annual willingness to pay (WTP) per household for water quality and aquatic habitat improvements[c]	\$9.70–\$15.54	\$5.63–\$8.59
Wetlands created or restored (acres)	193	
Green collar jobs (job years)	15,266	
Change in particulate matter ($PM_{2.5}$) due to increased trees ($\mu g/m^3$)	0.01569	
Change in seasonal ozone due to increased trees (ppb)	0.04248	
Electricity savings due to cooling effect of trees (kWh)	369,739,725	
Natural gas savings due to cooling effect of trees (kBtu)	599,199,846	
Fuel used (vehicles for construction and operation and maintenance) (gallons)	493,387	1,132,409
Sulfur dioxide (SO_2) emissions (metric tons)	(1,530)[d]	1,452
Nitrogen oxides (NO_x) emissions (metric tons)	(38)	6,356,083
Carbon dioxide (CO_2) emissions (metric tons)	(1,091,433)	347,970
Vehicle delay from construction and maintenance (hours of delay)	346,883	796,597

a. The 50% LID and 30' Tunnel options were chosen as example alternatives to illustrate the differences between green and traditional infrastructure approaches. This does not imply that a final decision has been made by PWD regarding the implementation of these options.

b. 28' Tunnel option in Delaware River Watershed.

c. WTP per household in Philadelphia, MA, including Bucks, Chester, Delaware, Montgomery, and Philadelphia counties.

d. Parentheses indicate negative values.

Relevant TBL Benefit Categories

A summary of the key benefit (and external costs) categories included in this TBL assessment is provided below. Most of these benefits accrue only with the LID-oriented green infrastructure options, and not under the traditional infrastructure alternatives.

Recreation. Under the LID-based options, streamside recreational opportunities will be increased as a result of stream restoration and riparian buffer improvements. Recreation will also improve in non-creekside parts of the City due to the general increase in vegetated and treed acreage in the City. These recreational benefits are not anticipated under the traditional infrastructure approaches.

Table S.2. City-wide present value benefits of key CSO options: Cumulative through 2049 (2009 million USD)

Benefit categories	50% LID option	30' Tunnel option[a]
Increased recreational opportunities	$524.5	
Improved aesthetics/property value (50%)	$574.7	
Reduction in heat stress mortality	$1,057.6	
Water quality/aquatic habitat enhancement	$336.4	$189.0
Wetland services	$1.6	
Social costs avoided by green collar jobs	$124.9	
Air quality improvements from trees	$131.0	
Energy savings/usage	$33.7	$(2.5)
Reduced (increased) damage from SO_2 and NO_x emissions	$46.3	$(45.2)
Reduced (increased) damage from CO_2 emissions	$21.2	$(5.9)
Disruption costs from construction and maintenance	$(5.6)	$(13.4)
Total	**$2,846.4**	**$122.0**

a. 28' Tunnel option in Delaware River Watershed.

Increased Community Aesthetics, Reflected in Higher Property Values. Trees and plants improve urban aesthetics and community livability and studies show that property values are higher when trees and other vegetation are present.

Heat Stress Reduction. Green infrastructure (trees, green roofs, and bio-retention areas) creates shade, reduces the amount of heat absorbing materials and emits water vapor – all of which cool hot air. This cooling effect will be sufficient to reduce heat stress-related fatalities in the City during extreme heat wave events.

Water Quality and Aquatic Ecosystem Improvements. The traditional infrastructure options (e.g., plant expansions, tunnels) are aimed at reducing the number of overflow episodes, but do little to directly improve the physical riparian area environment (i.e., riparian and aquatic ecosystems and habitat areas) or otherwise enhance living resources in many of the City's watershed environments. In contrast, the LID options, in conjunction with the related watershed restoration efforts, are expected to generate important improvements to these living natural resources.

Wetland Creation and Enhancement. The watershed restoration and related efforts, as associated with the LID options, are expected to create or enhance over 190 acres of wetlands in the relevant watersheds. These added and enhanced wetland acres will provide a range of services in the urban area watersheds.

Poverty Reduction from Local Green Jobs. Specialized labor is required for construction of conventional stormwater management solutions (e.g., boring, tunneling). Such skilled laborers might typically be already employed in the construction field. Green infrastructure creates the opportunity to hire local unskilled – and otherwise unemployed – laborers for landscaping and restoration activities. Thus the benefits of providing these local green jobs include the avoided costs of social services that the City would otherwise provide on behalf of the same people if they remained unemployed.

Energy Savings and Carbon Footprint Reduction. Green space helps lower ambient temperatures and, when incorporated on and around buildings, helps shade and insulate buildings from wide temperature swings, decreasing the energy needed for heating and cooling. In addition, diverting stormwater from wastewater collection, conveyance, and treatment systems reduces the amount of energy needed to pump and treat the water. Reduced energy demands in buildings, and increased carbon sequestration by added vegetation, result in a lower carbon footprint (reduced CO_2 emissions).

Air Quality Improvement. Trees and vegetation also improve air quality by filtering some airborne pollutants (e.g., particulate matter and ozone). Likewise, reduced energy consumption results in decreased emissions (e.g., SO_2 and NO_x) from power generation facilities. These air quality improvements can reduce the incidence and severity of respiratory illness.

Construction- and Maintenance-Related Disruption. All of the CSO options will result in some level of disruption due to construction and/or program activities. Social costs of disruption can include traffic delays, limited access to places of business, increased noise and pollution, and other inconveniences. Under all of the CSO alternatives, construction activities will likely result in occasional delays and increased travel times for passenger and commercial vehicle travelers in Philadelphia; however the level of disruption will be considerably less for the LID options than many of the traditional infrastructure alternatives.

1. Introduction

1.1 Background

There are numerous ways of managing stormwater runoff and combined sewer overflow (CSO) events in urban areas. These include traditional engineering approaches that rely largely on physical infrastructure such as large-scale concrete collection and storage systems (e.g., excavating and building large diameter tunnels), and pumping collected stormwater to wastewater treatment plants for treatment and discharge. Alternatively, there are more "natural" and environmentally friendly approaches that rely more on "green infrastructure," or Low Impact Development (LID) techniques, to help divert, store, and promote infiltration of stormwaters so that they help restore and enhance natural systems rather than overload traditional wastewater collection and treatment facilities. There are various possible levels and combinations of the traditional and green approaches that can be considered.

Both the traditional and green infrastructure approaches to stormwater and CSO management can be very expensive to retrofit within older urban areas (e.g., costing several billion dollars for a city like Philadelphia). Both approaches can also generate important environmental, social, and other benefits to local watersheds and urban-area communities. However, the green infrastructure, LID-oriented approaches may generate a broader and more valuable array of environmental, public health, and social benefits than do traditional CSO control strategies. In order to gain a clearer appreciation of which option (or mix of approaches) may be most valuable to a community, it is important to assess the types and levels of benefits associated with the alternative approaches. These benefits can then be compared to the costs of each option, so that community leaders can discern which approach will yield the largest net benefit to the community (where net benefits refer to present value benefits minus present value costs).

1.2 Objectives

The Philadelphia Water Department (PWD) currently is giving serious consideration to a wide array of options for controlling CSO events. PWD is especially interested in gaining a more complete understanding of the Triple Bottom Line (TBL) implications of green infrastructure approaches, and of more traditional approaches, in terms of their respective environmental, social, and other values. PWD, in concert with its engineering support contractor – Camp, Dresser and McKee (CDM) – retained Stratus Consulting to evaluate the benefits and external costs (i.e., costs beyond engineering cost estimates for building and operating the various control options) associated with a number of alternative approaches for controlling CSO events in the City of Philadelphia (the City).

Accordingly, this report provides a TBL-oriented benefit-cost assessment of the CSO control alternatives under consideration by PWD. The focus here is on the benefits and external costs of the alternatives. CDM is developing a separate report to describe the engineering design and performance aspects – and engineering cost estimates – for the alternatives. Ultimately, the TBL benefit results from this report, and the engineering cost information from CDM, will be combined to provide insights as to the estimated net benefits of the alternatives.

Throughout this report, we refer to the green infrastructure CSO control options as LID-based approaches. We categorize the different options based on different levels of implementation (e.g., the 50% LID option would manage runoff from 50% of impervious surfaces in Philadelphia through green infrastructure). Green infrastructure and LID are used interchangeably throughout the following chapters and appendices.

We also refer to the traditional infrastructure options according to different levels of implementation. For example, throughout the report we draw upon the "30' Tunnel" option as an example alternative. This option includes a system of storage tunnels serving all watersheds with an effective diameter of 30 ft. Alternative tunneling options (e.g., 15', 20', 25', and 35' options), are also being evaluated by PWD and the impacts of all alternatives are examined here.

1.3 Report Organization

This report is structured as follows:

- First, this main portion of the report provides a brief overview of the four PWD watershed areas addressed by the policy options, as well as abbreviated descriptions of the 16 CSO control options being considered for each area. More detailed descriptions of the watersheds and CSO control options are provided in the main body of the PWD Long Term CSO Control Plan Update (LTCPU).
- Second, a general description is provided of the data and methods used to conduct our TBL-oriented benefit-cost assessment of the alternatives. Also provided is an overview of the types of benefits and external costs we address within this assessment.
- Third, more detailed descriptions are offered of the estimated levels of benefits (and external costs) for each major benefit-cost category. An overview of the methods, data, and limitations associated with these estimates is also provided. (Detailed category-specific appendices, described below, furnish additional detail on the methods, data, findings, and limitations of the analysis for each type of benefit or external cost).

- Fourth, summaries are provided of the benefit estimates for two of the prominent CSO control options under consideration, aggregated across the four watershed areas. These summaries thus provide a city-wide overview of the physical and economic magnitude of benefits (and external costs) for two highlighted CSO control alternatives. The two highlighted CSO control options are the LID-50% option (reflecting a green infrastructure approach), and the 30' Tunnel option (reflecting a more traditional infrastructure approach).
- Fifth, a suite of detailed tables are provided that indicate watershed-specific estimates for each benefit and external cost category, for each CSO control option evaluated.
- Sixth, the key uncertainties inherent in this type of TBL-oriented benefit-cost analysis are discussed, and the results of several sensitivity analyses are provided to provide insights as to the level of stability of the estimates to alternative input values and assumptions.

The main body of this report is then followed by a series of detailed technical appendices – one for each benefit or external cost category assessed. These appendices describe the methods, data, findings, and caveats relevant to each endpoint, and also contain relevant reference citations. The appendices correspond to the following categories of assessed impacts:

- Appendix A: Recreational use and values (both creekside and non-creekside)
- Appendix B: Property values, as enhanced by the LID options
- Appendix C: Heat stress and related premature fatalities avoided
- Appendix D: Water quality and aquatic habitat enhancements and values
- Appendix E: Wetland enhancement and creation
- Appendix F: Poverty reduction benefits of local green infrastructure jobs
- Appendix G: Energy usage and related changes in carbon and other emissions
- Appendix H: Air quality pollutant removal from added vegetation
- Appendix I: Construction- and maintenance-related disruption impacts.

2. Relevant Watersheds and CSO Control Options

PWD's CSO program area covers about 40,500 acres (63 square miles) within the City. The boundaries of the CSO area fall within the watersheds of Tacony-Frankford Creek, Cobbs Creek, the Lower Schuylkill River, and the tidal portion of the Delaware River (Delaware Direct Watershed). The City's CSO program is managed on a watershed-basis and our analysis of CSO control options includes the evaluation of management alternatives in each of the four CSO watersheds.

The following sections provide a brief description of each CSO watershed and outlines the different CSO control options being considered by PWD.

2.1 Philadelphia's CSO Watersheds

The Tookany/Tacony-Frankford Watershed

The Tookany/Tacony-Frankford Watershed encompasses approximately 20,000 acres, or 29 square miles, within the north central portion of Philadelphia County and the southeastern portion of Montgomery County. The creek is referred to as Tookany Creek until it enters Philadelphia County at Cheltenham Avenue. It is then called Tacony Creek from the Montgomery County border until it meets with the historical Wingohocking Creek in Juniata Park. The section of stream from Juniata Park to the Delaware River is referred to as Frankford Creek.

The hydrology of the Tacony-Frankford system is highly modified. Most of the tributary system of Tacony Creek has been converted into sewers. Below what is now Juniata Park, the Tacony joins with buried tributaries to form Frankford Creek. In order to deal with flooding associated with large influxes of stormwater, the Frankford Creek was channelized and straightened in concrete a number of years ago. The concrete channel prevents interaction between Frankford Creek and the groundwater system and eliminates streambed habitat needed to support aquatic life. The area surrounding Frankford Creek is highly industrialized and much of the creek is inaccessible.

The Philadelphia County portion of the watershed accounts for about 62% (12,200 acres) of total watershed land area, and PWD's CSO program area covers almost all of this. The population within this part of the watershed is approximately 285,000, which results in an average population density of about 23 persons per acre. There are about 6.3 miles of stream along Tacony-Frankford Creek targeted for improvements under the different CSO control options (mainstem creek).

Cobbs Creek Watershed

Cobbs Creek is a subwatershed of the larger Darby-Cobbs Watershed, which encompasses approximately 80 square miles of land that drain to the mouth of Darby Creek or below, to its confluence with the Delaware Estuary. Cobbs Creek drains approximately 14,500 acres or 27% of the total Darby-Cobbs Watershed area. The upper portions and headwaters of Cobbs Creek, including East and West Branch Indian Creek, contain portions of Philadelphia, Montgomery, and Delaware Counties. The lower portion of Cobbs Creek Watershed, including the lower mainstem and Naylors Run, drain parts of Philadelphia and Delaware Counties. Cobbs Creek discharges to Darby Creek.

The Philadelphia County portion of the Cobbs Creek Watershed is about 3,600 acres, and falls almost entirely within PWD's CSO program area. This area encompasses about 11.5 miles of stream, including about 8.2 miles of mainstem creek and 3.3 miles of major tributaries. The population of the Philadelphia County portion of the watershed is about 107,000 (U.S. Census Bureau, 2000), which yields a population density of almost 30 persons per acre. Similar to the Tacony-Frankford Watershed, Cobbs Creek is very urbanized and its hydrologic system has been highly modified.

Lower Schuylkill River Watershed

The Schuylkill River Watershed includes portions of 11 counties, and encompasses an area of approximately 2,000 square miles. The river travels approximately 130 miles from its headwaters at Tuscarora Springs in Schuylkill County to its mouth at the Delaware River in Philadelphia. The Schuylkill River is the largest tributary to the Delaware River and is a major contributor to the Delaware Estuary.

The Philadelphia County portion of the Schuylkill River Watershed is approximately 23,000 acres. About half of this area falls within PWD's CSO area, which includes the tidal portion of the Schuylkill River, or the approximately 7 miles of river upstream of the confluence with the Delaware River.

Much of the land outside of the Schuylkill River CSO area is characterized by large open space areas and recreational amenities (e.g., East and West Fairmount Parks and Boathouse row). However, in the lower portion of the watershed, which coincides with the CSO boundaries, there is a significant amount of industrial land uses.

Within the CSO area, there are numerous active and inactive rail lines directly adjacent to the river, including the large and active East Side Yard for CSX Transportation Corporation (CSXT). Several major road corridors also run adjacent to and through the river, including I-95, I-76 (Schuylkill Expressway), I-676, Route 291/Passyunk Avenue, Grays Ferry Avenue, University Avenue, South Street, Walnut Street, Chestnut Street, and Market Street.

The population of the Philadelphia County portion of the Lower Schuylkill River Watershed is about 353,000 (U.S. Census Bureau, 2000), which yields a population density of about 16 persons per acre, on average. The majority of residents (about 82%) live within the CSO area, where population density is almost 30 persons per acre.

Lower Delaware River (Delaware Direct Watershed)

The 300-mile long Delaware River winds its way through four states on the eastern coast of the United States, encompassing 42 counties and 838 municipalities. The river serves a variety of important residential, commercial, and industrial functions, including fishing, transportation, power cooling, and recreational purposes. The river also serves as an important source of drinking water for PWD and other utilities in the regions through which it passes.

The Delaware Direct Watershed encompasses the lower 20 miles of the Delaware River, before it discharges to the ocean. The watershed is located entirely within the City. About 70% of total land area in the watershed falls within PWD's CSO boundaries, which includes the tidal portion of the Delaware River, or about 15.6 stream miles.

The population of the Delaware Direct Watershed is approximately 500,000 and close to 99% of residents live within the CSO area. Like all the CSO watersheds, this area is highly urbanized, however, it does not support the level of industrial activity as seen within the Schuylkill River CSO area. Residential and commercial uses account for about 63% of total land uses in the watershed, while industrial uses account for close to 9%.

2.2 CSO Control Options

For each watershed, PWD has developed a suite of CSO control options based on four primary approaches, including:

- Low-Impact Development
- Tunneling
- Transmission, Plant Expansion and Treatment
- Transmission and Satellite Treatment.

LID (green infrastructure approaches)

For each watershed, PWD has developed a range of LID CSO control options (e.g., 25, 50, 75, and 100% of runoff from impervious surfaces managed through green infrastructure), representing different levels of implementation. The LID approach focuses on restoring a more natural balance between stormwater runoff and infiltration, reducing pollutant loads, and controlling runoff rates at levels that minimize stream bank erosion. A variety of controls are incorporated into the different LID options, including disconnection of impervious cover, bioretention, subsurface storage and infiltration, green roofs, swales, and tree canopy. Land-based measures are a key part of this approach because they provide benefits to the community beyond water quality improvement (e.g., recreational opportunities, improved aesthetics, and increased home values).

The LID options also include a variety of water-based approaches to CSO control, including bed and bank stabilization and reconstruction, aquatic habitat creation, plunge pool removal, improvement of fish passage, and floodplain reconnection. The ultimate goal of this component of the LID program is to restore designated uses and ultimately remove CSO streams from the state’s list of impaired waters. Similar to the land-based approaches described above, stream restoration will provide a number of benefits beyond water quality improvement.

Traditional Infrastructure-based Management Measures

The Tunneling, Transmission, Plant Expansion and Treatment, and Transmission and Satellite Treatment options for CSO control include traditional storage, conveyance, and treatment measures within the collection and treatment system. For each watershed, PWD has developed a number of variations based on these three infrastructure-based approaches. For example, in each watershed, a range of different Tunneling options is currently being evaluated, along with a range of options for both Satellite Treatment and Plant Expansion.

The traditional infrastructure-based measures have two main drawbacks. First, as noted above, the LID-oriented measures provide several important environmental, social, and public health benefits to the community beyond water quality improvement. Traditional infrastructure-based measures typically do not provide these benefits.

Second, traditional infrastructure-based measures may not address the root causes of impairment in Philadelphia’s urban streams, where the primary causes of impairment are modified flow patterns and habitat degradation. Infrastructure-based measures are typically focused on removing loads of specific pollutants rather than restoring natural flow conditions and habitat. As such, they may assist in meeting some specific water quality parameters (e.g., reducing the number of overflow events), but do not necessarily support or enhance/restore the living resources (i.e., the aquatic and riparian ecosystems) of the watersheds.

To obtain maximum benefits and CSO control, PWD is currently considering many of the traditional infrastructure options (particularly the Plant Expansion options), in combination with LID measures. Traditional infrastructure options are expected to play an important role in developing cost-effective and feasible solutions. For more detailed information on the suite of CSO management options currently being considered by PWD, see LTCPU.

References

U.S. Census Bureau. 2000. 2000 Census of Population Social and Economic Characteristics, Philadelphia, Bucks, Chester, Delaware and Montgomery Counties, Pennsylvania.

3. General Methodology and Data

3.1 Overview of the TBL Approach

The TBL approach reflects the fact that society and its enterprises – including the institutions that work specifically in the public interest (e.g., water and wastewater utilities) – typically are engaged in activities intended to provide the greatest total value to the communities they serve. These values extend well beyond the traditional financial bottom line that portrays only cash flows (i.e., revenues and expenditures) of a standard financial analysis. PWD and similar utilities that serve the public interest also need to consider their stewardship and other responsibilities, and to thus account for how they may generate values that contribute towards the "social" and "environmental" bottom lines. Hence, a more complete and meaningful accounting of PWD activities needs to provide a TBL perspective that reflects all three bottom lines: financial, social, and environmental.

In many ways, this TBL perspective is very similar to how an economist would define a comprehensive benefit-cost analysis that attempts to account for the full range of internal and external costs and benefits of an activity (project, or program), including nonmarket outcomes. The TBL approach provides an organizing framework within which the broad array of benefits and costs can be portrayed and communicated. This TBL approach should include both those outcomes that can be quantified and reasonably well monetized in dollar terms, as well as outcomes that are less amenable to reliable valuation and instead require qualitative discussion.

Accordingly, this TBL assessment of the benefits and external costs of the various relevant CSO control options for Philadelphia relies to a large extent on the tools and methods deployed by natural resource economists to estimate market and nonmarket values for a broad array of relevant environmental and social impacts. The sections below, and the more technically-oriented appendices, provide additional detail for the broad range of impacts that are assessed in this TBL evaluation of the PWD's CSO control options.

3.2 Key Inputs to the TBL Analysis

As noted above, the TBL analysis evaluates CSO control options that have been defined by PWD and CDM. Accordingly, most of the key physical inputs to our analyses (e.g., number and general location of trees planted, the number of stream miles impacted, the types of vehicles used on various construction and maintenance activities, power requirements associated with construction, the timing of various project activities) were provided by CDM.

3.3 General Overview of Methods and Key Assumptions

Key assumptions and basic methodological approaches used for the overall TBL analysis are detailed below. Assumptions and methods associated with each specific benefit and external cost category are discussed in the subsequent section.

External costs and benefits. As part of our analysis, we evaluate the "external" or ancillary costs and benefits associated with each of the CSO options (i.e., costs that are not included in traditional engineering estimates of the expense to build and operate facilities). External costs include, for example, time spent and fuel lost in construction-related traffic delays, and air quality impacts associated with construction and implementation activities (including the carbon footprint of concrete requirements under the traditional infrastructure alternatives). Under the LID alternatives, many of the air quality and energy impacts result in ancillary benefits in the form of carbon sequestration, air pollutant removal, and energy savings due to the cooling effect and other impacts provided by adding trees and other vegetation.

General methods for quantifying and/or valuing outcomes. The benefit and external cost estimates are derived from standard approaches as developed and used by environmental impact and valuation professionals and organizations. Many of the key methods, models and data are developed and deployed routinely by the U.S. Environmental Protection Agency (EPA) and other relevant federal agencies. For example, the air quality impacts of added trees is based on a model developed and applied by the U.S. Forest Service for Philadelphia. The resulting estimates of projected changes in ambient air quality (i.e., ozone and particulate matter concentrations) is then analyzed using EPA's Environmental Benefits Mapping and Analysis Program (BenMAP), which estimates reductions in health risks and associated monetary values for the given change in ambient air quality. Similar reliance on well established federal and other models, methods, and data underlie most of the key benefit estimates derived in this study.

Time path for realizing benefits. Results presented below represent the discounted sum of annual values over the 40-year planning horizon (2010–2049). For each benefit and cost category, we applied a time path over which the different benefits and costs accrue. Our timelines are based on implementation, construction, and maintenance schedules provided by CDM, as well as on a tree growth model that applies to benefits dependent on the number of additional trees to be planted in the watershed. For example, the benefits associated with air pollutant removal from trees will not be fully realized in the first year of project implementation. Our analysis takes into account the percentage of trees planted each year as well as the rate at which the trees grow and mature (assumed here to be 20-years after they are planted).

Present value estimates. Our monetary results are in present value terms [2009 U.S. dollars (USD)] and are based on an inflation rate of 4% and a nominal discount rate of 4.875% applied over the 40-year planning horizon. Later in this report, we present the results of sensitivity analyses that were conducted to evaluate the impact of using alternative escalation and discount rates.

Additivity versus double-counting. The benefits presented below are additive, meaning they can be added together to generate a total value. However, the results of the property value analysis are likely to include some overlap and double-counting of benefits measured under several of the other benefit categories. For example, the anticipated energy savings enjoyed at tree-shaded properties are likely to be capitalized into the property values for those residences (depending on the extent to which current and prospective owners take anticipated energy costs into account when valuing properties). Likewise, enhanced greenspace-related recreational opportunities in the neighborhood are also likely to be capitalized (at least in part) in property values. At the same time, the property value analysis does reflect some unique values that are not embodied in the other estimated categories (e.g., aesthetics). Thus, the interpretation of the property value estimates needs to be carefully considered. For the purposes of this analysis, we include 50% of the estimated property value benefits to avoid this potential double-counting.

Omissions, biases, and uncertainties. Analyses of social and environmental benefits invariably require the use of assumptions and approaches (e.g., benefits transfer) that interject uncertainty about the accuracy or comprehensiveness of the empirical results. Throughout our analysis, and as detailed in the appendices, we have attempted to be explicit and reasonable about what assumptions and approaches we are adopting. We also provide summaries in each appendix of the key omissions, biases, and uncertainties (OBUs) that we believe are embedded in our work, and describe how the results of the analysis would likely have been impacted (e.g., whether benefits would have increased, decreased, or changed in an uncertain direction) if the omission or data limitation had been avoidable.

Sensitivity analyses. In conjunction with the OBU issues, we conducted several sensitivity analyses to explore how changing some of the key assumptions would impact our findings. The results of these sensitivity analyses are summarized in Chapter 6 (and are also described in relevant appendices).

4. The Benefits and External Costs of PWD's CSO Control Options

The TBL analysis of benefits and external costs is organized according to a series of benefit categories. The general approach and results for each category are described below. Considerable additional detail can be found in the associated appendices. It is important to note that not all options generate every type of benefit described below. Likewise, some options create external costs (negative benefits, such as added energy consumption and carbon emissions) within some of the categories.

4.1 Recreational Use and Values (creekside and non-creekside)

The green infrastructure, or LID-based, options include stream restoration and riparian buffer improvements, which will result in an anticipated increase in creekside (i.e., near stream) recreational opportunities in green areas along and adjacent to the impacted waters. Most of this added activity is anticipated for land-based, near water activities such as jogging, biking, walking, picnicking, and so forth. Little or no increases are expected in in-stream recreation (direct water contact or angling is not anticipated or encouraged in some relevant watershed areas).

Under the LID options, recreational opportunities will also improve in non-creekside areas, due to the general increase in vegetated and treed acreage in the relevant portions of the City. These non-creekside recreational benefits also are included in the analysis.

The more traditional infrastructure approaches (e.g., tunnels) are not expected to generate any appreciable changes in these types of recreational levels or values. While these approaches are aimed at reducing CSO overflow events – which will yield some water quality improvement – these options do not result in improved streamside or urban landscape conditions. Thus, there are no projected recreational benefits estimated for these options.

Total recreational benefits associated with improvements made under the LID options are a function of the additional recreational trips ("user days") taken as a result of these improvements, and the benefit (or direct use value) derived from each trip. To estimate additional recreational use and associated direct use benefits, we relied on a recent report prepared for the Philadelphia Parks Alliance by the Trust for Public Lands. The 2008 report, *How Much Value Does the City of Philadelphia Receive from its Park and Recreation System?* (Parks Report), provides visitation data and direct use values for a variety of recreational uses and activities at

Philadelphia's parks. We tailored these data to individual watersheds based on conversations with park staff, detailed watershed and park management plans, and on-site visits

Based on these methods and data, we estimate an increase of nearly 350 million outings over the 40-year period (i.e., 2010–2049) for the 50% LID option. Over 70% of these outings are for near-stream activities, and the balance are non-creekside. The monetized present value of these added activities over the 40-year period amounts to over $520 million (these and all other dollar values described in this report are in 2009 USD, unless otherwise noted). Additional detail is provided in Appendix A.

4.2 Enhanced Aesthetics (reflected in residential property values)

Trees and plants improve urban aesthetics and community livability, and several empirical studies show that property values are higher when trees and other vegetation are present in urban neighborhoods. Applying a benefits transfer approach to interpret the relevant body of LID-related published hedonic valuation literature, coupled with neighborhood-specific baseline property values, we derive an estimated aggregate increase in property values for each LID option and impacted city area. The literature used includes a Philadelphia-specific study published by Wachter and Wong (2006).

For the 50% LID option applied city-wide to all four watershed areas, the estimated value of enhanced residential property values amounts to over $1.1 billion. We reduce this by 50% to avoid potential double-counting with several of the other benefit categories, since our objective here is to capture aesthetics-related benefits only. The resulting $575 million in present value benefits only accounts for residential properties; enhanced values for nonresidential properties are not included in this analysis. Additional detail is provided in Appendix B.

4.3 Heat Stress-Related Premature Fatalities Avoided

The City has endured several excessive heat events (EHEs), with numerous documented cases of premature fatality attributed to heat stress in some summer periods (e.g., over 100 premature fatalities attributed to heat stress in the EHEs of 1993). The episodes have been studied extensively by the City, the federal Centers for Disease Control (CDC), and EPA.

Green infrastructure (trees, green roofs, and bio-retention areas) – such as would be implemented under the LID-oriented options – creates shade, reduces the amount of heat absorbing materials and emits water vapor – all of which cool hot air and reduce the urban heat island (UHI) effect. This cooling effect will be sufficient to actually reduce heat stress-related fatalities in the City during extreme heat wave events.

Applying the standard methods developed and applied for relevant federal agencies, our analysis (supported by Dr. Larry Kalkstein and his associates) links increases in vegetated areas to potential reductions in summer temperatures and, ultimately, to projected cases of heat stress fatalities avoided. City-wide, we estimate 196 premature fatalities avoided over the 40-year project planning horizon, for the 50% LID option.

Standard EPA methods and values (i.e., value of statistical life, VSL, estimates) were then used to monetize these reductions in premature fatalities. For the 50% LID option, the present value of the reduced risk of premature fatality from heat stress amounts to nearly $1.1 billion. This estimate does not include the avoided medical costs and reduced suffering of morbidity impacts (i.e., the costs associated with those individuals who would otherwise suffer adversity from heat stress, but would not be projected to die from the impact). As such, the omission of morbidity events means that our premature mortality-oriented estimates are probably a lower-bound of the total public health benefit attributable to the LID options. Additional detail is provided in Appendix C.

4.4 Water Quality and Aquatic Habitat Enhancements and Values

A core objective of any CSO control option is to improve water quality and aquatic ecosystems in the impacted watersheds. The traditional infrastructure options (e.g., plant expansions, tunnels) are aimed at reducing the number of overflow episodes, but do little to directly improve the physical riparian area environment (i.e., riparian and aquatic ecosystems and habitat areas) or otherwise enhance living resources in many of the City's watershed environments. In contrast, the LID options, in conjunction with the related watershed restoration efforts, are expected to generate improvements to these natural resources.

To estimate the value of these improvements, a benefits transfer approach was applied, drawing on a meta analysis of nonuse value estimates associated with different potential baseline levels and improvements in water quality. A primary objective of this meta-analysis was to develop a tool (regression model), based on existing (primary) studies, that could be used to predict what individual households would be willing to pay for improvements in water quality to a specified level. Using the regression tool, we were able to apply information related to the Philadelphia CSO control options (e.g., demographic data and expected water quality/habitat improvements under each option) to estimate total willingness to pay (WTP) for water quality improvements.

Due to differences in demographics and location (distance from the resource), we separately evaluated WTP for households within Philadelphia and nearby households outside of the City. The households outside of Philadelphia included in this analysis fall within the greater Philadelphia Metropolitan Area (MA; including Bucks, Chester, Delaware and Montgomery counties).

The results for the 50% LID option indicate an estimated annual WTP of approximately $10 to $15 per household per year, when the water quality and related habitat enhancements are fully realized. Over the 40-year analysis period, this amounts to an estimated city-wide value of over $330 million. Additional detail is provided in Appendix D.

4.5 Wetland Enhancement and Creation

Under the LID options, watershed restoration and related efforts are expected to create or enhance over 190 acres of wetlands in the relevant watersheds. We monetized these added and enhanced wetland acres according to the range of services they are expected to provide in the urban area watersheds, using a benefits transfer approach based on the relevant published literature of wetland values.

For the 50% LID option, these added wetland acres and related services are estimated to provide over $1.6 million in added value city-wide, in present value terms, over the 40-year project planning period. Additional detail is provided in Appendix E.

4.6 Poverty Reduction Benefits of Local Green Infrastructure Jobs

Jobs associated with large civil works projects, such as CSO control options, are not typically counted within an economically sound benefit-cost analysis. This is because the labor retained in such projects typically would be gainfully employed in other ventures (private or public investments), meaning that there typically is a *transfer* of employment across potential activities rather than a real net gain in jobs. Therefore, in this analysis of PWD's CSO control options, we are not counting jobs under any of the options as new employment creation benefits.

However, there are some relevant considerations to be taken into account for some of the CSO control options. Specifically, there are likely to be social benefits (e.g., avoided social costs) when jobs can be steered to local citizens who are typically unemployed (or under-employed) due to a lack of education and training and other social circumstances.

Specialized labor is required for construction of conventional stormwater management solutions (e.g., boring, tunneling). Such skilled laborers might typically be already employed in the construction field. In contrast, green infrastructure projects, as embodied in the LID options, creates the opportunity to hire unskilled – and otherwise unemployed – laborers for landscaping and restoration activities. Thus the benefits of providing these green jobs include the avoided costs of social services that the City would provide on behalf of the same people if they remained unemployed. These "green infrastructure jobs" therefore have the unique capability to provide not just employment, but a crucial stepping stone to help people escape from poverty. The benefits of providing "green infrastructure jobs" include the avoided costs of social services that the City would provide on behalf of the same unskilled people if they remained unemployed, outside the workforce, and trapped in poverty.

For the 50% LID option, we project over 15,000 job years will be created for low-skilled local workers, over the 40-year period, across the four watershed areas. Based on the avoided costs of social services linked to these added job years, we estimate a present value benefit of nearly $125 million. For addition detail, see Appendix F.

4.7 Energy Use and Related Changes in Carbon and Other Emissions

Green space helps lower ambient temperatures and, when incorporated on and around buildings, helps shade and insulate buildings from wide temperature swings, decreasing the energy needed for heating and cooling. In addition, diverting stormwater from wastewater collection, conveyance and treatment systems reduces the amount of energy needed to pump and treat the water, which in turn reduces emissions of greenhouse gases (GHG, including carbon dioxide, CO_2) and other air pollutants (e.g., sulfur dioxide, SO_2, and nitrogen oxides, NO_x) from power plants. Reduced energy demands in buildings, and increased carbon sequestration by added vegetation, also result in a lower carbon footprint (reduced CO_2 emissions).

Our analysis calculates the amount of energy consumption added (or reduced) by the various CSO control options, and calculates the value of the added energy costs (or the energy cost savings), at current energy prices. The energy use levels include, for example, the home energy cost savings provided by the shading offered by trees added under the LID options. Also included is the increased consumption of motor fuel associated with construction-related vehicle traffic delays imposed by any of the options. Some CSO control options generate net energy savings (i.e., the LID options), and others result in a net increase in energy use and costs (e.g., the tunnel options). It is important to note that our analysis includes only those energy costs that are external to engineering cost estimates. The cost of fuel used by construction and maintenance vehicles, and electricity costs associated with excavation and other construction activities are reflected in the cost estimates developed by CDM.

In addition to the direct expense of added energy consumed (or savings from use of less energy), we also assess the level of CO_2 emissions added (or reduced or sequestered) by each option. Thus, for example, the LID options reduce CO_2 emissions at power plants by providing energy savings at shaded homes, plus the added trees sequester some CO_2 as well. These reductions more than offset the added emissions associated with implementation-related activities, such as added vehicle fuel use during the installation of green infrastructure. The net savings in emissions are valued using a "social cost of carbon" estimate derived from the Intergovernmental

Panel on Climate Change (IPCC) of the climate change damages contributed by each metric ton (MT) of CO_2 equivalent (CO_2e) emitted. The value used is $12/MT.

In contrast, traditional infrastructure options tend to increase net CO_2 emissions, because they require extensive excavation activity and concrete, and also required added energy use in pumping and treating the collected and stored stormwaters. Again, the direct cost of the energy used in constructing and operating the traditional infrastructure approaches are not included in our cost estimates, because they are internal costs that are reflected in the capital and operation and maintenance (O&M) costs developed for each of those CSO control options (i.e., the energy cost is included in the engineering cost estimates provided by CDM). However, in our work, we do include the external costs associated with the added energy use required by these options.

Finally, the changes in energy use also change the amount of SO_2 and NO_x emitted from power plants. These changes in emissions are estimated based on region-specific data from EPA, and assigned monetary values based on EPA methods that reflect the average health benefit (or cost) associated with each ton of emission reduced (or added).

For the 50% LID option, our analysis indicates a net energy savings over the 40-year planning period of nearly 370 million kilowatt hours (kWh) of electricity and nearly 600 million British thermal units (Btus) of natural gas. The 50% LID option will result in close to 0.5 million gallons of "wasted" motor fuel consumed by vehicles delayed by construction activities. Emissions reductions over that period include over 1,500 MT of $SO_{2,}$ 1.1 million MT of CO_2, and a small reduction in NO_x emissions of 38 MT.

The monetized present value of these changes from the 50% LID option amount to nearly $34 million for energy savings, over $21 million for reduced CO_2 emissions, and over $46 million for reduced net damages from SO_2 and NO_x emissions. For additional detail, see Appendix G.

4.8 Air Quality Pollutant Removal from Added Vegetation

Trees and vegetation improve air quality by filtering some airborne pollutants (particulate matter and ozone). Likewise, reduced energy consumption results in decreased emissions (SO_2 and NO_x) from power generation facilities (as described and evaluated in the previous section). These air quality improvements can reduce the incidence and severity of respiratory illness.

To evaluate the air quality impacts of added trees, we used a model developed by the U.S. Forest Service, for application in Philadelphia. We analyzed the resulting estimates of projected changes in ambient air quality (i.e., ozone and particulate matter concentrations) using software developed by the EPA to calculate the avoided health effects from the contribution of trees to reducing ozone and $PM_{2.5}$ concentrations, and to estimate the economic value of the avoided health effects. EPA's BenMAP (Ver. 3.0.15), was used to conduct this analysis.

The avoidable air pollution-related health effects estimated in this analysis are:

- Premature mortality (from ozone and $PM_{2.5}$)
- Onset of irreversible chronic bronchitis ($PM_{2.5}$)
- Heart attacks (non-fatal acute myocardial infarctions) ($PM_{2.5}$)
- Hospital admissions (non-fatal) for respiratory and cardiovascular conditions (from ozone and $PM_{2.5}$)
- Emergency room visits for asthma (from ozone and $PM_{2.5}$)
- Respiratory symptoms (days of illness) (from ozone and $PM_{2.5}$)
- Work loss days ($PM_{2.5}$) and school absence (ozone).

The quantified estimates are then monetized using standard EPA dollar values for each applicable adverse health endpoint.

For the 50% LID option, applied across the four watershed areas, we estimate that after full implementation and tree maturation, the health effects avoided will include between 1 and 2.4 premature fatalities avoided per year, 1.2 heart attacks avoided per year, and over 700 cases of other respiratory illness days avoided per year. The present value of the associated monetized benefits is over $130 million over the 40-year period. Additional detail is provided in Appendix H.

4.9 Construction- and Maintenance-Related Disruption Impacts

All of the CSO options will result in some level of disruption due to construction and program activities. Social costs of disruption can include traffic delays, limited access to places of business, increased noise and pollution, and other inconveniences. Under all of the CSO alternatives, construction activities will likely result in occasional delays and increased travel times for passenger and commercial vehicle travelers in Philadelphia. Travel time delays can be caused by:

- General traffic slowdowns associated with an increase in the number of trucks and construction equipment on the road
- Slowdowns from trucks entering and exiting construction or landscaping sites
- Lane or road closures associated with construction in the roadway or road right-of-way.

In addition to the value of "lost" time spent in traffic, construction-related delays can result in increased costs associated with additional fuel used by vehicles as a result of slower speeds and occasional vehicle stops and idling.

Using standard methods and data for estimating traffic delays and associated fuel use and time loss, we estimated the 40-year present value of these external costs for each CSO control option. City-wide, the present value of these external costs for the 50% LID option is $5.6 million, and for the 30' Tunnel option, it is more than 200 times larger, at over $13.4 billion. Additional detail is provided in Appendix I.

References

Wachter, S.M. and G. Wong. 2006. What is a tree worth? Green-city strategies and housing prices. *Real Estate Economics* 36(2):2008.

5. Summary of Results

The following sections summarize the benefits and external costs of the CSO control options currently being considered by PWD. We first present the results of our analysis on a City-wide basis, highlighting the benefits and costs across the CSO watersheds. More detailed tables, providing benefits and costs in each watershed by category, are provided at the end of this chapter.

Again, it is important to note that throughout the following sections, we refer to the green infrastructure CSO control options as LID-based approaches. We categorize the different options based on different levels of implementation (e.g., the 50% LID option would manage runoff from 50% of impervious surfaces in Philadelphia through green infrastructure). Green infrastructure and LID are used interchangeably throughout the next chapter and appendices.

We also refer to the traditional infrastructure options according to different levels of implementation. For example, throughout the report we draw upon the "30' Tunnel" option as an example alternative. This option includes a system of storage tunnels serving all watersheds with an effective diameter of 30 ft. Alternative tunneling options (e.g., 15', 20', 25', and 35' options), are also being evaluated by PWD and the impacts of all alternatives are examined here.

5.1 Benefits of LID CSO Control Options

Figure 5.1 presents the total net benefits (defined here as benefits minus the external costs of construction disruption) for the LID CSO control options over the 40-year project evaluation period. City-wide, total present value benefits range from about $1,935 million (2009 USD) under the 25% LID option to more than $4,466 million under the 100% LID option.

The relative make up of total benefits by watershed is consistent across LID options. As shown in Figure 5.1, the Tacony-Frankford Creek Watershed accounts for about 20 to 22% of total benefits under each option. Cobbs Creek makes up about 8 to 11%, while the Schuylkill and Delaware River Watersheds account for about 25 to 27% and 42 to 44% of total net benefits, respectively.

Figure 5.2 shows the breakdown of total City-wide benefits by benefit category for the 50% LID option. As shown, reduced heat-stress fatalities, increased property values, and increased recreational opportunities make up the majority of total benefits. These categories account for 37, 20, and 18% of total benefits, respectively.

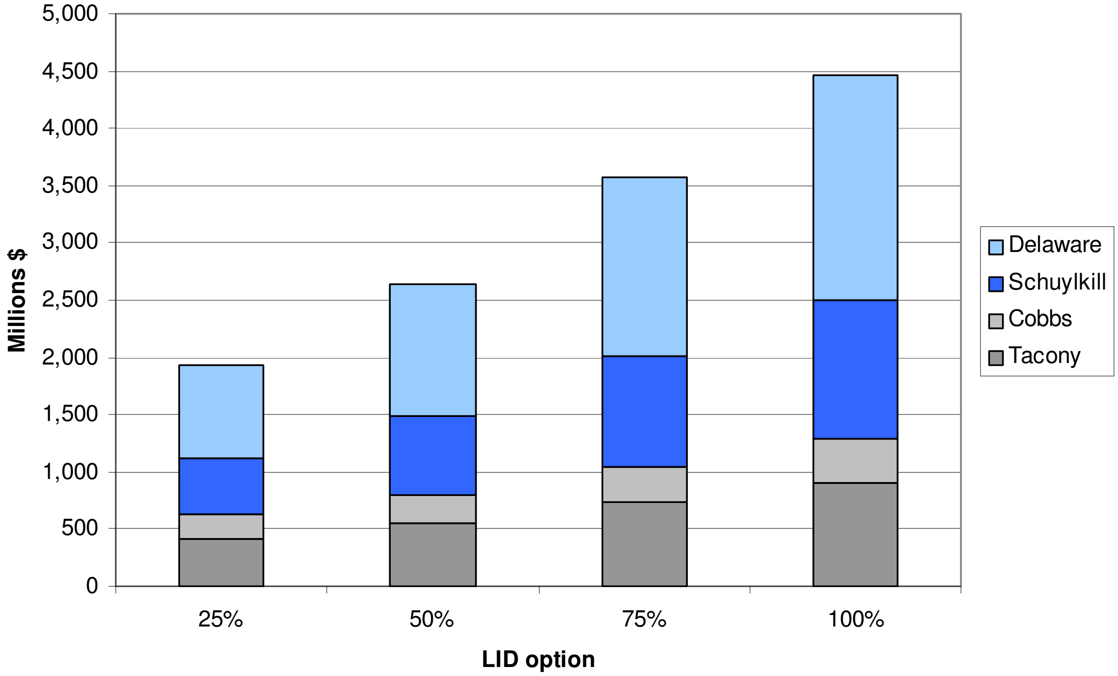

Figure 5.1. City-wide net benefits for LID options by watershed.

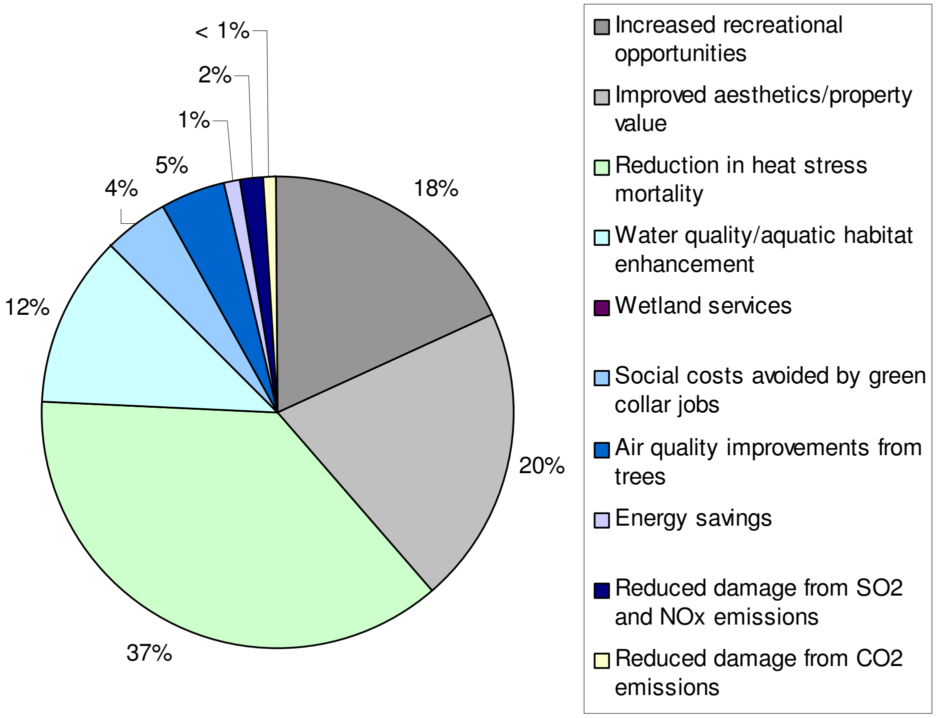

Figure 5.2. Shares of City-wide present value benefits of key CSO options: Cumulative through 2049.

The benefits associated with improved water quality and aquatic habitat also account for a substantial portion of total benefits (12%), while net energy savings, reduced NO_x and SO_2 emissions, and carbon sequestration all account for less than 2%. “Green jobs” and air quality improvements due to pollutant removal from trees, both account for about 5% of total benefits. The percent breakdown of benefit categories shown in Figure 5.2 is consistent across the LID options.

5.2 Benefits and External Costs of Example CSO Options

To show a more direct comparison of benefits and external costs of the different CSO control options, Figure 5.3 provides City-wide estimates for the LID and tunneling CSO Control options. These options were chosen to demonstrate the difference in net benefits between green and traditional infrastructure. The reporting of these results is not intended to indicate that a final PWD decision will be based on these two alternatives.

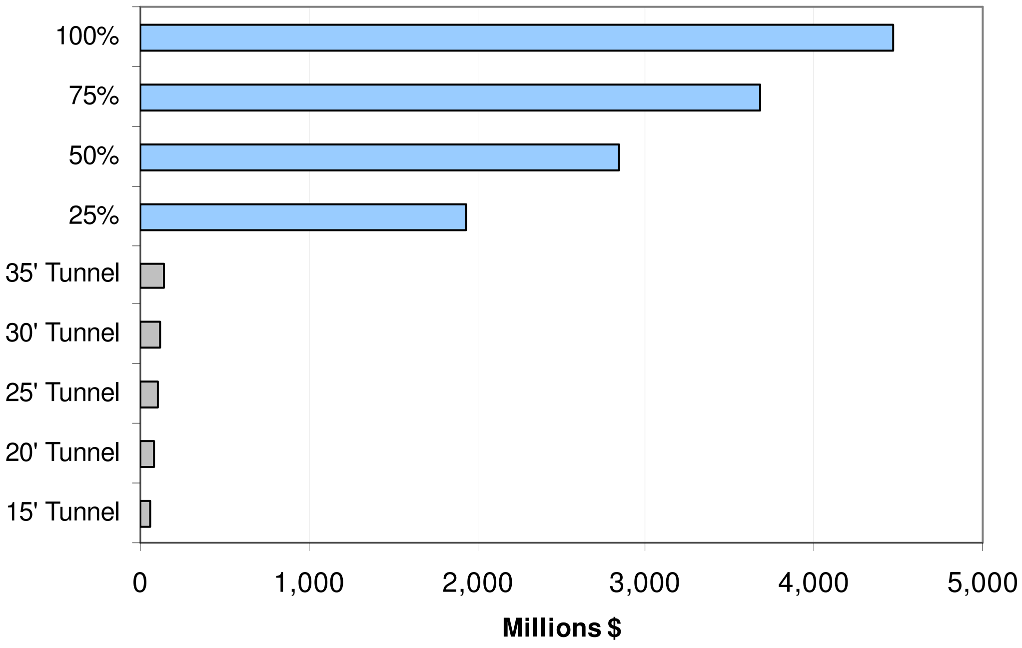

Figure 5.3. City-wide present value benefits/external costs of the LID and tunneling CSO control options, over 40-year project period (2009 USD).

As shown in Figure 5.3, on a City-wide basis, the net external costs of the tunneling options ranges from about $61.6 million under the 15’ Tunneling option, to more than $140 million under the 35’ Tunneling option. This compares to the range of net present value benefits for the LID options of $1,935 million to $4,466 million, as reported in Section 5.1 above.

Table 5.1 shows City-wide estimates for total net benefits (benefits minus external costs) of the 50% LID and 30’ Tunnel options over the 40-year project period. This comparison is intended to provide a bit more detail into the break down of the individual options. The ratio of the external costs of the tunneling options to the net benefits of the LID options varies considerably by watershed. Section 5.3 provides a comparison of the costs and benefits of these different options for each watershed.

As discussed earlier in this report, the physical unit measures associated with the monetary values presented above are an important component of our discussion of total benefits. For the LID options, for example, physical unit measures include the number of lives saved as a result of reduced heat stress, the number of new recreational visitor days, and the energy and carbon savings associated with increased vegetated area, among others.

Table 5.2 presents City-wide estimates for the physical unit measures associated with the 50% LID and 30’ Tunneling options. The measures shown below can be directly tied to the monetary values provided in Table 5.1.

5.3 Detailed Results by Watershed

The following tables provide detailed results for the CSO control options being evaluated in each of the CSO watersheds. Tables 5.3–5.6 show the present value estimates (2009 USD) for each benefit/external cost category, while Tables 5.7–5.10 provide the physical unit measures associated with these values. Finally, for comparison purposes, Figures 5.4–5.7 provide a visual depiction of the present value net benefits/external costs for the tunneling versus LID options within each watershed. The tables and figures included in the following pages include options in the Delaware River Watershed.

Table 5.1. City-wide present value benefits of key CSO options: Cumulative through 2049 (2009 million USD)

Benefit categories	50% LID option	30' Tunnel option[a]
Increased recreational opportunities	$524.5	
Improved aesthetics/property value (50%)	$574.7	
Reduction in heat stress mortality	$1,057.6	
Water quality/aquatic habitat enhancement	$336.4	$189.0
Wetland services	$1.6	
Social costs avoided by green collar jobs	$124.9	
Air quality improvements from trees	$131.0	
Energy savings/usage	$33.7	$(2.5)
Reduced (increased) damage from SO_2 and NO_x emissions	$46.3	$(45.2)
Reduced (increased) damage from CO_2 emissions	$21.2	$(5.9)
Disruption costs from construction and maintenance	$(5.6)[b]	$(13.4)
Total	**$2,846.4**	**$122.0**

a. 28' Tunnel option in Delaware River Watershed.
b. Parentheses indicate negative values.

Table 5.2. City-wide natural unit benefits of key CSO options: Cumulative through 2049

Benefit categories	50% LID option	30' Tunnel option[a]
Additional creekside recreational user days	247,524,281	
Additional non-creekside recreational user days	101,738,547	
Reduction in number of heat-related fatalities	196	
Annual WTP per household for water quality and aquatic habitat improvements[b]	$9.70–$15.54	$5.63–$8.59
Wetlands created or restored (acres)	193	
Green collar jobs (job years)	15,266	
Change in particulate matter ($PM_{2.5}$) due to increased trees ($\mu g/m^3$)	0.01569	
Change in seasonal ozone due to increased trees (ppb)	0.04248	
Electricity savings due to cooling effect of trees (kWh)	369,739,725	
Natural gas savings due to cooling effect of trees (kBtu)	599,199,846	
Fuel used (vehicles for construction and O&M) (gallons)	493,387	1,132,409
SO_2 emissions (metric tons)	(1,530)	1,452
NO_x emissions (metric tons)	(38)	6,356,083
CO_2 emissions (metric tons)	(1,091,433)	347,970
Vehicle delay from construction and maintenance (hours of delay)	346,883	796,597

a. 28' Tunnel option in Delaware River Watershed.
b. WTP per household in Philadelphia, MA, including Bucks, Chester, Delaware, Montgomery, and Philadelphia counties.

Table 5.3. Present value benefits of key CSO options in Tacony-Frankford Watershed: Cumulative through 2049 (2009 million USD)

Benefit categories	50% LID option	30' Tunnel option[a]
Increased recreational opportunities	$161.2	
Improved aesthetics/property value (50%)	$85.0	
Reduction in heat stress mortality	$249.9	
Water quality/aquatic habitat enhancement	$23.7	$13.3
Wetland services	$0.3	
Social costs avoided by green collar jobs	$27.0	
Air quality improvements from trees	$28.3	
Energy savings/usage	$7.3	$(0.4)
Reduced (increased) damage from SO_2 and NO_x emissions	$10.0	$(8.8)
Reduced (increased) damage from CO_2 emissions	$4.6	$(1.1)
Disruption costs from construction and maintenance	$(1.2)	$(2.2)
Total	**$596.0**	**$0.8**

a. 28' Tunnel option in Delaware River Watershed.

Table 5.4. Present value benefits of key CSO options in Cobbs Creek Watershed: Cumulative through 2049 (2009 million USD)

Benefit categories	50% LID option	30' Tunnel option[a]
Increased recreational opportunities	$100.2	
Improved aesthetics/property value (50%)	$24.8	
Reduction in heat stress mortality	$89.8	
Water quality/aquatic habitat enhancement	$30.6	$17.2
Wetland services	$0.3	
Social costs avoided by green collar jobs	$8.6	
Air quality improvements from trees	$9.0	
Energy savings/usage	$2.3	$(0.5)
Reduced (increased) damage from SO_2 and NO_x emissions	$3.2	$(6.5)
Reduced (increased) damage from CO_2 emissions	$1.5	$(1.0)
Disruption costs from construction and maintenance	$(0.4)	$(2.8)
Total	**$270.0**	**$6.5**

a. 28' Tunnel option in Delaware River Watershed.

Table 5.5. Present value benefits of key CSO options in Schuylkill River Watershed: Cumulative through 2049 (2009 million USD)

Benefit categories	50% LID option	30’ Tunnel option[a]
Increased recreational opportunities	$90.1	
Improved aesthetics/property value (50%)	$193.7	
Reduction in heat stress mortality	$297.1	
Water quality/aquatic habitat enhancement	$86.2	$48.5
Wetland services	$0.3	
Social costs avoided by green collar jobs	$28.9	
Air quality improvements from trees	$30.4	
Energy savings/usage	$7.8	$(0.6)
Reduced (increased) damage from SO_2 and NO_x emissions	$10.7	$(14.2)
Reduced (increased) damage from CO_2 emissions	$4.9	$(1.7)
Disruption costs from construction and maintenance	$(1.3)	$(3.4)
Total	**$748.9**	**$28.5**

a. 28’ Tunnel option in Delaware River Watershed.

Table 5.6. Present value benefits of key CSO options in Delaware River Watershed: Cumulative through 2049 (2009 million USD)

Benefit categories	50% LID option	30’ Tunnel option[a]
Increased recreational opportunities	$173.0	
Improved aesthetics/property value (50%)	$271.2	
Reduction in heat stress mortality	$420.9	
Water quality/aquatic habitat enhancement	$195.8	$110.0
Wetland services	$0.7	
Social costs avoided by green collar jobs	$60.4	
Air quality improvements from trees	$63.4	
Energy savings/usage	$16.3	$(0.9)
Reduced (increased) damage from SO_2 and NO_x emissions	$22.4	$(15.7)
Reduced (increased) damage from CO_2 emissions	$10.3	$(2.1)
Disruption costs from construction and maintenance	$(2.7)	$(5.1)
Total	**$1,231.6**	**$86.2**

a. 28’ Tunnel option in Delaware River Watershed.

Table 5.7. Natural unit benefits of key CSO options in Tacony-Frankford Watershed: Cumulative through 2049

Benefit categories	50% LID option	30' Tunnel option[a]
Additional creekside recreational user days	80,527,887	
Additional non-creekside recreational user days	22,714,215	
Reduction in number of heat-related fatalities	46	
Annual WTP per household for water quality and aquatic habitat improvements[b]	\$9.70–\$15.54	\$5.63–\$8.59
Wetlands created or restored (acres)	35	
Green collar jobs	3,303	
Electricity savings due to cooling effect of trees	79,771,661	
Natural gas savings due to cooling effect of trees	129,277,877	
Fuel used (vehicles for construction and O&M)	106,449	184,336
SO_2 emissions (metric tons)	(330)	283
NO_x emissions (metric tons)	(8)	1,082,609
CO_2 emissions (metric tons)	(235,478)	63,986
Disruption delay from construction and maintenance	74,840	129,672

a. 28' Tunnel option in Delaware River Watershed.

b. WTP per household in Philadelphia, MA, including Bucks, Chester, Delaware, Montgomery, and Philadelphia counties.

Table 5.8. Natural unit benefits of key CSO options in Cobbs Creek Watershed: Cumulative through 2049

Benefit categories	50% LID option	30' Tunnel option[a]
Additional creekside recreational user days	50,478,407	
Additional non-creekside recreational user days	8,629,946	
Reduction in number of heat-related fatalities	17	
WTP per household for water quality and aquatic habitat improvements[b]	\$9.70–\$15.54	\$5.63–\$8.59
Wetlands created or restored (acres)	39.93	
Green collar jobs	1,050	
Electricity savings due to cooling effect of trees	25,475,530	
Natural gas savings due to cooling effect of trees	41,285,620	
Fuel used (vehicles for construction and O&M)	33,995	235,991
SO_2 emissions (metric tons)	(105)	208
NO_x emissions (metric tons)	(3)	1,256,965
CO_2 emissions (metric tons)	(75,201)	59,809
Disruption delay from construction and maintenance	23,901	166,009

a. 28' Tunnel option in Delaware River Watershed.

b. WTP per household in Philadelphia, MA, including Bucks, Chester, Delaware, Montgomery, and Philadelphia counties.

Table 5.9. Natural unit benefits of key CSO options in Schuylkill River Watershed: Cumulative through 2049

Benefit categories	50% LID option	30' Tunnel option[a]
Additional creekside recreational user days	40,371,870	
Additional non-creekside recreational user days	22,991,914	
Reduction in number of heat-related fatalities	55	
Annual WTP per household for water quality and aquatic habitat improvements[b]	\$9.70–\$15.54	\$5.63–\$8.59
Wetlands created or restored (acres)	30	
Green collar jobs	3,535	
Electricity savings due to cooling effect of trees	85,676,380	
Natural gas savings due to cooling effect of trees	138,847,060	
Fuel used (vehicles for construction and O&M)	114,328	285,414
SO_2 emissions (metric tons)	(355)	456
NO_x emissions (metric tons)	(9)	1,653,470
CO_2 emissions (metric tons)	(252,908)	98,814
Disruption delay from construction and maintenance	80,380	200,775

a. 28' Tunnel option in Delaware River Watershed.

b. WTP per household in Philadelphia, MA, including Bucks, Chester, Delaware, Montgomery, and Philadelphia counties.

Table 5.10. Natural unit benefits of key CSO options in Delaware River Watershed: Cumulative through 2049

Benefit categories	50% LID option	28' Tunnel option[a]
Additional creekside recreational user days	76,146,118	
Additional non-creekside recreational user days	47,402,472	
Reduction in number of heat-related fatalities	78	
Annual WTP per household for water quality and aquatic habitat improvements[b]	\$9.70–\$15.54	\$5.63–\$8.59
Wetlands created or restored (acres)	88	
Green collar jobs	7,379	
Electricity savings due to cooling effect of trees	178,816,154	
Natural gas savings due to cooling effect of trees	289,789,289	
Fuel used (vehicles for construction and O&M)	238,615	426,667
SO_2 emissions (metric tons)	(740)	505
NO_x emissions (metric tons)	(18)	2,363,038
CO_2 emissions (metric tons)	(527,847)	125,361
Disruption delay from construction and maintenance	167,762	300,141

a. 28' Tunnel option in Delaware River Watershed.

b. WTP per household in Philadelphia, MA, including Bucks, Chester, Delaware, Montgomery, and Philadelphia counties.

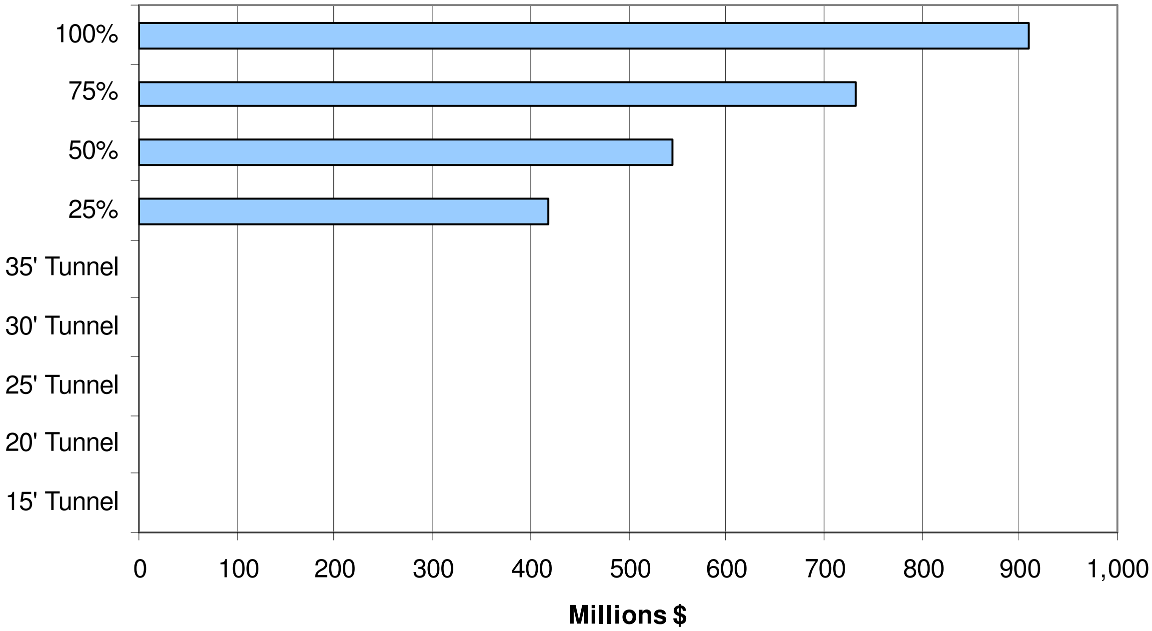

Figure 5.4. Benefits less external costs for key CSO options in the Tacony-Frankford Creek Watershed.

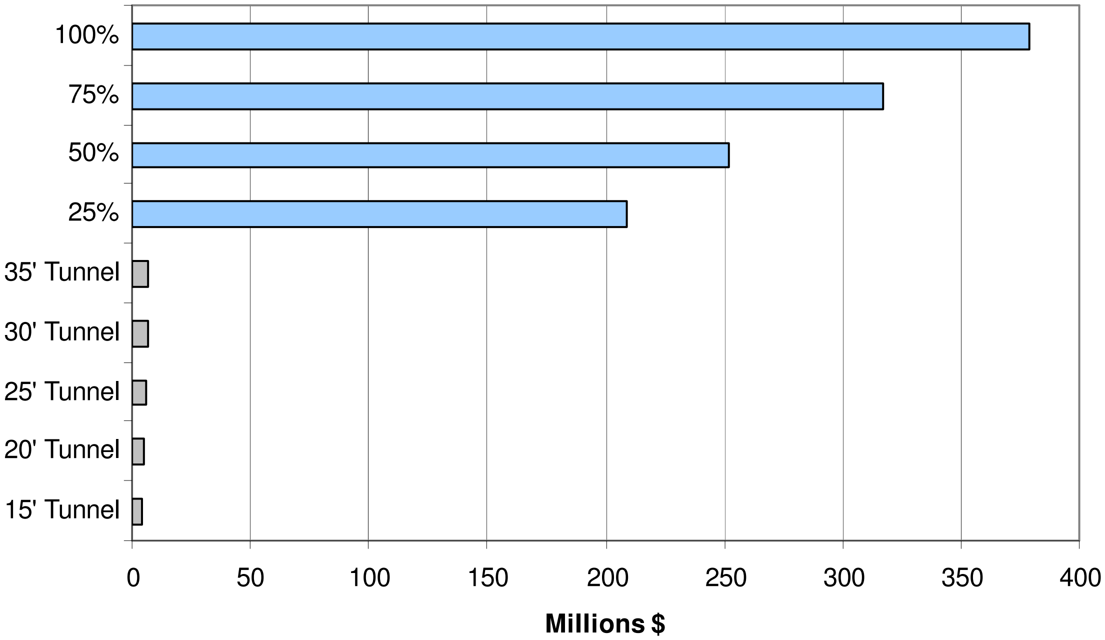

Figure 5.5. Benefits less external costs for key CSO options in the Cobbs Creek Watershed.

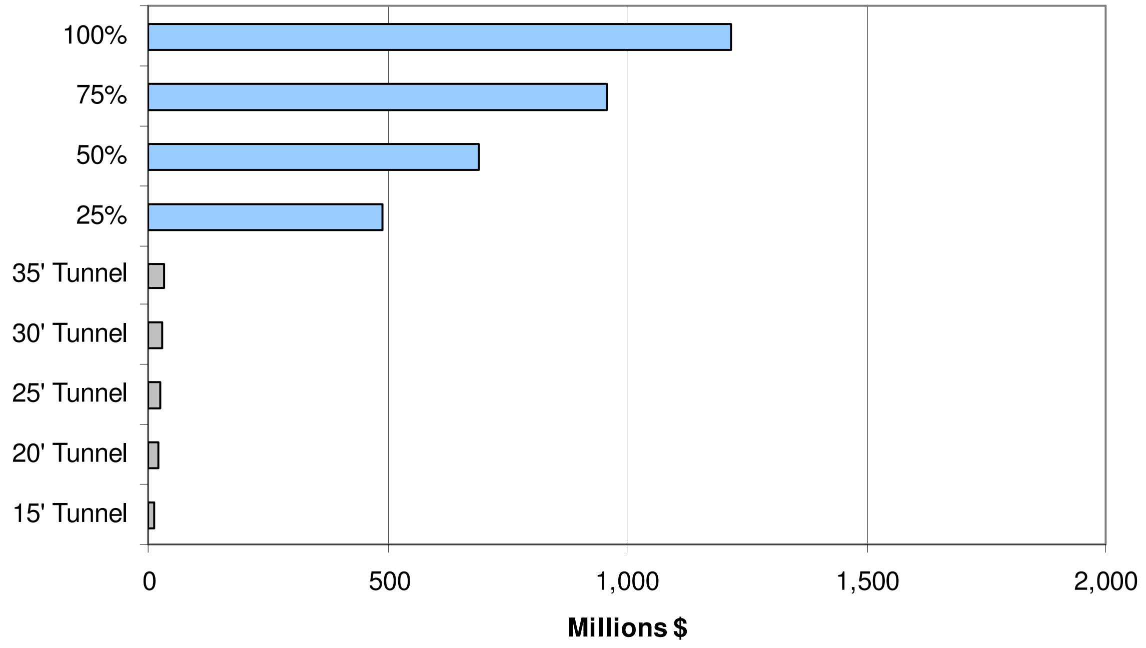

Figure 5.6. Benefits less external costs for key CSO options in the Schuylkill River Watershed.

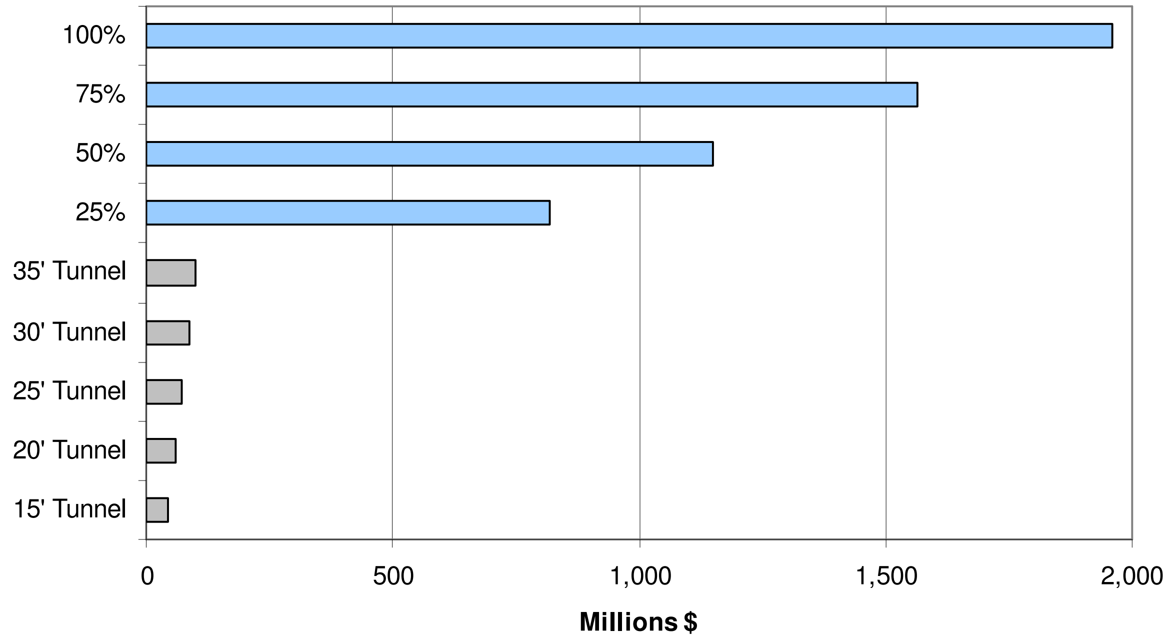

Figure 5.7. Benefits less external costs for key CSO options in the Delaware River Watershed.

6. Key Uncertainties and Sensitivity Analyses

As detailed in the appendices of this report, there are a number of uncertainties (e.g., discount rate, social cost of carbon) and potential sources of variability (e.g., changes in energy costs) surrounding our analysis. To explore the impacts of these uncertainties on our overall results, we implemented a series of sensitivity analyses. The results of these analyses are discussed below.

Sensitivity analysis involves systematically changing the value of a key input or variable to see how it affects the outcome of the analysis. The change in results shows how sensitive the project outcome is to changes in individual factors. Sensitivity analysis is often performed by varying a particular input by equal amounts greater to and less than the current value (e.g., +/- 50%). The ultimate purpose of sensitivity analysis is to understand which assumptions are important to the choice of a particular policy or project option, and what those assumptions would have to be to change the decision on which option to pursue.

As part of the sensitivity analysis, we have explored the effect of a number of key assumptions on our overall results, including:

- ***Discount rate***. It is common practice to perform a sensitivity analysis on the discount rate used to determine the present value of costs and benefits. We therefore evaluated the benefits and external costs of the CSO options under alternative discount rate scenarios. Under the first scenario, we raised the nominal discount rate to 6.5%, (up from 4.875% in the current analysis) to reflect a 2.5% real discount rate, given the cost escalator (i.e., general inflation rate) of 4%. As a second scenario, we lowered the real discount rate to 0% (because of intergenerational equity aspects associated with the LID options). This entails lowering the nominal discount rate to 4% (i.e., setting discount rate to same value as the price escalator). Table 6.1 shows the results of this analysis for the 50% LID and 30' Tunnel options.

  As shown in Table 6.1, under the 50% LID option, net benefits decrease by 27% city-wide when the discount rate is increased to 6.5% (i.e., future benefits are "discounted" at a higher rate). Under the 4% discount rate scenario, benefits increase by about 21% city-wide from the baseline analysis (where the discount rate is equal to 4.875%).

  Under the 30' Tunneling option, relative impacts are larger and more varied across watersheds. For example, in the Tacony-Frankford Watershed, increasing the discount rate to 6.5% results in a 66% decrease in net benefits. In dollar terms, this represents a decrease of about $550,000. The large percentage decrease is due to the relatively low net benefits associated with this option in the Tacony-Frankford Watershed. City-wide, net benefits decrease by 34% and increase by 27% under the 6.5% and 4% discount rate scenarios, respectively.

Table 6.1. Sensitivity analysis: Discount rates

	Present value net benefits (millions, 2009 USD)			% change from baseline estimate*	
Discount rate	**4.875%**	**6.5%**	**4.0%**	**6.5%**	**4.0%**
50% LID option					
Tacony	$596.0	$416.2	$737.0	-30%	24%
Cobbs	$270.0	$185.6	$335.7	-31%	24%
Schuylkill	$748.9	$551.9	$903.8	-26%	21%
Delaware	$1,231.6	$895.1	$1,495.4	-27%	21%
City-wide	$2,846.4	$2,048.7	$3,471.9	-27%	21%
30' Tunnel option					
Tacony	$0.8	$0.3	$1.3	-66%	59%
Cobbs	$6.5	$3.7	$8.7	-42%	34%
Schuylkill	$28.5	$18.9	$36.0	-34%	26%
Delaware	$86.2	$57.2	$108.6	-34%	26%
City-wide	$122.0	$80.1	$154.6	-34%	27%

- ***Social cost of carbon***. There is currently quite a debate among experts and in the literature regarding the true social cost of carbon. For our analysis, we assume a cost of $12 per ton (MT), as reported by the IPCC. To evaluate how an increase in the social cost of carbon would impact our results for the different CSO control options, we conducted a sensitivity analysis comparing benefits and external costs with a higher social cost of carbon of $48 versus the IPCC's average of $12. The $48 per ton is about half of the high-level estimates reported by the IPCC (which include values of $85 to $98 per MT). Table 6.2 shows the results of this analysis for the 50% LID and 30' Tunnel options. More detailed results are included in Appendix G of this report.

  As shown below, changing the social cost of carbon does not significantly impact the net benefits of the 50% LID option on a percentage basis. This is because the benefits associated with carbon sequestration and reduced emissions make up a very small component of the total net benefits (e.g., < 1% under the 50% LID option). In dollar terms, the change in net benefits under the 50% LID option amounts to more than $63 million.

Under the 30' Tunnel option, the impact of an increased social cost of carbon has a much larger relative effect on overall results. City-wide, net benefits decrease by about 15% with an increase in the social cost of carbon from $12/MT to $48 MT. In dollar terms, this change amounts to about $18 million.

Table 6.2. Sensitivity analysis: Social cost of carbon

	Present value net benefits (millions, 2009 USD)		
Social cost of carbon	$12/MT	$48/MT	% change from baseline estimate
50% LID option			
Tacony	$596.0	$609.7	2.30%
Cobbs	$270.0	$274.3	1.62%
Schuylkill	$748.9	$763.6	1.97%
Delaware	$1,231.6	$1,262.3	2.50%
City-wide	$2,846.4	$2,910.0	2.23%
30' Tunnel option			
Tacony	$0.8	$(2.5)	(400.25)%
Cobbs	$6.5	$3.5	(45.54)%
Schuylkill	$28.5	$23.4	(18.06)%
Delaware	$86.2	$79.9	(7.35)%
City-wide	$122.0	$104.3	(14.53)%

- ***Electricity prices***. Electricity and other fossil fuel-based energy prices are expected to increase if a federal climate policy is introduced. Energy prices can also increase in the future due to a number of other factors (as evident by the price volatility seen in recent years). For our analysis, we assume a conservative estimate of $0.10 per kWh of electricity. This assumption affects the benefits associated with electricity savings under the LID CSO control options (electricity costs associated with power use within any CSO control option are not included in our analysis, because they are included in engineering cost estimates).

  To evaluate the impact of our assumption for the current rate of electricity, we conducted a sensitivity analysis that doubled this rate (e.g., up to $0.20 per kWh). The analysis shows that the rate of electricity has a very small impact on net benefits of the LID options. In all cases, net benefits increased by close to 1% as a result of the additional savings that would occur with higher electricity rates.

- ***WTP for water quality improvements***. As reported in Appendix D, we conducted a sensitivity analysis to evaluate how WTP per household fluctuates in response to changes in baseline water quality and the level of water quality/habitat improvement (as defined by the WQ_{10}). The results of this sensitivity analysis (reported in Appendix D) indicate that within the reasonable range of assumptions related to these variables, WTP per household does not vary appreciably as these input values change, but seem to follow a reasonable progression. WTP is more sensitive to the actual improvement in water quality as opposed to the baseline index value used in the analysis.

A. Recreational Use and Values

The LID CSO control options currently being evaluated by PWD would provide (and enhance) recreational amenities within PWD's CSO watersheds. The LID options include a substantial increase in vegetated acreage (including "treed" acreage) throughout the City. Much of this "green" acreage would be in the form of trees planted along streets in residential areas or will be planted in areas that are currently vacant or abandoned. This "greening" of Philadelphia would increase enjoyment and participation in neighborhood activities such as walking, biking or jogging on sidewalks, bench sitting, and/or other general outdoor recreation.

In addition, under all of the LID options, PWD would implement a stream restoration program intended to improve aquatic habitat in affected water bodies. The program is focused on physical in-stream improvements (primarily within the main stem water body associated with each watershed), as well as on improvement and expansion of riparian areas. In some watersheds, this would include improving riparian lands located within Fairmount Park and/or other open space areas. Activities in these areas might include trail construction and restoration, removal of invasive species, and other activities that would improve access along streams and rivers within the combined sewer area. In other areas, access to water bodies would be improved through key land and trail connections, enhancing recreational use in these areas.

The following sections outline Stratus Consulting's methodology for estimating the benefits associated with the increased recreational opportunities that will be available under the LID options for CSO control. Estimates of total benefits within each watershed are also provided. As described below, this analysis addresses "direct use" benefits only. Nonuse values associated with increased recreational opportunities are addressed in a subsequent analysis (see Appendix D).

A.1 General Methodology

To estimate total benefits of increased recreational activity under the LID options, we separately evaluated the benefits derived from improvements made as part of the stream restoration program (which are planned for implementation under all of the LID options) and those associated with a general increase in vegetated acreage throughout the CSO watersheds. For the purposes of this analysis, we refer to these benefits as "creekside" and "non-creekside" benefits, respectively.

The following sections describe the general methodology used to evaluate creekside and non-creekside recreational benefits. Subsequent sections provide more detailed descriptions of how our analyses were tailored to each watershed.

A.1.1 Recreational use

As a first step to our analyses, we estimated the additional recreational use expected to occur under the different LID options in each watershed. To do this, we relied heavily on a recent report prepared for the Philadelphia Parks Alliance by the Trust for Public Lands. The 2008 report, *How Much Value Does the City of Philadelphia Receive from its Park and Recreation System?* (Parks Report), provides visitation data for a variety of recreational uses and activities at Philadelphia's parks.[1]

The Parks Report provides data for visitation to parks in Philadelphia in general, and does not report recreational use at individual parks. We therefore used a per-acre estimate (number of visits per acre of Philadelphia park land) to evaluate potential changes in recreational activity under the different LID options in each watershed. We tailored these per-acre estimates to individual watersheds based on conversations with park staff, detailed watershed and park management plans, and on-site visits. We also made assumptions related to per-acre recreational use in non-park areas (e.g., on residential streets). Assumptions related to per-acre use in each watershed are described in detail in subsequent sections.

Finally, the recreational use values reported in the Parks Report are for Philadelphia residents only. Our estimates therefore do not include recreational use (or benefits) for non-Philadelphia residents.

A.1.2 Direct use values

The total recreational benefits associated with improvements made under the LID options are a function of the additional recreational trips ("user days") taken as a result of these improvements, and the benefit (or direct use value) derived from each trip.

Because recreational activities are not traded in the market (i.e., there is no fee for participation), it can be difficult to establish the direct use values associated with them. However, economists have developed a number of techniques for valuing "non-market" goods and resources, such as recreation. For example, economists have often determined the value of a recreational experience based on the consumer's WTP for the recreational experience in the private marketplace.

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1. The number of park visits reported in the Parks Report were determined via a professionally conducted telephone survey of 600 Philadelphia residents. (The random-digit-dialed survey had an accuracy level of plus or minus 4%.) Residents were asked to answer for themselves; for those adults with children under the age of 18, a representative proportion were also asked to respond for one of their children.

For this analysis, we were able to rely on direct use values for specific recreational activities, as reported in the Parks Report. The model used to quantify these values is based on the "Unit Day Value" method as documented in Water Resources Council recreation valuation procedures by the U.S. Army Corps of Engineers. The Unit Day Value model counts park visits by specific activity, and assigns each activity a dollar value, based on WTP for park activities. For example, playing in a playground is worth $3.50 each time to each user. Running, walking, or rollerblading on a park trail is worth $4.00. For a more detailed description of how direct use values were calculated, see the Parks Report.

A.2 Non-creekside Recreation

To estimate benefits associated with a general increase in vegetated acreage (including treed acreage), we relied on inputs from CDM regarding the planned increase in vegetated acreage under the LID options for each watershed. We modified the number of vegetated acres provided by CDM to reflect only those acres that would result in additional or enhanced recreational activity. For example, we subtracted out the estimated number of acres expected to be planted in green roofs (also an input provided by CDM).

In addition to accounting for green roofs, we also subtracted the number of vegetated acres estimated for implementation in parking lots. To do this, we assumed that the vegetated acreage would be distributed based on the current pattern of impervious surface area in each watershed. For example, in the Tacony-Frankford Watershed, approximately 17% of impervious area (not including roofs) can be attributed to parking lots. We therefore assumed that 17% of the vegetated acreage planned under each alternative would be planted in parking lots. Thus, after accounting for green roofs, 17% of the remaining vegetated acreage planned for the Tacony-Frankford Watershed would not result in recreational benefits.

For the Schuylkill River Watershed, we also subtracted the number of acres identified in the Schuylkill River Master Plan (EDAW, 2003) as being available for recreational development (150 acres). This area was evaluated as part of the creekside recreational analysis. We assumed a similar area, on a per-stream mile basis, would be available for recreational development along the Delaware River and accounted for this in our analysis.

Table A.1 shows the planned increase in vegetated acreage assumed to result in recreational benefits for the LID CSO options in each watershed.

Table A.1. Planned increase in vegetated acreage assumed to result in recreational benefits under the LID options

	Tacony-Frankford	Cobbs Creek	Schuylkill	Delaware
25% LID	231	87	126	236
50% LID	822	312	832	1,715
75% LID	1,169	445	1,247	2,584
100% LID	1,404	534	1,528	3,171

Our next step was to estimate the number of recreational visits, or "user days," per acre for specific recreational activities that would occur as a result of the increases in vegetated acreage. We used visitation data for specific activities (e.g., walking the dog, walking on sidewalks/trails, and picnicking or bench sitting) from the Parks Report as the basis for this estimate. We then assumed that on a per-acre basis, the vegetated acreage planted under the LID options would support about 10% of the recreational activity seen at an average park in Philadelphia.

Table A.2 presents the annual additional recreational activity (in terms of "user days") under the LID CSO options in each watershed, assuming full program implementation. Table A.3 shows total additional recreational user days over the 40-year project evaluation period. The estimates shown in Table A.3 take into account the LID implementation timeline provided by CDM.

Table A.2. Additional non-creekside recreational user days under LID CSO control options each year (at full program implementation)

	Tacony-Frankford	Cobbs Creek	Schuylkill	Delaware
25% LID	310,000	117,300	169,200	317,300
50% LID	1,104,100	419,500	1,117,600	2,304,100
75% LID	1,571,300	597,500	1,676,300	3,472,900
100% LID	1,886,700	717,000	2,053,400	4,261,400

Table A.3. Additional non-creekside recreational user days under LID CSO control options over 40-year project period

	Tacony-Frankford	Cobbs Creek	Schuylkill	Delaware
25% LID	6,376,780	2,413,061	3,481,727	6,528,626
50% LID	22,714,215	8,629,946	22,991,914	47,402,472
75% LID	32,326,746	12,292,929	34,486,588	71,448,114
100% LID	38,815,401	14,751,738	42,245,022	87,670,535

A.2.1 Direct use value of additional recreational visits

To estimate the monetary value of additional recreational activity, we applied direct use values from the Parks Report for the recreational activities described above. We used 50% of the direct-use values reported in the Parks Report to account for differences in the value of recreational activities in parks versus non-park areas (i.e., walking on a sidewalk).

To estimate total benefits over the 40-year project life, we scaled annual benefits based on the LID implementation timelines provided by CDM. Table A.4 shows the present value benefits associated with non-creekside recreational activity expected to occur under the LID CSO options in each watershed.

Table A.4. Direct-use benefits associated with non-creekside recreational visits under LID CSO control options (present value estimates for 40-year project period)

	Tacony-Frankford	Cobbs Creek	Schuylkill	Delaware
25% LID	$4,499,952	$1,702,843	$2,456,977	$4,684,956
50% LID	$16,028,916	$6,089,960	$16,224,881	$34,016,111
75% LID	$22,812,265	$8,674,846	$24,336,416	$51,271,313
100% LID	$27,391,164	$10,409,972	$29,811,370	$62,912,556

A.3 Creekside Recreation

The following sections describe Stratus Consulting's approach for estimating recreational benefits associated with the stream restoration component of the LID CSO options. For this evaluation, we adapted our methodology to account for differences in current and expected changes in recreational use in each watershed. Further, the stream restoration program is assumed to be implemented under all of the LID alternatives, therefore total benefits are the same at each level of LID (25–100%).

Our methodology and assumptions are based on an extensive review of watershed and park management/master plans (documented at the end of this appendix), on-site visits with PWD staff, and discussions with Fairmount Park representatives.

A.3.1 Tacony-Frankford Watershed

Tacony Creek Park, a unit of the Fairmount Park System, accounts for the majority of creekside recreational lands in the Tacony-Frankford Watershed. The park consists of 302 acres of land (including Juniata Park Golf Course) that form a narrow corridor of park along Tacony Creek from the Montgomery/Philadelphia County border through Juniata Park. The park offers 2.5 miles of creekside trails and is reportedly used by residents for picnicking, running, walking, and fishing. Although an illegal activity, people do swim in the Tacony Creek Park section of the creek. Unsanctioned uses of the park include all terrain vehicle (ATV) use, dumping, graffiti, and drug activity.

Below Juniata Park Golf Course, the Tacony joins with now buried tributaries to form Frankford Creek. In order to deal with flooding and large influxes of stormwater, Frankford Creek has been completely channelized in concrete. The concrete channel prevents interaction between Frankford Creek and the groundwater system and eliminates streambed habitat needed to support aquatic life. The area surrounding Frankford Creek is highly industrialized and much of the creek is inaccessible.

Stream restoration activities in the Tacony-Frankford Watershed are focused on in-stream restoration and riparian area improvements along the 2.6 miles of stream through Tacony Creek Park and the 3.5 miles of Frankford Creek (south of Juniata Park through to the Frankford's confluence with the Delaware River). Major improvements related to recreational use include trail construction and restoration, expanded riparian areas, and improved access to the Tacony-Frankford main stem. Implementation of the Frankford Creek Greenway (as described in the Frankford Greenway Master Plan) is expected to include 3.1+ miles of trail and a number of recreational amenities.

Baseline recreational use

We first established a baseline estimate for current recreational activity in Tacony Creek Park. We limited the baseline to activity within the park because it is currently the only area in the Philadelphia County portion of the watershed that provides direct access to the main stem creek.

Our baseline estimate of recreational activity relies on survey data from the Tacony-Frankford River Conservation Plan (RCP), and qualitative descriptions from Fairmount Park Staff and the Tacony Creek Park Natural Lands Restoration Master Plan. We also used the Parks Report to help determine the mix of recreational activities occurring in the park.

The RCP survey reports stream-related recreational activity for the entire watershed (including tributaries). We therefore used geographic information systems (GIS) land use data to estimate the percentage of creek-related recreational activity that occurs along the Tacony main stem in Tacony Creek Park. We estimate that Tacony Creek Park currently supports about 70% of total creek-related recreation in the watershed. The remaining 30% is assumed to occur in tributaries and other areas of the watershed not relevant to our analysis.

Table A.5 shows the inputs and data sources used to establish a baseline estimate for recreational use along the creek. As shown below, the majority of residents in the Tacony-Frankford Watershed report that they rarely, if ever, spend recreational time along the creek. Conversations with park staff also indicate that this park gets very little use.

Table A.5. Assumptions and inputs used to establish baseline recreational use along Tacony-Frankford Creek

		Data source
General inputs		
2007 watershed population (Philadelphia County portion)	285,405	EPA BenMap 2007; Tacony-Frankford Integrated Watershed Management Plan (IWMP)
Percent of population less than 18 years old	26%	2000 Census
Recreational activities along the creek		
Percent of watershed residents under the age of 18 that recreate along the creek	12%	Tacony-Frankford RCP survey data as reported in the Tacony-Frankford IWMP
Percent of watershed residents over the age of 18 that recreate along the creek	39%	Tacony-Frankford RCP survey data as reported in the Tacony-Frankford IWMP
Average number of visits per year (both groups)	3	Tacony-Frankford RCP survey data as reported in the Tacony-Frankford IWMP
Mix of recreational activities		
Walk along creek	53%	Tacony-Frankford RCP survey data as reported in the Tacony-Frankford IWMP
Other non-contact activities	38%	Tacony-Frankford RCP survey data as reported in the Tacony-Frankford IWMP; Parks Report
Fishing	8%	Tacony-Frankford RCP survey data as reported in the Tacony-Frankford IWMP

Based on the assumptions and inputs shown above, we estimate that Tacony-Frankford Creek supports approximately 192,320 recreational visits to the creek each year. This amounts to about $406,000 in annual direct-use benefits.

Additional recreational visits under LID options

To estimate total creekside recreational benefits in the Tacony-Frankford Watershed, we separately evaluate recreational use under the LID CSO control options in the following locations:

- Tacony Creek Park
- Juniata Creek Golf Course
- The planned Frankford Creek Greenway.

Tacony Creek Park. As a first step to our analysis of recreational activity in Tacony Creek Park, we calculated the average number of per-acre visits to all Philadelphia parks for specific activities expected to occur in Tacony Creek Park. These activities include:

- Visits to playgrounds and tot lots
- Picnicking or bench-sitting
- Walking on trails
- Walking dog in park
- Birdwatching/nature
- Bicycling on trails
- Running on park trails
- Fishing.

We then assumed that under the LID/stream restoration improvements, Tacony Creek Park would likely support about 40% of the per-acre visitation experienced at an average park in Philadelphia. To estimate total visitation to the park, we therefore applied 40% of the average number of recreational visits per acre of park land in Philadelphia to the 174 acres of Tacony Park (excluding Juniata Park Golf Course). Our 40% assumption is based on the relative "local" nature of the park (e.g., compared to the regional appeal of East and West Fairmount parks), surrounding neighborhood demographics, and discussions with Fairmount Park representatives.

Based on these assumptions, we estimate that approximately 2.1 million people would visit Tacony Park each year under the LID options (at full program implementation). This includes the baseline estimate of individuals who already visit the park, as well as visits from individuals who would have visited a park elsewhere in Philadelphia if the improvements along Tacony Creek had not taken place. These factors are accounted for in our estimate of total benefits, as described below.

Juniata Park Golf Course. We based our estimate of additional visits to Juniata Park Golf Course on data reported in the *Juniata Park Golf Course Land Use and Feasibility Study* (EDAW, 2008). This report indicates that odors associated with CSO events in Tacony Creek are one of many limiting factors for increasing visitation to the course.

EDAW reports that there are currently about 11,350 rounds of golf played at Juniata Park each year (2007 estimate). This compares to an average of 28,375 rounds reported for other public courses in Philadelphia, or 40% of average use. We assume that under the LID options, use might increase to about 50% of the average use at other courses, or to 14,190 rounds of golf (an additional 2,800 rounds).

Based on an average of 3 golfers per round, we estimate that as a result of the CSO improvements, approximately 8,500 individuals will golf at Juniata Park Golf Course that otherwise would not have. This includes individuals who would have golfed elsewhere in the City (and are therefore not included in the overall benefit estimates reported below).

We use a conservative estimate for increase in use of the course as a result of CSO improvements because the park is plagued by non-CSO related problems such as graffiti and vandalism. In addition, Juniata Park is smaller than many other public courses and does not have the same historic or regional appeal as some of the other more well-used courses (e.g., Cobbs Creek Golf Course).

Frankford Creek Greenway. The planned Frankford Creek Greenway is a massive public works project that would include 3.1+ miles of trail construction along Frankford Creek and would restore much of Frankford Creek to its natural stream bottom. To estimate the number of visits to the new greenway, we relied on the same methodology described above for our analysis of increased use at Tacony Creek Park.

We first estimated the total area (acres) of the greenway, based on 3.5 stream miles and an assumed greenway width from the stream zone. Based on our assumptions, we estimate that the greenway would be approximately 190 acres. We then estimated per-acre visitation for activities expected to occur along the greenway.

With the exception of fishing and playgrounds/tot lots, the activities within the greenway were assumed to be the same as those included in the Tacony Creek Park analysis. We did not include fishing as a specific recreational activity because the concrete walls on the side of the stream channel are assumed to prevent direct contact with the stream. Additionally, it is unclear whether playgrounds and tot lots would be included as part of the greenway (they were not described in the Frankford Greenway Master Plan). As with the Tacony Creek Park analysis, we assumed that the Frankford Greenway would support about 40% of the recreational use of an average park in Philadelphia, on a per-acre basis.

Based on these inputs, we estimate that more than 1.9 million individuals will visit the greenway each year, once it is fully constructed.

Total additional recreational visits. We assume that under the LID options, approximately 70% of the recreational visits reported above would be "new" visits, meaning they would not have occurred if the LID stream restoration program had not been implemented. This assumption implies that the remaining 30% of recreational visits would have occurred at parks or golf courses elsewhere in the City if the LID improvements had not taken place. Although there is a marginal benefit associated with these visits (otherwise individuals would continue to visit the other parks), these benefits are not included in our analysis.

Table A.6 provides a summary of total additional recreational visits in the Tacony-Frankford Watershed under the LID options. The number of additional visits is reported on an annual basis (assuming full program implementation) as well as in terms of total visits over the 40-year project period. Total visits over the project period were determined based on the stream restoration implementation timeline provided by CDM.

Table A.6. Summary of total additional recreational visits in the Tacony-Frankford Watershed under LID options

Additional visits to Tacony Creek Park under LID options (minus baseline)	1,934,000
Visits to Frankford Greenway	1,910,000
Additional (person) visits to Juniata Park Golf Course	8,500
Percent of visits that are new recreational visits	70%
Additional annual recreational user days s	2,696,800
Additional recreational user days over 40-year project period	80,527,887

Direct use value of additional recreational visits

To estimate the monetary value of additional creekside recreational visits under the LID CSO control options, we applied direct-use values from the Parks Report, weighted by specific recreational activity. Based on these values, we estimate that the increased recreational activity will result in approximately $6.1 million each year (2009 USD), at full program implementation. This amounts to more than $145 million in direct use benefits over the 40-year project period, in present value terms (2009 USD). Present value estimates were determined based on the stream restoration implementation timeline provided by CDM.

A.3.2 Cobbs Creek Watershed

Cobbs Creek Park, located on the western edge of Philadelphia, accounts for the majority of recreational/park land in the Cobbs Creek Watershed. The Park's 220 acres encompass nearly 13 miles of stream that eventually drain to the Delaware River. The main stem, which is 8.2 miles, accounts for the majority of total stream length. The remaining stream length is made up of tributaries such as Indian Creek, and smaller, un-named streams.

For the purposes of this analysis, we focus solely on recreational use along the Cobbs Creek mainstem, as this will be the focus of PWD's stream restoration program. All improvements along the creek are expected occur within Cobbs Creek Park, which borders the creek throughout most of the CSO area. No additional recreational amenities are planned (i.e., nothing similar to the Frankford Creek Greenway). Stream restoration program activities are expected to result in improved water quality, restored and expanded trails, and improved access to the creek via expanded riparian areas.

To estimate recreational use along Cobbs Creek, we employed a methodology similar to the methodology used for our analysis of the Tacony-Frankford Watershed. Our methodology and results are described below.

Baseline recreational use

In the absence of data for current recreational use at Cobbs Creek Park, we relied on the per-acre baseline use established for Tacony Creek Park. We applied this baseline estimate to the 220 acres of Cobbs Creek Park, assuming that per-acre use is about 15% higher at Cobbs Creek Park than at Tacony Creek Park. This assumption was based on on-site visits and qualitative descriptions of each park. Based on our per-acre use application (with the 15% adjustment), we estimate that currently, Cobbs Creek Park supports about 280,000 visits each year.

Additional recreational visits to Cobbs Creek under the LID options

Similar to our analysis of recreational benefits in Tacony Creek Park, we calculated the average number of per-acre visits to all Philadelphia parks for specific activities expected to occur in the park under the LID options. We assumed the same mix of recreational activities for Cobbs Creek as we did for Tacony Creek Park.

We applied the per-acre estimates for specific recreational activities to Cobbs Creek Park and assumed that under the LID/stream restoration improvements, Cobbs Creek Park would likely support about 40% of the per-acre visitation experienced at an average park in Philadelphia. This assumption is based on the relative “local” nature of the park (e.g., compared to the regional appeal of East and West Fairmount parks), surrounding neighborhood demographics, and discussions with Fairmount Park representatives.

Based on these assumptions, we estimate that approximately 2.7 million people would visit Cobbs Creek Park each year under the LID options (at full program implementation). This includes the baseline estimate of individuals who already visit the park, as well as visits from individuals who would have visited a park elsewhere in Philadelphia if the improvements along Cobbs Creek had not taken place.

To estimate the number of additional visits under the LID options, we subtract out the baseline visits and assume that about 70% of the total visits are *new* visits (rather than visits that would otherwise have taken place at other city parks). Based on these assumptions, we estimate that improvements under the LID options will result in approximately 1.7 million additional visits each year, at full program implementation. This amounts to an additional 50.5 million visits over the 40-year project period, based on the implementation timeline provided by CDM.

Direct use value of additional recreational visits

To estimate the monetary value associated with these increased visits, we applied direct-use values from the Parks Report, weighted by specific recreational activity. We estimate that improvements under the LID options will result in approximately $3.9 million recreation-related benefits each year, at full program implementation. This amounts to $94 million in present value benefits (2009 USD) over the 40-year project period.

A.3.3 Schuylkill River Watershed

Our analysis of recreational benefits in the Schuylkill River Watershed relies on the information and data reported in the Tidal Schuylkill River Master Plan (EDAW, 2003). The study area of the Master Plan includes the eight-mile stretch of the tidal Schuylkill River (and adjacent land) from the Fairmount dam to the Delaware River. This area consists of a significant amount of industrial land uses that are adjacent to residential, open space, institutional, and other public uses such as the Philadelphia International Airport.

There are numerous active and inactive rail lines in the area, including the large and active East Side Yard for CSXT. Several major road corridors also run adjacent to and through the study area including I-95, I-76 (Schuylkill Expressway), I-676, Route 291/Passyunk Avenue, Grays Ferry Avenue, University Avenue, South Street, Walnut Street, Chestnut Street, and Market Street.

Land use data reveal that over half of the Master Plan study area (54.75%) is currently devoted to manufacturing, utilities, parking, and transportation (rail and street rights-of-way). Another 29% of land is categorized as wooded, vacant, or water (water associated with industrial uses, not the river and canals). Only 2.52% is currently categorized as recreation and 2.81% as residential of all types.

The Master Plan proposes a number of major public investments in the revitalization of the tidal Schuylkill River. These investments include greenway and trail improvements, including neighborhood linkages to the river and "streetscapes," as well as infrastructure improvements. Based on the Master Plan's full implementation, the potential development program for the study area could include the development of:

- Over 3,270 residential units
- Over 1,600,000 square feet of retail uses
- Over 11,300 square feet of restaurants
- Over 1,000,000 square feet of office space
- Over 2,000,000 square feet of flex/industrial space
- Over 100,000 square feet of cultural facilities

- Over 150 acres of new green space and park land
- Over 8 miles of new multi-purpose trails
- Marinas and boat storage for about 400 boats.

Improvements made as part of the LID CSO control options in the Lower Schuylkill River will play a role in the implementation of the Tidal Schuylkill River Master Plan. For our analysis of recreational benefits, we focus on the development opportunities described above that can be directly tied to LID CSO control implementation. Based on our understanding of the LID options, this includes the implementation of 150 "creekside" acres of new open space and park land, including trails and streetscape improvements, and the opportunities for new marinas and boat storage. The benefits associated with these improvements are described in the following sections.

Additional recreational visits associated with new green space

To evaluate recreational benefits, we first estimate per-acre visitation for specific recreational activities associated with the additional open space and park land, based on the Parks Report. We then assume that recreational areas in the Lower Schuylkill River would support about 60% of the use of an average Philadelphia Park. This is higher than the 40% estimate used for the Tacony and Cobbs Creek parks due to the park's more regional nature. However, due to the abundance of recreational opportunities just upstream of the CSO area (e.g., East and West Fairmount parks, Boathouse Row) and the heavy industrial nature of the area, this area will likely see less use than many other parks in the region.

Additionally, we also assume that only about 50% of recreational visits to the Lower Schuylkill open space areas will be "new" visits (i.e., visits would not have taken place at another park in the region). This is also based on the abundance of recreational opportunities located just upstream of the Schuylkill CSO area.

Based on these assumptions, we estimate that the improvements identified in the Schuylkill River Master Plan (associated with green space, trails, and pedestrian linkages only) will amount to about 1.3 million new recreational visits per year, assuming full program implementation. This amounts to about 40.2 million new visits over the 40-year project period, taking into account the stream restoration implementation timeline provided by CDM. Our analysis assumes no baseline level of visitation to this area due to its highly industrial nature and current land uses.

Additional recreational visits for boating and fishing

In addition to the benefits associated with new green space, the Master Plan identifies opportunities for the development of marinas and boat storage for about 400 boats. We include this in our analysis of recreational benefits because it can be directly tied to improvements in water quality as well as the implementation of aesthetic and recreational amenities (e.g., additional open space) under the LID CSO control options.

To estimate the number of new trips to the Lower Schuylkill River for fishing and boating, we rely on original survey data from the Parks Report, provided by the Trust for Public Lands.[2] We used these data to determine the number of average trips per year taken by Philadelphians who engage in fishing and/or boating. We then assume an average of 3 people per boat/fish trip and that about 60% of the trips taken on the Lower Schuylkill River would be "new trips" (i.e., would not have taken place elsewhere). Based on these assumptions, we estimate an additional 4,400 trips each year at full program implementation. This amounts to about 131,600 trips over the 40-year project period.

Direct use value of additional recreational visits

Similar to our analysis of Tacony and Cobbs Creek watersheds, we used direct-use values for specific recreational activities from the Parks Report to determine total benefits. Based on these values, we estimate the annual value of new recreational visits resulting from the implementation of 150 acres of open space, including trails and pedestrian linkages to the river, to be about $3.1 million (2009 USD) at full program implementation. Based on the implementation timeline provided by CDM, this amounts to more than $73.4 million in present value benefits (2009 USD) over the 40-year project period. Increased participation in boating and fishing in the Lower Schuylkill will provide an additional $19,172 in annual direct-use benefits, or a total of $460,000 in present value benefits over the 40-year project period.

A.3.4 Delaware River Watershed

In absence of specific data for the Delaware River Watershed, we assume that on a per-stream mile basis, the LID CSO control options for the Delaware River will include the same amount of open/green space area as planned for the Schuylkill River.

As noted above, there are about 150 acres (or about 21 acres per stream-mile) of open/green space planned for the Lower Schuylkill area, which encompasses about 8.7 miles of river. Applying this to the 15.6 miles of the Delaware River within PWD's CSO area, we estimate there will be about 341 acres of new open/green space under the LID CSO options. Similar to the Schuylkill Watershed, this additional acreage is separate from the vegetated acreage planned for areas throughout the watershed, as reported in the section on "non-creekside" recreational

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2. The raw survey data is unweighted and does not account for differences in demographic characteristics of the study population and the population of Philadelphia County.

benefits. For our evaluation of non-creekside benefits, we subtracted out the open/green space acreage planned for the area along the river.

We used the same methodology as described for the Schuylkill River to estimate the recreational benefits associated with this new area. Based on this methodology, we estimate that implementation of the stream restoration program under the LID CSO control options will result in about 2.6 million additional creekside recreational visits each year, at full program implementation. This amounts to about 76.1 million visits over the 40-year project period, taking into account the project implementation timeline.

In terms of direct use benefits, additional recreational visits to the Delaware River will result in an annual benefit of $5.8 million (2009 USD), at full program implementation. Over the 40-year project period, this amounts to $139 million in present value benefits (2009 USD).

A.4 Summary of Results

Tables A.7 and A.8 provide a summary of total recreational benefits associated with the LID CSO control options. Table A.7 shows the additional number of recreational visits and the direct-use benefits, in present value terms, associated with additional non-creekside recreation. Table A.8 shows the same results for the creekside recreational analysis.

Table A.7. Summary of additional recreational visits under the LID CSO control options, over the 40-year project period

	Tacony	Cobbs	Schuylkill	Delaware
Non-creekside recreation				
25% LID	6,376,780	2,413,061	3,481,727	6,528,626
50% LID	22,714,215	8,629,946	22,991,914	47,402,472
75% LID	32,326,746	12,292,929	34,486,588	71,448,114
100% LID	38,815,401	14,751,738	42,245,022	87,670,535
Creekside recreation[a]	80,527,887	50,478,407	40,371,870	76,146,118

a. Applies to all LID options.

Table A.8. Summary of monetized recreational benefits under the LID CSO control options, over the 40-year project period (present value[a])

	Tacony	**Cobbs**	**Schuylkill**	**Delaware**
Non-creekside recreation				
25% LID	$4,499,951	$1,702,843	$2,456,977	$$4,684,956
50% LID	$16,028,916	$6,089,960	$16,224,881	$34,016,111
75% LID	$22,812,264	$8,674,846	$24,336,416	$51,271,313
100% LID	$27,391,163	$10,409,972	$29,811,370	$62,912,556
Creekside recreation[b]	$145,154,937	$94,100,602	$73,900,681	$138,970,735

a. Present value estimates presented in 2009 USD, assuming a 4% inflation rate and 4.875% discount rate.
b. Applies to all LID options.

A.5 Omissions, Biases, and Uncertainties

To estimate the total recreational benefits under the LID alternatives, it was necessary to make a number of assumptions in the absence of specific data. In addition, a number of data omissions and uncertainties surrounding the analysis have been identified throughout this report. Table A.9 provides a summary of these assumptions and uncertainties and their likely impact on our estimation of recreational benefits.

Table A.9. Omissions, biases, and uncertainties

Assumption/methodology	**Likely impact on net benefits[a]**	**Comment/explanation**
Only "new" visits are included in the analysis	-	Our analysis only includes visits that would not have occurred elsewhere if the LID improvements had not been implemented. However, there is a marginal benefit associated with the trips that would have occurred in another location (or the individuals would continue to make trips to this location under the LID alternatives). Given the relatively low direct-use values, the exclusion of these benefits does not likely make a significant impact on overall benefits. Further, the percentage of total visits that are "new" is based on qualitative discussions and on-site visits. A degree of uncertainty surrounds these assumptions.

Table A.9. Omissions, biases, and uncertainties (cont.)

Assumption/methodology	Likely impact on net benefits[a]	Comment/explanation
Non-Philadelphia residents are not included in the analysis	+/++	The Parks Report includes park visitation data for Philadelphia residents only. Non-Philadelphia residents are therefore not included in our analysis due to lack of data on how often they visit Philadelphia Parks. Inclusion of these visitors would increase overall benefits, most likely in the Schuylkill and Delaware River watersheds, which have a more regional appeal.
Direct use values do not take into account the quality of the recreational experience	U	If the quality of recreational visits to CSO watersheds is higher (or lower) than for visits to an average park in Philadelphia, users might experience a higher (or lower) value per outing. Locational factors (e.g., proximity to existing parks or neighborhood demographics) may also affect the quality of the recreational experience.
The direct-use values used in this analysis are low compared to similar studies	+	The direct use values in the Parks Report are relatively low. However, in Philadelphia, recreational values are not expected to amount to as much as those in more remote areas. In the City, most people do not have to travel far to reach the parks, and residents spend a shorter time recreating once they get to the park. Further, based on qualitative descriptions of parks in the watershed, the quality of the experience seems to be lower than in other areas used in many valuation studies.
Analysis relies on average per-acre visitation estimates for all parks in Philadelphia	U-	Our analysis assumes that parks/recreational land in CSO watersheds support a certain percentage of recreational use of an average park in Philadelphia on a per-acre basis. This is based on on-site visits, review of park master plans, and discussions with park staff. Increasing/decreasing this assumption would impact net benefits. Locational factors (e.g., proximity to existing parks or neighborhood demographics) and the amount of contiguous land in improved areas may also affect per-acre use.
On-the ground implementation	U	There is a large degree of uncertainty surrounding planned activities under the LID options (e.g., location in the watershed) and how these activities will affect recreational use. It is therefore difficult to estimate the benefits associated with them. Our estimates are intended to provide an approximation of total benefits, based on our understanding of program implementation and the best available data for current recreational activity in Philadelphia.

a. Indicating how addressing the assumption or overcoming the omission would probably impact the analysis, using the following key: + would likely increase net benefits; ++ would increase net benefits significantly; U direction of change in net benefit is uncertain; - would diminish net benefits; -- would diminish net benefits significantly.

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B. Property Values, as Enhanced by the LID Options

B.1 Summary

Residential property value benefits are calculated for properties within the four watersheds relevant to this analysis: Cobbs Creek, Delaware Direct, Lower Schuylkill River, and Tacony-Frankford Creek. Specifically, benefits are quantified separately for properties within PWD's combined sewer area and those outside of the area; and the analysis is limited to the City. Benefits to properties outside of the combined sewer area and within the Lower Schuylkill River Watershed are excluded from the analysis because this area already has a considerable amount of LID, including East and West Fairmount Parks, and we do not anticipate any significant additional benefits to properties in this area. An estimate is provided for each of the other seven geographic areas using a range of benefits found in the literature. These estimates are meant to account for benefits that accrue to property owners from implementation of the LID options, or a significant aspect of the LID options (e.g., trees), that are unique from other benefit estimates presented in this report. Estimates of property value benefits from the green infrastructure LID options are summarized in Tables B.1 through B.4. Details on the derivation of these estimates are presented below.

B.2 Data and Methods

Estimates are calculated using neighborhood-level property count and price data from the Philadelphia "NIS neighborhoodBase," a database of spatial and numerical data maintained by the University of Pennsylvania's Cartographic Modeling Lab (CML, 2005). The total number of properties within a watershed (both within and outside of the combined sewer area) is compiled using GIS data obtained on neighborhood boundaries, watershed boundaries, and combined sewer area boundaries. The neighborhood data contain census housing unit counts, which are used to aggregate counts over several neighborhoods within a given watershed.

Using 2007 median sales price data from the NIS neighborhoodBase, a weighted average market value is derived for properties sold within a given geographic area of interest (e.g., within the combined sewer area for a given watershed). Each neighborhood has a portion of the total properties sold for a given geographic area in 2007. Multiplying each of these neighborhood proportions by its median sales price for 2007 and summing over all neighborhoods, we derive a weighted average market value. Using the median selling price data helps to mitigate sensitivity to extreme selling prices, since only a fraction of properties sell within a given year. Moreover, if a certain type of property sold more heavily in 2007, relative to a historical baseline of sales by property type (e.g., condominiums vs. single family homes), the median will be less sensitive to this. It is for these reasons that median selling price is favored over the mean.

Table B.1. Summary of residential property value benefits from 25% LID program elements (2009 USD)

	Within combined sewer area	Outside combined sewer area	Total
Total residential properties	503,882	48,544	552,426
Weighted average median sales price	$128,307	$152,920	$130,470
Estimated total market value of affected residential properties	$16,162,924,000	$1,855,841,000	$18,018,765,000
Low-end estimate of one-time increase in residential property value for 25% LID	$161,629,000	$2,941,000	$164,570,000
Average estimate of one-time increase in residential property value for 25% LID	$282,851,000	$5,146,000	$287,997,000
High-end estimate of one-time increase in residential property value for 25% LID	$404,073,000	$7,352,000	$411,425,000

Table B.2. Summary of residential property value benefits from 50% LID program elements (2009 USD)

	Within combined sewer area	Outside combined sewer area	Total
Total residential properties	503,882	48,544	552,426
Weighted average median sales price	$128,307	$152,920	$130,470
Estimated total market value of affected residential properties	$32,325,848,000	$3,711,682,000	$36,037,530,000
Low-end estimate of one-time increase in residential property value for 50% LID	$323,258,000	$5,881,000	$329,140,000
Average estimate of one-time increase in residential property value for 50% LID	$565,702,000	$10,292,000	$575,995,000
High-end estimate of one-time increase in residential property value for 50% LID	$808,146,000	$14,703,000	$822,850,000

Table B.3. Summary of residential property value benefits from 75% LID program elements (2009 USD)

	Within combined sewer area	Outside combined sewer area	Total
Total residential properties	503,882	48,544	552,426
Weighted average median sales price	$128,307	$152,920	$130,470
Estimated total market value of affected residential properties	$48,488,771,000	$5,567,523,000	$54,056,294,000
Low-end estimate of one-time increase in residential property value for 75% LID	$484,888,000	$8,822,000	$493,710,000
Average estimate of one-time increase in residential property value for 75% LID	$848,554,000	$15,438,000	$863,992,000
High-end estimate of one-time increase in residential property value for 75% LID	$1,212,219,000	$22,055,000	$1,234,274,000

Table B.4. Summary of residential property value benefits from 100% LID program elements (2009 USD)

	Within combined sewer area	Outside combined sewer area	Total
Total residential properties	503,882	48,544	552,426
Weighted average median sales price	$128,307	$152,920	$130,470
Estimated total market value of affected residential properties	$64,651,695,000	$7,423,364,000	$72,075,059,000
Low-end estimate of one-time increase in residential property value for 25% LID	$646,517,000	$11,763,000	$658,280,000
Average estimate of one-time increase in residential property value for 25% LID	$1,131,405,000	$20,585,000	$1,151,989,000
High-end estimate of one-time increase in residential property value for 25% LID	$1,616,292,000	$29,407,000	$1,645,699,000

The literature suggests a range of benefits from green storm water infrastructure, or LID, from 0% to 7%. This implies the average property value will increase anywhere from 0% to 7% due to LID additions to the surrounding landscape. A further discussion of the literature is provided later in this appendix. For the calculations below, we tighten this range to 2–5% for properties within the combined sewer area, with a mean increase of 3.5%, given that most of the studies provide estimates within this inner range.

In the absence of spatial data that outline the specific location and magnitude of LID installments, we calculate total market value of affected residential properties under four LID scenarios: 25%, 50%, 75%, and 100% LID coverage. Under the 50% scenario, for example, the total market value of affected residential properties for a given area is calculated as 50% of the total number of properties in that area times its weighted average median selling price.

Given that LID will be implemented within the combined sewer area, properties in the near vicinity of these changes will capitalize the greatest benefit (i.e., those properties within the combined sewer area). However, properties outside the combined sewer area will arguably accrue some benefit, though perhaps at a diminished rate. A number of studies reflect this “decay” in benefit as distance from the amenity increases (see Correll et al., 1978; Tyrvainen and Miettinen, 2000; Morancho, 2003; Wachter and Wong, 2006). For properties outside the combined sewer area, we adjust the benefit estimates range downward from 2%–5% to 1%–2.5%. This downward adjustment reflects the decay of benefits as indicated by the literature. Calculations for properties both within and outside the combined sewer area assume benefits accrue uniformly among affected properties.

Property value estimates from the literature encompass a wide range of benefits associated with LID. Many of these are not distinct from other benefits presented in this report (e.g., anticipated energy cost savings are likely to be capitalized, to some extent, in the increased property values of tree-shaded properties). In theory, changes in property values should reflect associated differences in air quality, water quality, energy usage (often relating to heat stress), flood control, and perhaps other benefits (particularly those qualitative in nature). For example, a property in an area with good air quality should sell for a higher amount relative to another property in an area with low air quality, all else equal. Thus, to simply add property value benefits with the benefits from improved air quality would be double-counting. This applies to most benefit categories in this report. Therefore, only a portion of the literature estimates should be considered unique from other benefits in this report, such as those stemming from aesthetic improvements. To account for this, we adjust estimates from the literature downward by 50% to arrive at a range of 1–2.5% for properties within the combined sewer area and 0.5–1.25% for properties outside the combined sewer area.

Tables B.1 through B.4 show the projected benefits under the four LID scenarios, within and outside of the combined sewer area. Under each scenario, the total market value of affected properties is multiplied by the endpoints of the corresponding benefit estimates range, along with the mean. This yields aggregated benefit estimates for increases in property values. For example, the estimated average benefits for properties within the combined sewer area under the 50% LID scenario is a one-time increase of $565.7 million.

Total property value benefits range, on average, from \$282.9 million to \$1.13 billion for properties within the combined sewer area and between \$5.1 and \$20.6 million for properties outside the combined sewer area, depending on the LID scenario. This leads to a total estimate of average benefits ranging from \$288.0 million for 25% LID to \$1.15 billion for 100% LID.[1]

B.3 Literature Used in the Benefits Transfer

The "benefits transfer" methodology is used to calculate the above estimates. Due to the high costs of carrying out original research, primarily in terms of time, existing estimates for property benefits associated with LID or specific aspects of LID are applied to the Philadelphia context. As Sample et al. (2003) and Powell et al. (2005) point out, more research is needed in quantifying the benefits of LID; therefore, the pool of studies from which to choose is somewhat small. However, a number of studies were reviewed and six studies were selected as good candidates for a benefits transfer, given their similar context and scope. All six studies estimate a bundle of benefits associated with trees/LID/green storm water management in general. These studies are summarized in Table B.5. A brief summary is offered for each study, along with the estimate itself.

Table B.5. Studies used in benefits transfer

Study	Summary of study	Estimate (% increase in value)
Ward et al. (2008)	Estimates effect of LID on adjacent properties relative to those farther away, in King County (Seattle), WA.	3.5–5.0%
Shultz and Schmitz (2008)	Proxies LID effects by looking at differentials for neighborhoods with clustered open spaces and greenways, etc., in Omaha, NE.	Greenways: 1.1–2.7%; clustered open space: 0.7–1.1%
McPherson et al. (2006)	References an uncited study that looks at the differentials between properties with ample trees vs. none or few trees (few details).	3–7%
Wachter and Wong (2006)	Estimates the effect of tree plantings on property values for select neighborhoods in Philadelphia.	2% (intrinsic value of trees)
Anderson and Cordell (1988)	Uses sales data from Athens-Clarke County (GA) to estimate the value of trees on residential property. Looks at differences between houses with five or more front yard trees and those that have fewer.	3.5–4.5%
Braden and Johnston (2003)	Uses meta-analysis of studies to estimate several benefit categories related to on-site storm water retention (green approach/LID) for managing storm water.	0–5%

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[1] Watershed-specific estimates are provided in Section B.4.

B.4 Watershed-Specific Results

The tables that follow (Tables B.6 through B.12) show the property value results, by watershed and LID option. The benefit estimates reported here reflect the 50% reduction in increased property values described above, so as to focus on the aesthetic value of improvements provided by the added vegetation (i.e., reflecting a conservative approach to precluding possible double counting of energy savings and other benefits that might be embedded within the property value estimates).

Table B.6. Summary table of estimates (within combined sewer area; Tacony-Frankford Creek Watershed)

LID option (% increase)	Low % increase	High % increase
25%	$22,160,000.00	$55,399,000.00
50%	$44,319,000.00	$110,798,000.00
75%	$66,479,000.00	$166,197,000.00
100%	$88,639,000.00	$221,596,000.00

Table B.7. Summary table of estimates (within combined sewer area; Cobbs Creek Watershed)

LID option (% increase)	Low % increase	High % increase
25%	$7,010,000	$17,525,000
50%	$14,020,000	$35,049,000
75%	$21,030,000	$52,574,000
100%	$28,040,000	$70,099,000

Table B.8. Summary table of estimates (within combined sewer area; Delaware Direct Watershed)

LID option (% increase)	Low % increase	High % increase
25%	$77,123,000	$192,808,000
50%	$154,246,000	$385,615,000
75%	$231,369,000	$578,423,000
100%	$308,492,000	$771,230,000

Table B.9. Summary table of estimates (within combined sewer area; Lower Schuylkill River Watershed)

LID option (% increase)	Low % increase	High % increase
25%	$55,337,000	$138,342,000
50%	$110,673,000	$276,683,000
75%	$166,010,000	$415,025,000
100%	$221,347,000	$553,367,000

Table B.10. Summary table of estimates (outside combined sewer area; Tacony-Frankford Creek Watershed)

LID option (% increase)	Low % increase	High % increase
25%	$2,133,000	$5,333,000
50%	$4,266,000	$10,666,000
75%	$6,399,000	$15,998,000
100%	$8,532,000	$21,331,000

Table B.11. Summary table of estimates (outside combined sewer area; Cobbs Creek Watershed)

LID option (% increase)	Low % increase	High % increase
25%	$81,000	$203,000
50%	$162,000	$406,000
75%	$244,000	$609,000
100%	$325,000	$812,000

Table B.12. Summary table of estimates (outside combined sewer area; Delaware Direct Watershed)

LID option (% increase)	Low % increase	High % increase
25%	$726,000	$1,816,000
50%	$1,453,000	$3,632,000
75%	$2,179,000	$5,447,000
100%	$2,905,000	$7,263,000

B.5 Omissions, Biases, and Uncertainties

To estimate property value benefits under the LID alternatives, it was necessary to make a number of assumptions in the absence of specific data. In addition, a number of data omissions and uncertainties surrounding the analysis have been identified throughout this report. Table B.13 provides a summary of these assumptions and uncertainties and their likely impact on our estimation of property value benefits.

Table B.13. Omissions, biases, and uncertainties

Assumption/ methodology	Likely impact on net benefits[a]	Comment/explanation
Focuses only on residential properties	++	Property values for commercial, industrial, and other non-residential properties are excluded from the analysis. Including the benefits to these properties would increase net benefits.
Based on benefits transfer approach, using range of 2–5%	U	The literature provides estimates for increases in residential property values from 0–7% due to LID implementation. We narrow this range to 2–5%. A Philadelphia-specific study, Wachter and Wong (2006), estimates the benefits to residential properties from tree plantings at 2%. Estimates used in this benefits transfer are assumed to be, on average, for a similar population and scale. Studies were chosen with these considerations.
Estimates are based on marginal changes to land market	U	Estimates used in the benefits transfer are based largely on hedonic analyses, which reflect benefits associated with marginal changes in a land market. We assume the aggregation of benefits over multiple properties around the City is a marginal change.
Reducing property value benefits to reflect potential double-counting	U	To avoid double-counting, we adjust property value benefits downward by 50%. This adjustment is ad hoc, but is used to estimate unique benefits to residential properties that are not estimated in other parts of the report. For example, enhanced aesthetics is a unique benefit, while reduced heat stress is not.
Number of affected properties	U	The number of residencies impacted depends on the LID option for which benefits are calculated. These range from 25%–100% as presented in Tables B.1–B.4.
Affected properties accrue benefits uniformly	U	All affected properties are assumed to accrue benefits uniformly. Considerations for baseline conditions or precise locations of LID implementations could not be made reliably in the absence of better data.

Table B.13. Omissions, biases, and uncertainties (cont.)

Assumption/ methodology	Likely impact on net benefits	Comment/explanation
Average property price is the weighted average of median prices from the affected neighborhoods	U, but small	The average property price for a given geographic area (used to derive total market value for that area) is calculated by taking the sales price for each neighborhood and multiplying by the share of residential properties sold within those neighborhoods, summing over all neighborhoods.

a. Indicating how addressing the assumption or overcoming the omission would probably impact the analysis, using the following key: + would probably increase net benefits; ++ would increase net benefits significantly; U direction of change in net benefit is uncertain; - would diminish net benefits; -- would diminish net benefits significantly.

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C. Heat Stress and Related Premature Fatalities Avoided

This appendix describes the methodology used to evaluate the benefits associated with the reduction in EHEs and heat-related fatalities under the LID CSO control options currently being considered by the PWD. Results of our analysis are also provided.

C.1 Introduction

EHEs have a well documented history of adverse public health impacts. Relatively recent demonstrations of this heat-health relationship include the loss of roughly 15,000 lives in France during the 2003 European EHE (Koppe et al., 2004; Valleron and Mendil, 2004) and over 700 deaths in Chicago, Illinois, in a July 1995 EHE (Kaiser et al., 2007). In addition to causing increased mortality, EHEs have also been associated with a range of morbidity impacts including increased emergency room use (NOAA, 1995) and hospitalizations (Semenza et al., 1999).

Philadelphia has its own tragic history of adverse public health impacts from EHEs. Notably, in 1991 and 1993, the county coroner determined EHEs were responsible for over 20 and 100 deaths, respectively (CDC, 1994; U.S. EPA, 2006). These findings drew significant attention to the heat-health relationship in Philadelphia and resulted in a number of formal responses including:

- The establishment of Philadelphia's Heat Task Force to help develop and implement EHE notification and response plans.
- Interest from the City in developing a meteorological warning system to predict when threatening conditions were expected. This ultimately led to the development of Philadelphia's Heat Watch Warning System, which predicts daily mortality increases based on forecast weather conditions (Kalkstein et al., 1996).

Concern about the heat-health issue continued to build and drive research from the late 1980s through the 1990s. A similar pattern developed with respect to examining how the urban environment can increase the severity and/or duration of residents' exposure to elevated temperatures. These associated health concerns, combined with interest in reducing the electrical demand within urban areas, helped spur research into what is commonly known as UHI issues, particularly the potential for different mitigation actions (U.S. EPA, 2008a). Within this field, one studied UHI mitigation strategy involves increasing the reflectiveness (i.e., albedo) of urban surfaces and/or increasing the acreage of urban vegetation (e.g., Hudischewskyj et al., 2001; Sailor, 2003).

The LID CSO control options are expected to increase the City's vegetated acreage. Thus, the envisioned LID programs will mimic urban revegetation programs focused on addressing the UHI. As a result, the LID options are expected to generate ancillary health benefits by reducing urban summer temperatures.

This appendix first provides a summary of results from studies that have estimated urban temperature reductions associated with increasing urban vegetation. As described below, these results are used to define a range of plausible scenarios for how the increase in vegetated acreage under the LID CSO control options could affect urban weather conditions in Philadelphia. The meteorological changes defined in these scenarios are then used to estimate the potential benefit of the LID programs in terms of avoided heat-attributable deaths. The appendix concludes with a series of final comments and considerations including a review of potential omissions, biases, and uncertainties in the study methods and results.

C.2 Modeled and Predicted Urban Temperature Reductions from Increased Urban Vegetation

Complex spatial models have been used to estimate how increasing urban vegetation can affect solar energy absorption and ultimately local meteorological values such as temperature and humidity. In these applications, the study area is first divided into grid cells. Each grid cell is then assigned to a land category class that has its own unique combination of attribute values (e.g., solar reflectivity/absorption, moisture, roughness). The impact of a program that increases urban vegetation is then accounted for by recalculating and reassigning attribute values in cells where the policy would be implemented.

For example, in the simplest approach, each grid cell would be assigned to one of two land categories, nonvegetated or vegetated. A policy to increase urban vegetation would then describe a percentage increase in vegetation, for example, a 10% increase in the study area. To simulate the effects of this policy, a new set of attribute values would be calculated for all cells initially assigned to the nonvegetated category. These new attribute values would reflect a weighted average of the nonvegetated and vegetated attribute values. In this hypothetical scenario, the new attribute value in previously nonvegetated cells would now be equal to 90% of the original nonvegetated attribute value plus 10% of the vegetated attribute. Values for cells originally categorized as vegetated would remain unchanged in this example. The policy's impact on urban conditions is then calculated by running an urban meteorology model for the base case and the policy case and calculating the difference between meteorological values of interest (e.g., average daily temperature).

This approach has previously been used to estimate the impact of a 10% increase in urban vegetated acreage for a number of U.S. cities, including Philadelphia (Hudischewskyj et al., 2001; Sailor, 2003), over a limited number of days. In the Hudischewskyj et al. (2001) study, the modeling was limited to considering the period July 14–15, 1995. Sailor (2003) modeled a number of multi-day events from June through August 1991–2001. Table C.1 presents the results of both studies with respect to changes in various air temperature measures.

Table C.1. Summary of urban temperature impact results from increasing urban vegetation in Philadelphia

Study	Vegetation scenario	Modeled temperature change result (°F)	Notes
Sailor (2003)	10% increase in urban vegetation from increased deciduous broadleaf tree cover	0.39 (average temperature)	Average temperature is the average of hourly differences calculated from 8 a.m. to 7 p.m.
		0.49 (maximum temperature)	Maximum temperature is the difference between the maximum daily temperatures in the control and policy cases
Hudischewskyj et al. (2001)	10% increase in urban vegetation (type of vegetation not clearly specified)	0.70 (maximum temperature 7/14)	Difference in maximum surface temperatures in base and policy case
		0.40 (maximum temperature 7/15)	

The results in Table C.1 suggest that increasing vegetation by 10% in Philadelphia might reduce urban temperatures by between 0.40°F and 0.70°F depending on the temperature measure (i.e., maximum vs. average temperature).

A similar study (Columbia University Center for Climate Systems Research et al., 2006) evaluated a number of potential changes to the urban landscape in New York City. The study estimated that there would be a 0.40°F reduction in temperature at 3 p.m. in New York City if 6.7% of the total city area represented were to receive shading by adding trees along streets. The study also estimated a potential 1.10°F reduction at 3 p.m. if 31% of the city area were converted from its current mix of grass areas, streets without trees, and impervious roofs to areas with trees and living (i.e., vegetated) roofs.

C.3 The Meteorological Impact of the LID Scenarios

The green CSO compliance alternatives are expected to reduce daily maximum temperatures in the watershed area as a result of increased shading and replacement of dark paved surfaces with vegetation that absorbs less solar radiation. However, the increase in vegetated acreage is also expected to increase humidity due to increased evapotranspiration. Collectively, this would increase the dewpoint temperature.

Depending on the LID option implemented, the resulting increase in vegetated acreage would be equivalent to a 6% to 31% increase in vegetated acreage measured as a percentage of the original impervious acreage across all CSO areas in the watersheds. This is similar to how the vegetated acreage increase was measured in Sailor (2003). The vegetation increase under the LID options is also roughly equivalent to a 4% to 21% increase in vegetated area when measured as a percentage of the total area covered by combined sewers across all watersheds. This is similar to how the change in vegetation was measured in the Columbia University Center for Climate Systems Research et al. (2006) study.

Because the increases in vegetation planned for implementation under the LID options are similar to the increases in vegetation evaluated in Sailor (2003) and Columbia University Center for Climate Systems Research et al. (2006), we used these studies to estimate the meteorological changes that would occur under the LID options. Specifically, the values of the temperature reductions in the temperature-only scenarios in Table C.2 bound the temperature change results reported in these earlier studies (see Table C.1 and associated discussion). The scenario results that incorporate changes in temperature and dewpoint are intended to increase the overall reality of the LID option impacts by addressing the expected increase in the dewpoint with the additional vegetation while hopefully providing an additional set of realistic estimates for consideration.

Table C.2. Alternative heat and relative humidity scenarios for Philadelphia LID compliance heat-mortality modeling

Scenario	Reduction in daily max temperature (°F)	Increase in daytime dew point temperature (°F)
1. Temperature only: minimum	0.25	0.00
2. Temperature only: maximum	1.75	0.00
3. Temperature and relative humidity: minimum	0.75	0.25
4. Temperature and relative humidity: maximum	1.25	0.50

C.4 Estimating Future Health Benefits from Reduced EHE Temperatures in Philadelphia

Our current analysis reflects an expansion in scope from our previous work that estimated potential public health benefits for a program that reduced EHE-attributable health impacts in Philadelphia during selected EHEs, by increasing urban vegetation (based on Kalkstein and Sheridan, 2003). Because a similar method is used for this effort, we first begin this section with a review of Kalkstein and Sheridan (2003) to present critical methods. The rest of this section provides an overview of how the meteorological scenario changes for analyses selected in Section C.2 were applied to the available regionally downscaled climate change data and the associated heat-mortality calculation system encompassed in Philadelphia's Heat Health Watch Warning System.

C.4.1 A review of Kalkstein and Sheridan (2003)

Kalkstein and Sheridan (2003) used a five-step process to estimate how a hypothetical change in urban temperature could affect heat-attributable mortality by evaluating a subset of summertime days specifically selected because they represented EHE conditions. The study is particularly relevant because Philadelphia was one of the study cities evaluated.

In the first step, each selected day was assigned to an air mass category based on available meteorological data. Air mass categories characterize weather conditions based on the values for a set of meteorological variables including temperature, dew point, wind speed, and cloud cover. Specific air mass categories include:

- Dry moderate (DM): A warm, comfortable air mass that occurs in Philadelphia frequently in summer.
- Dry polar (DP): Cooler than DM, but still quite warm in the summertime. Usually occurs immediately after the passage of a cold front.
- Dry tropical (DT): The hottest air mass in the summer, with temperatures usually exceeding 95 degrees and sometimes topping 100. Little cloud cover and low humidity lead to potentially rapid dehydration.
- Moist moderate (MM): A cloudy, mild air mass that may sometimes be associated with fog and light rain.
- Moist polar (MP): Usually a winter, rather than summer, air mass, this situation is often associated with storms moving up the East Coast.

- Moist tropical (MT): Very warm and humid air mass, sometimes associated with summer thunderstorms. Sticky and uncomfortable, and quite common in summer.
- Moist tropical plus (MT+) and Moist tropical plus plus (MT++): These are particularly hot and humid subsets of the MT air mass. Dewpoint temperatures are very high, temperatures are in the 90s, and overnight temperatures are the warmest of any air masses. These hot, humid conditions have historically led to increased mortality in Philadelphia.
- Transition (T): Associated with a frontal passage, when temperature, dewpoint, and other meteorological factors are changing rapidly.

In the second step, the study days with offensive air masses are identified. In short, those air masses that have daily mortality values that are consistently larger than longer-term averages are labeled offensive. The identification of offensive air masses relies on the evaluating time series data over multiple years to evaluate the relationships between daily mortality totals and air mass categories. In Philadelphia, the offensive air mass categories include: DT, MT+, and MT++.

In the third step, the heat-attributable mortality for each offensive air mass day is calculated. These calculations are completed using mortality algorithms developed using an iterative process to identify the regression equation that provides the best explanation of the observed difference in mortality from the longer term trends (i.e., the heat-attributable mortality). In this iterative process, meteorological variables and factors such as the timing of the offensive air mass day within the summer season and the persistence of the EHE are evaluated as potential explanatory variables.

The fourth step repeats the process for the study day while also accounting for the predicted change in temperature as a result of the increased urban vegetation. In the fifth step, the difference in mortality from the two scenarios is calculated and reported to indicate the impact of the increased urban vegetation.

Kalkstein and Sheridan (2003) found that the impact of increased vegetation varied according to the EHE event, and often day-to-day. Overall, the study reported a net reduction in the estimate of heat-attributable deaths with the increase in urban vegetation. However, the mortality reductions were not evenly distributed across days and some days showed an increase in the mortality estimates. The strength of the conclusions and ability to generalize the results across longer time periods are constrained by the limited number of summertime days and EHEs considered.

C.4.2 New study of increased vegetation with climate change

To develop a more detailed assessment of the potential heat-health impacts of the LID scenarios, the possible changes in temperature and relative humidity presented in Table C.2 were evaluated using the same general approach as in Kalkstein and Sheridan (2003) and described above in Section C.4.1. However, because the LID programs are expected to take a number of years for the vegetation targets to be fully achieved, the meteorological data used for the evaluation was provided by regionally downscaled General Circulation Model (GCM) results from a compilation of the A1 family of climate change emissions scenarios.

The downscaled meteorological results are produced for each day, from April 1 through August 31, in a representative year using a deterministic method that incorporates linear monthly regressions to help adjust the GCM results and ensure the probability distributions for the values for a baseline period in the 1990s are generally consistent with observed values during this time. This approach has been used for similar assessments of potential future heat impacts (e.g., Hayhoe et al., 2004). To try and capture inter-annual variability and provide results at different points in the LID project lifecycle, downscaled results were calculated for two future decades: 2020–2030 and 2045–2055. To help provide a point of reference, similar calculations were made for the 1990–2000 period.

The results of this evaluation are presented in Tables C.3 and C.4 in terms of the estimated number of heat-attributable deaths and offensive air mass days in each decade using the downscaled GCM data alone (the *control* results), and when accounting for the temperature and dewpoint temperature changes being evaluated for the LID scenarios.

Looking at the results a number the general conclusions can be drawn:

- Any measurable cooling provided by implementing an LID scenario is likely to provide some reduction in EHE-attributable mortality
- EHE-attributable mortality reductions are roughly proportional to the relative magnitude of the assumed temperature change
- The health benefits of the LID scenario implementation are relatively constant across the different decades, comparing the lives lost in the scenario to the control with the exception of the 1.75°F temperature reduction which has a noticeable increase in lives saved moving from the 2020s to the 2045–2055 period
- EHEs are likely to become an increasing risk to public health in Philadelphia without continued adaptation.

Table C.3. Estimated heat-attributable deaths assuming alternative temperature and dewpoint impacts from LID options

Year	Control	Year	Control	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Year	Control	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Total surplus heat-related mortality													
1990	75	2020	90	85	66	79	75	2045	121	118	86	97	93
1991	70	2021	50	47	34	39	36	2046	117	114	90	102	94
1992	32	2022	52	48	36	41	38	2047	98	91	75	82	78
1993	47	2023	155	150	122	135	127	2048	94	87	64	78	70
1994	120	2024	128	122	105	112	109	2049	138	130	111	121	116
1995	53	2025	61	55	43	51	47	2050	85	79	62	77	69
1996	69	2026	98	95	74	83	79	2051	171	165	149	158	154
1997	93	2027	86	83	63	77	71	2052	72	63	47	56	50
1998	56	2028	54	49	41	46	45	2053	105	97	74	87	78
1999	116	2029	117	105	83	93	91	2054	89	87	73	82	77
2000	60	2030	47	45	33	40	37	2055	147	143	110	134	122
Mean	**72**	**Mean**	**85**	**80**	**64**	**72**	**69**	**Mean**	**112**	**107**	**85**	**98**	**91**

Table C.4. Estimated offensive air mass days assuming alternative temperature and dewpoint impacts from LID options in various time periods

Year	Control	Year	Control	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Year	Control	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Total number of offensive days													
1990	54	2020	59	56	49	53	52	2045	73	72	60	62	61
1991	44	2021	43	41	35	36	35	2046	62	62	53	59	55
1992	32	2022	37	35	32	33	32	2047	61	58	53	56	54
1993	33	2023	76	75	69	72	69	2048	57	54	44	50	47
1994	67	2024	61	58	55	55	55	2049	74	71	67	69	67
1995	44	2025	46	44	37	40	38	2050	56	53	45	53	46
1996	45	2026	62	61	52	56	54	2051	76	74	70	70	70
1997	51	2027	61	61	52	59	55	2052	47	44	35	40	35
1998	41	2028	38	35	32	33	34	2053	60	58	51	55	53
1999	64	2029	65	62	56	57	57	2054	55	55	49	52	50
2000	42	2030	42	42	37	39	38	2055	79	78	69	76	74
Mean	**47**	**Mean**	**54**	**52**	**46**	**48**	**47**	**Mean**	**64**	**62**	**54**	**58**	**56**

Underlying most of the mortality estimates and most of the summary results identified above is the actual mortality algorithm that was incorporated for the offensive air mass days. This algorithm is presented as Equation 1.

Equation 1. Daily heat-attributable mortality

Daily heat attributable mortality = [-22.904+(1.79 × DIS)+(1.198 × Tmax) – (0.054 × Julian)] / 4.722

where:

DIS =	day in sequence value, where 1 is the first day of an offensive air mass, 2 is the second consecutive day, etc.
Tmax =	daily maximum temperature in °C
Julian =	time of year variable, with April 1 =1, April 2 = 2 … August 31 = 153
4.722 scalar **=**	adjustment value used so that the GCM 1990 control scenario mortality estimates match actual heat attributable mortality estimates for the decade.

The mortality algorithm shows why, because Tmax is the only meteorological variable in the equation, the mortality results can generally be sorted by in terms of the associated temperature changes. It also demonstrates why, with a coefficient value on maximum temperature of roughly 1, the results are generally proportional to the assumed temperature changes. However, this emphasis on the maximum temperature in the mortality algorithm overlooks that the assumed changes in dewpoint temperature do play an important role in the results as they influence the air mass categories a day is assigned to and thus, in some cases, whether it falls into an offensive or non-offensive category.

Perhaps the most important feature of both the mortality and EHE day estimates in Tables C.3 and C.4 is to note the significant variability within the year-by-year results for a scenario and across scenarios. Expressed as a percentage of the mean values for estimated EHE-attributable deaths, the standard deviation of the decadal results is roughly 45% in the 2020–2030 estimates and roughly 30% in the period 2045–2055. Within years, results for scenarios can be roughly 2–3 times as large when comparing the largest estimates to the smallest. In short, while the results show the benefits of pursuing an LID program in terms of reducing EHE-attributable mortality in Philadelphia, predicting the exact nature of benefits in any given time period is complicated and becomes increasingly uncertain if narrower time windows are considered.

C.5 Application to Philadelphia LID Option Scenarios

We used the temperature and relative humidity changes identified in Table C.2 to estimate changes in heat-related mortality under the LID alternatives. First, based on estimated increases in vegetated acreage, we assumed that Scenarios 1 and 3 represent a range of the changes that would occur under the 25% LID option. We also assumed that changes under the 100% LID option are best represented by Scenarios 2 and 4.

Based on these assumptions, we estimated the average number of lives each year, for three 10-year periods: 2020–2029, 2030–2039, and 2040–2049 under the 25% and 100% LID options. We then scaled the percent of benefits realized each year based on the timeline for program implementation provided by CDM and the effective tree model developed by Stratus Consulting (see Appendix H). We assume that no heat-reduction benefits are realized prior to 2020.

To estimate the number of lives saved under the 50% and 75% LID options, we scaled results for the 25% and 100% LID options based on the level (percentage) of LID for each option. We then estimated the monetary value associated with the number of lives saved under each LID option based on EPA's recommended VSL ($7,000,000). Table C.5 presents the results of this analysis on a City-wide basis.

Table C.5. City-wide benefits associated with reduced urban temperatures under the LID alternatives

CSO option	Number of lives saved, over 40-year period	Present value of lives saved (based on EPA's recommended VSL) (millions, 2009 USD)
25% LID	137	$739.4
50% LID	196	$1,057.6
75% LID	255	$1,375.9
100% LID	314	$1,694.1

To estimate benefits for each watershed, we allocated the City-wide estimates shown above based on watershed population. Table C.6 presents the present value benefits (for 40-year project period, 2009 USD) associated with reduced heat-related fatalities, by watershed.

Table C.6. Present value benefits associated with reduced heat-related fatalities under LID CSO options, allocated by watershed (millions, 2009 USD)

CSO option	% of total population in CSO watersheds	Tacony	Cobbs	Schuylkill	Delaware
25% LID	8%	$174.7	$62.8	$207.7	$294.2
50% LID	24%	$249.9	$89.8	$297.1	$420.9
75% LID	28%	$325.1	$116.8	$386.5	$547.5
100% LID	40%	$400.3	$143.8	$475.9	$674.2

C.6 Omissions, Biases, and Uncertainties Associated with Health Benefit Conclusions

The following sections provide a summary of the impact of critical assumptions and calculation approaches used to develop the results of this analysis.

C.6.1 Accuracy of any single temperature and dewpoint scenario result

Well-understood basic physical principles underlie the assumption that significantly increasing the vegetated acreage in Philadelphia through an LID program should reduce ambient temperatures and increase the relative humidity and dewpoint temperature. The extent of this change, however, is uncertain.

Past experiments calculate possible values using complex integrated models that also take the unrealistic step of instantaneously changing the nature of a significant portion of an urban area. The more realistic scenario is that these changes occur and are fully realized over time. What complicates calculating the associated impact of these changes is that they are also likely to be a function of other changes in the urban landscape. This uncertainty prevents assigning a likely direction of bias in the current estimates.

What the results and the mortality algorithm make clear though is that larger temperature reductions will, all else equal, increase the health benefit of LID implementation.

C.6.2 Uncertainty of climate change

Philadelphia has a long history of being adversely affected by EHEs. All else equal, climate change is likely to increase the public risks and impacts associated with future EHEs as shown in the results. However, while acceptance of climate change impacts continues to grow there is still considerable uncertainty over what the future climate will look like.

In particular, researchers have begun to note how several climate change-related impacts that were anticipated to begin appearing later in the century may have already begun and how the pace of climate change may be more rapid than previously anticipated. In this study, further warming would increase the number of EHE days. This would increase the mortality estimates across the control and LID scenarios and may have little impact on the estimate of lives saved with the LID scenarios. More importantly, increased warming could fundamentally alter the nature of the EHE-mortality relationship in Philadelphia. If tolerance/infrastructure thresholds are crossed in an increasingly warm climate before the population can adapt there is the chance that the mortality estimates presented could be conservative.

C.6.3 Changing population size, demographics and response to heat

Heat is a well-recognized public health threat in Philadelphia and the City has an active and aggressive education, notification, and response program to address EHE conditions. The current estimates assume that the future rate of EHE-attributable deaths in response to EHE conditions will remain unchanged. To the extent future heat programs become more effective or factors that make those most currently vulnerable to EHEs become less of an issue (e.g., better access and use of air conditioning), the current heat mortality estimates could be overstated. However, the potential benefits of the LID program, all else equal, could remain unchanged in this situation if the impact is relatively small. In addition, these estimates hold the City's population at a constant size for all time periods evaluated. The bias introduced as a result will result in an overstatement of impacts, all else equal, if the future population is expected to decline compared to 2000 levels. Results would similarly be understated if future populations are expected to grow relative to 2000 levels.

Heat has and will continue to be a public health threat in Philadelphia. By offering the potential to reduce urban temperatures, the envisioned LID scenarios directly address the fundamental nature of the risk associated with EHE conditions and hold the potential to help prevent lives being lost to future EHEs.

C.6.4 The benefits of nonfatal heat stress cases avoided are not included

This analysis has focused solely on the number of premature fatalities avoided due to the impact that LID options are projected to have on urban temperatures and heat stress deaths. The cooling anticipated from the green infrastructure approaches also will generate public health benefits for individuals who would otherwise suffer nonfatal heat stress-related episodes. For example, the LID approaches will reduce the number of nonfatal heat stress episodes, thereby reducing the pain, suffering, medical expenses, and other losses incurred by individuals who otherwise would have become ill or temporarily disabled by heat stress. Thus, the total anticipated value of reduced heat stress is underestimated here, because it focuses exclusively on mortality events and omits morbidity episodes.

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D. Water Quality and Aquatic Habitat Enhancements and Values

Under all of the CSO control options currently being evaluated by the PWD, water quality will be improved in streams and rivers within the City's CSO service area. Under the LID CSO options, stream restoration, wetlands, and increased vegetated area will also result in substantial aquatic habitat enhancements.

As described below, individuals in Philadelphia not only benefit from the direct use of these improved resources (e.g., through recreation), but also from knowing that these resources exist at a given level of quality. In environmental economics, this is referred to as "nonuse" value.

The following sections provide further background on nonuse values and outline Stratus Consulting's methodology for estimating nonuse values for improved water quality and aquatic habitat under the different CSO control options. Estimates for the benefits associated with these improvements are also provided.

D.1 Nonuse Values and Benefit Transfer

The different CSO control options yield different types and levels of water quality-related benefits. For example, stream restoration and water quality improvements under LID options will result in recreational benefits for many Philadelphia residents (see Appendix A). Recreational benefits accrue to individuals who actually participate in recreational activities, and are therefore quantified based on "use values" associated with different types of stream-side recreation.

For most residents in the greater Philadelphia area (including those who rarely or never participate in stream-related recreational activities), the different CSO control options will also result in some level of "nonuse" benefits. These nonuse benefits stem from the inherent value that individuals place on environmental goods and resources (in this case, water quality and habitat improvements). A frequently discussed basis for nonuse value is the desire to maintain the functioning of specific ecosystems.

In environmental economics, nonuse values are often referred to as existence and bequest values (King and Mazzotta, 2005). Existence value is the benefit generated today by knowing that a resource exists even if no use of the resource is anticipated. Bequest value is the value individuals gain from the preservation of the resource for use by their heirs. The term nonuse value is typically used in a more general manner to encompass both of these constructs (Harpman et al., 1994).

Nonuse values can only be estimated using techniques called "stated preference" methods. Contingent valuation (CV) has been the most commonly used stated preference method for estimating nonuse value, although more sophisticated variants (such as conjoint or choice set approaches) are now sometimes applied. In its simplest terms, CV is a survey-based technique used to elicit the maximum amount (in dollar terms) that an individual would be willing to pay for a resource (or an improvement to a resource) of a specified quality. Stated preference methods for conducting economic analysis are so named because values are obtained based on the stated preferences of individual survey respondents. An original stated preference study typically requires a significant amount of time and financial resources, because there are several important design and sampling features that need to be developed and pre-tested to ensure the reliability of the values derived from the survey instrument. For this reason, researchers often use the *benefits transfer* approach to estimate "willingness to pay" values.

Bergstrom and De Civita (1999, p. 79) offer the following definition of benefits transfer:

> Benefits transfer can be defined practically as the transfer of existing economic values estimated in one context to estimate economic values in a different context …. In the case of natural resource and environmental policies and projects, benefits transfer involves transferring value estimates from a "study site" to a "policy site" where sites can vary across geographic space and or time.

Benefits transfer is commonly used in economics, and there is a well-developed literature on how to correctly apply this method (e.g., Rosenberger and Loomis, 2003). Federal guidelines for economic analysis discuss how and when benefits transfer should be applied (U.S. EPA, 2000; U.S. OMB, 2003).

In the present case, we use benefits transfer to estimate average WTP per household in the greater Philadelphia Metropolitan Area (MA) for water quality and aquatic habitat improvements under each of the CSO control options. Our estimates are based on a meta-analysis, conducted by Van Houtven et al. (2007), of 131 WTP estimates from 18 studies (21 publications) conducted between 1977 and 2003. The WTP estimates included in the meta-analysis were all derived using stated preference methods.

D.2 Methodology

As noted above, to estimate WTP values for water quality and aquatic habitat improvements in Philadelphia, we relied on a meta-analysis of water quality valuation studies conducted by Van Houtven et al. (2007). A primary objective of the meta-analysis was to develop a tool (regression model), based on existing (primary) studies that could be used in benefits transfer analysis to predict WTP estimates for different policy scenarios. The following sections summarize the methodology used to conduct the meta-analysis and the assumptions made to transfer results of the analysis to Philadelphia.

D.2.1 Meta-analysis: data collection and common influences on WTP estimates

The studies included in the Van Houtven et al. analysis were limited to stated preference studies conducted in the United States and to studies that described water quality in terms that could be converted to a common 10-point scale. Once studies that met these criteria were selected, the authors identified common variables across the studies that were likely to influence WTP estimates. In general, these variables can be categorized as follows:

- **The water quality "commodity."** The authors converted the water quality changes evaluated in each study into a common metric. To do this, they constructed a 10-point water quality index, WQI_{10}. This index is based in part on the water quality ladder (WQL) developed by Vaughan (1986) as a way of conveying water quality to the general public, particularly survey respondents. Vaughan defined the ladder such that, for example, a water quality index value of 2.5 (out of 10) was "boatable," 5.1 was "fishable," and 7.0 was "swimmable." Many researchers (e.g., Desvousges et al., 1987 and others) have used Vaughan's WQL to obtain WTP estimates for changes in the "steps" of the ladder. Van Houtven et al.'s WQI_{10} maps water quality characteristics not specifically related to recreational use (e.g., habitat suitability) to the WQL. Figure D.1 shows a schematic of Vaughan's original WQL. Table D.1 shows some specific water quality measures associated with the different use levels identified.

- **Study population characteristics.** WTP relates primarily to individuals' preferences, which are determined at least in part by personal characteristics. For example, individuals who are active recreational users of water resources are also likely to have stronger preferences for improving freshwater quality. Thus, users typically place higher values on water quality changes than nonusers, all else equal.

  Further, individual values for water quality changes reflect both their willingness and their ability to pay. The economic conditions that affect an individual's perceived ability to pay for water quality changes can be captured (at least in part) through personal or household income. If water quality is a normal good, then increasing income is expected to have a positive effect on WTP.

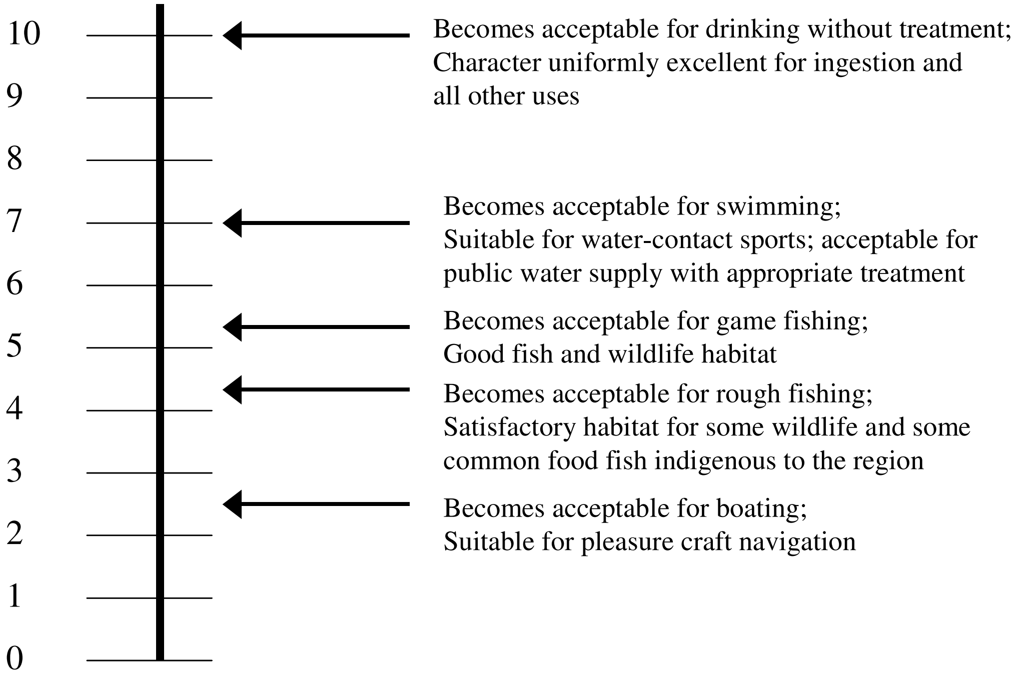

Figure D.1. Vaughan's (1986) water quality ladder.

Table D.1. Water quality characteristics for 5 classes of water use

	Fecal coliform (no./100 mL)	Dissolved oxygen (mg/L)	5-day BOD (mg/L)	Turbidity (NTU)	pH
Acceptable for drinking without treatment	0	7.0	0	5	7.25
Acceptable for swimming	200	6.5	1.5	10	7.25
Acceptable for game fishing	1,000	5.0	3	50	7.25
Acceptable for rough fishing	1,000	4.0	3	50	7.25
Acceptable for boating	2,000	3.5	4	100	4.25

Source: Russell et al., 2001.

- **Valuation method.** The magnitude of the value estimates for water quality changes is also expected to depend on the way in which the estimates were derived. As noted above, all of the WTP estimates included in the analysis are based on stated preference methods (either the CV method or conjoint analysis). However, a number of methodological differences have the potential to influence WTP. One potentially significant difference is the type of value elicitation format used (e.g., open-ended vs. dichotomous choice questions). WTP may also be influenced by whether the stated preference survey is conducted in person, over the phone, through a mailed questionnaire, or in another format. These variables are controlled for in the Van Houtven et al. (2007) analysis.

- **Other study characteristics.** WTP estimates may also be influenced by the overall quality of the methods and results of the study. Two potential indicators of study quality are the survey response rate and the publication outlet. Higher response rates and publication in peer-reviewed outlets are generally considered to reflect better quality studies. However, the publication selection process may result in estimation bias if, for example, reviewers and editors are more inclined to accept higher value estimates or if analysts are less likely to submit lower estimates (Stanley, 2001). Thus, while the expected effect of these characteristics on WTP is indeterminate, it is important to control for them in meta-analysis.

D.2.2 Meta-regression analysis

To evaluate societal preferences for water quality changes, Van Houtven et al. (2007) incorporated data from the 18 selected water valuation studies (based on the categories described in Section D.2.1 above) into a meta-regression analysis.

Table D.2 describes the specific variables used to estimate the author’s final regression models. The two primary variables of interest are WTP2000 (dependent variable), which is the estimated mean WTP per household for a defined change in water quality [converted to 2000 dollars using the consumer price index (CPI)], and $WQI_{10}CHANGE$, which captures the corresponding change in water quality in terms of the WQI_{10}.

The authors estimated the model using three different functional forms – linear, semi-log, and log-linear. Although all three of these forms are reasonable for approximating the relationship between WTP and the other variables, the log-linear approach has at least two conceptual advantages. First, it implies that, as changes in water quality approach zero, WTP also approaches zero. Second, it implies that the *marginal* effect of a water quality change on WTP depends on income. The semi-log model shares this second advantage; however, it also implies that if WTP increases with larger improvements in water quality, then it does so at an increasing rate.

Table D.2. Variables included in Van Houtven et al. meta-regression analysis

Variable	Description
WTP2000	Annual WTP for water quality change (in 2000 dollars)
WQI_{10}CHANGE	Water quality change (based on 10-point WQI)
WQ_REC_USE	= 1 if the water quality change described in the study includes a reference to recreational use support (e.g., suitable for recreational fishing)
WQI_{10}BASE	Baseline level of water quality from which water quality improves
ESTUARY	= 1 if the water quality change occurs in an estuary
LOCAL_FWATER	= 1 if the water quality change is restricted to freshwater in the local area (i.e., within a single waterbody, county, or metro area)
MIDWEST	= 1 if the affected waterbodies are in the Midwest region of the United States
SOUTH	= 1 if the affected waterbodies are in the Southern region of the United States
INCOME2000	Average household income (in thousands of 2000 dollars)
INCOME_APPROX	= 1 if average household income was approximated based on local Census data
PERCENT_USER	Percent of the sample population that are users of the affected water resource
PUBLISHED	= 1 if the study is published in a peer-reviewed book or journal
OPEN_ENDED	= 1 if the value was estimated from an open-ended valuation question
RESPONSE_RATE	Response rate for the survey used in the study
IN_PERSON	= 1 if the survey used in the study was administered with an in-person interview
STUDY_YR73	= Year SP survey was fielded (minus 1973)

Source: Van Houtven et al., 2007.

Van Houtven et al. report two similar model specifications for each functional form. The first is a full model with all of the main explanatory variables included, while the second is a restricted model using a more parsimonious specification. The restricted models exclude variables that are not individually significant at 0.10 level or less (based on t-statistics). As shown in Table D.2, the dropped variables include ESTUARY, LOCAL_FWATER, MIDWEST, SOUTH, OPEN_ENDED, and the interacted variable for INCOME2000 and INCOME_APPROX. Due to their conceptual and economic importance in the model, all water quality variables were retained in the restricted models regardless of their statistical significance.

Table D.3 shows the results of log-linear (full and restricted) models estimated by Van Houtven et al. The log-linear model is shown because this is the functional form we decided to use for our benefits transfer analysis. Although the numbers presented below are not inherently intuitive (because they are in logged form), the magnitude and sign of the coefficients provide a relative idea of how the different variables influence WTP estimates.

Table D.3. Meta-analysis regression results

Variables	**Model coefficient (full model)**	**Model coefficient (restricted model)**
Ln(WQI10CHANGE)	0.343	0.358
Ln(WQI$_{10}$CHANGE)xWQ_REC_USE	0.414*	0.465**
WQI$_{10}$BASE	0.091	0.08
ESTUARY	0.025	
LOCAL_FWATER	-0.11	
MIDWEST	0.329	
SOUTH	-0.052	
Ln(INCOME2000)	0.964*	0.897*
Ln(INCOME2000)xINCOME_APPROX	-0.008	
PERCENT_USER	0.011**	0.011**
PUBLISHED	0.960**	0.898**
OPEN_ENDED	0.051	
RESPONSE_RATE	-0.014	-0.013*
IN_PERSON	0.315	0.43
STUDY_YR73	-0.041**	-0.029**
CONSTANT	-0.399	-0.227

Note: ** and * respectively denote statistical significance at the 5% (p = 0.05) and 10% level (p = 0.10).

Source: Van Houtven et al., 2007.

As shown in Table D.3, most variables included in the model have a positive influence on WTP estimates (e.g., an individual with higher income will report higher WTP) to relative degrees. The negative effect of STUDY_YR73 indicates that, controlling for income and price effects, estimates of average real (inflation-adjusted) WTP for water quality improvements has declined over time. It is possible that this decline reflects changes in preferences over time; however, it may also be the result of other factors, such as possible changes in publication selection processes (e.g., by authors or editors) or in estimation methods, that tend to favor lower WTP estimates.

The effect of RESPONSE_RATE is also negative. The authors report that although there are no strong priors for how response rates should affect the magnitude of WTP estimates, these results suggest that surveys with lower response rates might exclude individuals with lower average WTP for water quality improvements.

For benefits transfer, the model coefficients shown above are multiplied by their respective input variable (the value of which is determined by the specific policy scenario). The sum of these products is then used to estimate WTP2000. For example, WTP estimates for the restricted model would be calculated as follows:

$$\begin{aligned}
&\text{Ln(WTP2000)} = -0.227 + (0.358 \times \text{Ln[WQI10CHANGE]}) \\
&+ (0.465 \times \text{Ln}(\text{WQI}_{10}\text{CHANGE}) \times \text{WQ\_REC\_USE}) + (0.08 \times \text{WQI}_{10}\text{BASE}) \\
&+ (0.897 \times \text{Ln(INCOME2000)}) + (0.011 \times \text{PERCENT\_USER}) \\
&+ (0.898 \times \text{PUBLISHED}) + (0.013 \times \text{RESPONSE\_RATE}) + (0.43 \times \text{IN\_PERSON}) \\
&+ (-0.029 \times \text{STUDY\_YR73})
\end{aligned}$$

D.2.3 Benefits transfer

As noted above, we used the log-linear model specification to predict WTP for the LID and non-LID CSO control options. We first estimated benefits associated with water quality/habitat changes under the 100% LID, 35’ Tunnel, and RTB HR01 alternatives. To estimate benefits associated with the less aggressive alternatives under each option (LID, Tunneling, Satellite Treatment), we scaled downwards based on the scope of the different alternatives. Further, we assumed the level of improvement under the Plant Expansion options to be equal to those of their corresponding LID component (e.g., benefits under the 100% LID + 215 MGD option will be the same as those estimated for the 100% LID option alone).

To provide a range of benefit values, we estimated results using both the full and restricted models from Van Houtven et al. We made the following assumptions in applying these models to Philadelphia:

- Benefits are estimated based on an average baseline water quality for all affected waterbodies (i.e., not by individual watershed). This is consistent with most studies included in the meta-analysis, which were conducted on a more regional scale. These estimates would be difficult to allocate across watersheds.
- We separately evaluate WTP per household for households within the City and households within the greater Philadelphia, MA but not within the City limits (including households in Bucks, Chester, Delaware, Montgomery counties). A number of factors led to this separate evaluation:
    - Households outside of the City have much higher incomes (on average) than households within Philadelphia. This affects WTP for water quality and ecological habitat improvements.
    - Distance from the water bodies being improved is expected to decrease WTP to some degree.

  - Households outside of the City are expected to have a much higher WTP for improvements in the Schuylkill and Delaware rivers (given their regional importance), as opposed to the more local Tacony and Cobbs creeks.
  - To account for these factors, we scaled WTP estimates for households outside of the City by 0.80 to account for distance and then multiplied these estimates by 0.61 (percent of CSO area stream miles in the Schuylkill and Delaware River watersheds).

- We assumed the baseline water quality in the affected streams and rivers (Cobbs Creek, Tacony Creek, and the tidal portions of the Schuylkill and Delaware rivers) to be 4.3 units. This score was determined based on knowledge of the WQI and affected streams. At 4.3, the water quality and habitat in the water body is assumed to support some “rough” fishing (not for game species), and is considered boatable.

- Under the 100% LID option, water quality is expected to improve by 2.5 units, up to 6.8. At this level, habitat (and fishing) is greatly improved but water quality levels do not allow for swimming.

- Under the most aggressive tunneling and satellite treatment options, water quality is assumed to improve by 1.2 units. This accounts for improved water quality but little change in aquatic habitat.

- In each case, we assumed that the stream restoration and water quality improvements will improve recreational opportunities in most areas (WQ_REC_USE equals 1). Although many residents do not use these areas for in-stream recreation, we can estimate the nonuse value they hold for these amenities.

- The variable PERCENT_USER is set at 0 because we are looking to capture only nonuse values in this part of the analysis.

- The variable INCOME_2000 is set at median household income for the City, which was estimated by the Census as $30,746 annually (lower than the 2000 national average). For households outside of the City but within the Philadelphia, MA, the model was estimated with INCOME_2000 equal to $64,736 (U.S. Census Bureau, 2000).

- The variables ESTUARY and LOCAL_FWATER were both set equal to 0.61 to reflect the percent of stream miles within PWD’s CSO boundaries that are considered “tidal” rather than freshwater.

- The study year is assumed to be 2009.

- Finally, consistent with Van Houtven et al., PUBLISHED was set at 0.5 (due to the uncertainties regarding whether this variable reflects study quality or publication bias). All other variables related to study format were set at the Van Houtven et al. sample means.

Based on these assumptions, Table D.4 shows the inputs used for each CSO control alternative for WTP for households within the City.

Table D.4. Meta-regression analysis inputs for Philadelphia CSO control options

	Variable input LID option	Variable input non-LID option
WQI_{10}CHANGE	2.5	1.2
WQI_{10}CHANGExWQ_REC_USE	2.5	1.2
Ln(WQI10CHANGE)	0.916	0.182
Ln(WQI_{10}CHANGE)xWQ_REC_USE	0.916	0.182
WQI_{10}BASE	4.3	4.3
ESTUARY	0.61	0.61
LOCAL_FWATER	0.61	0.61
MIDWEST	0	0
SOUTH	0	0
INCOME2000	30.746	30.746
INCOME2000xINCOME_APPROX	30.746	30.746
Ln(INCOME2000)	3.426	3.426
Ln(INCOME2000)xINCOME_APPROX	3.426	3.426
PERCENT_USER	0	0
PUBLISHED	0.5	0.5
OPEN_ENDED	0.6	0.6
RESPONSE_RATE	58.02	58.02
IN_PERSON	0.31	0.31
STUDY_YR73	36	36

Based on these inputs, Tables D.5 and D.6 show the results of the meta-analysis. Table D.5 shows estimated WTP in the greater Philadelphia, MA (per household) for water quality improvements under the 100% LID and most aggressive non-LID options. Table D.6 shows total present value estimates (over the 40-year project time period) for all CSO options within each watershed.

Table D.5. Estimated WTP (per household and total annual) for water quality improvements under the 100% LID and most aggressive non-LID options

	WTP per household per year (full model)	WTP per household per year (restricted model)	Total annual WTP (full model)	Total annual WTP (restricted model)
100% LID option				
City/County of Philadelphia	$11.48	$18.28	$6,774,451	$10,791,199
Philadelphia, MA (excluding Philadelphia County)[a]	$11.41	$17.40	$9,917,607	$15,119,047
Total annual WTP			$16,692,057	$25,910,246
Non-LID (most aggressive options)				
City/County of Philadelphia	$6.58	$9.99	$3,886,634	$5,898,359
Philadelphia, MA (excluding Philadelphia County)[a]	$6.55	$9.51	$5,689,925	$8,263,918
Total annual WTP			$9,576,559	$14,162,277

Note: Based on 1,459,331 households in Philadelphia, MA (2000 Census). Values adjusted to 2009 current year dollars based on percent increase in CPI from 2000.

a. Scaled to account for distance from waterbodies and WTP estimates for Delaware/Schuylkill only.

To estimate total benefits associated with the 24 different CSO alternatives, we applied a scalar based on the scope of each option compared to the most aggressive LID, Tunneling, or Satellite Treatment option. Consistent with our analysis of other benefits, we allocated benefits over the 40-year project time period based on construction and implementation timelines provided by CDM. We assumed that stream restoration and riparian improvements would occur under all the LID alternatives (25%–100% LID Options). Thus, at each level of LID, 75% of the maximum water quality/ecological habitat benefits will be realized (as a result of the stream restoration program). The remaining 25% of maximum benefits will vary based on the level of LID implemented.

To estimate WTP for water quality and ecological habitat improvements for each watershed, we allocated total WTP for households the City by restored stream mile within each affected CSO area. For households outside of Philadelphia County, but within the greater Philadelphia, MA, we allocated total WTP by restored stream mile within the Schuylkill and Delaware River CSO watersheds only. Thus, we assume $0 WTP by these households for improvements to Tacony-Frankford and Cobb creeks.

Table D.6. Total WTP in the Philadelphia, MA for water quality and ecological habitat improvements under different CSO control options (present value 2009 USD)

	Tacony	Cobbs	Schuylkill	Delaware
LID options/Transmission and new treatment capacity with LID component[a]				
25% LID	$21,576,660	$27,912,663	$78,631,310	$178,551,447
50% LID	$23,664,723	$30,613,888	$86,240,792	$195,830,619
75% LID	$25,752,787	$33,315,114	$93,850,273	$213,109,791
100% LID	$27,840,851	$36,016,339	$101,459,755	$230,388,963
Tunnel options[b]				
15’ Tunnel	$6,646,639	$8,598,429	$24,230,834	$55,021,981
20’ Tunnel	$8,862,185	$11,464,573	$32,307,779	$73,362,642
25’ Tunnel	$11,077,731	$14,330,716	$40,384,724	$91,703,302
30’ Tunnel	$13,293,277	$17,196,859	$48,461,668	$110,043,963
35’ Tunnel	$15,508,824	$20,063,002	$56,538,613	$128,384,623
Transmission and satellite treatment options				
25 Ofs	$15,508,824	$20,063,002	$56,538,613	$128,384,623
10 Ofs	$8,840,029	$11,435,911	$32,227,009	$73,179,235
4 Ofs	$2,481,412	$3,210,080	$9,046,178	$20,541,540
1 Ofs		$642,016	$2,985,239	

a. Analysis assumes that transmission treatment options will be combined with LID components to reach target level of water quality associated with each LID option.

b. Tunnel options in Delaware River Watershed are 15, 18, 21, 23, 28, and 31’.

Table D.6 shows total WTP (in present value terms) in the greater Philadelphia, MA (including Philadelphia City/County) for water quality and ecological improvements under each CSO control option. The benefit estimates shown below reflect total WTP based on the average WTP estimates per household as reported in Table D.5. Total benefits also reflect the aggregation of WTP by households within the City and those outside of the City but within the Philadelphia, MA.

D.3 Sensitivity Analysis

Stratus Consulting conducted a sensitivity analysis to evaluate how WTP per household fluctuates in response to changes in baseline water quality and the level of water quality/habitat improvement (as defined by the WQ_{10}). The results of this analysis (as summarized in Table D.7) indicate that within the reasonable range of assumptions related to these variables, WTP per household does not vary wildly as these inputs change but seem to follow a reasonable progression. WTP is more sensitive to the actual improvement in water quality as opposed to the baseline index value used in the analysis.

Table D.7. Summary of sensitivity analysis of household WTP for water quality improvements

				Household WTP within Philadelphia		Household WTP within Philadelphia, MA	
Scenario	**Baseline WQI**	**Increase in WQI**	**Endpoint WQI**	**Full model**	**Restricted model**	**Full model**	**Restricted model**
1	4.3	2.5	6.8	$11.48	$18.28	$23.39	$35.65
2	4.3	1.9	6.2	$ 9.32	$14.59	$19.00	$28.44
3	4.8	2	6.8	$10.14	$15.84	$20.67	$30.88
4	4.8	1.4	6.2	$7.74	$11.81	$15.78	$23.02
5	5	1.8	6.8	$9.54	$14.75	$19.44	$28.77
6	5	1.2	6.2	$7.02	$10.57	$14.30	$20.61
7	4.3	1.2	5.5	$6.58	$9.99	$13.42	$19.49

Numerous studies have examined water quality issues using a variety of techniques including CV (Hurley et al., 1999; Loomis et al., 2000; Whitehead, 2000; Stumborg et al., 2001; Eisen-Hecht and Kramer, 2002; Brox et al., 2003; Collins et al., 2005). To further validate our results, we reviewed many of these studies in order to obtain a range of current estimates. However, we found very few studies that evaluated water quality improvements within a context similar to the Philadelphia policy case. Very few studies have been conducted in urban areas and most studies include use values, as well as non-use values, in the stated WTP. The estimates for WTP per household reported in Table D.5 therefore reflect the lower end of the range of WTP values reported in most studies. However, we feel that these estimates represent a reasonable WTP per household.

D.4 Omissions, Biases and Uncertainties

In the absence of site-specific data, it was necessary to make a number of assumptions in order to estimate WTP per household for water quality and habitat improvements under the CSO control options. In addition, a number of data omissions and uncertainties surrounding the analysis have been identified throughout this report. Table D.8 provides a summary of these assumptions and uncertainties and their likely impact on total benefits.

Table D.8. Omissions, biases and uncertainties

Assumption/ methodology	Likely impact on net benefits[a]	Comment/explanation
Analysis of improvements in the Schuylkill and Delaware River watersheds include households in the Philadelphia, MA region (i.e., more than City residents).	--	The inclusion of households in Bucks, Chester, Delaware, and Montgomery counties substantially increases total WTP due to (1) the large number of households in these counties, and (2) the high average income of households in these counties, which is correlated with estimated WTP. In contrast, households in the City have a relatively low average income and, thus, a lower estimated WTP for water quality/habitat improvements. No adjustment is made to WTP estimates for these households even though they do not live close by. A distance adjustment would serve to decrease overall benefits.
In the absence of a study specific to the Philadelphia area, we relied on a meta-analysis of WTP for water quality/habitat improvements to estimate total benefits.	U	There are limitations of using the meta-regression model as a benefits transfer tool. For example, results provide very limited evidence about how WTP is related to the spatial characteristics of water quality changes. The meta-regression does not measure how WTP varies with respect to the proportion or amount of waters that are improved or the distance of the water quality changes from populations. This lack of specificity imposes limitations on the precision of policy-relevant benefits transfer, since policies almost always impact waterbodies in spatially non-uniform ways.
There are uncertainties surrounding the baseline WQI and estimated improvements under CSO options.	U	It is difficult to estimate the WQI index improvements in each watershed under the different CSO options. However, as demonstrated through sensitivity analysis (see Table D.7), this is not likely to have a significant impact on total benefits within the reasonable range of WQI estimates. Additionally, we currently assume that the Transmission/Treatment options combined with the LID options, will not achieve water quality and habitat benefits beyond those that would be achieved through the implementation of LID alone. Revising this assumption would serve to increase total benefits.

a. Indicating how addressing the assumption or overcoming the omission would probably impact the analysis, using the following key: + would likely increase net benefits; ++ would increase net benefits significantly; U direction of change in net benefit is uncertain; - would diminish net benefits; -- would diminish net benefits significantly.

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E. Wetland Enhancement and Creation

As described in the main body of this report, PWD is currently evaluating a number of LID options for controlling CSO events. A major component of these LID alternatives is an aggressive stream restoration program intended to improve water quality and aquatic habitat within affected streams. As part of the stream restoration program, PWD has planned for the enhancement and creation of a number of wetlands within each of the CSO watersheds.

Long regarded as wastelands, wetlands are now recognized as important features in the landscape that provide numerous beneficial services to people and to fish and wildlife. Some of these services include improved water quality, groundwater recharge, shoreline anchoring, flood control, and habitat for species. In addition, wetlands, like other natural resources such as streams and lakes, can provide positive amenity values for nearby residents. These include open space, enhanced views, increased wildlife, and a buffer against noise and other forms of pollution.

Increased awareness of the value of wetlands has resulted in a number of studies to determine the value of their services. However, determining the value of individual wetlands is difficult because they differ widely and do not all perform the same functions or perform functions equally well. Further, a number of factors can influence how a wetland is valued, including wetland size, location, surrounding environment, characteristics of the surrounding population, and others.

Despite these uncertainties, we provide estimates for the benefits associated with the enhancement and creation of wetlands in the CSO watersheds under the LID CSO options. Our analysis is based on a review of the wetland valuation literature. As shown below, our per-acre benefit estimates represent the lower end of the range from most studies. This is because many of the benefits associated with wetlands are captured in the other analyses described in this report (e.g., recreation and water quality – to some extent).

The following sections provide a summary of Stratus Consulting's approach to assigning a value (or range of benefits estimates) to the wetlands planned for implementation as part of the LID CSO control options. The results of this analysis are also provided.

E.1 Acres of Wetlands Planned

The first step to this analysis was to determine the number of wetland acres that would be restored or created in each of the CSO watersheds. For the Schuylkill and Delaware River Watersheds, this information was provided by PWD and CDM.

To obtain estimates for planned wetland acres in the Cobbs Creek Watershed, we relied on a November 2008 report provided by CDM: "Cobbs Creek: A Gateway to Many Places and to Cleaner Water." This report was completed by CDM in partnership with PWD.

In the absence of specific data for Tacony-Frankford Creek, we determined the number of wetland acres per restored stream mile in Cobbs Creek and applied that ratio to the number of restored stream miles planned for the Tacony-Frankford.

Table E.1 presents the number of wetland acres planned for enhancement/creation in each CSO watershed as part of the LID CSO stream restoration program.

Table E.1. Wetland acres restored and created under LID CSO options

	Tacony-Frankford	Cobbs	Schuylkill	Delaware
Wetland areas in need of vegetative enhancement (acres)	8.4	9.7		26.7
Wetland creation (acres)	26.3	30.3	30.1	61.3
Total acres (may not add due to rounding)	34.8	39.9	30.1	88.0

E.2 Wetland Value

To assign a range of per-acre values to the wetland acres planned for enhancement or creation, we conducted a literature review of wetland valuation studies. Although a number of these studies have been conducted, we did not find any studies that could be directly applied to the Philadelphia policy case. Very few valuation studies have been conducted in urban areas. In addition, many studies include very high per-acre or WTP estimates based on services that will not be provided by the relatively small number of wetland acres planned in Philadelphia (e.g., flood control is not a relevant service anticipated from the wetlands created or enhanced in this study area).

As described below, we therefore relied on estimates from two meta-analyses to obtain an average value per wetland acre. This approach allows us to provide a reasonable, yet conservative estimate for specific wetland functions.

E.2.1 Brief review of wetland valuation literature

The range of estimates associated with wetland valuation studies is remarkable. For example, Woodward and Wui (2001) report per-acre values from 39 different studies ranging from $5 to $1,877 (updated to 2009 USD). In a recent meta-analysis, Borisova-Kidder (2006) estimated per-acre values for wetlands in different regions of the United States ranging from $93 to $1,935 (2009 USD). The meta-analysis incorporated 72 separate observations of wetland value from 33 studies.

A broad range of valuation methodologies has been applied to value wetlands. The method most commonly used in the literature has been to observe the market prices of products related to wetland services and then ascribe the total revenue from the sale of such products as the value of the wetland (Brander et al., 2003). This methodology is not applicable to the situation in Philadelphia, where the wetlands planned for implementation are not expected to provide market-related products to any extent.

The contingent valuation method (CVM) (see Appendix D) has also been widely used. For example, a common method is to use a hypothetical referendum, where households are asked if they would vote in favor of a particular resource protection action, if it cost their household $X. The amount of $X varies across households, so that a demand curve can be traced. From this demand curve, WTP is calculated. WTP values are commonly reported in dollars per year (or per month or other specified period of time) per household.

As expected, different valuation methodologies have been applied to value different wetland services. For example, CVM, hedonic pricing, and the travel cost method (TCM) have been applied to value amenity and recreational values. Replacement cost has largely been used to value the role of wetlands in improving water quality, and the production function approach has been used to value the habitat and nursery services of wetlands. Further, wetland values have been reported in the literature in many different metrics, currencies, and referring to different years (e.g., WTP per household per year, capitalized values, marginal value per acre).

To exemplify the differences and range of value estimates associated with wetland valuation studies, Tables E.2 and E.3 present some observations from the literature.

Table E.2. Examples of values of wetlands

Value (April 2009 USD)	Description	Source
$14,047 per wetland acre	Using a discount rate of 3%, this study estimated that present values per wetland acre are: commercial fishery = $846; trapping = $401; recreation = $181; storm protection = $7,549; total of these values = $8,977/acre (1983$).	Costanza et al., 1989
$74 annually per household	This study examined what Ohio residents were willing to pay for increased protection of wetlands of the Maumee River and Western Lake Erie basins in Ohio.	De Zoysa, 1995
$10–$38 per household per year	This study estimated WTP for wetland preservation benefits in western Kentucky.	Dalecki et al., 1993
$1,392 per acre per year for 30 years ($381,401 per acre over 15 years)	This study estimated economic benefits of wetlands for wastewater treatment use, in terms of savings over conventional wastewater treatment methods.	Breaux et al., 1995
$8 and $27 annually per household	This study estimated WTP for preserving the Clear Creek wetland in western Kentucky.	Whitehead and Bloomquist, 1991
$169–$2,688 per acre lump sum	Values reflect the range of restoring wetlands from croplands, by estimating easement costs, restoration costs, and the present discounted value of perpetual crop production.	Heimlich, 1994
$106–$164 annually per respondent	Values reflect what respondents are willing to pay for protection of wetlands in New England.	Stevens et al., 1995
$56 annually per household	This study is a meta-analysis of 30 studies. The largest mean WTP by wetland function was in terms of flood control ($84), with the smallest for water generation ($20).	Brouwer et al., 1997
$657–$11,830 per acre for residents of the drainage basin, and from $9,463 to $80,380 across residents of the State of Michigan.	The study estimated wetland benefits for Saginaw Bay, Michigan.	Cangelosi et al., 2001
$4–$1,877 per acre annually	The predicted values per acre of single-service wetlands range from $4 for presence of amenities to $1,868 for presence of birdwatching opportunities, with most services having predicted values in the $275–$600 range (see Table E.3 for breakdown of all values).	Woodward and Wui, 2001
$93–$1,935 per wetland acre	This range of values is from a meta-analysis of 72 observations of wetland values from 33 studies. This range represents predicted values for different regions in the United States.	Borisova-Kidder, 2006

Table E.3. Per acre annual values of wetland services

Service	Mean value per acre[a] (April 2009 USD)
Flood	$641
Quality	$681
Quantity	$207
Recreational fishing	$583
Commercial fishing	$1,270
Bird hunting	$114
Bird watching	$1,978
Amenity	$5
Habitat	$498
Storm	$387

a The predicted values are obtained at the means of year and acre variables. It must be emphasized that the values do not represent marginal values and cannot be summed to obtain the value of multiple function wetlands.

Source: Woodward and Wui, 2001.

E.2.2 Applying wetland value estimates to PWD's LID options

As noted above, we relied on two meta-analyses to estimate the value of the wetlands planned for implementation under the LID CSO control options. The meta-analyses allowed us to assign a per-acre value to area of wetlands within each watershed.

The first analysis was conducted in 2006 by Borisova-Kidder as part of a Master's thesis. All of the studies included in this analysis (1) evaluated wetlands within the United States, and (2) allowed for the calculation of wetland value on a per-acre basis. Based on this criteria, the meta-analysis incorporated 72 separate observations of wetland value from 33 studies. The studies include 22 journal articles, seven research reports or academic papers, two chapters in a book, one PhD dissertation, and one Master's thesis.

Rather than apply the results of Borisova-Kidder's meta-regression analysis, which allows for valuation of wetlands with only one primary function (e.g., flood control, recreation), we use the average value of the 72 estimates included in the study. This amounts to about $303.38 per acre in 2009 USD (adjusted from 2003 USD based on the CPI). We applied this value to obtain a lower bound estimate for the value of each new acre of wetlands created. For restored wetlands, we used half of this amount, or $151.69 (2009 USD).

As an upper bound for per-acre value estimates, we relied on the results of Woodward and Wui's (2001) meta-regression analysis of the value of a single service wetland. Woodward and Wui's analysis focuses on two types of variation in wetland values: deviations from the valuation function due to bias or errors in estimation, and variations along the valuation function attributable to different wetland characteristics (e.g., whether it is suitable for flood control, habitat, water quality). These factors were controlled for through a number of variables included in the regression analysis (e.g., through dummy variables for wetland services as well as the valuation method).

The dependent variable in Woodward and Wui's regression model is the natural log of the value per acre of wetland converted to 1990 dollars. In addition to the variables discussed above, the regression analysis includes variables for the year the study was conducted, whether the wetland was a coastal wetland, whether the value was an estimate of producer's surplus, and whether the results had been published. Three additional dummy variables were included in the analysis to indicate whether the data, theory, or econometrics used in the study were deemed highly questionable (see Woodward and Wui, 2001, for more detail).[1]

The results of the meta-analysis are shown in Table E.3. As an upper bound for the value of wetlands in Philadelphia, we applied the value estimate for a single service wetland providing habitat. We chose to use the single service value for habitat because it represents a middle ground for the single service wetlands evaluated and it excludes values that are accounted for in other areas of our analysis (e.g., recreation) or that are not applicable to the Philadelphia policy case (e.g., flood control). As shown in Table E.3, Woodward and Wui estimate that the value of a single service wetland providing habitat amounts to about $498 per acre (2009 USD). To value restored wetlands (as opposed to newly created wetlands), we applied half this amount on a per-acre basis.

Based on the values described above, Table E.4 shows the range of annual benefit estimates for the new and restored wetlands planned under the LID options within each watershed. Present value estimates for the 40-year project period are also provided. These values were obtained based on the stream restoration timeline provided by CDM. The stream restoration program is expected to be fully implemented by 2025.

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[1] The authors recognize that important variables that determine a wetland's value are omitted from their model. For example, characteristics of the population near a wetland are particularly likely to influence the value placed on the area. However, such data could not be identified in most of the studies included in the analysis and these types of variables were therefore not included in the model. According to the authors, while the absence of these variables no doubt diminishes the explanatory power of the analysis, it need not bias the estimated coefficients if these variables are uncorrelated with the included set (Kennedy, 1986).

Table E.4. Total benefits provided by wetland services under LID options (2009 USD)

	Total annual wetland benefits (range of estimates assuming full program implementation)		Present value wetland benefits (range of estimates)	
Delaware River (tidal wetlands)				
Wetlands restored	$4,055	$6,657	$97,320	$159,751
Wetlands created	$18,585	$30,507	$445,910	$731,964
Total commitment	$22,640	$37,164	**$543,230**	**$891,715**
Schuylkill River (tidal wetlands)				
Wetlands created	$9,134	$14,994	$219,170	$359,769
Total commitment	$9,134	$14,994	**$219,170**	**$359,769**
Cobbs Creek				
Wetlands restored	$1,465	$2,405	$35,157	$57,711
Wetlands created	$9,183	$15,074	$220,335	$361,681
Total commitment	$10,649	$17,480	**$255,492**	**$419,392**
Tacony-Frankford Creek				
Wetlands restored	$1,276	$2,094	$30,608	$50,243
Wetlands created	$7,991	$13,117	$191,728	$314,723
Total commitment	$9,267	$15,211	**$222,336**	**$364,966**

E.3 Omissions, Biases, and Uncertainties

Although the economic literature on wetland valuation is relatively expansive, very few wetland valuation studies have been conducted in urban areas on wetlands similar to those planned for implementation in Philadelphia. We therefore relied on two meta-analyses reporting wetland value on a per-acre basis. Table E.5 identifies the key issues and uncertainties associated with this approach.

Table E.5. Omissions, biases, and uncertainties

Assumption/methodology	Likely impact on net benefits[a]	Comment/explanation
Wetland valuation studies are remarkably diverse in terms of the values obtained, the wetlands evaluated, and the characteristics of the studies.	U	Although we use an average estimate, as well as an estimate derived through meta-regression analysis, the characteristics of the wetlands in Philadelphia may be quite different than those of wetlands included in the base estimates. This could serve to increase or decrease overall benefits depending on the nature of these characteristics, however, we feel our estimates provide a reasonable range of benefits per acre given that they are intended to exclude the more "high-dollar" benefits associated with wetland services such as recreation and flood control.
The wetlands planned under the LID CSO control options are smaller in size than wetlands evaluated in most studies (and are not contiguous).	U	It is difficult to determine how this might impact overall benefits. On one hand, the scarcity of wetlands in the City may result in a higher value associated with them. On the other hand, larger wetlands can often provide additional ecosystem benefits that cannot be supported by wetlands of smaller size.
Our benefits transfer does not take into account demographic characteristics of surrounding communities.	-	Several of the wetland valuation studies included in the two meta-analyses are based on household WTP estimates, which are almost always correlated with average household income of the study population. Given the relatively low average income of households in Philadelphia (e.g., compared to the national average), the inclusion of demographic characteristics would likely slightly decrease the overall benefits.

a. Indicating how addressing the assumption or overcoming the omission would probably impact the analysis, using the following key: + would likely increase net benefits; ++ would increase net benefits significantly; U direction of change in net benefit is uncertain; - would diminish net benefits; -- would diminish net benefits significantly.

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F. Poverty Reduction Benefits of Local Green Infrastructure Jobs

Benefit-cost analysis of public infrastructure investment projects does not traditionally consider job creation as a category of project benefits. Although creating jobs is universally perceived as beneficial, it is reasoned that jobs created by public investment are no more beneficial than jobs created by the private sector.

A public investment project must be funded with revenues drawn from the private sector – in this case, from PWD rate revenues collected from customers. If these funds were instead allowed to remain in private hands and be used for other private purposes, it is argued that an equivalent level of jobs would be supported. Stated another way, any jobs created by public investment are generally created at the expense of jobs in the private sector, so there is no net benefit in the overall level of employment arising from public expenditures (instead, under normal conditions, there is simply a transfer of employment across locations and sectors).

The only exception to this reasoning is the special case of a severe economic downturn in which private demand is so depressed that job creation is more assured through public expenditures. Despite the fact that recent economic events actually reflect this special case, the approach adopted here does not attempt to evaluate benefits of job creation in that context. Instead, we examine the value of specific types of job opportunities created within a certain socioeconomic niche.

In the popular media, “green jobs” or “green collar jobs” are described as encompassing many diverse job categories that have a bearing on environmental improvement in one way or another. In contrast, this analysis focuses only on the unique character of jobs created in the construction and maintenance of green infrastructure systems installed for purposes of urban stormwater management as part of an aggressive campaign to transform urban landscapes and neighborhoods. “Green infrastructure jobs” as defined here are essentially landscaping jobs, suitable for unskilled laborers and requiring no experience. There are significant social benefits that result from creating these specific types of jobs in an urban setting as part of a greening campaign. Such jobs can serve as a crucial stepping stone out of poverty for otherwise unemployed persons who reside in the very same neighborhoods in which the greening is targeted. The stabilizing and transforming effects of the green infrastructure on these neighborhoods reinforces and supports the benefits of providing employment to this population that is outside the labor force and trapped in poverty.

Traditional infrastructure – consisting of multi-billion dollar concrete tunnels – produces no such benefits. When the large construction contractors engage in large-scale traditional infrastructure projects, they have pre-negotiated labor agreements with all of the appropriate trade unions that enable them to expedite the project with no obstacles to obtaining the required labor when and where it is needed. For the most part, traditional stormwater infrastructure requires skilled laborers such as those represented by the trade unions. As implied by their status as union members, these are also people who are already in the labor force. When a city water department implements a traditional infrastructure project in this manner, the net effect is just to bid these already employed workers away from other construction projects.

This appendix presents some additional background on the connections between green infrastructure and poverty. The methodology employed in evaluating the poverty reduction benefits of "green infrastructure jobs" is described, and results are summarized and discussed.

F.1 Urban Poverty and Green Infrastructure

Most large older cities have been faced with long-standing problems in coping with poverty in their midst. Philadelphia is a typical example, as made clear in results of the U.S. Census Bureau's 2005–2007 American Community Survey (U.S. Census Bureau, 2008).

- Median household income in 2007 was $34,767 in Philadelphia, compared to $50,007 for the nation as a whole – 30% less household income at the median.
- Using a household income of $25,000 per year as a measure of poverty status, there were 212,093 households below this level in Philadelphia in 2007 – 38% of all households in the City. Nationally, the proportion of households with incomes below $25,000 per year was 25%.
- In Philadelphia, 57.8% of people over age 16 were in the labor force, compared to 64.7% for the nation as a whole.

Cities incur many types of costs in coping with poverty. Many types of assistance programs are supported to help people in poverty. But one of the greatest expenditure categories is unfortunately coping with crime, for which the poverty trap is a major causative factor. In this regard, Philadelphia is incurring relatively high costs (Heller, 2008).

- Philadelphia has the highest incarceration rate of any big U.S. city. The recidivism rate is 80% and the annual cost per inmate is among the highest at $30,000 per year.
- The City spends about $1 billion per year on the criminal justice system, which is about a quarter of the City budget.

The growing movement to transform urban landscapes with green infrastructure in the name of stormwater management and energy conservation holds the promise of a number of spillover benefits in reducing poverty. The installation and maintenance of green infrastructure requires large amounts of unskilled labor in what is essentially landscaping work. Large amounts of the work is to be performed in neighborhoods where many unemployed and relatively unskilled people live in poverty. Moreover, the transforming effect of green infrastructure on these neighborhoods can provide a foundation to stabilize troubled communities, reduce crime rates, and set a course for further progress against poverty. In the words of a leading green infrastructure activist, "If you give opportunities to the young men and women of this community to support themselves and their families, the need to build a jail goes away" (Carter, 2007).

Proof of these broader spillover benefits of green infrastructure is provided in the experience of the "Weed and Seed" program of the Community Capacity Development Office of the U.S. Department of Justice (U.S. DOJ, 2009). Launched in 2003, this program is now being demonstrated in 300 sites across the country. The strategy involves a two-pronged approach: law enforcement agencies and prosecutors cooperate in "weeding out" violent criminals and drug abusers, and public agencies and community-based private organizations collaborate to "seed" much-needed human services, including prevention, intervention, treatment, and neighborhood restoration programs. Through coordinated use of federal, state, local, and private-sector resources, neighborhood restoration strategies focus on economic development, employment opportunities for residents, and improvements to the housing stock and physical environment of the neighborhood. In the period between 2003 and 2006, major crimes decreased 2% within Weed and Seed areas (Baker, 2009).

F.2 Estimating Poverty Reduction Benefits of "Green Infrastructure Jobs"

The methodology for estimating benefits of "green infrastructure jobs" is based on the expectation that providing such jobs to unskilled residents within the targeted neighborhoods will provide these individuals with an important stepping stone on the path out of poverty which would not otherwise exist. The presence of the green infrastructure in these neighborhoods will enhance the opportunity for community stabilization and recovery that can further support progress against poverty.

As discussed above, society spends large amounts every year in its efforts to cope with the effects of poverty. If PWD chooses an LID approach to CSO control providing "green infrastructure jobs" to unskilled and unemployed residents who are currently living in poverty, they will be less impoverished and impose a lower level of societal costs. If PWD chooses a traditional infrastructure approach, the jobs created will be much less likely to be filled by unskilled workers who are currently not in the workforce, yielding no benefits in reducing the societal cost of poverty.

The benefits of "green infrastructure jobs" are estimated by multiplying the total number of jobs created by an assumed per-employee amount of societal costs that will be avoided due to the altered poverty status of the new employee. The number of labor hours required for construction and maintenance of the LID alternatives was estimated as part of the engineering cost analysis. It is further assumed that one-quarter of these hours will be supervisory positions and therefore less likely to result in the hiring of unskilled and otherwise unemployed people. The avoided societal cost of poverty per non-supervisory employee used to value this benefit is estimated to be about $10,000 per year. This figure is derived from a review of different sources, as described below.

A 1993 analysis produced by the Institute for the Study of Civic Values reviewed local budget data sources for Philadelphia and produced an estimate of the total public cost of poverty shown in Table F.1. This estimate seems low because it does not include an element relating to coping with crime.

Table F.1. Estimate of the cost of poverty in Philadelphia

Element	Estimated annual cost (1992 USD millions)
Income, Medicaid, food stamps	1,000
Health and social services	400
Public housing	150
Community development	100
Homeless expenditure	15
Education	200
Total	**2,000**

Source: Schwartz, 1993.

A 1998 analysis by Wharton researchers also employed a bottom-up approach to identify direct poverty related expenditures in the City's 1996 budget amounting to about a billion dollars (Summers and Jakubowski, 1996). This study left out additional costs of crime and education, although acknowledging their potential significance. It also omitted direct expenditures by the Federal government that were estimated to be on the order of another billion dollars by Schwartz.

In a landmark study in the mid-1990s, econometric research was applied to a survey of U.S. cities and demonstrated statistically that a high incidence of urban poverty not only increases direct poverty expenditures of city governments, but also significantly increases the cost of many other seemingly unrelated city services (Pack, 1998). Applying the approaches of Summers and Jakubowski as well as those of Pack to the Philadelphia 2009 city budget, implies that as much as $3.5 billion of the $4 billion total is attributable to poverty. That total still omits additional direct poverty related outlays in Philadelphia by the Federal government.

A top-down national analysis of the "avoidable costs of poverty" was developed in a study prepared for the Entergy Corporation (Oppenheim and MacGregor, 2006), yielding the estimates shown in Table F.2.

Table F.2. National estimate of the avoidable costs of poverty

Element	**Description**	**Estimated annual cost (2005 USD millions)**
Crime	Cost of criminal activity, including property losses, costs of the judicial and correctional system, and security costs.	660,791
Health	Costs of health care, including costs that are preventable by improving health care and costs of low-income health care that are spread through society.	335,841
Unemployment/ underemployment	Costs of unemployment and underemployment, including unemployment compensation, job training, and the multiplier effects of lost economic activity.	222,492
Anti-poverty investments	Costs of current anti-poverty investments, including costs for social services, elderly services, income supports, affordable housing, food, education, energy and utility supports, and block grants for community services and community development.	270,053
Total		**1,489,178**

Source: Oppenheim and MacGregor, 2006.

Another top-down analysis developed by the Center for American Progress (Holzer et al., 2007) produced a national estimate of the cost of poverty from a different perspective. Their approach was to compute the costs to society resulting from having children grow up in poverty. They focused on the individual as a means of capturing both lost economic productivity and additional costs associated with higher crime and poorer health later in life. Although this is a different approach to the analysis, it covers many of the same impacts in arriving at an estimate of the total cost of poverty. They summarize their results in terms of the net impact on the U.S. Gross Domestic Product (GDP), as shown in Table F.3.

Table F.3. Economic costs of poverty in the United States

Element	Estimated annual cost (% of GDP)
Foregone earnings	1.3
Crime	1.3
Health	1.2
Total	**3.8**

Source: Holzer et al., 2007.

Their indicated percentage of GDP attributable to poverty (3.8%) translates into a national cost estimate of about $500 billion per year which is only about one-third the national cost estimate developed in the previously discussed study for the Entergy Corporation. The differences lie in the approaches used to assign part of the cost of crime to poverty and also in the lack of accounting for the costs of social assistance programs in the work by the Center for American Progress which the Entergy study showed to be 18% of the total. In addition, the authors of the Center for American Progress study stressed that it was their very deliberate analytical objective to produce a lower bound estimate of the cost of poverty. In contrast to their results, another interesting study of the cost of poverty in Ontario (Laurie, 2008) produced an estimate that poverty expenditures accounted for between 5.5 and 6.6% of the provincial GDP.

The Philadelphia region (including the suburbs) is the fourth largest urban area in the United States in terms of GDP (PricewaterhouseCoopers, 2006). Apportioning the $500 billion national estimate from the Center for American Progress study on the basis of the Philadelphia share of national GDP yields an estimate of the cost of poverty to the region of $12 billion per year. Apportioning the $500 billion instead on the basis of the share of the nation's low-income households that lie within the City yields an estimate of about $3 billion per year. If a higher percentage of GDP (e.g., ~6% found in Ontario) is applied, the Philadelphia share of the $500 billion would be closer to $5 billion per year.

This latter range of "top-down" estimates is similar to the $2.0 to $3.5 billion per year range derived from the several "bottom-up" estimates for Philadelphia described earlier. However, the bottom-up studies mostly omitted direct Federal expenditures. The Entergy study described above is judged to provide the most complete top-down estimate of the total annual cost of poverty in the United States. Apportioning their $1.5 trillion per year national estimate on the basis of the share of the nation's low-income households that lie within the City yields an estimate of about $9 billion per year.

In estimating the spillover benefits of "green collar jobs" in reducing the costs of poverty, it is assumed that currently unemployed people living in poverty would be hired into the unskilled, non-supervisory positions. By the latest Census figures, there are about 227,500 such people residing in the City. If the $12 billion per year estimate of the cost of poverty is correct, it implies an annual cost of $57,000 per unemployed person in Philadelphia. An estimate of $9 billion per year implies about $45,000 per unemployed person per year. An estimate of $5 billion per year implies $25,000 per unemployed person per year. An estimate of $3 billion per year implies $15,000 per unemployed person per year.

The benefit assumed here is $10,000 per year in offsets to all the societal costs of coping with poverty. Hence an estimated savings of $10,000 per year is multiplied times the number of work years in "green infrastructure jobs" provided by each LID option.

F.3 Results

Table F.4 presents a summary of the total number of work years in "green infrastructure jobs" provided by each of the LID options in each watershed over the 40-year implementation period. Table F.5 presents a similar summary of the total present value (over 40 years) of the avoided societal cost of poverty attributable to the provision of these "green infrastructure jobs."

Table F.4. Total work years in "green infrastructure jobs" provided by LID alternatives

LID %	Delaware	Schuylkill	Cobbs	Tacony	Totals
25	3,341	1,607	476	1,490	**6,914**
50	7,379	3,535	1,050	3,303	**15,266**
75	11,307	5,409	1,608	5,040	**23,364**
100	14,778	7,081	2,105	6,590	**30,554**

Table F.5. Total present value (2009 USD millions) of "green infrastructure jobs" provided by LID alternatives

LID %	Delaware	Schuylkill	Cobbs	Tacony	Totals
25	28	13	4	12	**57**
50	60	29	9	27	**125**
75	93	44	13	41	**192**
100	121	58	17	54	**251**

F.4 Omissions, Biases, and Uncertainties

The analysis of poverty reduction benefits of "green infrastructure jobs" is straightforward; multiplying the number of work years provided times the estimated amount of avoided social costs. The basis for the estimate of the societal costs of poverty is the largest area of uncertainty in this procedure, as described further in Table F.6.

Table F.6. Omissions, biases, and uncertainties affecting valuation of "green infrastructure jobs"

Assumption/ methodology	Likely impact on net benefits[a]	Comment/explanation
It is assumed that LID options can be implemented in a manner that makes most non-supervisory "green infrastructure jobs" available to the target population.	-	If it is not possible to make many of the "green infrastructure jobs" available to the target population of unskilled and otherwise unemployed people living in poverty, then the spillover benefits of poverty reduction will be correspondingly reduced. We have assumed 75% of the job hours can be targeted to the relevant population.
The estimated value of the societal costs of poverty is supported by only a half dozen studies that were designed for different purposes.	U	Despite extensive research on poverty, the total social cost of poverty is not as well studied as a concept. We found only a few studies. Although they seem to bound a roughly comparable overall order of magnitude, confidence would be enhanced if there were a few more estimates to draw from.
It is assumed that the societal costs of poverty are reduced by $10,00 if a targeted recipient obtains a "green infrastructure job."	U	There is evidence that an unskilled job, alone, is inadequate to boost a person out of poverty. A skilled job is required. Thus, "green infrastructure jobs" are just a stepping stone on the path out of poverty. We assumed a $10,000 reduction in the avoided societal costs of coping with poverty.

a. Indicating how addressing the assumption or overcoming the omission would probably impact the analysis, using the following key: + would probably increase net benefits; ++ would increase net benefits significantly; U direction of change in net benefit is uncertain; - would diminish net benefits; -- would diminish net benefits significantly.

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G. Energy Usage and Related Changes in Carbon and Other Emissions

This appendix provides a summary of Stratus Consulting's approach for estimating the net energy use, and associated external costs, of the CSO control options currently being evaluated by the PWD. As described below, we have identified several key categories related to energy use (and associated emissions) for quantitative assessment, including:

- Electricity and natural gas savings due to cooling effect under the LID CSO control options
- "Wasted" fuel consumed by vehicles stuck in traffic delays caused by construction and maintenance activities
- Resulting energy costs and/or cost savings
- Carbon emissions/offsets associated with energy use (including fuel used by construction and maintenance vehicles) and/or savings under each option
- Estimated social value of carbon emissions and/or savings
- NO_x and SO_2 emissions/offsets, and associated health costs, related to energy use and/or savings under each option.

The following sections identify key inputs and assumptions used in our analysis and describe the general methodology employed to evaluate energy-related benefits and external costs. Final results for each CSO watershed are also presented.

G.1 Key Inputs and Assumptions

To estimate the energy-related benefits and external costs under each CSO control option, we employed standard industry methodology. In the absence of specific data, it was also necessary to make a number of assumptions based on our understanding of the different program components. Key inputs and assumptions are detailed below. Individual assumptions related to specific program components are provided in subsequent sections.

- **Energy costs.** To estimate the monetary benefits of electricity and natural gas savings under the LID options, we used PECO estimated electricity rates and natural gas rates provided by CDM ($0.10/kWh and $0.0135/MM Btu, respectively). The electricity rates used in this analysis are relatively conservative. Section G.4.2 discusses how our overall results change as electricity rates are increased. To estimate the cost of additional fuel consumed in construction -related traffic delays, we assumed a cost of $2.50 per gallon of gasoline.

- **Energy-related emissions factors.** We evaluate emissions of CO_2, SO_2, and NO_x associated with net energy use under each CSO option. To do this, we use average air pollution emission factors for the State of Pennsylvania's electricity sector [in terms of tons of emissions per megawatt hour (MWh); EIA, 2007]. When the specific generating plants cannot be determined for an electricity grid like Philadelphia's, these estimated emissions are used at the state or regional level. The EIA estimates that Pennsylvania's CO_2 emission factor is 0.574 MT/MWh. SO_2 and NO_x factors at Pennsylvania power plants are estimated at 0.0041 and 0.00076 MT/MWh, respectively. To estimate emissions related to the use of natural gas, we use the CO_2 emission factor of 0.0527 MT of CO_2/MM Btu (EIA, 2007).

- **Social cost of carbon**. Another input used for this analysis is the dollar value assigned to GHG emissions, measured in CO_2e. The social cost of carbon is estimated as the aggregate net economic value of damages from climate change across the globe, and is expressed in terms of future net benefits and costs that are discounted to the present (IPCC, 2007). The most recent IPCC Assessment Report contained peer-reviewed estimates of the social cost of carbon. The IPCC found an average value of $12 per MT CO_2, but added that the range around this mean is large. For example, in a survey of 100 estimates, the values ran from USD $-3 per MT CO_2 up to $95 per MT CO_2. The often-cited Stern Review on the Economics of Climate Change estimates a social cost of carbon at $85 per MT CO_2 (Stern, 2006).

  For this analysis, the IPCC's average value of $12 was used when calculating social benefits and costs, which produces conservative estimates for the benefits and costs associated with GHG emissions (a conservative estimate). To determine total costs over the 40-year project period, we escalated the social cost of carbon by 2.4% per year,[1] above the general rate of inflation.

- **Cooling effect and carbon sinks of green infrastructure**. To estimate the benefits associated with the cooling effect and carbon sinks under the LID options, we relied on previous studies by the U.S. Department of Agriculture (USDA) Forest Service. The Urban Forest Effects Model (UFORE) provides estimates of energy savings via shading

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[1] The United Kingdom has established an official estimate of the social cost of carbon for use in many of its project evaluations and models the growth rate of the cost at 2.4% per year.

of trees and insulation by green roofs. It also provides carbon storage and sequestration data by species of tree. For our research, we used one type of tree of average size and average storage capabilities for all the cooling and carbon sinks. We also assumed that 30% of trees planted would be close enough to buildings to provide shading. Our results can easily be adjusted for specific species of trees.

- **Engineering estimates versus external costs**. The amount of energy required for excavation and other construction activities serves as a key input into our analysis. However, the costs associated with this energy use (i.e., electricity costs and the cost of fuel for construction and maintenance vehicles) are not included in our estimate of total benefits and external costs. The cost of energy used for these purposes is assumed to be included in the engineering cost estimates for each CSO option. However, we estimate and include the external costs associated with the energy consumption [e.g., CO_2, sulfur oxides (SO_x), and NO_x emissions and costs].

G.2 Methods

G.2.1 Estimating the external costs of traditional infrastructure CSO control options

We first estimated total energy use (electric and gasoline) under each of the non-LID CSO control options. Total electrical energy use was calculated based on power requirements for excavation, building, equipment, and pumping, as provided by CDM. Total fuel use was determined based on the estimated number of vehicle miles traveled (VMT) by construction and maintenance vehicles throughout the course of the project. Total fuel use also took into account the additional fuel used by individuals traveling on Philadelphia roadways as a result of construction-related traffic delays (see Appendix I).

Based on estimated total energy use, we were able to estimate total NO_x, SO_2, and carbon emissions (and associated monetary costs) under each CSO option. The individual components of our analysis are described below.

Emissions associated with energy used for excavation, building, equipment, and pumping. CDM provided estimates of the power needed for excavation, building, equipment, and pumping under each of the traditional infrastructure CSO control option (i.e., tunneling, plant expansion, and satellite treatment). We used these inputs to estimate total emissions generated under each option.

To determine total carbon emissions, we used average air pollution emission factors for the State of Pennsylvania's electricity sector (0.574 MT of CO_2/MWh) (EIA, 2007). We applied these estimates to total power use required under each option. The monetary cost of these emissions was then estimated based on IPCC's average estimate for the social cost of carbon ($12/MT).

In addition to carbon emissions, we also evaluated the SO_x and NO_x emissions associated with electricity use under the different CSO control options. This analysis was also based on average air pollution emission factors for Pennsylvania power plants (EIA, 2007). We applied these emission factors (0.00414 MT SO_2/MWh and 0.000766 MT NO_x/MWh) to total electricity use under each option.

We then estimated the human health costs of SO_2 and NO_x emissions based on EPA-generated national averages. These estimates reflect the change in health risks, and associated values, of a typical ton of emissions for each pollutant (U.S. EPA, 2008b). They do not reflect only benefits in the local area, but take into account long-range transport of the pollution (emissions in one location spread over a wide area).

EPA estimates that the health-related costs of SO_x emissions from electricity-generating sources ranges from $25,234 to $53,985 per ton. For NO_x emissions, these costs range from $2,681 to $5,733 per ton. To determine total costs of SO_x and NO_x under the CSO control options, we applied the midpoints of these estimates to total emissions.

It should be noted that the power requirements provided by CDM for excavation, building, and equipment were provided as totals over the 40-year period, and the power requirements for pumping were provided as annual estimates. It is difficult to estimate energy-related costs far into the future due to a number of significant variables. These include a change in the generation mix for electricity, a change in retail energy prices, changes in both the social costs of carbon emissions and air pollution, and the change in the price of carbon emissions under a federal or regional carbon policy.

Emissions associated with fuel used by heavy construction vehicles. To evaluate fuel use and emissions associated with construction activities, we relied on CDM's estimate for the number of heavy-duty truck trips under each CSO control option. We estimated the total gallons of diesel fuel consumed by heavy-duty trucks based on an average distance of 20 miles per truck trip and an average mile per gallon of 6.6 (U.S. EPA, 2007).

We then calculated CO_2, SO_x, and NO_x emissions associated with heavy-duty vehicles based on emission factors for heavy-duty trucks (lbs CO_2/mile) as determined by the South Coast Air Quality Management District (SCAQMD, 2007). The social cost of carbon was used to measure the costs of carbon emissions from these truck trips. For SO_x and NO_x emissions, we applied the midpoint of EPA's estimates for health-related costs of SO_2 and NO_x from mobile sources. EPA's estimates range from $13,200 to $28,264 and $4,357 to $9,350 for SO_x and NO_x, respectively.

Emissions associated with fuel use by concrete delivery trucks. To determine the external costs associated with heavy-duty trucks used to deliver concrete materials, we used the same approach mentioned above. Because the number of concrete trucks under each option was not an input provided by CDM, we assumed the number of these trucks to equal half of the number of heavy-duty trucks used for excavation and construction.

Concrete manufacturing. One of the most energy-intensive industrial processes in the world is the production of cement, a key ingredient in the large amounts of concrete used in construction of traditional CSO infrastructure. The cement manufacturing process uses both electricity and a significant amount of fossil fuels directly in a heating process. While the direct energy costs of cement manufacturing do not affect this benefit-cost analysis, the carbon and air pollution costs that result do play a role. We were able to analyze the energy used and resulting carbon emissions and air pollution that result from this process.

First, using the total cubic feet of concrete (an input provided by CDM), we estimated the amount of cement used for each non-LID scenario based on standard concrete-cement conversion methods. We estimate the energy and emissions associated with the cement manufacturing process for each of the non-LID scenarios based on standard energy/emissions factors (Worrell and Galitsky, 2004, and as described above).

Traffic disruption. Under all of the CSO control options, construction and maintenance activities will cause traffic delays on Philadelphia roadways. There is an increase in fuel use associated with these delays due to increased time spent idling and traveling at slower speeds. The methods used to estimate additional fuel used as a result of construction-related delays are detailed in Appendix I. However, actual fuel use and associated costs are reported in the energy use/cost category in Tables G.1 through G.8.

We used standard emissions conversion factors, as described above, to estimate tons of CO_2, SO_x, and NO_x emitted into the atmosphere as a result of this additional fuel use.

G.2.2 Estimating the external costs and benefits of green infrastructure

Emissions associated with energy used for excavation. Similar to the traditional infrastructure options, the LID options will require large amounts of power (electricity) to excavate areas for LID coverage. This input was provided by CDM. We use the same methods as described above to estimate the external costs of emissions associated with this energy use.

Emissions associated with fuel used by construction and operation vehicles. For the development of green infrastructure, heavy-duty vehicles will be needed during the construction process. For the LID options, we used the same techniques and assumptions described above to estimate emissions associated with these vehicles. As part of this analysis, we also included the emissions generated by operations and maintenance vehicles. For these trucks, we assume an average truck trip of 15 miles and an average mile per gallon of 20.2.

Table G.1. Energy-related benefits and external costs of CSO control options in the Tacony-Frankford Creek Watershed, over 40-year project period (present value, 2009 USD)

	Energy savings (costs)	Air quality health-related improvements (costs)	Carbon footprint reduction benefit (cost of increase)
LID options			
25% LID	$2,994,995	$4,380,801	$2,022,051
50% LID	$7,274,893	$9,989,179	$4,574,863
75% LID	$10,164,800	$13,920,497	$6,955,968
100% LID	$12,671,820	$17,492,296	$8,790,891
Plant expansion options (excluding LID component)[a]			
215 MGD	($32,635)	($240,406)	($36,526)
298 MGD	($37,299)	($262,233)	($41,239)
490 MGD	($55,050)	($600,679)	($79,752)
820 MGD	($81,063)	($840,455)	($120,971)
Tunneling options			
15’ Tunnel	($124,142)	($4,127,396)	($469,015)
20’ Tunnel	($194,652)	($5,461,468)	($644,125)
25’ Tunnel	($286,028)	($ 6,988,847)	($851,115)
30’ Tunnel	($401,457)	($8,781,757)	($1,098,570)
35’ Tunnel	($538,551)	($10,722,019)	($1,376,390)
Satellite treatment options			
25 Ofs	($ 2,152)	($108,395)	($12,248)
10 Ofs	($8,748)	($443,600)	($49,884)
4 Ofs	($36,550)	($1,945,197)	($212,250)
1 Ofs	($104,928)	($5,620,441)	($608,916)

a. Plant expansion options are not planned for implementation on their own but will be combined with some level of LID.

Table G.2. Energy-related benefits and external costs of CSO control options in the Cobbs Creek Watershed, over 40-year project period (present value, 2009 USD)

	Energy savings (costs)	Air quality health-related improvements (costs)	Carbon footprint reduction (increase)
LID options			
25% LID	$956,469	$1,399,034	$645,753
50% LID	$2,323,278	$3,190,101	$1,461,008
75% LID	$3,246,186	$4,445,589	$2,221,428
100% LID	$4,046,817	$5,586,264	$2,807,421
Plant expansion options (excluding LID component)[a]			
63 MGD	($17,580)	($363,341)	($60,090)
233 MGD	($19,353)	($497,537)	($73,871)
404 MGD	($19,851)	($539,720)	($82,551)
Tunneling options			
15’ Tunnel	($189,398)	($2,946,459)	($409,049)
20’ Tunnel	($265,640)	($3,918,187)	($558,469)
25’ Tunnel	($389,503)	($5,202,623)	($771,474)
30’ Tunnel	($513,954)	($6,450,870)	($979,242)
35’ Tunnel	($661,099)	($7,745,230)	($1,206,602)
Satellite treatment options			
25 Ofs	($1,500)	($113,581)	($12,967)
10 Ofs	($7,119)	($626,085)	($67,436)
4 Ofs	($19,703)	($1,889,297)	($197,383)
1 Ofs	($33,685)	($3,307,472)	($341,548)

a. Plant expansion options are not planned for implementation on their own but will be combined with some level of LID.

Table G.3. Energy-related benefits and external costs of CSO control options in the Schuylkill River Watershed, over 40-year project period (present value, 2009 USD)

	Energy savings (costs)	Air quality health-related improvements (costs)	Carbon footprint reduction (increase)
LID options			
25% LID	$3,216,685	$4,705,069	$2,171,724
50% LID	$7,813,382	$10,728,581	$4,913,495
75% LID	$10,917,201	$14,950,896	$7,470,850
100% LID	$13,609,791	$18,787,081	$9,441,595
Plant expansion options (excluding LID component)[a]			
157 MGD	($15,316)	($349,321)	($57,000)
747 MGD	($33,322)	($727,346)	($119,692)
1,336 MGD	($49,501)	($988,837)	($172,595)
Tunneling options			
15’ Tunnel	($272,527)	($7,429,041)	($842,353)
20’ Tunnel	($362,014)	($9,537,170)	($1,100,347)
25’ Tunnel	($478,079)	($11,840,716)	($1,394,327)
30’ Tunnel	($621,589)	($14,238,048)	($1,715,633)
35’ Tunnel	($793,412)	($16,506,514)	($2,045,052)
Satellite treatment options			
25 Ofs	($6,648)	($705,765)	($70,845)
10 Ofs	($20,567)	($2,224,732)	($220,716)
4 Ofs	($51,597)	($5,728,678)	($563,893)
1 Ofs	($115,829)	($12,774,988)	($1,256,428)

a. Plant expansion options are not planned for implementation on their own but will be combined with some level of LID.

Table G.4. Energy-related benefits and external costs of CSO control options in the Delaware River Watershed, over 40-year project period (present value, 2009 USD)

	Energy savings (costs)	Air quality health-related improvements (costs)	Carbon footprint reduction (increase)
LID options			
25% LID	$6,713,580	$9,820,003	$4,532,630
50% LID	$16,307,399	$22,391,744	$10,255,012
75% LID	$22,785,416	$31,204,186	$15,592,497
100% LID	$28,405,151	$39,210,732	$19,705,661
Plant expansion options (excluding LID component)[a]			
225/130	($130,530)	($1,259,852)	($179,991)
225/250	($134,230)	($1,690,557)	($207,334)
495/950	($221,295)	($2,439,859)	($278,522)
495/1250	($228,070)	($2,848,114)	($305,397)
Tunneling options			
15’ Tunnel	($408,423)	($9,101,348)	($1,115,480)
18’ Tunnel	($489,540)	($10,503,691)	($1,304,735)
23’ Tunnel	($682,323)	($12,903,993)	($1,670,979)
28’ Tunnel	($929,218)	($15,726,970)	($2,112,658)
31’ Tunnel	($1,089,041)	($17,824,366)	($2,422,831)
Satellite treatment options			
25 Ofs	($8,811)	($438,766)	($49,371)
10 Ofs	($24,959)	($1,167,302)	($133,045)
4 Ofs	($64,856)	($3,331,932)	($367,354)
1 Ofs	($137,147)	($6,784,880)	($750,802)

a. Plant expansion options are not planned for implementation on their own but will be combined with some level of LID.

Table G.5. Non-monetized energy-related benefits and external costs of CSO control options in the Tacony-Frankford Creek Watershed, over 40-year project period

	Air quality – emissions (reductions)		Energy use (savings)			
	SO_2 (MT)	NO_x (MT)	Natural gas (kBtu)	Fuel (gallons)	Electricity (kWh)	CO_2 emissions (reductions)
LID options						
25% LID	(145.05)	3.41	(38,028,191)	59,440	(35,046,202)	(105,045)
50% LID	(330.20)	(8.24)	(129,277,877)	106,449	(79,771,661)	(235,478)
75% LID	(463.54)	5.56	(183,776,322)	182,578	(111,990,066)	(358,536)
100% LID	(583.72)	16.55	(221,563,669)	247,575	(141,029,264)	(453,597)
Plant expansion options[a]						
215 MGD	6.67	11.19		14,985		2,361
298 MGD	7.29	12.78		17,126		2,666
490 MGD	17.39	21.10		25,277		5,155
820 MGD	24.95	32.03		37,222		7,819
Tunneling options						
15’ Tunnel	133.56	375,913.37		57,002		26,553
20’ Tunnel	176.62	561,135.30		89,378		36,885
25’ Tunnel	225.74	793,910.46		131,335		49,197
30’ Tunnel	283.22	1,082,609.31		184,336		63,986
35’ Tunnel	345.42	1,421,147.25		247,285		80,737
Satellite treatment options						
25 Ofs	3.55	1.75		988		720
10 Ofs	14.57	6.93		4,017		2,868
4 Ofs	63.47	28.51		16,783		12,071
1 Ofs	183.27	80.61		48,179		34,379

a. Plant expansion options are not planned for implementation on their own but will be combined with some level of LID.

Table G.6. Non-monetized energy-related benefits and external costs of CSO control options in the Cobbs Creek Watershed, over 40-year project period

	Air quality – emissions (reductions)		Energy use (savings)			CO_2 emissions (reductions)
	SO_2 (MT)	NO_x (MT)	Natural gas (kBtu)	Fuel (gallons)	Electricity (kWh)	
LID options						
25% LID	(46.32)	1.09	(12,144,517)	18,983	(11,192,203)	(33,547)
50% LID	(105.45)	(2.63)	(41,285,620)	33,995	(25,475,530)	(75,201)
75% LID	(148.03)	1.78	(58,690,006)	58,307	(35,764,660)	(114,501)
100% LID	(186.42)	5.29	(70,757,609)	79,064	(45,038,492)	(144,859)
Plant expansion options[a]						
63 MGD	12.71	12.26		8,072		3,884
233 MGD	16.93	14.35		8,886		4,775
404 MGD	18.68	15.83		9,115		5,336
Tunneling options						
15’ Tunnel	94.69	475,999.78		86,965		24,465
20’ Tunnel	126.19	665,540.02		121,974		33,620
25’ Tunnel	167.55	962,260.15		178,847		46,873
30’ Tunnel	207.52	1,256,965.47		235,991		59,809
35’ Tunnel	248.74	1,598,573.93		303,556		74,109
Satellite treatment options						
25 Ofs	3.81	1.65		689		739
10 Ofs	20.74	7.94		3,269		3,761
4 Ofs	62.20	22.23		9,047		10,887
1 Ofs	108.61	37.85		15,467		18,756

a. Plant expansion options are not planned for implementation on their own but will be combined with some level of LID.

Table G.7. Non-monetized energy-related benefits and external costs of CSO control options in the Schuylkill River Watershed, over 40-year project period

	Air quality – emissions (reductions)		Energy use (savings)			
	SO_2 (MT)	NO_x (MT)	Natural gas (kBtu)	Fuel (gallons)	Electricity (kWh)	CO_2 emissions (reductions)
LID options						
25% LID	(156)	4	(40,843,047)	63,840	(37,640,331)	(112,820)
50% LID	(355)	(9)	(138,847,060)	114,328	(85,676,380)	(252,908)
75% LID	(498)	6	(197,379,493)	196,092	(120,279,600)	(385,075)
100% LID	(627)	18	(237,963,870)	265,900	(151,468,287)	(487,172)
Plant expansion options[a]						
157 MGD	12	11		7,033		3,684
747 MGD	26	24		15,300		7,737
1,336 MGD	35	35		22,729		11,156
Tunneling options						
15’ Tunnel	237	742,003		125,136		47,605
20’ Tunnel	305	987,092		166,225		62,539
25’ Tunnel	379	1,291,300		219,519		79,755
30’ Tunnel	456	1,653,470		285,414		98,814
35’ Tunnel	528	2,069,410		364,310		118,737
Satellite treatment options						
25 Ofs	23	8		3,053		3,850
10 Ofs	72	23		9,444		11,937
4 Ofs	186	58		23,692		30,399
1 Ofs	415	129		53,185		67,707

a. Plant expansion options are not planned for implementation on their own but will be combined with some level of LID.

Table G.8. Non-monetized energy-related benefits and external costs of CSO control options in the Delaware River Watershed, over 40-year project period

	Air quality – emissions (reductions)		Energy use (savings)			CO$_2$ emissions (reductions)
	SO$_2$ (MT)	NO$_x$ (MT)	Natural gas (kBtu)	Fuel (gallons)	Electricity (kWh)	
LID options						
25% LID	(325)	8	(85,243,992)	133,241	(78,559,566)	(235,468)
50% LID	(740)	(18)	(289,789,289)	238,615	(178,816,154)	(527,847)
75% LID	(1,039)	12	(411,953,001)	409,267	(251,036,931)	(803,695)
100% LID	(1,308)	37	(496,657,118)	554,963	(316,131,196)	(1,016,782)
Plant expansion options[a]						
225/130 MGD	37	49		59,935		11,634
225/250 MGD	49	52		61,634		13,402
495/950 MGD	67	77		101,611		18,003
495/1,250 MGD	78	80		104,722		19,740
Tunneling options						
15’ Tunnel	292	1,089,554		187,535		64,559
18’ Tunnel	337	1,298,714		224,781		75,805
23’ Tunnel	415	1,770,355		313,301		98,203
28’ Tunnel	505	2,363,038		426,667		125,361
31’ Tunnel	572	2,754,184		500,053		144,203
Satellite treatment options						
25 Ofs	14	7		4,046		2,875
10 Ofs	38	19		11,460		7,689
4 Ofs	109	50		29,780		20,947
1 Ofs	222	103		62,973		42,744

a. Plant expansion options are not planned for implementation on their own but will be combined with some level of LID.

Energy savings and emissions offsets: trees. When properly placed, trees can affect energy consumption by shading buildings, providing evaporative cooling, and by blocking winter winds (USDA, 2007). Using data obtained from the USDA, we calculated the energy savings from trees based on average heating and cooling per building. This allowed us to estimate savings in energy costs for the entire community of shaded buildings. We also estimated the reduction in emissions (offsets) associated with these savings.

Energy savings and emissions offsets: green roofs. Green roofs provide insulation and shade for buildings, thus reducing their need for both heating and cooling costs. Using energy savings estimates confirmed by two separate studies, we quantified the energy savings associated with green roofs under each LID CSO control option. To estimate electricity savings (from reduced cooling), we applied an average savings of 0.39 kWh/sq ft of green roof. For natural gas savings (from reduced heating), we used an estimate of 123 MM Btu per building (Doshi, 2005; Green Roofs for Healthy Cities, Undated).

Green sinks – trees. Trees provide a valuable resource for green infrastructure projects by removing (sequestering) CO_2. Trees therefore act as a carbon sink by removing the carbon and storing it as cellulose in their trunk, branches, leaves, and roots while releasing oxygen back into the air. The USDA's UFORE model estimates the CO_2 storage capacity for many species of trees. For our analysis, we used the storage capacity associated with the average-sized tree from the UFORE model as a model for all trees planted under the LID options. We estimated carbon stored simply by multiplying the storage capacity of an average tree according to the USDA by the number of total trees planted.

Green sinks – green roof and bioretention. Green roofs and vegetated bioretention areas also store large amounts of CO_2. The United Kingdom's Department of Environment, Food and Rural Affairs (DEFRA) provides an estimate of sequestered CO_2 per 1,000 square meters (U.K. DEFRA, 2007). Using this rule of thumb, we calculated CO_2 sinks based on the total estimated new green acreage under each LID scenario.

G.3 Summary of Results

Tables G.1 through G.8 show the energy-related benefits and external costs for the different CSO control options in each watershed. Tables G.1 through G.4 show results in physical units (e.g., tons of emissions, energy savings). Tables G.5 through G.8 show the monetary values tied to the physical units in Tables G.1 through G.4. As shown, the largest benefits and costs (in terms of monetary value) under each option can generally be attributed to a reduction of SO_x and NO_x emissions (or net emissions). Under some of the LID options, reductions in NO_x emissions do not completely offset the NO_x emissions associated with energy use (thus, there are positive net emissions).

G.4 Uncertainties and Sensitivity Analysis

G.4.1 Omissions, biases, and uncertainties

To estimate energy savings, costs, and emissions under the different CSO control options, it was necessary to make a number of assumptions. In addition, a number of data omissions and uncertainties surrounding the analysis have been identified throughout this report. Table G.9 provides a summary of these assumptions and uncertainties and their likely impact on the results of our analysis.

Table G.9. Omissions, biases, and uncertainties

Assumption/ methodology	Likely impact on net benefits[a]	Comment/explanation
Estimates of the social cost of carbon are wide ranging and uncertain	+	The IPCC evaluated a range of cost estimates and found an average of \$12/MT CO_2. Many recent estimates of the social cost of carbon are found in the upper bound of IPCC's range, including the Stern estimate of \$85. Section G.4.2 shows the results of a sensitivity analysis in which a higher social cost of carbon of \$48 is used.
Electricity prices are conservative	+	A federal climate policy could increase fossil fuel based energy prices at a much higher rate than the estimates provided in this study. However, an economy-wide policy that would limit GHG emissions is expected, but not a certainty. Section G.4.2 shows the results of a sensitivity analysis in which higher electricity rates are used.
GHG emissions associated with electricity generation in Pennsylvania vary	U	GHG emission factors from power plants vary from plant to plant and from region to region. The actual emissions from the CSO options may be higher or lower than the average emissions factor for the State of Pennsylvania used in this analysis. The emissions factors used in this analysis are the best available option.
Transportation fuel costs	U	An average cost of gasoline and diesel fuel were chosen based on recent prices and adjusted to rise with inflation. It should be noted that fuel prices are volatile and many experts expect fuel prices will rise faster than inflation during the life of this project life. These increases would be expected to be even larger under a federal climate policy. However, technology gains in vehicle efficiency could ease any price increases.
Reduction of energy usage from the planting of trees	-	The blocking of wind in the winter and the shading of buildings during summertime depend on the type of tree planted and the distance and direction from the building. This analysis assumed an estimate of 30% of total trees planted were properly placed to shade during the summer and block wind during the winter. The analysis may be sensitive to this assumption. Benefits would be decreased if 30% is too high.

Table G.9. Omissions, biases, and uncertainties (cont.)

Assumption/ methodology	Likely impact on net benefits[a]	Comment/explanation
Carbon sequestration from trees are based on USDA's UFORE analysis of the benefits of Philadelphia's urban forest	U	Different species of trees at different stages of life are able to sequester carbon in varying amounts. This analysis used an average sized tree to calculate total carbon sequestration. A tree growth model was used to simulate the different stages of sequestration as the trees grow over time.

a. Indicating how addressing the assumption or overcoming the omission would probably impact the analysis, using the following key: + would likely increase net benefits; ++ would increase net benefits significantly; U direction of change in net benefit is uncertain; - would diminish net benefits; -- would diminish net benefits significantly.

G.4.2 Sensitivity analysis

We conducted a sensitivity analysis to evaluate the effect of electricity rates and the social cost of carbon on our overall results. This sensitivity analysis compares the benefits and external costs of two CSO control options (50% LID and 30' Tunnel) when a higher social cost of carbon (\$48/MT CO_2) versus the IPCC's average (\$12/MT CO_2) is used. Our analysis also evaluates the effect on energy savings under the LID options if a doubling in the price of electricity is assumed. Table G.10 shows the results of this analysis.

Table G.10. Sensitivity analysis for city-wide present value benefits of key CSO options: Cumulative through 2049

	50% LID option	30' Tunnel option
Social cost of carbon increase	Total benefits minus external costs	
\$12	\$2,846.4	\$122.0
\$48	\$2,910.0	\$104.3
Percent change in overall results	2.23%	-14.53%
Electricity rate increase resulting from a enacted federal climate policy	Energy savings (usage)	
\$0.1 kWh	\$2,846.4	\$122.0
\$0.2 kWh	\$2,874.9	\$122.0
Percent change in overall results	1.00%	0%

a. Our external cost analysis does not include higher electricity costs associated with the engineering costs for the 30' Tunnel option, but it is assumed that electricity costs would double in this scenario as well. This would be reflected in engineering cost estimates for this option.

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H. Air Quality Pollutant Removal from Added Vegetation

The LID CSO control options currently being evaluated by the PWD would provide (and enhance) recreational amenities within PWD's CSO watersheds. Under the LID options, PWD plans to substantially increase vegetated acreage (including "treed" acreage) throughout the City. Expanding the amount of trees and vegetated acres in Philadelphia will help improve Philadelphia's air quality by removing air pollutants from the atmosphere. Conventional air pollution is a persistent problem for most cities in the United States. Even after decades of concerted federal and state efforts to improve air quality, the majority of the U.S. population lives in areas with ambient air quality above the National Ambient Air Quality Standards (NAAQS). The two air pollutants most damaging to human health are ozone (a gaseous pollutant that is a primary ingredient of smog) and fine particulate matter ($PM_{2.5}$, aerosol particles less than 2.5 microns in diameter, commonly referred to as soot).

The following sections outline Stratus Consulting's methods for estimating the health benefits associated with the improved air quality due to increasing the number of trees that will be planted under the LID options for CSO control. Estimates of total health benefits deriving from trees planted within each watershed are also provided. Additional benefits of air quality relating to avoiding certain air emissions (such as sulfur dioxide and hydrocarbons) related to construction and changes in vehicle traffic are presented in Appendix G.

H.1 Impacts of Trees on Ozone and Particulate Matter

Trees and shrubs have an important effect on reducing important air pollutants including ozone and particulate matter. In addition to other benefits, trees reduce air pollution concentrations. Increased plantings of some tree species (especially trees that naturally emit low levels of biogenic volatile organic compounds) can be a viable component of an air pollution control strategy because trees remove small but significant amounts of ozone and particulate matter from the ambient air. Trees thus can help reduce the air pollution exposure levels of the local population, and help urban areas meet air quality goals.

Ozone (and other gaseous pollutants) are taken into the leaves of trees through stomata respiration. Once inside the leaf, ozone diffuses into intercellular spaces and reacts with inner-leaf surfaces (Nowak et al., 2006). Additional ozone and particulate matter are removed from the ambient air by direct interaction with the leaf surface. Although some particles are absorbed into the leaves, most particles are retained on the surface of the leaf, with 50% assumed to be re-

released to the atmosphere. The remainder is washed off during rain events, or deposited during autumn leaf drop, effectively removing the particulate matter from the air.

A U.S. Forest Service report on the benefits of the Philadelphia urban forests (USDA, 2007) estimates that the existing forest cover in Philadelphia removes 0.33% of the annual mean ozone, and 0.38% of the annual mean particulate matter (PM_{10}), from Philadelphia's air. This removal is from the entire amount of trees and shrubs in Philadelphia. There are an estimated 2.1 million trees covering 15.7% of the land area of Philadelphia; an additional 5.9% of the land area is covered by shrubs.

These Forest Service estimates of the impact of Philadelphia's trees are used as the basis for the air pollution-related health analysis, and the subsequent economic benefit analysis, reported in this appendix. This analysis assumes that $PM_{2.5}$ is reduced by the same proportion (0.38%) as total respirable particulate matter (PM_{10}), and calculates the avoidable health effects from reducing $PM_{2.5}$ levels.

H.2 Philadelphia Air Quality Situation

Like most major cities in the United States, EPA currently classifies Philadelphia County (and the entire greater Philadelphia metropolitan area) as exceeding the current NAAQS for both ozone and $PM_{2.5}$. Recent ozone levels[1] in Philadelphia exceed the current ozone standard by 19%. Philadelphia County's $PM_{2.5}$ levels are below the national fine particle standards (maximum 2008 monitor value in Philadelphia County had an annual mean of 13.49 $\mu g/m^3$, compared with the NAAQS of 15.0 $\mu g/m^3$), although higher $PM_{2.5}$ levels in adjoining counties result in the Philadelphia metropolitan area being classified as a $PM_{2.5}$ non-attainment area. As a designated non-attainment area, Philadelphia must develop and periodically update their State Implementation Plan, identifying additional control measures that will allow Philadelphia to achieve attainment by 2015, and maintain the level of the standards thereafter.

Air pollution levels in Philadelphia vary year to year, reflecting variability both in meteorology and economic activity. Non-attainment designations are based on three years of monitoring data to accommodate the year-to-year variability. Philadelphia's air quality has been generally getting better over time, as numerous federal, state, and local emission control requirements take effect.

This analysis of the air pollution impacts of increasing the number of trees in Philadelphia County uses monitor data from 2007 (the most recent complete year at the time of the analysis). In 2007, the highest monitor in Philadelphia County had a second highest 8-hour ozone level (the

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[1] The three-year (2006–2008) ozone fourth highest maximum for eight hour ozone in Philadelphia County is 89 ppb. The 2008 revision to the ozone NAAQS set the standard (as measured by the same metric) at 75 ppb.

averaging time of the NAAQS) of 110 parts per billion (ppb); the lowest monitor was 87 ppb (all exceeding the NAAQS). The 2007 annual mean $PM_{2.5}$ levels at the highest monitor in Philadelphia County was 14.83 μg/m^3 (below the standard of 15.0 and the lowest monitor was 12.77).

The initial air pollution levels in this analysis are derived from the 2007 ozone and $PM_{2.5}$ air quality monitors in Philadelphia County. In this analysis the county-wide population-weighted average annual average $PM_{2.5}$ level is 13.60 μg/m^3. The county-wide population-weighted seven month (April through October) seasonal average of the daily 8-hour maximum ozone is 42.4 ppm. Changes in the seasonal average of ozone are the determinates of ozone's impact on human health, rather than changes in peak daily values used to determine attainment of the ozone NAAQS.

As described above, increasing the size of the urban forest in Philadelphia County is expected to lower the ambient ozone and $PM_{2.5}$ concentrations. Using the relationship from the Forest Service report (USDA, 2007) that the current 2.1 million tree urban forest reduces ozone by 0.33% and $PM_{2.5}$ by 0.38%, an increase in the number of trees planted in the 50% LID option[2] would reduce recent (2007) ozone levels by 0.04 ppb, and $PM_{2.5}$ by 0.02 μg/m^3 when the trees are fully mature. The benefits analysis assumes that future ozone and $PM_{2.5}$ levels will be reduced by the same amount (for the same number of planted trees). Varying the number of trees planted, such as in other LID options, is assumed to proportionally effect the changes in ozone and $PM_{2.5}$ levels.

H.3 Human Health Effects of Ozone and $PM_{2.5}$ Exposure

The adverse health effects of ozone and $PM_{2.5}$ are well established, and are extensively documented in recent EPA documents such as EPA's Regulatory Impact Analysis (RIA) for the 2008 revisions to the ozone NAAQS (U.S. EPA, 2008b). Adverse human health effects that can be avoided by reducing ambient levels of ozone and $PM_{2.5}$ include premature mortality and a broad array of respiratory and cardiovascular health effects. Health effects occur not only above the level of the NAAQS, but also below the level of the standards.

The avoidable air pollution-related health effects estimated in this analysis are:

- Premature mortality (from ozone and $PM_{2.5}$)
- Onset of irreversible chronic bronchitis ($PM_{2.5}$)

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[2] The 50% LID option includes planting 637,000 trees if implemented in all four watersheds, or an increase of 30% in the total number of trees in Philadelphia County.

- Heart attacks (non-fatal acute myocardial infarctions) ($PM_{2.5}$)
- Hospital admissions (non-fatal) for respiratory and cardiovascular conditions (from ozone and $PM_{2.5}$)
- Emergency room visits for asthma (from ozone and $PM_{2.5}$)
- Respiratory symptoms (days of illness) (from ozone and $PM_{2.5}$)
- Work loss days ($PM_{2.5}$) and school absence (ozone).

This analysis uses software developed by the EPA to calculate the avoided health effects from the contribution of trees to reducing ozone and $PM_{2.5}$ concentrations, and to estimate the economic value of the avoided health effects. EPA's BenMAP (U.S. EPA, 2008a), the Environmental Benefits Mapping and Analysis Program (Ver. 3.0.15), was used to conduct this analysis.

H.4 Methods of Estimating Health Effects of Improvements in Air Pollution from an Increase in the Number of Trees

The fundamental method used in this analysis is to calculate the avoided health effects associated with "rolling-back" the air quality levels recorded by Philadelphia monitors in 2007 by the Forest Service's estimate of the percentage that trees reduce air pollution. As a first step in the analysis, BenMAP estimated the health effects associated with reducing 2007 monitor levels of both ozone and $PM_{2.5}$ by 1%. These estimated health effects are proportionally adjusted to estimate the health effects associated with the specific estimated air pollution changes resulting from increasing the amount of urban forest in Philadelphia by the amounts associated with tree planting in each of the LID options.

The BenMAP closest monitor algorithm was used to estimate the population-weighted average change in ozone and $PM_{2.5}$ by assigning the population in Philadelphia (BenMAP forecast for 2010 = 1,438,198, based on 2000 tract level Census data and EPA forecasts of county-level population changes) to the closest monitor to their point of residence. There are four EPA monitors in Philadelphia County; all four monitors record ozone and $PM_{2.5}$ levels.

The health effects analysis methods are adopted from the methods used by EPA in the 2008 ozone NAAQS RIA (U.S. EPA, 2008b). BenMAP was used to estimate the avoided health effects using a concentration-response function from each of the individual concentration-response functions that EPA used in the 2008 ozone NAAQS RIA.

Because the benefits calculations are dominated by premature mortality associated with $PM_{2.5}$, the benefit estimates are made using two different estimates of $PM_{2.5}$-related adult premature mortality. This use of two estimates creates a high estimate and a low estimate for the benefits. The high estimate is from a concentration-response function derived from a long-term cohort tracking epidemiology study in six eastern U.S. cities (Laden et al., 2006). The low estimate is from a long-term cohort tracking epidemiology study of 50 cities nationwide (Pope et al., 2002).

The health analysis estimates the annual cases in Philadelphia of each category of avoided health effects associated with implanting each of the four LID options. Table H.1 presents a representative result; the numbers of avoided cases for implementing the 50% LID option in all four watersheds (e.g., the health benefits of planting 637,000 trees, when the trees reach mature size).

Table H.1. Avoided cases in Philadelphia County for the 50% LID option implemented in all four watersheds (assuming 2010 population)

Health effect	Avoided cases
Premature mortality	1.0 deaths/year (low estimate from Pope et al., 2002)
	2.4 deaths/year (high estimate from Laden et al., 2006)
New cases of chronic bronchitis	0.4 cases/year
Heart attacks	1.2 cases/year
Hospital admissions (all types)	1.0 cases/year
Asthma attacks	23 cases/year
Respiratory illness days	708 days of illness/year
Work loss days and school absence	250 days/year

Varying the number of trees planted, such as in other LID options, is assumed to proportionally effect the health benefits of the changes in ozone and $PM_{2.5}$ levels.

H.5 Economic Valuation of the Avoided Health Effects

In order to include the air quality-related health effects in a benefit-cost analysis containing other benefit categories (energy savings, cooling effects, etc.), it is useful to estimate the economic value of the health effects. For purposes of air pollution policy analysis, the EPA estimates the value of avoiding a case of each estimated health effect, and these estimates (expressed in terms of 2006 prices and forecasted 2010 income levels) are used in this analysis. The EPA valuation estimates are included in the BenMAP software (U.S. EPA, 2008a), which was used to conduct both the health and valuation analyses.

According to economic theory, the best measure of the value of reducing the risk of an adverse health effect is the average that individuals are WTP to reduce the risk a small amount. EPA's methods for valuing air pollution health effects use WTP valuation measures wherever possible, relying on periodic EPA reviews of existing economic studies. However, for certain endpoints reliable WTP studies are not available. EPA has developed alternative methods for valuing the health effects without WTP valuations. The alternative methods produce a lower value estimate than a WTP method because they only consider a portion of the total demand (WTP) for avoiding a health risk. For example, hospital admissions are valued using the medical costs incurred during the stay in the hospital; this ignores the pain and suffering components of value that would be included in WTP. Heart attacks are valued using a combination of medical cost information plus the lost stream of income from people not able to re-enter the workforce (or who must work at a reduced level of income) after a heart attack. The heart attack valuation thus also ignores the pain and suffering components of WTP, and does not include lost income for people assumed to be out of the workforce (e.g., retirees and unemployed adults).

Background and detailed sources of all values used in this analysis are available in the BenMAP documentation and technical appendices (U.S. EPA, 2008a). The values for each health effect are presented in Table H.2.

Table H.2. Values for one case of each health effect

Health effect	Value per case (2006 prices, 2010 income)
Premature mortality	$7,000,000
Chronic bronchitis	$196,000
Heart attack	$141,000 to $233,000 (varies by age)
Hospital admission	$15,000 to $33,000 (varies by cause of hospitalization and age)
Emergency room visit	$336
Asthma attack	$189
Illness day	$18 to $59 (varies by illness)
Work loss days	$143
School absence	$89

Using the methods described above, the total annual health value implementing the 50% LID option in all four watersheds (an increase of 30% in the number of trees in Philadelphia County) is between $12.5 million (based on the low estimate of $PM_{2.5}$ adult mortality from Pope et al., 2002) and $20.5 million (with the high estimate of $PM_{2.5}$ adult mortality from Laden et al., 2006). The corresponding annual benefits per tree planted are between $19 (low estimate) and $45 (high estimate). The mean per tree annual benefit is $32. Varying the number of trees planted, such as in other LID options, is assumed to proportionally affect the total health benefits of the changes in ozone and $PM_{2.5}$ levels, but the benefit per tree will remain constant.

As described in the following sections however, these benefit estimates are not realized immediately when a tree is planted. The schedule in planting trees, plus the time required for a tree to grow to maturity, significantly reduce the present value of planting each tree due to discounting of the value of the avoided health effects.

H.6 Estimates of Trees Planted, the Timeline for Planting Trees, and Time to Reach Maturity

The number of trees planted under each LID option in each of the four watersheds are presented in Table H.3.

Table H.3. Number of trees planted in each watershed under the LID options

	Tacony-Frankford	Cobbs Creek	Schuylkill	Delaware
25% LID	38,612	12,331	41,470	86,553
50% LID	137,537	43,923	147,718	308,304
75% LID	195,743	62,511	210,231	438,776
100% LID	235,032	75,059	252,429	526,848

There are two assumptions about trees that influence the benefits estimation: the schedule for tree planting, and the time it takes for trees to grow to maturity. Both of these factors result in the full air quality health benefits of the increased number of trees being realized well after the LID program activities begin.

The timeline of program activities provided by CDM shows the total number of trees planted in each LID option will be planted over a 35-year period. Approximately 10% of the trees will be planted over the first 6 years of the planting program, 35% planted over the following 14 years, and 55% planted over the final 15 years. Planting begins in 2010, and is not completed until 2045.

When initially planted trees are not fully mature, and cannot produce the full air quality improvement benefits immediately. For the purpose of this analysis, each newly planted tree is assumed to take 20 years to reach maturity in terms of improving air quality. Newly planted trees are assumed to grow at a uniform rate (in air quality removal terms) throughout the 20-year growth period. After the 20-year growth period, the air quality improving characteristics of a planted tree are assumed to remain constant, with urban forestry management practices replacing the trees as necessary to maintain the same effective level of air pollution improvements.

The combination of the 35 year planting schedule and the 20-year tree growth assumption results in the full benefits of air quality improvements for an LID option not being realized until 55 years after the planting begins. The effect of the time delays in the planted trees reaching their full effect on air quality and human health is reflected in the benefit cost analysis through discounting the value of the health effects from the year the health effects are realized back to the time the LID program begins. The discount rate (4.875%) and project initiation year (2008) are the same as used in all portions of the benefits analysis.

H.7 Estimated Economic Benefits

Table H.4 presents a summary of the present value of the health related benefits deriving from air quality improvements resulting from the trees planted in each LID option.

Table H.4. Present value of air quality-related health benefits from tree planting under the LID options (USD millions)

	Tacony-Frankford	Cobbs Creek	Schuylkill	Delaware	Total
25% LID	$7.9	$2.5	$8.5	$17.8	$36.8
50% LID	$28.3	$9.0	$30.4	$63.4	$131.0
75% LID	$40.2	$12.8	$43.2	$90.2	$186.5
100% LID	$48.3	$15.4	$51.9	$108.3	$223.9

H.8 Omissions, Biases, and Uncertainties

To estimate the health benefits from air quality improvements associated with planting trees under the LID alternatives, it was necessary to make a number of assumptions in the absence of specific data. In addition, a number of data omissions and uncertainties surrounding the analysis have been identified throughout this report. Table H.5 provides a summary of these assumptions and uncertainties and their likely impact on our estimation of our air quality related health benefits from tree planting.

Table H.5. Omissions, biases, and uncertainties

Assumption/methodology	Likely impact on net benefits	Comment/explanation
Air quality improvements are based on the Forest Service analysis of the air quality benefits of the existing Philadelphia urban forest	U	The ozone and $PM_{2.5}$ improvements from increasing the number of trees in Philadelphia's urban forest is projected to increase proportionally as the size of the urban forest is increased. Changes in species composition of the planted trees may make the relationship nonlinear, making the impact on benefits uncertain.
Non-Philadelphia residents are not included in the analysis	+	Planting trees in Philadelphia County will likely improve air quality in adjoining counties as well. Air quality improvements in the densely populated adjoining locations are not included in the analysis, and would increase the benefits.
Trees are assumed to decrease $PM_{2.5}$ the same amount that the USDA UFORE analysis estimated PM_{10} is reduced by the existing Philadelphia urban forest	--	$PM_{2.5}$ is more toxic than an equal amount of PM_{10}. If trees are less effective at reducing $PM_{2.5}$ concentrations than in reducing PM_{10}, the tree planting will result in smaller $PM_{2.5}$ changes than estimated in this report. $PM_{2.5}$ contributes more to the total benefit value than ozone, so a smaller change in $PM_{2.5}$ levels would reduce benefits more than a comparable degree of change in ozone.
Trees are assumed to have the same reductions in ozone and PM levels in the future as they do now	-	Over the past several decades air quality levels in Philadelphia have been improving steadily since air pollution programs began to substantially reduce emissions. This trend will generally continue as older cars are retired, additional control programs are implemented, etc. If air quality is cleaner in the future, the impact of additional trees could be less, resulting in smaller improvements in $PM_{2.5}$ and ozone levels than modeled here.

+ would increase benefits; ++ would increase net benefits significantly; U uncertain direction of change; - would diminish net benefits; -- would diminish net benefits significantly

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I. Construction- and Maintenance-Related Disruption Impacts

Under all of the CSO options, construction activities will likely result in occasional delays and increased travel times for passenger and commercial vehicle travelers in Philadelphia. Travel time delays can be caused by:

- General traffic slowdowns associated with an increase in the number of trucks and construction equipment on the road
- Slowdowns from trucks entering and exiting construction or landscaping sites
- Lane or road closures associated with construction in the roadway or road right-of-way.

In addition to the value of "lost" time spent in traffic, construction-related delays can result in increased costs associated with additional fuel used by vehicles as a result of slower speeds and occasional vehicle stops and idling.

The following sections outline Stratus Consulting's approach for estimating the costs associated with travel time delay and additional fuel used under the different CSO options. Cost estimates associated with construction-related delays are also provided.

I.1 Impact of Additional Construction and Maintenance Vehicles on Philadelphia Roadways

To estimate travel time delay caused by an increase in the number of construction and maintenance vehicles on Philadelphia's roadways, we first estimated the number of miles traveled by these vehicles under the different CSO alternatives. We calculated total VMT based on inputs received from CDM, including the number of heavy truck trips over the construction period and total person-hours of O&M labor per year. We made several assumptions regarding average trip length per vehicle, number of concrete trucks under the non-LID alternatives, and the average number of employees per truck (crew size) for O&M vehicles.

Table I.1 shows the inputs and assumptions used to determine additional truck miles traveled under the different CSO options.

Table I.1. Inputs and assumptions for estimating additional VMT under CSO options

	LID alternatives
Heavy truck trips	
Vehicle trips (heavy trucks/construction)	Provided by CDM for each alternative
Vehicle trips (concrete trucks)	For non-LID alternatives, assumed to equal ½ of heavy vehicle construction trips
Average trip length (miles)	20
Light truck trips (LID options only)	
Person-hours of O&M labor per year	Provided by CDM for each LID alternative
Working hours per year	2,000
Persons per truck (crew size)	4
Number of additional trucks on the road each day	Number of employees divided by crew size
Average trip length (miles)	15

Using the total VMT by construction and maintenance vehicles under each option, we were able to estimate the travel time delay caused by these vehicles based on methodology developed by the Texas Transportation Institute (TTI) (Schrank and Lomax, 2007). The following sections outline our general approach and provide monetary and non-monetary cost estimates for construction-related impacts under each of the CSO alternatives. Non-monetary estimates are presented in terms of total hours of delay.

Step 1: Determine congested peak period VMT. This first step is based on the assumption that an increase in the number of construction vehicles on Philadelphia's roadways will only affect vehicles already traveling in congested conditions. Thus, vehicles traveling in uncongested conditions would continue to travel at "free-flow" speeds despite the addition of extra vehicles. We assume that congestion is typically only experienced during certain times of the day (i.e., during "peak" periods).

Based on the TTI's Annual Mobility Report (Schrank and Lomax, 2007), peak period travel accounts for 50% of DVMT. Further, TTI estimates that in Philadelphia, 63% of peak period travel is spent in congested conditions. Thus, approximately 32% (50% × 63%) of DVMT is considered to be congested, peak period travel.

Step 2: Determine VMT impacted. Only a small percentage of congested peak period travel will experience traffic delays or slow downs due to an increase in the number of trucks on the road. To determine total VMT affected, we assume that for each heavy construction vehicle mile traveled, an additional 30 vehicle miles (or 30 vehicles) are impacted. Thus, if 10 million vehicle miles are traveled under a given CSO option, we assume that 300 million passenger and/or commercial vehicle miles are traveled at slower speeds. In the absence of specific roadway data, this assumption is intended to serve as a benchmark to provide an order of magnitude of costs.

Step 3: Estimate impact on traffic speed. We assume construction vehicle travel to be consistent with current traffic patterns, with approximately 42% of travel taking place on highways and 58% on arterial roads (Schrank and Lomax, 2007). TTI reports that during peak periods, the average highway speed in Philadelphia is about 45.6 miles per hour (mph). On arterial roads, the average speed is approximately 27.5 mph. We estimate that the speed of affected vehicles will decrease by approximately 8 and 10% on highways and arterial roads, respectively (to 42 and 24.8 mph). Again, in the absence of specific roadway data, this assumption is intended to serve as a benchmark to provide an order of magnitude for potential impacts.

Step 4: Estimate travel time and determine annual delay. The fourth step involves calculating the amount of time it would take to travel the affected vehicle miles at decreased speeds and at current (or baseline) speeds. This calculation yields travel time on an hourly basis and was performed separately for arterials and freeways under each scenario. Total annual vehicle *delay* was then determined by comparing travel time under decreased speeds for each alternative to travel times at current speeds.

To determine total person delay, we distinguish between heavy truck travel and passenger vehicle travel. Based on TTI data, we assume that 5% of total travel can be attributed to heavy trucks and that these vehicles typically have only one passenger (the truck driver). Passenger vehicles are assumed to contain an average of 1.25 passengers per vehicle, including the driver (Schrank and Lomax, 2007).

Based on the steps described above, we were able to estimate travel time delay caused by construction and implementation activities under each CSO option. Our estimates reflect total delay over the 40-year project period. To estimate annual delay over the project life, we allocated total delay based on construction and implementation timelines provided by CDM.

Table I.2 provides total person-delay estimates (accounting for 1.25 persons per passenger vehicle) for the CSO options in each watershed.

Table I.2. Total vehicle delay caused by additional construction and maintenance vehicles on Philadelphia roadways under PWD's CSO options (person-hours)

	Tacony	Cobbs	Schuylkill	Delaware
LID options				
25% LID	41,801	13,349	44,895	93,701
50% LID	74,840	23,901	80,380	167,762
75% LID	128,378	40,998	137,881	287,772
100% LID	174,087	55,596	186,973	390,233

Table I.2. Total vehicle delay caused by additional construction and maintenance vehicles on Philadelphia roadways under PWD's CSO options (person-hours) (cont.)

	Tacony	Cobbs	Schuylkill	Delaware
Transmission and new treatment capacity (excluding LID component)[a]				
Level 1	10,541	5,678	4,947	42,162
Level 2	12,048	6,251	10,763	43,357
Level 3	17,781	6,412	15,989	71,479
Level 4	26,184			73,667
Tunnel options[b]				
15' Tunnel	40,098	61,176	88,027	131,922
20' Tunnel	62,873	85,803	116,932	158,123
25' Tunnel	92,388	125,811	154,421	220,393
30' Tunnel	129,672	166,009	200,775	300,141
35' Tunnel	173,954	213,537	256,275	351,764
Transmission and satellite treatment options				
25 Ofs	695	485	2,147	2,846
10 Ofs	2,826	2,299	6,643	8,062
4 Ofs	11,806	6,364	16,666	20,949
1 Ofs	33,892	10,880	37,413	44,299

a. Levels 1–4 correspond to the different capacity options within each watershed (e.g., for Tacony-Frankford Watershed, Levels 1–4 are 215, 298, 490, and 820 MGD, respectively.

b. Tunnel options in Delaware River Watershed are 15, 18, 21, 23, 28 and 31'.

I.2 Wasted Fuel

To calculate wasted fuel due to vehicles moving at slower speeds, we again draw upon methodology developed by TTI. We first calculate average fuel economy based on a linear regression applied to a modified version of fuel consumption reported by Raus (1981), as follows:

Average fuel economy = 8.8 + 0.25 (average speed)

This equation is applied to average speeds for arterials and freeways. Annual fuel consumed as a result of the delay under each CSO option is then calculated:

Annual fuel consumed = Travel delay (vehicle hours) × Average speed / Average fuel economy

The additional fuel use associated with construction-related delay is reported under the "energy usage/savings" category for each CSO alternative (Appendix G). The value of this "wasted" fuel is also reported as part of this category (in terms of total energy costs). However, we can provide an idea of total costs associated with additional fuel used as a result of construction-related delay. At $3.00 per gallon, additional fuel use amounts to about 16% of the total costs estimated for travel time delay, which is reported below.

I.3 The Value of Travel Time Delay Caused by Additional Construction Vehicles on the Roadways

To determine the value of extra time spent in traffic, we applied hourly rates used by the U.S. Department of Transportation and TTI to value an individual's time. Hourly rates for passenger vehicle travelers are weighted by a standard to account for both leisure and work-related travel (approximately $16.00 per hour). Heavy truck travel (assumed to be commercial truck travel) represents hourly wage plus fringe benefits (approximately $84 per hour). These values are based on 2005 TTI estimates and inflated by 3% to reflect 2008 values.

Table I.3 shows the total value of travel time delay caused by additional vehicles on Philadelphia roadways. The values shown here represent present value estimates for the 40-year project timeline. Similar to hours of delay, these costs were allocated by year based on construction and implementation timelines provided by CDM.

Table I.3. Monetary value of total vehicle delay caused by additional construction and maintenance vehicles on Philadelphia roadways under PWD's CSO options (present value, 2009 USD)

	Tacony	Cobbs	Schuylkill	Delaware
LID options				
25% LID	$677,244	$216,282	$727,374	$1,518,111
50% LID	$1,210,066	$386,441	$1,299,636	$2,712,484
75% LID	$2,077,509	$663,464	$2,231,286	$4,656,943
100% LID	$2,818,088	$899,972	$3,026,684	$6,317,026
Transmission and new treatment capacity (excluding LID component)[a]				
Level 1	$177,872	$95,815	$83,479	$711,433
Level 2	$203,292	$105,483	$181,616	$731,600
Level 3	$300,043	$108,195	$269,800	$1,206,134
Level 4	$441,823	NA	NA	$1,243,061

Table I.3. Monetary value of total vehicle delay caused by additional construction and maintenance vehicles on Philadelphia roadways under PWD's CSO options (present value, 2009 USD) (cont.)

	Tacony	Cobbs	Schuylkill	Delaware
Tunnel options[b]				
15' Tunnel	$676,617	$1,032,283	$1,485,367	$2,226,049
20' Tunnel	$1,060,923	$1,447,835	$1,973,102	$2,668,168
25' Tunnel	$1,558,954	$2,122,931	$2,605,699	$3,718,904
30' Tunnel	$2,188,081	$2,801,233	$3,387,882	$5,064,569
35' Tunnel	$2,935,292	$3,603,223	$4,324,377	$5,935,660
Transmission and satellite treatment options				
25 Ofs	$11,731	$8,177	$36,234	$48,025
10 Ofs	$47,680	$38,799	$112,099	$136,036
4 Ofs	$199,213	$107,387	$281,222	$353,488
1 Ofs	$571,892	$183,593	$631,312	$747,498

a. Levels 1–4 correspond to the different capacity options within each watershed (e.g., for Tacony-Frankford Watershed, Levels 1–4 are 215, 298, 490, and 820 MGD, respectively.

b. Tunnel options in Delaware River Watershed are 15, 18, 21, 23, 28, and 31'.

I.4 Delay Associated with Temporary Lane/Road Closures

To estimate annual vehicle delay associated with detours and temporary lane and/or road closures, we would ideally know the location and duration of each closure as well as the number of travelers affected and their speed over the impacted area. Because we are uncertain of how these variables might vary under each alternative, we do not include the impact of lane and road closures in our overall analysis.

In the absence of this detailed information, we can provide a rough benchmark estimate of annual delay caused by construction activities in the roadway based on the following assumptions:

- Five percent of travelers are impacted
- Each affected traveler experiences an average of a 5-minute delay per lane/road closure and/or detour
- Affected travelers experience the delay twice a day, an average 250 days each year (total working days in a year)

- Vehicles will experience these delays on arterial streets as opposed to freeways
- Travelers can experience delays throughout the day (not just during peak periods)
- Heavy trucks account for approximately 5% of total traffic and typically contain only one person (the driver)
- Passenger vehicles have an average of 1.25 persons per vehicle.

Based on these assumptions, we estimate that increased construction activities under the different CSO options could delay Philadelphia truck drivers and passenger vehicle occupants by an additional 12,200 hours each year (about 15,100 person-hours). If this is assumed to be the average impact each year over the 40-year project, total vehicle delay would amount to about 490,000 hours.

The key variables here are the percent of travelers affected and the amount of time and frequency that each vehicle is delayed. Again, it is uncertain how these variables might vary across the different options. The assumptions described above are intended to provide a benchmark estimate from which to gauge potential impacts.

Table I.4 shows the inputs and the order-of-magnitude estimate associated with this city-wide impact.

Table I.4. Inputs and preliminary estimates for total delay caused by lane closures and/or detours

	Input/preliminary estimate
Daily vehicle-miles of travel (1,000s) on arterial roads	48,235
Arterial road lane miles	8,240
Total number of vehicles on arterial roads per day	5,850
Percent of total travelers affected	5%
Total travelers affected	290
Daily hours of delay	49
Number of days delay is experienced	250
Annual hours of vehicle delay	12,200
Annual hours of delay for heavy trucks	610
Annual hours of passenger vehicle person-delay	14,480
Total annual hours of person delay	15,100

This estimate will vary each year depending on the level of activity in any given year. In the absence of this information, it is difficult to estimate the present value of this benefit. Further, due to lack of more detailed information, we were unable to calculate the cost of wasted fuel due to idling and slower speeds associated with this type of delay.

I.5 Other Non-quantifiable Impacts

I.5.1 Neighborhood and business access issues

In some cases, access to residential areas and local businesses may be made difficult by construction and maintenance activities. In residential areas, access issues can result in increased travel time for residents having to choose alternate routes in traveling to and from their homes. Employees and customers of local businesses may also experience increased travel times from having to choose alternate routes or visit other businesses. Some local businesses may temporarily see a decline in the number of customers visiting their businesses.

I.5.2 Temporary construction impacts

Other public impacts from construction and maintenance can include mitigation or repair of construction-related damage due to tunneling settlement and vibration or equipment damage to private property. Additional impacts may include noise, dust, vibration, and safety issues associated with construction activities. These impacts are typically experienced by residents and businesses within the project area, including those located on streets where detours have been routed. These miscellaneous other social costs will not likely represent a large portion of overall project costs and in the absence of specific data, they are described qualitatively.

I.6 Omissions, Biases, and Uncertainties

As detailed throughout this report, to estimate traffic-related impacts associated with the different CSO control options, it was necessary to make a number of assumptions. Many of these assumptions are based on Philadelphia-specific data (average speeds, annual VMT, etc.) or represent standard industry estimates (e.g., number of person per vehicle, wage rates). Although there is a degree of uncertainty surrounding these assumptions, they are developed based on well-accepted methodology (see Schranx and Lomax, 2007) that has been used to evaluate mobility and traffic patterns in urban areas for a number of years.

Additional uncertainties surrounding our analysis of construction-related costs generally stem from a lack of specific data related to on-the-ground implementation of the CSO options (location, expected road closures, etc.). Table I.5 provides a summary of these assumptions and uncertainties and their likely impact on total benefits.

Table I.5. Omissions, biases and uncertainties

Assumption/ methodology	Likely impact on net benefits[a]	Comment/explanation
Analysis does not include the impact of temporary lane and/or road closures during construction.	++	Depending on their timing and location, temporary lane and road closures could significantly increase the overall costs associated with construction disruption, in terms of additional time spent in traffic and wasted fuel. Further, individual businesses could experience significant impacts if they are located on a closed road. This would not likely result in substantial impacts on a city-wide basis (e.g., residents would continue to shop, just in different locations).
Analysis assumes miles traveled by additional construction vehicles on highways versus arterial roads, follows current traffic patterns.	U	It is unclear how this assumption affects our current estimates. If construction vehicles spend more time driving on arterial roads, impacts would be greater because we assume a larger impact on arterial roads for each vehicle. (e.g., we estimate that the speed of affected vehicles will decrease by approximately 8 and 10% on highways and arterial roads, respectively)
Analysis includes assumption for VMT impacted by additional construction vehicles.	U	To determine total VMT affected, we assume that for each heavy construction vehicle mile traveled, an additional 30 vehicle miles (or 30 vehicles) are impacted. In the absence of specific roadway data, this assumption is intended to serve as a benchmark to provide an order of magnitude of costs.

a. Indicating how addressing the assumption or overcoming the omission would probably impact the analysis, using the following key: + would likely increase net benefits; ++ would increase net benefits significantly; U direction of change in net benefit is uncertain; - would diminish net benefits; -- would diminish net benefits significantly.

References

Raus, J. 1981. *A Method for Estimating Fuel Consumption and Vehicle Emissions on Urban Arterials and Networks.* Report No. FHWA-TS-81-210. Office of Research and Development, Washington, DC. April.

Schrank, D. and T. Lomax. 2007. The 2007 Urban Mobility Report. Texas Transportation Institute. Texas A&M University System.

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Supplemental Documentation
Volume 3

Basis of Cost Opinions

Updated: September 1, 2009

Combined Sewer Overflow Control Alternatives Costing Tool Reference Manual

September, 2009

Table of Contents

1.0 INTRODUCTION AND OVERVIEW

The Philadelphia Water Department (PWD) has developed an alternatives cost estimation calculation tool (ACT) for use in planning level screening and comparison of CSO control technologies. The ACT provides planning-level cost estimates to facilitate the evaluation and comparison of preliminary alternatives for Philadelphia's Long Term CSO Control Plan Update.

The cost opinions created using the ACT are to be considered Level 4 cost estimates, as designated by The Association for the Advancement of Cost Engineering Recommended Practice No. 18R-97 (AACE, 2005), and actual costs are expected to fall within a range of 30% less to 50% more than the cost opinions given in this section. This estimate class and accuracy is appropriate for long term planning level use.

This user reference manual presents an overview of the contents, working and internal logic of the ACT.

1.1 Alternatives Costing Tool Scope

The ACT is an EXCEL workbook-based program which provides capital and operation and maintenance (O&M) costs of wet-weather conveyance, storage and treatment facilities based on costing algorithms developed from evolving and expanding national data sets, from PWD, and other regional capital and O&M cost data. Key outputs include:

- Current year (anticipated 2009) capital cost
- Current year O&M costs
- Present worth based on capital costs and projected O&M costs
- Future years' O&M costs based on assumed inflation
- Annual debt service costs
  Total capital costs

The user is to develop control alternatives which include conceptual level determinations of facility size, type and configuration. This information is entered into the costing tool through standardized templates. The ACT is configured to allow the user to rapidly evaluate sizing and configuration alternatives. Assumptions and calculations are displayed in a step-wise manner in the ACT, while providing the user the ability to reference the source data.

1.2 Control Technologies

Figure 1.2-1 displays the control technologies which are included in the ACT. The costing methodologies, inputs (conceptual design values) to be provided by the user, and conceptual design approach assumptions to be incorporated into the ACT are detailed in Section 2.0.

Table 1.2-1 ACT Technology Summary

Source Controls: Land-Based Stormwater Management (Green Stormwater Infrastructure) Private I/I Reduction Municipal I/I Reduction
Storage: Conventional Tunnel Tank Storage
Conveyance: Open Cut Pipe Pump Station Short-Bore Tunnel (Trenchless) Sewer Separation
Treatment: Retention Treatment Basin Vortex Separation High-Rate Clarification Screening Disinfection
Miscellaneous

1.3 Terminology

For purposes of this documentation the following definitions will apply. The specific meanings of some terms may vary depending on the context.

Control Element

"Control Element" means a facility serving as one component of a control alternative. A high-rate treatment (HRT) facility or a relief interceptor would be examples of control elements. Source reduction through municipal collection system rehabilitation or through green stormwater infrastructure would also be examples of control elements. The ACT will output estimated capital costs for control elements (e.g., the capital cost of a 30 million gallon per day (mgd) HRT based on the design and other parameters set by the user and the system-wide design assumptions discussed below in Section 2).

Control Alternative

"Control alternative" means an array of one or more control elements providing watershed-level overflow control at some specified level of performance. A relief interceptor sewer discharging to a HRT facility that was sized for eight overflows per typical year would be an example of a watershed-control alternative. The capital cost of a control alternative is the sum of the control element capital costs.

Construction Costs

"Construction costs" means the raw costs of building new control facilities, upgrading or expanding existing facilities or rehabilitating existing sewerage (i.e., the contractors' bid costs). Construction costs include: general conditions, overhead and profit, mobilization, demobilization, contractor's bonds and insurance, and sub-contractor markups.

Non-Construction Costs

Non-construction costs include all costs related to a control alternative other than building costs. Design and construction engineering costs are examples. Estimated non-construction costs, except for land acquisition, are based on a percentage of construction costs.

Capital Costs

Capital costs will be the sum of the estimated construction costs and the estimated non-construction costs.

Planning Period

For purposes of control alternatives evaluation, the planning period will be set at a default of 40 years. The planning period is relevant to calculating the present worth of various control elements.

Useful Life

The useful life of a control element is the period during which the control element will operate without requiring replacement or substantial reconstruction to maintain design performance. Preventive and corrective maintenance are assumed when establishing the useful lives of the control element components.

1.4 Economic Parameters

The following parameters have been incorporated into the ACT as standard values.

1.4.1 Useful Life

Useful life is relevant to alternatives evaluation because of the extended planning period. Present worth calculations need to include structural replacement or rehabilitation and equipment replacement costs that would occur during the planning period (e.g., a storage tank with effluent pumps coming on line in 2029 would likely require pump replacement or major overhaul before 2048). Because of the intermittent operation of wet-weather facilities, traditional estimates of equipment useful life may be inappropriate.

1.4.2 Discount Rate

The discount rate utilized by the ACT to calculate the present worth of control elements is an input variable. The default discount rate is 4.875%, and is based on the Department of Interior Federal water resources planning discount rate for fiscal year 2008.

1.4.3 Construction Cost Base Date

The base date, likely to be the current year, is a user input, and represents the date that the opinion of cost is in terms of. The default base date in the ACT is January 2009 as the base date for estimated construction costs.

1.4.4 Cost Inflation

Future Capital Costs

The ACT estimates future capital costs both in current year dollars and in future dollars. The default inflation value in the ACT is 4.0%.

Operations and Maintenance Cost Inflation

Base date (January 2009) O&M costs are inflated to the first year of operation as input into the model and for subsequent years throughout the planning period. The initiation of operation will be assumed to occur on January 1 of the year following construction completion. The default O&M cost inflation in the ACT is 4.0%.

1.4.5 Cost Indexes

Because the cost estimating sources were based on different dates and geographic locations, the cost estimates for the base year and base location were adjusted through cost indexes. Specifically, the Engineering News Record Construction Cost Index (ENRCCI) was used to adjust for the year of the cost estimate, and the 2008 RSMeans Location Factor (RSMeans) was used to adjust for the geographic location of the cost estimates. Table 1.4.5-1 shows the cost indexes for the cost estimating sources. The default base ENRCCI in the ACT is 8549, and the default RSMeans in the ACT is 115.2.

Table 1.4.5-1 Summary of Base Index Values for ACT Technologies Cost Data

Technology	Cost Equation Data Base Index Values			
	ENRCCI Construction	RS Means Construction	ENRCCI O&M	RS Means O&M
Default ACT Project Analysis	8551	100.0	8551	100.0
Land-Based Stormwater Management	7966	115.2	8141	115.2
Private I/I Removal	8551	100.0	8551	100.0
Municipal I/I Removal	8551	100.0	8551	100.0
Conventional Tunnel	8551	100.0	8551	100.0
Tank Storage	8551	100.0	8551	100.0
Open Cut Pipe	7312	92.9	6771 (Detroit)	103.9 (Detroit)
Pump Station	8551	100.0	7939 (PWD)	115.2 (PWD)
			7966 (EPA)	100.0 (EPA)
Trenchless Technologies	8578	113.2	6771 (Detroit)	103.9 (Detroit)
Sewer Separation	8551	100.0	8551	100.0
Retention Treatment Basins	8551	100.0	8551	100.0
Vortex Separation	8551	100.0	8551	100.0
High-Rate Clarification	8551	100.0	8551	100.0
Screening	8551	100.0	8551	100.0
Disinfection	8551	100.0	8551	100.0

Note: The unit cost values in the subsequent appendices reflect unadjusted costs. The index values are used for adjustment of cost to the project analysis ENRCCI and RSMeans values input by the user.

2.0 COST ESTIMATING APPROACH

This section outlines the wet-weather controls that are included in the ACT and the methodologies to be used in the ACT to scale estimated capital costs to the sizes and complexities identified by the user.

2.1 Non-Construction Costs

The ACT includes non-construction costs and economic parameters that impact the estimated total capital cost of a given control alternative.

The ACT automatically assigns non-construction costs to the construction costs calculated for a control element. With the exception of land acquisition and easement costs which are determined by the user, each non-construction cost is calculated as a percent of the estimated construction cost either before or after other multipliers are applied.

2.1.1 Construction Contingency

Construction contingencies are added to take into account how far advanced a design has proceeded. This contingency takes into account any design development concerns based on the status and phase of the project. For the initial planning work that is being done, a 25 percent contingency is added to the construction cost, which already includes (implicitly), the contractor's overhead and mark-up. The construction cost with this contingency included will be referred to as the opinion of probable construction cost.

2.1.2 Project Contingency

The ACT adds a project contingency to the opinion of probable construction cost. This contingency typically ranges from 5 to 30% depending upon such things as the level of difficulty of the project, the volatility of the bidding climate for the project type, the level of complexity of the site conditions, and the type and stage of funding being required. The default project contingency in the ACT is 20%.

2.1.3 Capitalized Interest

Capitalized interest, or interest during construction, reflects interest payments on the amount borrowed (through bonds), payment of which is deferred during construction. The ACT calculates the cost of capitalizing interest during construction based on the anticipated duration(s) of construction input by the user. For planning purposes, the annual draws on construction funding will be assumed to be straight line.

2.1.4 Land Acquisition and Easements/Rights-of-Way

Because of the specificity of local conditions, the ACT will not include a standard multiplier for land acquisition, easements and Rights-of-Way (ROW). Upon identifying preliminary routing (for relief or consolidation interceptors) or sites for control facilities, the user should overlay the potential routes and sites with existing easements and ROW to identify the need for new easements, ROW or parcels. The user will enter the total estimated costs for land acquisition, easements and ROW into the ACT.

2.1.5 Engineering and Implementation

Engineering and implementation costs are added as a percentage to the total of all costs described above. The ACT has a default setting of 20%, and is intended to address the following typical project costs:

- Permitting
- Engineering design
- Construction oversight /resident engineering
- Administration and program management
- Finance bonding costs
- Legal
- Geotechnical
- Survey
- Public participation.

2.1.6 Contractor's Overhead and Profit and Indirect Costs

Cost estimate sources presented in the ACT are in two different levels of cost. Most cost sources are in terms of construction costs as defined above: contractor's bid cost including overhead and profit and indirect costs. However, a few cost sources assembled directly from materials, labor, and equipment estimates are in terms of direct construction costs, excluding contractor's overhead and profit and indirect costs. Table 2.1.6 shows the breakdown between construction and direct construction in the ACT.

Overhead and profit and indirect costs are applied to the cost sources based on direct construction costs. The default value for contractor's overhead and profit in the ACT is 20%. The default value for contractor's indirect costs in the ACT is 4%.

Table 2.1.6 ACT Technology Cost Source Level of Cost

Technology Cost Curve/Cost Module	Direct Construction Cost (i.e. materials, labor, equipment)	Construction Cost Including Contractor's Overhead, Profit and Indirect Costs
Land Based Stormwater Management	X	
Trenchless Technologies	X	
Open Cut Pipe	X	
All Other Technologies		X

2.2 Construction Cost Approach

2.2.1 Cost Scaling

The ACT scales construction costs based on a series of cost per facility size equations developed for each of the structural control alternatives outlined in Section 2.3. Otherwise, it assembles construction and O&M costs from smaller components (e.g. material cost of a particular type and size of pipe, energy cost for pumping at a specific total dynamic head, flow rate, duration and electrical rate, etc).

2.2.2 Cost Data Sources

A variety of construction cost estimate data sources were used in development of the ACT. National wet-weather control facility costs of facilities in operation, as well as unit cost breakouts for such facilities (as they are available) were used extensively. These costs were updated for time and location.

The ACT also relied on cost curve data sets that have been developed for other wet weather programs nationally, such as: Perth Amboy, New Jersey; Indianapolis, Indiana; Cincinnati; Allegheny County, PA; Detroit, Michigan and Omaha, Nebraska. Data was also provided from the Philadelphia Water Department (PWD), and the Detroit Water and Sewer Department (DWSD). These cost curves were used for comparison purposes to verify the feasibility of the selected cost curve for a given technology. This combined knowledge base allowed for comparison of different cost estimation methodologies for each technology within the ACT.

The United States Environmental Protection Agency (U.S. EPA) publications containing control facilities cost data and cost curves will be used as a secondary source of guidance. These cost estimating curves were compared to installed project data, and adjusted chronologically using ENRCCI Index values.

2.3 Cost Estimation Methodology

The following subsection outlines inputs, default assumptions and methodologies used in the ACT to estimate construction costs of various control technologies that were identified in Section 1.2.

2.3.1 Land-Based Stormwater Management (Green Stormwater Infrastructure)

Land Based Stormwater Management (LBSM) costs are estimated using unit-area estimates. Underlying those unit-area estimates are more precise engineering cost opinions based on real site plans representing a variety of technologies, land use types, sizes, and land ownership.

A range of stormwater management plans using different LID techniques was selected. Five of these represented plans submitted by private developers and approved as complying with Philadelphia's stormwater ordinance and regulations. Ten plans were considered public funded projects, including two PWD demonstration projects. Engineering cost estimates were developed based on materials, labor, overhead, and profit using unit costs from RSMeans CostWorks (see example in Table 2.3.1-1). Costs were adjusted to represent construction taking place within Philadelphia with union labor rates in 2008 dollars and are considered construction costs with overhead, profit and without indirect costs.

Direct construction costs were estimated using materials and labor quantities for the following two cases:

- The marginal construction cost (beyond the cost of traditional measures) to implement each LBSM approach assuming that redevelopment is already taking place.
- The full construction cost required to implement each LBSM approach by retrofitting traditional development on an existing site.

Table 2.3.1-1 Example of Project Cost Estimate based on Quantities and Unit Costs

Category	Material	Units	Quantity	Unit Cost	Total Cost	Source*
Trees	Deciduous Tree	total	6	$385.00	$2,310.00	Means 32 93 4320 1600
	Bark Mulch	sq. yd	10.66	$6.15	$65.56	Means 32 91 1316 0100
	Geotextile Separation Fabric	sq. yd	10.67	$1.95	$20.80	Means 02620-300-0110
	Planting Backfill Mixture	cu. Yd	9.48	$29.50	$279.70	Means 31 05 1310 0700
	Hauling Backfill Mixture to Site	cu. Yd	9.48	$30.55	$289.66	Calculation
	Excavation	cu. Yd	10.67	$2.75	$29.31	Calculation
Porous Pavement	Pervious Asphalt	sq. yd	652.36	$20.90	$13,634.32	2X cost of traditional pavement
	AASHTO No. 57 Choker	cu. yd	18.12	$37.69	$682.94	Means 31 05 1610 0300
	AASHTO No. 2 Coarse Aggregate	sq. yd	652.36	$9.55	$6,230.04	Means 32 11 2323 0302
	Non-Woven Geotextile	sq. yd	784.36	$1.95	$1,529.50	Means 02620-300-0110
	Excavation	cu. Yd	217.88	$2.75	$598.84	Calculation
	Hauling Asphalt Materials to Site	cu. yd	163.20	$30.55	$4,985.76	Calculation
	Hauling for excavated soil	cu. Yd	217.88	$30.55	$6,656.17	Calculation
Pipe Trench Under Porous Pavement	24" Perf. Pipes	ft	774.00	$62.00	$47,988.00	Means 3311 1325 3070
	24" LF HDPE Header	ft	22.00	$62.00	$1,364.00	Means 3311 1325 3070
	Gravel	sq. yd	95.30	$15.40	$1,467.56	Means 32 11 2323 0300
	AASHTO No. 2 Coarse Aggregate	sq yd	91.21	$9.55	$871.06	Means 32 11 2323 0302
	Hauling Aggregate to Site	cu yd	91.21	$30.55	$2,786.47	Calculation
Inlet Structure	Reinforced Concrete Inlet Box	total	1	$4,800.00	$4,800.00	Means 334913-10-1000
	Excavation volume	cu. Yd	4.74	$2.75	$13.03	Calculation
	Hauling for excavated soil	cu. yd	4.74	$30.55	$144.83	Calculation
	Footing	each	1	$27.78	$27.78	Anecdotal
	Reinforced Concrete Top Unit	total	1	$440.00	$440.00	Means 33-49-1310-1300
	Heavy Duty Inlet Frame	total	1	$1,125.00	$1,125.00	Means 02630-110-1582
	AASHTO Coarse Aggregate Size No. 57	cu yd	0.67	$37.69	$25.13	Means 31 05 1610 0300
	Hauling Aggregate to Site	cu yd	0.67	$30.55	$20.37	Calculation
Outlet Structure	Cast Iron Manhole Frame and Cover	total	1	$505.00	$505.00	Means 33-44-1313-2100
	Precast Manhole Slab	total	1	$650.00	$650.00	Means 33-49-1310-1400
	Precast Reinforced Concrete Inlet Box	total	1	$4,800.00	$4,800.00	Means 334913-10-1000
	Cast Iron Trap	total	1	$550.00	$550.00	Means 22-13-1660-1160
	AASHTO Coarse Aggregate Size No. 57	cu yd	0.89	$37.69	$33.50	Means 31 05 1610 0300
	Hauling Aggregate to Site	cu yd	0.89	$30.55	$27.15	Calculation
Cleanout (Storm water piping)	Cast Iron Cleanout Housing	total	1	$880.00	$880.00	Means 22-05-7620-0280
	8" Dia. PVC Cleanout with Screw Plug	ft	0.75	$14.30	$10.73	Means 33-31-1325-2080
	8" Dia. PVC Spool Piece	ft	0.33	$14.30	$4.77	Means 33-31-1325-2080
Piping	12" Dia. PVC Pipe	ft	80.00	$23.50	$1,880.00	Means 33-31-1325-2160
	Redevelopment Cost				**$107,727**	

* Most unit costs are taken from R.S. Means Costworks Version 11.0, Building Construction Cost Data 2008. Some are based on local bid data or best engineering judgment. Some are calculations based on combinations of individual items and are too complex to describe in this table. Detailed calculations are available on request.

LBSM Input Variables

To calculate the construction cost of a LBSM technology, the following variables must be input into the ACT by the user:

Impervious Area - For calculating the LBSM construction cost, the user must first input the calculated impervious area (in acres) proposed for the LBSM technology alternative. This value will be determined by the user based on the alternative design.

Control Type - Next, the type of control is to be selected out of the five LBSM technologies: Bioretention, Green Roof, Porous Pavement, Street Trees, and Subsurface Infiltration.

Control Level - The third input variable is the control level, either retrofit or redevelopment.

Based on the user input values, the ACT will calculate direct construction costs as well as operation and maintenance (O&M) costs. These values were developed from unit costs per acre for each scenario provided in the ACT. A summary of the LBSM unit costs is provided in Table 2.3.1-6. A summary of LBSM O&M costs is provided in Table 2.3.1-14.

Summary of Results

The results from the takeoffs of LID stormwater management plans are summarized in the following sections. Descriptions of the projects that are selected for the analysis are listed in Table 2.3.1-2. A list of the cost estimates that were calculated for direct construction costs are shown in Table 2.3.1-3. The estimates were summarized into five categories: bioretention, subsurface infiltration, green roof, porous pavement and street trees in Table 2.3.1-4. Each category was further broken down into a redevelopment and retrofit cost. Due to the small sample size costs for bioretention, subsurface infiltration and porous pavement do not appear to be significantly different. For the purpose of the study the pooled value for all controls was assigned to these three types.

Table 2.3.1-2 Project Descriptions and Characteristics

Project Name	BMP Type	Land Use	Lot Size (sq ft)	Pre Construction Impervious Cover (sq ft)	Post Construction Impervious Cover (sq ft)
Private (1)	Subsurface Infiltration	High Density Residential	23760	21701	23760
47th and Grays Ferry Traffic Triangle	Bioretention	Street	6835	19318	19318
Private (2)	Green Roof	High Density Mixed Use	30593	0	23012
Public (2)	Pervious Pavement and Detention	School	52254	43655	52254
Private (3)	Subsurface Infiltration	School and Parking	371239	107530	121384
Mill Creek Tree Trench	Subsurface Infiltration	Street	1131	17346	17346
Private (4)	Green Roof and Pervious Pavement	High Density Residential	64600	25874	52230
Private (5)	Subsurface Infiltration	Commercial	122839	0	105415
Public (4)	Bioretention	Parking	551470	12235	424870
Public (5)	Subsurface Infiltration	School	95738	81218	29053
Curb Extension	Bioretention	Street	190	3508	3358
Swale without Parking	Bioretention	Street	192	2716	2550
Swale with Parking	Bioretention	Street	192	2429	2263
Planter with parking	Bioretention	Street	175	922	862
Planter without parking	Bioretention	Street	99	1147	1067
Street Trees	street trees	Street	43560	43560	43000*

* - 30.2 trees per acre placed in 16 sq. ft. tree boxes.

Table 2.3.1-3 Direct Construction Cost Estimates in 2008 Dollars

Project Name	BMP Type	Cost Estimates ($/impervious acre)		Actual Project Cost (PWD projects)
		Redevelopment	Retrofit	($/acre)
Private (1)	Subsurface Infiltration	$150,000	$230,000	
47th and Grays Ferry Traffic Triangle	Bioretention	$72,000	$80,000	$150,000
Private (2)	Green Roof	$290,000	$570,000	
Public (2)	Pervious Pavement and Detention	$85,000	$128,000	
Private (3)	Subsurface Infiltration	$44,000	$79,000	
Mill Creek Tree Trench	Subsurface Infiltration	$100,000	$120,000	$170,000
Private (4a)	Green Roof	$200,000	$430,000	
Private (4b)	Pervious Pavement	$190,000	$410,000	
Private (5)	Subsurface Infiltration	$120,000	$170,000	
Public (4)	Bioretention	$150,000	$200,000	
Public (5)	Subsurface Infiltration	$200,000	$350,000	
Curb Extension	Bioretention	$50,000	$65,100	
Swale without Parking	Bioretention	$70,000	$90,000	
Swale with Parking	Bioretention	$80,000	$100,000	
Planter with parking	Bioretention	$130,000	$160,000	
Planter without parking	Bioretention	$80,000	$100,000	
Street Trees	street trees	$15,000	$18,000	

Table 2.3.1-4 Summary of Direct Construction Cost Estimates [ENRCCI 7966; RSMEAN 115.2]

Control	**Type**	**Minimum Cost ($ / impervious acre)**	**Median Cost ($ / impervious acre)**	**Mean Cost ($ / impervious acre)**	**Max Cost ($ / impervious acre)**
Bioretention	Retrofit	$65,000	$120,000	$160,000	$410,000
	Redevelopment	$44,000	$90,000	$110,000	$200,000
Subsurface Infiltration	Retrofit	$65,000	$120,000	$160,000	$410,000
	Redevelopment	$44,000	$90,000	$110,000	$200,000
Green Roof	Retrofit	$430,000	$500,000*	$500,000	$570,000
	Redevelopment	$200,000	$250,000*	$250,000	$290,000
Porous Pavement	Retrofit	$65,000	$120,000	$160,000	$410,000
	Redevelopment	$44,000	$90,000	$110,000	$200,000
Street Trees	Retrofit	$18,000	$18,000	$18,000	$18,000
	Redevelopment	$15,000	$15,000	$15,000	$15,000

* Other cities have been experiencing costs in the range of $7-16 per square foot ($305,000 - $700,000 per impervious acre), with a typical range of $10-14 per square foot ($435,000 - $610,000 per impervious acre). A

recent green roof at Temple-Ambler campus was approximately $11 per square foot ($480,000 per impervious acre). The least expensive green roofs in Chicago, which has the largest-scale program in the U.S., are on the order of $6-7 per square foot ($285,000 per impervious acre), and this may be a reasonable estimate of what can be achieved in the future with a large-scale program in Philadelphia.

Learning Curve Assumptions

Over the long term, the cost of low impact development techniques is expected to decline for a number of reasons. A list of estimated long-term reduced construction costs in shown in Table 2.3.1-5 and summary statistics are shown in Table 2.3.1-6. The reductions shown in this table are credited to improvements in site layouts, a reduction in the cost for materials, reduction in design costs, and reductions in perceived risk as low impact development becomes the standard way of doing business.

Better Site Design: Site designers are required to comply with Philadelphia's stormwater regulations today. However, design features needed to comply are often added as an afterthought, after the site layout has been determined. Designs are very dense and do not leave open space for stormwater management (or resident enjoyment). This forces stormwater management features into underground, infrastructure-intensive facilities. Over time, local engineers will adopt better site design techniques. In the estimates in Table 2.3.1-5, it is assumed that impervious area on each site is reduced by 20% compared to the actual designs submitted in recent years. A 20% reduction is reasonable; the Philadelphia stormwater regulations provide an incentive for a 20% reduction, and there is a precedent for this level of reduction in surrounding states.

Reductions in Material Cost: As low impact development techniques such as porous pavement and green roofs become the standard way of doing business, materials needed to build them will no longer be considered specialty materials. For example, the estimates in Table 2.3.1-5 assume that in the future porous pavement have the same unit cost as traditional pavement today.

Reductions in Design Cost: Because low impact development techniques are unfamiliar to many local engineers, design costs are currently high relative to total construction cost. In the Alternative Costing Tool, future design costs are assumed to be no more than a project of "typical complexity" on the ASCE engineering fee cost curve (discussed in more detail in ACT cost curve). This assumption does not affect the direct construction costs shown in Table 2.3.1-5.

Reductions in Perceived Risk: In the ACT, a relatively low contingency will be used for low impact development, assuming that contractors will perceive less risk over time as these techniques become the standard way of doing business. This assumption does not affect the direct construction costs shown in Table 2.3.1-5.

Table 2.3.1-5 Summary of Direct Construction Cost Estimates with Improved Development Practices and Economies of Scale in 2008 Dollars

Project Name	BMP Type	Cost Estimates ($/impervious acre)		Percent Reduction	
		Redevelopment	Retrofit	Redevelopment	Retrofit
Private (1)	Subsurface Infiltration	$110,000	$180,000	27%	24%
47th and Grays Ferry Traffic Triangle	Bioretention	$57,000	$64,000	20%	20%
Private (2)	Green Roof	$230,000	$460,000	20%	20%
Public (2)	Pervious Pavement	$66,000	$100,000	22%	22%
Private (3)	Subsurface Infiltration	$35,000	$63,000	20%	20%
Mill Creek Tree Trench	Subsurface Infiltration	$80,000	$100,000	19%	19%
Private (4a)	Green Roof	$160,000	$340,000	20%	20%
Private (4b)	Pervious Pavement	$120,000	$290,000	36%	27%
Private (5)	Subsurface Infiltration	$90,000	$130,000	20%	20%
Public (4)	Bioretention	$120,000	$160,000	20%	20%
Public (5)	Subsurface Infiltration	$160,000	$280,000	20%	20%
Curb Extension	Bioretention	$43,000	$52,000	20%	20%
Swale without Parking	Bioretention	$58,000	$74,000	20%	20%
Swale with Parking	Bioretention	$70,000	$80,000	20%	20%
Planter with parking	Bioretention	$100,000	$130,000	20%	20%
Planter without parking	Bioretention	$60,000	$79,000	20%	20%
Street Trees	street trees	$12,000	$15,000	20%	20%

The green roof cost estimate for improved development practices is based on the direct construction cost estimate with no improved practices/economies of scale.

Table 2.3.1-6 Summary Statistics of Direct Construction Cost Estimates with Improved Development Practices and Economies of Scale in 2008 Dollars

Control	Type	Minimum Cost ($ / impervious acre)	Median Cost ($ / impervious acre)	Mean Cost ($ / impervious acre)	Max Cost ($ / impervious acre)
Bioretention	Retrofit	$52,000	$100,000	$130,000	$290,000
	Redevelopment	$35,000	$80,000	$80,000	$160,000
Subsurface Infiltration	Retrofit	$52,000	$100,000	$130,000	$290,000
	Redevelopment	$35,000	$80,000	$80,000	$160,000
Green Roof	Retrofit	$340,000	$400,000	$400,000	$460,000
	Redevelopment	$160,000	$200,000	$200,000	$230,000
Porous Pavement	Retrofit	$52,000	$100,000	$130,000	$290,000
	Redevelopment	$35,000	$80,000	$80,000	$160,000
Street Trees	Retrofit	$15,000	$15,000	$15,000	$15,000
	Redevelopment	$12,000	$12,000	$12,000	$12,000

* Based on anecdotal information, resulting costs of approximately $6-9 per square foot ($260,000 - $395,000 per impervious acre) are in line with the experience of the large-scale program in Chicago.

Public-Sector Cost Sharing Assumptions

For some land use types, it is assumed that entities other than PWD assume a portion of the stormwater retrofit capital and O&M costs as follows:

- Schools (50% PWD, 50% other public entities)
- Park and recreation facilities (50% PWD, 50% other public entities)
- Other public lands - libraries, police, fire, health, etc. (50% PWD, 50% other public entities)
- Street trees - not part of green streets; this refers to street trees in the absence of other controls (50% PWD, 50% other public entities)
- Sidewalk replacement grant programs (50% PWD, 50% other public entities)
- Waterfront sewer separation (0% PWD, 100% other entities)
- Retrofit of vacant and abandoned lands (0% PWD, 100% other entities)
- Private lands affected by the stormwater ordinance and regulations (0% PWD, 100% other entities)

Operations & Maintenance Cost Analyses

Operations and maintenance (O&M) costs were summarized into five categories, Porous Pavement, Subsurface Vault, Green Roofs, Bioretention, and Street Trees, for the selected LID stormwater management plans. For each category O&M costs were broken down into required operations and maintenance activities as described in the Philadelphia Stormwater Management Guidance Manual. Operations and maintenance activities, length and frequency were also estimated. The operations and maintenance labor costs associated with each LID design were determined from union contract agreements with the city of Philadelphia. The operations and maintenance costs were marked up to cover the costs associated with overhead & profit, estimated at 25%. The labor rates that were used in the analysis are shown in Table

2.3.1-7. The equipment costs utilized in the analysis are presented in Table 2.3.1-8. All equipment costs are from RS Means Costworks 2008. Materials costs were assumed to be the 10% of the median marginal redevelopment cost (see Table 2.3.1-6) distributed over 25 years.

Table 2.3.1-7 Labor Rates

General Description	Class	Basic Hourly Rate	Fringe Benefits
Truck Driver	Journeyman Class II	$22.60	$11.37
Truck Driver	Journeyman Class III	$22.85	$11.37
Landscape Laborer	Class I	$17.13	$16.87
Landscape Laborer	Class II	$17.88	$16.87

Table 2.3.1-8 Equipment Costs

General Description	Units	Unit Cost
Rent Vacuum Truck, hazardous materials, 5000 gallons	per day	$335.00
Rented sewer/catch basin vacuum, 14 cy, 1500 gallon	per day	$485.00
Truck, pickup, 3/4 ton, 2 wheel drive	per day	$80.50

The O&M activity and schedule associated with porous pavement are included in Table 2.3.1-9.

Table 2.3.1-9 Porous Pavement O&M Activities

Activity	Schedule	Visits Per Year Per Impervious Acre	Hours Per Visit Per Impervious Acre	Total Hours Per Year per Impervious Acre
Vacuum porous asphalt or concrete surface with commercial cleaning unit (Pavement washing systems and compressed air units are not recommended)	Twice per Year	2	4	8
Clean out inlet structures within or draining to the subsurface bedding beneath porous surface	Twice per Year	2	4	8
Maintain records of all Inspections and maintenance activity	Ongoing	1	1	1

The O&M activity and schedule associated with subsurface infiltration are included in Table 2.3.1-10.

Table 2.3.1-10 Subsurface Infiltration O&M Activities

Activity	Schedule	Visits Per Year Per Impervious Acre	Hours Per Visit Per Impervious Acre	Total Hours Per Year per Impervious Acre
Regularly clean out gutters and catch basins to reduce sediment load to infiltration system. Clean intermediate sump boxes, replace filters, and otherwise clean pretreatment areas in directly connected systems	As needed	3	5	15
Inspect and clean as needed all components of and connections to subsurface infiltration systems	Twice per Year	2	3	6
Evaluate the drain-down town of the subsurface infiltration system to ensure the drain-down time of 24-72 hours	Twice per Year	2	1	2
Maintain records of all inspections and maintenance	Ongoing	1	1	1

The O&M activity and schedule associated with green roofs are included in Table 2.3.1-11.

Table 2.3.1-11 Green Roof O&M Activities

Activity	Schedule	Visits Per Year Per Impervious Acre	Hours Per Visit Per Impervious Acre	Total Hours Per Year per Impervious Acre
Roof drains should be cleared when soil substrate, vegetation, debris or other materials clog the drain inlet. Sources of sediment and debris may be identified and corrected	As needed	2	3	6
Plant material should be maintained to provide 90% plant cover. Weeding should be manual with no herbicides or pesticides used. Weeds should be removed regularly	As needed	2	8	16
Irrigation can be accomplished either through hand watering or automatic sprinkler system if necessary during the establishment period.	As needed	5	1	5
Growing medium should be inspected for evidence of erosion from wind or water. If erosion channels are evident, they can be stabilized with additional growth medium similar to the original material.	Quarterly	4	3	12
Inspect drain inlet pipe and containment system	Annually	1	4	4
Test growing medium for soluble nitrogen content. Fertilize as needed	Annually	1	1	1

Activity	Schedule	Visits Per Year Per Impervious Acre	Hours Per Visit Per Impervious Acre	Total Hours Per Year per Impervious Acre
Maintain a record of all inspections and maintenance activity	Ongoing	1	1	1

The O&M activity and schedule associated with bioretention are included in Table 2.3.1-12.

Table 2.3.1-12 Bioretention O&M Activities

Activity	Schedule	Visits Per Year Per Impervious Acre	Hours Per Visit Per Impervious Acre	Total Hours Per Year per Impervious Acre
Remulch void areas	As needed	1	0.5	0.5
Treat diseased trees and shrubs	As needed	1	0.5	0.5
Keep overflow free and clear of leaves	As needed	3	0.5	1.5
Inspect soil and repair eroded areas	Monthly	12	0.5	6
Remove litter and debris	Monthly	12	0.5	6
Clear leaves and debris from overflow	Monthly	12	0.5	6
Inspect trees and shrubs to evaluate health, replace if necessary	Twice per Year	2	1	2
Inspect underdrain cleanout	Twice per Year	2	2	4
Verify drained out time of system	Twice per Year	2	1	2
Add additional mulch	Annually	1	1	1
Inspect for sediment buildup, erosion, vegetative conditions, etc.	Annually	1	1	1
Maintain records of all inspections and maintenance activity	Ongoing	1	1	1

The O&M activity and schedule associated with street trees are included in Table 2.3.1-13.

Table 2.3.1-13 Street Trees O&M Activities

Activity	Schedule	Visits Per Year Per Impervious Acre	Hours Per Visit Per Impervious Acre	Total Hours Per Year per Impervious Acre
Treat diseased trees and shrubs	As needed	3	3	9
Remove litter and debris	Monthly	12	1	12
Inspect trees and shrubs to evaluate health	Twice per Year	2	3	6

A summary of annual operation and maintenance costs are listed in Table 2.3.1-14.

Table 2.3.1-14 Annual Operation & Maintenance Costs [ENRCCI 8141; RSMEAN 115.2]

Control	Annual O&M Costs ($/imp. Acre/yr)
Porous Pavement	$2,400
Subsurface Infiltration	$2,900
Green Roof	$4,000
Bioretention	$3,100
Street Tree	$1,800

<u>Personnel Estimates for Green Streets</u>

Based on the assumptions presented in the operations and maintenance descriptions, each acre of impervious drainage area requires approximately 24 hours of labor per year. Street lengths and widths vary widely, but on average the street and two sidewalks on one block make up approximately 0.5 acres of impervious surfaces. Assuming each employee averages 1600 hours of task work per year (excluding vacation, training), the following estimates are reached:

- 12 hours of labor are required per block of green streets per year.
- A 2-person crew can visit 266 blocks once per year, 133 blocks twice per year, or 66 blocks four times per year. In all cases, the crew would visit approximately 1 block per day.
- Streets and sidewalks make up 10,774 acres in the City-wide combined areas. A program to mitigate a portion of these through green infrastructure would result in the following estimated personnel requirements:
  - 10% (1,077 ac): 17 employees
  - 25% (2,693 ac): 41 employees
  - 50% (5,387 ac): 81 employees
  - 75% (8,080 ac): 122 employees
  - 100% (10,774 ac): 162 employees

Life Cycle Assumptions

During the analysis a literature study was conducted on lifespan assumptions for each of the five categories of LID stormwater management designs and results can be found in Table 2.3.1-15.

Table 2.3.1-15 Life Cycle Assumptions

Control	Lifespan
Bioretention	25[1]
Green Roofs	25-30[1,2]
Subsurface Infiltration	25[1]
Porous Pavement	25[1]
Street Trees	25-40[1,2]

[1]- EconNorthwest, 2007

[2]- internal communications

Based on these results, green infrastructure is typically overhauled or replaced every 25-40 years. Based on this and assuming a comprehensive O&M program, it appears reasonable to assume that an overhaul will not be performed until the end of the LTCPU planning horizon of 40 years. However, replacement costs are discussed in the following section in case they are needed.

Replacement Costs

Replacement cost is determined by assuming that most traditional stormwater infrastructure components do not need replacing based on PWDs existing infrastructure life cycle. Traditional components include inlets, manholes, diversion structures, and pipes and related materials (i.e. gravel and fill). Most green infrastructure components have a shorter lifecycle and may need to be replaced more often. These costs are weighted with a percentage to determine the extent of the components cost to the replacement for a given LID technique. Trees and plants have definite lifecycles and are assumed to be replaced completely if used in a given technique. Components such as gravel and soil are assumed to be replaced to a lesser extent, because their functionality is longer lasting. Other specific components, such as porous pavement and green roof components are assumed to be replaced completely. Table 2.3.1-16 is an example of how replacement costs are determined

Table 2.3.1-16 Example Specific Material Replacement Costs

Material	Units	Quantity	Unit Cost	Total Cost	Replacement Cost % Of Original	Replacement Cost
Deciduous Tree	total	6	$385.00	$2,310.00	100%	$2,310
Bark Mulch	sq. yd	10.7	$6.15	$65.56	100%	$66
Geotextile Separation Fabric	sq. yd	10.7	$1.95	$20.80	100%	$21
Planting Backfill Mixture	cu. Yd	9.5	$29.50	$279.70	100%	$280
Hauling Backfill Mixture to Site	cu. Yd	9.5	$30.55	$289.66	100%	$290
Excavation	cu. Yd	10.7	$2.75	$29.31	100%	$29
Porous Pavement						
Pervious Asphalt	sq. yd	652	$10.45	$6,817.16	100%	$6,817
AASHTO No. 57 Choker	cu. yd	18	$37.69	$682.94	50%	$341
AASHTO No. 2 Coarse Aggregate	sq. yd	652	$9.55	$6,230.04	50%	$3,115
Non-Woven Geotextile	sq. yd	784	$1.95	$1,529.50	50%	$765
Excavation	cu. Yd	218	$2.75	$598.84	50%	$299
Hauling Asphalt Materials to Site	cu. yd	163	$30.55	$4,985.76	100%	$4,986
Hauling for excavated soil	cu. Yd	218	$30.55	$6,656.17	50%	$3,328
Pipe Trench Under Porous Pavement						
24" Perf. Pipes	ft	774	$62.00	$47,988.00	0%	$0
24" LF HDPE Header	ft	22	$62.00	$1,364.00	0%	$0
Gravel	sq. yd	95	$15.40	$1,467.56	0%	$0
AASHTO No. 2 Coarse Aggregate	sq yd	91.2	$9.55	$871.06	0%	$0
Hauling Aggregate to Site	cu yd	91.2	$30.55	$2,786.47	0%	$0
Inlet Structure						
Reinforced Concrete Inlet Box	total	1	$4,800.00	$4,800.00	0%	$0

Material	Units	Quantity	Unit Cost	Total Cost	Replacement Cost % Of Original	Replacement Cost
Excavation volume	cu. Yd	4.7	$2.75	$13.03	0%	$0
Hauling for excavated soil	cu. yd	4.7	$30.55	$144.83	0%	$0
Footing	each	1	$27.78	$27.78	0%	$0
Reinforced Concrete Top Unit	total	1	$440.00	$440.00	0%	$0
Heavy Duty Inlet Frame	total	1	$1,125.00	$1,125.00	0%	$0
Coarse Aggregate Size No. 57	cu yd	0.67	$37.69	$25.13	0%	$0
Hauling Aggregate to Site	cu yd	0.67	$30.55	$20.37	0%	$0

The summary of estimated replacement costs for specific control techniques is summarized in Table 2.3.1-17.

Table 2.3.1-17 Replacement costs

Control	Median Cost ($ / Impervious Acre)
Bioretention	$35,000
Subsurface Infiltration	$35,000
Green Roof	$220,000
Porous Pavement	$35,000
Street Trees	$12,000

Literature Review

A literature review of documents referencing stormwater management construction cost information utilizing low impact development was performed. The estimates were then updated to account for changes in cost due to inflation and location. Cost estimates were adjusted for inflation using the ENR cost index and adjusted for location using RS Means location factors. Stormwater management practices are listed in Table 2.3.1-18. This table lists the redevelopment construction cost ranges from CWP, 2007. The retrofit construction cost ranges are listed within Table 2.3.1-19. The construction cost range for retrofits are broken down into three stormwater management practices pond retrofit, new storage retrofit, and urban on-site retrofit. Urban on-site retrofit is the most similar to the type of development we expect in Philadelphia.

Table 2.3.1-18 Construction Cost Ranges by Category for New Development

Stormwater Practice	Min ($/impervious acre)	Median ($/impervious acre)	Max ($/impervious acre)
Constructed Wetlands	$2,100.00	$3,000.00	$10,000.00
Extended Detention	$2,300.00	$4,000.00	$7,800.00
Wet Ponds	$3,200.00	$8,700.00	$30,000.00
Water Quality Swales	$11,000.00	$19,000.00	$38,000.00
Bioretention	$21,000.00	$27,000.00	$44,000.00
Infiltration	$21,000.00	$27,000.00	$44,000.00
Residential Green Rooftop	$11,000.00	$28,000.00	$51,000.00
Filtering Practices	$19,000.00	$60,000.00	$83,000.00
Non-Residential Green Roof	$23,000.00	$95,000.00	$1,100,000.00

Table 2.3.1-19 Construction Cost Range by Category for Retrofit

Stormwater Practice	Min ($/impervious acre)	Median ($/impervious acre)	Max ($/impervious acre)
Pond Retrofit	$3,800	$12,000	$39,000
New Storage Retrofit	$9,400	$20,000	$34,000
Urban On-site Retrofit	$61,000	$92,000	$160,000

Additional & Validation Cost Estimates

The continued implementation of additional green infrastructure and LID stormwater features in Philadelphia has allowed for the addition of more projects and plans, which can be used to validate the original cost estimates created in the beginning of this memo. Additional estimates include an on street retrofit and a compilation of the draft PWD standard details for stormwater management.

An example project is a street level tree planter and subsurface infiltration system. The construction cost estimate for the project was determined to be $250,000 per impervious acre. The construction cost estimate for the project is within the maximum range of the retrofit cost estimates in Table 2.3.1-4.

PWD has drafted several standard details for street retrofits of green infrastructure. These include on street planters, porous pavement and other types of street retrofits to manage stormwater. Table 2.3.1-20 is a summary of the construction cost estimates for the standard detail plans with a summary of the average and median of these estimates.

Table 2.3.1-20: Construction Cost Estimates of Draft PWD Standard Details

Standard Detail Description	Retrofit Cost ($ / Impervious Acre)
Curb Extention - Apex Inlet	$162,000
Curb Extention - End Inlet	$168,000
Mid-Block Curb Extention	$116,000
Infiltration Planter	$138,000
Porous Pavement	$151,000
Tree Planter	$79,000
Tree Planter - No Tree Grate	$38,000
Tree Planter Direct Opening	$158,000
Tree Planter Direct Opening - No Tree Grate	$116,000
Tree Planter w/additional storage	$128,000
Tree Planter w/additional storage - No Tree Grate	$86,000
Tree Trench	$108,000
Tree Trench - No Tree Grates	$82,000
Average	$118,000
Median	$116,000

2.3.2 Municipal Inflow and Infiltration Reduction

The ACT allows for planning level estimation of rehabilitation costs of municipal sewer infrastructure in an effort to reduce inflow and infiltration (I/I). Calculations for estimating cost of these rehabilitation alternatives are structured into the ACT with the user providing any additional costs for O&M of a given alternative. The ACT includes rehabilitation costs for the following municipal I/I reduction measures. Tables 2.3.2-1 and 2.3.2-2 summarize the Municipal I/I unit costs within the ACT.

Pipe Lining

The ACT determines pipe lining costs based on the following user inputs:

- Type of lining (cured-in-place or user defined)
- Pipe diameter (8-inch through 48-inch; see Table 2.3.2-1 for unit costs)
- Pipe length (in linear feet)

The ACT calculates the cost of pipe lining per linear foot of pipe installed. A default unit cost per linear foot, varying by pipe diameter, is provided in the ACT. The user has the ability to change this unit cost, but must provide acceptable documentation of the basis of cost.

Manhole Rehabilitation

The ACT assumes that manhole rehabilitation includes sealing manholes and installing water tight frames and covers. The user inputs the number of manholes to be rehabbed, which are multiplied by a default unit cost value ($2500 per manhole) to determine the total manhole rehabilitation cost. The user has the ability to change this unit cost, but must provide documentation of the basis of cost.

Catch Basin Rehabilitation

Catch basin rehabilitation includes sealing-off the connection from a catch basin to a sanitary or combined sewer. Construction cost estimates are based upon the input of number of catch basins or storm inlets to be removed, with a default unit cost per rehabilitation to be applied ($600 per catch basin). This unit cost does not include the new pipe and surface restoration required to reroute the catch basin. These items can be calculated separately in the open cut pipe section of the ACT. The ACT unit cost is configured for this default type of catch basin rehabilitation; the user has the ability to change this unit cost, but must provide documentation of the basis of cost.

Service Lateral Spot Repair

The ACT estimates the cost spot repair cost of municipal service laterals. Existing laterals would be reconnected with street wyes replaced. Construction cost estimates are based upon the input of linear feet of laterals to be repaired, with a default unit cost to be applied ($350 per LF repaired). The unit cost value in the ACT is configured for this default type of service lateral repair. The user has the ability to change this unit cost, but must provide acceptable documentation of the basis of cost.

Table 2.3.2-1 Municipal Pipe Lining Unit Costs in ACT [ENRCCI 8551; RSMEAN 100]

Diameter (in)	CIPP Pipe Lining Unit Cost ($/LF)
8	$137
10	$159
12	$199
15	$258
18	$280
21	$318
24	$395
27	$476
30	$572
36	$706
42	$846
48	$985

Table 2.3.2-2 Municipal Pipe Lining Unit Costs in ACT [ENRCCI 8551; RSMEAN 100]

Technology	Default Unit Cost	Units	User Defined Unit Cost Option?	O&M Cost Estimate
Manhole Rehabilitation	$2500	Per manhole	Yes	User to input a lump sum value for all Municipal I/I reduction alternatives where applicable.
Catch Basin Rehabilitation	$600	Per catch basin	Yes	
Service Lateral Pipe Repair	$350	Per LF of lateral repair	Yes	

2.3.3 Private Inflow and Infiltration Removal

As for municipal collection sewer rehabilitation, the user may choose to evaluate the cost-effectiveness of wet-weather flow reduction by reducing I/I from private sources. Calculations for estimating cost of these removal alternatives are structured into the ACT with the user providing any additional costs for O&M of a given alternative. The ACT includes rehabilitation costs for the following private I/I reduction measures. Table 2.3.3-1 summarizes the Private I/I unit costs within the ACT.

Service Lateral Lining

This work includes spot repairs to the service lateral from a house or other building to the sewer pipe. Construction cost estimates are based upon the input of the combined length (in LF) of service laterals which require lining, with a default unit cost per LF to be applied ($120 per LF). The unit cost value in the ACT is configured for this default type of service lateral repair. The user has the ability to change this unit cost, but must provide acceptable documentation of the basis of cost.

Sump Pump Discharge Rerouting

For existing homes or other establishments with a sump pump that discharges flow from footing drains (and possibly roof leaders) into the sanitary system, this work includes constructing a hard pipe from the sump pump through the basement wall to an adequate discharge location (work will conform to applicable plumbing codes and other municipal regulations). The user will input the number of homes or other establishments for which this work will be performed, with a default unit cost per home to route sump pump discharge below grade to storm system ($4,700 per rerouting). The user has the ability to change this unit cost, but must provide acceptable documentation of the basis of cost.

Footing Drain Disconnection

For existing homes or other establishments where footing drains (and possibly roof leaders) are tied into the interior sanitary plumbing, this work includes removing and replacing portions of the basement floor as needed to separate the interior plumbing so that footing drains are routed to new sump. This work also includes constructing a hard pipe form the sump pump through the basement wall to a curb drain system, or existing catch basin. The unit cost includes the homeowner’s share of the curb drain system cost. The user will input the number of homes or other establishments for which this work will be performed, with a default unit cost applied ($8,000 per disconnection). The user has the ability to change this unit cost, but must provide acceptable documentation of the basis of cost.

Exterior Roof Leader Disconnect

For buildings where roof leaders are tied into the footing drains and make their way to the sanitary lateral, this work includes disconnecting (cutting) the down pipe and providing a discharge to the ground for homes or other establishments with an adequate discharge location and where local codes permit. The user will need to specify the estimated number of roof leaders to be disconnected, as well as distinguish the type of roof leader disconnection. The user also needs to specify whether will be performed by the homeowner or municipality. The user has the ability to change this unit cost, but must provide acceptable documentation of the basis of cost.

Private Drain Disconnection

This work includes sealing the connection from a driveway drain or other private storm drain to a sanitary sewer. It also includes re-routing the drain line to an existing storm outlet or constructing a new drain outlet. The user will need to specify the estimated number of drains to remove and the total length of new storm sewer required. Based on these assumptions, a default unit cost is applied ($600 per disconnection). The user has the ability to change this unit cost, but must provide acceptable documentation of the basis of cost.

Table 2.3.3-1 Private I/I Removal Unit Costs [ENRCCI 8551; RSMEAN 100]

Technology	Default Unit Cost	Units	User Defined Unit Cost Option?	O&M Cost Estimate
Service Lateral Lining	$120	Per LF of lateral lining	Yes	User to input a lump sum value for all Private I/I reduction alternatives where applicable.
Sump Pump Discharge Rerouting	$4700	Per sump pump rerouting	Yes	
Footing Drain Disconnection	$8000	Per disconnection	Yes	
Exterior Roof Leader Disconnection	$20	Per homeowner disconnection	Yes	
	$70	Per municipality disconnection		
Private Drain Disconnection	$600	Per drain disconnection	Yes	

2.3.4 Sewer Separation

Sewer separation construction costs were based on three components: new sanitary sewer construction costs, sewer lateral construction costs, and streetscape reconstruction cost. Unit cost data is based on recent construction bids received by PWD and are considered construction costs with overhead, profit and indirect costs included. Data is summarized in Table 2.3.4.1.

Table 2.3.4.1 Sewer Separation Component Costs [ENRCCI: 8551; RSMeans: 115.2]

Component	Unit Cost	Units
New Sanitary Sewers	$1,700,000	$/mile
Lateral from new sewer to property	$6,000	$/lateral
Interior plumbing modifications - Residential	$6,000	$/lateral
Interior plumbing modifications - Non-Residential	$20,000	$/lateral
Concrete Street Base	$6	$/square foot
Asphalt Paving	$3	$/square foot
Concrete Sidewalk	$7	$/square foot
Concrete Curb	$26	$/foot

2.3.5 Open Cut Pipe

The ACT performs cost estimation for new conveyance. Open cut installation of gravity sewer pipe is included as a technology alternative in the ACT. Construction cost estimates for open cut pipe in the ACT require the following user input values:

- Pipe cross-section, either circular or a box section;
- The nominal size of the cross-section in terms of diameter for circular pipe or a specified box size
  - Circular pipe nominal diameters range between six and 108 inches. In addition to the nominal diameter, the pipe material must be chosen by the user from a menu list (PVC, Class II, III, IV, and V concrete pipe, or ductile iron).
  - Box culverts range in size between four foot by eight foot and 12 foot by 12 foot. The orientation of the box is also an input value, either wide or tall dependant on the orientation of the longer side of the box. A "wide" box would have a longer horizontal orientation, while a "tall" box would have a longer vertical orientation. The orientation designation of a square box will have no effect on unit cost.
- The proposed length of the pipe in the street as well as the length of the pipe out of the street, both in linear feet.
- The average depth to the pipe invert in vertical feet. The maximum depth to invert is 24 vertical feet.
- The volume percentage of rock excavation to total excavation.
- The pavement type. The tool has default values for eight inch bituminous pavement or 11.5 inch pavement. There is also an option of a user-defined pavement type in which the user must input the pavement thickness and the street restoration unit cost in dollars per square yard.
- The user must define the street restoration efforts, choosing between two configurations: a partial street opening which equals the trench width plus one foot on either side of the trench, or a complete restoration equal to the entire street width. The street width is a user input.
- The number of manholes and their typical diameter.
- The number of utility crossings encountered in the street.
- The number of service laterals to be installed or restored.
- Any sidewalk or curb restoration anticipated, and several user inputs for this type of restoration if it is needed.
- User defined costs including: railroad costs, stream crossing costs, additional force main costs, and miscellaneous.
- Finally, several open pipe construction conditions are estimated as a percentage of total construction cost. These conditions include dewatering requirements, flow maintenance requirements, and traffic maintenance requirements.

The total cost estimate for open cut is determined by summing numerous direct unit construction costs (e.g. pipe material costs, equipment and labor costs for soil excavation).

Open Cut cost data is considered to be direct construction costs excluding overhead and profit, and indirect costs, and are summarized in Tables 2.3.5-1 through 2.3.5-14. The base index values for all open cut pipe cost data is ENRCCI 7312 and RS Means 92.9.

Figure 2.3.5-1 displays the open cut pipe cost estimating schematic which outlines the methodology followed in the ACT.

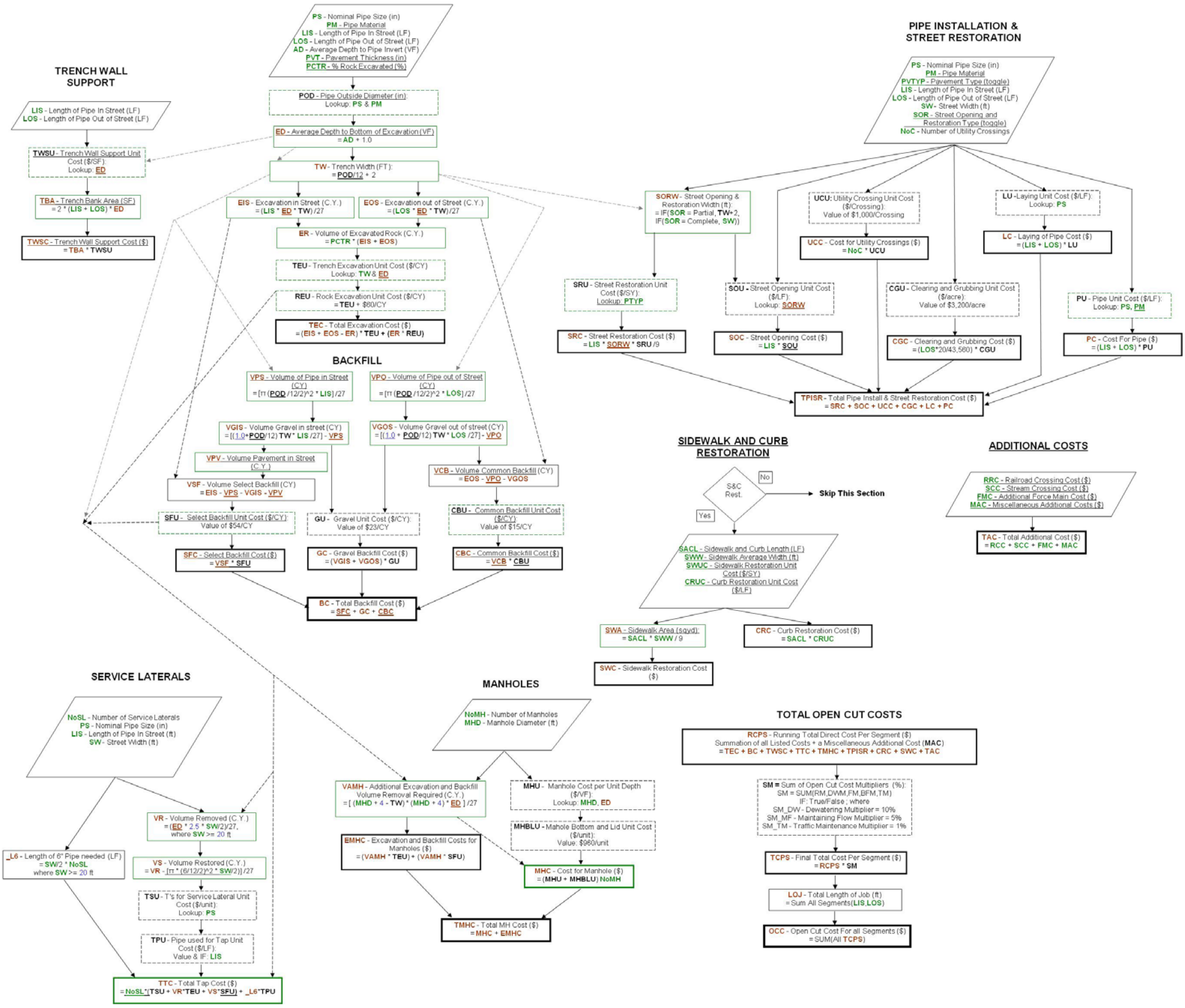


Figure 2.3.5-1 Open Cut Pipe Logic and Flow Diagram

Table 2.3.5-1 Pipe Material Unit Cost Values used in the ACT ($/LF) [ENRCCI 7312; RS MEANS 92.9]

Pipe Diameter (in)	Pipe Classification					
	CL II	CL III	CL IV	CL V	PVC	Ductile Iron
6	-	-	-	-	-	14.6
8	-	-	-	3.3	3.3	16.15
10	-	-	-	5.6	5.6	22
12	-	-	13	14	7.7	26.5
14	-	-	-	-	-	34.5
15	-	-	15	16	10.9	-
16	-	-	-	-	-	37.5
18	-	17	18	20	13.3	47
20	-	-	-	-	-	55
21	-	21	23	28	17.5	-
24	-	27	29	33	23.9	70.5
27	30	31	34	44	24.5	-
30	37	37	41	51	41.4	-
33	42	44	51	62	-	-
36	49	51	61	74	62.6	-
42	66	68	78	101	82.8	-
48	80	85	100	126	109.3	-
54	97	101	123	166	118.9	-
60	123	132	156	184	-	-
66	149	156	190	218	-	-
72	176	175	226	252	-	-
78	209	224	269	306	-	-
84	258	276	330	369	-	-
90	289	308	365	404	-	-
96	320	337	400	442	-	-
102	351	372	444	482	-	-
108	359	409	491	526	-	-

Table 2.3.5-2 Pipe Laying Unit Cost used in ACT [ENRCCI 7312; RS MEANS 92.9]

Pipe Diameter (in)	Cost ($/LF)
0	0.00
6	6.70
8	6.70
10	6.70
12	7.70
15	8.80
18	9.90
21	12.30
24	13.30
27	15.40
30	17.60
33	19.70
36	20.70
42	25.50
48	27.60
54	28.70
60	32.90
66	35.10
72	37.20
78	40.00
84	42.00
90	45.00
96	47.00
102	49.00
108	52.00

Table 2.3.5-3 Box Culvert Unit Costs [ENRCCI 7312; RS MEANS 92.9]

Box Culvert Size	Material Cost ($/LF)	Laying Cost ($/LF)
8'x4'	$395	$23.00
8'x6'	$435	$27.00
8'x8'	$474	$31.00
10'x6'	$553	$30.00
10'x8'	$632	$35.00
10'x10'	$711	$42.00
12'x4'	$632	$27.00
12'x6'	$751	$33.00
12'x8'	$830	$40.00
12'x10'	$909	$49.00
12'x12'	$988	$60.00

Note: Reinforced Concrete Box Sewer per ASTM C 1433

Table 2.3.5-4 Trench Width Values used in ACT [ENRCCI 7312; RS MEANS 92.9]

Pipe Diameter (in)	Range of Trench Depth		
	0' to 10'	11' to 16'	17' to 25'
6	2.5	2.5	2.5
8	2.5	2.5	3
10	2.5	2.5	3
12	2.5	2.5	3
15	3	3.5	3.5
18	3.5	4	4
21	4	4.5	4.5
24	4	4.5	4.5
27	4.5	5	5
30	4.5	5	5
33	5	5.5	5.5
36	5.5	6	6
42	6.5	6.5	6.5
48	7	7	7
54	7.5	7.5	7.5
60	8.5	8.5	8.5
66	9	9	9
72	9.5	9.5	9.5
78	10	10	10
84	10.5	10.5	10.5
90	11	11	11
96	12	12	12
102	12.5	12.5	12.5
108	13	13	13

Table 2.3.5-5 Trench Wall Support Unit Cost Used in ACT [ENRCCI 7312; RS MEANS 92.9]

Excavation Depth (ft)	Unit Cost ($/Bank SF)
5	0.06
6	0.06
7	0.06
8	0.06
9	0.06
10	0.06
11	0.06
12	0.06
13	0.06
14	0.06
15	0.06
16	33
17	33
18	33
19	33
20	33
21	33
22	33
23	33
24	33
25	33

Table 2.3.5-6 Trench Excavation Unit Costs used in the ACT ($/CY) [ENRCCI 7312; RS MEANS 92.9]

Depth (ft)	Trench Width (ft)																
	0	2.5	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
5	0	9	9	-	-	-	-	-	-	-	-	-	-	-	-	-	-
6	0	12	10	9	9	8	-	-	-	-	-	-	-	-	-	-	-
7	0	14	13	12	10	10	9	9	8	8	8	7	7	7	7	6	6
8	0	16	15	13	12	12	10	10	10	9	9	9	8	8	8	8	8
9	0	18	16	14	13	13	12	12	12	11	11	10	10	10	10	10	9
10	0	20	18	16	14	14	13	13	12	11	11	11	10	10	10	10	9
11	0	23	20	17	16	15	14	13	13	12	11	11	11	10	10	10	9
12	0	25	23	19	17	16	15	14	14	13	12	12	11	11	10	10	10
13	0	27	25	21	19	17	16	15	14	13	13	12	12	11	11	10	10
14	0	29	27	24	20	18	17	16	15	14	13	13	12	12	11	11	11
15	0	30	29	25	23	20	18	17	16	15	15	14	13	13	12	12	12
16	0	33	30	27	24	21	20	18	17	16	16	15	14	14	13	13	12
17	0	36	32	28	26	24	21	20	18	18	17	16	15	15	14	14	13
18	0	38	34	29	27	25	23	21	19	19	18	17	16	16	15	15	14
19	0	40	37	30	28	26	24	23	21	20	19	18	18	17	17	16	16
20	0	42	38	33	30	27	26	24	23	22	21	20	19	19	18	17	17
21	0	44	39	36	31	29	27	25	24	23	22	21	20	19	19	18	18
22	0	45	42	37	33	30	28	26	25	24	23	22	21	20	20	19	18
23	0	47	44	39	34	31	29	27	26	24	23	22	22	21	20	20	19
24	0	50	45	40	37	33	30	29	27	26	25	24	23	22	21	21	20
25	0	52	47	42	38	34	32	30	28	27	26	25	24	23	22	22	21

Table 2.3.5-7 Street Opening Unit Costs used in the ACT [ENRCCI 7312; RS MEANS 92.9]

Opening Width (ft)	Cost ($/LF)
2	0
4.5	3.3
5	4.4
5.5	4.4
6	5.6
6.5	6.7
7	6.7
7.5	7.7
8	8.8
8.5	8.8
9	9.9
10	11.0
11	12.1
12	13.2
13	14.3
14	15.4
15	16.5
16	17.6

Table 2.3.5-8 Pipe Tap Unit Cost used in the ACT [ENRCCI 7312; RS MEANS 92.9]

Pipe Diameter (in.)	Cost ($/unit)
8	160
10	165
12	170
15	186
18	191
21	202
24	213
27	234
30	245
33	266
36	292
42	340
48	388

Table 2.3.5-9 Additional Pipe Tap Costs ($/LF) [ENRCCI 7312; RS MEANS 92.9]

In Street?	Cost ($/LF)	Comment
No	38	Under Grass
Yes	65	Under Pavement -granular backfill. For CDF use pipe sheet.

Table 2.3.5-10 Manhole Unit Costs used in ACT [ENRCCI 7312; RS MEANS 92.9]

Manhole Depth (ft.)	MH Diameter (ft.)									
	0	4*	5	6	7	8	9	10	11	12
5	0	$800	$1,500	-	-	-	-	-	-	-
10	0	$1,100	$2,100	$3,300	$3,700	$5,900	$6,500	$6,700	$9,800	$12,000
15	0	$1,500	$2,600	$4,300	$4,900	$7,500	$8,300	$8,500	$12,500	$15,400
20	0	$1,800	$3,100	$5,300	$6,000	$9,000	$10,100	$10,200	$15,100	$18,700
25	0	$2,100	$3,700	$6,200	$7,100	$10,600	$11,900	$11,900	$17,800	$22,100

* Note: The ACT has a four foot diameter manhole as the default manhole diameter suggestion

Table 2.3.5-11 Street Restoration Unit Cost used in ACT [ENRCCI 7312; RS MEANS 92.9]

Name	Total Thickness (in)	Cost ($/SY)	Description
8" Bit.	14	33	6" Stone, 6" Bit. Base, 2" Bit Surface
11.5" Phila. Spec.	17.5	43	Standard Philadelphia Street Section: 6" Stone, 8" Cement Base, 2" Bit. Base, 1.5" Bit Surface

Table 2.3.5-12 Curb and Sidewalk Restoration Unit Costs used in ACT [ENRCCI 7312; RS MEANS 92.9]

Restoration Type	Unit Cost	Description
Curb Restoration ($/LF)	$17	Typical 4” Concrete with 4” of Stone
Sidewalk Restoration ($/SY)	$30	

Table 2.3.5-13 Miscellaneous Installation and Restoration Costs Associated with Open Cut Pipe [ENRCCI 7312; RS MEANS 92.9]

Description	Units	Unit Cost
Select backfill unit cost	$/CY	54
Gravel Unit Cost	$/CY	23
Common Backfill Unit Cost	$/CY	15
Manhole Bottom and Lid Unit Cost	$/unit	960
Utility Crossing/Relocation Unit Cost	$/unit	1000
Clearing and Grubbing Unit Cost	$/acre	3200
Rock Excavation Unit Cost - in add to TEU	$/CY	60

Table 2.3.5-14 Miscellaneous Construction Cost Multipliers used in the ACT [ENRCCI 7312; RS MEANS 92.9]

Category	Added Cost
In Rock (Y/N)?	50.00%
Dewatering Required (Y/N)?	10.00%
Flow Maintenance Required (Y/N)?	5.00%
In Brownfields (Y/N)?	5.00%
Traffic Maintenance Required (Y/N)?	1.00%

Conveyance Pipe O&M Costs

Maintenance of open-cut and trenchless pipes are based upon the same data set, and the costs to maintain both conveyance means can be estimated in a similar manner. The reference for O&M of both is a 2003 Detroit Water and Sewer Department (DWSD) report titled *Wastewater Master Plan Volume 4: Capital Improvements Program*. This report analyzed operation and maintenance of the conveyance pipe in the DWSD system between 1992 and 1996, and developed target maintenance frequency equations for three most important maintenance issues: pipe cleaning, root intrusion removal, and TV inspections. The report also provided an audit of O&M costs and assigned a maintenance unit cost in dollars per linear foot of pipe for each of the three maintenance issues. These values were updated for time and location within the ACT using ENR CCI and RS Means index values respectively.

Similar to the pipe maintenance analysis, an additional analysis of O&M costs related to manhole cleaning was determined in the DWSD report. This value is reported in dollars per manhole per year.

An additional option for calculating O&M costs for conveyance pipe in the ACT is for the user to input their own unit costs. The default configuration is based on the same units used in the DWSD report. Table 2.3.5-15 contains open cut pipe O&M costs.

Table 2.3.5-15 Open Cut Pipe O&M Cost Data [ENRCCI 7312; RS MEANS 92.9]

Detroit Conduit O&M	$/LF-yr	4.00
Detroit Manhole O&M	$/MH-yr	2.60
Detroit O&M ENRCCI		6771.00
Detroit O&M Means		103.90

2.3.6 Pump Stations

For purposes of the ACT, all pump stations were assumed to be constructed as stand-alone structures − not part of a larger treatment or storage facility.

Construction cost estimates including overhead and profit, and indirect costs for three different pump station types were developed: custom built wet-well/dry well, submersible, and deep tunnel dewatering. Deep tunnel dewatering pump stations can be significantly deeper than typical pump stations and will be used to dewater CSO storage tunnels. Custom built wet-well/dry-well and submersible pump stations are typical wet weather pump types, and will be used for collection and interceptor transmission, pumping into and dewatering satellite treatment facilities, and pumping into and through treatment plants. Low, intermediate, and high cost curves were determined for custom built wet-well/dry well and submersible pump stations. The primary factor for selecting a cost curve range is total dynamic head (TDH). For the purposes of cost estimating in the ACT, high cost custom built wet-well/dry well pump stations generally have a TDH greater than 70 feet, whereas high cost submersible pump stations generally have a TDH greater than 50 feet. A secondary factor for selecting a cost curve range is standby power. For the purposes of cost estimating in the ACT, intermediate cost pump stations are generally shallower than high cost pump station and have standby power, whereas low cost pump stations are generally shallower and without standby power.

The ACT provides pump station cost estimates based on the following user inputs:

- Type of pump station including low, intermediate, and high cost range
- Required firm pumping capacity

In addition, the user has the option of adding user defined cost multipliers for pump station facility components which could add to typical pump station costs such as: bar screens, maintenance dewatering pumps, grit removal provisions, odor control, variable speed motors, and special building requirements for motors and electrical controls.

The custom built wet-well/dry-well and submersible pump station cost estimating curves were based on the 2006 text book reference *Pumping Station Design (Third Edition).* The deep tunnel dewatering pump station cost curve was based on a collection of costs for existing and proposed large capacity deep tunnel dewatering pump stations in the United Stated. These costs were in the form of bids and basis of design costs, and a power trendline was developed through the cost data points.

Pump station construction cost data is included in Figure 2.3.6-1.

The design curves for pump stations were developed from Jones et al. *Pumping Station Design (3rd Ed.).* Cost estimation curves from this publication were developed from a range of pump station installations around the US, and classified as either a custom built wet-well/dry-well facilities (Figure 2.3.6-1) or submersible facilities (Figure 2.3.6-2).

From each of these classifications, a low, intermediate, and high cost curve was developed to encapsulate the range of costs which can be encountered in different pump station applications.

The selection of which curve to use is dependant primarily on depth and secondarily on whether standby power is needed at the station. Table 2.3.6-1 is a matrix for selecting low, intermediate or high cost curves. These curves represent construction costs including contractor's overhead and profit and indirect costs.

In addition, a cost estimation curve was provided for deep tunnel dewatering pump stations (Figure 2.3.6-3). This curve was developed from project cost data of installed dewatering pump stations. (Note: Figure 2.3.6-3 also displays two curves along with equations, developed via the *Pumping Station Design (3rd Ed.)* method. These curves are used for comparison; the ACT only contains one cost estimation curve for deep tunnel dewatering).

Table 2.3.6-1 Cost Curve Selection Matrix for Pump Stations
[ENRCCI 8551; RS MEANS 100]

Cost Curve	Depth[1]	Standby Power[2]
High	Deep	Yes or No
Intermediate	Shallow	Yes
Low	Shallow	No

[1] Deep Depths: Submersible (>50' TDH)
Custom-Built Wet Well-Dry Well (>70' TDH)
[2] Standby Power: Back-up generators or dual electrical supply

For custom-built wet well/dry well pumping stations, the selected curves are as follows:

$$\text{High Cost Curve: } y = 803{,}151x^{0.9002}$$
$$\text{Intermediate Cost Curve: } y = 385{,}002x^{0.8941}$$
$$\text{Low Cost Curve: } y = 182{,}255x^{0.8914}$$

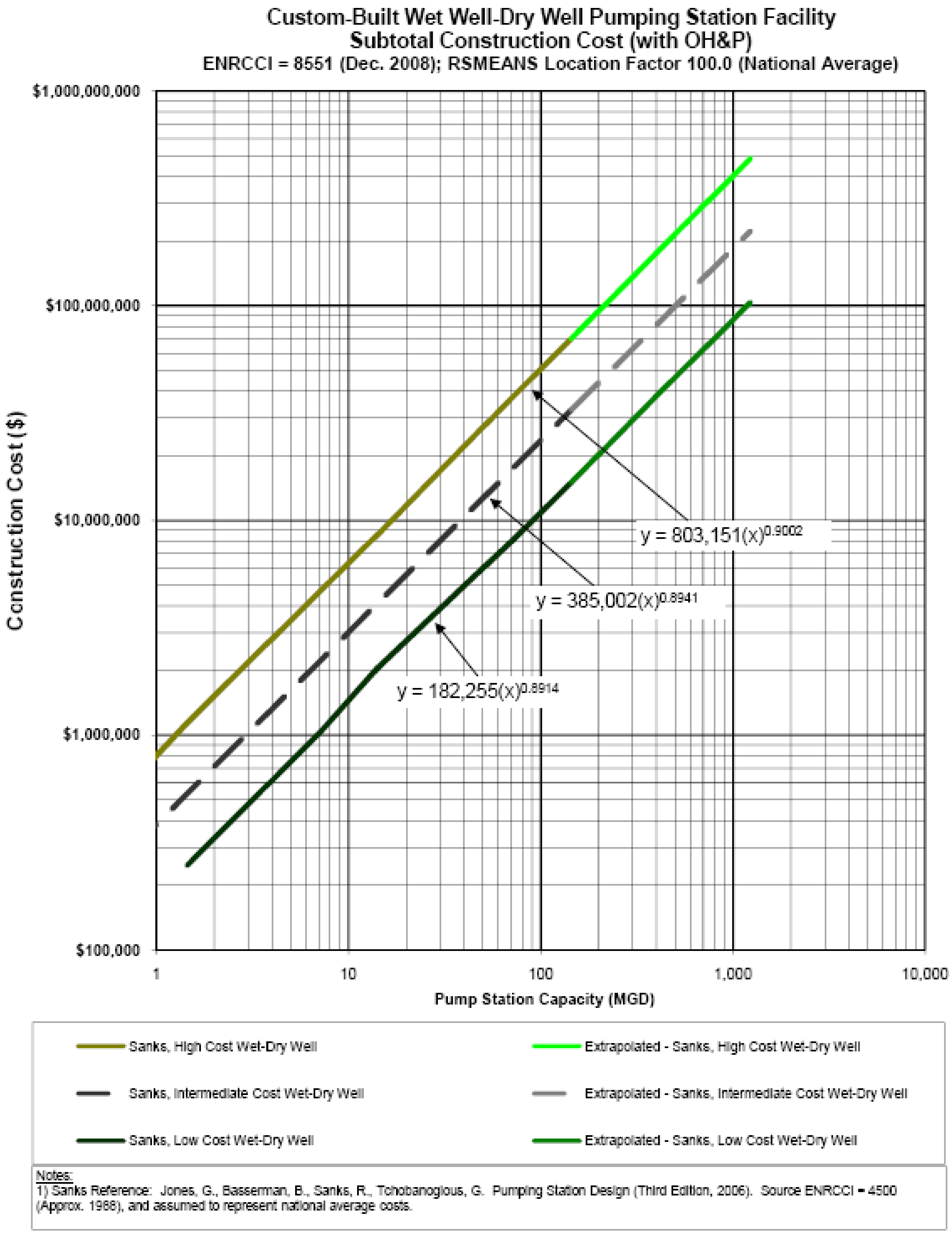
For submersible pumping stations, the selected curves are as follows:

$$\text{High Cost Curve: } y = 1{,}077{,}394x^{0.6158}$$
$$\text{Intermediate Cost Curve: } y = 473{,}381x^{0.6910}$$
$$\text{Low Cost Curve: } y = 207{,}992x^{0.7662}$$

For deep tunnel dewatering pumping stations, the equation for the selected curve was:

$$y = 1{,}077{,}394x^{0.6158}$$

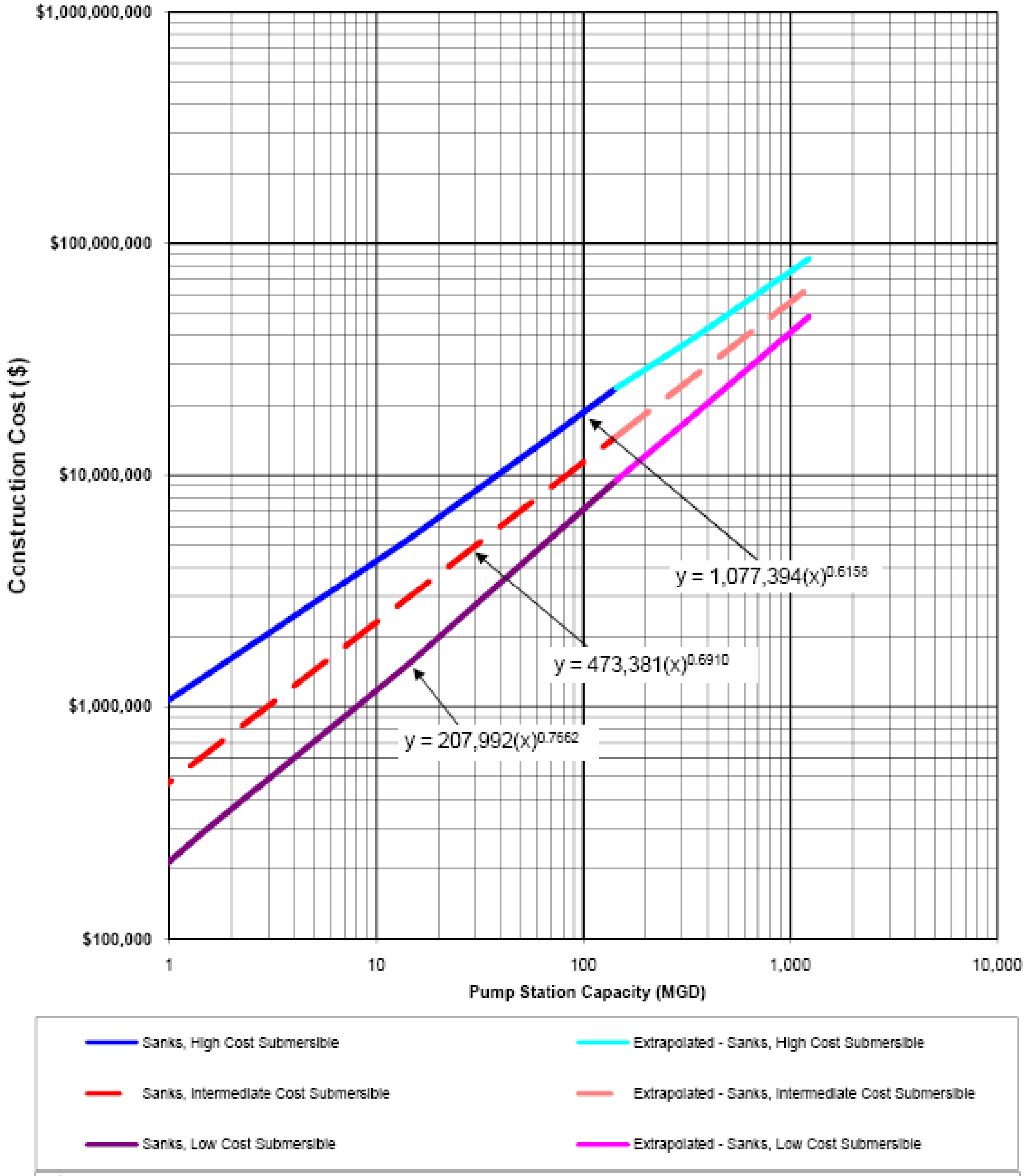
For all pump station cost estimate equations, y equals construction cost in dollars, and x equals pump station capacity in MGD.



Notes:
1) Sanks Reference: Jones, G., Basserman, B., Sanks, R., Tchobanoglous, G. Pumping Station Design (Third Edition, 2006). Source ENRCCI = 4500 (Approx. 1988), and assumed to represent national average costs.

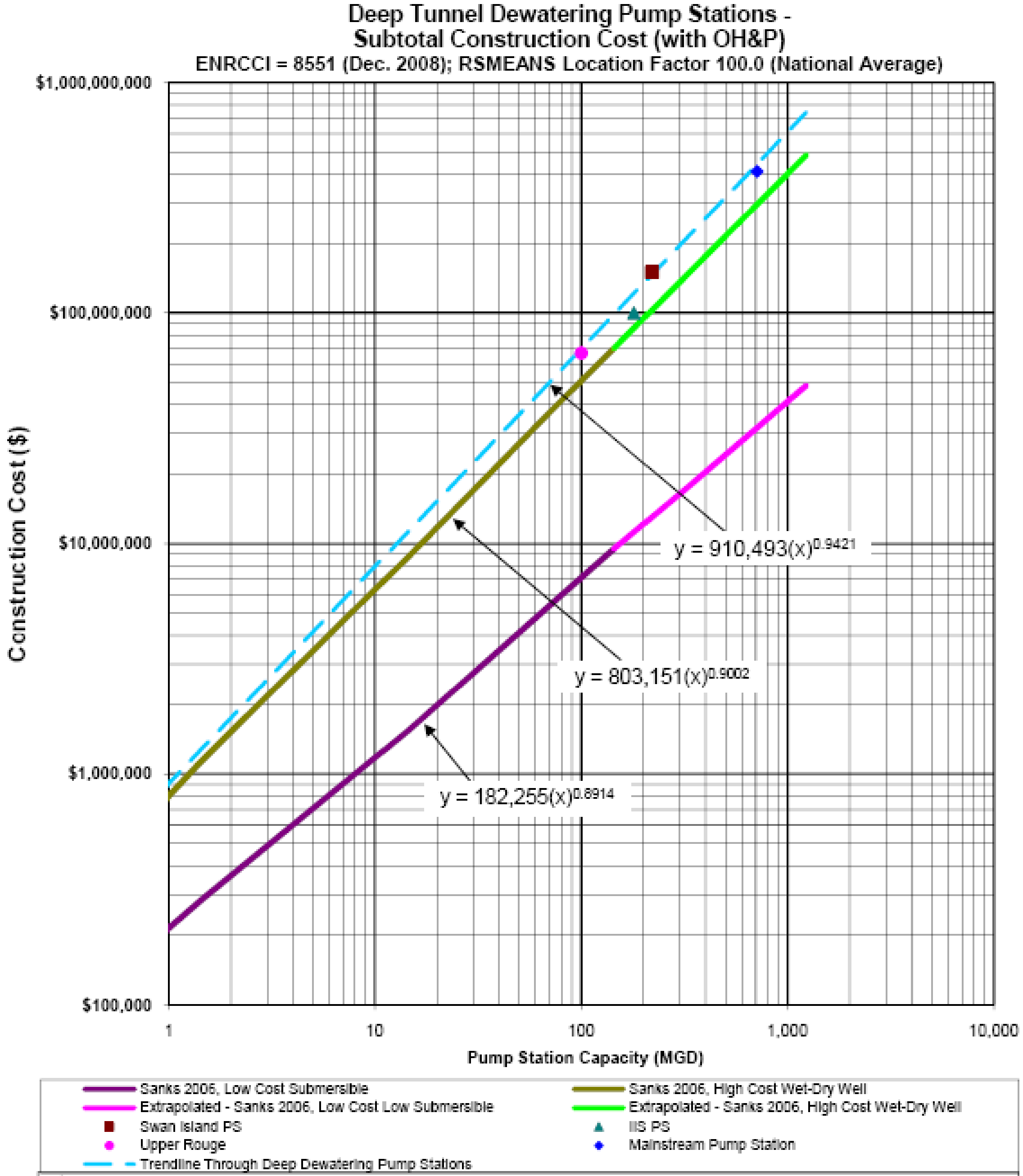
Figure 2.3.6-1 Custom-Built Wet-Well / Dry-Well Pump Station Curves [ENRCCI 8551; RS MEANS 100]

Submersible Pumping Station Facility
Subtotal Construction Cost (with OH&P)
ENRCCI = 8551 (Dec. 2008); RSMEANS Location Factor 100.0 (National Average)



Notes:
1) Sanks Reference: Jones, G., Basserman, B., Sanks, R., Tchobanoglous, G. Pumping Station Design (Third Edition, 2006). Source ENRCCI = 4500 (Approx. 1988), and assumed to represent national average costs.

Figure 2.3.6-2 Submersible Pump Station Curves [ENRCCI 8551; RS MEANS 100]



Notes:

1) Sanks Reference: Jones, G., Basserman, B., Sanks, R., Tchobanoglous, G. Pumping Station Design (Third Edition, 2006). Source ENRCCI = 4500 (Approx. 1988), and assumed to represent national average costs.

2) Swan Island Dewatering Pump Station: City of Portland (220 mgd capacity, 150 ft deep); based on correspondence with Corollow Engineers. *Limitations: unknown cost type (bid, bod, etc), unknown year of cost (construction started 2002, ended 2006) assumed 2001.*

3) IIS Pump Dewatering Pump Station: Milwaukee (180 mgd capacity, approx. 300 ft deep); based on Dec. 14, 2007 Black and Veatch Report titled: IIS Pump Station Upgrade Conceptual Design Report Contract NO. J01009E01. *Limitation: basis of design cost.*

4) Upper Rogue Dewatering Pump Station: Detroit (100 mgd capacity, 185 ft deep); based on conceptual design costs determined by CDM in 2005. *Limitation: basis of design cost.*

5) Mainstream Pump Station: Chicago TARP (2 levels of pumps: 710 MGD High TDH, 320 MGD Low TDH; used 710 MGD as the representative capacity); cost estimated from highest of the three lowest bid prices (dated 1979) provided by Chief Engineer at MWRDGC. *Limitations: unknown if costs include excavation and other geotech. unknown which bid won the job.*

Figure 2.3.6-3 Deep Tunnel Dewatering Pump Station Curves [ENRCCI 8551; RS MEANS 100]

Pump Station O&M Costs

Pump station O&M costs are calculated based on three cost components: energy costs, material costs and labor costs. Energy costs are calculated based upon user input values for the annual volume pumped (in mgd), the dynamic head (in feet), the "wire to water" efficiency, and electrical rate (in dollars per kilowatt-hour). The "wire to water" efficiency is the overall efficiency of the pump, motor and variable speed drive. This efficiency is the product of the efficiency percentages of these three components and is a percentage represented as a decimal value.

Three different options can be applied to calculate both material and labor costs for pump stations in the ACT. The first method is derived from USEPA document 430/9-78-009, *Innovative and Alternative Technology Assessment Manual* dated February 1980. This document includes cost curves for both materials and labor annual cost as a function of wastewater flow (in mgd).

The second option for determining costs of pump station material and labor in the ACT was derived from cost data provided by PWD. Labor and material costs were calculated for each of 13 pumping stations based on materials purchased, annual maintenance man hours (including overtime hours) and an average hourly labor rate including fringe benefits applied from actual laborer salary data for calendar year 2007. Also applied to the labor costs is a site specific work overhead percentage. The total annual labor and material costs were plotted individually against the rated pump station capacity (in mgd), and a linear line of best fit of these points determined the labor and materials cost equations.

The final option for calculating O&M costs for pumping stations in the ACT is for the user to input their own cost equation. The default configuration is for a linear cost equation with rated capacity (in mgd) as the independent variable. Figure 2.6.3-4 summarizes the pump station O&M cost curves based on pump station capacity and compares the PWD costs to EPA O&M cost data.

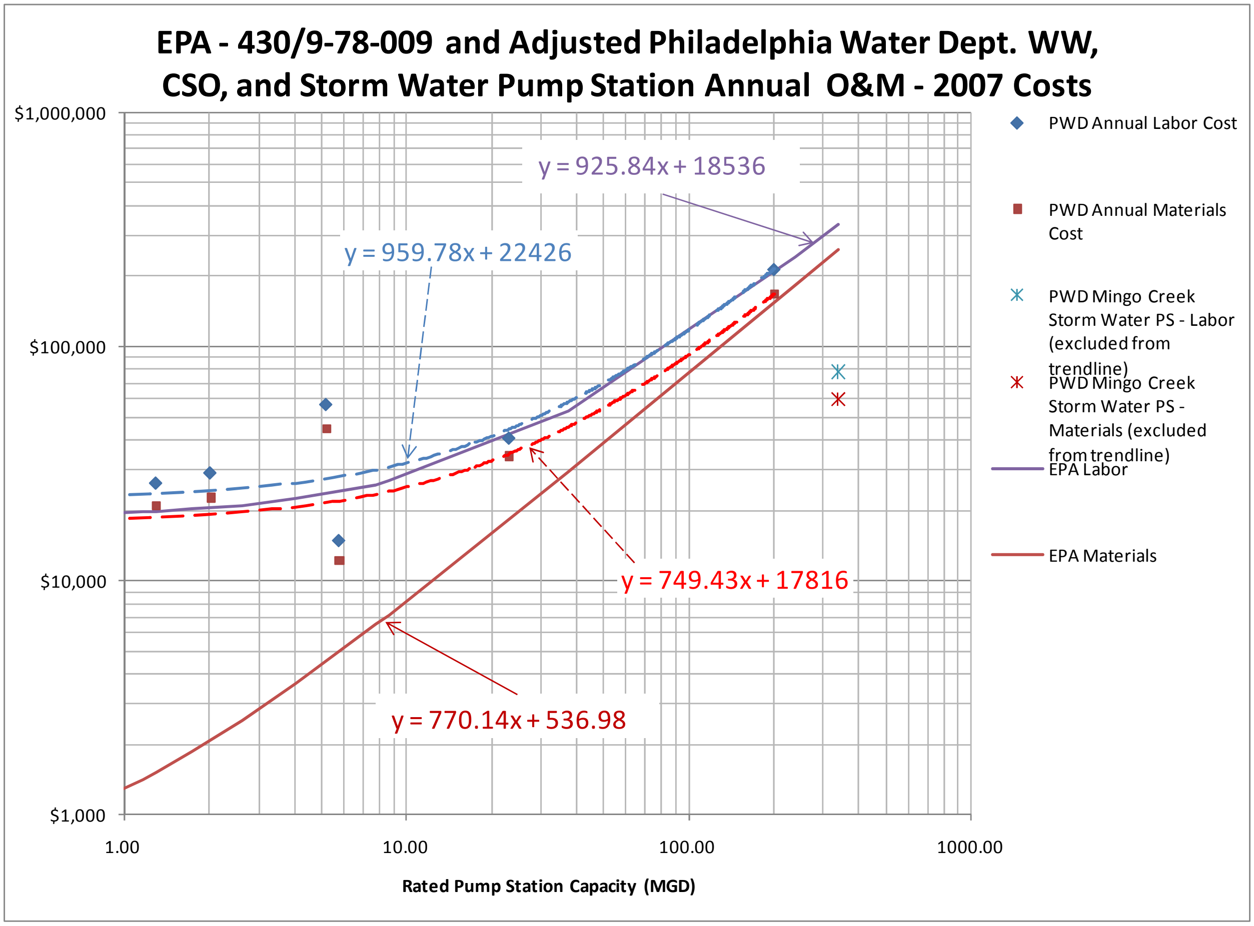


Figure 2.6.3-4 Pump Station Operations and Maintenance Costs [ENRCCI: 7939(PWD), 7966(EPA); RSMeans: 115.2 (PWD), 100.0 (EPA)]

2.3.7 Force Mains

There is not a separate control category for force mains in the ACT. Construction costs for force mains are to be calculated in the same manner as open-cut pipe, with the exception that the construction cost will assume installation of ductile iron pipe. Air release valves can be added as additional costs in the open-cut pipe cost estimate worksheet in the ACT.

2.3.8 Short-Bore Tunnel (Trenchless)

Trenchless methods of pipeline construction can be superior to open cut methods, or the only option for special applications. Trenchless methods result in less surface disturbance, minimize pavement damage, and reduce utility conflicts, which is important when working in urban areas. Trenchless methods should be used when crossing highways, railroads, and other obstacles that are poorly suited for open cut methods. Trenchless methods might be less expensive than open cut methods depending on various factors including pipe depth, pipe diameter, distance between pits, geology, the bidding environment, etc. Trenchless methods can be used for pipe depths deeper than what is feasible for open cut methods.

Many trenchless methods exist; however, the two most applicable methods were included in the ACT for cost estimating purposes: Microtunneling, and Pipe Jacking. These two methods work by pushing segments of pipe through the ground from a Jacking Pit. Microtunneling utilizes a micro-tunnel boring machine (MTBM) for advancement at the front of the pipe segments, whereas Pipe Jacking utilizes an open face. Pipe Jacking is typically a little less expensive, but because it utilizes an open face it should not be used below the groundwater table. Pipe Jacking is less favored than Microtunneling for diameters less than 48 inches and greater than 72 inches. For cost estimating purposes it is reasonable to not consider Pipe Jacking, and assume that Microtunneling will be used on all trenchless jobs. Both techniques require a Receiving Pit for retrieving equipment at the end of a pipe run. Significant cost savings can occur when two or more pipe runs share the same receiving or jacking pit.

Trenchless costs are sensitive to the geology at the pit locations and along the pipe run. For planning level cost estimation, basic geological conditions can be identified along the pipe run (e.g. soil, rock, and mixed), and in the pits (soil, rock). Mixed face conditions occur when both rock and soil conditions are experienced along the pipe run. Mixed face conditions should be avoided when possible, and will increase the uncertainty of the cost estimate. Steel pipe is recommended in mixed face conditions.

The ACT provides construction cost estimates for pipelines constructed by trenchless methods based on the following user inputs:

- Pipeline
    - Method (Microtunneling or Pipe Jacking)
    - Nominal Pipe Size (ranging between 24 to 144 inches, but extreme minimum and maximum sizes are not feasible for all applications)
    - Pipe Material (RCP, HOBAS, Composite FRP, Steel)
    - Pipe Length (distance between pits)
    - Ground Type (Soil, Rock, Mixed)
- Jacking and Receiving Pits

  - Depth of Soil (i.e. depth from the ground surface to the bottom of excavation in soil)
  - Depth of Rock (i.e. depth from the bottom of excavation in soil to the bottom of excavation in rock)
  - Manhole at Pit (yes, or no)

Planning level trenchless unit costs are presented in Tables 2.3.8-1 through 2.3.8-10 and are in terms of direct construction costs (i.e. materials, labor, and equipment), and do not include contractor's overhead and profit and indirect costs.

The total direct construction cost estimate for a trenchless pipeline is determined by the summation of the following cost groups: piping, pits, and manholes or just backfill. The piping costs listed by the soil group are complete and include the pipe material costs. Pit costs are determined by summing the Set Floor, Thrust Wall & Jacking Frames cost, cost per vertical foot in soil, and additional cost per vertical foot in rock. More specifically, costs per vertical foot are calculated separately for each depth group. When in rock, the cost per vertical foot in soil and additional cost in rock is summed together. The manhole costs per vertical foot are complete. If a manhole is not built the backfill cost per vertical foot should be used.

Trenchless tunneling costs ultimately depend on site specific and local geotechnical conditions, and other factors; the planning level unit costs presented in Tables 2.3.8-1 through 2.3.8-10 represent optimum conditions and other assumptions:

- Planning level classifications of geotechnical soil conditions were used: soil, rock, mixed face.
- Ground improvement costs were not included.
- Production rates reflect work in urban streets with timely delivery of materials.
- Jacking and receiving pits were estimated using soldier piles and lagging for earth support.
- Rock was assumed to be below 15,000 psi compressive strength.
- Risk of boulders and manmade obstructions were not considered.
- Dewatering costs were excluded.

The planning level unit costs presented in Tables 2.3.8-1 through 2.3.8-10 were developed by summing numerous direct unit construction costs (e.g. pipe material costs, equipment and labor costs for soil excavation). The logic for assembling the costs was based on engineering judgment and current industry practices. Unit cost sources and methods include:

- Labor Costs
  - Labor rates for Philadelphia.
  - Workman's compensation, liability insurance, and taxes were included in the labor rates.
  - Provisions for some overtime were included.
  - The following were excluded: stewards, surveyors, costs for off-shift, 10 hour shifts, and weekend work.
  - Crew size based on assumed collective bargaining coverage for this type of work.

- Equipment and operating costs represent compiled "owned" equipment rates for the Northeast area of the country.
- Material quotations were solicited from various vendors and represent budget estimates.

General guidelines for using the trenchless unit costs include the following:

- Mixed face areas should be avoided if possible; tunneling at a deeper depth in rock is preferred.
- Tunneling in "mixed face" conditions if necessary, should be limited to steel pipe as the machine tends to deflect in the interface areas, thus stressing the joints on concrete or Hobas type pipes.
- Pipe runs with diameters less than 36 inches should be limited in length to less than 500 feet, due to the inability to remove intermediate jacking stations.
- Small diameter concrete or clay pipes should be limited to 400 feet.
- Hobas discourages pipes larger than 84 inches from being used for direct microtuneling or jacking as the bell / gasket bank will deform on the larger sizes.
- Diameters greater than 108 inches should not be "jacked" using open face machines, TBM's should be employed and segments should be considered.
- Shafts deeper than 30 feet to 50 feet should be constructed using circular caissons, which can ultimately be used as the permanent access.
- Tunneling in rock should be limited to machines 60 inches and above in diameter, this is due to face access for cutter head replacement and the limited power of the smaller machines.

Table 2.3.8-1 Microtunneling: Reinforced Concrete Non-Pressure Pipe Unit Costs used in the ACT [ENRCCI 8578; RS MEANS 113.2]

Lining system: R. Concrete Non-Pressure Pipe	Pipe Internal Diameter	Pipe Material Unit Cost	Soil				Rock				Mixed Ground			
			Short Range 150-300’	Medium Range 300-600’	Long Range 600-1000’	Extra Long Range >1000’	Short Range 150-300’	Medium Range 300-600’	Long Range 600-1000’	Extra Long Range >1000’	Short Range 150-300’	Med Range 300-600’	Long Range 600-1000’	Extra Long Range >1000’
	(Inches)	($/LF)	($/LF)	($/LF)	($/LF)	($/LF)	($/LF)	($/LF)	($/LF)	($/LF)	($/LF)	($/LF)	($/LF)	($/LF)
	24	160	558	448	N/R	N/R	N/R	N/R	N/R	N/R	N/R	N/R	N/R	N/R
	30	140	581	472	N/R	N/R	N/R	N/R	N/R	N/R	N/R	N/R	N/R	N/R
	36	180	611	501	N/R	N/R	688	578	N/R	N/R	650	540	N/R	N/R
	42	200	715	580	553	511	772	637	610	568	744	609	582	540
	48	230	788	652	629	586	868	733	709	666	828	693	669	626
	54	270	971	792	752	699	1,095	917	877	824	1,033	855	815	762
	60	310	1,035	857	824	768	1,171	992	960	904	1,103	925	892	836
	66	360	1,159	956	919	855	1,305	1,103	1,066	1,002	1,232	1,030	993	929
	72	410	1,322	1,119	1,085	1,020	1,602	1,399	1,365	1,300	1,462	1,259	1,225	1,160
	78	480	1,451	1,242	1,211	1,142	1,754	1,536	1,504	1,436	1,603	1,389	1,358	1,289
	84	570	1,644	1,434	1,410	1,339	2,105	1,895	1,871	1,800	1,875	1,665	1,641	1,570
	90	630	1,962	1,712	1,682	1,597	2,333	2,083	2,053	1,969	2,148	1,898	1,868	1,783
	96	690	2,091	1,842	1,812	1,727	3,167	2,917	2,888	2,803	2,629	2,380	2,350	2,265
	108	950	2,711	2,619	2,416	2,380	3,638	3,545	3,342	3,306	3,175	3,082	2,879	2,843
	120	1,300	3,310	3,216	2,973	2,933	4,395	4,301	4,058	4,018	3,853	3,759	3,516	3,476
	144	2,060	4,344	4,294	4,032	3,998	5,680	5,630	5,367	5,333	5,012	4,962	4,700	4,666

Note: “N/R” indicates configurations which are not recommended for alternatives.

Table 2.3.8-2 Microtunneling: HOBAS GRP Pipe Unit Costs used in the ACT [ENRCCI 8578; RS MEANS 113.2]

Lining system: HOBAS GRP Pipe	Pipe Internal Diameter	Pipe Material Unit Cost	Soil				Rock				Mixed			
			Short Range 150-300’	Medium Range 300-600’	Long Range 600-1000’	Extra Long Range >1000’	Short Range 150-300’	Medium Range 300-600’	Long Range 600-1000’	Extra Long Range >1000’	Short Range 150-300’	Medium Range 300-600’	Long Range 600-1000’	Extra Long Range >1000 ft
	(Inches)	($/LF)	($/LF)	($/LF)	($/LF)	($/LF)	($/LF)	($/LF)	($/LF)	($/LF)	($/LF)	($/LF)	($/LF)	($/LF)
	24	198	618	508	N/R	N/R	N/R	N/R	N/R	N/R	N/R	N/R	N/R	N/R
	30	264	686	577	N/R	N/R	N/R	N/R	N/R	N/R	N/R	N/R	N/R	N/R
	36	345	771	661	N/R	N/R	847	738	N/R	N/R	809	700	N/R	N/R
	42	420	928	793	766	724	986	850	823	781	957	822	795	753
	48	476	1025	890	887	823	1106	971	947	904	1066	931	917	864
	54	571	1261	1083	1044	990	1387	1208	1168	1115	1324	1146	1106	1053
	60	635	1348	1170	1137	1081	1484	1305	1273	1217	1416	1238	1205	1149
	66	745	1530	1327	1290	1226	1676	1473	1437	1373	1603	1400	1364	1300
	72	810	1706	1502	1468	1403	1985	1782	1748	1683	1846	1642	1608	1543
	78	900	1852	1642	1612	1543	2146	1937	1906	1837	1999	1790	1759	1690
	84	1000	2051	1841	1817	1746	2512	2302	2278	2207	2282	2072	2048	1977

Note: “N/R” indicates configurations which are not recommended for alternatives.

Table 2.3.8-3 Microtunneling: Composite FRP Pipe Unit Costs used in the ACT [ENRCCI 8578; RS MEANS 113.2]

	Pipe Internal Diameter	Pipe Material Unit Cost	Soil				Rock				Mixed			
			Short Range 150-300’	Medium Range 300-600’	Long Range 600-1000’	Extra Long Range >1000’	Short Range 150-300’	Medium Range 300-600’	Long Range 600-1000’	Extra Long Range >1000’	Short Range 150-300’	Medium Range 300-600’	Long Range 600-1000’	Extra Long Range >1000’
	(Inches)	($/LF)	($/LF)	($/LF)	($/LF)	($/LF)	($/LF)	($/LF)	($/LF)	($/LF)	($/LF)	($/LF)	($/LF)	($/LF)
Lining System: Composite FRP Pipe	24	116	514	404	N/R	N/R	N/R	N/R	N/R	N/R	N/R	N/R	N/R	N/R
	30	152	593	484	N/R	N/R	N/R	N/R	N/R	N/R	N/R	N/R	N/R	N/R
	36	182	613	503	N/R	N/R	690	580	N/R	N/R	651	541	N/R	N/R
	42	223	738	603	576	534	795	660	633	591	766	631	604	562
	48	254	812	676	653	610	892	757	733	690	852	717	693	650
	54	314	1015	836	796	743	1139	961	921	868	1077	899	859	806
	60	346	1071	893	860	804	1207	1028	996	940	1139	960	928	872
	66	398	1197	994	957	893	1343	1141	1104	1040	1270	1067	1030	966
	72	434	1346	1143	1109	1044	1626	1423	1389	1324	1486	1283	1249	1184
	78	490	1461	1252	1221	1152	1764	1546	1514	1446	1612	1399	1367	1299
	84	522	1596	1386	1362	1291	2057	1847	1823	1752	1827	1617	1593	1522
	90	613	1945	1695	1665	1580	2316	2066	2036	1952	2130	1880	1850	1766
	96	672	2073	1824	1794	1709	3149	2899	2870	2785	2611	2362	2332	2247
	110	770	2531	2439	2236	2200	3458	3365	3162	3126	2994	2902	2699	2663

Note: “N/R” indicates configurations which are not recommended for alternatives.

Table 2.3.8-4 Microtunneling: Steel Pipe Unit Costs used in the ACT [ENRCCI 8578; RS MEANS 113.2]

	Pipe Internal Diameter	Pipe Material Unit Cost	Soil				Rock				Mixed			
			Short Range 150-300’	Medium Range 300-600’	Long Range 600-1000’	Extra Long Range >1000’	Short Range 150-300’	Medium Range 300-600’	Long Range 600-1000’	Extra Long Range >1000’	Short Range 150-300’	Medium Range 300-600’	Long Range 600-1000’	Extra Long Range >1000’
	(Inches)	($/LF)	($/LF)	($/LF)	($/LF)	($/LF)	($/LF)	($/LF)	($/LF)	($/LF)	($/LF)	($/LF)	($/LF)	($/LF)
Lining system: Steel Pipe	24	124	544	434	N/R	N/R	N/R	N/R	N/R	N/R	N/R	N/R	N/R	N/R
	30	136	559	449	N/R	N/R	N/R	N/R	N/R	N/R	N/R	N/R	N/R	N/R
	36	148	575	465	N/R	N/R	651	541	N/R	N/R	613	503	N/R	N/R
	42	172	681	546	518	477	738	603	576	534	710	575	547	506
	48	198	748	612	589	546	828	693	670	627	788	653	630	587
	54	248	939	761	721	668	1064	886	846	793	1002	824	784	731
	60	299	1012	834	802	746	1148	970	938	881	1080	902	870	814
	66	353	1138	935	898	834	1285	1082	1045	981	1212	1009	972	908
	72	409	1304	1102	1068	1003	1585	1382	1348	1283	1445	1242	1208	1143
	78	472	1424	1215	1184	1115	1718	1509	1478	1409	1571	1362	1331	1262
	84	536	1587	1378	1353	1282	2048	1839	1814	1743	1818	1609	1584	1513
	90	571	1877	1627	1597	1513	2248	1998	1969	1884	2063	1813	1783	1699
	96	599	1971	1721	1692	1607	3047	2797	2767	2683	2509	2259	2230	2145
	108	772	2447	2355	2152	2116	3374	3281	3079	3043	2911	2818	2616	2580
	120	1033	3004	2910	2667	2627	4090	3996	3753	3713	3547	3453	3210	3170
	144	1199	3430	3381	3118	3084	4766	4716	4474	4419	4098	4049	3796	3752

Note: “N/R” indicates configurations which are not recommended for alternatives.

Table 2.3.8-5 Pipe Jacking: Reinforced Concrete Non-Pressure Pipe Unit Costs used in the ACT [ENRCCI 8578; RS MEANS 113.2]

Lining system: Reinforced Concrete Non-Pressure Pipe	Pipe Internal Diameter	Pipe Material Unit Cost	Soil				Rock				Mixed			
			Short Range 150-300'	Medium Range 300-600'	Long Range 600-1000'	Extra Long Range >1000'	Short Range 150-300'	Medium Range 300-600'	Long Range 600-1000'	Extra Long Range >1000'	Short Range 150-300'	Medium Range 300-600'	Long Range 600-1000'	Extra Long Range >1000'
	(Inches)	($/LF)	($/LF)	($/LF)	($/LF)	($/LF)	($/LF)	($/LF)	($/LF)	($/LF)	($/LF)	($/LF)	($/LF)	($/LF)
	24	160	530	420	N/R	N/R	663	525	N/R	N/R	N/R	N/R	N/R	N/R
	30	140	554	444	N/R	N/R	693	555	N/R	N/R	N/R	N/R	N/R	N/R
	36	180	583	473	N/R	N/R	729	591	N/R	N/R	N/R	N/R	N/R	N/R
	42	200	682	546	519	477	853	683	649	596	767	614	584	537
	48	230	747	611	588	544	934	764	735	680	840	687	662	612
	54	270	919	740	700	647	1149	925	875	809	1034	833	788	728
	60	310	979	800	768	711	1224	1000	960	889	1101	900	864	800
	66	360	1099	896	859	795	1374	1120	1074	994	1236	1008	966	894
	72	410	1123	1033	999	934	1404	1291	1249	1168	1263	1162	1124	1051
	78	480	1362	1151	1120	1051	1703	1439	1400	1314	1532	1295	1260	1182
	84	570	1531	1321	1296	1225	1914	1651	1620	1531	1722	1486	1458	1378
	90	630	1812	1562	1532	1447	2265	1953	1915	1809	2039	1757	1724	1628
	96	690	1926	1675	1645	1560	2408	2094	2056	1950	2167	1884	1851	1755
	108	950	N/R	N/R	N/R	N/R	N/R	N/R	N/R	N/R	N/R	N/R	N/R	N/R
	120	1300	N/R	N/R	N/R	N/R	N/R	N/R	N/R	N/R	N/R	N/R	N/R	N/R
	144	2060	N/R	N/R	N/R	N/R	N/R	N/R	N/R	N/R	N/R	N/R	N/R	N/R

Note: “N/R” indicates configurations which are not recommended for alternatives.

Table 2.3.8-6 Pipe Jacking: Reinforced Concrete Non-Pressure Pipe Unit Costs used in the ACT [ENRCCI 8578; RS MEANS 113.2]

Lining system: HOBAS GRP Pipe	Pipe Internal Diameter	Pipe Material Unit Cost	Soil				Rock				Mixed			
			Short Range 150-300'	Medium Range 300-600'	Long Range 600-1000'	Extra Long Range >1000'	Short Range 150-300'	Medium Range 300-600'	Long Range 600-1000'	Extra Long Range >1000'	Short Range 150-300'	Medium Range 300-600'	Long Range 600-1000'	Extra Long Range >1000'
	(Inches)	($/LF)	($/LF)	($/LF)	($/LF)	($/LF)	($/LF)	($/LF)	($/LF)	($/LF)	($/LF)	($/LF)	($/LF)	($/LF)
	24	198	590	480	N/R	N/R	N/R	N/R	N/R	N/R	N/R	N/R	N/R	N/R
	30	264	659	549	N/R	N/R	N/R	N/R	N/R	N/R	N/R	N/R	N/R	N/R
	36	345	743	633	N/R	N/R	929	791	N/R	N/R	836	712	N/R	N/R
	42	420	895	759	732	690	1119	949	915	863	1007	854	824	776
	48	476	984	849	825	782	1230	1061	1031	978	1107	955	928	880
	54	571	1210	1031	991	938	1513	1289	1239	1173	1361	1160	1115	1055
	60	635	1292	1113	1081	1024	1615	1391	1351	1280	1454	1252	1216	1152
	66	745	1470	1266	1229	1165	1838	1583	1536	1456	1654	1424	1383	1311
	72	810	1620	1416	1382	1317	2025	1770	1728	1646	1823	1593	1555	1482
	78	900	1762	1552	1521	1452	2203	1940	1901	1815	1982	1746	1711	1634
	84	1000	1938	1728	1703	1632	2423	2160	2129	2040	2180	1944	1916	1836

Note: “N/R” indicates configurations which are not recommended for alternatives.

Table 2.3.8-7 Pipe Jacking: Composite FRP Pipe Unit Costs used in the ACT [ENRCCI 8578; RS MEANS 113.2]

Lining System: Composite FRP Pipe			Soil				Rock				Mixed			
	Pipe Internal Diameter	Pipe Material Unit Cost	Short Range 150-300'	Medium Range 300-600'	Long Range 600-1000'	Extra Long Range >1000'	Short Range 150-300'	Medium Range 300-600'	Long Range 600-1000'	Extra Long Range >1000'	Short Range 150-300'	Medium Range 300-600'	Long Range 600-1000'	Extra Long Range >1000'
	(Inches)	($/LF)	($/LF)	($/LF)	($/LF)	($/LF)	($/LF)	($/LF)	($/LF)	($/LF)	($/LF)	($/LF)	($/LF)	($/LF)
	24	116	486	376	N/R	N/R	619	481	N/R	N/R	N/R	N/R	N/R	N/R
	30	152	566	456	N/R	N/R	705	567	N/R	N/R	N/R	N/R	N/R	N/R
	36	182	585	475	N/R	N/R	731	593	N/R	N/R	N/R	N/R	N/R	N/R
	42	223	705	569	542	500	875	705	671	619	790	637	606	559
	48	254	771	635	612	568	958	788	759	704	864	711	686	636
	54	314	963	784	744	691	1193	969	919	853	1078	877	832	772
	60	346	1015	836	804	747	1260	1036	996	925	1137	936	900	836
	66	398	1137	934	897	833	1412	1158	1112	1032	1274	1046	1004	932
	72	434	1147	1057	1023	958	1427	1315	1272	1191	1287	1186	1147	1074
	78	490	1372	1161	1130	1061	1712	1448	1410	1323	1542	1304	1270	1192
	84	522	1483	1273	1248	1177	1866	1603	1572	1483	1674	1438	1410	1330
	90	613	N/R	N/R	N/R	N/R	N/R	N/R	N/R	N/R	N/R	N/R	N/R	N/R
	96	672	N/R	N/R	N/R	N/R	N/R	N/R	N/R	N/R	N/R	N/R	N/R	N/R
	110	770	N/R	N/R	N/R	N/R	N/R	N/R	N/R	N/R	N/R	N/R	N/R	N/R

Note: “N/R” indicates configurations which are not recommended for alternatives.

Table 2.3.8-8 Pipe Jacking: Steel Pipe Unit Costs used in the ACT [ENRCCI 8578; RS MEANS 113.2]

	Pipe Internal Diameter	Pipe Material Unit Cost	Soil				Rock				Mixed			
			Short Range 150-300'	Medium Range 300-600'	Long Range 600-1000'	Extra Long Range >1000'	Short Range 150-300'	Medium Range 300-600'	Long Range 600-1000'	Extra Long Range >1000'	Short Range 150-300'	Medium Range 300-600'	Long Range 600-1000'	Extra Long Range >1000'
	(Inches)	($/LF)	($/LF)	($/LF)	($/LF)	($/LF)	($/LF)	($/LF)	($/LF)	($/LF)	($/LF)	($/LF)	($/LF)	($/LF)
Lining system: Steel Pipe	24	124	532	422	N/R	N/R	665	528	N/R	N/R	599	475	N/R	N/R
	30	136	547	437	N/R	N/R	684	546	N/R	N/R	615	492	N/R	N/R
	36	148	562	452	N/R	N/R	703	565	N/R	N/R	632	509	N/R	N/R
	42	172	669	534	507	465	836	668	634	581	753	601	570	523
	48	198	707	571	548	505	884	714	685	631	795	642	617	568
	54	248	887	708	669	615	1109	885	836	769	998	797	753	692
	60	299	957	778	745	689	1196	973	931	861	1077	875	838	775
	66	353	1078	875	838	774	1348	1094	1048	968	1213	984	943	871
	72	409	1219	1015	981	916	1524	1269	1226	1145	1371	1142	1104	1031
	78	472	1334	1124	1093	1024	1668	1405	1366	1280	1501	1265	1230	1152
	84	536	1475	1265	1240	1168	1844	1581	1550	1460	1659	1423	1395	1314
	90	571	1727	1477	1447	1362	2159	1846	1809	1703	1943	1662	1628	1532
	96	599	1805	1555	1525	1440	2256	1944	1906	1800	2031	1749	1716	1620
	108	772	N/R	N/R	N/R	N/R	N/R	N/R	N/R	N/R	N/R	N/R	N/R	N/R
	120	1033	N/R	N/R	N/R	N/R	N/R	N/R	N/R	N/R	N/R	N/R	N/R	N/R
	144	1199	N/R	N/R	N/R	N/R	N/R	N/R	N/R	N/R	N/R	N/R	N/R	N/R

Notes: “N/R” indicates configurations which are not recommended for alternatives.

Table 2.3.8-9 Jacking Pit Unit Cost Values used in the ACT [ENRCCI 8578; RS MEANS 113.2]

Pipe Diameter Range (inch)	Jacking Pit Footprint - Length x Width (ft x ft)	Receiving Pit Footprint - Length x Width (ft x ft)	Set Floor, Thrust Wall & Jacking Frames (Receiving Pit Cost is 75% of Jacking Pit Cost)	Jacking Pit in Soil (Receiving Pit Cost is 75% of Jacking Pit Cost)					Additional Cost if Pit in Rock (Receiving Pit Cost is 75% of Jacking Pit Cost)				
				0-30' Deep ($/VF)	31-60' Deep ($/VF)	61-90' Deep ($/VF)	91-120' Deep ($/VF)	121-150' Deep ($/VF)	0-30' Deep ($/VF)	31-60' Deep ($/VF)	61-90' Deep ($/VF)	91-120' Deep ($/VF)	121-150' Deep ($/VF)
24 - 36	16 x 10	12 x 10	24,000	3,330	3,700	4,070	4,810	5,920	720	800	880	960	1,040
42 - 54	18 x 12	12 x 12	32,000	4,050	4,500	4,950	5,850	7,200	1,080	1,200	1,320	1,440	1,560
60 - 72	20 x 14	14 x 14	39,000	4,860	5,400	5,940	7,020	8,640	1,440	1,600	1,760	1,920	2,080
78 - 84	24 x 14	14 x 14	45,000	5,670	6,300	6,930	8,190	10,080	1,800	2,000	2,200	2,400	2,600
90 - 108	26 x 16	16 x 16	74,000	7,020	7,800	8,580	10,140	12,480	2,790	3,100	3,410	3,720	4,030
120 - 144	28 x 20	20 x 20	96,000	8,370	9,300	10,230	12,090	14,880	3,780	4,200	4,620	5,040	5,460

Table 2.3.8-10 Jacking Pit Manhole, Backfill & Bracing Removal Unit Cost Values used in the ACT [ENRCCI 8578; RS MEANS 113.2]

Pipe Diameter Range (inch)	Manhole, Backfill & Bracing Removal						Just Backfill				
	Manhole Diameter (ft)	0-30' Deep ($/VF)	31-60' Deep ($/VF)	61-90' Deep ($/VF)	91-120' Deep ($/VF)	121-150' Deep ($/VF)	0-30' Deep ($/VF)	31-60' Deep ($/VF)	61-90' Deep ($/VF)	91-120' Deep ($/VF)	121-150' Deep ($/VF)
24 - 36	6	1,627	1,350	1,485	1,755	2,025	675	750	825	975	1,125
42 - 54	8	2,350	1,800	1,980	2,340	2,700	900	1,000	1,100	1,300	1,500
60 - 72	10	3,517	2,450	2,695	3,185	3,675	1,125	1,250	1,375	1,625	1,875
78 - 84	12	4,633	3,300	3,630	4,290	4,950	1,350	1,500	1,650	1,950	2,250
90 - 108	16	6,608	4,675	5,143	6,078	7,013	1,688	1,875	2,063	2,438	2,813
120 - 144	20	8,833	6,000	6,600	7,800	9,000	2,250	2,500	2,750	3,250	3,750

2.3.9 Conventional Tunnel - Storage/Conveyance

The term Conventional Tunnel refers to large diameter tunnels created by tunnel boring machines (TBM) that are advanced from the TBM location, unlike Short-Bore Tunnels (Trenchless) that are advanced from the pit location.

Supplemental materials outside of the ACT were used to determine key components of a complete CSO storage tunnel alternative cost, including cost estimates for Conventional Tunnels in Rock and Primary Tunnel components, and some Secondary Tunnel Alternative components. The following sections document the supplemental materials and ACT modules used to determine a complete CSO storage tunnel alternative cost.

The Primary Tunnel components include the following:

- Shafts
  - Work
  - Maintenance
  - Vent
  - Access
- CSO Tunnel Components
  - CSO vortex near surface structure
  - CSO drop shaft structure
  - Adits (tunnel connecting CSO drop shafts to the storage tunnel)

The Secondary Tunnel Alternative components include the following:

- New or modified CSO regulating structures
- Consolidation piping – near surface piping that directs flow from the CSO regulators to the CSO vortexing/drop structures
- Tunnel dewatering pump station

Supplemental Materials - Conventional Tunnel in Rock and Primary Tunnel Components

A tunnel costing spreadsheet was developed to estimate the cost of conventional rock tunnels and primary tunnel components. The key user inputs used for determining a tunnel cost estimate include:

- Tunnel
  - Tunnel Inside Diameter
  - Tunnel Length
  - Lining Type (Cast in place, or Segmental)
  - Corrosion Protection Liner (Yes, or No)
- Shafts (numerous types)
  - Number of shafts
  - Shaft diameter
  - Depth in soil
  - Depth in rock

- CSO Tunnel Components
    - Design flowrate

It should be noted and emphasized that there is no industry standard cost estimating tool for rock tunnel construction available at this time (i.e. equivalent of RS Means®, Mining Cost Services® etc.). This is due to the highly sensitive nature of the cost of tunneling relative to geology, depth, groundwater issues, the end use and application of the structures, among many other labor, finance and risk allocation issues. The result is that there is no uniform way of evaluating the cost across the industry.

Therefore, the user of the spreadsheet should be extremely careful and cognizant of the implication of each factor on the tunneling method and related cost. As such, the program can render a reasonable planning level estimate of the potential tunnel cost if it is used within the ranges specified herein. For variations beyond these values, the formulas will need to be revised.

The estimated cost is based on the assumption of using a tunnel boring machine (TBM) (open or shielded) as the tunneling method. The TBM deep tunnel drilling will be assumed to be in full rock face, which offers two choices of ground support, including temporary support plus cast in place (CIP) as well as Concrete Segmental lining. Most of the tunnel cost elements were based on a conventional tunnel in New York, detailed cost estimate for a conventional tunnel in St. Louis, MO, and general rule of thumb values for tunnel construction.

The formulas used to adjust the estimated cost of tunnel are empirical and in general vary by using power functions. The adjustment for diameter is considered to be proportional with tunnel diameter or linear function (power of 1) with the ratio of tunnel diameters. The adjustment for tunnel length is done based on a power function to account for the spread of the fixed cost items over the longer tunnel, meaning a gradual decrease in estimated cost per foot as the tunnel gets longer. Although these powers are variable and can be changed, they have been set to 0.3-0.25 for excavation and final lining, respectively. The values used are based on personal judgment of the overall trend in the adjustment curve.

Costs associated with site Mobilization/Demobilization are estimated based on the tunnel diameter and length. The length of the tail or starter tunnel in rock can be selected as needed and again a rule of thumb for this level of planning is to use a minimum of 10 times the tunnel excavated diameter to allow for assembly of the machine and its back up system. Cost per unit for hand mining of the starter/tail tunnel is calculated by the spreadsheet and the length is deducted from the length of the bored tunnel.

A short list of assumption behinds the conventional tunnel cost estimate is listed as follows:

- Construction of main tunnel to be performed by TBMs.
- Tunnel cost varies proportional to tunnel diameter.
- Tunnel cost will decrease with tunnel length within a certain range. The rate of decrease is estimated by using a power function (power of 0.25-0.3).

- Tunnel is in uniform ground. Mixed face conditions are not accounted for and it is recommended to choose the vertical alignment to stay within rock.
- Variation of rock types is acceptable.
- Tunneling is done with a circular profile and by a tunnel boring machine.
- Open hard rock TBMs will be used for excavation of rock while installing temporary support, and followed by CIP concrete lining. Alternatively, one pass system can be used with double shield machine and concrete segmental lining. Additional cost of tunneling is reflected in the cost per foot of segments.
- Access to the tunnel is through the work shaft and not portals.
- No exceptional or extraordinary complications exist in the ground, normal variation of lithology and some structural features are included. Unusual conditions with high groundwater pressure, abnormal in situ stresses, extended area of fault zones, contaminated ground, encountering high volume of methane, etc. is not considered in the costs.
- Normal contracting practice with design-bid-build is assumed to be used for the project.
- Operations are based on 24 hour activities and full access to the site 7 days a week.
- Cost of tunneling comprises labor, equipment, and consumables, with 1/3 rule.
- Geographical impact is primarily in terms of labor cost, and can impact the 1/3 contribution of the labor.
- Shaft depths in the range of around 200 ft can be estimated based on unit price of excavation. Deeper shafts may require special provisions.
- Shaft diameters of 10-75 ft can be estimated based on unit prices, larger shafts may need special provisions.
- Excavation cost includes transportation of muck in the tunnel and off the site within reason. Additional cost of muck haulage to a long distance or special provisions of dump sites was not accounted for.

CSO vortex drop shaft costs were determined by using Sage Timberline software to estimate the cost of numerous structures, based on basis of design drawings, designed to handle specific flow rates.

ACT - Conventional Tunnel Module

The cost estimate from the supplemental materials can be input into the Conventional Tunnel module. The user input parameters are listed as follows:

- Length of Tunnel
- Inside Diameter of Tunnel
- Unit Cost of Tunnel ($/gal)

Supplemental Materials - Secondary Tunnel Alternative Components

Cost estimates for new or modified CSO regulator structures were determined by using Sage Timberline software to estimate the cost of numerous structures, based on basis of design drawings, designed to handle specific flow rates.

ACT - Secondary Tunnel Alternative Structures Components

Consolidation piping was costed with unit costs from the open cut pipe module of the ACT.

Deep CSO storage dewatering pump stations were costed with unit costs from the pump station module of the ACT. Specifically the deep tunnel dewatering pump station costing curve was used.

Supplemental Materials - CSO Storage Tunnel O&M Costs

Supplemental materials were used outside of the ACT to determine O&M costs for CSO storage tunnels. Conventional CSO storage tunnel O&M was largely based on two WEFTEC 2007 Session 8 references:

- Murphy, S. Operations and Maintenance Requirements for Storage Tunnels and In-System Storage Facilities
- Sherrill, J. Fujita, G. Budget Development for Operations/Maintenance Requirements For CSO/SSO Control Facilities

These references provided a general framework to perform O&M cost estimates. Tunnel storage O&M activities were broken into two groups: event (operations), and non-event (maintenance). Non-event activities are maintenance activities on the tunnel, dewatering pump station, and associated structures, that occur when the tunnel is not being operated. Event activities are operations activities that occur immediately before a CSO storage event, while the tunnel is filling, and while the tunnel is being dewatered and flushed. Guidelines for estimating event and non-event labor hours were provided, along with a breakout of labor hours per labor classification. Guidelines for marking up labor hours to include training, vacation, and other benefits were included. In addition, estimates for materials and electrical costs were provided.

Several modifications to the cost estimating approach were performed. The primary consumer of electricity was the dewatering pump station, and was calculated directly. Additional cost markups for tunnel length and dewatering pump station capacity was included in the estimate.

The following inputs were used to estimate an annual O&M cost:

- Estimates of annual event duration
- Labor rates for specific labor classifications
- Pump station electrical consumption
    - Annual Volume Pumped

    - Total Dynamic Head
    - Wire to Water Efficiency
    - Electrical Rate
- Tunnel Length
- Pump Station Capacity

ACT – Conventional Tunnel O&M

Upon completion of a CSO storage tunnel O&M cost estimate from the supplemental materials, the cost can be input to the Conventional Tunnel Module of the ACT in terms of dollars per gallon. From this value, the ACT will provide a present worth analysis of the conventional storage tunnel alternative for comparison with other planning alternatives.

2.3.10 Tank Storage

Off-line tank storage within the collection system can be used to reduce combined sewer overflows (CSOs) or sanitary sewer overflows (SSOs) by storing wet-weather flows. After an event, the stored combined sewage and flushed solids would be conveyed to the existing interceptor system (by gravity or pumping) for treatment at the treatment plant.

A costing curve for tank storage was developed for the ACT based on tank storage costing curves used for other CSO control programs around the nation, as well as cost data of completed storage tanks in varying CSO and SSO storage applications. The following items are included in the cost estimation equation for surface storage facilities:

- A below-grade, cast-in-place, covered storage tank between 0.1 and 30 MG of storage.
- Each tank includes an automated flushing system.
- Odor control is required.
- A control building is required.

If pumping into the surface storage facility is required or if it must be dewatered via pumping, the pump station is to be provided in a separate structure, and its costs are accounted for separately in the ACT. Dewatering pumping is required if gravity dewatering time exceeds 48 hours from the end of an event.

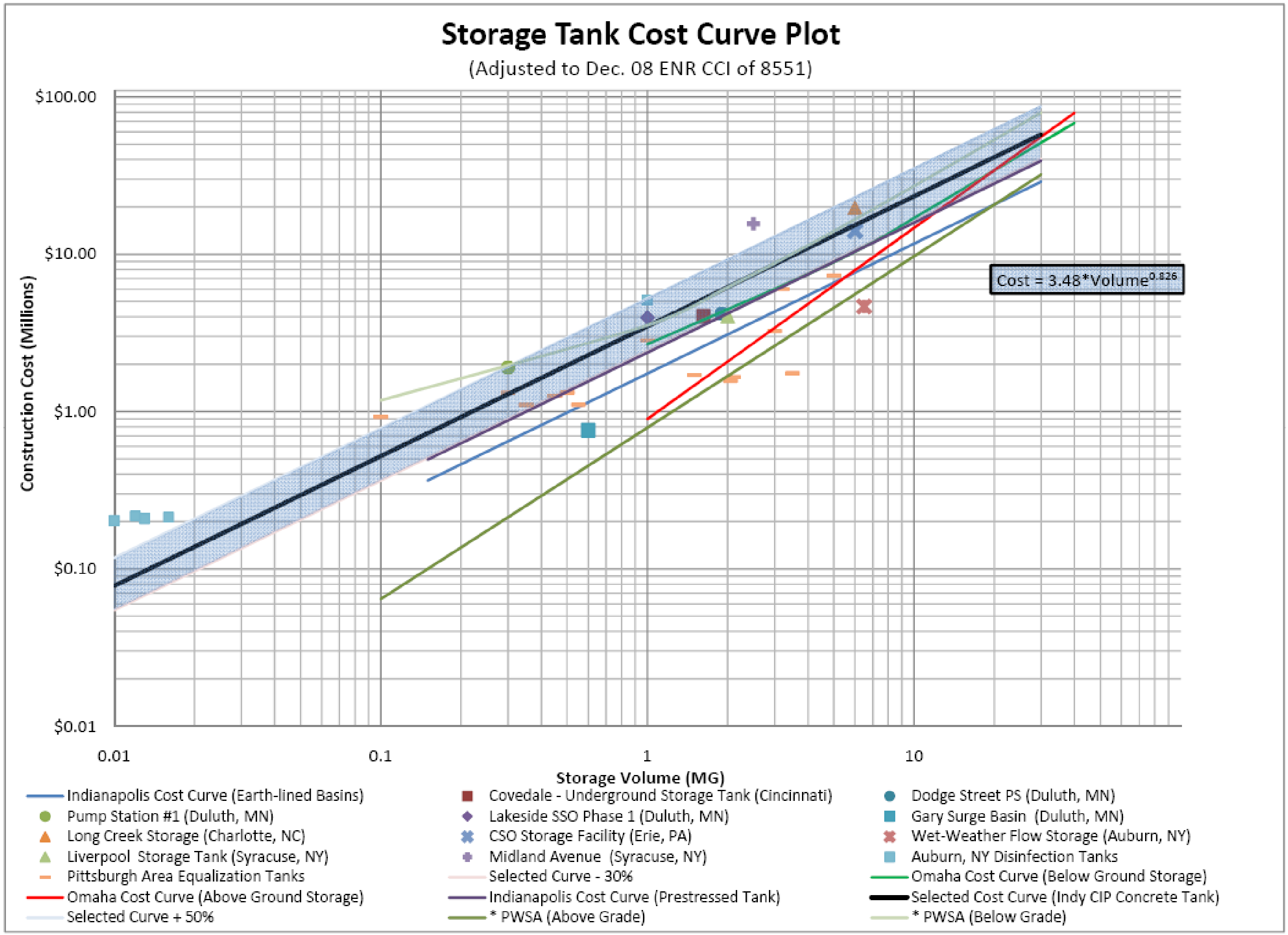
Conveyance from the existing collection system to the storage facility or from the facility to the interceptor will be accounted for separately in the ACT.

Figure 2.3.10-1 displays the plot of the data used for determining the storage tank cost curve for the ACT. The user must input the tank storage to calculate the initial facility cost. The equation for the storage tank costing curve is:

$$y = 3.48x^{0.826}$$

Where y equals cost in million dollars and x equals the storage volume in MG

O&M Costs for CSO storage tanks were estimated based on the WEFTEC07 approach for CSO/SSO facility O&M. This methodology is used for Retention Treatment Basins as well.



* Source: PWSA *Basis of Cost for CSO Control Technologies* , March 2007

Figure 2.3.10-1 Storage Tank Cost Curve [ENRCCI 8551; RS MEANS 100]

2.3.11 Screening

While screens serve as a pre-treatment device in several types of high rate treatment facilities, fine screens can also serve as a stand-alone CSO control measure with disinfection. With screen sizes ranging from 4 to 6 mm, these facilities can be very effective at removing floatables, including sanitary trash.

Screening facility costs are estimated as a standalone technology within the ACT. However, since screening facilities are not designed to remove fecal solids, disinfection generally must be achieved via chlorination and dechlorination. Chlorination/dechlorination facilities are included in the ACT as a separate control technology, and described further in Section 2.3.15 of this manual. For disinfection at screening facilities, the use of sodium hypochlorite for chlorination and sodium bisulfite for dechlorination will be the default assumptions. Any wastewater pumping required as part of the screening facility will be accounted for separately in the ACT; Section 2.3.6 details pump station cost estimation within the ACT.

The cost curve equation for screening was developed from construction cost data provided by the PM, BC, and BPs, as well as cost curves from other CSO control programs around the nation. The curve is displayed in Figure 2.311-1. The equation of the selected curve for screening is:

$$y = 0.0834x^{0.843}$$

Where y equals construction cost in million dollars, and x equals treatment capacity in MGD

From the equation of the selected curve, the user is to input the design flow rate in MGD.

O&M costs for screening facilities are estimated based on the WEFTEC07 approach for CSO/SSO facility O&M. An example O&M calculation for a screening facility is provided below.

Example Calculation for Determination of O&M Costs for Screening Facilities

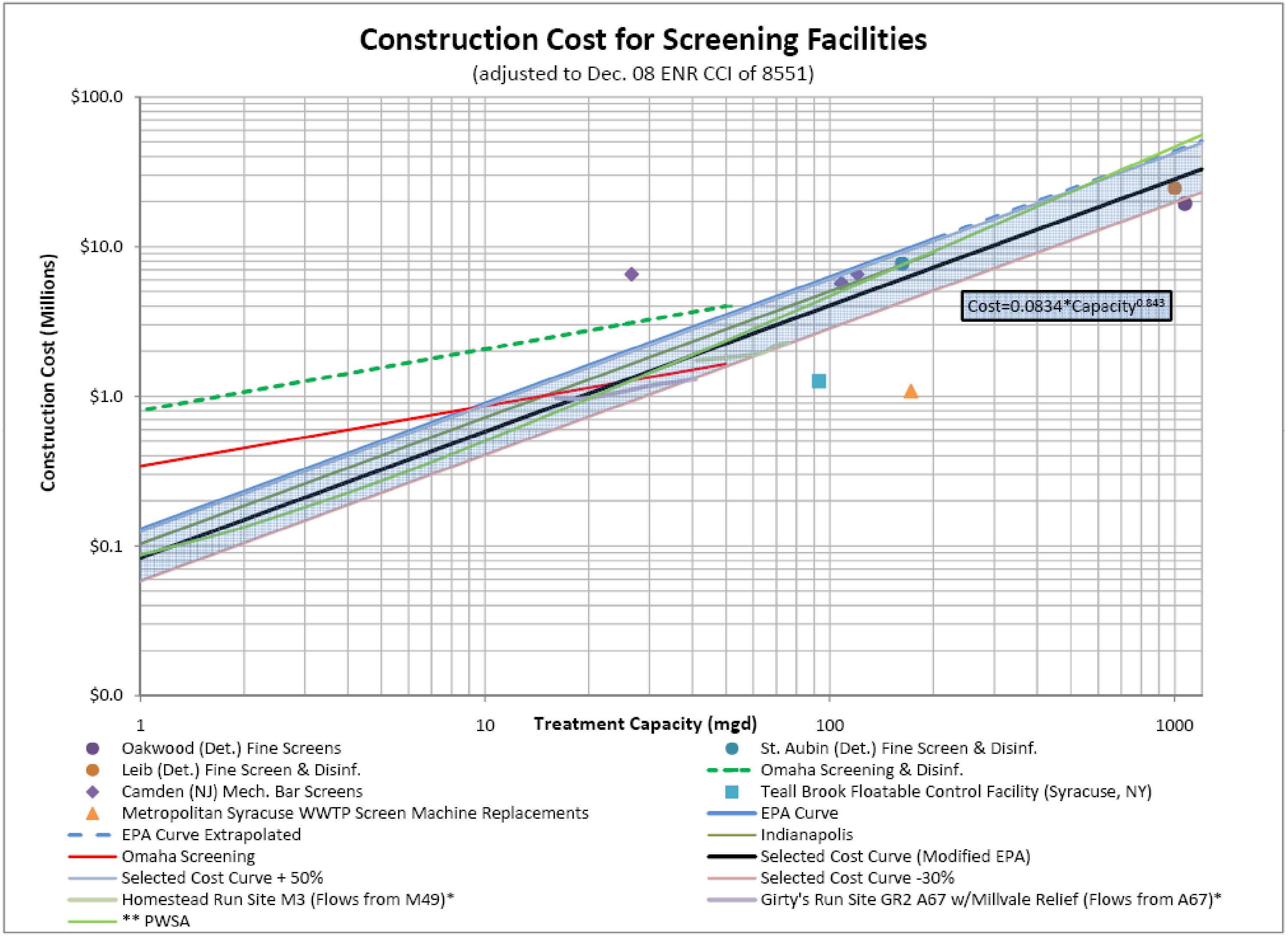
Notes:

1. *Input variables are highlighted in yellow.*
2. *O&M Costs for chlorine disinfection are included*

	Annual "Task" Hours	***Annual Staff Hours***	***Hourly Rate***	***Annual Costs***
Annual Number of Non-Task Hours per Full-Time Employee	480			
Maintenance				
Supervisory Maintenance	80	104	$150	$15,600
Non-Supervisory Maintenance	1570	2041	$100	$204,100
Total:	1650	2145		$219,700
Annual Event-Hrs*	800			
Operations				
Supervisory Operations (0.6 hours / event hour)	480	624	$150	$93,600
Non-Supervisory Operations (3.6 hours / event hour)	2880	3744	$100	$374,400
Total:	3360	4368		$468,000
Non-Staff Resources ($70,000 / year)				$70,000
Total Annual O&M Costs				**$757,700**

Source: Budget Development for Operations/Maintenance Requirements for CSO/SSO Control Facilities, WEFTEC 2007.

* Annual event hours include pre-event, treatment and post-event periods as defined in the WEFTEC source paper.



* Source: *ALCOSAN Overflow Control Facilities Alternatives* , August 2008

** From PWSA *Basis of Costs for CSO Control Technologies* , March 2007

Figure 2.311-1 Screening Facility Construction Cost Curve [ENRCCI 8551; RS MEANS 100]

2.3.12 Vortex Separation

Vortex separator capital cost and operations and maintenance costs were assumed to be similar whether they are built at an existing water pollution control plant or at satellite locations. Planning-level estimates of their costs are described in Analysis of Wet Weather Alternatives for Southeast WPCP, Supplemental Documentation Volume 10.

2.3.13 Retention Treatment Basins

Retention treatment basins (RTBs) are satellite HRT facilities designed to provide screening, settling, skimming (with a fixed baffle) and disinfection of combined sewer flows before discharging to the receiving water. RTBs serve to capture combined sewage during small wet weather events and are gradually dewatered after the event for treatment at a wastewater treatment plant. In larger events, RTBs will begin to overflow and discharge treated effluent, but the captured volume left at the end of the event is also dewatered for treatment.

RTBs can be designed with a variety of screen types, disinfection methods and basin geometries. The surface loading rates can also vary but are typically higher than rates used for design of primary clarifiers. RTBs can be constructed above or below grade but typically require at least an above-grade process/control building. If pumping of the combined sewer flow is required, the pump station may be integral to the RTB facility or constructed as a separate structure.

For planning purposes, all RTBs will be assumed to be configured as described below. The RTB facilities are assumed to include:

- Coarse, mechanically cleaned bar screens at the headworks of the facility.
- Disinfection via chlorination using sodium hypochlorite with sodium bisulfite dechlorination. The basins are sized to achieve the design chlorine contact time at the design flow rate with no additional volume for pre-disinfection settling. The tool allows for an assumed design contact time of 10 to 30 minutes at design flow.
- A settling/contact basin with flushing provisions. Assumed rectangular basin configuration with side water depths to approximately 20 ft.
- Captured volume including solids are dewatered to the interceptor.
- A fixed baffle located just upstream of the effluent weir to provide skimming.
- Provisions to dewater the facility to the interceptor system, including pumping if required.
- An option for an above or below ground facility, which will be covered with odor control.
- A building for screenings removal, chemical storage, electrical and process control.
- A basin divided into two parallel compartments just below grade, with an effluent weir and geometry based on a design surface overflow rate of 6,000 gallons per day (gpd)/square foot (sf).
- If pumping is required, it will be provided in a separate structure. Its costs will be accounted for separately in the ACT.

Design factors to be input into the ACT by the user will include:

- Design flow rate

- Chlorine contact time

Figure 2.3.13-1 displays the selected retention treatment basin facility cost estimating curve and equation, and is considered a construction cost with overhead, profit and indirect costs included.

Given the unique nature of RTBs, actual facility construction costs from around the country are a good source for developing planning level costs. In the mid to late 1990's, a number of retention treatment basins were constructed in Michigan as part of the Rouge River National Wet Weather Demonstration Project. Due to the readily available actual construction cost data for each of these RTBs, nine were selected to serve as the basis for deriving planning level construction costs.

The verified data was plotted with facility volume as the dependant variable. As a test of fit, a USEPA cost curve[1] for tank storage capital costs was plotted to determine any fit with the RTB actual construction cost data. The EPA curve was used due to the similar structural configurations among tank storage and RTBs, and that this particular cost curve was based on a large, wide ranging data set. The curve was updated for time, and modified by a factor of 50% for a more complete fit with the verified data points. The resulting curve fit well enough to render it the selected curve for costing RTB capital costs. All verified points are displayed in Figure 2.3.13-1 along with the selected costing curve. The cost equation from the selected curve is:

$$y = 9.72x^{0.826}$$

Where y equals construction cost in million dollars, and x equals facility volume in MG

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[1] *Combined Sewer Overflow Control*, United States Environmental Protection Agency, September 1993

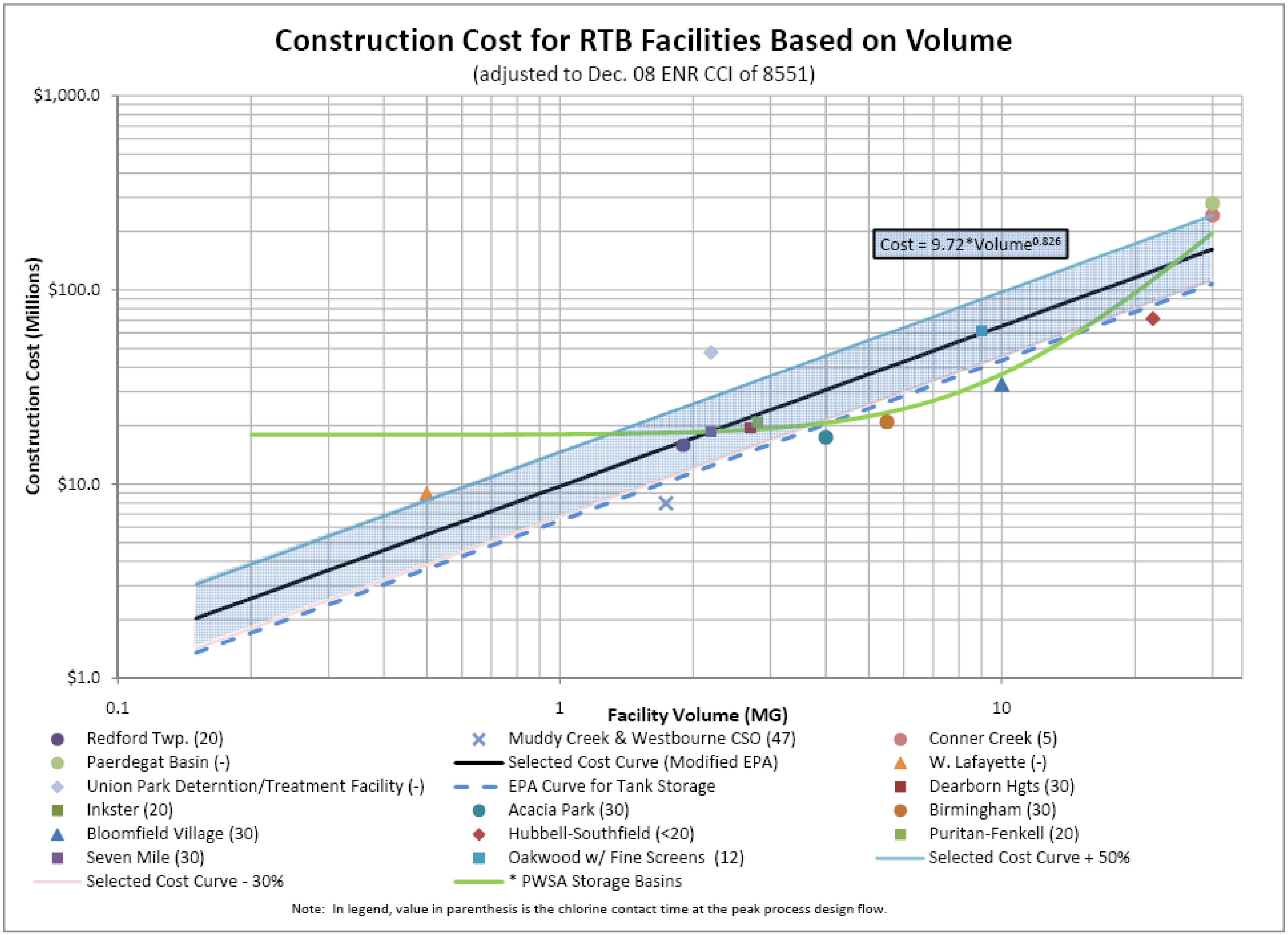


Figure 2.3.13-1 Retention Treatment Basin Cost Curve based on Facility Volume [ENRCCI 8551; RS MEANS 100]

RTB O&M Costs

O&M cost estimates for RTBs were developed based on the WEFTEC07 approach for CSO/SSO facility O&M. An example calculation is provided below, and Figures 2.3.13-2 through 2.3.13-4 display supplemental estimate curves based on the WEFTEC approach.

Example Calculation for Determination of O&M Costs for Retention Treatment Basins

Note: Input variables are highlighted in yellow.

Peak Treatment Rate (MGD)	250				
Design Chlorine Contact Time (minutes)	20				
Basin Volume (MG)	3.47				
	Annual "Task" Hours	***Annual Staff Hours***	***Hourly Rate***	***Annual Costs***	***Notes***
Annual Number of Non-Task Hours per Full-Time Employee	480				
Total Maintenance	2319				See Figure 2.3.13-2 for curve & equation**
Supervisory Maintenance (15% of total)	348	452	$89	$40,255	
Non-Supervisory Maintenance (85% of total)	1972	2563	$54	$138,403	
Annual Event-Hrs*	1400				
Total Operations	2955				See Figure 2.3.13-3 for curve & equation**
Supervisory Operations (11% of total)	325	423	$92	$38,881	
Non-Supervisory Operations (89% of total)	2630	3419	$63	$215,422	
Non-Staff Resources				$98,642	See Figure 2.3.13-4 for curve & equation**
			Total Annual O&M Costs	**$531,604**	

Source: Budget Development for Operations/Maintenance Requirements for CSO/SSO Control Facilities, WEFTEC 2007.

* Annual event hours include pre-event, treatment and post-event periods as defined in the WEFTEC source paper.

** Curves obtained from cited source.

Estimated Data Points from Reference

Basin Size (MG)	Annual Manhours
2.5	1400
3.75	2600
5	3300
7.5	4400
10	5300
12.5	5800
15	6400
20	7100
25	7800
30	8300
35	8700
40	9100

Assumed Straight-Line Extrapolation at Low End

Basin Size (MG)	Annual Manhours
0	500
2.5	1411

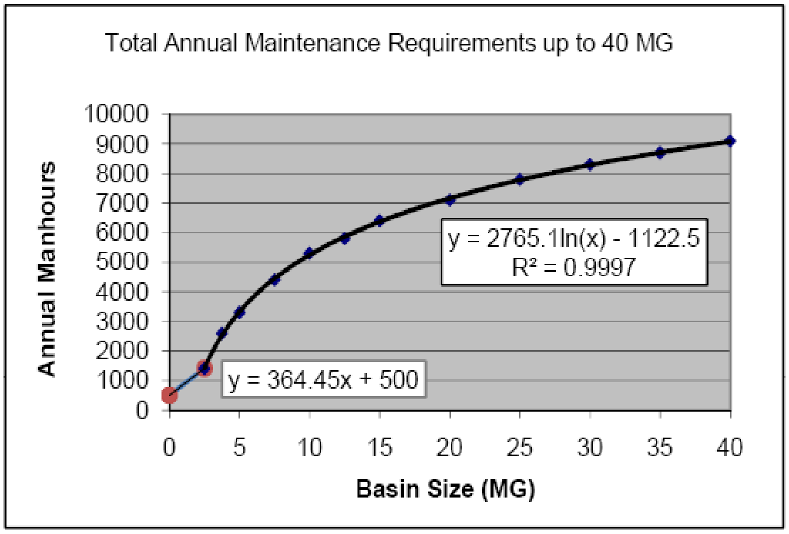


Figure 2.3.13-2 Typical Annual Maintenance Staff for RTBs [ENRCCI 8551; RS MEANS 100]

Estimated Data Points from Reference

Annual Event-Hrs	Annual Manhours
250	1000
500	1750
750	2250
1000	2550
1500	3050
2000	3300
2500	3700
3000	3800
3600	4050

Assumed Straight-Line Extrapolation at Low End

Annual Event-Hrs	Annual Manhours
0	0
250	979

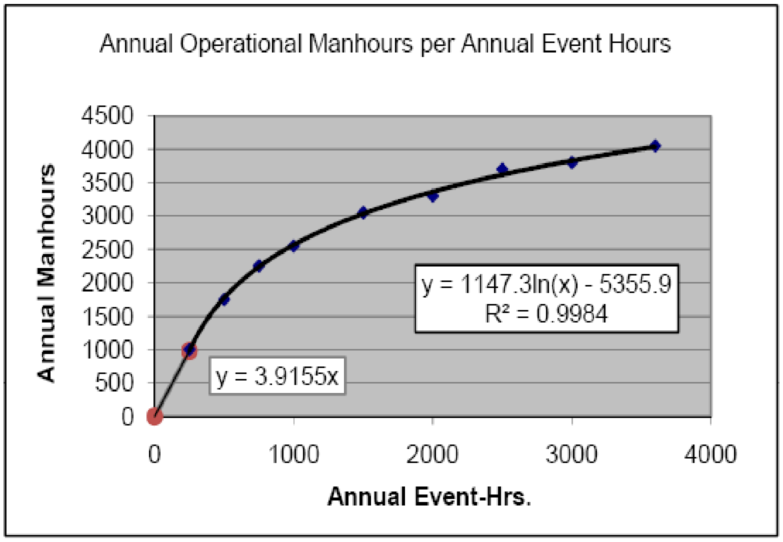


Figure 2.3.13-3 Typical Annual Staff Operation for RTBs [ENRCCI 8551; RS MEANS 100]

Estimated Data Points from Reference

Basin Size (MG)	Annual Non-Staff Resources ($)
2.5	$70,000
3.75	$110,000
5	$137,500
7.5	$175,000
10	$210,000
12.5	$235,000
15	$255,000
20	$290,000
25	$320,000
29	$340,000

Assumed Straight-Line Extrapolation at Low End

Basin Size (MG)	Annual Non-Staff Resources ($)
0	0
2.5	$62,585

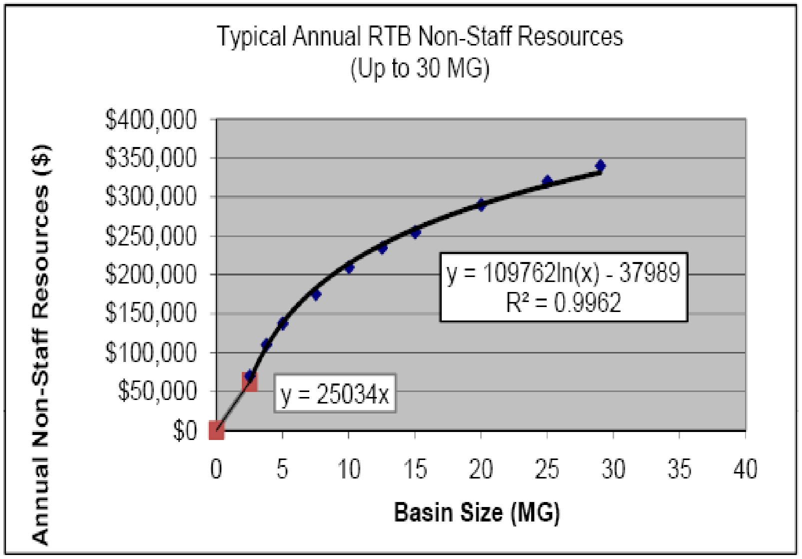


Figure 2.3.13-4 Typical Annual Non-Staff Resources for RTBs [ENRCCI 8551; RS MEANS 100]

Table 2.3.13-1 – Miscellaneous RTB Construction Cost Multipliers applied in ACT [ENRCCI 8551; RS MEANS 100]

Description	Units	Value
Foundation Cost Multiplier	%	15%
Sitework Cost Multiplier	%	6%
Dewatering Multiplier	%	2%
Dechlorination Multiplier	%	3%

Table 2.3.13-2 RTB Design Assumptions used in ACT [ENRCCI 8551; RS MEANS 100]

Description	Value
Overflow Rate	6000 gpd/sf
Footprint Area Multiplier	125%
Basin Freeboard	4 ft

2.3.14 High Rate Clarification

High rate clarification capital cost and operation and maintenance costs were assumed to be similar whether they are built at an existing water pollution control plant or at satellite locations. Planning-level estimates of their costs are described in Supplemental Documentation Volumes 9 through 11.

2.3.15 Disinfection

Disinfection is assumed to be a component of all high rate treatment (HRT) facilities. All costs for disinfection (including contact tanks or conduits) will be included in the cost estimates for applicable alternatives, with sizing scaled to appropriate design flows.

As a default assumption, the equipment and appurtenance costs for chlorination using sodium hypochlorite and dechlorination using sodium bisulfite. However, it is recognized that UV disinfection may be a viable alternative for HRC, and an option to select UV disinfection is included in the ACT.

The users are to select a disinfection type, and input the design flow rate for the disinfection alternative into the ACT.

Figure 2.3.15-1 displays the selected disinfection cost estimating curve and equation.

Chlorination/Dechlorination Construction Costs

The construction cost curve equation for chlorination / dechlorination facilities was developed from the 1993 USEPA report *Combined Sewer Overflow Control*. It was compared to construction cost data provided by other CSO control programs around the nation. The equation of the selected curve for chlorination / dechlorination facilities, displayed in Figure 2.3.15-1 is:

$$y = 0.223x^{0.464}$$

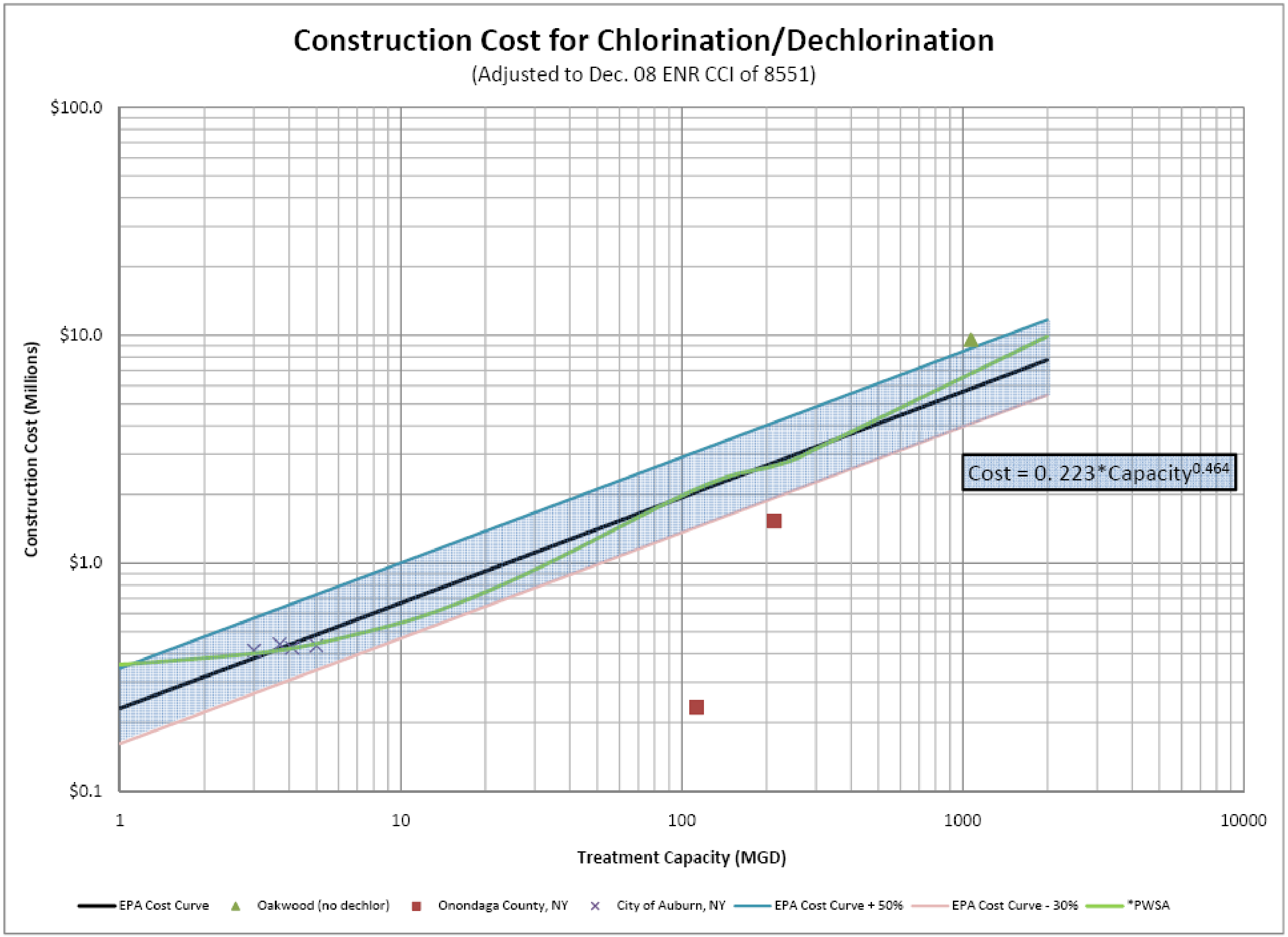
Where y equals construction cost in million dollars, and x equals treatment capacity in MGD.

Ultraviolet Disinfection Construction Costs

The cost curve equation for UV disinfection facilities was developed from the City of Indianapolis *CSO Control Cost Estimating Procedures Memo* which modified a chlorination cost curve found in the 1993 USEPA report *Combined Sewer Overflow Control*. It was compared to cost curves from other CSO control programs around the nation. The equation of the selected curve for ultraviolet disinfection, displayed in Figure 2.3.15-3 is:

$$y = 0.719x + 0.540$$

Where y equals construction cost in million dollars, and x equals treatment capacity in MGD



* Source: PWSA *Basis of Cost for CSO Control Technologies* , March 2007

Figure 2.3.15-1 Chlorination / Dechlorination Construction Cost Curve [ENRCCI 8551; RS MEANS 100]

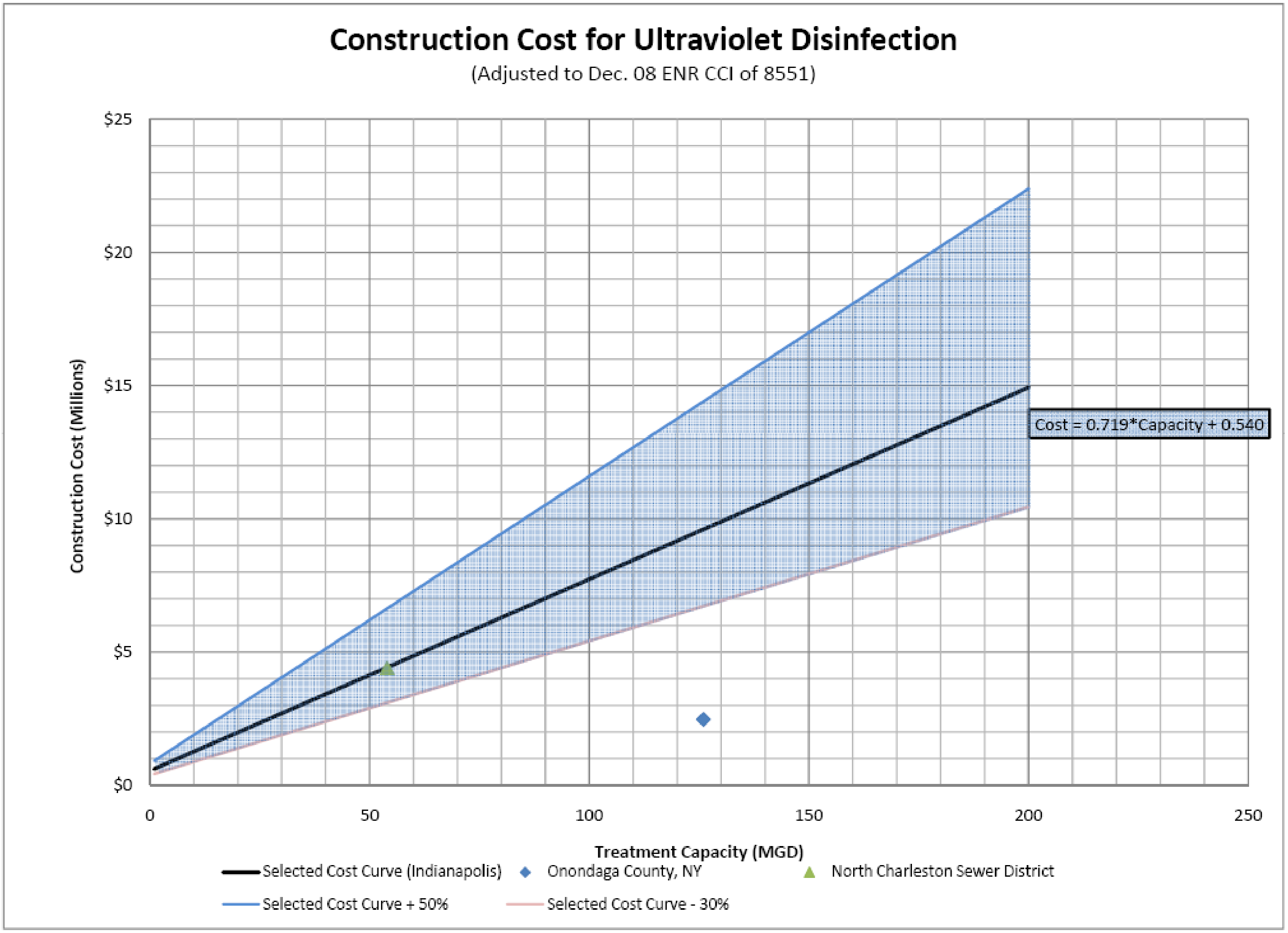


Figure 2.3.15-3 Construction Cost Curve for Ultraviolet (UV) Disinfection [ENRCCI 8551; RS MEANS 100]

Chlorination/Dechlorination & Ultraviolet Disinfection O&M Costs

Disinfection facility O&M cost equations are provided for both ultraviolet disinfection and chlorination/dechlorination facilities. These equations were developed from the City of Indianapolis CSO Program[2], and are based on USEPA curves adjusted to the proper ENRCCI value.

O&M costs for chlorination / dechlorination facilities were derived from the City of Indianapolis *CSO Control Cost Estimating Procedures Memo* which modified a chlorination cost curve found in the 1993 USEPA report *Combined Sewer Overflow Control*. For the ACT, the curve was updated to a base period of December 2008. The resulting cost curve, displayed in Figure 2.3.15-2, is:

$$y = (\text{Current ENRCCI}/6635) * 12.531 * x^{0.614}$$

Where y equals construction cost in $Thousands, and x equals facility capacity in MGD.

O&M costs for UV disinfection facilities were derived from the City of Indianapolis *CSO Control Cost Estimating Procedures Memo* which modified a chlorination cost curve found in the 1993 USEPA report *Combined Sewer Overflow Control*. For the ACT, the curve was updated to a base period of December 2008. The resulting cost curve, displayed in Figure 2.3.15-4, is:

$$y = (\text{Current ENRCCI}/6635) * 5475 * x$$

Where y equals construction cost in dollars, and x equals facility capacity in MGD.

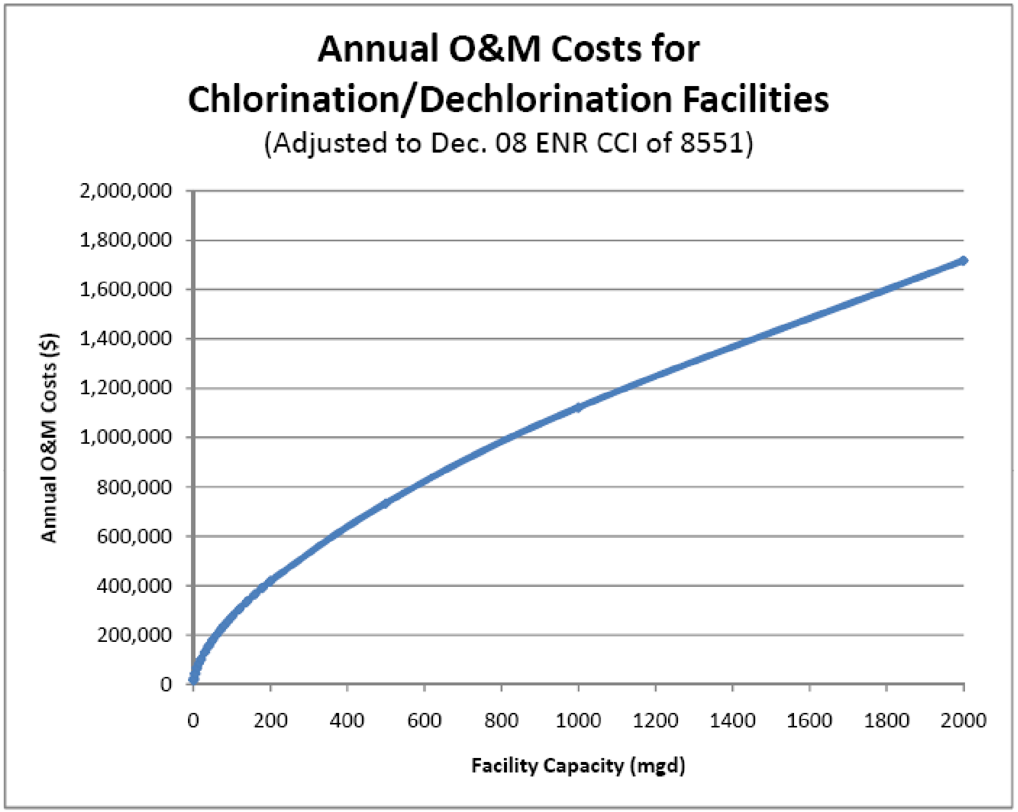
---

[2] *Cost Estimating Procedures for Raw Sewage Overflow Control Alternatives Evaluation.* City of Indianapolis, September 2003.

Base ENRCCI: **8,551**

Cost Table for New CSO Chlorination/Dechlorination Disinfection Treatment Facilities

Facility Capacity (mgd)	Annual O&M Cost ($)
1	16,149
2	24,716
5	43,383
10	66,398
15	85,167
20	101,622
30	130,348
40	155,531
50	178,370
60	199,498
70	219,303
80	238,040
90	255,893
100	272,994
120	305,331
140	335,642
160	364,320
180	391,643
200	417,817
500	733,366
1000	1,122,415
2000	1,718,000



The cost table above is based on the following conditions:

1. Annual O&M costs are derived from the USEPA construction cost curves using the current ENRCCI, which is an acceptable estimate between a range of 1 and 2000 mgd.
2. Curve defined by the equation below is based on the use of sodium hypochlorite and sodium bisulfite.

Annual O&M Cost Equation:

Cost ($Thousands) = (Current ENRCCI / 6635) * 12.531 * $Q^{0.614}$

*6,635 was the ENRCCI from March 2003.

*Q = Facility Capacity (mgd)

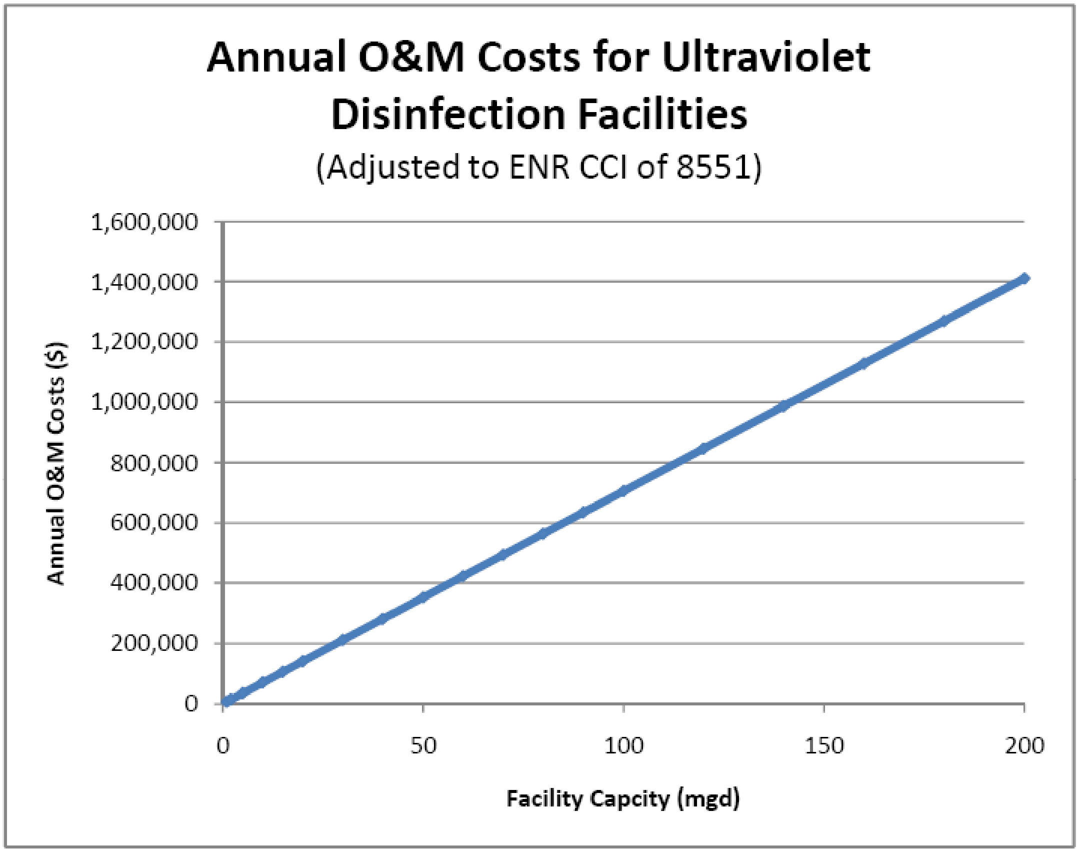
Source: USEPA Cost Curves as Reported in Indianapolis CSO Control Cost Estimating Procedures Memo

Figure 2.3.15-2 O&M Cost Curve for Chlorination / Dechlorination Facilities [ENRCCI 8551; RS MEANS 100]

Base ENRCCI: **8,551**

Cost Table for New CSO UV Disinfection Treatment Facilities

Facility Capacity (mgd)	Annual O&M Cost ($)
1	7,056
2	14,112
5	35,280
10	70,560
15	105,840
20	141,120
30	211,681
40	282,241
50	352,801
60	423,361
70	493,922
80	564,482
90	635,042
100	705,602
120	846,723
140	987,843
160	1,128,964
180	1,270,084
200	1,411,205



The cost table above is based on the following conditions:

1. Annual O&M is estimated between a range of 1 and 100 mgd based on recent author references (Cotton et al.) as cited in Indianapolis CSO Program documentation.

Annual O&M Cost Equation:

Cost ($M) = (Current ENRCCI / 6635) * 5475 * Q

*6,635 was the ENRCCI from March 2003.

*Q = Facility Capacity (mgd)

Figure 2.3.15-4 O&M Cost Curve for Ultraviolet (UV) Disinfection [ENRCCI 8551; RS MEANS 100]

3.0 LIFECYCLE COSTS

3.1 Introduction to Lifecycle Costs

The user will be evaluating alternative control elements (e.g., storage vs. satellite treatment) and control alternatives. Control alternatives are arrays of control elements (e.g., a relief interceptor and one 5-mg storage tank at the bottom of the sewershed vs. two 2-mg tanks along the existing interceptor) to provide the same level of watershed-wide wet-weather control.

The various control elements and control alternatives will be compared economically based on comparative life cycle costs. Lifecycle costs are the total costs of building, operating and maintaining a control element for the planning period of the WWP.

3.2 Planning Period and Temporal Framework

The ACT allows for user-specified construction end dates and construction duration periods for each control implemented.

3.3 Present Worth Analysis

Lifecycle costs of alternative control elements will be compared based on their respective present worth. The ACT will calculate the present worth of control elements based on the design parameters entered by the user.

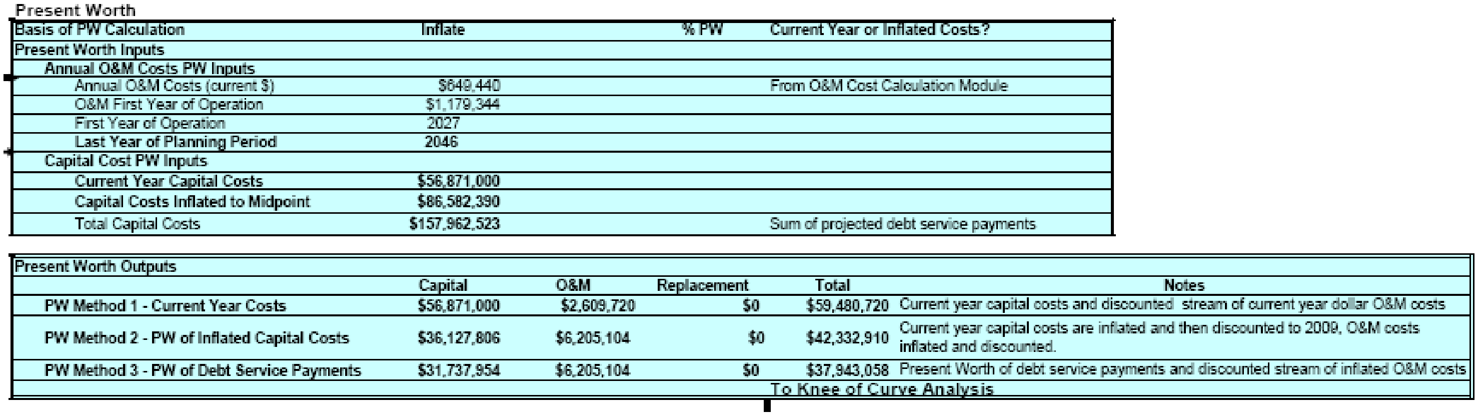
Present worth is the value, expressed in present dollars of the capital costs and the stream of future O&M costs generated by a control element. Calculating the present worth of alternative control elements allows for comparisons between various mixes of capital and O&M costs over the planning period.

The ACT calculates present worth for capital costs, O&M and replacement costs in three different ways. For analysis of alternatives, The City of Philadelphia's Long Term Control Plan Update describes costs and benefits derived using method 2.

> **Method 1** – **Current Year Costs –** Costs are not inflated under Method 1. Capital costs are expressed in current dollars. O&M costs are expressed in current dollars. The current year value of the future stream of O&M payments are discounted back to the current year, as are future replacement costs. This methodology is simplistic but obviates the complexities involved in predicting inflation rates and the mid-point of construction.
>
> **Method 2** (default in ACT)– Under Method 2, current year capital costs are inflated to the mid-point of construction at the input capital costs inflation rate and then deflated back to current year using the discount factor. O&M costs are inflated to the years of implementation and the inflated stream of costs is discounted back to the current year. Replacement costs are inflated to the replacement year and then discounted back.
>
> **Method 3** – Method 3 recognizes the reality of bond financing for major capital projects such as wet weather controls and addresses the current value of the future stream of

debt service payments. Capital costs are inflated to midpoint of construction. Debt service payments, based on the inflated capital costs are then discounted as a stream of future payments back to current year. O&M costs are inflated to the years of implementation and the inflated stream of costs is discounted back to the current year. Replacement costs are inflated to the replacement year and then discounted back.

An example of the results of these three methodologies is shown below on Figure 4.3-1 excerpted from the ACT Schematic diagram, provided in Appendix A to this document.



Present Worth

Basis of PW Calculation	Inflate	% PW	Current Year or Inflated Costs?
Present Worth Inputs			
Annual O&M Costs PW Inputs			
Annual O&M Costs (current $)	$649,440		From O&M Cost Calculation Module
O&M First Year of Operation	$1,179,344		
First Year of Operation	2027		
Last Year of Planning Period	2046		
Capital Cost PW Inputs			
Current Year Capital Costs	$56,871,000		
Capital Costs Inflated to Midpoint	$86,582,390		
Total Capital Costs	$157,962,523		Sum of projected debt service payments

Present Worth Outputs					
	Capital	O&M	Replacement	Total	Notes
PW Method 1 - Current Year Costs	$56,871,000	$2,609,720	$0	$59,480,720	Current year capital costs and discounted stream of current year dollar O&M costs
PW Method 2 - PW of Inflated Capital Costs	$36,127,806	$6,205,104	$0	$42,332,910	Current year capital costs are inflated and then discounted to 2009, O&M costs inflated and discounted.
PW Method 3 - PW of Debt Service Payments	$31,737,954	$6,205,104	$0	$37,943,058	Present Worth of debt service payments and discounted stream of inflated O&M costs

To Knee of Curve Analysis

Figure 4.3-1 – Example of Present Worth Methodologies within the ACT

Land Costs

Land acquisition costs will be entered into the present worth calculations at current (2009) values and will be inflated by the ACT if the inflation function is activated. As discussed more fully in Section 2.1.4 of this document, estimated land acquisition costs will be provided by the user due to the location specific nature of the potential cost, and inputted by the user into the ACT for the specific alternative run. Where the control element may reasonably be contained within an existing ROW or if the land requirements for various alternatives are substantially identical, it might be reasonable to omit land acquisition costs from the present worth analysis.

Salvage Value

The ACT does not account for the salvage value of control elements.

3.4 Replacement Costs

Because of the long planning period, mechanical equipment and depending on the initiation of operation, potentially structural facilities will be at the ends of their respective useful lives prior to the end of the planning period. Therefore, replacement costs for equipment or structural facilities requiring replacement or substantial rehabilitation prior to 2048 must be included in the present worth analysis.

The user has the option of inputting a replacement cost and a renewal/replacement frequency for applicable equipment in an alternative. The ACT calculates the present value of these replacement costs given the user input values and the default planning period.

4.0 References

The Association for the Advancement of Cost Engineering. 2005. Cost Estimate Classification System – As Applied in Engineering, Procurement, and Construction for the Process Industries (AACE International Recommended Practice No. 18R-97).

Center for Watershed Protection. 2007. Urban Subwatershed Restoration Manual No. 3 Urban Stormwater Retrofit Practices Version 1.0. Ellicott City, Maryland.

ECONorthwest. 2007. The Economics of Low-Impact Development: A Literature Review. Eugene, Oregon.

Philadelphia Water Department. 2008. Philadelphia Stormwater Management Guidance Manual Version 2.0.

United States Environmental Protection Agency. 1993. Combined Sewer Overflow Control (625/R-93/007).

United States Environmental Protection Agency. 1980. Innovative and Alternative Technology Assessment Manual (430/9-78-009).

Philadelphia Combined Sewer Overflow Long Term Control Plan Update

Supplemental Documentation
Volume 4

Hydrologic and Hydraulic Modeling

Updated: September 1, 2009

V4.1 BASELINE MODEL DEVELOPMENT

Development of the baseline model for the LTCPU was significantly important. The baseline model is the foundation from which all alternatives were built and resulting data compared against. Accurately simulating the current hydrologic conditions and hydraulic infrastructure was essential to producing valuable and reliable results. The methods and input data utilized in order to create the baseline model with respect to the hydrology, hydraulics and the calibration and validation, are discussed in the subsections following. Detailed analyses of the Water Pollution Control Plants (WPCP) for the Southeast, Northeast and the Southwest Drainage Districts (SEDD, NEDD and SWDD) were performed to determine the WPCP treatment capacities, pumping rates, WPCP piping and head works. The WPCPs exiting conditions were used for each of the baseline models. The maximum treatment rate for the SEDD WPCP (SEWPCP), NEDD WPCP (NEWPCP) and SWDD WPCP (SWWPCP) used for the baseline models were 280 mgd, 435 mgd and 480 mg respectively. Please refer to the supplemental documentation volume numbers 6, 7 and 8 for stress testing of the WPCPs.

v4.1.1 Hydrologic Model Development

The baseline model was developed using the EPA-SWMM4 software. The RUNOFF module in SWMM4 requires the input of several physical parameters to determine the rainfall-runoff response from modeled combined-sewer and separate sanitary sewer subcatchments.

- Subcatchment area
- Subcatchment width (used to determine overland flow length)
- Percent directly connected impervious area (effective impervious area)
- Subcatchment ground slope
- Manning’s roughness coefficient for both pervious and impervious areas
- Depression storage for both pervious and impervious areas (initial abstraction)
- Soil infiltration parameters
- Rainfall dependent inflow and infiltration parameters
- Baseflow ranges
- Precipitation input data
- Evaporation input data

Each parameter is discussed in greater detail in the following subsections.

Subcatchment Area

Natural stormwater drainage subcatchment area can be determined by constructing drainage divides on topographic maps and is dependent upon the detail of the topographic information. Combined sewer subcatchment area is determined based on detailed sewer plans within the City and the topographic maps needed to determine surface drainage to sewer inlet locations. The delineation of sanitary sewer subcatchment area inside the City is based on detailed sewer plans. Subcatchment areas outside of the City were delineated with a tool in ArcView using USGS 30-meter DEMs to identify drainage divides. Subcatchment areas within the City were defined based on detailed sewer plats. The RUNOFF model represents all stormwater runoff subcatchments as rectangular areas defined by the subcatchment width parameter. RUNOFF simulates surface runoff from drainage areas using three "planes" of overland flow. One plane represents all impervious surfaces directly connected to the hydraulic system and include initial abstraction or surface detention storage (puddles, cracks, etc.) which do not permit immediate runoff. A second plane represents all pervious areas and impervious areas not directly connected to the hydraulic system. The third plane is defined as the fraction of the directly connected area that provides no detention storage and thus produces runoff immediately. The runoff from the drainage area is the sum of the flow off the three planes. The complete hydrologic model consists of 2098 subcatchments representing the entire PWD service area.

Subcatchment Width

The width of the subcatchment is the physical width of overland flow. Since real subcatchments are not rectangular with properties of symmetry and uniformity, it is necessary to adopt other procedures to obtain the width for more general cases. This is important because if the slope and roughness are fixed, the width can be used to alter the hydrograph shape. For the PWD combined sewer system (CSS) models, width was initially taken to be double the square root of the subcatchment's area and later treated as a calibration parameter.

Directly Connected Impervious Area (DCIA)

The percent imperviousness of a subcatchment is a parameter that can be reasonably estimated from aerial photos or land use maps. However, not all of the impervious area is directly connected to the drainage system, or is "effective" when simulating a hydrologic response from these areas. For example, if a rooftop drains onto a pervious area, this should not be included as directly connected. The total percent impervious area was used as the initial effective impervious area and then reduced during the calibration process to best simulate the observed hydrologic response over a range of precipitation events.

In generating initial estimates of gross impervious cover the following method was employed. For all areas within the City of Philadelphia, GIS coverage of impervious areas derived from 2004 orthodigital photographs was used. This coverage delineates all land use in the City into pervious or "natural surfaces," comprised of lawns, parks, marshes, golf courses, wooded areas and cemeteries, as well as several different classifications of impervious areas. Impervious land uses were broken down into the following types:

- Alleys
- Buildings
- Building Centers
- Concrete/Asphalt Slabs/Patios
- Ditches (Asphalt or Concrete)
- Driveways
- Institutions
- Lakes
- Medians
- Parking
- Pedestrian Bridges
- Parking Islands
- Pond
- Pools
- Railroad Ballast
- Railroad Bridges
- Reservoirs
- Rivers
- Sidewalks
- Shoulders
- Streams
- Tanks
- Travel Bridges
- Travelways

For each RUNOFF subcatchment, the area of these land uses was summed to generate a total impervious area. Impervious areas in each subcatchment were summed and divided by the total area in order to get the first estimate of subcatchment "effective" impervious area.

For residential land uses outside of the City for areas contributing stormwater and do not have any flow monitoring data , population densities were developed using 2000 census and block area data. Two equations, Stankowski (1974) and Manning et al (1987) that use population density as the independent variable to define percent impervious were selected for this modeling application. The equations are expressed as:

Stankowski, $I = 0.117D^{0.792 - 0.039 \log D}$

Manning, $I = 10v4.95\text{-}81.27(0.974)^{PD}$

Where I = Percent impervious
PD = Population density per acre
D = Population density per square mile

Percent impervious estimates for each census block were calculated with both equations. For population densities less than 35 persons per acre (ppa), the Stankowski and Manning equations were averaged. However, only the Manning estimate was used when the population density was greater than 35 ppa. This distinction was made because the Stankowski equation is less accurate for high density urban areas.

Each land use classification was assigned a percent impervious cover based upon regional averages and/or population density. If monitoring data was available for the shed monitoring data was used to reach upon a percent impervious number.

Slope

The subcatchment slope should reflect the average slope along the pathway of overland flow to inlet locations. For a simple geometry, the calculation is the elevation difference divided by the length of flow. Subcatchments containing highway ramps underwent a more technical slope procurement procedure in order to prevent distortion of the slopes due to the grade of the ramp.
ArcGIS was utilized in order to calculate the slopes for these subcatchments. Generally, the topographic lines representing the ramps were removed and new raster layers were created. From the new raster layers, slopes were calculated using the remaining topographic lines.

Manning's Roughness Coefficient

Manning's roughness values must be estimated for both pervious and impervious overland flow. Manning's roughness for impervious surfaces was set to 0.013 and for pervious surfaces to 0.1 or 0.05. Roughness is an empirical value and may be treated as a calibration parameter when necessary.

Depression Storage

Depression (retention) storage is the rainfall abstraction volume that must be filled prior to the occurrence of runoff on both pervious and impervious areas. In RUNOFF, every subcatchment is divided into three subareas: Pervious area with depression storage, impervious area with zero depression storage and impervious area with depression storage. By default, the model assumes 25% of the impervious area has zero depression storage. This default value was not altered in the LTCPU model setup. In the model, water stored as depression storage on pervious areas is subject to infiltration and evaporation. Water stored in depression storage on impervious areas is depleted only by evaporation therefore replenishment of the retention storage typically takes longer when compared to pervious areas. Depression storage is an empirical value and may be treated as a calibration parameter when necessary. Following calibration, impervious depression storage was set as 0.02, 0.05, or 0.1 inches and pervious depression storage was set at 0.15 or 0.1 inches. These values were selected based on literature review and past modeling experience with the City's existing hydrologic models of combined sewer areas.

Pervious Area Infiltration Parameters

The rate of infiltration is a function of soil properties in the drainage area, ground slopes and ground cover. RUNOFF computes the rate of infiltration into the soil using either the Horton method or Green-Ampt method, as selected by the user. In each method, a set of infiltration parameters is required to represent soil properties. For the LTCPU hydrologic model, the Green-Ampt method is used to estimate infiltration rates. The Green-Ampt equation for infiltration has physically based parameters that can be estimated based on soil characteristics. The soil parameters used in this method are:

- Average Capillary Suction
- Saturated Hydraulic Conductivity
- Initial Moisture Deficit

Soil information for the Philadelphia watersheds was obtained at the beginning of the PWD CSO program in the early 1990s. Information was obtained from the U.S. Department of Agriculture's (USDA) Natural Resources Conservation Service (NRCS), which is responsible for collecting, storing, maintaining and distributing soil survey information for privately owned lands in the United States. Initial infiltration parameters were assigned to each subshed based on soil texture classification. Saturated hydraulic conductivity was treated as a calibration parameter.

Flow Routing

Subcatchments are divided into three subareas that represent impervious area with and without depression (detention) storage and pervious area with depression (detention) storage. Overland flow is generated from each of the three subareas by approximating them as non-linear reservoirs. When inputs to the non-linear reservoir (rainfall/snowmelt) exceed the outputs (evapotransporation & infiltration) for any of the three subareas, outflow is generated using the Manning's equation.
The kinematic wave approximation is used as the basic flow routing algorithm across the three planes of flow. This approximation assumes the friction slope is equal to the ground slope of the plane. This flow routing algorithm is applied sequentially to the impervious (with detention) plane, the pervious plane and the impervious (without detention) plane.

Hydrologic routing techniques that apply the kinematic wave approximation algorithms are used to route the overland flow through the pipe, culvert, channel and lake networks as required.

Rainfall Dependent Inflow and Infiltration (RDI/I)

Rainfall-Dependent Inflow and Infiltration (RDI/I) into sanitary sewer systems has long been recognized as a major source of operating problems, causing poor performance of many sewer systems. The three major components of wet-weather wastewater flow into a sanitary system - base wastewater flow (BWF), groundwater infiltration (GWI) and RDI/I are illustrated in Figure v4.1.1 below.

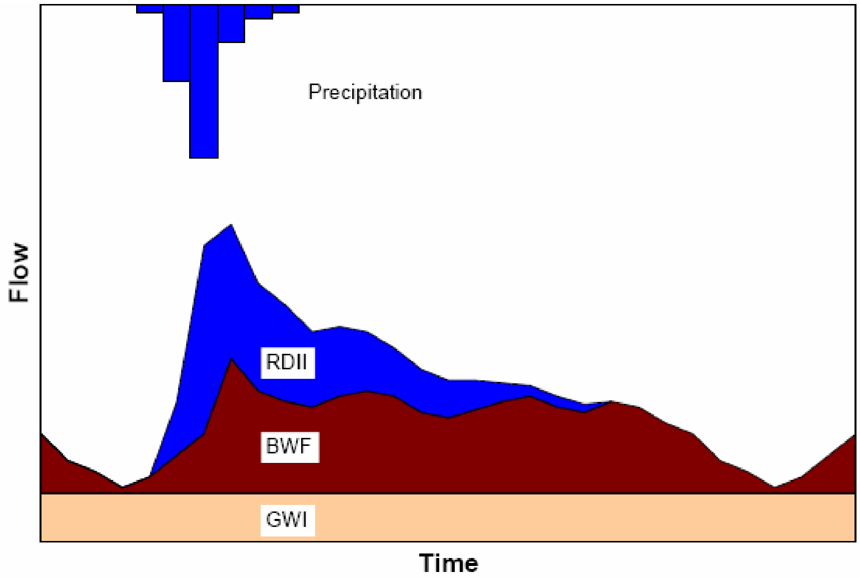


Figure v4.1.1 Three components of wet-weather wastewater flow (EPA, 2007)

The RTK hydrograph generation method to define the RDI/I response for the sanitary sewer systems has two steps. The first step is to define RTK parameters in response to one unit of rainfall over one unit of time. Three unit hydrographs are typically used because the shape of an RDI/I hydrograph is too complex to be well represented by a single unit hydrograph. The RDI/I hydrograph can be generated using less than three sets of R, T and K. However, experience indicates that it often requires three unit hydrographs to adequately represent the various ways that precipitation becomes RDI/I. The first triangle represents the most rapidly responding inflow component and has a T of one to three hours. The second triangle includes both rainfall-derived inflow and infiltration and has a longer T value. The third triangle includes infiltration that may continue long after the storm event has ended and has the longest T value. In this first step, the RTK parameters for each of the three triangles are defined for each unit rainfall over one unit time frame. The sum of the R values for each of the three unit hydrographs (i.e., R1, R2 and R3) must equal the total R value for the rainfall event. Figure v4.1.2 below depicts a summation of three unit hydrographs into a total RDI/I hydrograph in response to one unit rainfall over one unit time frame. This unit hydrograph is described by the following parameters:

- R - The fraction of rainfall volume that enters the sewer system and equals the volume under the hydrograph
- T - The time from the onset of rainfall to the peak of the unit hydrograph in hours

- K - The ratio of time to recession of the unit hydrograph to the time to peak
- A - Sewered area
- P - Rainfall depth over one unit time
- Volume - Volume of RDI/I in unit hydrograph
- Qp - Peak flow of unit hydrograph

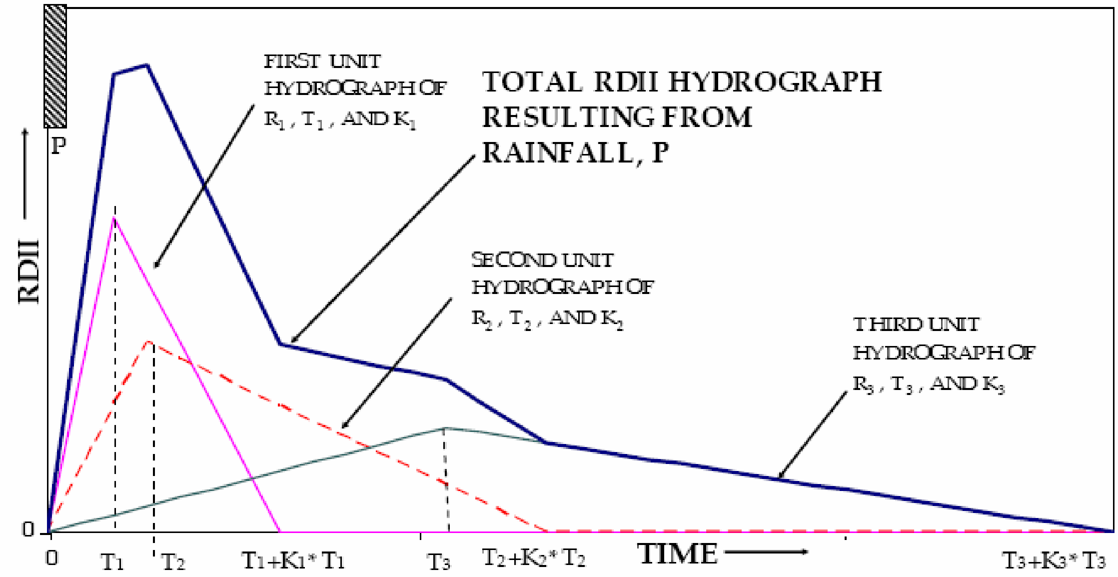


Figure v4.1.2 Summation of three unit hydrographs (EPA, 2007)

RDI/I analysis was performed on sewersheds with separate sanitary sewers contributing to the combined sewer system. This analysis was performed to more accurately account for the excess rain water entering the sanitary sewers through a combination of inflows from directly connected downspout pipes, sump pumps, foundation drains, manhole openings and large defects along streams and infiltration through saturated soils and an elevated groundwater table into small leaks in degraded sewer pipes and joints. RDI/I decrease the available sewer capacity available to convey stormwater runoff through the trunks and into the interceptor. The RUNOFF module uses three sets of unit hydrographs defined by R, T and K values to represent the shape of the RDI/I hydrograph. Please refer to the Model Calibration and Validation section for details on RDI/I parameters used in the model.

Evaporation Input Data

Evaporation data is required by the model in the form of average monthly evaporation rates, although finer time increments may be input as negative flows by creating an evaporation time series. Evaporation data usually can be obtained from the NWS or from other pan measurements.

Limited long-term daily evaporation data exists for the Philadelphia area. Neither the Philadelphia Airport nor the Wilmington Airport records evaporation data. Average monthly evaporation (inches per day) are used for all SWMM4 models determined from New Castle County, Delaware recorded daily evaporation data from 1956 through 1994.

Temperature Input Data and Snowmelt

Temperature time series input data can be used to run a snowmelt routine in SWMM4. The average snowfall volume and frequency for Philadelphia, however, does not account for a significant portion of the average annual precipitation. Therefore, the snowmelt routine was not employed. Instead several snowfall events that occurred during the year 2005, which was selected as the basis for the typical year, were modified to represent snowmelt time series based on PWD non-heated raingage observations, Philadelphia International Airport observed hourly snowfall, daily snow cover and daily maximum temperatures.

The RUNOFF hydrographs are saved in binary format for input to the EXTRAN block of SWMM to perform hydraulic routing in sewer and/or open channel system networks.

v4.1.2 Hydraulic Model Development

This section describes the process by which the Hydraulic models of PWD's combined and separate sanitary sewer system has been developed. The hydraulic model was developed using the EXtended TRANsport (EXTRAN) block of the U.S. EPA's Storm Water Management Model Version 4 (SWMM4; Huber and Dickinson, 1998). The Tier 2 models were developed by refining and adding hydraulic elements to the Tier 1 EXTRAN models. The Tier 1 EXTRAN models in combination with the U.S. Army Corps of Engineers' Storage, Treatment, Overflow, Runoff Model (STORM; Hydrologic Engineering Center, 1977) were used to represent the hydraulic elements and evaluate alternatives for the 1997 LTCP (for more information refer to System Hydraulic Characterization June 27 1995).

The EXTRAN module of SWMM is used to analyze and simulate flow through the combined sewer system. EXTRAN uses a link-node description of sewer and open channel systems facilitating the physical prototype and the mathematical solution of the gradually-varied unsteady flow (St.Venant) equations, which forms the mathematical basis of the model. The links transmit the flow from node to node. The primary dependant variable for the links is discharge. The primary dependant variable for the nodes is head, which is assumed to be changing in time, but constant throughout any one node. To reiterate the list of elements required by SWMM to calculate the flow in the sewers, values for the following variables are necessary:

- Pipes
- Junctions
- Orifices
- Weirs
- Pumps
- Outfalls

The information required to accurately represent these elements within the model were obtained from the return plans (as-built), contract drawings and drainage plats available through the Engineering Records Viewer (ERV) developed by the City of Philadelphia. Values which did not match the drawings were modified to bring them current with plan drawings. Individual descriptions of how these elements are modeled follow below.

Pipes

Pipes are the conveyance element in the EXTRAN models. For the EXTRAN model the following pipe information is required.

- Pipe name.
- Pipe's upstream and downstream nodes
- Initial flow in the pipe.
- Shape of the pipe (the pipes that can be modeled circular, rectangular, horseshoe, egg, basket handle, trapezoidal channel, parabolic/power function channel, irregular (natural) channel, horizontal ellipse, vertical ellipse, arch, bridge).
- Pipe dimensions (depth, width, area, side slopes, power function parameters and natural section data).
- Offsets of pipes (if the pipe does not begin or end at the invert (bottom) of the upstream or downstream node an offset value describing the difference from the bottom of the upstream and or downstream node and the pipe bottom needs was provided).
- Manning's roughness coefficient, the manning's coefficient is usually the property of the pipe's building material. The manning's coefficient may be changed in to account for additional sediment depositions and unintended restriction like rubble in the pipe.
- Minor losses (entrance, exit and additional losses).
- Sediment depth in the pipe.

Very short pipes can cause mathematical instabilities in the model. Short pipes are converted to equivalent pipes that have lengths that will satisfy the courant condition while maintaining the same head loss as the original (this is achieved the manipulating the Manning's roughness coefficient). The following procedures were followed to represent the pipes in the model. Pipes in a branch with the same shape, slope and make material may have been combined together to hydraulically represent one single equivalent pipe. If necessary, minor expansions may have been ignored if occurring between two pipes of the same diameter, slope and same material so as to combine all the section in to one longer stable section. If the need arose to combine pipes of varying capacities, slopes, shapes and make material; the diameter of the resulting section was set equal to the most constricting pipe in the series and the manning's coefficient was adjusted so as an equivalent flow was conveyed and head loss was maintained as the original section. Some of the offsets when the pipe invert is not the same as the node invert may cause mathematical instabilities; if such instabilities were seen a minimal storage was provided to remove the instability and if the problem still persisted the last resort was to change the slope of the pipe so as the pipe invert matched the water surface at the node if the problem still persists then pipe slope was changed to set pipe invert equal to the node invert (when ever the slope of the pipe is changed the manning's coefficient should be changed so that the flow and head loss would match the original section of the pipe). Broadly the pipes in the waste water collectors system can be separated in to 4 categories; trunk sewers that collect sanitary and wet weather flow from house lateral branches, street inlets etc. and bring them to the regulators, the dry weather flow pipes that take all of the dry weather sanitary and a percentage of the wet weather flow to interceptor, the interceptors that collect the flows from the dry weather flow pipes and deliver the flows to downstream interceptor system or the WPCPs, the wet weather overflow pipes that convey the flow that cannot be accommodated in either the dry weather pipes or interceptor to the receiving water.

Junctions (Nodes)

Nodes are the connection points for the pipes. The primary dependant variable for the nodes is head, which is assumed to be changing in time, but constant throughout any one node. Flow and volume continuity are calculated at nodes in the EXTRAN model. The nodes in the model can be actual manholes and places where there is pipe size and or slope and or pipe material change or there is a hydraulic control structure in the pipe network. Nodes at locations where a manhole does not exist were simulated in a manner so as they do not flood out. The following information is required to model a node in EXTRAN:

- Junction Name
- Ground elevation/Top of the node, for manholes with bolted down covers an increase in top of the node higher than the actual top may be provided to mimic the excess head built up that can be handled by the node before the mode floods.
- Invert elevation (Bottom of the junction)
- Constant inflow if any in to the junction, this can be the average dry weather flow that the junction receives from the surrounding sewer sheds (More description about the baseflow distribution can be found in the hydrology section above).
- Initial water depth in the junction above invert
- Junction location data (x,y) for spatial location.
- Junction volume calculation parameters (either default plan surface area (12.6 ft^2) or fixed plan surface area other than default value or power function defining the plan surface areas or set of depth and plan surface area pairs). The volume other than default volumes is required for junctions that mimic storage elements or non-standard manholes or chambers.

In sections where multiple pipes may be combined in to one longer section it is important to keep track of the node that has the lowest top elevation. If flooding occurs in a section of pipes, the hydraulic grade line will be controlled by the node with the lowest top elevation. In these situations the node with the lowest top elevation should be correctly represented so as to get the correct hydraulic representation. The information required to accurately represent the junctions within the model were obtained from the return plans (as-built), contract drawings and drainage plats available through the Engineering Records Viewer (ERV) developed by the City of Philadelphia. Values which did not match the drawings were modified to bring them current with plan drawings.

Orifices

Two types of orifices are used within the LTCPU model, static and variable. Static orifice opening sizes remain constant over the length of a simulation. The variable orifices opening cross-section is controlled by either a set of time closure rules or head level in a control node (this can be any node in the model). EXTRAN internally converts the orifices to equivalent pipes of 200 feet and a manning's coefficient representing the same head loss as the orifice. Following are the parameters necessary to define an orifice in EXTRAN:

- Upstream and Downstream nodes

- Type of orifice (side outlet circular, bottom outlet circular, side outlet rectangular, bottom outlet rectangular, time-history side outlet circular orifice with gated controls, time-history bottom outlet circular orifice with gated controls, time-history side outlet rectangular orifice with gated controls, time-history bottom outlet rectangular orifice with gated controls, side outlet circular orifice with timed closure with gated controls, bottom outlet circular orifice with timed closure with gated controls, side outlet rectangular orifice with timed closure with gated controls, bottom outlet rectangular orifice with timed closure with gated controls, side outlet circular orifice with head-dependent gated control, bottom outlet circular orifice with head-dependent gated control, side outlet rectangular orifice with head-dependent gated control, bottom outlet rectangular orifice with head-dependent gated control)
- Orifice coefficient
- Orifice offset from the bottom of the junction invert.
- Dimensions of the orifice (depth, width area).
- Orifice control information (time history data for timed closure orifices, node from which the controls are based on, orifice completely open cross-sectional area, orifice completely closed cross-sectional area, rate of orifice closure and flow direction restrictions.)

If the static orifice causes mathematical instabilities then they may be modeled in the EXTRAN model as equivalent pipes that mimic the same flow characteristics and head loss as the orifice. The information required to accurately represent the orifices within the model were obtained from the return plans (as-built), contract drawings and drainage plats available through the Engineering Records Viewer (ERV) developed by the City of Philadelphia. Values which did not match the drawings were modified to bring them current with plan drawings.

Weirs

For all EXTRAN models used in LTCPU analyses all weirs were modeled as equivalent pipes with the head loss and flow characteristics simulating those that would be produced from a weir. The information required to model a weir is:

- Upstream and downstream junctions for the weir.
- Type of weir
- Weir length and height to the crest of the weir
- Weir coefficient.

The information required to accurately represent the weirs within the model were obtained from the return plans (as-built), contract drawings and drainage plats available through the Engineering Records Viewer (ERV) developed by the City of Philadelphia. Values which did not match the drawings were modified to bring them current with plan drawings.

Pumps

Pumps in EXTRAN are modeled to lift the flows to a higher head at a pre-specified rate. Pumps can be offline pumps that pump flow based on the volume in the pumped junction. The pump curve is defined by three pump rates and three corresponding pump volumes measured at the pumped junction. The pump rates remain constant between each volume in the pumped junction. Another type of pump is the inline pump where the pump rate depends on the head level in the pumped junction. Three sets of head level and respective pump rates are provided with the pump rate remaining constant between each head level. EXTRAN allows simulation of a three-point head discharge pump. The pumping rate depends on the water level difference between the pumped junction and the discharge junction. A set of differential head and pump rate pairings is provided and the pump rate varies linearly between each head and pump rate pair. The fourth type of pump that can be modeled is the variable speed inline pump. In this type of pump the pump rate is based on the depth in the pumped junction. Pumping rate varies linearly between input depth in the pumped junction and the pump rate pairs. Lastly, a lift station type pump may be simulated. This pump type more realistically simulates the operation of a typical pump station. The pump rates are provided for each of the pumps and each one turns on at a given depth and stays on until the depth goes below the "pump-off" depth. Pump station and WPCP data, wet well depths and corresponding pumping rates were studied to determine the type of pump and curves used for the EXTRAN model. For all the models used in the LTCPU analysis the variable speed inline pump mentioned above was used. To model a pump the following information is required:

- Pump Type
- Pumped junction name
- Pump discharge junction name
- Pairs of pumped junction depth and corresponding pump rates
- Volume of wet well (for the offline pump)
- Pump on and off water levels in the pumped junction.

The information required to accurately represent the pumps within the model were obtained from either pump station monitoring data or pump manufacturer's specification sheets.

Outfalls

Outfalls are the discharge points in the EXTRAN models. The outfalls can either have a boundary condition that the head has to overcome for outflow to occur or the outfalls can be free outfalls without any boundary conditions. For most of the sections in the EXTRAN model where the outfalls are in the tidal sections of the rivers (Schuylkill and Delaware) the outfalls have boundary conditions equal to the mean tide (-4.89 ft). For the non-tidal sections in the model the outfalls do not usually have outfall boundary conditions. For special conditions like the gravity flow into the WPCPs, where the plant boundary had to be overcome to reach the WPCP, the appropriate boundary conditions are applied. Another special condition is the computer controlled outflows where the outflow only occurs once a predetermined head has been reached and the appropriate head boundary conditions are applied.

To model the outfall in EXTRAN the following information was needed:

- Name of the outfall
- Boundary condition to be applied.

Regulators

Regulators are structures in the CSS that prevent flow from going to the receiving waters in dry weather and control the flow that reaches the WPCPs in wet weather. Significant differences in design approaches and philosophies can be observed from system to system. The various types of regulators include weir diversions into side or bottom orifices, float-controlled gates, tipping-plate gates, vortex drop shafts, leaping weirs, motor-operated sluice gates and a number of other configurations. A brief description of the modeling approaches for the types of regulators used for the LTCPU analyses is mentioned below. The PWD system includes a variety of regulator types. A regulator's function is to divert all the dry weather and part of the wet weather flow (e.g. storm flow) into a dry weather outlet pipe (DWO) that feeds the interceptor pipes, delivering the flows to the WPCPs. Any excess wet weather flow that can not be accommodated in the DWO goes in the storm over flow pipe (SWO) and overflows in to the receiving water by way of an outfall. There are 5 types of common regulators simulated in the EXTRAN models:

- Slot regulators
- Sluice gate regulator
- Water hydraulic
- Computer controlled
- Brown and Brown regulators (B&B)

Other than the above listed regulators, two types of additional structures are used for storm relief:

- Dams
- Side overflow weirs
- Tide Gates

Slots

The slot-type regulators divert dry weather flow into the DWO conduit through an orifice constructed at the bottom of the combined trunk sewer. During storms, the wet weather flow can exceed the capacity of the orifice and/or the DWO and rise above the orifice and flow over a dam (where static dam are constructed to enhance the DWO capacity) to a SWO and onto the receiving water. Adjustable plates are utilized in some instances to allow for changes in the diverted flows. At a minimum, this orifice opening is sufficiently large to convey dry weather flow plus a certain percentage of the storm flow. In some locations, static dams are constructed to work in conjunction with the slot in order to enhance the capture of both dry and wet-weather flow. For this type of regulator structure in EXTRAN, the regulator is modeled as a node with inflow from trunk(s) and the flow into the DWO from the regulating chamber is modeled as a fixed orifice (orifice dimensions equal the slot opening) and if the flow from the regulating chamber does not pass through tide gates, then the section representing a dam leading to the SWO is modeled as a weir (weir dimensions are made to represent the dam section). If the flow from the regulating chamber to the SWO passes through a tide gate then the dam section leading to the SWO is modeled as an orifice (orifice dimensions simulate the opening above the dam).

Sluice gates regulators

Sluice gates located in the regulating chambers manage flow to the DWO by controlling the size of the opening from the trunk sewer. Typically, this type of regulator consists of a dam constructed in the invert of the trunk sewer downstream of the sluice gate opening. The dam diverts flow into the regulator chamber under dry weather conditions. During storms, the sluice gate may be lowered to a predetermined height and the tide gate (if present) on the SWO is opened. When flows return to normal dry weather conditions, the sluice gate returns to the fully opened position and the tide gate is closed. The sluice gate may be operated manually or automatically either by computer controls or based on water hydraulics. For this type of regulator structure in EXTRAN, the regulator is modeled as a node with inflow from trunk(s) and the flow in to the DWO from the regulating chamber is modeled as a fixed orifice (orifice dimensions equal the sluice gate opening) if the DWO opening is static. If the flow in to the DWO passes through an automated opening that change based on levels in a control node then the opening is modeled as a variable orifice with controls mimicking the actual sluice gate controls. If the flow from the regulating chamber does not pass through tide gates, then the section representing dam leading to the SWO is modeled as a weir (weir dimensions are made to represent the dam section). If the flow from the regulating chamber to the SWO passes through a tide gate then the dam section leading to the SWO is modeled as an orifice (orifice dimensions are set to represent the opening above the dam).

Water Hydraulic Control

There were regulators in the CSS originally designed to operate under City-water hydraulic control. These systems no longer operate in that mode, but now function as static dams. The regulator gates are fixed in the full open position and the tide gates are fixed in a fully closed position. CSOs occur when the water level in the trunk exceeds the top of the tide gates. In their current operating mode, these structures create a large (or near optimum) amount of storage in the trunk sewer during wet weather. This condition minimizes overflows to the receiving waters. For this type of regulator structure in EXTRAN, the regulator is modeled as a node with inflow from trunk(s) and the flow into the DWO from the regulating chamber is modeled as a fixed orifice (orifice dimensions equal the sluice gate opening). Flow from the regulating chamber does not pass through tide gates, so the section leading to the SWO is modeled as a weir (weir dimensions are made to represent the dam section).

Computer controlled

Computer controlled regulators use level monitors and Programmable Logic Controllers (PLCs) to locally regulate the opening and closing of the regulator and tide gates to achieve in-system storage. This is accomplished through the monitoring of the trunk sewer water level relative to a storage set point. During wet-weather flow, the trunk sewer water level will rise above the dam elevation and flow will begin to store behind the gate. When the set point depth is reached, the PLC lowers the regulator gate and actuates the tide gate to maintain the water level at the storage set point. For this type of regulator structure in EXTRAN, the regulator is modeled as a node with inflow from trunk(s) and if flow into the DWO passes through an opening that changes based on water levels in a control node, the orifice is modeled as a variable orifice with controls mimicking the actual gate controls based on control node depths. If the tide gate openings leading to the SWO are also based on levels then they are also represented as variable orifice(s) to mimic the actual controlled openings.

Brown and Brown regulators (B&B)

Brown and Brown regulators B&B regulators are float operated regulators with controls on the openings into the regulator chamber and the DWO. The opening at the gate from the combined sewer trunk to the regulating chamber is variable and is controlled by a float in the chamber. For this type of regulator structure in EXTRAN, the regulator is modeled as a node with inflow from trunk(s) and if the flow into the DWO passes through an opening that changes based on water levels in a control node then the orifice is modeled as a variable orifice with controls mimicking the actual orifice gate controls. If the orifice gate is chained open and acts as a static orifice then it is modeled as a static orifice. If the flow from the regulating chamber does not pass through tide gates, the section representing the dam leading to the SWO is modeled as a weir (weir dimensions are made to represent the dam section). If the flow from the regulating chamber into the SWO passes through a tide gate, the dam section leading to the SWO is modeled as an orifice (orifice dimensions are set to represent the opening above the dam).

Dams

The static dams utilized in the storm relief systems operate in the same manner as the static dams in the combined sewer system. In the relief system, static dams divert wet weather flows from the trunk sewer into the storm relief sewer. For this type of structure in EXTRAN the structure is modeled as a node with inflow from trunk(s) and if the flow from the regulating chamber does not pass through tide gates, then the section representing the dam leading to the SWO is modeled as a weir (weir dimensions are made to represent the dam section). If the flow from the regulating chamber into the SWO passes through a tide gate then the dam section leading to the SWO is modeled as an orifice (orifice dimensions are set to represent the opening above the dam).

Side Overflow Weirs (SOW)

SOWs operate in a similar manner to dam-type regulators except SOWs are constructed on the side of the trunk sewer, parallel to direction of flow. When the hydraulic grade line in the trunk sewer exceeds the weir crest elevation, the storm flow spills laterally over the top of the weir into the relief sewer and ultimately into the receiving water. With the weir crest constructed parallel rather than perpendicular to the direction of flow, the hydraulic capacities in the trunk are not restricted due to downstream control. In a few isolated cases, the side-discharge control function is accomplished through a conduit rather than a weir. In these cases, while the sewer may be circular, baskethandle or another standard sewer shape, the geometry of the flow to the discharge is otherwise identical to the SOW. For this type of structure in EXTRAN the structure is modeled as a node with inflow from trunk(s) and the SOW is modeled as a weir with an offset and an opening that represent the SOW dimensions and offset.

Tide gates

Tide gates are one-way gates that allow the flow to go to the receiving water but prevent the backwater from the receiving water body to enter the combined sewer system. Tide gates are installed in combined sewer systems to prevent back-flooding of the combined sewer system by high tides or high stages in the receiving waters. This back-flooding can cause flooding of regulator structures and introduce the receiving water to the interceptor system. In combined systems, tide gates are installed in the outfall sewer just beyond the regulator or between the regulator and the receiving water. Tide gates can be differentiated into two categories: (1) vertical tide gates; and (2) horizontal tide gates.

Vertical tide gates are hinged at the top and designed to permit discharge with a small differential head on the upstream side of the gate and to close tightly with a small differential head on the downstream side of the gate. Vertical tide gates can be further classified depending on the material used for their flap: (1) Cast iron; (2) pontoon; and (3) timber. Cast iron gates are comprised of solid iron while pontoon gates are fabricated of layered sheet metal which forms air cells in the gate, increasing its buoyancy. Generally, cast iron gates are used for smaller sizes and timber or pontoon gates for larger sizes. Sluice gates are also present in the PWD sewer system. These are classified as horizontal tide gates. Opening and closing of horizontal tide gates is governed by a predetermined water level in either the regulating chamber or combined trunk sewer. Sluice gates are generally comprised of cast iron. The tide gates are represented in the EXTRAN model as one-way equivalent pipes, the flow from which can only flow in the downstream direction.

v4.1.3 Model Simplification

Once all the information is compiled into the model the models are simulated and error checks performed to find mathematical and implementation problems. The models were put through a thorough Quality Assurance procedure. The EXTRAN model gets inflow information from the preceding hydrologic and or hydraulic model runs. After creating the model, it was simplified by reducing the amount of nodes and pipes within the network. The goal of the simplification process was to increase the efficiency by decreasing run-time, while keeping the integrity of the model results. A simplification process was completed to increase the computational speed of the model, effectively decreasing the model run-time. The simplification process followed the steps outlined below:

- Increase the minimum length of the pipes for all feasible situations to 1000 feet.
- Most branches shorter than 1000 feet were identified and eliminated.
- All pipes in a branch with the same shape and slope were combined.
- Expansions were ignored if occurring between two pipes of the same diameter.
- Branches having pipes of varying capacities and shapes and not having a series of similar pipe sizes to combine to a length of 1000 feet were combined regardless and the diameter was set equal to the most constricting pipe in the series.
- If slopes were changed to meet the 1000 foot pipe length requirement, the Manning's coefficient was adjusted accordingly.
- If baseflow existed at a node to be eliminated, the baseflow was transferred to the downstream node if less than 500 feet from the eliminated node, otherwise it was loaded to the upstream node.
- Equivalent pipes were avoided where possible to conserve volumes.

The resulting simplified model allowed for a larger time step (20 seconds) to be used without violating the Courant conditions and, thus, decreasing the computational burden of the model. Continuous simulations were performed using the RUNOFF and EXTRAN models and the results from the simulations were directly or indirectly used to evaluate effects of various alternatives for LTCPU.

v4.1.4 Model Calibration / Validation

Development of the SWMM model for the LTCPU was followed by a calibration and optimization of the parameters for both modules. During the calibration of any model, it should not be expected that simulated results will match perfectly the measured data, since the measured data is subjected to some degree of error, while the model is an approximation of the system hydrology and hydraulics. Therefore, the measured data must be thoroughly reviewed and any limitations must be identified before adjusting calibration parameters. Note that the model calibration is accomplished by finding the best comparison between simulated and measured runoff characteristics over a range of storm events.

Model calibration is accomplished by adjusting initial estimates of the selected variables, within a specified range, to obtain a satisfactory correlation between simulated and measured flow and volume. The variables selected to adjust or calibrate were parameters that typically cannot be measured accurately (e.g., percent impervious, soil infiltration parameters, etc) and which have the greatest affect on the accuracy of the results. The calibration parameters were prioritized according to their influence on the model results, which can vary from one drainage system to another and on several model simulations (sensitivity analysis) on the PWD LTCP.
For the hydrologic calibration, the following data was assessed:

- Precipitation Data
- CSS Trunk Monitor Data
- DCIA Calibration
- RTK Distribution

For the hydraulic validation, the following elements were considered:

- WPCP Inflow and Pumping Data
- Validation Results

Simulations were performed using different model settings and compared using a combination of quantitative and qualitative measures. These combinations are detailed in Table v4.1.1 below with the characteristics for each specific presentation outlined next to each measure.

v4.1.5 Hydrologic Model Calibration

Calibration of the hydrologic model was an iterative process by which RUNOFF module parameters were changed, within acceptable ranges based on available data, from initial estimated values to ones that quantitatively provide the best match between modeled results and observed data.

Table v4.1.1 Details and characteristics of the measures to define the "goodness-of-fit" for calibration and validation results.

Event Volume		
Measure	**Type**	**Basis**
slope of regression line, scatter plot of simulated vs. observed data	Quantitative	A slope equal to 1 represents equality between simulated and observed event volumes. transformation for use in performance spreadsheet: absolute value of (1 – slope) A lower number is better.
probability value for t-test of slope equal to 1, scatter plot of simulated vs. observed data	Quantitative	null hypothesis: slope is not significantly different from 1 alternative hypothesis: slope is significantly different from 1 Reject the null hypothesis for small p-values. transformation for use in performance spreadsheet: none A higher number is better.
intercept of regression line, scatter plot of simulated vs. observed data	Quantitative	An intercept equal to 0 is ideal. transformation for use in performance spreadsheet: absolute value of intercept A lower number is better.
probability value for t-test of intercept equal to 0, scatter plot of simulated vs. observed data	Quantitative	null hypothesis: intercept is not significantly different from zero alternative hypothesis: intercept is significantly different from zero Reject the null hypothesis for small p-values. transformation for use in performance spreadsheet: none A higher number is better.
r-squared value about equal-fit line, scatter plot of simulated vs. observed data	Quantitative	measures scatter transformation for use in performance spreadsheet: none A higher number is better.
slope of regression line, double mass plot of cumulative simulated and observed data over time	Quantitative	A slope equal to 1 represents equality between simulated and observed event volumes. transformation for use in performance spreadsheet: absolute value of (1 - slope) A lower number is better.
intercept of regression line, double mass plot of cumulative simulated and observed data over time	Quantitative	An intercept equal to 0 is ideal. transformation for use in performance spreadsheet: absolute value of intercept A lower number is better.
simulated and observed cumulative frequency distributions of data, small events	Qualitative	*Small events are defined as those where rainfall volume does not exceed depression/interception storage, and no runoff takes place. This distinction is left to the best judgment of the person reviewing the graph. A rating of L or H indicates that more calibration is required.* L: simulated event volumes are lower than observed event volumes M: simulated event volumes are approximately equal to observed event volumes H: simulated event volumes are higher than observed event volumes transformation for use in performance spreadsheet: L=H=1; M=2 A higher number is better.
simulated and observed cumulative frequency distributions of data, medium events	Qualitative	*Medium events are defined as those where runoff occurs from impervious cover, but not from pervious cover. This distinction is left to the best judgment of the person reviewing the graph. A rating of L or H indicates that more calibration is required.* L: simulated event volumes are lower than observed event volumes M: simulated event volumes are approximately equal to observed event volumes H: simulated event volumes are higher than observed event volumes transformation for use in performance spreadsheet: L=H=1; M=2 A higher number is better.
simulated and observed cumulative frequency distributions of data, large events	Qualitative	*Large events are defined as those where runoff occurs from pervious cover. This distinction is left to the best judgment of the person reviewing the graph. A rating of L or H indicates that more calibration is required.* L: simulated event volumes are lower than observed event volumes M: simulated event volumes are approximately equal to observed event volumes H: simulated event volumes are higher than observed event volumes transformation for use in performance spreadsheet: L=H=1; M=2 A higher number is better.

Event Peak Flow

Measure	**Type**	**Basis**
slope of regression line, scatter plot of simulated vs. observed data	Quantitative	A slope equal to 1 represents equality between simulated and observed peak flows. transformation for use in performance spreadsheet: absolute value of (1 - slope) A lower number is better.
probability value for t-test of slope equal to 1, scatter plot of simulated vs. observed data	Quantitative	null hypothesis: slope is not significantly different from 1 alternative hypothesis: slope is significantly different from 1 Reject the null hypothesis for small p-values. transformation for use in performance spreadsheet: none A higher number is better.
intercept of regression line, scatter plot of simulated vs. observed data	Quantitative	An intercept equal to 0 is ideal. transformation for use in performance spreadsheet: absolute value of intercept A lower number is better.
probability value for t-test of intercept equal to 0, scatter plot of simulated vs. observed data	Quantitative	null hypothesis: intercept is not significantly different from 0 alternative hypothesis: intercept is significantly different from 0 Reject the null hypothesis for small p-values. transformation for use in performance spreadsheet: none A higher number is better.
r-squared value about equal-fit line, scatter plot of simulated vs. observed data	Quantitative	measures scatter transformation for use in performance spreadsheet: none A higher number is better.

Time to Peak

Measure	**Type**	**Basis**
time when event peak flow occurs, simulated and observed event time series plots	Qualitative	*The reviewer looks at all time series plots and makes a qualitative determination whether, on balance, simulated event peaks are different from observed event peaks. A rating of E or L indicates that more calibration is required.* E: simulated event peaks occur earlier than observed event peaks M: simulated event peaks occur at approximately the same time as observed event peaks L: simulated event peaks occur later than observed event peaks transformation for use in performance spreadsheet: E=L=1; M=2 A higher number is better.
volume under the recession limb, simulated and observed event time series plots	Qualitative	*The recession limb is defined as the portion of the event after the last peak. The reviewer looks at all time series plots and makes a qualitative determination whether, on balance, simulated volumes are different from observed volumes. A rating of L or H indicates that more calibration is required.* L: simulated recession limb volumes are lower than observed event volumes M: simulated recession limb volumes are approximately equal to observed event volumes H: simulated recession limb volumes are higher than observed event volume transformations for use in performance spreadsheet: L=H=1; M=2 A higher number is better.

Precipitation data

The main goal in acquiring precipitation data was to get the most detailed and consistent (temporally and spatially) data available for the periods in which hydraulic data were available for the Philadelphia CSS service area. It was determined after extensive review and QA assessment that the PWD 24-raingage network data required bias adjustment and normalization to provide the spatial and temporal consistency necessary for the calibration process. Details of the precipitation data analyses and adjustment procedures are presented in Supplemental Documentation 5: Precipitation Analysis.

The SWMM RUNOFF module requires assignment of an input rainfall time series for each stormwater runoff or sanitary sewer RDI/I basin in the model. Inverse distance-squared weighting is used to estimate rainfall in areas between rain gauges. A one-square-kilometer grid is imposed over the PWD service area. Next, a rainfall value for every time step is assigned to each grid element by inverse distance-squared weighting of the rainfall values from three nearby surrounding gages. Finally, the gridded precipitation values are area-weighted to provide average rainfall values for each individual sewershed in the model. In this manner, the bias adjusted 15-minute accumulated rainfall data for the PWD 24-raingage network is distributed to RUNOFF model basin areas using the Inverse Distance Weighted (IDW) method. Details of this distribution procedure may be found in Supplemental Documentation 5: Precipitation Analysis.

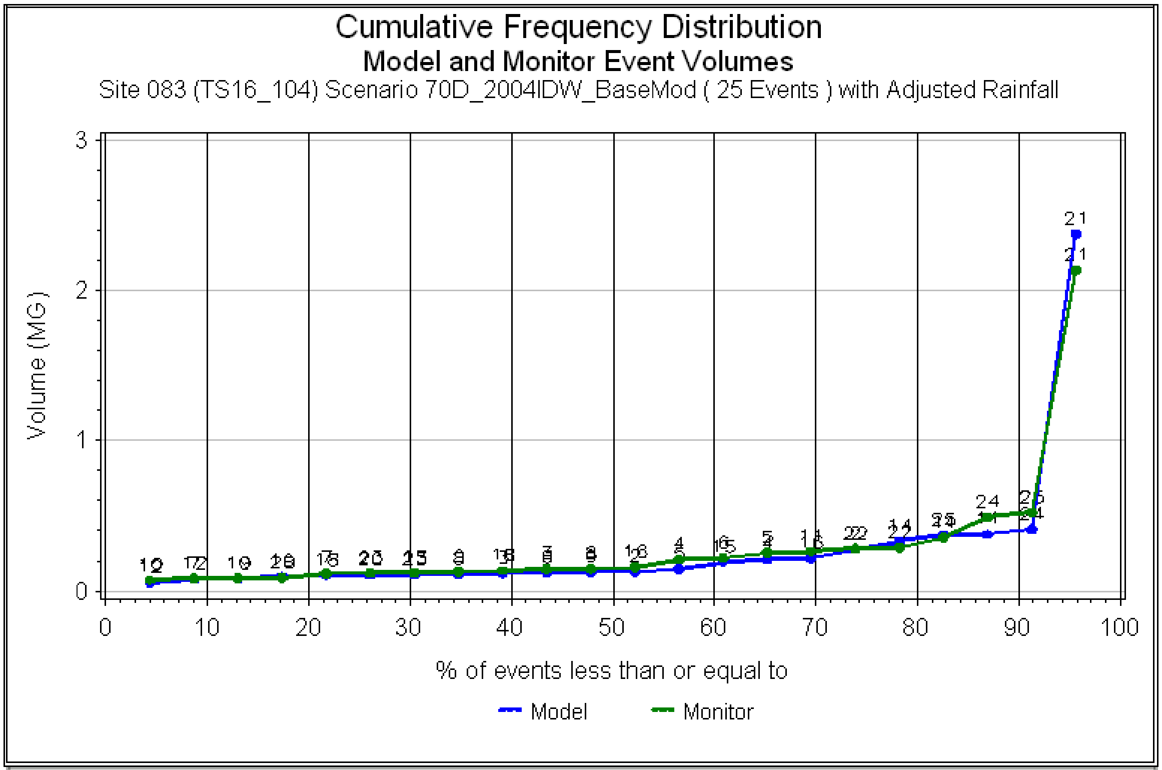
Combined Sewer System Trunk Monitor Data

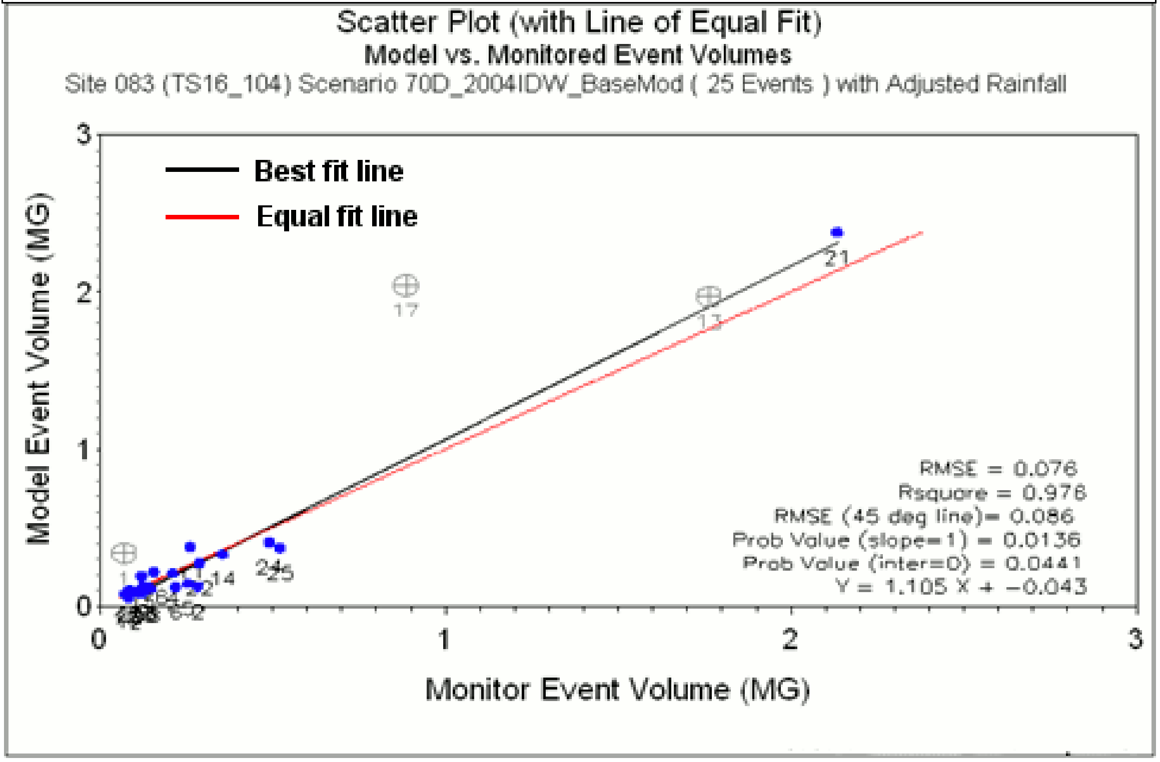
Flow data taken from flow monitors located in trunk sewers throughout the combined sewer area were analyzed and then used to adjust calibration parameters for the hydrologic models. There were six combined trunk sewer monitors having sufficient usable data to perform calibration analyses. These six flow monitors are presented in Table v4.1.2 below. Included in the table are the model pipe names of the monitor location, the area draining to the monitor, the calibration period and corresponding drainage districts.

Table v4.1.2 Trunk monitor calibration information.

Monitor	District	Pipe Name	Data Range	Drainage Area (ac)
79	SW	TS27-3308	1/1/2002-9/2/2002	4.33
83	SW	TS16-104	1/1/2004-12/31/2004	19.65
84	SW	TS13-108	1/13/2004-5/2/2006	25.11
85	SW	TC06-112	10/25/2002-7/28/2004	98.56
S42-130	SW	TR25-104	4/26/2006-9/19/06	73.05
D54-15	SE	TD54-604	5/26/2006-9/15/2006	167.19

Hydrograph decomposition was performed on the data from the above flow monitors to extract the wet weather portion. This flow was used to compare to the simulated model flow. To assess the goodness of fit of the model output to observed data a series of plots were created including scatter plots of event volumes, time to peak and peak flows, Cumulative Frequency Distributions (CFDs), Cumulative mass regression plots and timeseries plots for each event. A selection of result plots for monitor 83 is presented collectively as Figure v4.1.3 below. The r-squared, slope, intercept and the equal fit line from the scatter plots and the qualitative assessment of the timeseries plots were used to determine the level of fit for model output compared to observed data.


Cumulative Frequency Distribution
Model and Monitor Event Volumes
Site 083 (TS16_104) Scenario 70D_2004IDW_BaseMod (25 Events) with Adjusted Rainfall


Scatter Plot (with Line of Equal Fit)
Model vs. Monitored Event Volumes
Site 083 (TS16_104) Scenario 70D_2004IDW_BaseMod (25 Events) with Adjusted Rainfall

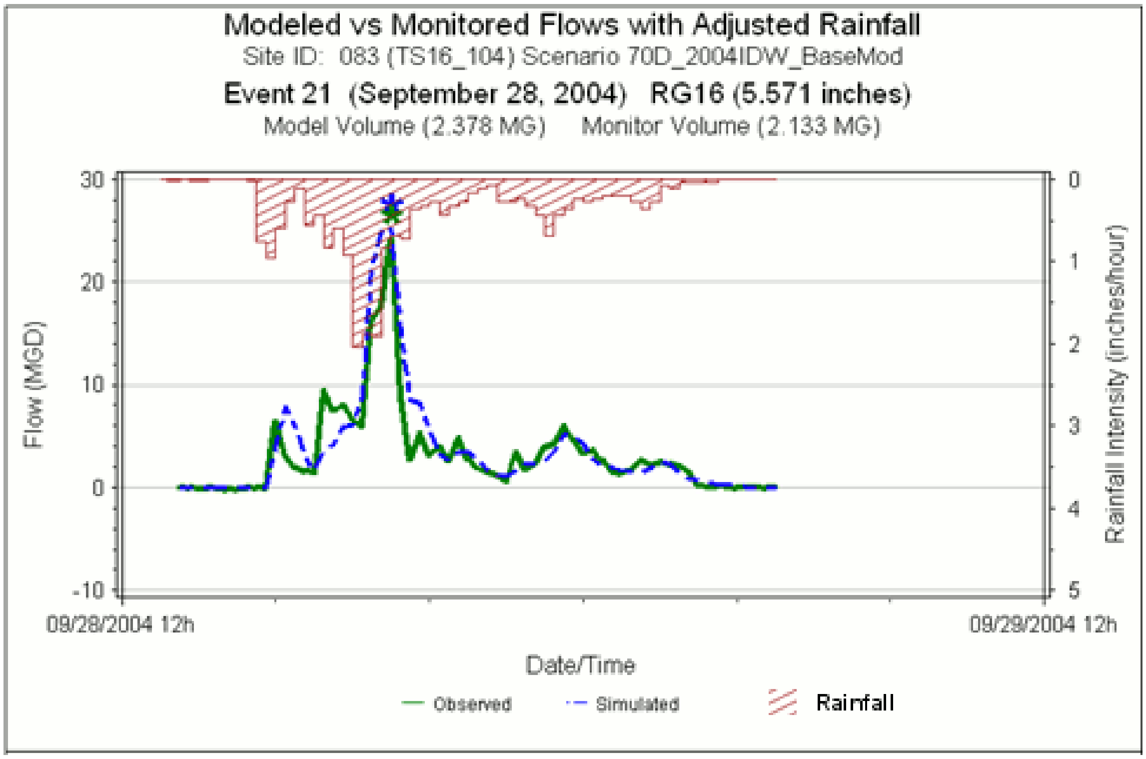


Figure v4.1.3 Result plots for Site 83 including the CFD, event volume scatter plot and the September 28, 2004 event timeseries plot.

The results for each model run were organized into a performance spreadsheet and model parameters that provided the best fit calibration scenario were chosen.

Parameters Adjusted

Model calibration is accomplished by adjusting initial estimates of the selected variables, within a specified range, to obtain a satisfactory correlation between simulated and measured flow and volume. The variables selected to adjust or calibrate were parameters that typically cannot be measured accurately (e.g., percent impervious, soil infiltration parameters, etc) and which have the greatest affect on the accuracy of the results. The calibration parameters were prioritized according to their influence on the model results, which can vary from one drainage system to another and on several model simulations (sensitivity analysis) on the PWD LTCP.

Directly Connected Impervious Area (DCIA)

For all sewersheds with monitored trunk sewers, directly connected impervious area (DCIA) in the best-fit model was lower than gross impervious cover derived from aerial photography. The ratio of DCIA to total gross impervious area ranged from 50% to 100%. Because the majority of sewersheds are unmonitored and the measurements themselves have uncertainty associated with them, it is reasonable to present this value as a range. Presented below are ranges associated with specific areas in the drainage district.

- 5 monitors in trunk sewers: Adjustments in the best-fit model range from 50% to 95% of gross impervious cover.

- Cobbs Creek watershed model: Adjustments were made watershed-wide based on USGS streamflow records. Adjustments were made in combined and separate areas and in areas inside and outside the City. This calibration process had a higher level of uncertainty than the trunk monitors. Adjustments ranged from 50% to 100% of total impervious cover.
- Tookany/Tacony-Frankford Creek watershed model: Adjustments were made watershed-wide based on USGS streamflow records. Adjustments were made in combined and separate areas and in areas inside and outside the City. This calibration process had a higher level of uncertainty than the trunk monitors. Adjustments ranged from 50% to 75% of total impervious cover.

Based on the histogram shown below (Figure v4.1.4), the mean and most common adjustment is 70% of DCIA. This value is used in the best-fit model, with the exception of monitored sheds. To account for the uncertainty that exists in the monitoring data a high and low range of DCIA were chosen for the LTCPU models. The high estimate for DCIA for the unmonitored shed was assumed to be 80 percent of the gross impervious and for the low estimate it was assumed as 60 percent of gross impervious. For the calibrated sheds an increment of 10 percent in calibrated DCIA was used to account for the high uncertainty estimate and a 10 percent decrease from the Calibrated DCIA was used to represent the low estimate of the uncertainty.

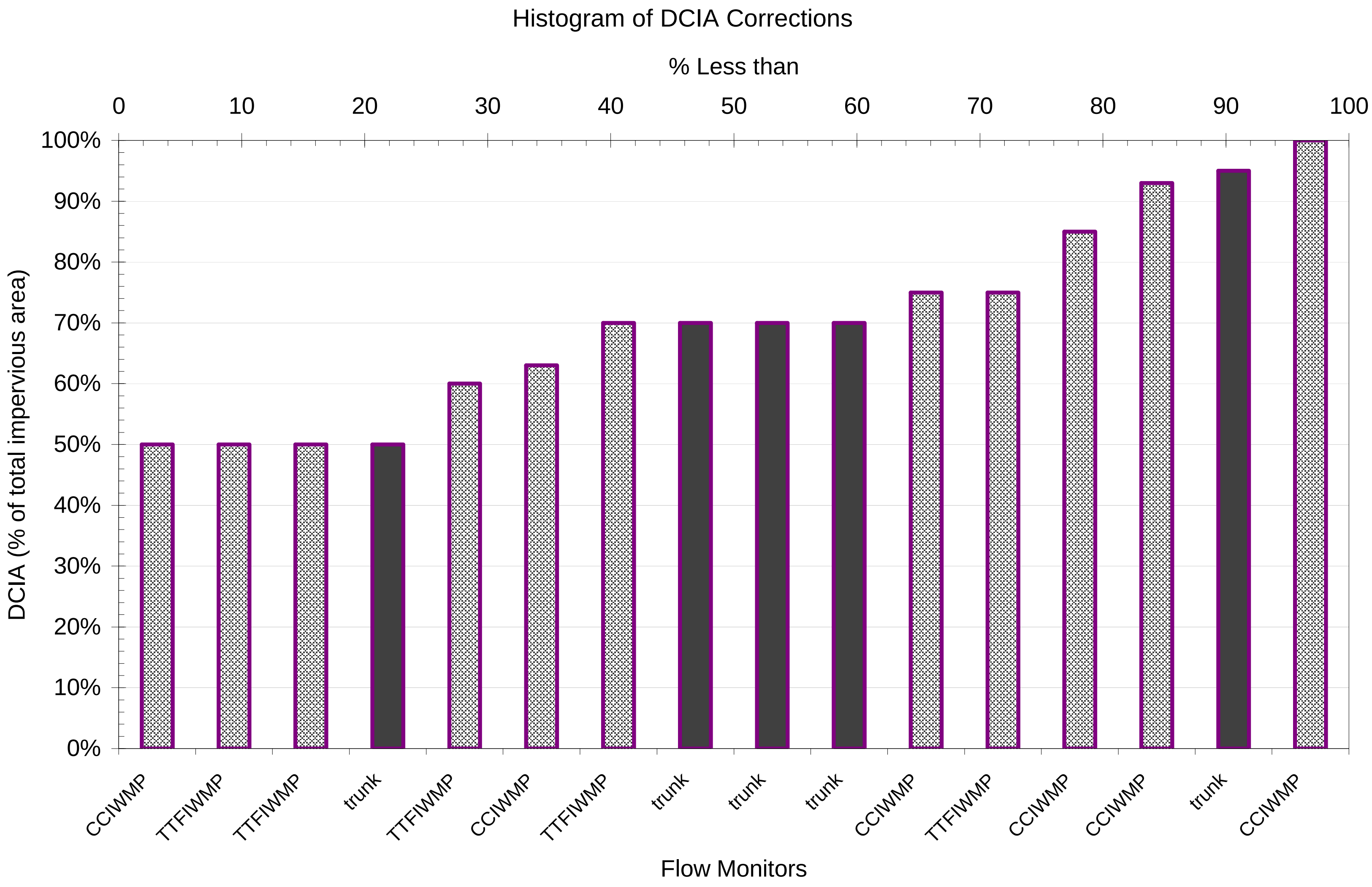


Figure v4.1.4 Histogram of resulting calibrated DCIA percentages of gross impervious area for available monitors within the drainage district.

RTK Distribution

The purpose of this task was to determine an acceptable average R-value range within the simplified SWMM model to represent rainfall dependent inflow and infiltration volumes (RDI/I) across all un-monitored separate sanitary sewer area. The existing RDI/I values from the 39 flow monitoring sites discussed previously were used in this process. The full range of R-Values showed no apparent correlation to population density, geographic location or size of monitored shed, therefore, the analysis included:

- Ranking of the 39 sites based on R-value.
- Creation of a histogram and cumulative frequency distribution plot.
- Upper (80 percentile) and lower (20 percentile) limit determination based on the central tendency about the median.

The resulting histogram is presented as Figure v4.1.5 below. The final median R-Value to represent the watershed area is 0.0401.

An in-depth RDI/I analysis was conducted for the city of Philadelphia to account for the contribution to the CSS within the LTCPU models. The first step in the process was data collection (described in section 2.1) and assessment. To define the RTK values for the city, a selection of flowmeter sites was made from the 39 sites available. Selection of the flowmeter sites was based on the quantity and quality of data existing at each site and of the 39, 13 provided a satisfactory amount of observed flow data. The selected flowmeter site ID, contributing area and the location (district) are shown below in Table v4.1.3.

Table v4.1.3 Sites chosen for full RTK analysis.

Site ID	Contributing Area (Acres)	Drainage District	Data Date Range
5	9361	NE	6/2000 to 9/2001
27	674	NE	8/1999 to 4/2000
29	656	NE	9/1999 to 10/1999
40	4557	SW	8/1999 to 9/2001
44	1986	NE	11/1999 to 4/2000
49	1784	SE	5/2000 to 8/2002
57	164	SW	6/2000 to 9/2001
70	276	NE	6/2000 to 9/2001
72	301	NE	3/2001 to 5/2005
75	179	NE	6/2001 to 7/2004
77	162	NE	9/2000 to 7/2002
95	3540	NE	6/2004 to 5/2006
96	12594	NE	6/2004 to 5/2006

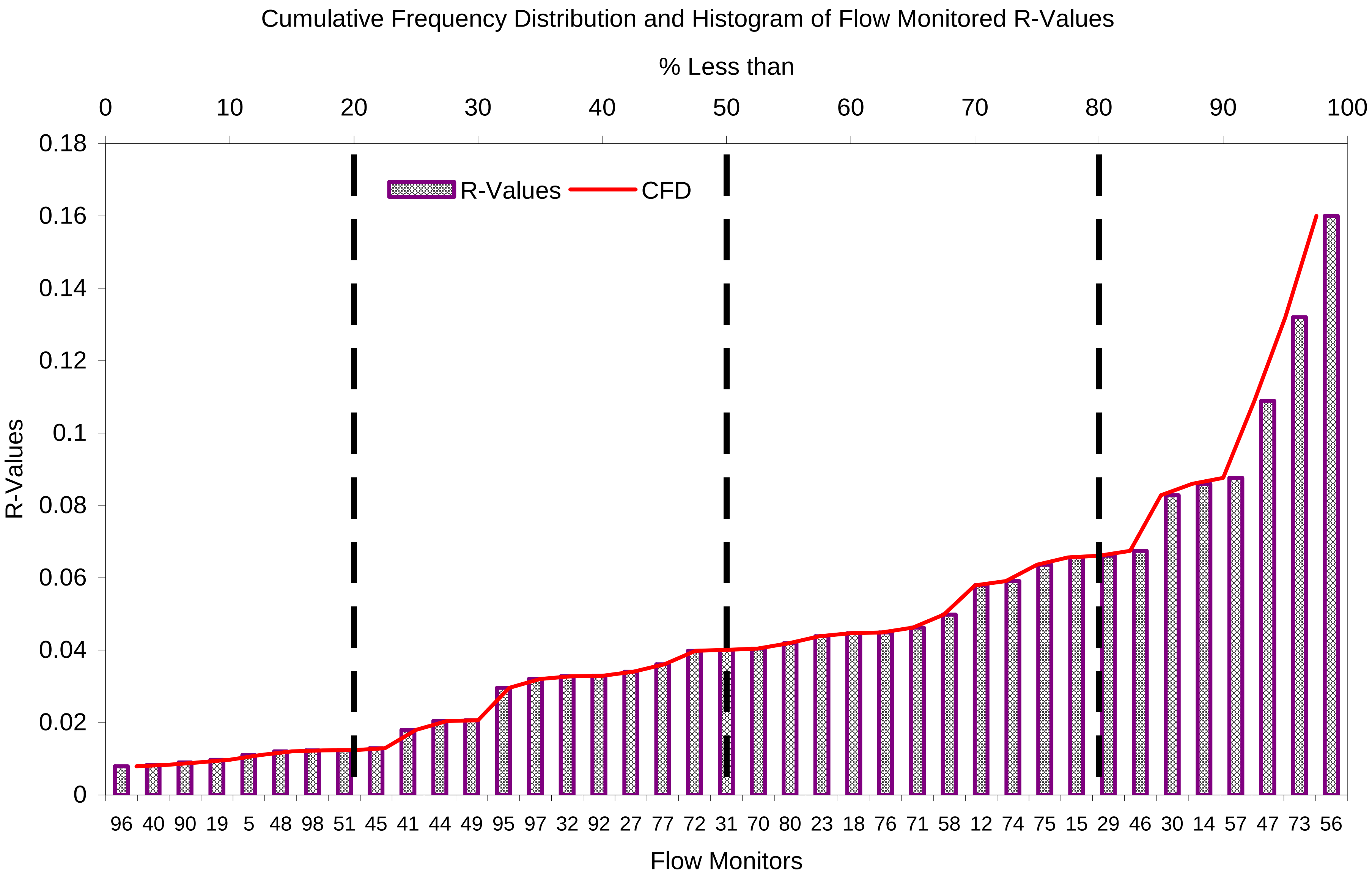


Figure v4.1.5 Histogram of resulting calibrated R-values for selected monitors within the drainage district.

1. Quality assurance procedure carried out on above selected sites. The raw flowmeter data was formatted and imported into a QA template. Data was checked for date/time inconsistencies, unusable data due to flowmeter malfunctions or missing data. Data was flagged at each timestep to identify data as good, missing, unusable or interpolated. Flags were used to help calculate statistical information on the data and to facilitate understanding of anomalous data in subsequent data processing steps (e.g., SHAPE analysis). If previous Quality checks had been done to older data sets, those data were re-evaluated and brought up to current quality standards
2. After quality assurance of the data, it was formatted and imported into CDM SHAPE software. Rain data from the Allflows.mdb database was generated specific to each flowmeter site (i.e., raingage ID and time frame). Within the SHAPE software, weekday and weekend dry-weather flow patterns were determined. Hydrograph decomposition was performed by adjusting groundwater points through the entire time frame of the data. During groundwater adjustment, wet-weather event boundaries were delineated. R-values and inflow and infiltration values for each flowmeter site were calculated and exported.
3. The exported data for all events were further assessed for anomalies (i.e., events affected by snow, holiday patterns or extreme events) that may skew analysis results. If events existed fulfilling any of these criterion, they were removed from the event list and were not included in subsequent analyses.

4. The R-Values (calculated for each event) are summarized to get average values for each month. The events are sorted based on month, year and then day. The average for each month was calculated two ways:
    1. The arithmetic average
    2. The volume weighted average calculated using the I/I depth and rainfall depth for each event

   The method chosen to use in further analyses was determined by how well the data flowed from month to month (i.e., which showed smoother transitions)
5. Exported parameters from SHAPE and the calculated average R-values are inserted to a Microsoft EXCEL spreadsheet created to analyze the fast (RTK1), medium (RTK2) and slow (RTK3) response of rainfall dependent inflow and infiltration (RDII). The RDII volume from observed and simulated data is calculated and plotted for each event at each flowmeter site. Based on volume comparison, the R, T and K values are manipulated to produce a more closely matched comparison of volumes. Adjustment of RTK values followed these guidelines:

   i. Divide the R value exported from SHAPE analysis three ways (fast, medium and slow response R-values) for each month
   ii. For first run arbitrarily choose T and K values for one month
      a. The month with the most data was chosen
   iii. Run the program
      a. The resulting hydrograph produced by summing the three response hydrographs equals the total simulated RDII response
   iv. Adjust RTK values based on how well the simulated RDII response matches the observed RDII response
   v. Once the RTK values produce an acceptable match to the observed hydrograph, the RTK values are placed in another Microsoft EXCEL

spreadsheet to check the shape of each unit hydrograph corresponding to the fast, medium and slow responses

        a. Adjustments are made (if necessary) to make transitions between the three phases smooth (i.e., without dips)

    vi. Once adjusted (or fine-tuned), the TK values are applied to all other months.
    vii. R-values are adjusted for each month to create matching hydrographs while the TK values remain static

Final values for RTK at each flowmeter site were distributed to all sheds contributing to that flowmeter in the simplified runoff master sheet

6. A second EXCEL spreadsheet was utilized to check the unit hydrographs resulting from the RTK values specific to each site. This was done to make certain the transitions between the response curves remained fluid, without disruption due to dips. If there are disruptions, the values are adjusted slightly and distributed to the remaining months. For the remaining months the TK values remain static, while the R-values are adjusted.
7. The R, T and K values from the last step were used for the RUNOFF simulation. Runoff results produced from SWMM were plotted with SAS for verification and observed versus simulated responses compared
    a. If hydrographs did not produce an acceptable match, refinement of the RTK parameter values was done and the data re-imported to the SWMM runoff input file
    b. The SWMM model was re-run and data plotted
    c. The process was repeated until an acceptable match was created

An example of an acceptable matching hydrograph and corresponding best-fit volume scatter plot are shown in Figure v4.1.6.

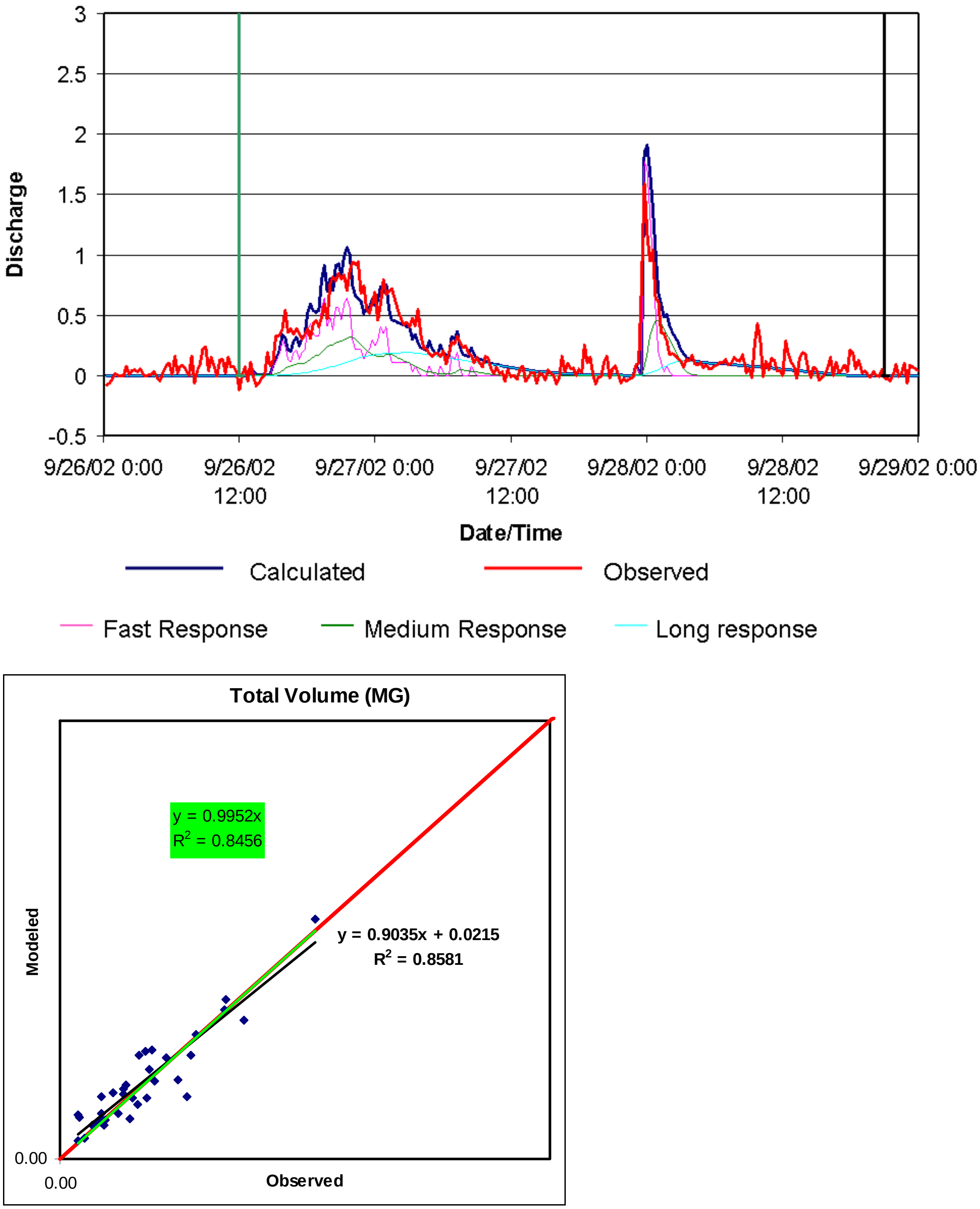


Figure v4.1.6 Examples of an Acceptable Observed to Simulated Data Hydrograph and Best-Fit Volume Scatter Plot Match from the RTK Template Analysis Spreadsheet Tool.

During this process, four sites were chosen as templates for the remaining 26 flowmeter sites and all remaining un-metered sanitary sewer shed loading points. Selection of the four sites to use as templates was based on flowmeter data consistency, accuracy and precision of observed hydrographs compared to estimated hydrographs. The size of the contributing area to the flowmeter was used as the criteria for distributing the templates to the un-metered sheds. Table v4.1.4 outlines the four sites selected as templates.

Table v4.1.4 Listing of the sites chosen as templates and the corresponding ranges of application.

Site ID	Contributing Area	Area Range to Apply
75	179	area < 300 acres
70	276	300 acres ≤ area ≤ 1000 acres
40	4557	1000 acres ≤ area ≤ 5000 acres
5	9361	area > 5000 acres

Distribution among un-metered sheds

The distribution of template RTK values to un-metered sheds was based on the contributing drainage area to each outlet node. The un-metered shed names were searched respective outlets identified. The contributing area to each outlet was totaled. Based on the total contributing area to each outlet, template IDs were assigned to each shed draining to that outlet. The template IDs associated RTK parameters to each shed. The RTK templates and boundary conditions are those outlined in Table v4.1.4 above.

Outlying Community User Input Hydrographs

The outlying community areas chosen for direct time series input are DELCORA, Bucks County (MB-1) and Lower Southampton Township (MSH-1). These areas were selected based on the magnitude of the contributing flows and the availability of acceptable quality data for the period of interest.

The procedures described herein were used to create SWMM4 EXTRAN K3-line timeseries input data for selected outlying community sanitary sewer connections to the Philadelphia combined sewer system (CSS). The timeseries data are to be used to define wet weather flow response from these areas in continuous simulations performed for the 2005 representative year selected for LTCPU project evaluations. Filling missing or errant data is required in order to generate continuous timeseries over the one-year simulation period. The outlying community areas chosen for direct timeseries input are DELCORA, Bucks County (MB-1) and Lower Southampton Township (MSH-1). These areas were selected based on the magnitude of the contributing flows and the availability of acceptable quality data for the period of interest.

Bucks County and Lower Southampton Township timeseries flow data source is the 2.5-minute permanent billing meter data obtained from the PWD real-time unit (RTU) database. Quality assurance and quality control (QAQC) procedures including inspection of monthly timeseries plots were used to flag errant or missing data. The accepted data is then averaged to 15-minute intervals.

DELCORA flow data is obtained from hourly Southwest WPCP influent flow data measured at the plant. Quality assurance and quality control procedures including inspection of monthly timeseries plots were used to flag errant or missing data. The accepted data is then interpolated to 15-minute intervals.

Data Gap Filling Procedures

Identification and filling of data gaps are required in order to generate continuous timeseries data needed for performing the typical year model simulations for 2005 data. First, all data gaps and their durations are identified. Next, each data gap is characterized as either wet weather or dry weather flow with the corresponding procedures used for gap filling as described below.

The procedure for Dry Weather Flow is as follows. For small data gaps of less than 1 hour, linear interpolation was performed. Missing or errant data over one or more hours was filled using the nearest previous day's dry weather flow (DWF) data.

The procedure for Wet Weather Flow is as follows. For small data gaps of less than 1 hour, linear interpolation was performed. Wet weather events with missing or errant data periods of one hour duration or more were filled for the entire wet weather event boundaries as defined by the RDI/I analysis. Model simulation results using RDI/I RTK shape parameters previously calibrated for these areas were used to generate the wet weather flow by subtracting baseflow. The calculated wet weather flow for each timestep was added to the timeseries nearest previous day's DWF data.

The continuous flow timeseries generated for the year 2005 that contained diurnal and seasonal time varying baseflow patterns. In contrast, RUNOFF model generated hydrographs used for all other model areas simply have wet weather hydrograph responses added to a constant average baseflow. In order to represent the wet weather responses from the K3 line timeseries input areas more consistently with the modeled areas from the RUNOFF module, hydrograph separations were performed on the K3 timeseries data using CDM SHAPE software to extract the wet weather response hydrograph. The final timeseries was constructed by adding a constant average baseflow to the separated wet weather response K3 timeseries

High and Low Baseflow Estimates

Average monthly dry weather flow rates are determined from WPCPs hourly influent flow data based on days with complete records of average hourly flow data and for which there is no rainfall recorded at any of the PWD rain gages on that day or the previous two days. Annual average dry weather flow (baseflow) rates are determined from these monthly values. Average annual dry weather flow rates for each WPCP over the period 1999 through 2005 are presented in Figure v4.1.7. Average annual flow rates for the period 1999 through 2005 have been standardized dividing by the 7-year average in order to better compare relative changes in inter- annual baseflow rates between drainage districts and are presented by the time series plots in Figure v4.1.8. Note: the time period from 1999 through 2005 is selected because significant reductions from dry weather flow rates prior to this period are generally observed as a result of tidal inflow eliminations.

High and low average annual dry weather flow rates are used to establish upper and lower estimates of available wet weather treatment capacity (worst and best case scenarios) for LTCPU project evaluations. Cumulative frequency distribution plots of average monthly dry weather flow rates over the period 1999 through 2005 are presented for each WPCP in Figure v4.1.9. The values representing the 80th and 20th percentiles for each WPCP, presented in Table v4.1.5, are selected for determining high and low baseflow estimates, respectively. These low, median and high baseflow estimates are expressed as a fraction of current SWMM EXTRAN model dry weather WPCP influent flow. These baseflow multiplication factors are presented in Table v4.1.6 for each drainage district model.

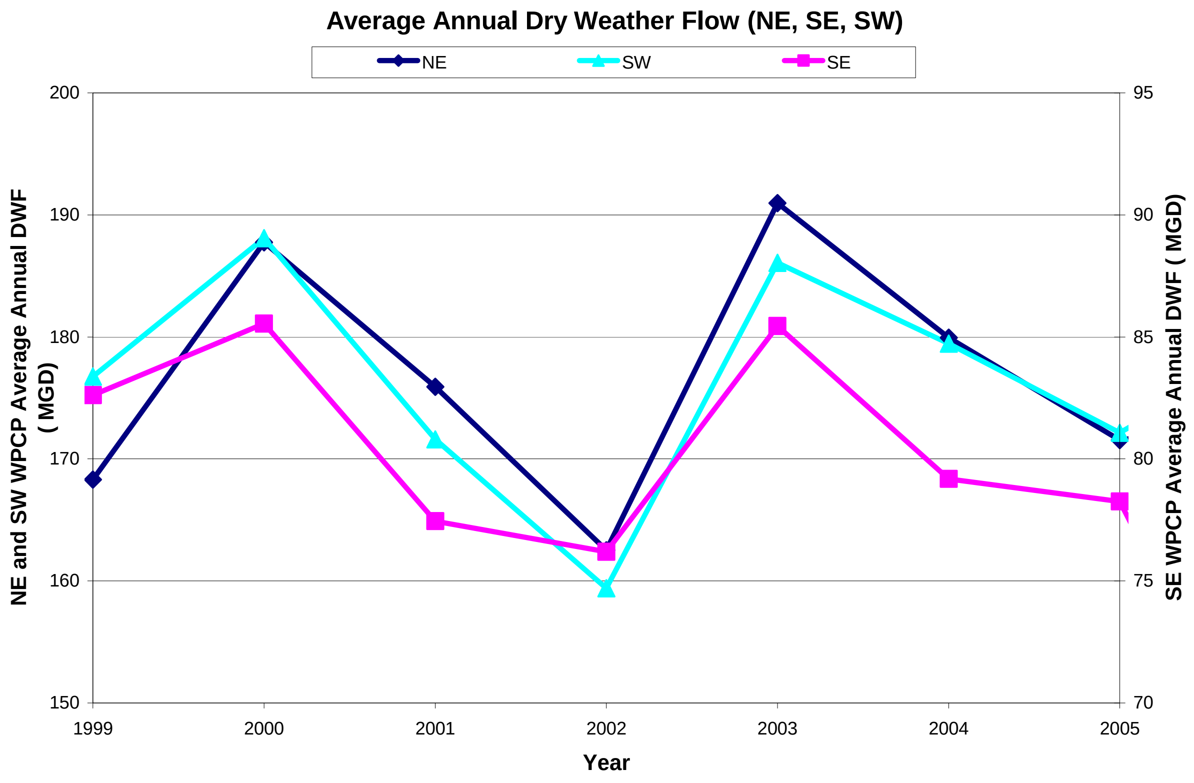


Figure v4.1.7 Average annual dry weather flow rates for each WPCP over the period 1999 through 2005.

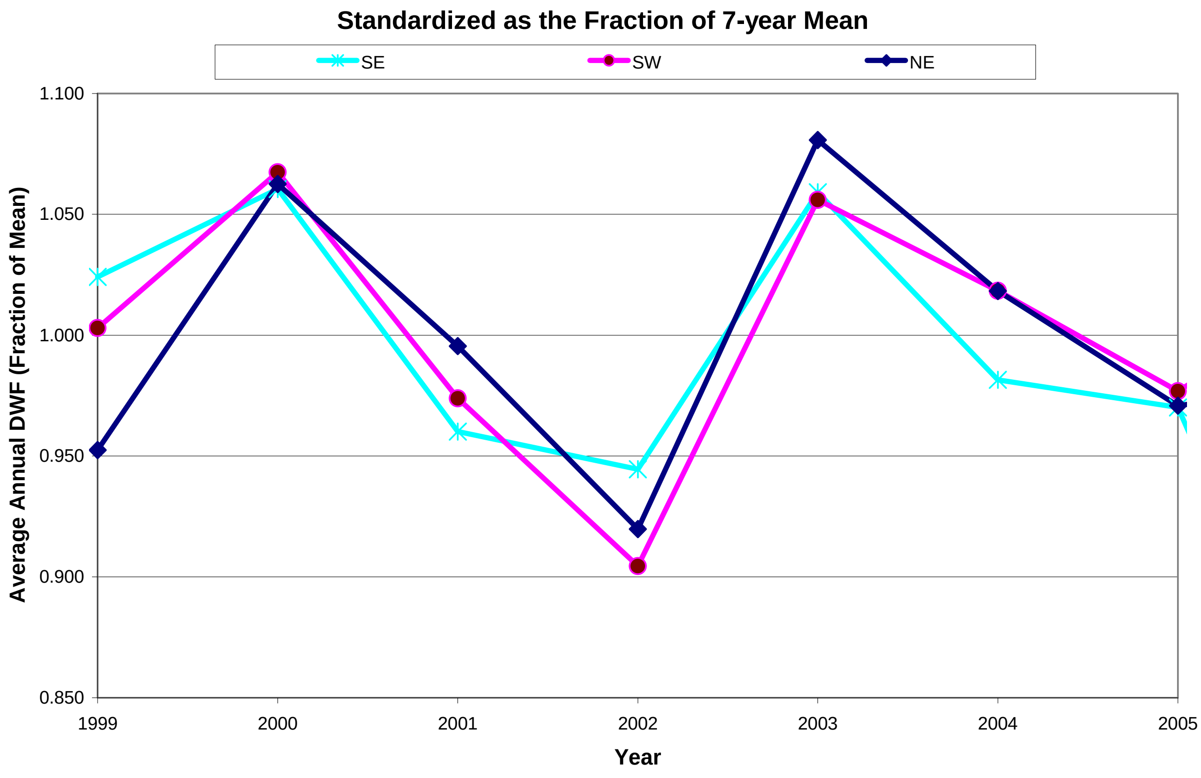


Figure v4.1.8 Standardized **a**verage annual flow rates for the period 1999 through 2005.

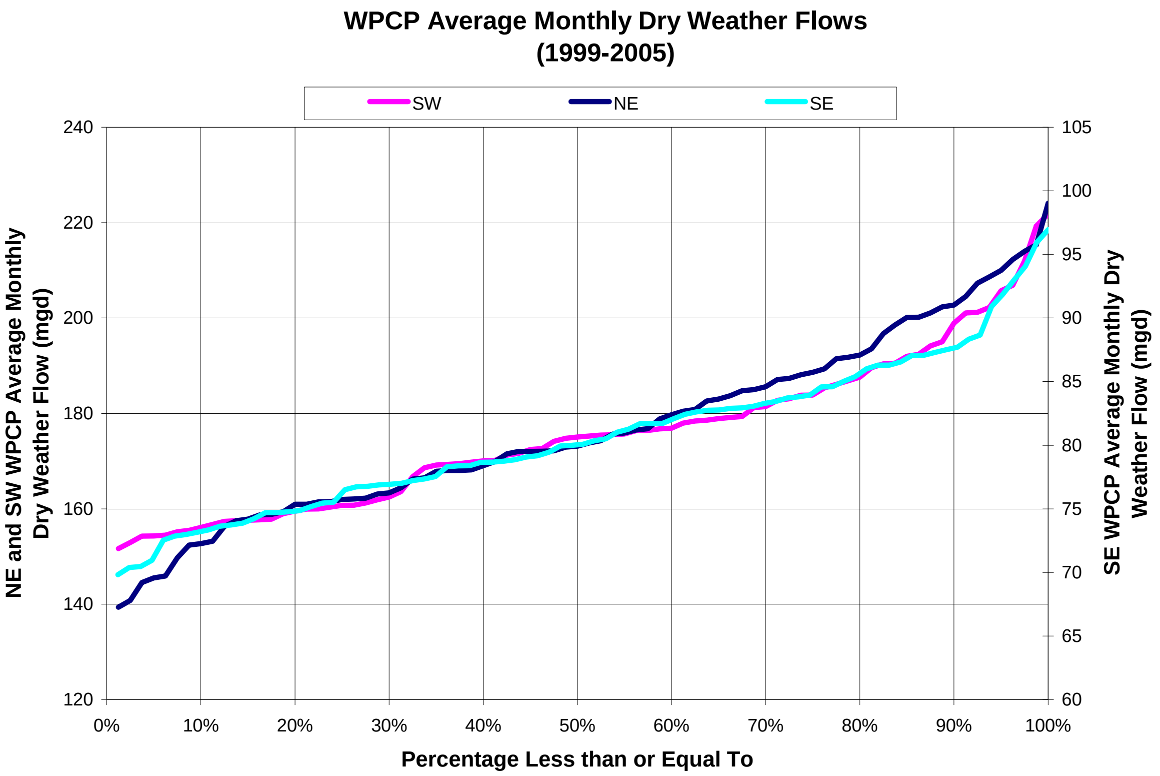


Figure v4.1.9 Cumulative frequency distribution plots of average monthly dry weather flow rates over the period 1999 through 2005.

Table v4.1.5 Average Monthly Baseflow Statistics (1999 - 2005)

WPCP	DWF Percentiles (mgd)		
	20th	50th	80th
SE	75	80	86
NE	161	173	192
SW	160	175	188

Table v4.1.6 SWMM EXTRAN Model Baseflow Multiplier Factors for Low, Median and High Flow Scenarios

WPCP	SWMM EXTRAN Baseflow Multiplier Factors		
	Low	Median	High
SE	0.938	1.003	1.073
NE	0.911	0.980	1.088
SW	0.892	0.979	1.049

v4.1.6 Hydraulic Model Validation

Once the hydrologic models have been calibrated based on combined trunk and sanitary sewer monitoring data, the system hydraulic models were validated against observed pollution control plants (WPCP) influent flow and level data for the calendar year 2005. The results for each drainage district are subsequently discussed using the quantitative and qualitative best-fit measures outlined in Table v4.1.1 as a guide for model result accuracy.

WPCP Inflow and Pumping Data

PWD monitors level and inflow at its three water pollution control plants. These flows were compared to simulated flows for a range of storm events during the calendar year 2005. WPCP influent flow and pump wet-well level data are stored in average hourly time intervals. A QA process was performed on the flow data, during which errant or missing data were removed. The observed flow time increments were interpolated to a 15-minute time interval before being imported into the SHAPE program along with the rainfall data for analysis. The data underwent hydrograph decomposition and the wet-weather portion of the flow coming to the plant was extracted.
The model parameters adjusted to best match the monitored WPCP influent flow and level data included plant head boundaries, pump curves, metering head losses and QA of regulator gate settings.

Southeast Drainage District

The results of final Southeast Drainage District (SEDD) hydraulic model validation, performed using SE WPCP influent hydrograph separated wet-weather flow data, are presented in Figures v4.1.10 through v4.1.12. Linear regression analysis is performed comparing model estimated SE WPCP influent wet weather flow volumes (y-axis) to monitored event volume (x-axis) using IDW rainfall data for the calendar year 2005. The events that have been excluded from the regression analysis based on the protocols described previously are presented in the scatter plots with different symbols and shading so they can be distinguished from those events included in the regression. Ideally the plots would reveal a one to one relationship, meaning the model simulated exactly the monitored runoff volume for each event.

Figure v4.1.10 is a scatter plot with the linear regression analysis results used to determine quantitatively how well the model simulated total event volumes treated at the SE WPCP. The red-dashed line is the 45-degree line that would indicate a perfect fit with an r-squared value of 1. Figure v4.1.11 is an overlay of model and monitored SE WPCP influent wet-weather event volume cumulative frequency distribution (CFD) plots. Figure v4.1.12 is an overlay of model and monitored hydrograph time-series plots for the October 22, 2005 storm event. The plots display a good correlation between observed and simulated event volumes over the full range of events analyzed. Any significant systematic deviation between simulated and observed data would indicate events of a certain volume range were not being adequately simulated by the model.

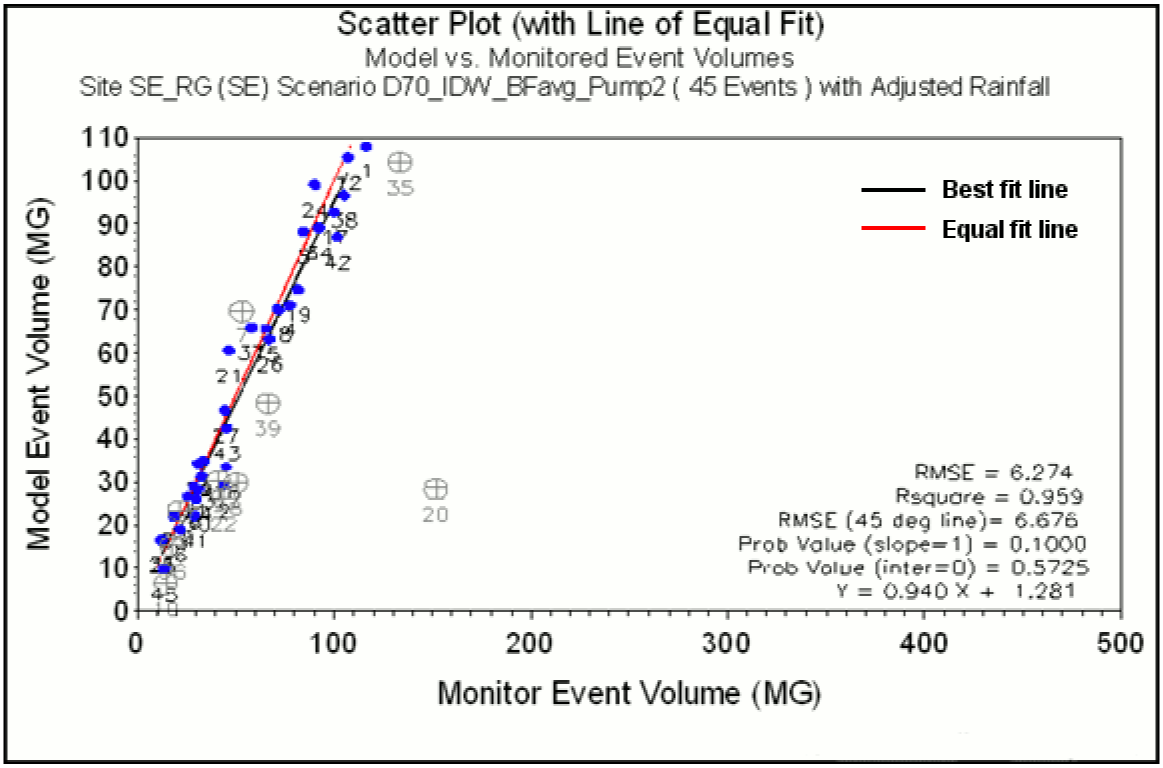


Figure v4.1.10 SE WPCP linear regression of modeled versus monitored event volumes

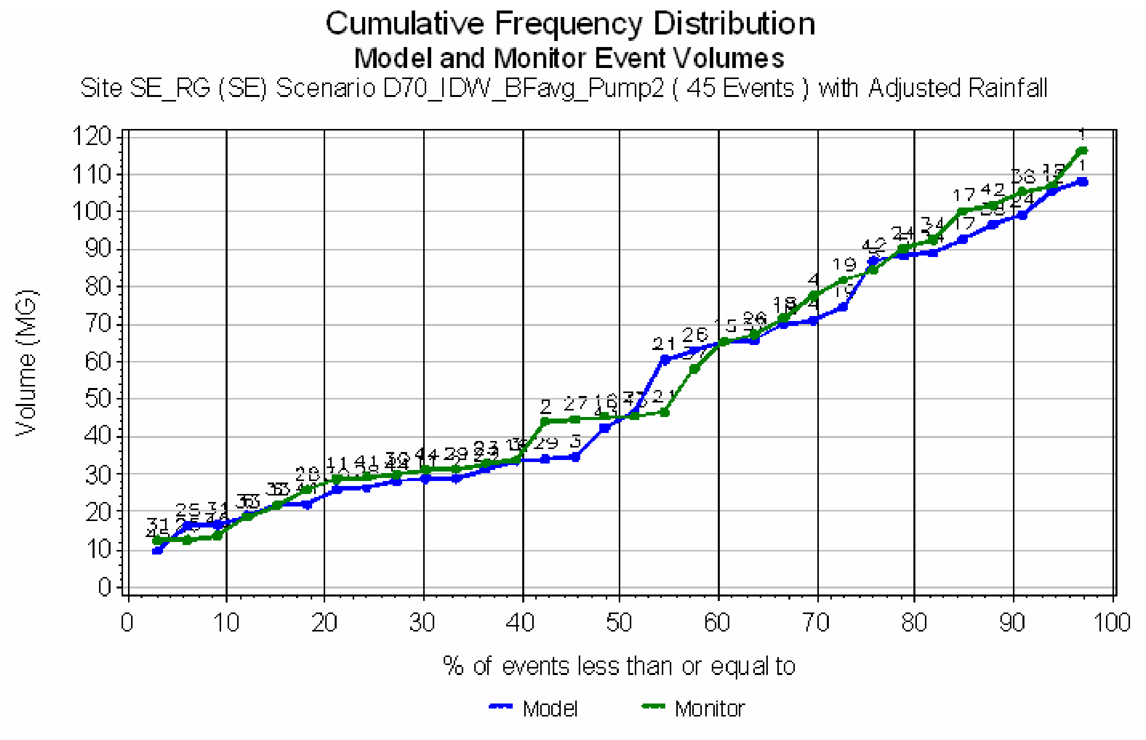


Figure v4.1.11 SE WPCP CFD plots of monitored and modeled event volumes

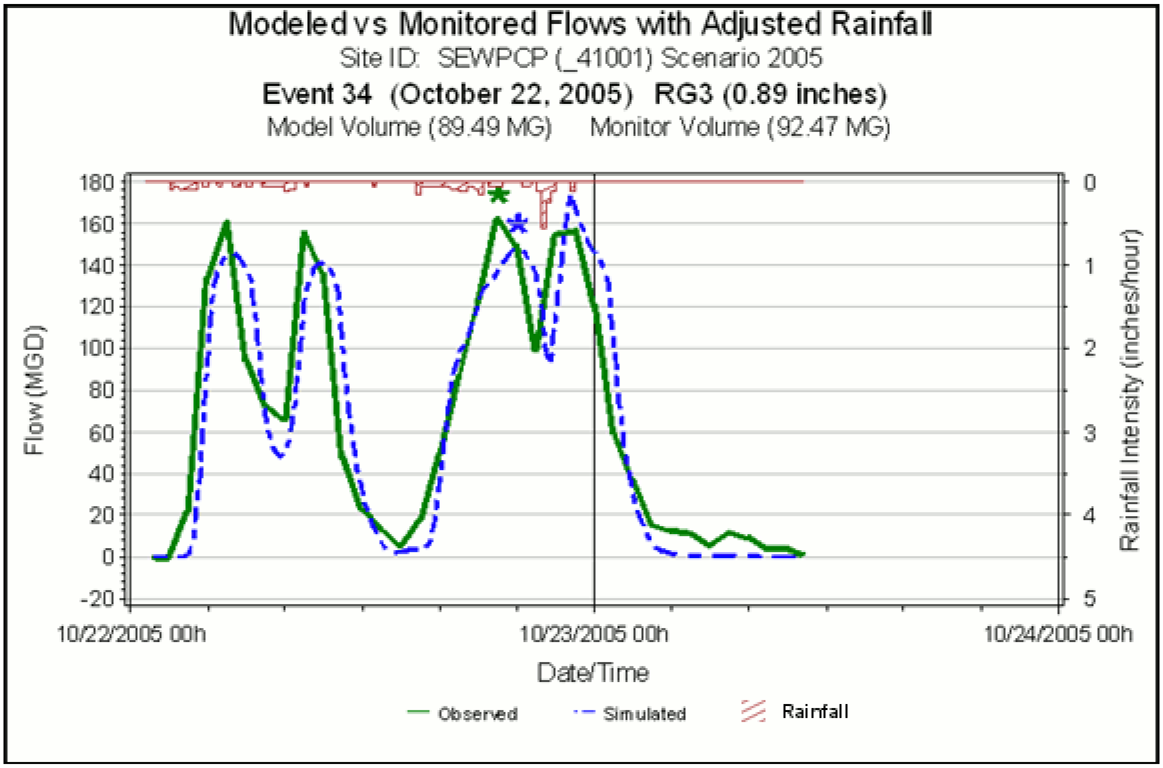


Figure v4.1.12 SE WPCP model and monitored wet-weather flow time-series plot for the October 22, 2005 event

Southwest Drainage District

Final validation plots for the Southwest drainage district (SWDD) hydraulic model are presented in Figures v4.1.13 through v4.1.16. The plots are presented separately for the two interceptor systems that feed the Southwest Water Pollution Control Plant (WPCP), the Southwest High Level (SWHL) and the Southwest Low Level (SWLL). The events that have been excluded from the calibration analyses, using the set of protocols described previously, are presented in the scatter plots with different symbols and shading so they can be distinguished from those included in the regression analyses.

Figure v4.1.13 shows the linear regression analysis used to determine quantitatively how well the SWHL simulated the wet-weather event volumes. The monitored wet-weather event volumes are on the horizontal axis and the modeled event volumes are on the vertical axis. (The red-dashed line is the 45-degree line that would indicate a perfect fit with an r-squared value of 1.0). Figure v4.1.14 shows the cumulative frequency distribution (CFD) plots of the monitored and the modeled wet-weather volume from the SWHL. This plot is used to check if the wet-weather volumes being simulated are different from the observed for various sized storms. Similarly figure v4.1.15 and v4.1.16 show the linear regression analysis and the cumulative frequency distribution plots for the SWLL interceptor system. The curves at the SW interceptors match each other reasonably well with no significant deviation for each plot.

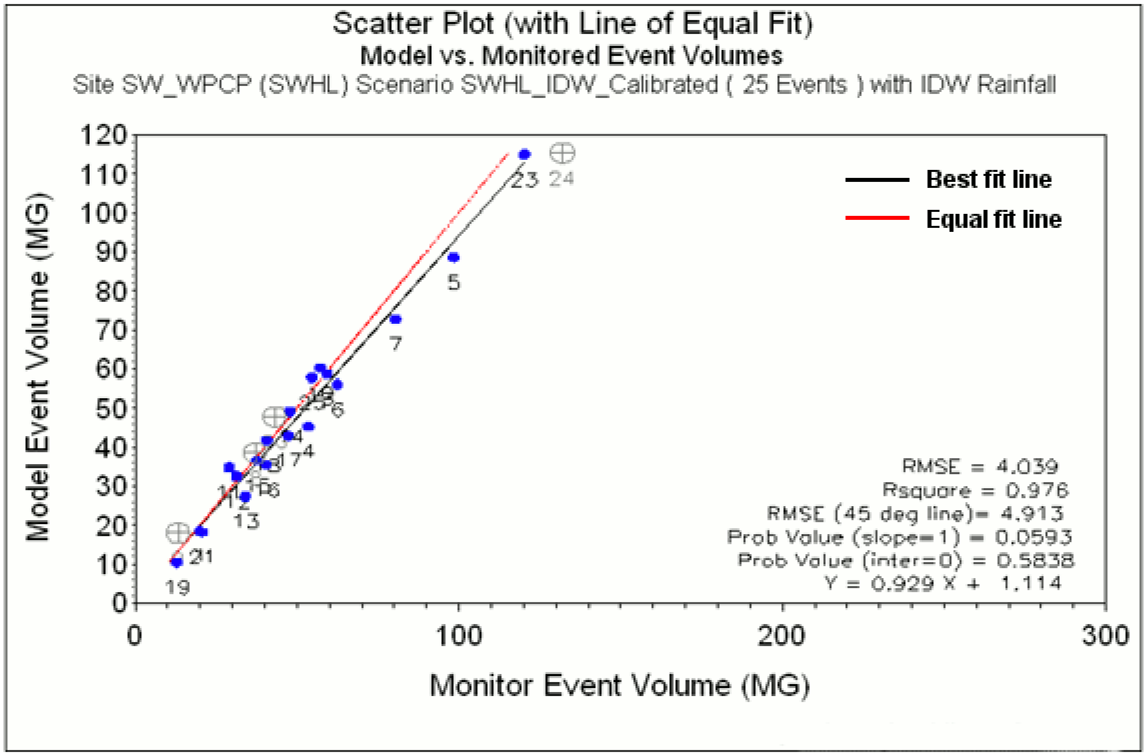


Figure v4.1.13 SWHL linear regression of modeled versus monitored event volumes

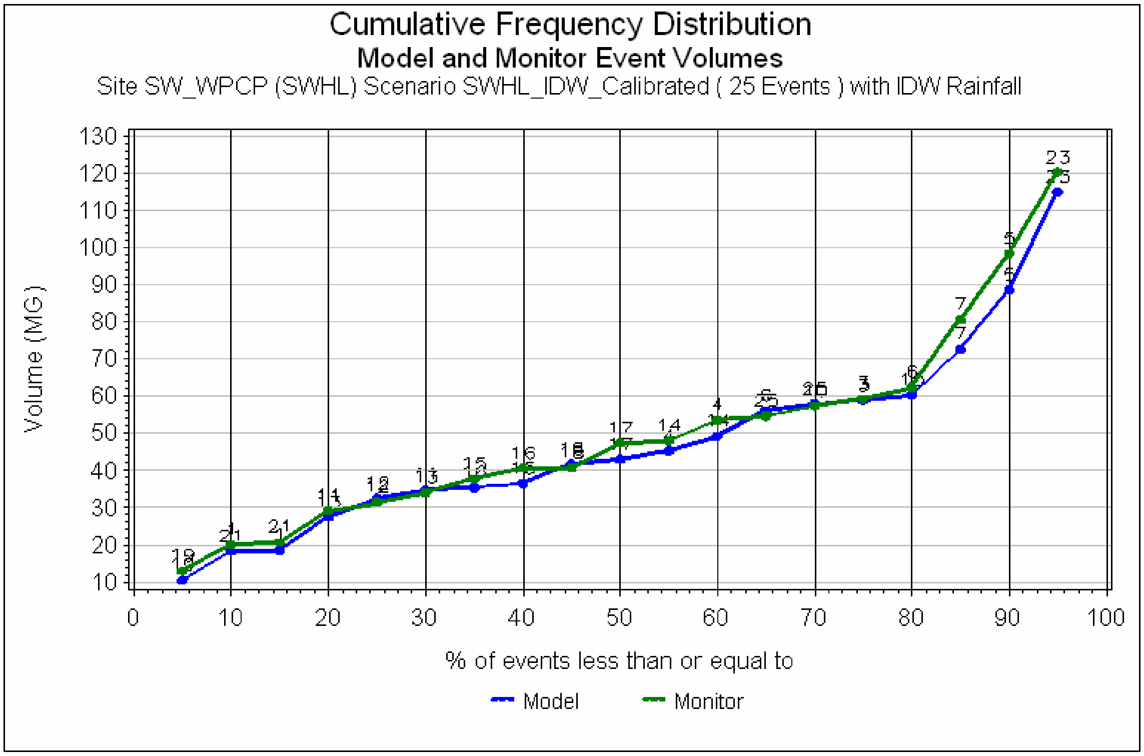


Figure v4.1.14 CFD Monitored and Modeled event volumes SWHL

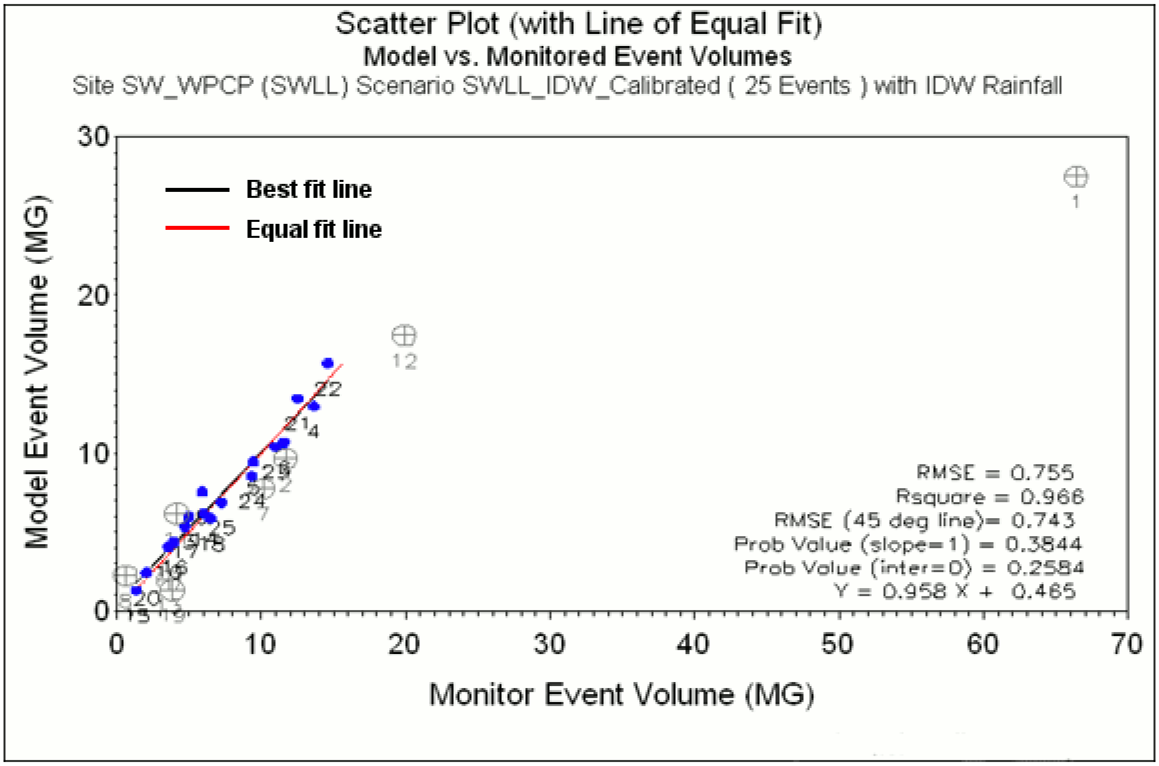


Figure v4.1.15 SWLL linear regression of modeled versus monitored event volumes

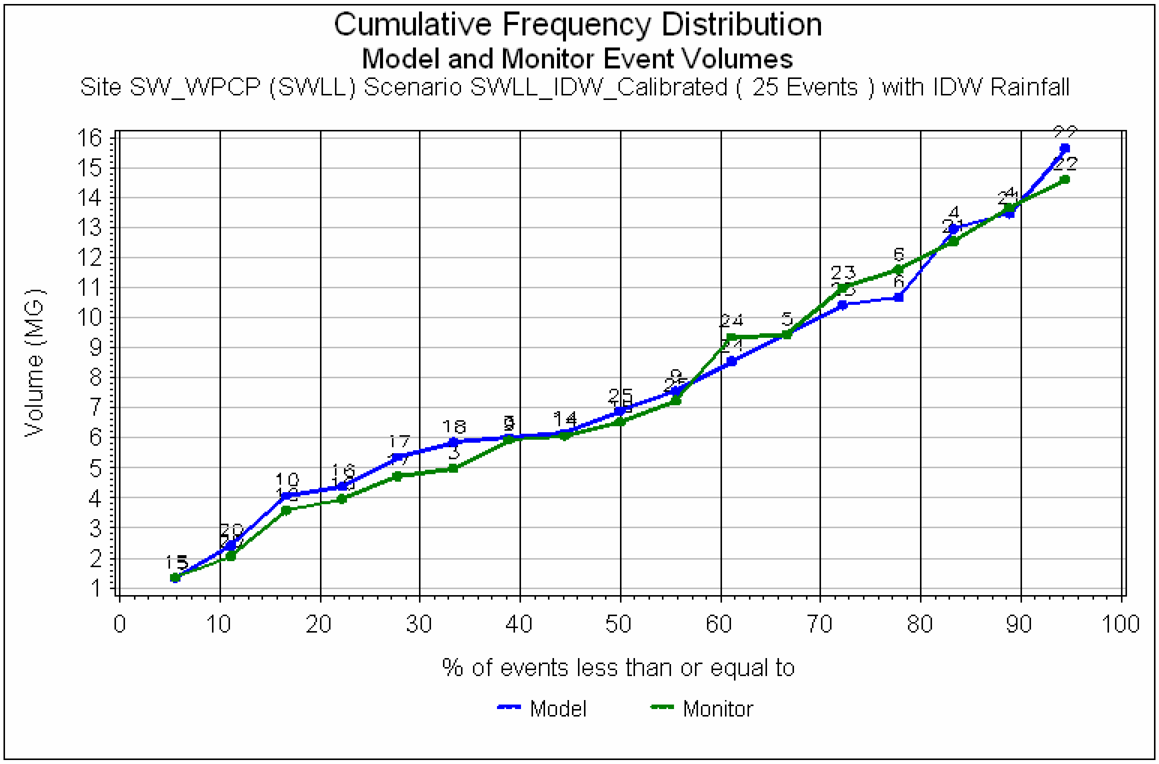


Figure v4.1.16 CFD Monitored and Modeled event volumes SWHL

Northeast Drainage District

The Northeast Water Pollution Control Plant (NE WPCP) receives combined sewer flows by gravity from the Northeast High-Level system (NEHL) and through pumping from the Northeast Low-Level system (NELL). These two drainage systems connect at the NE WPCP and can be modeled separately or as a single combined model. The NEHL system is comprised of two interceptor systems: the Frankford High Level (FHL) and the Tacony (T). The NELL system is comprised of five interceptor systems: the Somerset Low-Level (SOM), the Upper-Frankford Low-Level (UFLL), the Lower Frankford Low-Level (LFLL), the Upper Delaware Low-Level (UDLL) and the Pennypack (P).

Final validation plots for the Northeast drainage district (NEDD) model are presented in Figures v4.1.17 through v4.1.30. These plots include scatter plots of model versus monitored WPCP influent wet-weather event volumes showing linear regression analysis results, cumulative frequency distribution plots of model and monitored WPCP influent wet-weather event volumes and selected model and monitored influent wet-weather flow hygrographs. Plots are first presented for the total NE WPCP and the combined NELL. Calibration plots are also presented for each of the following three metered plant influent lines, FHL, the combined SOM and UFLL and the UDLL which also includes flow from the LFLL. The same event list is used for all analyses. Events are excluded from the calibration analyses based on the set of protocols described previously and are distinguished from those included in the regression plots by use of different symbols and shading.

The plots generally display a good correlation between observed and simulated event volumes over the full range of events analyzed. Any significant systematic deviation between simulated and observed data would indicate events of a certain volume range were not being adequately simulated by the model.

Significant systematic under-estimation of the combined SOM/UFLL influent wet-weather event volumes is indicated by the linear regression and CFD as presented in Figure v4.1.25 and Figure v4.1.26. However, inspection of individual influent wet-weather flow hygrographs for the January 7 and July 1, 2005 rainfall events presented in Figure v4.1.27 and Figure v4.1.28, respectively, reveal a very close overall correlation between modeled and monitored hydrographs. In fact, the correlation between modeled and monitored hydrographs for the combined SOM/UFLL appears to be much better than that for the UDLL, as illustrated in Figure v4.1.29 and Figure v4.1.30, which shows a higher correlation in the linear regression and CFD plots than the combined SOM/UFLL.

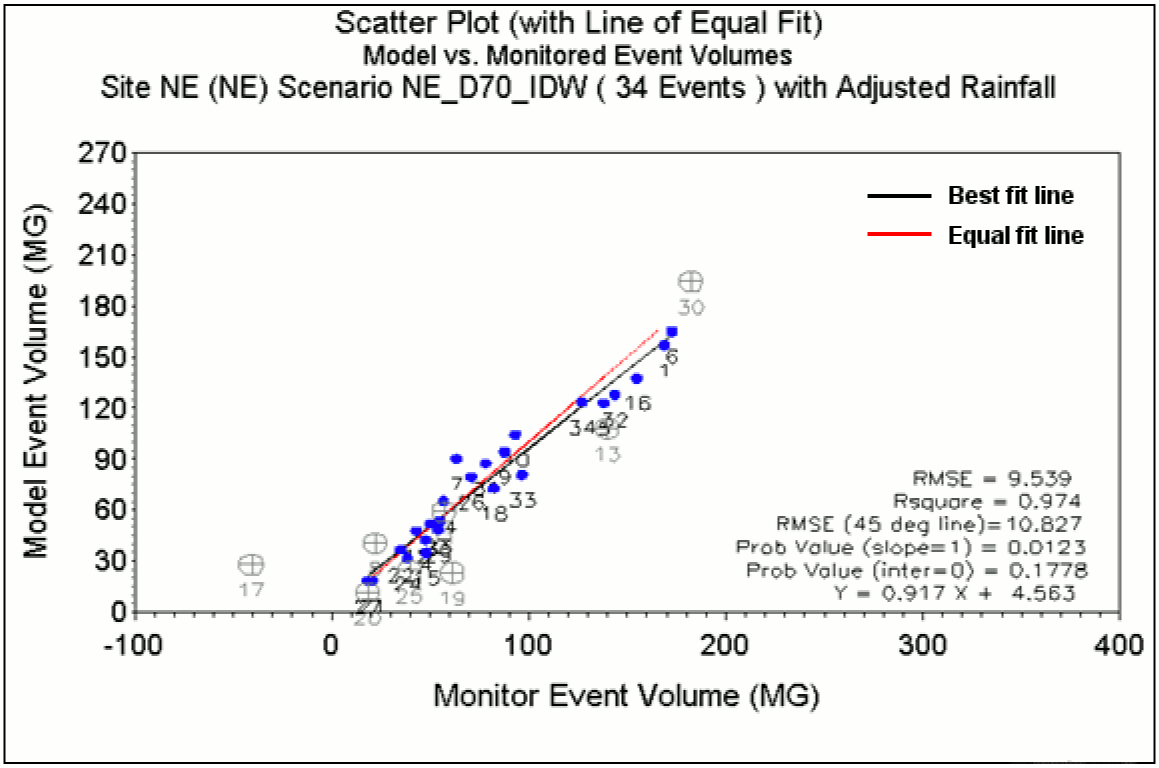


Figure v4.1.17 NE WPCP linear regression of modeled versus monitored event volumes

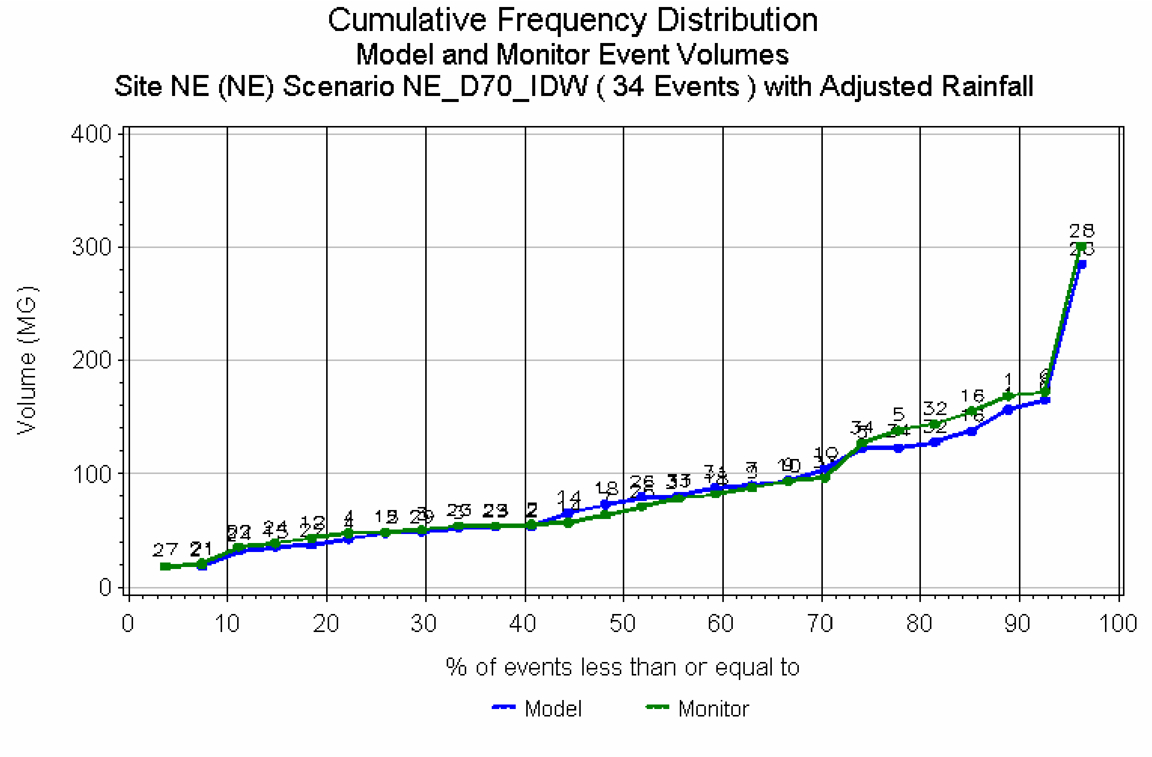


Figure v4.1.18 NE WPCP CFD of modeled and monitored event volumes

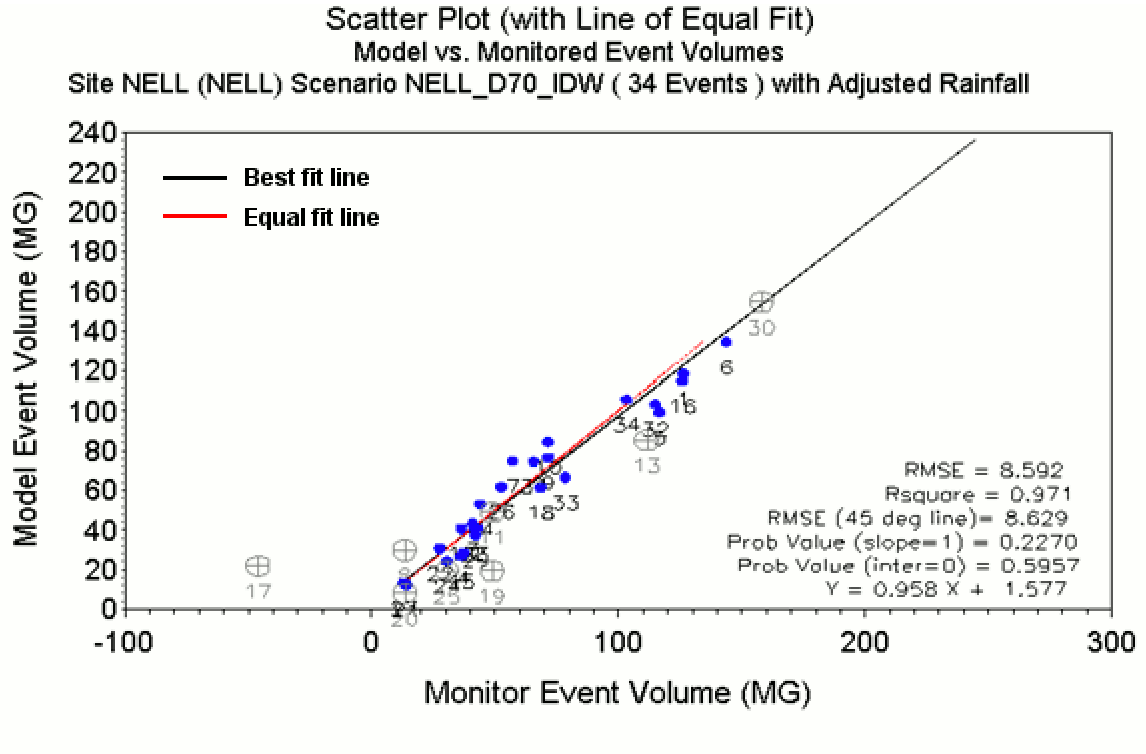


Figure v4.1.19 NELL linear regression of modeled versus monitored event volumes

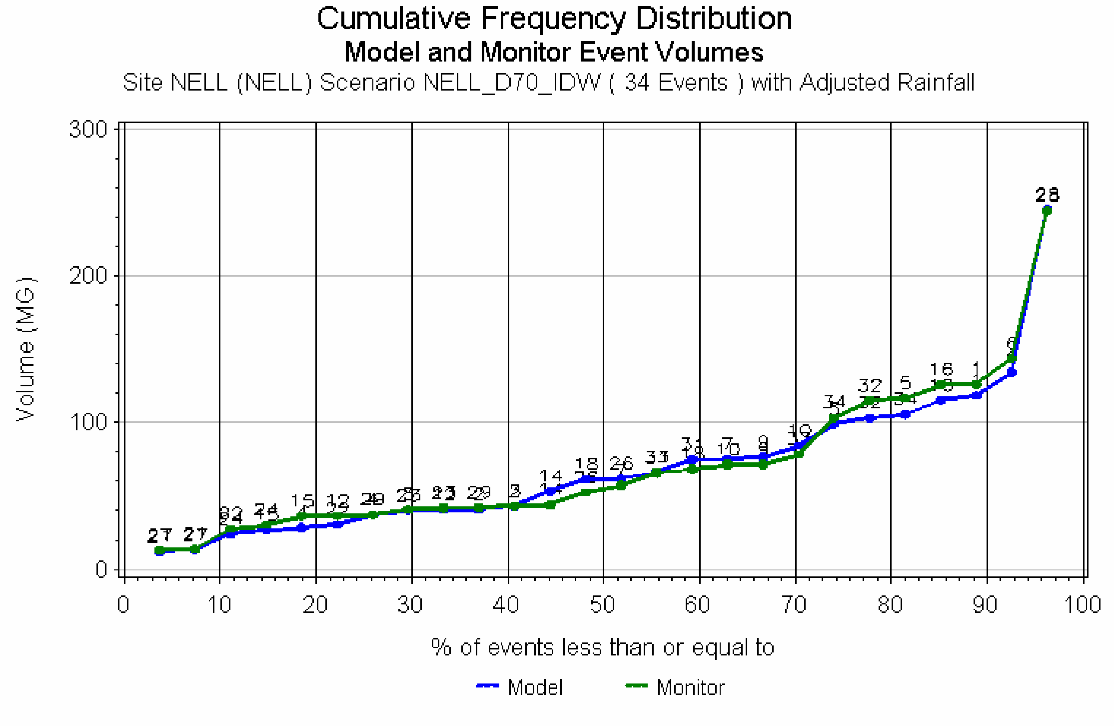


Figure v4.1.20 NELL CFD of modeled and monitored event volumes

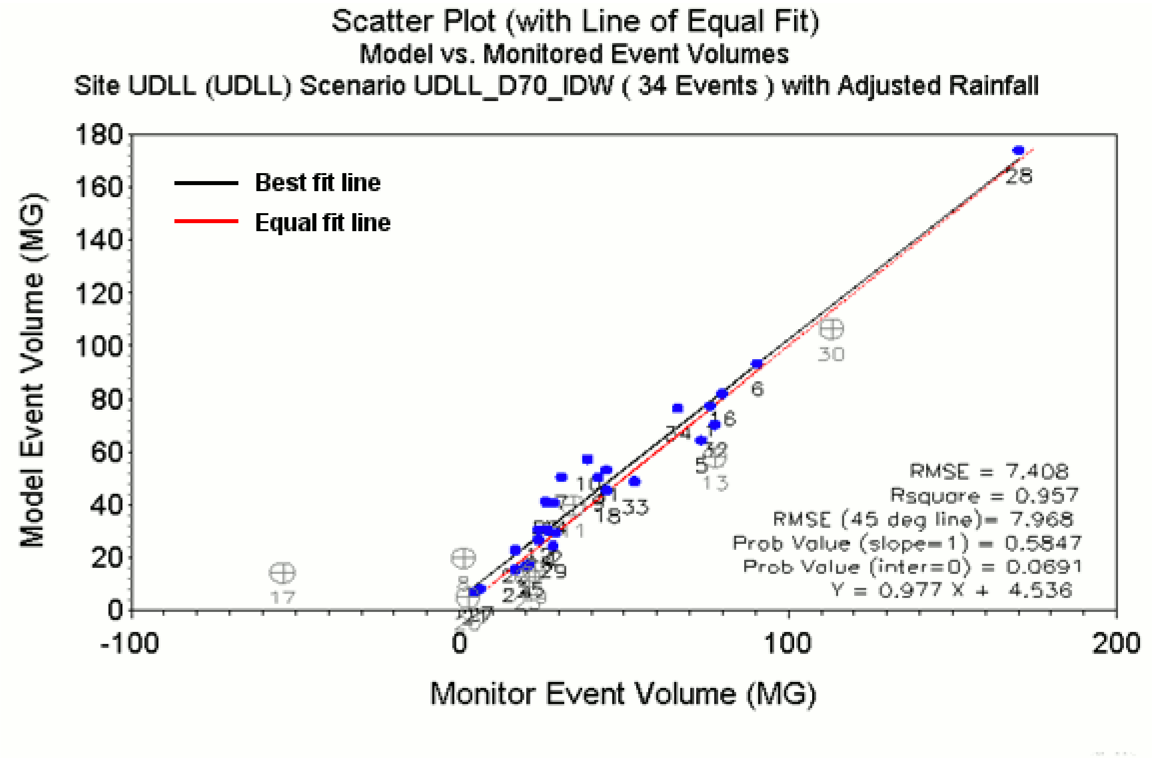


Figure v4.1.21 UDLL linear regression of modeled versus monitored event volumes

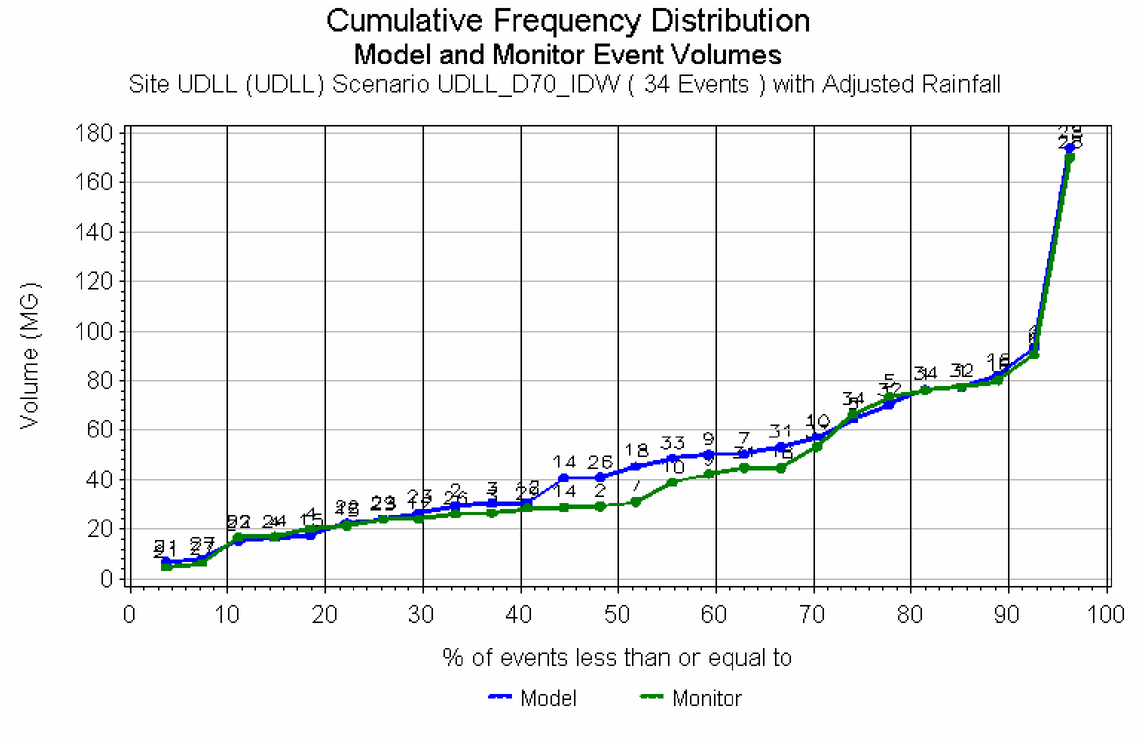


Figure v4.1.22 UDLL CFD of modeled and monitored event volumes

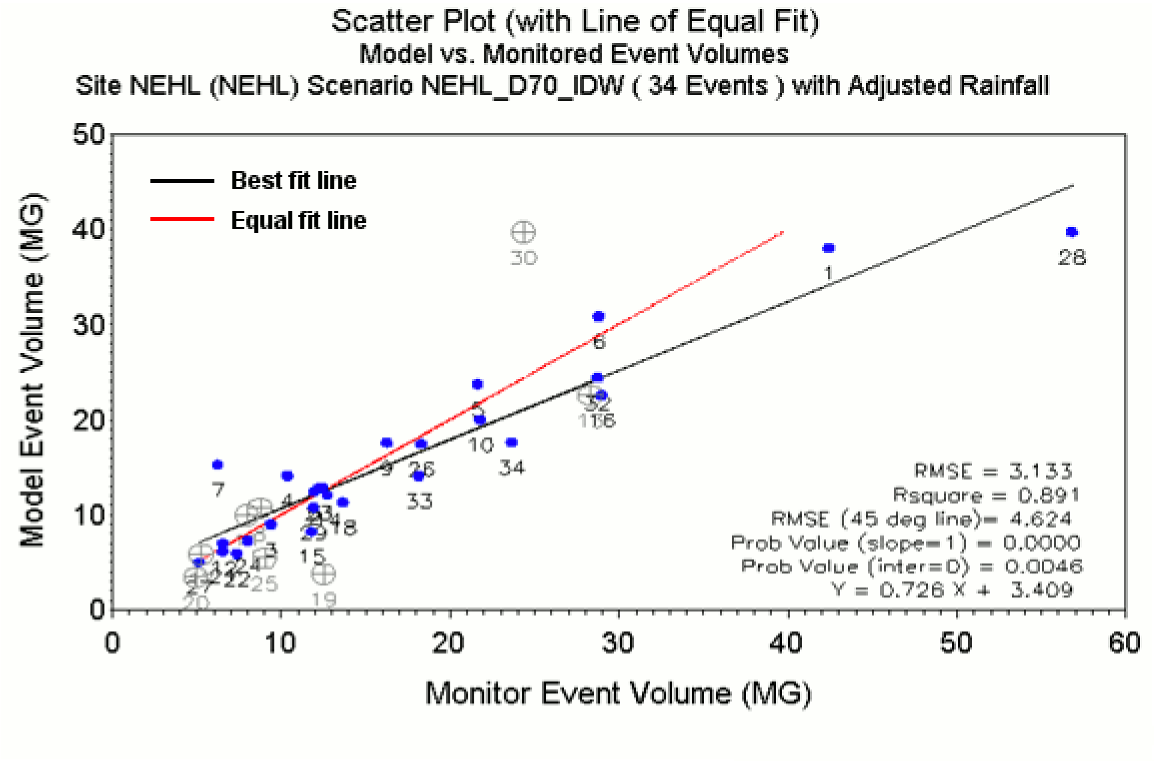


Figure v4.1.23 NEHL linear regression of modeled versus monitored event volumes

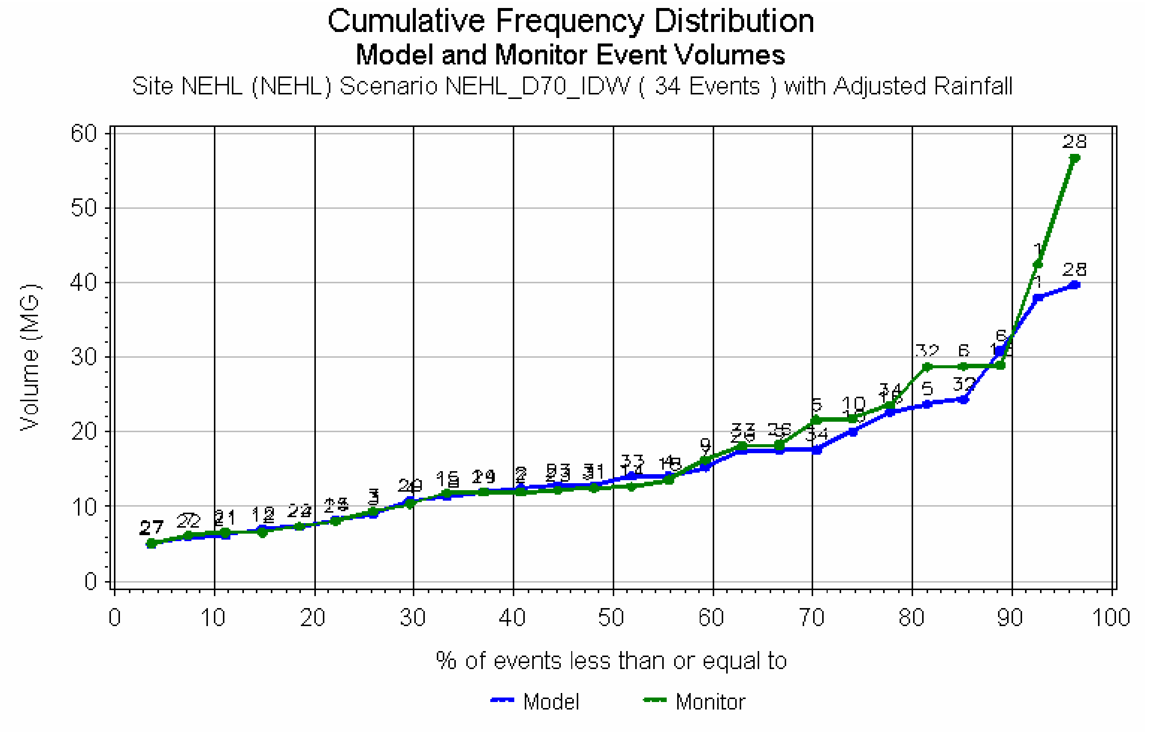


Figure v4.1.24 NEHL CFD of modeled and monitored event volumes

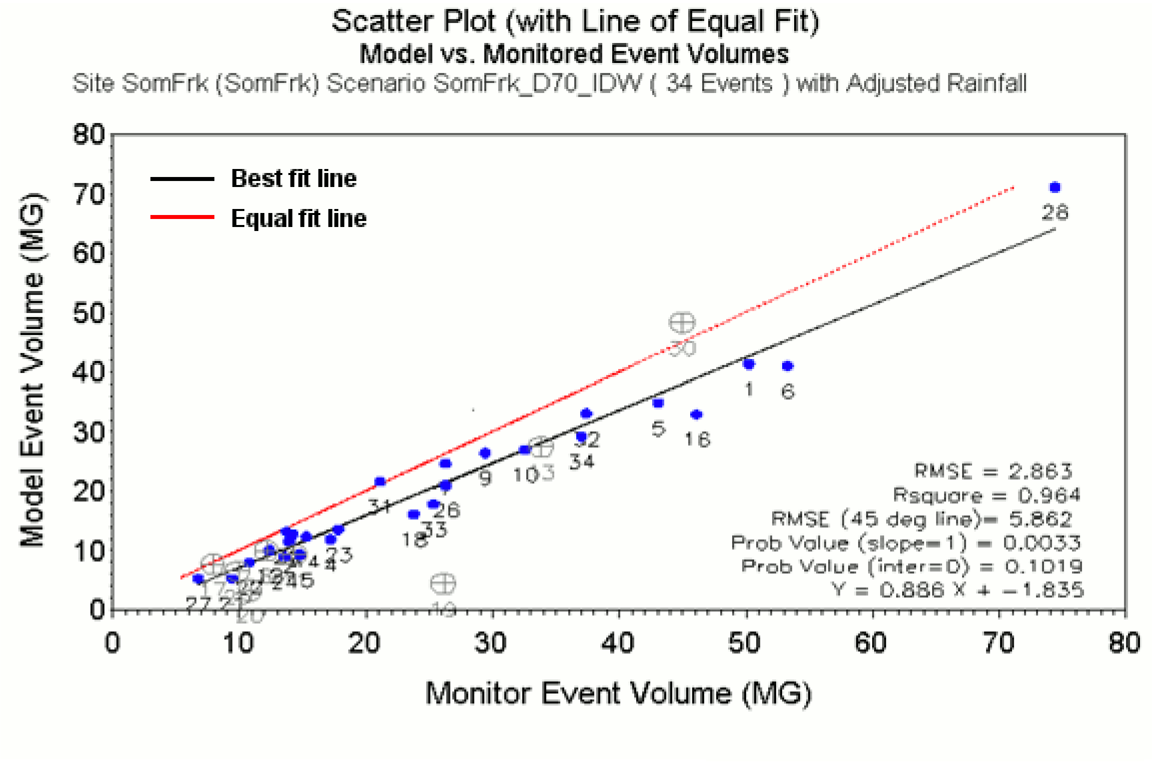


Figure v4.1.25 Som-Frk linear regression of modeled versus monitored event volumes

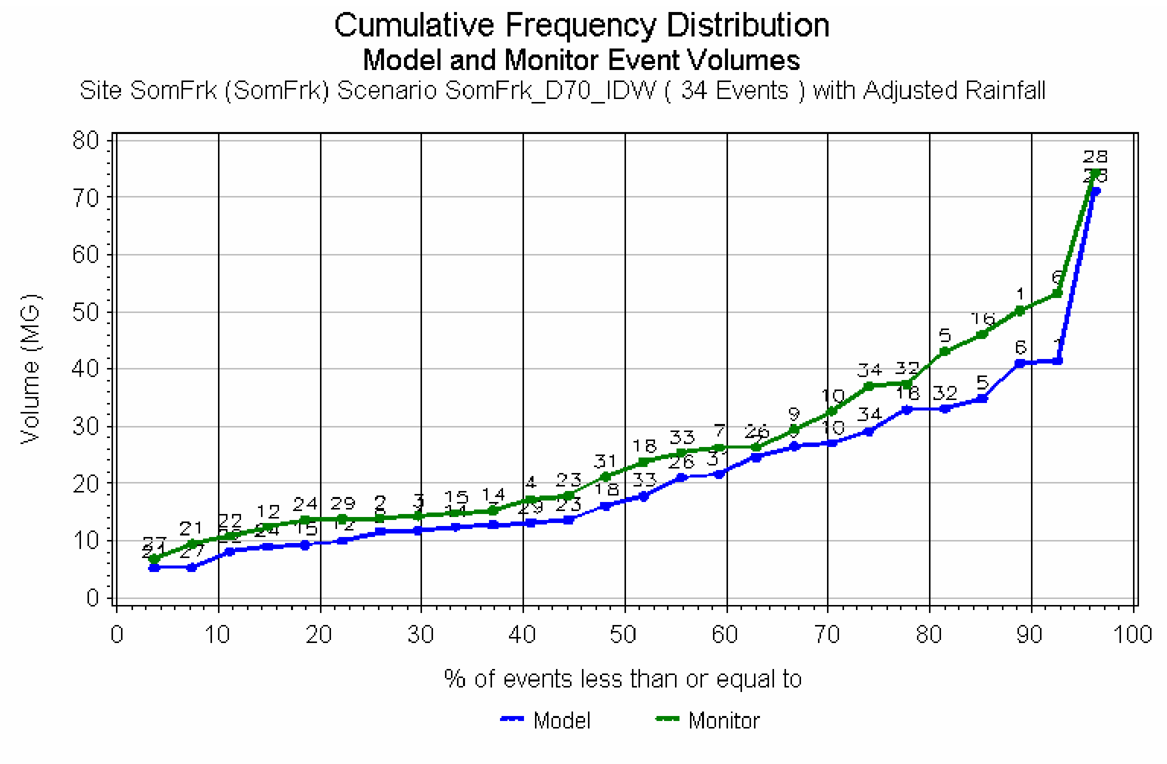


Figure v4.1.26 Som-Frk CFD of modeled and monitored event volumes

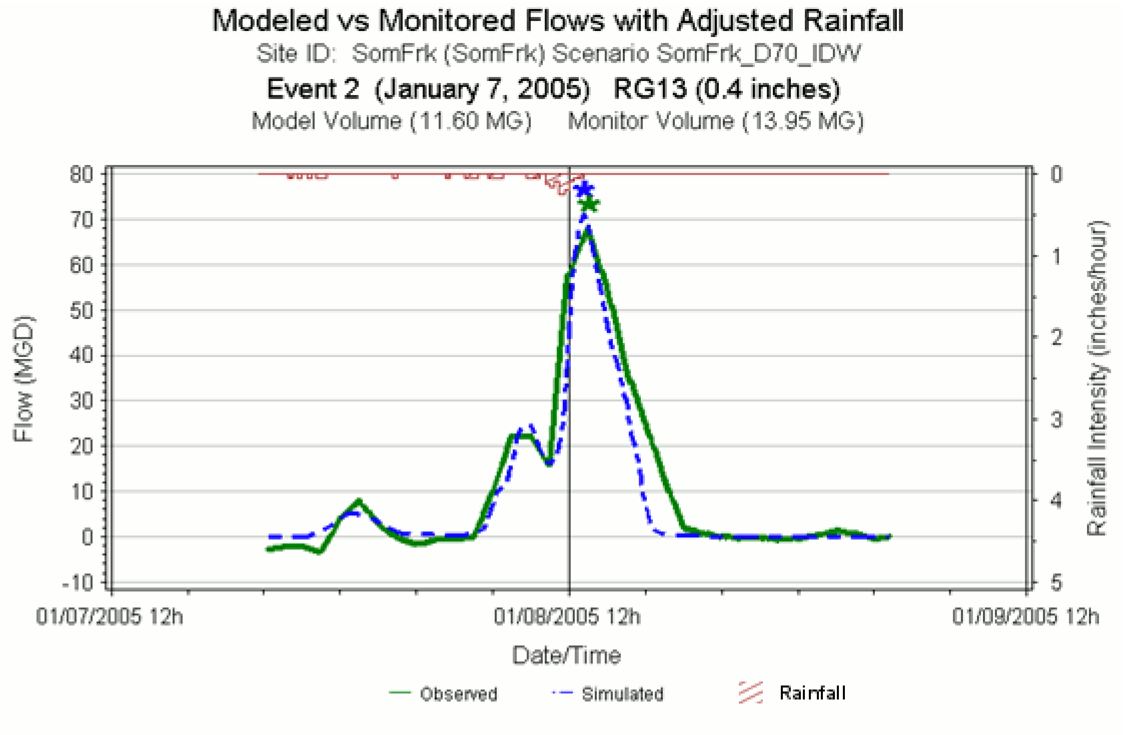


Figure v4.1.27 Som-Frk model and monitored wet-weather flow time-series plot for the January 7, 2005 event

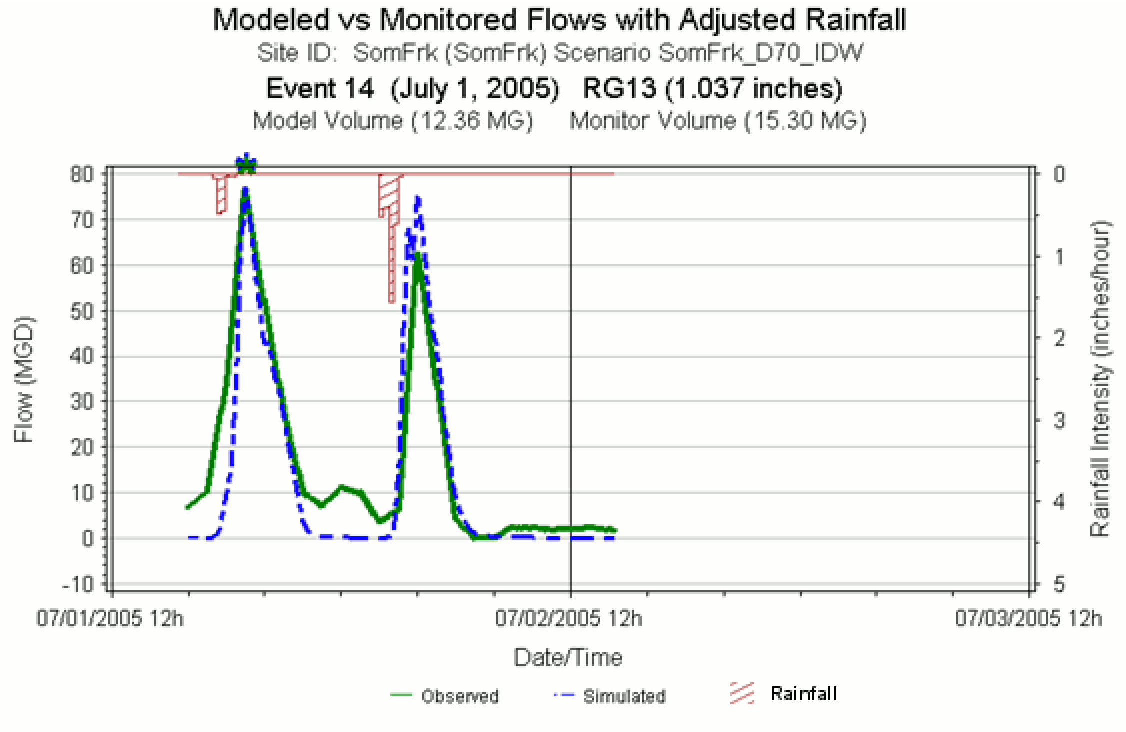


Figure v4.1.28 Som-Frk model and monitored wet-weather flow time-series plot for the July 1, 2005 event

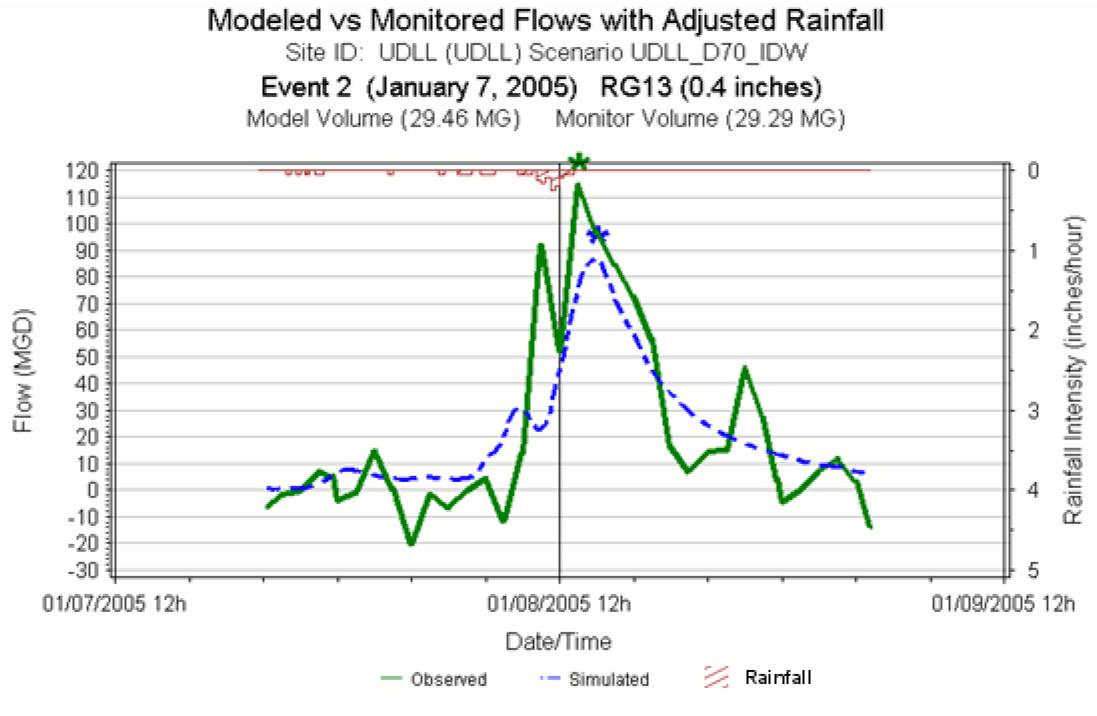


Figure v4.1.29 UDLL model and monitored wet-weather flow time-series plot for the January 7, 2005 event

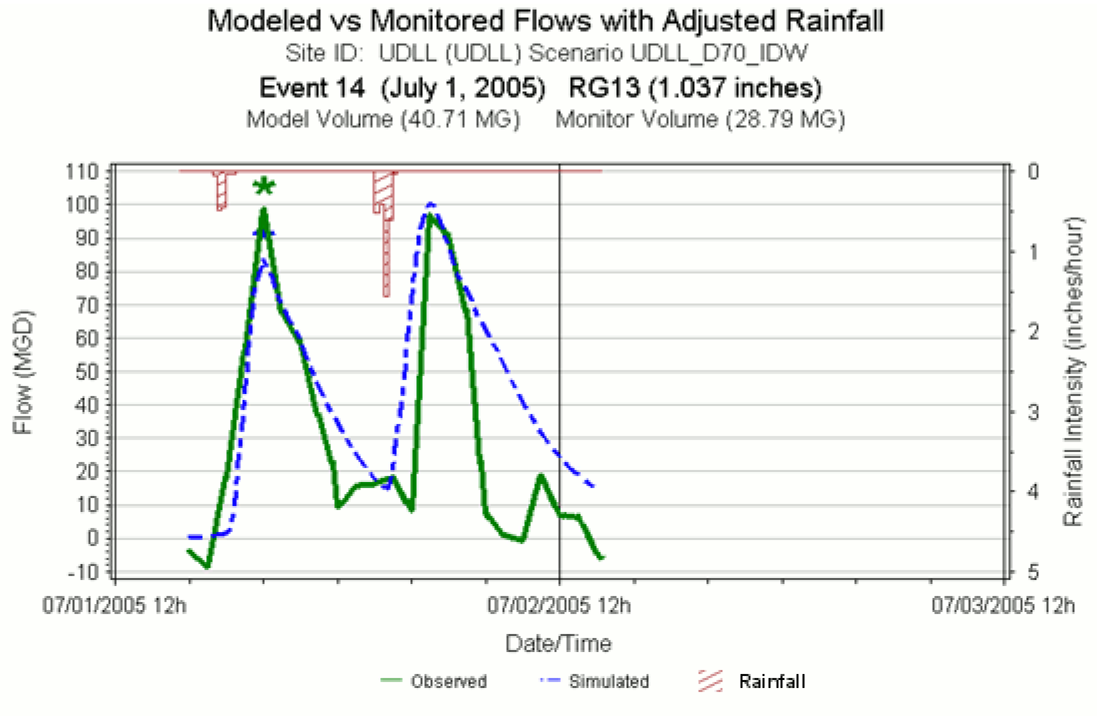


Figure v4.1.30 UDLL model and monitored wet-weather flow time-series plot for the July 1, 2005 event

4.2 CHARACTERIZATION OF BASELINE CONDITIONS – SYSTEM RESPONSE TO WET WEATHER

The response of the CSS to wet weather conditions is detailed for each WPCP drainage district through model simulations of calibrated LTCPU baseline models using typical year rainfall and the median range of estimated hydrologic parameters. Statistics for each rainfall event causing a CSO are presented for each drainage district in Table v4.2.1 through Table v4.2.3. These tables include a list and count of regulators overflowing and estimates of rainfall, runoff, and overflow volumes for each event.

Table v4.2.1 NEDD Response to Wet Weather Conditions

Rainfall Events			CSO Regulators Overflowing		NEDD Rain Gage Rainfall Depth Statistics					Flow Depth Values		
Start Time	End Time	Duration (hrs)	List	Count	Average Depth (inches)	Max Depth (inches)	Min Depth (inches)	Max Intensity (in/hr)	Min Intensity (in/hr)	RDI/I (inches)	Runoff (inches)	Overflow (inches)
1/3/05 19:00	1/4/05 5:00	8	D22, R18	2	0.08	0.14	0.05	0.05	0.002	0.001	0.015	0.000
1/5/05 1:00	1/6/05 23:00	42	D02, D03, D05, D08, D12, D18, D19, D22, D25, F04, F05, F09, F10, F11, F13, F21, F23, F24, P02, R13, R14, R18, T01, T03, T04, T08, T10, T11, T13, T14, T15	31	0.93	1.10	0.81	0.14	0.001	0.014	0.384	0.134
1/7/05 21:00	1/8/05 20:00	17	D02, D03, D05, D07, D08, D12, D17, D18, D19, D20, D21, D22, D23, D25, F03, F04, F05, F07, F08, F09, F10, F11, F12, F13, F14, F21, F23, F24, P02, R13, R14, R15, R18, T01, T03, T04, T05, T06, T08, T09, T10, T11, T13, T14, T15	45	0.52	0.62	0.40	0.30	0.001	0.008	0.204	0.109
1/11/05 15:00	1/12/05 8:00	12	D02, D03, D05, D07, D08, D12, D17, D18, D19, D20, D21, D22, D23, D25, F04, F05, F07, F08, F09, F10, F11, F13, F21, F23, F24, P02, R13, R14, R18, T01, T03, T04, T05, T08, T09, T10, T11, T13, T14, T15	40	0.57	0.69	0.48	0.23	0.001	0.008	0.241	0.156

Rainfall Events			CSO Regulators Overflowing		NEDD Rain Gage Rainfall Depth Statistics					Flow Depth Values		
Start Time	**End Time**	**Duration (hrs)**	**List**	**Count**	**Average Depth (inches)**	**Max Depth (inches)**	**Min Depth (inches)**	**Max Intensity (in/hr)**	**Min Intensity (in/hr)**	**RDI/I (inches)**	**Runoff (inches)**	**Overflow (inches)**
1/13/05 23:00	1/14/05 21:00	15	D02, D03, D04, D05, D06, D07, D08, D11, D12, D13, D15, D17, D18, D19, D20, D21, D22, D23, D24, D25, F03, F04, F05, F06, F07, F08, F09, F10, F11, F12, F13, F14, F21, F23, F24, F25, P01, P02, P03, P05, R13, R14, R15, R18, T01, T03, T04, T05, T06, T08, T09, T10, T11, T13, T14, T15	56	1.72	1.90	1.56	0.44	0.001	0.022	0.846	0.731
1/25/05 13:00	1/27/05 2:00	32	D05, D17, D18, D19, D22, D25, F04, F05, F09, F10, F11, F21, P02, R18, T01, T03, T04, T08, T10, T11, T13, T14, T15	23	0.58	0.59	0.57	0.11	0.01	0.007	0.209	0.079
2/4/05 9:00	2/4/05 22:00	8	D05, D22, D25, F04, F05, F10, F11, F21, R18, T01, T08, T10, T14	13	0.34	0.35	0.33	0.06	0.013	0.004	0.134	0.059
2/10/05 5:00	2/10/05 12:00	3	R18	1	0.03	0.08	0.02	0.04	0.004	0.001	0.012	0.001

Rainfall Events			CSO Regulators Overflowing		NEDD Rain Gage Rainfall Depth Statistics					Flow Depth Values		
Start Time	End Time	Duration (hrs)	List	Count	Average Depth (inches)	Max Depth (inches)	Min Depth (inches)	Max Intensity (in/hr)	Min Intensity (in/hr)	RDI/I (inches)	Runoff (inches)	Overflow (inches)
2/14/05 9:00	2/15/05 7:00	15	D02, D03, D05, D07, D08, D12, D17, D18, D19, D20, D21, D22, D23, D25, F04, F05, F07, F08, F09, F10, F11, F13, F21, F23, F24, P02, R13, R14, R18, T01, T03, T04, T05, T08, T09, T10, T11, T13, T14, T15	40	1.13	1.41	0.93	0.18	0.003	0.018	0.478	0.324
2/16/05 14:00	2/17/05 0:00	3	D03, D05, D12, D17, D18, D19, D22, D23, D25, F04, F05, F09, F10, F11, F13, F21, F23, F24, P02, R14, R18, T01, T03, T04, T08, T10, T11, T13, T14, T15	30	0.21	0.26	0.14	0.18	0.018	0.002	0.077	0.039
2/21/05 10:00	2/22/05 8:00	16	D03, D05, D17, D18, D19, D21, D22, D25, F04, F05, F09, F10, F11, F21, F23, R18, T01, T03, T04, T08, T10, T13, T14, T15	24	0.58	0.58	0.58	0.09	0.01	0.008	0.235	0.114
2/25/05 11:00	2/25/05 22:00	4	D05, D17, D18, D19, D22, D25, F04, F05, F09, F10, F11, F21, R18, T01, T03, T04, T08, T10, T13, T14, T15	21	0.23	0.23	0.23	0.10	0.02	0.003	0.087	0.041

Rainfall Events			CSO Regulators Overflowing		NEDD Rain Gage Rainfall Depth Statistics					Flow Depth Values		
Start Time	**End Time**	**Duration (hrs)**	**List**	**Count**	**Average Depth (inches)**	**Max Depth (inches)**	**Min Depth (inches)**	**Max Intensity (in/hr)**	**Min Intensity (in/hr)**	**RDI/I (inches)**	**Runoff (inches)**	**Overflow (inches)**
3/1/05 11:00	3/2/05 2:00	8	D02, D03, D05, D08, D12, D17, D18, D19, D20, D21, D22, D23, D25, F03, F04, F05, F07, F08, F09, F10, F11, F13, F21, F23, F24, P02, R13, R14, R18, T01, T03, T04, T05, T06, T08, T09, T10, T11, T13, T14, T15	41	0.49	0.50	0.48	0.19	0.013	0.006	0.199	0.119
3/8/05 4:00	3/8/05 18:00	11	D03, D05, D12, D17, D18, D19, D21, D22, D25, F04, F05, F09, F10, F11, F13, F21, F23, F24, P02, R14, R18, T01, T03, T04, T08, T10, T11, T13, T14, T15	30	0.43	0.48	0.37	0.13	0.001	0.006	0.173	0.095
3/11/05 22:00	3/12/05 6:00	7	D22	1	0.09	0.11	0.06	0.06	0.001	0.001	0.022	0.000
3/20/05 3:00	3/21/05 2:00	22	D22, D25, F04, F05, F10, F11, F21, R18, T01, T08	10	0.31	0.43	0.25	0.09	0.001	0.004	0.117	0.023

Rainfall Events			CSO Regulators Overflowing		NEDD Rain Gage Rainfall Depth Statistics					Flow Depth Values		
Start Time	**End Time**	**Duration (hrs)**	**List**	**Count**	**Average Depth (inches)**	**Max Depth (inches)**	**Min Depth (inches)**	**Max Intensity (in/hr)**	**Min Intensity (in/hr)**	**RDI/I (inches)**	**Runoff (inches)**	**Overflow (inches)**
3/23/05 6:00	3/24/05 6:00	25	D02, D03, D05, D07, D08, D12, D17, D18, D19, D20, D21, D22, D23, D24, D25, F03, F04, F05, F06, F07, F08, F09, F10, F11, F12, F13, F14, F21, F23, F24, P02, R13, R14, R18, T01, T03, T04, T05, T06, T08, T09, T10, T11, T13, T14, T15	46	1.00	1.28	0.83	0.29	0.001	0.013	0.434	0.246
3/27/05 19:00	3/29/05 14:00	40	D02, D03, D04, D05, D07, D08, D11, D12, D15, D17, D18, D19, D20, D21, D22, D23, D24, D25, F03, F04, F05, F06, F07, F08, F09, F10, F11, F12, F13, F14, F21, F23, F24, P02, P05, R13, R14, R15, R18, T01, T03, T04, T05, T06, T08, T09, T10, T11, T13, T14, T15	51	1.54	1.74	1.35	0.33	0.001	0.025	0.665	0.453

Rainfall Events			CSO Regulators Overflowing		NEDD Rain Gage Rainfall Depth Statistics					Flow Depth Values		
Start Time	End Time	Duration (hrs)	List	Count	Average Depth (inches)	Max Depth (inches)	Min Depth (inches)	Max Intensity (in/hr)	Min Intensity (in/hr)	RDI/I (inches)	Runoff (inches)	Overflow (inches)
4/1/05 22:00	4/4/05 0:00	48	D02, D03, D04, D05, D06, D07, D08, D09, D11, D12, D13, D15, D17, D18, D19, D20, D21, D22, D23, D24, D25, F03, F04, F05, F06, F07, F08, F09, F10, F11, F12, F13, F14, F21, F23, F24, F25, P01, P02, P03, P04, P05, R13, R14, R15, R18, T01, T03, T04, T05, T06, T07, T08, T09, T10, T11, T12, T13, T14, T15	60	3.01	3.48	2.80	0.63	0.001	0.051	1.456	1.234
4/7/05 22:00	4/8/05 15:00	12	D02, D03, D05, D07, D08, D12, D17, D18, D19, D20, D21, D22, D23, D24, D25, F03, F04, F05, F07, F08, F09, F10, F11, F13, F14, F21, F23, F24, P02, R13, R14, R18, T01, T03, T04, T05, T08, T09, T10, T11, T13, T14, T15	43	0.81	1.07	0.53	0.36	0.001	0.010	0.365	0.235

Rainfall Events			CSO Regulators Overflowing		NEDD Rain Gage Rainfall Depth Statistics					Flow Depth Values		
Start Time	**End Time**	**Duration (hrs)**	**List**	**Count**	**Average Depth (inches)**	**Max Depth (inches)**	**Min Depth (inches)**	**Max Intensity (in/hr)**	**Min Intensity (in/hr)**	**RDI/I (inches)**	**Runoff (inches)**	**Overflow (inches)**
4/23/05 7:00	4/24/05 7:00	20	D02, D03, D04, D05, D07, D08, D11, D12, D17, D18, D19, D20, D21, D22, D23, D24, D25, F03, F04, F05, F07, F08, F09, F10, F11, F12, F13, F14, F21, F23, F24, P02, R13, R14, R15, R18, T01, T03, T04, T05, T06, T07, T08, T09, T10, T11, T13, T14, T15	49	0.57	0.88	0.33	0.47	0.001	0.006	0.241	0.172
4/27/05 2:00	4/27/05 11:00	8	R18, T01, T08, T14	4	0.08	0.17	0.04	0.09	0.002	0.001	0.018	0.005
4/30/05 4:00	5/1/05 15:00	29	D02, D03, D05, D07, D08, D12, D17, D18, D19, D20, D21, D22, D23, D24, D25, F03, F04, F05, F06, F07, F08, F09, F10, F11, F12, F13, F14, F21, F23, F24, P01, P02, P03, R13, R14, R18, T01, T03, T04, T05, T06, T08, T09, T10, T11, T13, T14, T15	48	1.03	1.27	0.58	0.36	0.002	0.015	0.414	0.231
5/2/05 19:00	5/3/05 1:00	2	R18, T08	2	0.04	0.06	0.01	0.05	0.002	0.001	0.007	0.000

Rainfall Events			**CSO Regulators Overflowing**		**NEDD Rain Gage Rainfall Depth Statistics**					**Flow Depth Values**		
Start Time	**End Time**	**Duration (hrs)**	**List**	**Count**	**Average Depth (inches)**	**Max Depth (inches)**	**Min Depth (inches)**	**Max Intensity (in/hr)**	**Min Intensity (in/hr)**	**RDI/I (inches)**	**Runoff (inches)**	**Overflow (inches)**
5/20/05 5:00	5/20/05 23:00	17	D02, D03, D05, D07, D08, D12, D17, D18, D19, D20, D21, D22, D25, F04, F05, F09, F10, F11, F13, F21, F23, F24, P02, R13, R14, R18, T01, T03, T04, T08, T10, T11, T13, T14, T15	35	0.93	1.04	0.85	0.14	0.001	0.010	0.396	0.254
6/3/05 6:00	6/4/05 7:00	25	D02, D03, D05, D08, D12, D17, D18, D19, D21, D22, D25, F04, F05, F09, F10, F11, F13, F21, F23, F24, P02, R13, R14, R18, T01, T03, T04, T05, T08, T10, T11, T13, T14, T15	34	0.86	1.19	0.67	0.18	0.001	0.010	0.372	0.212
6/6/05 18:00	6/7/05 7:00	11	D02, D03, D04, D05, D06, D07, D08, D09, D11, D12, D13, D15, D17, D18, D19, D20, D21, D22, D23, D24, D25, F03, F04, F05, F06, F07, F08, F09, F10, F11, F12, F13, F14, F21, F23, F24, F25, P01, P02, P03, P05, R13, R14, R15, R18, T01, T03, T04, T05, T06, T07, T08, T09, T10, T11, T12, T13, T14, T15	59	1.02	1.34	0.73	0.96	0.002	0.012	0.505	0.461

Rainfall Events			**CSO Regulators Overflowing**		**NEDD Rain Gage Rainfall Depth Statistics**					**Flow Depth Values**		
Start Time	**End Time**	**Duration (hrs)**	**List**	**Count**	**Average Depth (inches)**	**Max Depth (inches)**	**Min Depth (inches)**	**Max Intensity (in/hr)**	**Min Intensity (in/hr)**	**RDI/I (inches)**	**Runoff (inches)**	**Overflow (inches)**
6/7/05 11:00	6/7/05 17:00	1	R18, T03, T04, T05, T08, T09, T10, T13	8	0.01	0.18	0.00	0.18	0.002	0.001	0.008	0.003
6/8/05 17:00	6/8/05 21:00	2	F10, F11	2	0.04	0.14	0.01	0.10	0.009	0.000	0.004	0.000
6/10/05 11:00	6/10/05 23:00	6	D02, D03, D05, D06, D07, D08, D11, D12, D13, D15, D17, D18, D19, D20, D21, D22, D23, D24, D25, F03, F04, F05, F06, F07, F08, F09, F10, F11, F12, F13, F14, F21, F23, F24, F25, P01, P02, P03, R13, R14, R15, R18, T01, T03, T04, T05, T06, T08, T09, T10, T11, T12, T13, T14, T15	55	0.85	1.45	0.25	1.00	0.001	0.009	0.320	0.259
6/16/05 14:00	6/16/05 22:00	5	D05, D08, D22, D25, F04, F05, F11, F21, F24, R18, T03, T04, T05, T08, T09, T10, T11, T13, T14, T15	20	0.08	0.20	0.01	0.18	0.001	0.000	0.030	0.011
6/22/05 17:00	6/22/05 22:00	5	P02	1	0.05	0.21	0.01	0.16	0.001	0.001	0.004	0.000

Rainfall Events			CSO Regulators Overflowing		NEDD Rain Gage Rainfall Depth Statistics					Flow Depth Values		
Start Time	**End Time**	**Duration (hrs)**	**List**	**Count**	**Average Depth (inches)**	**Max Depth (inches)**	**Min Depth (inches)**	**Max Intensity (in/hr)**	**Min Intensity (in/hr)**	**RDI/I (inches)**	**Runoff (inches)**	**Overflow (inches)**
6/27/05 9:00	6/28/05 11:00	26	D02, D03, D05, D07, D08, D12, D17, D18, D19, D20, D21, D22, D23, D25, F03, F04, F05, F07, F08, F09, F10, F11, F12, F13, F14, F21, F23, F24, P02, R13, R14, R15, R18, T01, T03, T04, T05, T06, T08, T09, T10, T11, T13, T14, T15	45	0.87	1.15	0.65	0.32	0.001	0.009	0.384	0.207
6/29/05 22:00	6/30/05 5:00	6	D05, D12, D15, D17, D18, D19, D20, D21, D22, D25, F03, F04, F05, F06, F07, F08, F09, F10, F11, F12, F13, F14, F21, P02, R13, R14, R18, T03, T04, T05, T06, T08, T09, T10, T11, T13, T14, T15	38	0.27	0.63	0.01	0.62	0.001	0.003	0.091	0.065

Rainfall Events			CSO Regulators Overflowing		NEDD Rain Gage Rainfall Depth Statistics					Flow Depth Values		
Start Time	**End Time**	**Duration (hrs)**	**List**	**Count**	**Average Depth (inches)**	**Max Depth (inches)**	**Min Depth (inches)**	**Max Intensity (in/hr)**	**Min Intensity (in/hr)**	**RDI/I (inches)**	**Runoff (inches)**	**Overflow (inches)**
7/1/05 16:00	7/2/05 11:00	17	D02, D03, D04, D05, D06, D07, D08, D12, D13, D15, D17, D18, D19, D20, D21, D22, D23, D24, D25, F03, F04, F05, F06, F07, F08, F09, F10, F11, F12, F13, F14, F21, F23, F24, F25, P01, P02, P03, P05, R13, R14, R15, R18, T01, T03, T04, T05, T06, T08, T09, T10, T11, T13, T14, T15	55	0.99	1.97	0.27	0.96	0.001	0.013	0.439	0.347
7/5/05 16:00	7/6/05 9:00	12	D02, D03, D05, D07, D08, D12, D17, D18, D19, D20, D21, D22, D23, D24, D25, F03, F04, F05, F07, F08, F09, F10, F11, F13, F14, F21, F23, F24, P02, R13, R14, R18, T01, T03, T04, T05, T06, T08, T09, T10, T11, T13, T14, T15	44	0.33	0.68	0.17	0.39	0.001	0.003	0.138	0.074
7/6/05 23:00	7/7/05 6:00	5	D22, F04, F05, F10, F21, R18, T01, T03, T04, T05, T06, T08, T09, T10, T11, T13, T14, T15	18	0.13	0.58	0.02	0.56	0.001	0.003	0.025	0.013

Rainfall Events			CSO Regulators Overflowing		NEDD Rain Gage Rainfall Depth Statistics					Flow Depth Values		
Start Time	End Time	Duration (hrs)	List	Count	Average Depth (inches)	Max Depth (inches)	Min Depth (inches)	Max Intensity (in/hr)	Min Intensity (in/hr)	RDI/I (inches)	Runoff (inches)	Overflow (inches)
7/8/05 0:00	7/8/05 23:00	19	D02, D03, D04, D05, D06, D07, D08, D09, D11, D12, D13, D15, D17, D18, D19, D20, D21, D22, D23, D24, D25, F03, F04, F05, F06, F07, F08, F09, F10, F11, F12, F13, F14, F21, F23, F24, F25, P01, P02, P03, P04, P05, R13, R14, R15, R18, T01, T03, T04, T05, T06, T07, T08, T09, T10, T11, T12, T13, T14, T15	60	1.97	3.07	1.25	1.17	0.001	0.023	1.186	1.040
7/15/05 17:00	7/15/05 21:00	2	T01	1	0.04	0.54	0.00	0.53	0.003	0.000	0.001	0.000
7/16/05 16:00	7/18/05 22:00	48	D02, D03, D04, D05, D06, D07, D08, D09, D11, D12, D13, D15, D17, D18, D19, D20, D21, D22, D23, D24, D25, F03, F04, F05, F06, F07, F08, F09, F10, F11, F12, F13, F14, F21, F23, F24, F25, P01, P02, P03, P04, P05, R13, R14, R15, R18, T01, T03, T04, T06, T08, T09, T10, T11, T12, T13, T14, T15	58	1.92	3.14	0.52	2.30	0.001	0.022	1.010	0.837

Rainfall Events			CSO Regulators Overflowing		NEDD Rain Gage Rainfall Depth Statistics					Flow Depth Values		
Start Time	**End Time**	**Duration (hrs)**	**List**	**Count**	**Average Depth (inches)**	**Max Depth (inches)**	**Min Depth (inches)**	**Max Intensity (in/hr)**	**Min Intensity (in/hr)**	**RDI/I (inches)**	**Runoff (inches)**	**Overflow (inches)**
7/25/05 3:00	7/25/05 16:00	10	D05, D22, F04, F05, F10, F11, F21, R13, R14, R18, T01, T04, T08	13	0.19	0.26	0.10	0.19	0.003	0.002	0.039	0.006
7/27/05 19:00	7/28/05 5:00	5	D17, D18, D22, D25, F04, F05, F09, F10, F11, F13, F21, R18, T01, T03, T04, T08, T10, T13, T14, T15	20	0.14	0.20	0.10	0.10	0.002	0.002	0.039	0.015
8/6/05 3:00	8/6/05 8:00	2	D05, D08, D22, D25, F03, F04, F05, F11, F21, F23, F24, R18, T03, T04, T05, T08, T09, T10, T11, T13, T14, T15	22	0.07	0.40	0.01	0.29	0.01	0.000	0.040	0.019
8/8/05 6:00	8/9/05 17:00	30	D05, D17, D18, D19, D22, D23, D24, D25, F04, F05, F09, F10, F11, F21, F24, P02, R18, T01, T03, T04, T08, T10, T11, T13, T14, T15	26	0.40	0.73	0.20	0.38	0.001	0.004	0.112	0.043

Rainfall Events			CSO Regulators Overflowing		NEDD Rain Gage Rainfall Depth Statistics					Flow Depth Values		
Start Time	**End Time**	**Duration (hrs)**	**List**	**Count**	**Average Depth (inches)**	**Max Depth (inches)**	**Min Depth (inches)**	**Max Intensity (in/hr)**	**Min Intensity (in/hr)**	**RDI/I (inches)**	**Runoff (inches)**	**Overflow (inches)**
8/14/05 21:00	8/15/05 10:00	13	D02, D03, D04, D05, D06, D07, D08, D11, D12, D13, D15, D17, D18, D19, D20, D21, D22, D23, D24, D25, F03, F04, F05, F06, F07, F08, F09, F10, F11, F12, F13, F14, F21, F23, F24, F25, P01, P02, P03, P05, R13, R14, R15, R18, T01, T03, T04, T05, T06, T07, T08, T09, T10, T11, T13, T14, T15	57	0.75	1.28	0.34	1.27	0.001	0.006	0.344	0.300
8/16/05 12:00	8/17/05 11:00	21	D02, D03, D05, D07, D08, D12, D15, D17, D18, D19, D20, D21, D22, D23, D25, F03, F04, F05, F06, F07, F08, F09, F10, F11, F12, F13, F14, F21, F23, F24, P02, R13, R14, R18, T01, T03, T04, T05, T06, T08, T09, T10, T11, T13, T14, T15	46	0.57	0.87	0.37	0.34	0.001	0.005	0.256	0.143

Rainfall Events			CSO Regulators Overflowing		NEDD Rain Gage Rainfall Depth Statistics					Flow Depth Values		
Start Time	**End Time**	**Duration (hrs)**	**List**	**Count**	**Average Depth (inches)**	**Max Depth (inches)**	**Min Depth (inches)**	**Max Intensity (in/hr)**	**Min Intensity (in/hr)**	**RDI/I (inches)**	**Runoff (inches)**	**Overflow (inches)**
8/27/05 10:00	8/28/05 16:00	31	D02, D03, D05, D08, D12, D17, D18, D19, D21, D22, D23, D25, F03, F04, F05, F07, F08, F09, F10, F11, F13, F21, F23, F24, P02, R13, R14, R15, R18, T01, T03, T04, T05, T06, T07, T08, T09, T10, T11, T13, T14, T15	42	0.55	0.78	0.30	0.41	0.001	0.006	0.189	0.112
8/29/05 17:00	8/30/05 1:00	2	D02, D03, D04, D05, D07, D08, D12, D17, D18, D19, D20, D21, D22, D23, D25, F03, F04, F05, F06, F07, F08, F09, F10, F11, F12, F13, F14, F21, F23, F24, P02, P03, R13, R14, R15, R18, T01, T03, T04, T05, T06, T07, T08, T09, T10, T11, T12, T13, T14, T15	50	0.35	0.72	0.01	0.72	0.008	0.002	0.218	0.180
8/31/05 19:00	8/31/05 22:00	1	T01	1	0.03	0.09	0.01	0.09	0.009	0.000	0.003	0.000

Rainfall Events			CSO Regulators Overflowing		NEDD Rain Gage Rainfall Depth Statistics					Flow Depth Values		
Start Time	**End Time**	**Duration (hrs)**	**List**	**Count**	**Average Depth (inches)**	**Max Depth (inches)**	**Min Depth (inches)**	**Max Intensity (in/hr)**	**Min Intensity (in/hr)**	**RDI/I (inches)**	**Runoff (inches)**	**Overflow (inches)**
9/14/05 9:00	9/15/05 0:00	12	D02, D03, D05, D08, D12, D17, D18, D19, D20, D21, D22, D23, D24, D25, F04, F05, F07, F08, F09, F10, F11, F12, F13, F14, F21, F23, F24, P01, P02, P03, R13, R14, R18, T01, T03, T04, T05, T06, T08, T09, T10, T11, T13, T14, T15	45	0.42	0.84	0.13	0.43	0.001	0.005	0.153	0.089
9/15/05 7:00	9/15/05 22:00	10	D03, D05, D08, D12, D17, D18, D19, D20, D21, D22, D23, D24, D25, F03, F04, F05, F07, F08, F09, F10, F11, F12, F13, F14, F21, F23, F24, P02, R13, R14, R15, R18, T01, T03, T04, T05, T06, T07, T08, T09, T10, T11, T12, T13, T14, T15	46	0.36	0.91	0.10	0.48	0.002	0.003	0.170	0.110
9/17/05 21:00	9/18/05 4:00	7	D02, D22, D25, F04, F05, F07, P02, R18, T01, T03, T04, T05, T08, T09, T10, T11, T13, T14, T15	19	0.10	0.36	0.01	0.34	0.003	0.001	0.039	0.025
9/26/05 20:00	9/27/05 5:00	8	D05, D17, D18, D22, D25, F04, F05, F09, F10, F11, F21, R18, T01, T03, T04, T08, T10, T13, T14	19	0.17	0.20	0.09	0.12	0.001	0.002	0.053	0.023
9/29/05 12:00	9/29/05 19:00	3	R18, T08	2	0.07	0.11	0.04	0.05	0.008	0.001	0.012	0.001

Rainfall Events			CSO Regulators Overflowing		NEDD Rain Gage Rainfall Depth Statistics					Flow Depth Values		
Start Time	**End Time**	**Duration (hrs)**	**List**	**Count**	**Average Depth (inches)**	**Max Depth (inches)**	**Min Depth (inches)**	**Max Intensity (in/hr)**	**Min Intensity (in/hr)**	**RDI/I (inches)**	**Runoff (inches)**	**Overflow (inches)**
10/7/05 14:00	10/9/05 12:00	44	D02, D03, D04, D05, D06, D07, D08, D09, D11, D12, D13, D15, D17, D18, D19, D20, D21, D22, D23, D24, D25, F03, F04, F05, F06, F07, F08, F09, F10, F11, F12, F13, F14, F21, F23, F24, F25, P01, P02, P03, P04, P05, R13, R14, R15, R18, T01, T03, T04, T05, T06, T07, T08, T09, T10, T11, T12, T13, T14, T15	60	3.31	3.86	2.85	0.96	0.001	0.051	1.687	1.443
10/11/05 0:00	10/11/05 14:00	12	D12, D17, D18, D19, D22, D23, D25, F04, F05, F07, F08, F09, F10, F11, F12, F13, F14, F21, R18, T08, T11, T13, T15	23	0.18	0.33	0.07	0.20	0.002	0.001	0.055	0.011
10/11/05 18:00	10/15/05 5:00	82	D02, D03, D05, D08, D12, D18, D19, D20, D21, D22, D23, D25, F03, F04, F05, F07, F08, F09, F10, F11, F12, F13, F14, F21, F23, F24, P01, P02, P03, R13, R14, R15, R18, T01, T03, T04, T05, T06, T08, T09, T10, T11, T13, T14, T15	45	1.51	2.14	1.22	0.34	0.001	0.026	0.569	0.231

Rainfall Events			CSO Regulators Overflowing		NEDD Rain Gage Rainfall Depth Statistics					Flow Depth Values		
Start Time	**End Time**	**Duration (hrs)**	**List**	**Count**	**Average Depth (inches)**	**Max Depth (inches)**	**Min Depth (inches)**	**Max Intensity (in/hr)**	**Min Intensity (in/hr)**	**RDI/I (inches)**	**Runoff (inches)**	**Overflow (inches)**
10/21/05 9:00	10/21/05 19:00	10	D05, D22, D25, F04, F05, F09, F10, F11, F21, R18, T01, T08, T14	13	0.22	0.27	0.18	0.08	0.001	0.002	0.077	0.026
10/22/05 2:00	10/23/05 6:00	24	D02, D03, D04, D05, D07, D08, D12, D17, D18, D19, D20, D21, D22, D23, D25, F03, F04, F05, F06, F07, F08, F09, F10, F11, F12, F13, F14, F21, F23, F24, P01, P02, P03, P05, R13, R14, R15, R18, T01, T03, T04, T05, T06, T08, T09, T10, T11, T13, T14, T15	50	0.94	1.20	0.80	0.32	0.002	0.014	0.383	0.205
10/24/05 18:00	10/26/05 10:00	38	D02, D03, D05, D08, D12, D17, D18, D19, D20, D21, D22, D23, D25, F04, F05, F07, F08, F09, F10, F11, F13, F14, F21, F23, F24, P02, R13, R14, R18, T01, T03, T04, T06, T08, T09, T10, T11, T13, T14, T15	40	1.28	1.61	1.10	0.25	0.002	0.024	0.532	0.251
11/6/05 21:00	11/7/05 3:00	2	D22, F05, F10, F11, R18, T01, T03, T04, T05, T08, T10, T13, T14	13	0.08	0.12	0.04	0.12	0.012	0.001	0.018	0.005

Rainfall Events			CSO Regulators Overflowing		NEDD Rain Gage Rainfall Depth Statistics					Flow Depth Values		
Start Time	**End Time**	**Duration (hrs)**	**List**	**Count**	**Average Depth (inches)**	**Max Depth (inches)**	**Min Depth (inches)**	**Max Intensity (in/hr)**	**Min Intensity (in/hr)**	**RDI/I (inches)**	**Runoff (inches)**	**Overflow (inches)**
11/10/05 1:00	11/10/05 9:00	4	D02, D03, D05, D08, D12, D17, D18, D19, D22, D23, D25, F04, F05, F07, F08, F09, F10, F11, F13, F14, F21, F23, F24, P02, R13, R14, R18, T01, T03, T04, T05, T06, T08, T09, T10, T11, T13, T14, T15	39	0.21	0.31	0.15	0.27	0.002	0.002	0.064	0.032
11/16/05 17:00	11/17/05 7:00	9	D02, D03, D04, D05, D07, D08, D11, D12, D17, D18, D19, D20, D21, D22, D23, D24, D25, F03, F04, F05, F06, F07, F08, F09, F10, F11, F12, F13, F14, F21, F23, F24, P01, P02, P03, R13, R14, R15, R18, T01, T03, T04, T05, T06, T08, T09, T10, T11, T13, T14, T15	51	0.97	1.09	0.79	0.31	0.009	0.012	0.419	0.310

Rainfall Events			CSO Regulators Overflowing		NEDD Rain Gage Rainfall Depth Statistics					Flow Depth Values		
Start Time	**End Time**	**Duration (hrs)**	**List**	**Count**	**Average Depth (inches)**	**Max Depth (inches)**	**Min Depth (inches)**	**Max Intensity (in/hr)**	**Min Intensity (in/hr)**	**RDI/I (inches)**	**Runoff (inches)**	**Overflow (inches)**
11/21/05 16:00	11/22/05 20:00	23	D02, D03, D05, D07, D08, D12, D17, D18, D19, D20, D21, D22, D23, D24, D25, F03, F04, F05, F07, F08, F09, F10, F11, F12, F13, F14, F21, F23, F24, P02, R13, R14, R18, T01, T03, T04, T05, T06, T08, T09, T10, T11, T13, T14, T15	45	0.97	1.12	0.81	0.21	0.001	0.014	0.410	0.222
11/29/05 17:00	11/30/05 9:00	10	D02, D03, D04, D05, D06, D07, D08, D11, D12, D15, D17, D18, D19, D20, D21, D22, D23, D24, D25, F03, F04, F05, F06, F07, F08, F09, F10, F11, F12, F13, F14, F21, F23, F24, P01, P02, P03, P05, R13, R14, R15, R18, T01, T03, T04, T05, T06, T08, T09, T10, T11, T13, T14, T15	54	0.98	1.39	0.74	0.36	0.001	0.013	0.407	0.316
12/4/05 12:00	12/4/05 22:00	7	D22, D25, F11, F21, R18	5	0.12	0.24	0.05	0.05	0.001	0.002	0.040	0.004
12/6/05 11:00	12/6/05 19:00	6	D22	1	0.06	0.09	0.04	0.04	0.001	0.001	0.012	0.000
12/9/05 8:00	12/9/05 21:00	10	D05, D18, D22, D25, F04, F05, F09, F10, F11, F21, R18, T01, T03, T04, T08, T10, T13, T14	18	0.21	0.34	0.07	0.11	0.001	0.002	0.083	0.025

Rainfall Events			CSO Regulators Overflowing		NEDD Rain Gage Rainfall Depth Statistics					Flow Depth Values		
Start Time	**End Time**	**Duration (hrs)**	**List**	**Count**	**Average Depth (inches)**	**Max Depth (inches)**	**Min Depth (inches)**	**Max Intensity (in/hr)**	**Min Intensity (in/hr)**	**RDI/I (inches)**	**Runoff (inches)**	**Overflow (inches)**
12/11/05 12:00	12/11/05 22:00	8	D22, F21, R18	3	0.10	0.14	0.02	0.04	0.001	0.002	0.032	0.003
12/15/05 19:00	12/16/05 15:00	13	D02, D03, D04, D05, D07, D08, D12, D17, D18, D19, D20, D21, D22, D23, D25, F03, F04, F05, F07, F08, F09, F10, F11, F12, F13, F14, F21, F23, F24, P02, P05, R13, R14, R15, R18, T01, T03, T04, T05, T06, T08, T09, T10, T11, T13, T14, T15	47	1.19	1.69	1.04	0.30	0.001	0.019	0.493	0.357
12/25/05 13:00	12/26/05 11:00	20	D02, D03, D05, D08, D12, D17, D18, D19, D20, D21, D22, D23, D25, F03, F04, F05, F07, F08, F09, F10, F11, F13, F14, F21, F23, F24, P02, R13, R14, R18, T01, T03, T04, T05, T06, T08, T09, T10, T11, T13, T14, T15	42	0.61	0.71	0.55	0.18	0.001	0.008	0.240	0.131
12/29/05 7:00	12/30/05 1:00	18	D05, D12, D13, D15, D17, D18, D19, D20, D21, D22, D23, D25, F04, F05, F06, F07, F08, F09, F10, F11, F12, F13, F14, F21, P02, R18, T01, T03, T04, T08, T10, T11, T13, T14, T15	35	0.46	1.14	0.34	0.46	0.001	0.006	0.180	0.071

Rainfall Events			**CSO Regulators Overflowing**		**NEDD Rain Gage Rainfall Depth Statistics**					**Flow Depth Values**		
Start Time	**End Time**	**Duration (hrs)**	**List**	**Count**	**Average Depth (inches)**	**Max Depth (inches)**	**Min Depth (inches)**	**Max Intensity (in/hr)**	**Min Intensity (in/hr)**	**RDI/I (inches)**	**Runoff (inches)**	**Overflow (inches)**
12/31/05 13:00	12/31/05 22:00	7	D05, D12, D22, D25, F04, F05, F09, F10, F11, F13, F21, F24, P02, R18, T01, T03, T04, T08, T10, T11, T13, T14, T15	23	0.13	0.16	0.11	0.09	0.001	0.002	0.043	0.015

Table v4.2.2 SEDD Response to Wet Weather Conditions

Rainfall Events			SEDD CSO Regulators Overflowing		SEDD Rain Gage Rainfall Depth Statistics					SEDD Flow Depth Values		
Start Time	**End Time**	**Duration (hrs)**	**List**	**Count**	**Average Depth (inches)**	**Max Depth (inches)**	**Min Depth (inches)**	**Max Intensity (in/hr)**	**Min Intensity (in/hr)**	**RDI/I (inches)**	**Runoff (inches)**	**Overflow (inches)**
1/5/05 2:00	1/7/05 0:00	41	D37, D38, D39, D40, D44, D47, D51, D68, D71, D73	10	0.98	1.08	0.89	0.12	0.001	0.003	0.422	0.018
1/7/05 23:00	1/8/05 20:00	15	D37, D38, D39, D40, D41, D44, D45, D47, D48, D51, D51A, D61, D66, D67, D68, D71, D73	17	0.46	0.56	0.40	0.17	0.001	0.001	0.164	0.038
1/11/05 16:00	1/12/05 7:00	10	D37, D38, D39, D40, D41, D44, D45, D47, D48, D51, D51A, D61, D66, D68, D71, D73	16	0.49	0.59	0.46	0.17	0.001	0.001	0.196	0.063
1/13/05 23:00	1/14/05 22:00	15	D37, D38, D39, D40, D41, D42, D44, D45, D46, D47, D48, D50, D51, D51A, D52, D54, D58, D61, D62, D63, D64, D65, D66, D67, D68, D69, D70, D71, D72, D73	30	1.69	1.78	1.56	0.44	0.001	0.004	0.811	0.621
1/25/05 13:00	1/27/05 0:00	32	D37, D38, D39, D40, D44, D47, D51, D51A, D61, D68, D71, D73	12	0.58	0.59	0.57	0.11	0.01	0.002	0.226	0.018
2/4/05 9:00	2/4/05 21:00	8	D37, D47, D51, D68	4	0.34	0.35	0.33	0.06	0.013	0.001	0.125	0.003
2/14/05 10:00	2/15/05 9:00	15	D37, D38, D39, D40, D41, D44, D45, D47, D48, D51, D51A, D61, D68, D71, D72, D73	16	1.05	1.41	0.83	0.18	0.002	0.003	0.398	0.121

Rainfall Events			SEDD CSO Regulators Overflowing		SEDD Rain Gage Rainfall Depth Statistics					SEDD Flow Depth Values		
Start Time	**End Time**	**Duration (hrs)**	**List**	**Count**	**Average Depth (inches)**	**Max Depth (inches)**	**Min Depth (inches)**	**Max Intensity (in/hr)**	**Min Intensity (in/hr)**	**RDI/I (inches)**	**Runoff (inches)**	**Overflow (inches)**
2/16/05 15:00	2/16/05 23:00	3	D37, D38, D39, D40, D41, D44, D47, D48, D51, D51A, D61, D68, D71	13	0.20	0.26	0.14	0.18	0.02	0.001	0.081	0.010
2/21/05 10:00	2/22/05 8:00	16	D37, D38, D39, D40, D41, D44, D45, D47, D51, D51A, D68, D71, D73	13	0.58	0.58	0.58	0.09	0.01	0.002	0.242	0.032
2/25/05 11:00	2/25/05 21:00	4	D37, D39, D40, D44, D47, D51, D51A, D68, D71	9	0.23	0.23	0.23	0.10	0.02	0.001	0.087	0.005
3/1/05 11:00	3/2/05 0:00	8	D37, D38, D39, D40, D41, D43, D44, D45, D47, D48, D51, D51A, D58, D61, D62, D63, D65, D66, D67, D68, D71, D73	22	0.49	0.50	0.48	0.19	0.013	0.001	0.202	0.061
3/8/05 4:00	3/8/05 18:00	7	D37, D38, D39, D40, D41, D44, D45, D47, D48, D51, D51A, D61, D66, D68, D71, D73	16	0.40	0.45	0.36	0.13	0.011	0.001	0.169	0.034
3/11/05 22:00	3/12/05 5:00	6	D47, D51, D51A	3	0.10	0.11	0.07	0.06	0.002	0.000	0.031	0.000
3/20/05 3:00	3/20/05 23:00	20	D37, D40, D47, D51, D51A	5	0.36	0.43	0.25	0.09	0.001	0.001	0.157	0.002
3/23/05 5:00	3/24/05 4:00	20	D37, D38, D39, D40, D41, D44, D45, D46, D47, D48, D51, D51A, D52, D58, D61, D62, D63, D64, D65, D66, D67, D68, D69, D70, D71, D72, D73	27	1.16	1.38	0.91	0.24	0.001	0.003	0.574	0.203

Rainfall Events			SEDD CSO Regulators Overflowing		SEDD Rain Gage Rainfall Depth Statistics					SEDD Flow Depth Values		
Start Time	**End Time**	**Duration (hrs)**	**List**	**Count**	**Average Depth (inches)**	**Max Depth (inches)**	**Min Depth (inches)**	**Max Intensity (in/hr)**	**Min Intensity (in/hr)**	**RDI/I (inches)**	**Runoff (inches)**	**Overflow (inches)**
3/27/05 20:00	3/29/05 12:00	39	D37, D38, D39, D40, D41, D42, D43, D44, D45, D46, D47, D48, D50, D51, D51A, D52, D54, D58, D61, D62, D63, D64, D65, D66, D67, D68, D69, D70, D71, D72, D73	31	1.59	1.74	1.49	0.31	0.001	0.004	0.725	0.344
4/1/05 23:00	4/3/05 12:00	36	D37, D38, D39, D40, D41, D42, D43, D44, D45, D46, D47, D48, D49, D50, D51, D51A, D52, D53, D54, D58, D61, D62, D63, D64, D65, D66, D67, D68, D69, D70, D71, D72, D73	33	2.81	3.19	2.62	0.59	0.001	0.008	1.231	0.827
4/7/05 22:00	4/8/05 16:00	12	D37, D38, D39, D40, D41, D44, D45, D46, D47, D48, D51, D51A, D52, D58, D61, D62, D63, D64, D65, D66, D67, D68, D69, D71, D72, D73	26	0.75	1.07	0.53	0.36	0.001	0.002	0.393	0.175

Rainfall Events			SEDD CSO Regulators Overflowing		SEDD Rain Gage Rainfall Depth Statistics					SEDD Flow Depth Values		
Start Time	**End Time**	**Duration (hrs)**	**List**	**Count**	**Average Depth (inches)**	**Max Depth (inches)**	**Min Depth (inches)**	**Max Intensity (in/hr)**	**Min Intensity (in/hr)**	**RDI/I (inches)**	**Runoff (inches)**	**Overflow (inches)**
4/23/05 8:00	4/24/05 8:00	19	D37, D38, D39, D40, D41, D42, D43, D44, D45, D46, D47, D48, D50, D51, D51A, D52, D54, D58, D61, D62, D63, D64, D65, D66, D67, D68, D69, D70, D71, D72, D73	31	0.78	0.84	0.73	0.57	0.004	0.002	0.302	0.162
4/30/05 4:00	5/1/05 15:00	29	D37, D38, D39, D40, D41, D42, D43, D44, D45, D46, D47, D48, D50, D51, D51A, D52, D54, D58, D61, D62, D63, D64, D65, D66, D67, D68, D69, D70, D71, D72, D73	31	1.07	1.39	0.58	0.36	0.001	0.003	0.544	0.210
5/20/05 5:00	5/21/05 2:00	17	D37, D38, D39, D40, D41, D44, D45, D47, D48, D51, D51A, D58, D61, D63, D65, D66, D67, D68, D69, D70, D71, D72, D73	23	0.95	1.02	0.89	0.19	0.001	0.002	0.409	0.176
5/21/05 17:00	5/22/05 0:00	6	D61	1	0.05	0.11	0.02	0.10	0.004	0.000	0.014	0.000
5/28/05 16:00	5/28/05 21:00	2	D51, D61, D62, D64, D71	5	0.06	0.13	0.01	0.13	0.007	0.000	0.022	0.000
6/3/05 6:00	6/4/05 7:00	25	D37, D39, D40, D44, D47, D51, D51A, D66, D68, D71, D72, D73	12	0.74	0.85	0.66	0.11	0.001	0.002	0.305	0.031

Rainfall Events			SEDD CSO Regulators Overflowing		SEDD Rain Gage Rainfall Depth Statistics					SEDD Flow Depth Values		
Start Time	**End Time**	**Duration (hrs)**	**List**	**Count**	**Average Depth (inches)**	**Max Depth (inches)**	**Min Depth (inches)**	**Max Intensity (in/hr)**	**Min Intensity (in/hr)**	**RDI/I (inches)**	**Runoff (inches)**	**Overflow (inches)**
6/6/05 20:00	6/7/05 8:00	9	D37, D38, D39, D40, D41, D42, D43, D44, D45, D46, D47, D48, D49, D50, D51, D51A, D52, D53, D54, D58, D61, D62, D63, D64, D65, D66, D67, D68, D69, D70, D71, D72, D73	33	1.12	1.41	0.73	0.93	0.009	0.003	0.810	0.717
6/10/05 14:00	6/11/05 0:00	3	D37, D38, D39, D40, D41, D42, D43, D44, D45, D46, D47, D48, D50, D51, D51A, D52, D53, D54, D58, D61, D62, D63, D64, D65, D66, D67, D68, D69, D71, D72, D73	31	0.57	0.83	0.25	0.40	0.067	0.001	0.256	0.174
6/16/05 16:00	6/16/05 22:00	4	D39, D40, D47, D51, D51A, D61, D68, D71	8	0.11	0.16	0.09	0.16	0.001	0.000	0.048	0.002
6/22/05 17:00	6/23/05 3:00	4	D66, D67, D68, D69, D70, D71, D72, D73	8	0.08	0.21	0.01	0.18	0.002	0.000	0.071	0.052
6/27/05 9:00	6/28/05 10:00	26	D37, D38, D39, D40, D41, D44, D45, D47, D48, D51, D51A, D52, D61, D62, D64, D66, D68, D71, D73	19	0.70	0.96	0.55	0.24	0.001	0.002	0.249	0.036
6/29/05 22:00	6/30/05 4:00	2	D39, D44, D47, D66, D68	5	0.11	0.63	0.03	0.62	0.001	0.000	0.021	0.004

Rainfall Events			SEDD CSO Regulators Overflowing		SEDD Rain Gage Rainfall Depth Statistics					SEDD Flow Depth Values		
Start Time	**End Time**	**Duration (hrs)**	**List**	**Count**	**Average Depth (inches)**	**Max Depth (inches)**	**Min Depth (inches)**	**Max Intensity (in/hr)**	**Min Intensity (in/hr)**	**RDI/I (inches)**	**Runoff (inches)**	**Overflow (inches)**
7/1/05 16:00	7/2/05 14:00	18	D37, D38, D39, D40, D41, D42, D43, D44, D45, D46, D47, D48, D49, D50, D51, D51A, D52, D53, D54, D58, D61, D62, D63, D64, D65, D66, D67, D68, D69, D71, D72, D73	32	0.94	1.97	0.64	0.96	0.004	0.003	0.290	0.215
7/5/05 16:00	7/6/05 8:00	11	D37, D38, D39, D40, D41, D42, D43, D44, D45, D46, D47, D48, D50, D51, D51A, D52, D54, D58, D61, D62, D63, D64, D65, D66, D67, D68, D69, D70, D71, D72, D73	31	0.52	0.75	0.26	0.50	0.003	0.001	0.288	0.172
7/8/05 0:00	7/9/05 1:00	17	D37, D38, D39, D40, D41, D42, D43, D44, D45, D46, D47, D48, D49, D50, D51, D51A, D52, D53, D54, D58, D61, D62, D63, D64, D65, D66, D67, D68, D69, D70, D71, D72, D73	33	2.11	2.75	1.80	0.85	0.005	0.005	1.020	0.759
7/15/05 17:00	7/16/05 0:00	3	D39, D44, D45, D47, D48, D50, D51, D51A, D52, D54, D58, D61, D63, D66, D68	15	0.23	0.82	0.02	0.60	0.002	0.000	0.088	0.034

Rainfall Events			SEDD CSO Regulators Overflowing		SEDD Rain Gage Rainfall Depth Statistics					SEDD Flow Depth Values		
Start Time	**End Time**	**Duration (hrs)**	**List**	**Count**	**Average Depth (inches)**	**Max Depth (inches)**	**Min Depth (inches)**	**Max Intensity (in/hr)**	**Min Intensity (in/hr)**	**RDI/I (inches)**	**Runoff (inches)**	**Overflow (inches)**
7/16/05 17:00	7/18/05 21:00	48	D37, D38, D39, D40, D41, D42, D43, D44, D45, D46, D47, D48, D49, D50, D51, D51A, D52, D53, D54, D58, D61, D62, D63, D64, D65, D66, D67, D68, D69, D70, D71, D72, D73	33	1.69	2.10	1.18	1.37	0.002	0.004	0.708	0.536
7/25/05 3:00	7/25/05 13:00	9	D47, D51	2	0.14	0.20	0.10	0.09	0.009	0.000	0.021	0.000
7/27/05 20:00	7/28/05 3:00	4	D37, D39, D40, D47, D51, D51A	6	0.13	0.17	0.11	0.09	0.01	0.000	0.044	0.001
8/4/05 17:00	8/4/05 20:00	3	D47, D51	2	0.02	0.09	0.01	0.09	0.001	0.000	0.006	0.000
8/8/05 16:00	8/9/05 19:00	20	D37, D38, D39, D40, D41, D43, D44, D45, D47, D48, D51, D51A, D52, D54, D58, D61, D62, D63, D64, D65, D66, D67, D68, D69, D70, D71, D72, D73	28	0.71	1.36	0.20	0.65	0.001	0.001	0.375	0.177
8/15/05 0:00	8/15/05 13:00	2	D37, D38, D39, D40, D41, D42, D43, D44, D45, D46, D47, D48, D49, D50, D51, D51A, D52, D53, D54, D58, D61, D62, D63, D64, D65, D66, D67, D68, D69, D70, D71, D72, D73	33	1.09	1.28	0.76	1.27	0.009	0.003	0.505	0.450

Rainfall Events			SEDD CSO Regulators Overflowing		SEDD Rain Gage Rainfall Depth Statistics					SEDD Flow Depth Values		
Start Time	**End Time**	**Duration (hrs)**	**List**	**Count**	**Average Depth (inches)**	**Max Depth (inches)**	**Min Depth (inches)**	**Max Intensity (in/hr)**	**Min Intensity (in/hr)**	**RDI/I (inches)**	**Runoff (inches)**	**Overflow (inches)**
8/16/05 13:00	8/17/05 5:00	14	D37, D38, D39, D40, D41, D44, D47, D48, D51, D51A, D68, D71	12	0.47	0.60	0.36	0.25	0.003	0.001	0.179	0.019
8/27/05 12:00	8/28/05 1:00	7	D37, D38, D39, D40, D41, D44, D45, D47, D48, D51, D51A, D61, D62, D64, D66, D67, D68, D71, D73	19	0.40	0.70	0.27	0.36	0.013	0.001	0.133	0.033
8/29/05 17:00	8/30/05 3:00	2	D37, D38, D39, D40, D41, D42, D43, D44, D45, D46, D47, D48, D50, D51, D51A, D52, D58, D61, D63	19	0.27	0.68	0.01	0.63	0.009	0.001	0.106	0.059
9/14/05 12:00	9/15/05 2:00	10	D37, D38, D39, D40, D41, D42, D43, D44, D45, D46, D47, D48, D50, D51, D51A, D52, D54, D58, D61, D62, D63, D64, D65, D66, D67, D68, D69, D70, D71, D72, D73	31	0.55	0.95	0.03	0.55	0.009	0.001	0.311	0.146
9/15/05 8:00	9/15/05 23:00	7	D37, D38, D39, D40, D41, D42, D43, D44, D45, D46, D47, D48, D50, D51, D51A, D52, D54, D58, D61, D62, D63, D64, D65, D66, D67, D68, D69, D70, D71, D72, D73	31	0.71	1.30	0.09	0.95	0.001	0.002	0.433	0.276
9/17/05 21:00	9/18/05 2:00	2	D39	1	0.08	0.36	0.01	0.34	0.01	0.000	0.005	0.000

Rainfall Events			SEDD CSO Regulators Overflowing		SEDD Rain Gage Rainfall Depth Statistics					SEDD Flow Depth Values		
Start Time	**End Time**	**Duration (hrs)**	**List**	**Count**	**Average Depth (inches)**	**Max Depth (inches)**	**Min Depth (inches)**	**Max Intensity (in/hr)**	**Min Intensity (in/hr)**	**RDI/I (inches)**	**Runoff (inches)**	**Overflow (inches)**
9/26/05 20:00	9/27/05 5:00	8	D37, D39, D40, D44, D47, D51, D51A, D68, D71	9	0.17	0.19	0.15	0.10	0.01	0.000	0.062	0.003
9/29/05 13:00	9/29/05 17:00	2	D47, D51, D51A	3	0.06	0.08	0.05	0.05	0.01	0.000	0.018	0.000
10/7/05 16:00	10/9/05 10:00	42	D37, D38, D39, D40, D41, D42, D43, D44, D45, D46, D47, D48, D49, D50, D51, D51A, D52, D53, D54, D58, D61, D62, D63, D64, D65, D66, D67, D68, D69, D70, D71, D72, D73	33	3.46	3.71	2.86	1.25	0.006	0.007	1.955	1.488
10/11/05 0:00	10/12/05 18:00	41	D37, D38, D39, D40, D41, D44, D47, D51, D51A, D61, D71	11	0.47	0.67	0.37	0.14	0.009	0.001	0.177	0.008
10/13/05 0:00	10/15/05 2:00	50	D37, D38, D39, D40, D41, D44, D45, D47, D48, D51, D51A, D52, D58, D61, D62, D63, D64, D65, D66, D67, D68, D71, D73	23	0.78	1.03	0.54	0.32	0.013	0.002	0.265	0.052
10/21/05 9:00	10/21/05 16:00	6	D47, D51	2	0.22	0.23	0.20	0.08	0.009	0.000	0.082	0.001
10/22/05 2:00	10/23/05 6:00	22	D37, D38, D39, D40, D41, D43, D44, D45, D47, D48, D51, D51A, D52, D61, D62, D63, D64, D66, D67, D68, D71, D73	22	0.94	1.07	0.82	0.29	0.009	0.002	0.378	0.053

Rainfall Events			**SEDD CSO Regulators Overflowing**		**SEDD Rain Gage Rainfall Depth Statistics**					**SEDD Flow Depth Values**		
Start Time	**End Time**	**Duration (hrs)**	**List**	**Count**	**Average Depth (inches)**	**Max Depth (inches)**	**Min Depth (inches)**	**Max Intensity (in/hr)**	**Min Intensity (in/hr)**	**RDI/I (inches)**	**Runoff (inches)**	**Overflow (inches)**
10/24/05 18:00	10/26/05 8:00	34	D37, D38, D39, D40, D41, D43, D44, D45, D47, D48, D51, D51A, D61, D62, D66, D67, D68, D71, D72, D73	20	1.12	1.34	0.98	0.20	0.009	0.002	0.449	0.068
11/6/05 21:00	11/7/05 1:00	2	D40, D47, D51	3	0.07	0.10	0.04	0.09	0.012	0.000	0.020	0.000
11/10/05 1:00	11/10/05 14:00	11	D37, D39, D40, D41, D44, D47, D48, D51, D51A, D61, D62, D64, D68, D71	14	0.19	0.31	0.15	0.27	0.009	0.000	0.058	0.005
11/16/05 17:00	11/17/05 9:00	9	D37, D38, D39, D40, D41, D43, D44, D45, D46, D47, D48, D50, D51, D51A, D52, D54, D58, D61, D62, D63, D64, D65, D66, D67, D68, D69, D70, D71, D72, D73	30	0.99	1.09	0.79	0.31	0.012	0.002	0.465	0.259
11/21/05 16:00	11/22/05 20:00	22	D37, D38, D39, D40, D41, D43, D44, D45, D47, D48, D51, D51A, D58, D61, D62, D63, D64, D65, D66, D67, D68, D69, D71, D72, D73	25	0.97	1.11	0.81	0.21	0.009	0.002	0.454	0.101

Rainfall Events			SEDD CSO Regulators Overflowing		SEDD Rain Gage Rainfall Depth Statistics					SEDD Flow Depth Values		
Start Time	**End Time**	**Duration (hrs)**	**List**	**Count**	**Average Depth (inches)**	**Max Depth (inches)**	**Min Depth (inches)**	**Max Intensity (in/hr)**	**Min Intensity (in/hr)**	**RDI/I (inches)**	**Runoff (inches)**	**Overflow (inches)**
11/29/05 17:00	11/30/05 10:00	10	D37, D38, D39, D40, D41, D43, D44, D45, D46, D47, D48, D50, D51, D51A, D52, D54, D58, D61, D62, D63, D64, D65, D66, D67, D68, D69, D70, D71, D72, D73	30	0.97	1.39	0.74	0.34	0.009	0.002	0.371	0.233
12/4/05 12:00	12/4/05 22:00	8	D37, D47, D51	3	0.16	0.25	0.05	0.06	0.009	0.000	0.088	0.001
12/9/05 8:00	12/9/05 22:00	12	D37, D40, D47, D51, D51A, D68, D71, D73	8	0.25	0.41	0.13	0.11	0.013	0.001	0.120	0.004
12/15/05 18:00	12/16/05 15:00	13	D37, D38, D39, D40, D41, D44, D45, D47, D48, D51, D51A, D58, D61, D62, D63, D65, D66, D67, D68, D69, D70, D71, D72, D73	24	1.20	1.43	1.01	0.28	0.009	0.003	0.502	0.229
12/25/05 13:00	12/26/05 12:00	20	D37, D38, D39, D40, D41, D44, D47, D48, D51, D51A, D61, D62, D66, D67, D68, D71, D73	17	0.58	0.70	0.51	0.18	0.013	0.002	0.225	0.029
12/29/05 7:00	12/29/05 23:00	15	D37, D40, D47, D51, D51A, D61, D71	7	0.35	0.37	0.34	0.08	0.013	0.001	0.144	0.002
12/31/05 14:00	12/31/05 19:00	3	D40, D47, D51, D51A	4	0.12	0.13	0.10	0.08	0.009	0.000	0.038	0.000

Table v4.2.3 SWDD Response to Wet Weather Conditions

Rainfall Events			SWDD CSO Regulators Overflowing		SWDD Rain Gage Rainfall Depth Statistics					SWDD Flow Depth Values		
Start Time	End Time	Duration (hrs)	List	Count	Average Depth (inches)	Max Depth (inches)	Min Depth (inches)	Max Intensity (in/hr)	Min Intensity (in/hr)	RDI/I (inches)	Runoff (inches)	Overflow (inches)
1/3/05 18:00	1/4/05 6:00	12	R01, R01A, R02, R04, R05, S04, S06, S16, S20, S33, S42A	11	0.07	0.12	0.05	0.05	0.001	0.001	0.017	0.000
1/5/2005	5:00 AM	42	C06, C17, R01, R01A, R02, R03, R04, R05, R06, S02, S04, S05, S06, S09, S10, S11, S12, S12A, S14, S16, S18, S19, S20, S22, S23, S24, S25, S26, S31, S33, S36, S36A, S37, S38, S42, S42A, S44, S45, S46, S50	40	0.95	1.22	0.76	0.39	0.001	0.017	0.381	0.059
1/7/2005	3:00 AM	27	C06, C09, C11, C12, C13, C14, C17, C18, C22, C28A, C29, C30, C31, C32, R01, R01A, R02, R03, R04, R05, R06, S01, S02, S04, S05, S06, S07, S08, S09, S10, S11, S12, S12A, S14, S16, S18, S19, S20, S22, S23, S24, S25, S26, S31, S33, S36A, S37, S42, S42A, S44, S45, S50	52	0.44	0.57	0.35	0.18	0.001	0.007	0.164	0.053

Rainfall Events			SWDD CSO Regulators Overflowing		SWDD Rain Gage Rainfall Depth Statistics					SWDD Flow Depth Values		
Start Time	**End Time**	**Duration (hrs)**	**List**	**Count**	**Average Depth (inches)**	**Max Depth (inches)**	**Min Depth (inches)**	**Max Intensity (in/hr)**	**Min Intensity (in/hr)**	**RDI/I (inches)**	**Runoff (inches)**	**Overflow (inches)**
1/11/2005	11:00 AM	11	C06, C11, C12, C14, C17, C29, C31, R01, R01A, R02, R03, R04, R05, R06, S01, S02, S04, S05, S06, S09, S10, S11, S12, S12A, S14, S16, S18, S20, S22, S23, S24, S25, S26, S31, S33, S36A, S37, S42, S42A, S44, S45, S50	42	0.46	0.59	0.36	0.17	0.001	0.007	0.176	0.062
1/13/2005	2:00 PM	15	C01, C04, C04A, C05, C06, C07, C09, C10, C11, C12, C13, C14, C15, C17, C18, C19, C20, C21, C22, C23, C24, C25, C26, C27, C28A, C29, C30, C31, C32, C33, R01, R01A, R02, R03, R04, R05, R06, R24, S01, S02, S04, S05, S06, S07, S08, S09, S10, S11, S12, S12A, S13, S14, S15, S16, S17, S18, S19, S20, S21, S22, S23, S24, S25, S26, S31, S32, S33, S36, S36A, S37, S38, S42, S42A, S44, S45, S46, S50	77	1.70	1.85	1.56	0.46	0.001	0.035	0.798	0.587

Rainfall Events			SWDD CSO Regulators Overflowing		SWDD Rain Gage Rainfall Depth Statistics					SWDD Flow Depth Values		
Start Time	**End Time**	**Duration (hrs)**	**List**	**Count**	**Average Depth (inches)**	**Max Depth (inches)**	**Min Depth (inches)**	**Max Intensity (in/hr)**	**Min Intensity (in/hr)**	**RDI/I (inches)**	**Runoff (inches)**	**Overflow (inches)**
1/25/2005	1:00 AM	32	C06, C17, C29, R01, R01A, R02, R03, R04, R05, R06, S02, S04, S05, S06, S10, S11, S14, S16, S18, S20, S23, S26, S31, S33, S36A, S37, S42A, S44, S50	29	0.57	0.59	0.57	0.11	0.01	0.006	0.207	0.030
2/2/2005	8:00 PM	5	R01A, R04, S04, S20, S42A	5	0.06	0.06	0.06	0.02	0.01	0.001	0.015	0.000
2/4/2005	11:00 PM	8	R01, R01A, R02, R04, R05, S04, S05, S06, S14, S16, S18, S20, S26, S33, S36A, S42A, S50	17	0.33	0.35	0.33	0.06	0.013	0.004	0.133	0.018
2/9/2005	9:00 AM	10	R01A, R02, R04, R05, S04, S20, S42A	7	0.07	0.13	0.04	0.05	0.001	0.002	0.017	0.000
2/14/2005	7:00 AM	15	C06, C11, C12, C13, C14, C17, C22, C28A, C29, C30, C31, R01, R01A, R02, R03, R04, R05, R06, S01, S02, S04, S05, S06, S10, S11, S12, S12A, S14, S16, S18, S20, S22, S23, S24, S25, S26, S31, S33, S36A, S37, S42, S42A, S44, S45, S50	45	1.00	1.41	0.83	0.18	0.001	0.020	0.403	0.152

Rainfall Events			SWDD CSO Regulators Overflowing		SWDD Rain Gage Rainfall Depth Statistics					SWDD Flow Depth Values		
Start Time	**End Time**	**Duration (hrs)**	**List**	**Count**	**Average Depth (inches)**	**Max Depth (inches)**	**Min Depth (inches)**	**Max Intensity (in/hr)**	**Min Intensity (in/hr)**	**RDI/I (inches)**	**Runoff (inches)**	**Overflow (inches)**
2/16/2005	12:00 AM	3	C06, C17, C29, R01, R01A, R02, R03, R04, R05, R06, S02, S04, S05, S06, S10, S11, S14, S16, S18, S20, S23, S26, S31, S33, S36A, S37, S42, S42A, S50	29	0.19	0.26	0.14	0.18	0.02	0.003	0.070	0.015
2/21/2005	7:00 AM	16	C06, C17, R01, R01A, R02, R03, R04, R05, R06, S01, S02, S04, S05, S06, S10, S11, S14, S16, S18, S20, S23, S26, S31, S33, S36A, S37, S42, S42A, S44, S45, S50	31	0.58	0.58	0.58	0.09	0.01	0.009	0.234	0.055
2/25/2005	10:00 PM	4	C06, C17, R01, R01A, R02, R03, R04, R05, R06, S02, S04, S05, S06, S10, S11, S14, S16, S18, S20, S23, S26, S31, S33, S36A, S37, S42A, S50	27	0.23	0.23	0.23	0.10	0.02	0.004	0.090	0.018
2/26/2005	5:00 PM	4	R01A, R04, R05, S04, S20, S42A	6	0.06	0.06	0.06	0.02	0.01	0.002	0.015	0.000

Rainfall Events			SWDD CSO Regulators Overflowing		SWDD Rain Gage Rainfall Depth Statistics					SWDD Flow Depth Values		
Start Time	**End Time**	**Duration (hrs)**	**List**	**Count**	**Average Depth (inches)**	**Max Depth (inches)**	**Min Depth (inches)**	**Max Intensity (in/hr)**	**Min Intensity (in/hr)**	**RDI/I (inches)**	**Runoff (inches)**	**Overflow (inches)**
3/1/2005	6:00 AM	8	C06, C11, C12, C17, C28A, C29, C31, R01, R01A, R02, R03, R04, R05, R06, S01, S02, S04, S05, S06, S08, S09, S10, S11, S12, S12A, S14, S16, S18, S20, S22, S23, S24, S25, S26, S31, S33, S36A, S37, S42, S42A, S44, S45, S50	43	0.48	0.50	0.47	0.19	0.013	0.007	0.171	0.053
3/8/2005	10:00 PM	8	C06, C11, C12, C17, C29, R01, R01A, R02, R03, R04, R05, R06, S01, S02, S04, S05, S06, S10, S11, S12, S14, S16, S18, S20, S22, S23, S24, S25, S26, S31, S33, S36A, S37, S42, S42A, S44, S45, S50	38	0.40	0.45	0.36	0.16	0.001	0.008	0.158	0.045
3/11/2005	5:00 AM	6	R01, R01A, R02, R04, R05, S04, S06, S16, S20, S26, S33, S42A	12	0.09	0.11	0.07	0.06	0.002	0.001	0.028	0.001
3/20/2005	12:00 AM	20	C29, R01, R01A, R02, R04, R05, S04, S05, S06, S14, S16, S18, S20, S26, S33, S36A, S37, S42A, S50	19	0.34	0.43	0.25	0.09	0.001	0.004	0.121	0.007

Rainfall Events			SWDD CSO Regulators Overflowing		SWDD Rain Gage Rainfall Depth Statistics					SWDD Flow Depth Values		
Start Time	**End Time**	**Duration (hrs)**	**List**	**Count**	**Average Depth (inches)**	**Max Depth (inches)**	**Min Depth (inches)**	**Max Intensity (in/hr)**	**Min Intensity (in/hr)**	**RDI/I (inches)**	**Runoff (inches)**	**Overflow (inches)**
3/23/2005	9:00 AM	27	C06, C09, C10, C11, C12, C13, C14, C15, C17, C18, C22, C24, C25, C28A, C29, C30, C31, C32, R01, R01A, R02, R03, R04, R05, R06, S01, S02, S04, S05, S06, S08, S09, S10, S11, S12, S12A, S14, S16, S18, S19, S20, S22, S23, S24, S25, S26, S31, S33, S36, S36A, S37, S38, S42, S42A, S44, S45, S46, S50	58	1.13	1.38	0.92	0.24	0.001	0.023	0.490	0.188

Rainfall Events			SWDD CSO Regulators Overflowing		SWDD Rain Gage Rainfall Depth Statistics					SWDD Flow Depth Values		
Start Time	**End Time**	**Duration (hrs)**	**List**	**Count**	**Average Depth (inches)**	**Max Depth (inches)**	**Min Depth (inches)**	**Max Intensity (in/hr)**	**Min Intensity (in/hr)**	**RDI/I (inches)**	**Runoff (inches)**	**Overflow (inches)**
3/27/2005	4:00 PM	40	C04, C04A, C06, C07, C09, C10, C11, C12, C13, C14, C15, C17, C18, C19, C20, C21, C22, C23, C24, C25, C27, C28A, C29, C30, C31, C32, C33, R01, R01A, R02, R03, R04, R05, R06, S01, S02, S04, S05, S06, S08, S09, S10, S11, S12, S12A, S14, S15, S16, S17, S18, S19, S20, S21, S22, S23, S24, S25, S26, S31, S33, S36, S36A, S37, S38, S42, S42A, S44, S45, S46, S50	70	1.55	1.74	1.34	0.31	0.001	0.036	0.663	0.325

Rainfall Events			SWDD CSO Regulators Overflowing		SWDD Rain Gage Rainfall Depth Statistics					SWDD Flow Depth Values		
Start Time	**End Time**	**Duration (hrs)**	**List**	**Count**	**Average Depth (inches)**	**Max Depth (inches)**	**Min Depth (inches)**	**Max Intensity (in/hr)**	**Min Intensity (in/hr)**	**RDI/I (inches)**	**Runoff (inches)**	**Overflow (inches)**
4/1/2005	8:00 PM	69	C01, C02, C04, C04A, C05, C06, C07, C09, C10, C11, C12, C13, C14, C15, C17, C18, C19, C20, C21, C22, C23, C24, C25, C26, C27, C28A, C29, C30, C31, C32, C33, C34, C35, C36, C37, R01, R01A, R02, R03, R04, R05, R06, R12R, R24, S01, S02, S04, S05, S06, S07, S08, S09, S10, S11, S12, S12A, S13, S14, S15, S16, S17, S18, S19, S20, S21, S22, S23, S24, S25, S26, S31, S32, S33, S36, S36A, S37, S38, S42, S42A, S44, S45, S46, S50	83	2.82	3.19	2.54	0.59	0.001	0.078	1.232	0.825

Rainfall Events			SWDD CSO Regulators Overflowing		SWDD Rain Gage Rainfall Depth Statistics					SWDD Flow Depth Values		
Start Time	**End Time**	**Duration (hrs)**	**List**	**Count**	**Average Depth (inches)**	**Max Depth (inches)**	**Min Depth (inches)**	**Max Intensity (in/hr)**	**Min Intensity (in/hr)**	**RDI/I (inches)**	**Runoff (inches)**	**Overflow (inches)**
4/7/2005	8:00 PM	12	C06, C09, C11, C12, C13, C14, C15, C17, C18, C19, C21, C22, C24, C25, C28A, C29, C30, C31, C32, R01, R01A, R02, R03, R04, R05, R06, S01, S02, S04, S05, S06, S08, S09, S10, S11, S12, S12A, S14, S16, S18, S19, S20, S22, S23, S24, S25, S26, S31, S33, S36, S36A, S37, S38, S42, S42A, S44, S45, S46, S50	59	0.78	1.07	0.53	0.36	0.001	0.013	0.347	0.153

Rainfall Events			SWDD CSO Regulators Overflowing		SWDD Rain Gage Rainfall Depth Statistics					SWDD Flow Depth Values		
Start Time	**End Time**	**Duration (hrs)**	**List**	**Count**	**Average Depth (inches)**	**Max Depth (inches)**	**Min Depth (inches)**	**Max Intensity (in/hr)**	**Min Intensity (in/hr)**	**RDI/I (inches)**	**Runoff (inches)**	**Overflow (inches)**
4/23/2005	1:00 PM	28	C01, C04, C04A, C05, C06, C07, C09, C10, C11, C12, C13, C14, C15, C17, C18, C19, C21, C22, C24, C25, C28A, C29, C30, C31, C32, C33, C34, C37, R01, R01A, R02, R03, R04, R05, R06, R24, S01, S02, S04, S05, S06, S07, S08, S09, S10, S11, S12, S12A, S13, S14, S15, S16, S17, S18, S19, S20, S21, S22, S23, S24, S25, S26, S31, S33, S36, S36A, S37, S38, S42, S42A, S44, S45, S46, S50	74	0.73	0.88	0.39	0.57	0.001	0.009	0.271	0.136
4/27/2005	8:00 AM	5	R01, R01A, R02, R04, R05, S04, S05, S20	8	0.09	0.17	0.03	0.09	0.001	0.001	0.019	0.000
4/27/2005	9:00 PM	5	S31, S36A, S37, S42A	4	0.04	0.16	0.01	0.09	0.001	0.000	0.005	0.000

Rainfall Events			SWDD CSO Regulators Overflowing		SWDD Rain Gage Rainfall Depth Statistics					SWDD Flow Depth Values		
Start Time	**End Time**	**Duration (hrs)**	**List**	**Count**	**Average Depth (inches)**	**Max Depth (inches)**	**Min Depth (inches)**	**Max Intensity (in/hr)**	**Min Intensity (in/hr)**	**RDI/I (inches)**	**Runoff (inches)**	**Overflow (inches)**
4/30/2005	8:00 PM	29	C04, C06, C07, C09, C10, C11, C12, C13, C14, C17, C18, C22, C28A, C29, C30, C31, C32, C33, R01, R01A, R02, R03, R04, R05, R06, R24, S01, S02, S04, S05, S06, S08, S09, S10, S11, S12, S12A, S13, S14, S15, S16, S17, S18, S19, S20, S21, S22, S23, S24, S25, S26, S31, S33, S36, S36A, S37, S38, S42, S42A, S44, S45, S46, S50	63	1.03	1.39	0.58	0.36	0.001	0.017	0.417	0.139
5/2/2005	10:00 PM	2	R01A, R02, R04, R05	4	0.03	0.07	0.01	0.05	0.006	0.001	0.005	0.000
5/20/2005	3:00 AM	17	C06, C11, C12, C13, C14, C17, C22, C24, C29, C30, C31, R01, R01A, R02, R03, R04, R05, R06, S01, S02, S04, S05, S06, S09, S10, S11, S12, S12A, S14, S16, S18, S20, S22, S23, S24, S25, S26, S31, S33, S36A, S37, S42, S42A, S44, S45, S50	46	0.88	1.02	0.67	0.19	0.001	0.010	0.341	0.150
5/21/2005	1:00 AM	1	S16, S18, S26, S42A	4	0.03	0.10	0.01	0.10	0.005	0.000	0.005	0.000

Rainfall Events			SWDD CSO Regulators Overflowing		SWDD Rain Gage Rainfall Depth Statistics					SWDD Flow Depth Values		
Start Time	**End Time**	**Duration (hrs)**	**List**	**Count**	**Average Depth (inches)**	**Max Depth (inches)**	**Min Depth (inches)**	**Max Intensity (in/hr)**	**Min Intensity (in/hr)**	**RDI/I (inches)**	**Runoff (inches)**	**Overflow (inches)**
5/28/2005	9:00 PM	2	R04, S10, S12, S16, S18, S23, S26, S36A, S42A	9	0.05	0.13	0.01	0.13	0.007	0.000	0.009	0.001
6/3/2005	1:00 PM	30	C06, C11, C12, C14, C17, C22, C28A, C29, C30, C31, R01, R01A, R02, R03, R04, R05, R06, S01, S02, S04, S05, S06, S10, S11, S14, S16, S18, S20, S22, S23, S24, S25, S26, S31, S33, S36A, S37, S42, S42A, S44, S45, S50	42	0.79	0.93	0.66	0.13	0.001	0.012	0.333	0.092

Rainfall Events			SWDD CSO Regulators Overflowing		SWDD Rain Gage Rainfall Depth Statistics					SWDD Flow Depth Values		
Start Time	**End Time**	**Duration (hrs)**	**List**	**Count**	**Average Depth (inches)**	**Max Depth (inches)**	**Min Depth (inches)**	**Max Intensity (in/hr)**	**Min Intensity (in/hr)**	**RDI/I (inches)**	**Runoff (inches)**	**Overflow (inches)**
6/6/2005	9:00 PM	9	C01, C02, C04, C04A, C05, C06, C07, C09, C10, C11, C12, C13, C14, C15, C16, C17, C18, C19, C20, C21, C22, C23, C24, C25, C26, C27, C28A, C29, C30, C31, C32, C33, C34, C35, C36, C37, R01, R01A, R02, R03, R04, R05, R06, R12R, R24, S01, S02, S03, S04, S05, S06, S07, S08, S09, S10, S11, S12, S12A, S13, S14, S15, S16, S17, S18, S19, S20, S21, S22, S23, S24, S25, S26, S30, S31, S32, S33, S35, S36, S36A, S37, S38, S42, S42A, S44, S45, S46, S50, S51	88	1.16	1.77	0.73	1.41	0.009	0.013	0.647	0.563

Rainfall Events			SWDD CSO Regulators Overflowing		SWDD Rain Gage Rainfall Depth Statistics					SWDD Flow Depth Values		
Start Time	**End Time**	**Duration (hrs)**	**List**	**Count**	**Average Depth (inches)**	**Max Depth (inches)**	**Min Depth (inches)**	**Max Intensity (in/hr)**	**Min Intensity (in/hr)**	**RDI/I (inches)**	**Runoff (inches)**	**Overflow (inches)**
6/10/2005	5:00 AM	5	C01, C02, C04, C04A, C05, C06, C07, C09, C10, C11, C12, C13, C14, C15, C17, C18, C19, C20, C21, C22, C23, C24, C25, C27, C28A, C29, C30, C31, C32, C33, C34, C35, C36, C37, R01, R01A, R02, R03, R04, R05, R06, R24, S01, S02, S03, S04, S05, S06, S07, S08, S09, S10, S11, S12, S12A, S13, S14, S15, S16, S17, S18, S19, S20, S21, S22, S23, S24, S25, S26, S30, S31, S32, S33, S36, S36A, S37, S38, S42, S42A, S44, S45, S46, S50	83	0.60	0.83	0.25	0.60	0.001	0.004	0.320	0.228

Rainfall Events			SWDD CSO Regulators Overflowing		SWDD Rain Gage Rainfall Depth Statistics					SWDD Flow Depth Values		
Start Time	**End Time**	**Duration (hrs)**	**List**	**Count**	**Average Depth (inches)**	**Max Depth (inches)**	**Min Depth (inches)**	**Max Intensity (in/hr)**	**Min Intensity (in/hr)**	**RDI/I (inches)**	**Runoff (inches)**	**Overflow (inches)**
6/16/2005	1:00 AM	5	C01, C04, C04A, C05, C06, C07, C09, C10, C11, C12, C13, C14, C17, C18, C22, C28A, C29, C30, C31, C32, C33, C34, C35, C37, R01, R01A, R02, R03, R04, R05, R06, R24, S01, S02, S04, S05, S06, S08, S09, S10, S11, S12, S12A, S14, S16, S18, S19, S20, S22, S23, S24, S25, S26, S31, S33, S36, S36A, S37, S38, S42, S42A, S44, S45, S50	64	0.20	0.51	0.01	0.47	0.001	0.001	0.107	0.066
6/22/2005	1:00 AM	5	C06, C17, C18, C19, C22, C25, C28A, C29, C30, R01, R01A, R02, R03, R04, R05, R06, S04, S11, S12, S12A, S14, S16, S17, S18, S19, S20, S22, S23, S24, S25, S26, S31, S32, S33, S36, S36A, S37, S38, S42, S42A, S44, S45, S46, S50	44	0.17	0.73	0.01	0.72	0.002	0.001	0.060	0.023

Rainfall Events			SWDD CSO Regulators Overflowing		SWDD Rain Gage Rainfall Depth Statistics					SWDD Flow Depth Values		
Start Time	**End Time**	**Duration (hrs)**	**List**	**Count**	**Average Depth (inches)**	**Max Depth (inches)**	**Min Depth (inches)**	**Max Intensity (in/hr)**	**Min Intensity (in/hr)**	**RDI/I (inches)**	**Runoff (inches)**	**Overflow (inches)**
6/27/2005	11:00 AM	26	C06, C09, C11, C12, C17, C22, C28A, C29, C30, C31, C32, R01, R01A, R02, R03, R04, R05, R06, S01, S02, S04, S05, S06, S08, S09, S10, S11, S12, S12A, S14, S16, S18, S20, S22, S23, S24, S25, S26, S31, S33, S36A, S37, S42, S42A, S44, S45, S50	47	0.64	0.96	0.38	0.24	0.001	0.006	0.241	0.061
6/29/2005	3:00 AM	3	S05, S06, S10, S11, S12, S12A, S13, S15, S16, S17, S18, S19, S21, S23, S24, S25, S26, S31, S36A, S37, S42A	21	0.06	0.63	0.01	0.62	0.001	0.001	0.023	0.009

Rainfall Events			SWDD CSO Regulators Overflowing		SWDD Rain Gage Rainfall Depth Statistics					SWDD Flow Depth Values		
Start Time	**End Time**	**Duration (hrs)**	**List**	**Count**	**Average Depth (inches)**	**Max Depth (inches)**	**Min Depth (inches)**	**Max Intensity (in/hr)**	**Min Intensity (in/hr)**	**RDI/I (inches)**	**Runoff (inches)**	**Overflow (inches)**
7/1/2005	8:00 PM	18	C01, C04, C04A, C05, C06, C07, C09, C10, C11, C12, C13, C14, C15, C17, C18, C19, C20, C21, C22, C24, C25, C28A, C29, C30, C31, C32, C33, C34, C35, C36, C37, R01, R01A, R02, R03, R04, R05, R06, R24, S01, S02, S03, S04, S05, S06, S07, S08, S09, S10, S11, S12, S12A, S13, S14, S15, S16, S17, S18, S19, S20, S21, S22, S23, S24, S25, S26, S30, S31, S32, S33, S35, S36, S36A, S37, S38, S42, S42A, S44, S45, S46, S50	81	0.81	1.97	0.44	0.96	0.004	0.009	0.298	0.220

Rainfall Events			SWDD CSO Regulators Overflowing		SWDD Rain Gage Rainfall Depth Statistics					SWDD Flow Depth Values		
Start Time	**End Time**	**Duration (hrs)**	**List**	**Count**	**Average Depth (inches)**	**Max Depth (inches)**	**Min Depth (inches)**	**Max Intensity (in/hr)**	**Min Intensity (in/hr)**	**RDI/I (inches)**	**Runoff (inches)**	**Overflow (inches)**
7/5/2005	9:00 AM	12	C06, C07, C09, C10, C11, C12, C13, C14, C15, C17, C18, C19, C20, C21, C22, C23, C24, C25, C26, C27, C28A, C29, C30, C31, C32, C33, R01, R01A, R02, R03, R04, R05, R06, S01, S02, S04, S05, S06, S07, S08, S09, S10, S11, S12, S12A, S13, S14, S15, S16, S17, S18, S19, S20, S21, S22, S23, S24, S25, S26, S31, S32, S33, S35, S36, S36A, S37, S38, S42, S42A, S44, S45, S46, S50	73	0.58	1.02	0.26	0.80	0.003	0.008	0.258	0.146

Rainfall Events			SWDD CSO Regulators Overflowing		SWDD Rain Gage Rainfall Depth Statistics					SWDD Flow Depth Values		
Start Time	**End Time**	**Duration (hrs)**	**List**	**Count**	**Average Depth (inches)**	**Max Depth (inches)**	**Min Depth (inches)**	**Max Intensity (in/hr)**	**Min Intensity (in/hr)**	**RDI/I (inches)**	**Runoff (inches)**	**Overflow (inches)**
7/7/2005	12:00 PM	18	C01, C04, C04A, C05, C06, C07, C09, C10, C11, C12, C13, C14, C15, C16, C17, C18, C19, C20, C21, C22, C23, C24, C25, C26, C27, C28A, C29, C30, C31, C32, C33, C34, C35, C36, C37, R01, R01A, R02, R03, R04, R05, R06, R12R, R24, S01, S02, S03, S04, S05, S06, S07, S08, S09, S10, S11, S12, S12A, S13, S14, S15, S16, S17, S18, S19, S20, S21, S22, S23, S24, S25, S26, S30, S31, S32, S33, S35, S36, S36A, S37, S38, S42, S42A, S44, S45, S46, S50, S51	87	2.01	2.75	1.38	0.85	0.005	0.029	1.038	0.758
7/12/2005	11:00 PM	2	C17, C18, C19, C20, C21, C22, C24, C25, C28A, C29, C30, R01, R01A, R02, R03, R04, R05, R06, S20, S24, S26, S31, S32, S33, S36A, S37, S38, S42, S42A, S44, S45, S46	32	0.12	0.75	0.01	0.71	0.006	0.001	0.038	0.012

Rainfall Events			SWDD CSO Regulators Overflowing		SWDD Rain Gage Rainfall Depth Statistics					SWDD Flow Depth Values		
Start Time	**End Time**	**Duration (hrs)**	**List**	**Count**	**Average Depth (inches)**	**Max Depth (inches)**	**Min Depth (inches)**	**Max Intensity (in/hr)**	**Min Intensity (in/hr)**	**RDI/I (inches)**	**Runoff (inches)**	**Overflow (inches)**
7/13/2005	8:00 PM	1	S42A	1	0.01	0.06	0.00	0.06	0.001	0.000	0.001	0.000
7/14/2005	9:00 PM	2	C06, R01A, R02, R04, R05	5	0.03	0.15	0.00	0.08	0.001	0.000	0.004	0.000
7/15/2005	8:00 PM	74	C01, C02, C04, C04A, C05, C06, C07, C09, C10, C11, C12, C13, C14, C15, C16, C17, C18, C19, C20, C21, C22, C23, C24, C25, C27, C28A, C29, C30, C31, C32, C33, C34, C35, C36, C37, R01, R01A, R02, R03, R04, R05, R06, R12R, R24, S01, S02, S03, S04, S05, S06, S07, S08, S09, S10, S11, S12, S12A, S13, S14, S15, S16, S17, S18, S19, S20, S21, S22, S23, S24, S25, S26, S30, S31, S32, S33, S36, S36A, S37, S38, S42, S42A, S44, S45, S46, S50	85	1.80	2.45	0.79	1.37	0.001	0.034	0.887	0.678
7/25/2005	1:00 PM	9	C06, R01, R01A, R02, R04, R05, S04, S05, S06, S16, S20, S26, S33, S42A	14	0.12	0.20	0.08	0.09	0.007	0.001	0.024	0.001

Rainfall Events			SWDD CSO Regulators Overflowing		SWDD Rain Gage Rainfall Depth Statistics					SWDD Flow Depth Values		
Start Time	**End Time**	**Duration (hrs)**	**List**	**Count**	**Average Depth (inches)**	**Max Depth (inches)**	**Min Depth (inches)**	**Max Intensity (in/hr)**	**Min Intensity (in/hr)**	**RDI/I (inches)**	**Runoff (inches)**	**Overflow (inches)**
7/27/2005	6:00 AM	4	C06, C17, R01, R01A, R02, R04, R05, S04, S05, S06, S10, S11, S14, S16, S18, S20, S23, S26, S31, S33, S36A, S37, S42A, S50	24	0.13	0.17	0.08	0.09	0.003	0.001	0.038	0.005
8/4/2005	12:00 AM	3	C11, C12, C17, R01, R01A, R02, R03, R04, R05, R06, S01, S02, S04, S05, S06, S10, S11, S12, S14, S16, S18, S20, S22, S33, S50	25	0.05	0.43	0.00	0.43	0.001	0.000	0.041	0.023
8/8/2005	5:00 PM	29	C06, C11, C12, C17, C18, C22, C25, C28A, C29, C30, C31, R01, R01A, R02, R03, R04, R05, R06, S01, S02, S04, S05, S06, S08, S09, S10, S11, S12, S12A, S14, S16, S17, S18, S19, S20, S21, S22, S23, S24, S25, S26, S31, S32, S33, S36, S36A, S37, S38, S42, S42A, S44, S45, S46, S50	54	0.69	1.39	0.20	0.94	0.001	0.005	0.216	0.085

Rainfall Events			SWDD CSO Regulators Overflowing		SWDD Rain Gage Rainfall Depth Statistics					SWDD Flow Depth Values		
Start Time	End Time	Duration (hrs)	List	Count	Average Depth (inches)	Max Depth (inches)	Min Depth (inches)	Max Intensity (in/hr)	Min Intensity (in/hr)	RDI/I (inches)	Runoff (inches)	Overflow (inches)
8/15/2005	5:00 PM	56	C01, C02, C04, C04A, C05, C06, C07, C09, C10, C11, C12, C13, C14, C15, C16, C17, C18, C19, C20, C21, C22, C23, C24, C25, C26, C27, C28A, C29, C30, C31, C32, C33, C34, C35, C36, C37, R01, R01A, R02, R03, R04, R05, R06, R12R, R24, S01, S02, S03, S04, S05, S06, S07, S08, S09, S10, S11, S12, S12A, S13, S14, S15, S16, S17, S18, S19, S20, S21, S22, S23, S24, S25, S26, S30, S31, S32, S33, S35, S36, S36A, S37, S38, S42, S42A, S44, S45, S46, S50, S51	88	1.50	1.79	0.86	1.27	0.003	0.014	0.732	0.520
8/19/2005	4:00 PM	3	R01, R01A, R02, R04, R05	5	0.03	0.06	0.01	0.04	0.009	0.000	0.004	0.000

Rainfall Events			**SWDD CSO Regulators Overflowing**		**SWDD Rain Gage Rainfall Depth Statistics**					**SWDD Flow Depth Values**		
Start Time	**End Time**	**Duration (hrs)**	**List**	**Count**	**Average Depth (inches)**	**Max Depth (inches)**	**Min Depth (inches)**	**Max Intensity (in/hr)**	**Min Intensity (in/hr)**	**RDI/I (inches)**	**Runoff (inches)**	**Overflow (inches)**
8/27/2005	5:00 PM	26	C01, C04, C04A, C05, C06, C07, C09, C10, C11, C12, C13, C14, C15, C17, C18, C19, C20, C21, C22, C24, C25, C28A, C29, C30, C31, C32, C33, C34, C35, C37, R01, R01A, R02, R03, R04, R05, R06, R24, S01, S02, S04, S05, S06, S08, S09, S10, S11, S12, S12A, S14, S15, S16, S17, S18, S19, S20, S21, S22, S23, S24, S25, S26, S31, S32, S33, S36, S36A, S37, S38, S42, S42A, S44, S45, S46, S50	75	0.70	1.09	0.30	0.61	0.002	0.007	0.300	0.189
8/29/2005	1:00 AM	2	C28A, C29, R04, S01, S02, S03, S04, S05, S06, S07, S08, S09, S10, S11, S12, S12A, S13, S14, S15, S16, S17, S18, S19, S20, S21, S22, S23, S24, S25, S26, S31, S33, S36, S36A, S37, S42A, S50	37	0.18	0.68	0.01	0.63	0.009	0.001	0.054	0.024

Rainfall Events			SWDD CSO Regulators Overflowing		SWDD Rain Gage Rainfall Depth Statistics					SWDD Flow Depth Values		
Start Time	**End Time**	**Duration (hrs)**	**List**	**Count**	**Average Depth (inches)**	**Max Depth (inches)**	**Min Depth (inches)**	**Max Intensity (in/hr)**	**Min Intensity (in/hr)**	**RDI/I (inches)**	**Runoff (inches)**	**Overflow (inches)**
9/14/2005	9:00 PM	29	C01, C04, C04A, C05, C06, C07, C09, C11, C12, C13, C17, C31, C32, C33, C34, C37, R01, R01A, R02, R03, R04, R05, R06, R24, S01, S02, S03, S04, S05, S06, S07, S08, S09, S10, S11, S12, S12A, S13, S14, S15, S16, S17, S18, S19, S20, S21, S22, S23, S24, S25, S26, S31, S33, S36, S36A, S37, S42, S42A, S44, S46, S50	61	0.79	2.25	0.08	0.95	0.001	0.004	0.213	0.101
9/17/2005	12:00 AM	2	C06, R01A, R02, R04, R05, S05, S16	7	0.06	0.36	0.01	0.34	0.01	0.001	0.009	0.000
9/26/2005	5:00 AM	8	C06, C09, C11, C12, C17, C29, C31, R01, R01A, R02, R03, R04, R05, R06, S02, S04, S05, S06, S10, S11, S14, S16, S18, S20, S23, S26, S31, S33, S36A, S37, S42, S42A, S45, S50	34	0.19	0.22	0.15	0.18	0.007	0.002	0.072	0.018
9/29/2005	5:00 PM	3	R01, R01A, R02, R04, R05, S04, S06, S16, S18, S20, S26, S33, S36A, S42A	14	0.07	0.08	0.05	0.05	0.002	0.001	0.015	0.001

Rainfall Events			**SWDD CSO Regulators Overflowing**		**SWDD Rain Gage Rainfall Depth Statistics**					**SWDD Flow Depth Values**		
Start Time	**End Time**	**Duration (hrs)**	**List**	**Count**	**Average Depth (inches)**	**Max Depth (inches)**	**Min Depth (inches)**	**Max Intensity (in/hr)**	**Min Intensity (in/hr)**	**RDI/I (inches)**	**Runoff (inches)**	**Overflow (inches)**
10/6/2005	11:00 PM	2	C06, C09, C31, R01, R01A, R02, R04, R05	8	0.02	0.13	0.01	0.13	0.009	0.000	0.005	0.000
10/7/2005	8:00 PM	66	C01, C02, C04, C04A, C05, C06, C07, C09, C10, C11, C12, C13, C14, C15, C16, C17, C18, C19, C20, C21, C22, C23, C24, C25, C26, C27, C28A, C29, C30, C31, C32, C33, C34, C35, C36, C37, R01, R01A, R02, R03, R04, R05, R06, R12R, R24, S01, S02, S03, S04, S05, S06, S07, S08, S09, S10, S11, S12, S12A, S13, S14, S15, S16, S17, S18, S19, S20, S21, S22, S23, S24, S25, S26, S30, S31, S32, S33, S35, S36, S36A, S37, S38, S42, S42A, S44, S45, S46, S50, S51	88	3.47	3.73	2.90	1.25	0.001	0.050	1.935	1.506

Rainfall Events			SWDD CSO Regulators Overflowing		SWDD Rain Gage Rainfall Depth Statistics					SWDD Flow Depth Values		
Start Time	**End Time**	**Duration (hrs)**	**List**	**Count**	**Average Depth (inches)**	**Max Depth (inches)**	**Min Depth (inches)**	**Max Intensity (in/hr)**	**Min Intensity (in/hr)**	**RDI/I (inches)**	**Runoff (inches)**	**Overflow (inches)**
10/11/2005	3:00 AM	98	C06, C11, C12, C17, C29, C31, R01, R01A, R02, R03, R04, R05, R06, S01, S02, S04, S05, S06, S07, S08, S09, S10, S11, S12, S12A, S13, S14, S15, S16, S17, S18, S19, S20, S22, S23, S24, S25, S26, S31, S33, S36, S36A, S37, S42, S42A, S44, S45, S50	48	1.19	1.54	0.94	0.32	0.003	0.013	0.402	0.074
10/21/2005	7:00 AM	40	C06, C07, C09, C10, C11, C12, C13, C14, C17, C18, C22, C28A, C29, C30, C31, C32, R01, R01A, R02, R03, R04, R05, R06, S01, S02, S04, S05, S06, S08, S09, S10, S11, S12, S12A, S14, S16, S17, S18, S19, S20, S22, S23, S24, S25, S26, S31, S33, S36, S36A, S37, S38, S42, S42A, S44, S45, S46, S50	57	1.18	1.35	1.02	0.29	0.007	0.014	0.465	0.115

Rainfall Events			SWDD CSO Regulators Overflowing		SWDD Rain Gage Rainfall Depth Statistics					SWDD Flow Depth Values		
Start Time	**End Time**	**Duration (hrs)**	**List**	**Count**	**Average Depth (inches)**	**Max Depth (inches)**	**Min Depth (inches)**	**Max Intensity (in/hr)**	**Min Intensity (in/hr)**	**RDI/I (inches)**	**Runoff (inches)**	**Overflow (inches)**
10/24/2005	4:00 PM	43	C06, C17, C22, C28A, C29, R01, R01A, R02, R03, R04, R05, R06, S01, S02, S04, S05, S06, S08, S09, S10, S11, S12, S12A, S14, S16, S18, S20, S22, S23, S24, S25, S26, S31, S33, S36A, S37, S42, S42A, S44, S45, S50	41	1.12	1.34	0.99	0.20	0.008	0.011	0.438	0.084
11/6/2005	6:00 AM	2	C06, C17, C22, C28A, C29, R01, R01A, R02, R03, R04, R05, R06, S04, S05, S06, S10, S11, S12, S14, S16, S18, S20, S23, S24, S26, S31, S33, S36A, S37, S42A	30	0.08	0.12	0.04	0.12	0.012	0.001	0.026	0.003
11/10/2005	5:00 PM	11	C06, C09, C11, C12, C17, C22, C28A, C29, C30, C31, C32, R01, R01A, R02, R03, R04, R05, R06, S01, S02, S04, S05, S06, S08, S09, S10, S11, S12, S12A, S14, S16, S18, S20, S22, S23, S24, S25, S26, S31, S33, S36, S36A, S37, S38, S42, S42A, S44, S45, S46, S50	50	0.20	0.32	0.14	0.27	0.009	0.002	0.067	0.022

Rainfall Events			SWDD CSO Regulators Overflowing		SWDD Rain Gage Rainfall Depth Statistics					SWDD Flow Depth Values		
Start Time	**End Time**	**Duration (hrs)**	**List**	**Count**	**Average Depth (inches)**	**Max Depth (inches)**	**Min Depth (inches)**	**Max Intensity (in/hr)**	**Min Intensity (in/hr)**	**RDI/I (inches)**	**Runoff (inches)**	**Overflow (inches)**
11/16/2005	12:00 PM	16	C04, C06, C07, C09, C10, C11, C12, C13, C14, C15, C17, C18, C22, C24, C25, C28A, C29, C30, C31, C32, C33, R01, R01A, R02, R03, R04, R05, R06, S01, S02, S04, S05, S06, S08, S09, S10, S11, S12, S12A, S13, S14, S15, S16, S17, S18, S19, S20, S21, S22, S23, S24, S25, S26, S31, S33, S36, S36A, S37, S38, S42, S42A, S44, S45, S46, S50	65	1.00	1.09	0.79	0.33	0.008	0.010	0.435	0.253
11/21/2005	10:00 PM	23	C06, C09, C11, C12, C13, C14, C17, C18, C22, C28A, C29, C30, C31, C32, R01, R01A, R02, R03, R04, R05, R06, S01, S02, S04, S05, S06, S08, S09, S10, S11, S12, S12A, S14, S16, S18, S20, S22, S23, S24, S25, S26, S31, S33, S36A, S37, S42, S42A, S44, S45, S50	50	0.95	1.11	0.81	0.21	0.008	0.012	0.393	0.110
11/24/2005	7:00 PM	3	S42A	1	0.02	0.05	0.01	0.05	0.009	0.000	0.002	0.000

Rainfall Events			**SWDD CSO Regulators Overflowing**		**SWDD Rain Gage Rainfall Depth Statistics**					**SWDD Flow Depth Values**		
Start Time	**End Time**	**Duration (hrs)**	**List**	**Count**	**Average Depth (inches)**	**Max Depth (inches)**	**Min Depth (inches)**	**Max Intensity (in/hr)**	**Min Intensity (in/hr)**	**RDI/I (inches)**	**Runoff (inches)**	**Overflow (inches)**
11/29/2005	9:00 AM	16	C04, C06, C07, C09, C10, C11, C12, C13, C14, C15, C17, C18, C22, C23, C24, C25, C28A, C29, C30, C31, C32, C33, R01, R01A, R02, R03, R04, R05, R06, S01, S02, S04, S05, S06, S08, S09, S10, S11, S12, S12A, S13, S14, S15, S16, S17, S18, S19, S20, S21, S22, S23, S24, S25, S26, S31, S33, S36, S36A, S37, S38, S42, S42A, S44, S45, S46, S50	66	0.94	1.39	0.74	0.34	0.002	0.011	0.388	0.237
12/4/2005	8:00 AM	24	R01, R01A, R02, R04, R05, S04, S05, S06, S14, S16, S18, S20, S26, S33, S36A, S42A, S50	17	0.20	0.34	0.05	0.09	0.002	0.002	0.082	0.006
12/6/2005	6:00 PM	6	R01, R01A, R02, R04, R05, S04, S20, S33, S42A	9	0.07	0.10	0.02	0.04	0.002	0.000	0.024	0.000
12/9/2005	10:00 PM	12	C06, C17, C29, R01, R01A, R02, R04, R05, S04, S05, S06, S14, S16, S18, S20, S26, S33, S36A, S37, S42A, S44, S50	22	0.28	0.48	0.13	0.16	0.003	0.003	0.104	0.010

Rainfall Events			SWDD CSO Regulators Overflowing		SWDD Rain Gage Rainfall Depth Statistics					SWDD Flow Depth Values		
Start Time	**End Time**	**Duration (hrs)**	**List**	**Count**	**Average Depth (inches)**	**Max Depth (inches)**	**Min Depth (inches)**	**Max Intensity (in/hr)**	**Min Intensity (in/hr)**	**RDI/I (inches)**	**Runoff (inches)**	**Overflow (inches)**
12/11/2005	3:00 AM	16	R01, R01A, R02, R04, R05, S04, S05, S06, S16, S20, S26, S33, S42A	13	0.10	0.21	0.01	0.05	0.009	0.001	0.050	0.002
12/15/2005	1:00 PM	14	C06, C07, C09, C10, C11, C12, C13, C14, C15, C17, C18, C22, C24, C25, C28A, C29, C30, C31, C32, R01, R01A, R02, R03, R04, R05, R06, S01, S02, S04, S05, S06, S08, S09, S10, S11, S12, S12A, S14, S16, S18, S20, S22, S23, S24, S25, S26, S31, S33, S36A, S37, S38, S42, S42A, S44, S45, S46, S50	57	1.21	1.43	1.01	0.28	0.009	0.020	0.499	0.259
12/25/2005	1:00 AM	34	C06, C07, C09, C10, C11, C12, C13, C17, C22, C28A, C29, C30, C31, C32, R01, R01A, R02, R03, R04, R05, R06, S01, S02, S04, S05, S06, S08, S09, S10, S11, S12, S12A, S14, S16, S18, S20, S22, S23, S24, S25, S26, S31, S33, S36A, S37, S38, S42, S42A, S44, S45, S50	51	0.62	0.73	0.52	0.25	0.003	0.007	0.250	0.075

Rainfall Events			SWDD CSO Regulators Overflowing		SWDD Rain Gage Rainfall Depth Statistics					SWDD Flow Depth Values		
Start Time	**End Time**	**Duration (hrs)**	**List**	**Count**	**Average Depth (inches)**	**Max Depth (inches)**	**Min Depth (inches)**	**Max Intensity (in/hr)**	**Min Intensity (in/hr)**	**RDI/I (inches)**	**Runoff (inches)**	**Overflow (inches)**
12/29/2005	2:00 AM	15	C17, R01, R01A, R02, R04, R05, S04, S05, S06, S14, S16, S18, S20, S23, S26, S31, S33, S36A, S37, S42A, S50	21	0.37	0.46	0.31	0.09	0.012	0.004	0.143	0.015
12/31/2005	11:00 PM	3	C06, C17, C29, R01, R01A, R02, R03, R04, R05, S04, S05, S06, S10, S11, S14, S16, S18, S20, S23, S26, S31, S33, S36A, S37, S42A, S50	26	0.11	0.13	0.10	0.10	0.009	0.001	0.037	0.004

4.3 ALTERNATIVE MODEL DEVELOPMENT

The alternative model was built using the baseline model as its foundation. Some changes were made to the baseline models to represent the projects that are in the process of being implemented. The alternative models that were developed with these changes in them form the basis of various analyses that were performed for the LTCPU.

v4.3.1 WPCP Expansion

LTCPU Section 8 Infrastructure-Based Control Measures describes the WPCPs and their expansion scenarios. More information on the stress testing of the WPCPs can be found in Supplemental Documentation Volumes 6, 7 and 8. More information on the WPCP Wet Weather Treatment Alternatives can be found in Supplemental Documentation Volumes 9, 10 and 11.
Based on these studies the WPCP capacities for each of the drainage district were chosen.

For the alternative model the WPCP treatment rates 330 mgd, 650 mgd and 540 mgd were chosen for the SEWPCP, NEWPCP and SWWPCP respectively.

For the SEDD and SWDD these treatment rates can be delivered to the respective WPCP with minor improvements. For the SEDD the treatment rate at SEWPCP can achieved by process improvements and improvements to the influent pumping at SEWPCP. For the SWDD the treatment rate at SWWPCP can achieved by improvements at the SWWPCP. For the NEDD two additional barrels would need to be built to deliver the flow from the high level interceptor system to achieve peak flow of 650 mgd at the NEWPCP.

The alternative models were developed to include the above changes so as to achieve the peak treatment flow at each of the WPCPs.

v4.3.2 Infrastructure Improvements

The following infrastructure improvements have been included in all alternatives evaluated as part of the LTCPU.

Indian Creek Daylighting In-System Storage

The project is located in the Cobbs Creek Watershed at the confluence of the East Branch Indian Creek and the West Branch Indian Creek. Currently the West Branch Indian Creek flows into a culvert within which the outfall of CSO regulator C_05 discharges before merging with the East Branch Indian Creek to form the main stem of Indian Creek. The proposed project will divert the creek out of the culvert and restore the surrounding stream channel. The approximately 700 feet of 6’ x 6’ culvert will now be over-sized for conveying CSO flows from regulator C_05 and will be modified to allow storage of a majority of this flow during wet weather and release to the collection system for treatment at the SW WPCP as capacity becomes available.

T14 Real-Time-Control In-System Storage

CSO outfall T14 is a very large sewer (21' by 24') that discharges into the Tacony Creek during periods of moderate to heavier rainfall. The T14 combined trunk sewer has a volume of approximately 10 million gallons upstream of the regulator chamber. To use as much of this storage as possible, a control structure is needed in the sewer. Installation of a crest gate is proposed in order to retain flow within the sewer. This gate will reduce CSO discharges to the creek by utilizing the sewer for in-system storage. This control technology provides an additional margin of protection against wet weather discharges while maintaining flood protection for upstream communities. The crest gate retains the stored flow in the sewer and a new connector pipe and control gates drain the stored flow for treatment at the NE WPCP as capacity becomes available.

Rock Run Relief Real-Time-Control In-System Storage

The Rock Run Relief Sewer provides flood relief to combined sewersheds in PWD's Northeast Drainage District (NEDD). The Rock Run Relief structure, R15, is a side overflow weir which diverts wet weather flows into the Rock Run Relief Sewer at R15 once flow levels exceed the diversion weir height. This proposed project will utilize approximately 2.3 MG of the 11 ft diameter relief sewer for storage of combined sewer flows through a control structure, inflatable dam or hydraulic gate, constructed within the outfall pipe along with a new connector pipe to the Tacony Interceptor and control gate to drain the flow for treatment at the NE WPCP as capacity becomes available.

v4.3.3 Waterfront Disconnection

Currently, stormwater runoff from the two interstate highways (I-95 and I-76) along Philadelphia's riverfronts is discharged to the combined sewer system, using wet weather capacity and increasing overflow from sewersheds along the waterfronts. The area represented by I-95 is approximately 2.1% of impervious area in the Delaware Direct watershed. Currently, the Pennyslvania Department of Transportation has plans to expand the capacity of a portion of I-95 by adding new lanes. This major construction project provides an opportunity to incorporate a stormwater management component concurrently with the transportation component. In this concept, stormwater runoff from new and existing lanes will be diverted from the combined sewer system. New separate storm sewers will be constructed from I-95 to the waterfront, with appropriate stormwater quality treatment included as appropriate. This infrastructure can be sized to accommodate not just runoff from the highway, but runoff from future redevelopment projects along the waterfront.

Interstate Highways and Waterfront Land

ArcGIS was used to identify the areas between the highway and the river. The highway area was also identified. Properties located close to the Delaware and Schuylkill waterfronts present opportunities for sewer separation, appropriate pretreatment of stormwater and direction of stormwater to public or private permitted outfalls. It is important to note the same land-based stormwater management techniques being considered for the combined sewer system can function as pretreatment for runoff entering a separate storm sewer system. This runoff would no longer be included in PWD's CSO management program but would continue to be managed through PWD's larger stormwater and watershed management programs.

Table v4.3.1 lists the "waterfront" drainage area currently draining to combined sewers. Waterfront can be defined in one of two ways. Defined as all land between interstate highways and rivers, it comprises approximately 4% of combined drainage area. This percentage is highest in the southeast drainage district at 7%. Defined more narrowly as the area between combined sewer regulator structures and the river, the waterfront area comprises approximately 2% of drainage area. There is also a long-term potential to disconnect the interstate highways themselves from the combined sewer system.

Table v4.3.1 Distribution of Waterfront Land

Land Location	Combined-Sewered Impervious Area (ac)				Combined-Sewered Impervious Area (% of total)			
	City-Wide	SED D	NED D	SWD D	City-Wide	SED D	NED D	SWD D
Non-Waterfront	43,414	8,700	20,060	14,654	95.8	91.5	98.4	94.9
Between Regulator Structures and Rivers	681	157	245	279	1.6	1.8	1.2	1.9
Between Major Highways and Rivers	1,507	578	234	695	3.5	6.6	1.2	4.7
Highway	315	165	94	56	0.7	1.9	0.5	0.4
Waterfront + Highway	1,822	743	327	752	4.2	8.5	1.6	5.1

v4.3.4 Green Stormwater Infrastructure Model Details

Philadelphia's stormwater regulations require a minimum level of performance from post-construction stormwater management structures. Rather than focusing on differences in structure between different land-based practices, we will assume that an appropriate practice or mix of practices can be designed to meet this level of performance. We will model a generic structure that meets management goals through some combination of storage, infiltration and slow release.

To improve modeling efficiency, stormwater management will be modeled separately from combined sewer system hydraulics. Outflow hydrographs from stormwater management structures will be used as inflow hydrographs for the sewer system. This section describes sizing and configuration of model elements that will approximate the requirements of the Philadelphia stormwater regulations.

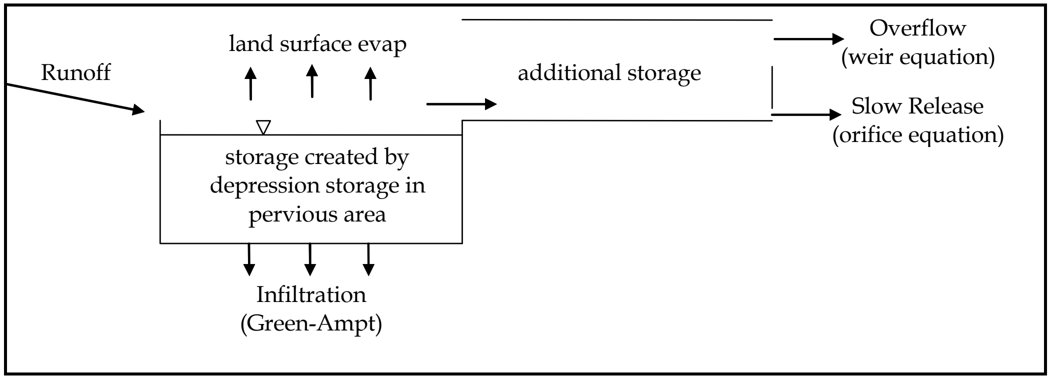


Figure v4.3.1 Conceptual Diagram of Modeling Approach

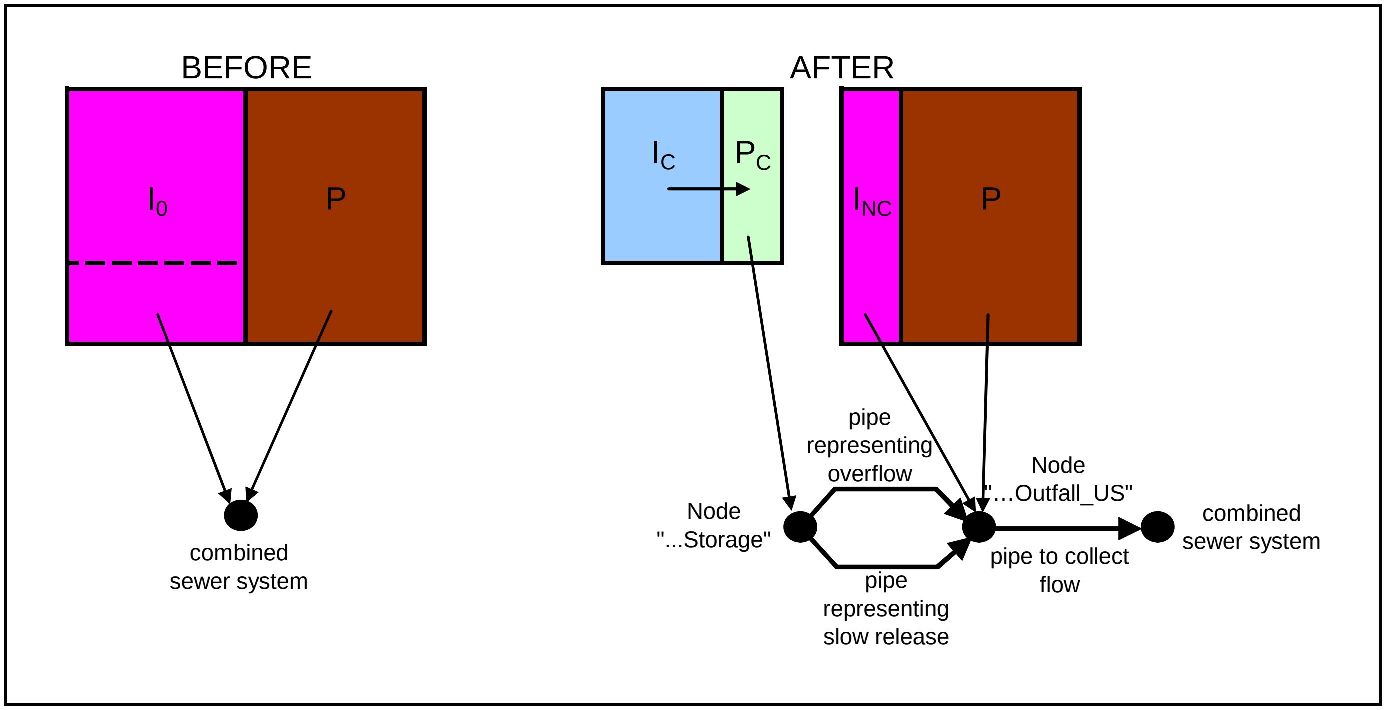


Figure v4.3.2 Schematic Diagram of Modeling Approach

Identified in the schematic diagram above, portions of the subcatchments are divided up and labeled as follows:

I_0 = impervious area of original model subshed (ac)
P = pervious area of original subshed (ac)
I_C = impervious area draining to stormwater controls (ac)
P_C = bottom area of stormwater controls (ac)
I_{NC} = impervious area not draining to controls (ac)

The portion of the impervious drainage area to be controlled is calculated. The area to be occupied by stormwater control structures is included in this area.

$$(I_C + P_C) = I_0 \text{ x } X$$

Where X = percentage of original impervious area to be controlled, designated by the user

Next, the bottom area of stormwater controls and the impervious drainage area can be calculated.

$$P_C = (I_C + P_C) / (R + 1)$$
$$I_C = R \text{ x } P_C$$

Where R = ratio of controlled impervious area to stormwater control bottom area , designated by the user

Next, the impervious area not draining to controls is calculated.

$$I_{NC} = I_0 - I_C - P_C$$

In SWMM, these numbers are entered as percent impervious and total area.

Total area (controlled) = $I_C + P_C$
Total area (not controlled) = $I_{NC} + P$
Percent impervious (controlled) = $I_C / (I_C + P_C)$
Percent impervious (not controlled) = $I_{NC} / (I_{NC} + P)$

The Philadelphia Stormwater Regulations require control of a water quality volume equal to 1.0 inch of runoff from the directly connected impervious area. This volume includes two components, an infiltration volume and a treat-and-release volume. The infiltration volume is the minimum of the water quality volume or the volume that can be infiltrated in an acceptable period.

$$V_I = \min\left[\left(V_{WQ} \text{ x } I_c \text{ x } (43{,}560 \text{ ft}^2 / \text{ac}) \text{ x } (1 \text{ ft}/12 \text{ in})\right), \left(P_C \text{ x } K_{sat} \text{ x } T \text{ x } (43{,}560 \text{ ft2/ac}) \text{ x } (1 \text{ ft}/12 \text{ in})\right)\right]$$

Where V_I = infiltration volume (ft^3)
V_{WQ} = water quality volume = 1.0 in
K_{sat} = saturated vertical hydraulic conductivity of soil under stormwater control (in/hr)
T = allowable time for standing water to infiltrate soil, designated by user (hr)

The infiltration volume determines depression storage in the pervious area representing stormwater controls.

$$D_C = [V_I / (P_C \times 43{,}560\ ft^2/1\ ac)] \times (12\ in/1\ ft)$$

Where D_C = depression storage in pervious area representing stormwater controls (in)

The treat-and-release volume is the difference between the water quality volume and infiltration volume, if any. This volume is represented in the model as a storage node, with orifice and weir controls on its outflow, which will only receive runoff after depression storage is full. The weir height (difference between invert and overflow elevation) of this pipe is designated by the user and the cross-sectional area is calculated to give the required storage volume.

$$V_{TR} = (V_{WQ} \times I_C \times 43{,}560\ ft^2/ac \times 1\ ft/12\ in) - V_I$$
$$A_N = V_{TR} / H_w$$

Where A_N = surface area of storage element (ft^2)
V_{TR} = treat-and-release volume (ft^3)
H_W = weir height in storage node, designated by user (ft)

A weir control is added to allow larger storms to overflow the storage element. This discharge is assumed to receive no significant detention or water quality treatment. The total height of the storage element is set at an arbitrary value greater than the weir height to allow high flows to exit the storage element unimpeded.

The stormwater regulations designate an allowable release rate for the treat-and-release volume in combined-sewered areas, based on 24-hour detention of a reference volume equal to runoff from a 1-year, 24-hour storm. The average allowable release rate is calculated as this volume released over 24 hours:

$$Q_{ave} = [(2.64\ in) / (24\ hrs)] \times (1\ ft/12\ in) \times (43{,}560\ ft^2/ac) \times (1\ hr/3600\ s) = 0.11\ cfs/ac$$

Where Q_{ave} = allowable average controlled release rate per acre of impervious drainage area

It is assumed that with a submerged orifice control, the peak release rate is approximately twice the average:

$$Q_{peak} \sim 2 \times Q_{ave} = 0.22\ cfs/ac$$

Where Q_{peak} = maximum allowable controlled release rate per acre of impervious drainage area

An orifice control sufficient to provide this level of detention can be estimated by solving the submerged orifice equation.

$$D_O = (4\ A_O / \pi)\ \hat{}\ (1/2)$$

Where A_{ref} = cross-sectional area of the storage node if it were required to store this volume (ft^2)
A_O = area of orifice to release reference volume in targeted time (ft^2)

C_D = submerged orifice discharge coefficient, designated by user (dimensionless)
g = gravitational constant (ft/s^2)
D_O = orifice diameter (ft)

EXTRAN converts the slow-release orifice to an equivalent pipe with a diameter equal to the orifice diameter. The model automatically lowers the invert of this pipe to approximately simulate a bottom-discharge orifice and calculates a roughness coefficient (assuming flow given by Manning's equation and slope equal to the change in head divided by the change in length) to provide approximately the same head loss that would have been provided by an orifice. To prevent backwater affects on the orifice from non-LID sheds loading to the downstream node of the storage pipe, the invert elevation of the upstream storage node is increased by 30' and an offset equal to the increase is added to the downstream node of the storage pipe to keep the slope parameters intact. Any offset existing at the upstream storage node was removed. The orifice control is modeled as a static orifice without gated controls.

The stormwater regulations require management of a channel protection volume on some sites. Management of this volume does not require storage of the entire volume and management of the water quality volume meets part of this requirement. The approach below is based on a practical interpretation of how these controls might be designed by site engineers, assuming a relatively lenient interpretation of the requirement.

Runoff during the most intense 30 minutes of a 1-yr, 24-hour NRCS Type II event will be approximately as follows:

$$Q_{runoff} = (0.306) / (0.5 \text{ hrs}) = 1.62 \text{ in/hr} = 1.63 \text{ cfs/ac}$$

The NRCS approximate method of reservoir routing (Urban Hydrology for Small Watersheds, Figure 6-1) suggests that a storage volume equal to 52% of the runoff volume will be needed to reduce the peak runoff to the allowable peak release rate. This storage volume is calculated and the water quality volume is subtracted to determine additional storage needed to meet the channel protection requirement. This volume is added to the volume in the storage element. The orifice control is not changed.

Total storage volume required = 52% x 2.64 in = 1.37 in
$V_{ch\text{-}add} = (1.37 \text{ in} – 1.00 \text{ in}) \times (1 \text{ ft}/12 \text{ in}) \times I_C \times (43{,}560 \text{ ft}^2/1 \text{ ac}) \times I_{ch}$
$A_{ch\text{-}add} = V_{ch\text{-}add} / H_W$

Where $V_{ch\text{-}add}$ = additional volume to be added to storage element (ft^3)
I_{ch} = portion of controlled impervious area subject to channel protection requirement (%)
$A_{ch\text{-}add}$ = additional cross-sectional area to be added to storage element (ft^2)

In the special case where infiltration is sufficient to manage the entire water quality volume and no additional channel protection volume is required, the surface area of the storage pipe is set arbitrarily to 50 ft^2 and the orifice diameter is set to 10 ft. These settings should be sufficient to allow effectively uncontrolled flow through the storage element.

Validation of Prototype EXTRAN Model

Single-Subshed, Constant-Inflow Case

RUNOFF and EXTRAN elements were set up for a single subshed ('47TH-ST') according to the equations in the previous section, with 50% of impervious cover served by LID. Based on impervious cover (1.15 ac), the peak allowable slow release flow was calculated (0.22 cfs/ac x 1.15 ac = 0.253 cfs). A constant flow of 0.300 cfs was introduced to the storage element. Once the storage element reached equilibrium under this condition, flow in the controlled release orifice was 0.253 cfs. Overflow reached a constant value of 0.047 cfs (0.300 cfs – 0.253 cfs) as expected.

Single-Subshed, Single-Event Comparison to Spreadsheet Solution

A hydrologic model and the same hydraulic model from the single-subshed, constant-inflow case was run with 25-yr, 24-hour NRCS Type III rainfall distribution. This distribution was chosen to test the model response to a variety of runoff intensities. At lower intensities, runoff intensity does not exceed slow release orifice capacity. When runoff intensity exceeds slow release capacity, storage begins to fill. When depth in the storage element exceeds the overflow elevation, flow occurs in the pipe representing an overflow weir.

The table below shows the SWMM RUNOFF water balance before and after application of stormwater BMPs serving all impervious cover in a subshed. As expected, infiltration increases and surface runoff decreases by approximately the same amount.

Table v4.3.2 RUNOFF Water Balance

	pre-LID		post-LID	
	cu.ft.	in	cu.ft.	in
Total Precipitation (Rain plus Snow)	117,990.00	6.501	117,990.00	6.501
Total Infiltration	40,035.60	2.206	50,269.60	2.770
Total Evaporation	357.05	0.020	388.67	0.021
Total Surface Runoff from Watersheds	77,622.50	4.277	67,347.50	3.711
Impervious Area Runoff from Watersheds......	58,654.30	6.463	0.00	0.000
Pervious Area Runoff from Watersheds........	18,968.00	2.090	18,968.00	1.941
Impervious to Pervious Area Runoff..........	0.00	0.000	54,077.40	2.979
Infiltration over the Pervious Area...	40,035.60	4.412	50,269.60	5.144

A time series of runoff was input to a spreadsheet model of a stormwater control structure that performs a mass balance of storage volume, controlled release and overflow on a one-minute time step. The algorithm followed for each time step was as follows:

1. Controlled runoff is taken from SWMM RUNOFF output.
2. Storage volume = storage volume (from previous time step) + runoff – slow release volume (from previous time step).
3. Overflow volume is the difference between storage volume and the volume of the storage element. If storage does not exceed volume of the storage element, overflow volume = 0.
4. Storage volume = storage volume (from step 2) – overflow volume.
5. Depth = storage volume (from step 4) divided by storage element cross-sectional area.
6. Slow release is calculated using the orifice diameter and submerged orifice equations discussed in the previous section.

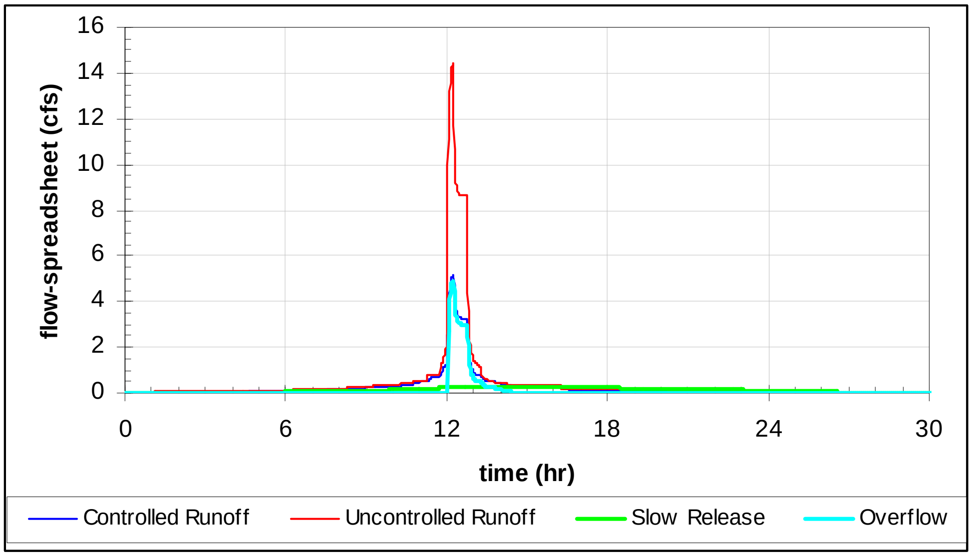


Figure v4.3.3 Spreadsheet Solution

An EXTRAN model was constructed with the same dimensions, same hydrologic input and same time step as the spreadsheet model. For the purpose of validating the SWMM model, the spreadsheet solution was assumed to be exact. In other words, the SWMM model is considered valid if it matches the spreadsheet model within a reasonable tolerance. The figure and table below compare results of the two models. Volumes and peak flows match within 1% or less, an acceptable margin of error for the application.

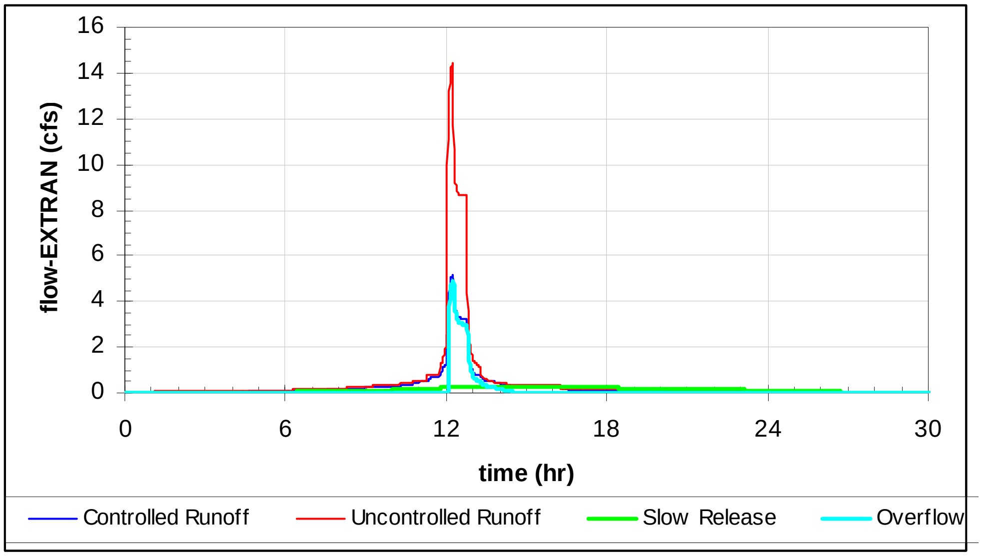


Figure v4.3.4 EXTRAN Solution

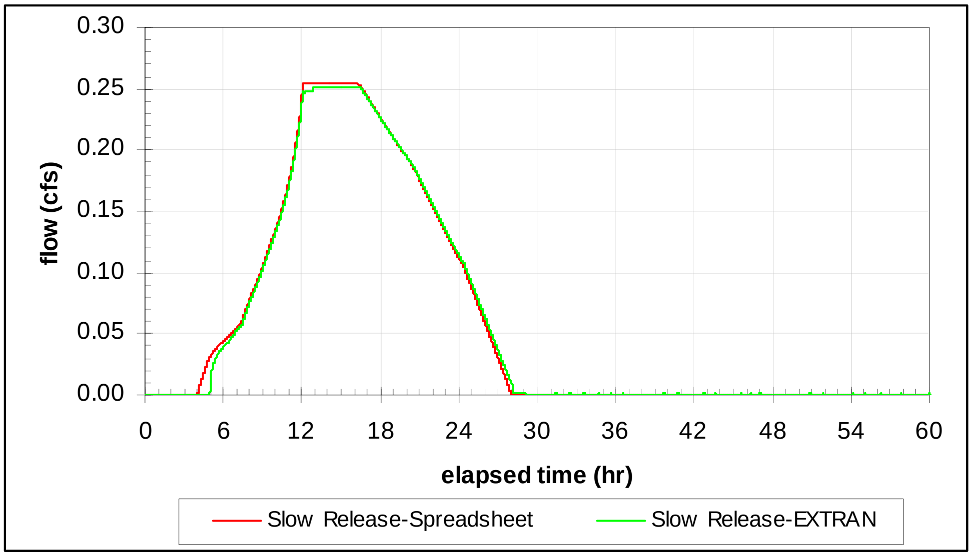


Figure v4.3.5 Comparison of Slow Release

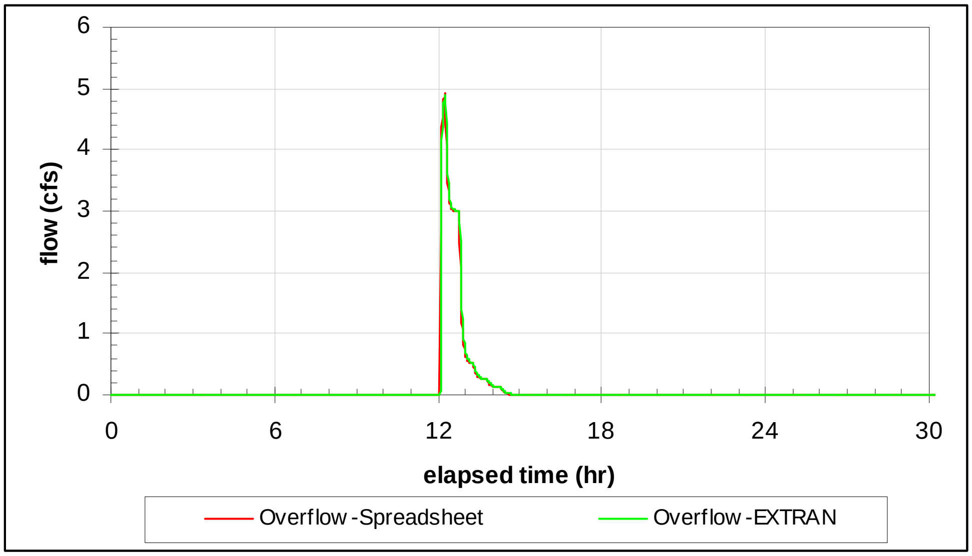


Figure v4.3.6 Comparison of Overflow

Table v4.3.3 Comparison of Volumes and Peak Flows

	spreadsheet	EXTRAN	Difference
Slow release volume (cu.ft.)	12,629	12,557	-0.57%
Overflow volume (cu.ft.)	11,565	11,587	0.19%
Peak slow release (cfs)	0.254	0.252	-0.80%
Peak slow release (cfs/ac)	0.203	0.201	-0.80%
Peak slow release (cfs/ac imperv.)	0.221	0.219	-0.80%
Peak overflow (cfs)	4.91	4.90	-0.32%
Peak overflow+slow release (cfs)	5.17	5.14	-0.44%

v4.3.5 LID Model Runs

Scenarios

- A: storage/infiltration/treatment = 1" over all impervious area not excluded
- B: storage/infiltration/treatment = 1" over all impervious area not excluded, plus 20% DCIA reduction for parcels over 1 ac and not classified as "direct drainage" as defined by stormwater program
- C: storage/infiltration/treatment = 1" over all impervious area not excluded, plus channel protection requirement for parcels over 1 ac and not classified as "direct drainage" as defined by stormwater program
- sensitivity runs
  - D: infiltrate 1" or maximum that can be infiltrated in 24 hours, whichever is less
  - E: store and slow release 1" everywhere, no infiltration
  - F: increase infiltration/water quality volume to 1.5"
  - H: partial failure – reduce infiltration rates by 50%, remove 50% of slow release orifices

Combinations

[(A, B, C = 3) x (# of runs needed to define a curve ~ 10)] + (D, E, F, H) ~ 34

Interpretation of Results

- Determine an area (or range) to be affected by the stormwater ordinance over the planning horizon.
- Adjust acreage affected by ordinance for practices that may provide a lower level of performance than the ordinance (green roofs and trees). (i.e., perform an analysis to estimate X ac served by bioretention provides the same function as Y ac covered by a green roof).
- Determine an area (or range) to be affected by incentives for private land not subject the ordinance.
- Determine an area (or range) of public land to be targeted for stormwater management.
- Evaluate results of sensitivity runs.
- Choose a single run (or set of runs) to represent source controls and produce a baseline model to be used for infrastructure evaluation projects.

v4.3.6 Deep Tunnels

For a tunnel storage alternative, CSO flows in excess of the interceptor capacity are diverted via a modified or new diversion structure to a series of secondary tunnel structures that convey flow into the storage tunnel. The approach to model the tunnels for all three districts was to simulate the tunnels as storage nodes. To model the tunnels as a storage node, the length of the tunnel to be modeled is obtained by doing a preliminary tunnel alignment. Once the length is determined models are set up for varying tunnel diameters. The tunnel is assumed to be circular.

The diameters range from 15 to 35 feet and are increased by an interval of 2.5 feet for each simulation. Using the tunnel length and the diameter a volume is calculated. Using eighty percent (80%) of the calculated volume, a storage node 20 feet deep with constant surface area is simulated.

The storage section representing the tunnel volume itself has a plan surface area that will satisfy the tunnel volume requirements. The maximum tunnel drain down rate was set so that the tunnel would drain down in 24 hours when the capacity of the WPCP is available. All the outfalls that will contribute to the tunnel are connected to the storage node. Figure v4.3.7 shows a visual representation of the tunnel in the models.

The following steps were followed to setup the models.

1. The tunnel model is built on top of the model that has all the alternatives in the LTCPU.
2. Any flow that goes over the dam in a regulator connected to the tunnel is assumed to go in the tunnel. The only exceptions are the regulators that have the computer controlled overflow gates; in these cases the flows that currently go to the receiving water are assumed to go to the tunnel.
3. All the overflows from the regulator are conveyed to the tunnel using additional conveyance conduits. The conveyance conduits were sized to not cause any backwater conditions at the regulators.
4. The bottom of the tunnel storage junction is a 10 feet high section with small plan surface area so that the tunnel volume can be drained with out causing long tails towards the end of the drain down.
5. The storage section representing the tunnel volume itself is 20 feet deep and has a plan surface area that will satisfy the tunnel volume requirements
6. There is an overflow pipe just above the storage section representing the tunnel volume (Figure v4.3.7).
7. The tunnel drain down pipe is rated to only allow a maximum flow. This maximum flow is set so that the tunnel can be drain down in 24 hours, at this rate.
8. The tunnel drain down pipe is connected to another downstream pipe that conveys the flow from the tunnel drain down and the interceptors that convey flow to the WPCP in the given drainage district. The pipe that combines both these flows is rated to deliver a maximum flow to which each of the WPCPs will be expended to. This final pipe is also setup in a way that the flow from the interceptors is given priority over the tunnel drain down.
9. The tunnel will only drain down when there is capacity left over at the WPCP after the flows from the existing interceptors are treated.

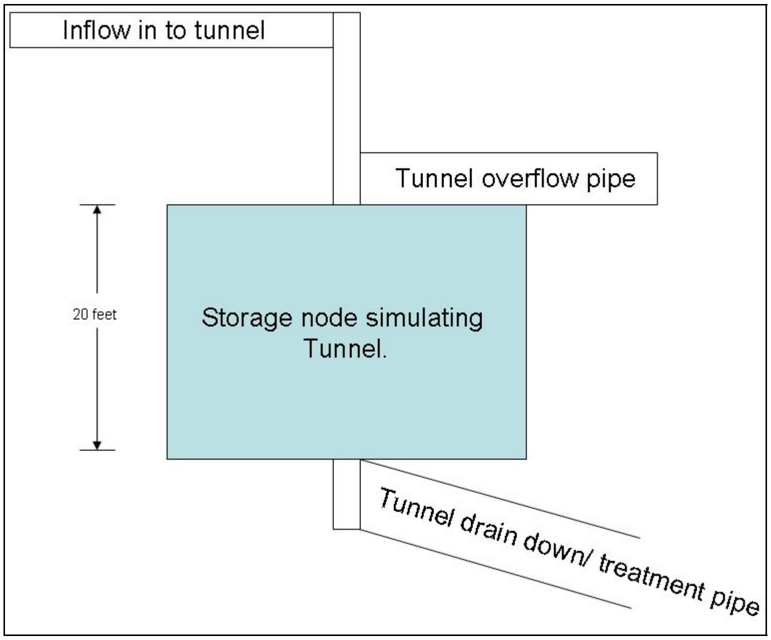


Figure v4.3.7 Storage depicting the tunnel

The volume captured by the tunnel over the course of a one-year simulation was calculated as the difference between the overflow produced from the simulated tunnel scenario and the corresponding baseline scenario. There are two baseline scenarios, each representing the upper and lower boundary of an uncertainty range for DCIA, baseflow and RDI/I watershed characteristics. Each baseline scenario has the interceptors draining to the plant with pumping boundary conditions limiting the high level interceptors' inflow into the WPCP. The baseline plant capacities for the SEDD, NEDD and SWDD are 280, 435 and 480 MGD, respectively.

SEDD Tunnel

The SEWPCP was assumed to be expanded to treat 330 MGD. The total length of the tunnel, excluding the drain down section, is 5.9 miles. The inflow into the tunnel model is the total flow produced from each regulator's outfall. Table 4.3.4 presents the tunnel length and corresponding volume of the storage node for the SEDD tunnel. The volumes shown in the first row represent the total tunnel volume and the second row shows the 80% tunnel volume that was used for the simulations.

Table v4.3.4 Length Volume and Drain down Data for the SEDD Tunnel Model

	Tunnel Diameter (ft)								
	15	17.5	20	22.5	25	27.5	30	32.5	35
	Tunnel volume (Million Gallons)								
Tunnel Volume	41.4	56.4	73.7	93.2	115.1	139.3	165.8	194.6	225.6
Volume used For simulation	33.2	45.1	58.9	74.6	92.1	111.4	132.6	155.6	180.5
Peak Tunnel Drain Down rate (MGD)	33.2	45.1	58.9	74.6	92.1	111.4	132.6	155.6	180.5

NEDD tunnel

It was assumed the NEWPCP will be expanded to treat 650 MGD. The total NEDD tunnel length is estimated to be 10 miles. The tunnel length along the Delaware was estimated as 5.3 miles and along Tacony as 4.7 miles. The tunnel for the NEDD was simulated as one storage node as it is also assumed that the tunnel along the Tacony and Delaware in the NEDD are interconnected. Table v4.3.5 presents the tunnel length and corresponding volume of the storage node. The volumes shown in the first row are the total volumes of the tunnel and the 80% volume used for simulations is presented in the second row.

Table v4.3.5 Length Volume and Drain down Data for the NEDD Tunnel Model.

	Tunnel Diameter (ft)								
	15	17.5	20	22.5	25	27.5	30	32.5	35
	Tunnel volume (Million Gallons)								
Tunnel Volume	70.1	95.4	124.6	157.7	194.7	235.6	280.3	329	381.6
Volume used For simulation	56.1	76.3	99.7	126.2	155.7	188.5	224.3	263.2	305.3
Peak Tunnel Drain Down rate (MGD)	56.1	76.3	99.7	126.2	155.7	188.5	224.3	263.2	305.3

The NEDD also includes all regulators draining to the Upper Frankford Low Level (UFLL), Lower Frankford Low Level (LFLL) and the Pennypack (PP) interceptor systems in addition to the regulators draining to the UDLL, SOM and TAC interceptor systems. The overflow from the regulators along these interceptor systems were conveyed to the tunnel.

SWDD tunnel

It is assumed the SWWPCP will be expanded to treat 540 MGD. The total SWDD tunnel length is estimated to be 13.7 miles. The tunnel length along the Schuylkill was estimated as 6.4 miles and along Cobbs Creek as 7.3 miles. The tunnel for the SWDD was simulated as one storage node; it is also assumed that the tunnel along the Cobbs Creek and Schuylkill River in the SWDD are interconnected. Table v4.3.6 presents the tunnel length and corresponding volume of the storage node. The volumes shown in the first row are the total volumes of the tunnel and the 80% volume used for simulations is presented in the second row.

Table v4.3.6 Length Volume and Drain down data for SWDD Tunnel.

	Tunnel Diameter (ft)								
	15	17.5	20	22.5	25	27.5	30	32.5	35
	Tunnel volume (Million Gallons)								
Tunnel Volume	95.9	130.5	170.4	215.7	266.3	322.2	383.4	450	521.9
Volume used For simulation	76.7	104.4	136.3	172.5	213	257.8	306.7	360	417.5
Peak Tunnel Drain Down rate (MGD)	76.7	104.4	136.3	172.5	213	257.8	306.7	360	417.5

The SWDD includes all regulators draining to the Central Schuylkill East Side (CSES), Central Schuylkill West Side (CSWS), Lower Schuylkill West Side (LSWS), Southwest Main Gravity (SWMG), Cobbs Creek High Level (CCHL) and the Cobbs Creek Low Level (CCLL). The overflow from the regulators along these interceptor systems were conveyed to the tunnel.

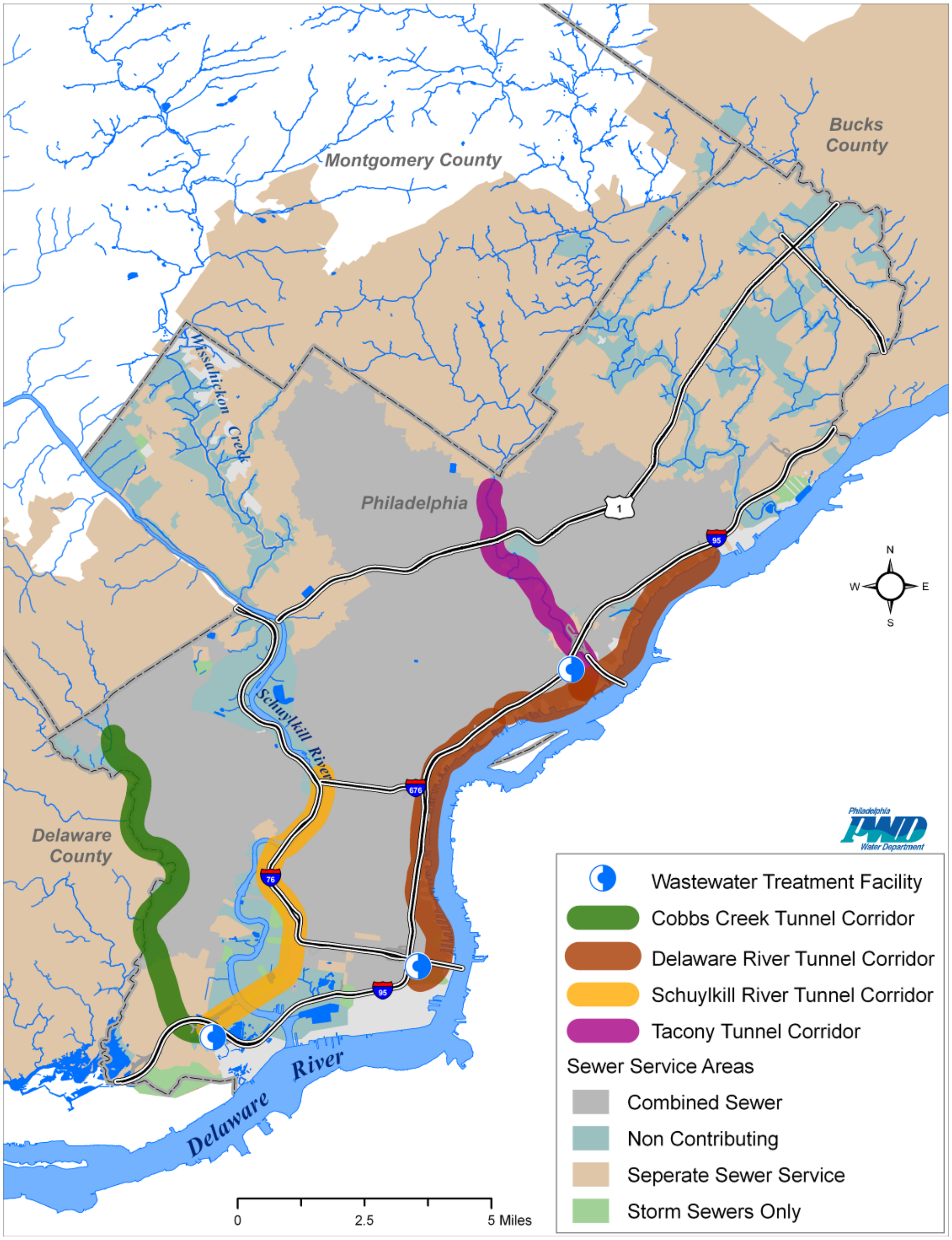


Figure v4.3.8 Potential Tunnel Alignment.

v4.3.7 Spreadsheet Analysis Procedure for the "All Transmission" and Satellite Treatment Unit Alternatives

Prior to building a model representing parallel interceptor systems and satellite treatment facilities, spreadsheet tools were created to align a parallel conveyance system to capture and convey flow to the respective WPCP of the existing interceptor system being paralleled. In this section, parallel transmission and treatment alternatives are referred to as "all transmission". Output from a SAS processing tool served as input to the spreadsheets. The SAS tool identifies a peak flow value and overflow volume for each overflow goal at every regulator in the system having an outfall. The spreadsheet analyzes each regulator producing an overflow for each green stormwater infrastructure implementation scenario for all overflow goals 1 through 25 events per year.

All Transmission Alternative and Satellite Treatment Alternative Descriptions

Building a conveyance sewer to capture and deliver overflow from the regulators in the existing interceptor system is the foundation from which these alternatives have been created. Using the estimated peak overflow numbers produced from the SAS program – discussed in further detail below – as input to the preliminary spreadsheets provides a preview into the effectiveness of building a parallel interceptor system. The spreadsheets are designed to size parallel interceptors using a targeted overflow frequency and corresponding overflow rate with the sizing limited to an assumed constructability limit (12 ft x 12 ft box sewer). Once the constructability limit has been reached or exceeded, either another parallel system is required to continue conveying flow to the WPCP or a satellite treatment unit must be built.

In the case of building a satellite treatment unit, another spreadsheet tool was developed to appropriately size and place the unit. The input to this particular spreadsheet is the same as the all transmission spreadsheet. The satellite treatment spreadsheet is automated to place units at regulators where half the total interceptor system overflow rate to convey to the WPCP or the constructability limit has been reached or exceeded. For some watersheds and interceptor systems, the location of a satellite treatment unit has been predetermined based on availability of land. In these situations, the automated process is manually overridden and pipe dimensions are calculated based on the predetermined location.

The processes and details of each spreadsheet and an overview of the SAS program algorithm used to generate the overflow numbers used as input to the spreadsheets are presented below.

Conveyance Logistics

The loading priority within both spreadsheets for parallel interceptor conveyance to the plant is based on spatial logistics. The assumption was made that the amount of flow delivered by the existing interceptor systems modeled under free outfall (no restrictions at the plant) conditions is the maximum flow that can be treated at the plant. For the Northeast drainage district the plant capacity is 650 MGD, for the Southeast drainage district the plant capacity is 330 MGD and the Southwest drainage district is 540 MGD. Any flow delivered by the parallel interceptor conveyance pipes to the WPCP that exceeds the capacities above would have to be treated using high-rate treatment trains, which would be located at the WPCP.

It is important to understand that each parallel interceptor system is analyzed independently of the others within the same watershed. For instance, the Schuylkill watershed contains regulators along five (5) interceptor systems and regulators in each interceptor system was sized and underwent satellite treatment unit analysis without being affected by analyses done on the regulators in the other interceptor systems. This is mainly due to the possibility that building the parallel interceptor and/or satellite treatment placement alternatives may not be feasible for all – or any – of the interceptor systems within a watershed and therefore, these systems should be analyzed as independent operations to determine which interceptor systems show the most benefit from the parallel system. This also allows for flexibility in choosing the best "package" of options to create the most appropriate alternative to mitigate the overflows in any particular watershed. This analysis process is applied to all systems throughout the city until the overflow target has been met and delivered to the plant or the constructability limit for a single open cut conveyance sewer has been reached in order to determine which interceptor systems are best suited for the all transmission and/or satellite treatment unit alternative.

SAS Tool Description

The inputs to the SAS program are the capture dataset for each regulator (described in section v4.3.12), land-based control model simulation output and an outfall list. The program uses these three inputs to determine the corresponding peak event overflow treatment rate required to satisfy targeted overflow frequencies between 1 and 25 overflows per year.

The SAS program analyzes the treatment rates required at each of the outfalls in the Combined Sewer System (CSS) so that a targeted overflow frequency is achieved. For instance, if an outfall overflows fifty (50) times a year and the treatment capacity exists to treat the third largest overflow among the fifty (50), then there will be only two (2) storm events that will cause an overflow. The rest of the 48 events can be treated. This is the premise under which the program was written. The steps outlined below were followed in order to calculate targeted overflow numbers for each regulator:

1. The overflow data from the EXTRAN model for each regulator having an outfall is loaded into the SAS program. The input data is in 15-minute average wet weather flow data.
2. One of the options in the program is averaging of the 15-minute input flow data to 30 minutes or 1 hour flow.
    a. For the purposes of the all transmission and satellite treatment spreadsheet analyses the 15-minute flow data was averaged over the hour.
3. SAS uses the regulators' generated event lists contained in the capture input data file to retain only events that produced overflows.
4. The type of processed flow data – raw 15 minute or averaged 30 minute or 1 hour flow data – is selected and merged with the overflow event list from step 3. For each regulator, the peak overflow rate for each of the events is extracted and then ranked in descending order.
5. The program steps through each ranked regulator dataset and determines the number of events overflowing, the respective total overflow rate, untreated volumes and treated volumes.
    a. For example, for a given regulator, the second peak overflow treatment rate produced from a given event in the sorted list from step 4 is set equal to the available treatment capacity. Referring to Table v4.3.7 below, this value equals 14 cfs.

b. All overflow events that have peak overflows equal to or less than this value are considered treated – or captured as labeled in Table v4.3.7.
c. The number of events with peak overflow values greater than the available treatment capacity value is determined, which for this example is equal to 1 as there is only one event that is ranked as having a greater peak overflow rate. This overflow frequency number represents one of the targeted overflow goals that will be analyzed within the all transmission and satellite treatment analysis spreadsheets.
d. The regulator's untreated volume for the respective overflow frequency is calculated by summing the residual overflow rate and converting it to a volume.
e. The treated volume – or captured volume – is the difference between the total ranked overflow volume for all events and the untreated volume as calculated in the previous step.
f. The SAS program steps through each ranked event comparing and calculating the overflow numbers as described above for target overflow frequencies 1 through 25.

All Transmission and Satellite Treatment Spreadsheet Descriptions

Of the two spreadsheets, the all transmission spreadsheet is the more straightforward and least complex as it essentially follows the alignment and slopes of the existing interceptor without exception. Implementing the algorithm to place the satellite treatment units made the second spreadsheet inherently more difficult to build and maintain. Additional factors that came into consideration as the satellite treatment spreadsheet was being built included the calculation of reverse grade interceptor conveyance pipes to deliver flow upstream to the satellite treatment units and manual overrides to the automated selection of satellite treatment unit locations because of predetermined land availability. As a result, the satellite treatment unit spreadsheet was built to only analyze 1, 4, 10 and 25 overflows per year for each green stormwater infrastructure implementation level, as opposed to the all transmission spreadsheet which calculates pipe dimensions for all targeted overflows from 1 through 25 for each green stormwater infrastructure implementation level.

All Transmission Analysis Methodology

The spreadsheet analysis for the all transmission alternative is developed to exactly mimic the existing parallel systems. The slope and segment length is taken to be that of the existing interceptor segment it is paralleling. The spreadsheet also provides the depth of cover in order to estimate the amount of excavation necessary for each pipe segment.

The dimensions of the conveyance pipes are estimated using the existing interceptor pipe segment slope and the cumulative overflow rate captured at the nearest upstream regulator outfall, prior to any loading from the nearest contributing downstream regulator's outfall. These numbers are used within the Manning equation – representing full flow conditions – to determine the box sewer dimensions.

The parallel interceptor collects and conveys overflow by moving upstream from the plant through interceptor systems until the sum of target peak overflow rates exceed the assumed constructability limit for open cut conveyance sewers – set to be a 12 ft x 12 ft box sewer. The spreadsheet also summarizes the total system wide untreated overflow volume and total peak overflow rates for each scenario.

Satellite Treatment Location Analysis Methodology

Generally, the satellite treatment location spreadsheet is setup to calculate the total overflow rate for all regulator outfalls contributing overflows to the system and at the regulator where half of that flow is reached or exceeded, the spreadsheet places a satellite treatment unit. Manual overrides were necessary for some interceptor systems where locations were known to have sufficient land available to build a treatment unit.

Because the algorithm places the satellite treatment unit at the regulator where half the total overflow of the interceptor system is reached or exceeded, at least part of the parallel system will have to be built at reverse grade as compared to the corresponding existing interceptor system segments. Due to the potentially high variability of satellite treatment locations for interceptor systems where predetermined locations do not exist – e.g. the interceptor systems within the Schuylkill watershed – the reverse grade pipe segment dimensions, slopes and depth to cover calculations were extensive and had to be done for each scenario and each interceptor system independently. Also, depending on the target overflow rate, the size of the satellite treatment units varied. All these numbers are summarized within the satellite treatment analysis spreadsheets.

Table v4.3.7 The example below assumes the second event's peak treatment rate – 14 cfs – set as the available treatment capacity. The residual overflow rates, used to calculate the overflow untreated and treated volumes are included and the resulting overflow event number.

Time	Event Overflow Rate (cfs)	Total Event Overflow Volume (cu.ft)	Ranked Overflow Event Number	Event Peak Overflow (cfs)	Total Overflow Volume for All Ranked Events (cu.ft)	Total Available Treatment Rate (cfs)	Event Residual Overflow (cfs)	New Overflow Event Number	Overflow Volume After Treatment (cu.ft)	Treated Volume (cu.ft)
1/1/2005 18:15	1	93600	1	25	142200	14	0	1	25200	68400
1/1/2005 18:30	2						0			
1/1/2005 18:45	25						11			
1/1/2005 19:00	24						10			
1/1/2005 19:15	20						6			
1/1/2005 19:30	15						1			
1/1/2005 19:45	14						0			
1/1/2005 20:00	3						0			
1/1/2005 8:15	2	36900	2	14			0	Captured	0	36900
1/1/2005 8:30	13						0			
1/1/2005 8:45	14						0			
1/1/2005 9:00	5						0			
1/1/2005 9:15	6						0			
1/1/2005 9:30	1						0			
1/1/2005 0:15	1	11700	3	4			0	Captured	0	11700
1/1/2005 0:30	2						0			
1/1/2005 0:45	3						0			
1/1/2005 1:00	4						0			
1/1/2005 1:15	3						0			

v4.3.8 Street Trees

Concepts

Street trees are desirable, but by themselves provide a level of control lower than the level defined by Philadelphia's stormwater regulations. Therefore, an "equivalency ratio" was determined defining the relative benefits of these measures and other stormwater management measures. For example, "1.0 ac of impervious surface covered by tree canopy results in the same runoff volume reduction as 0.X ac of impervious surface draining to an infiltration bed meeting the level of performance defined by PWD's stormwater regulations."

Under PWD's regulations and demonstration programs, trees are often used in combination with other practices such as bioretention and tree trenches under sidewalks. We can assume the level of performance for these facilities will meet the regulations. This section is only applicable to trees functioning as a green stormwater interception mechanism independently.

For the purposes of this study, it was assumed that pervious surfaces do not need to be managed. This approach applies only to street trees over impervious surfaces, typically street trees. As the city becomes greener in the future, street trees by themselves could be viewed as a temporary solution that can be implemented relatively quickly on a large scale, while more comprehensive street greening solutions such as tree trenches and infiltration inlets will take longer to implement. If a more pessimistic (but still green) view is taken, it can still be thought that in some areas, street trees can be seen as being the only desirable controls.

Ideal Model

In forestry research, trees and soils are being modeled as the complex three-dimensional systems they are. This is beyond the scope and appropriate level of detail for the LTCPU, but it is worth examining the processes to determine which can be simplified.

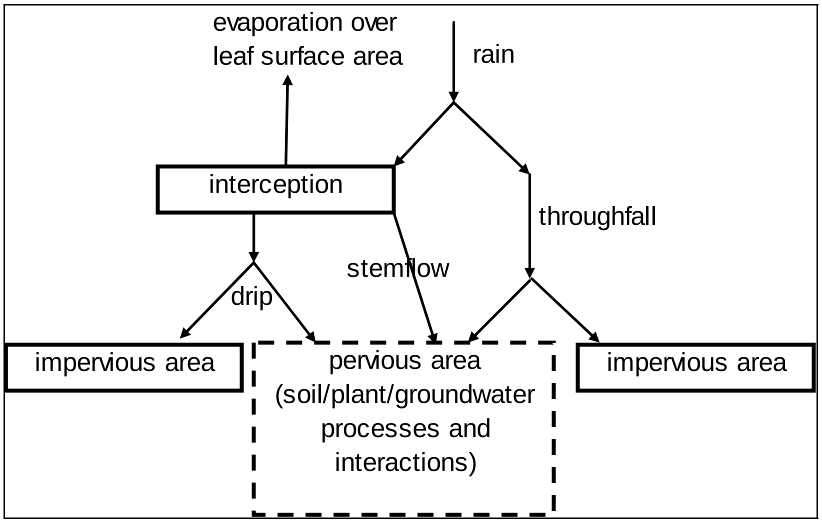


Figure v4.3.9 Conceptual model of tree canopy interception, storage and stemflow.

- Throughfall: Rain falls directly through the tree either because there is no leaf in its path or because it strikes hard enough to move the leaves out of its way. Throughfall may fall on a pervious surface (tree well) or impervious surface (pavement). This can happen at any time during the storm.
- Interception: Rain either ponds on curved leaf surfaces, or "sticks" to leaves through surface tension. Together, these two phenomena comprise canopy storage. When canopy storage is exceeded, water either drips off the tree or flows down the stem.
- Stemflow: For a street tree or other tree planted in impervious cover, all stemflow flows to the pervious area or tree well. A portion of drip falls on pervious cover and a portion on impervious cover, since part of the tree canopy covers both types of surfaces.
- Canopy evaporation: Water stored in the canopy is exposed to the air over the entire leaf surface, not just over the ground projection ("footprint") of the tree.
- Infiltration/Evaporation/Transpiration from soil: Once water reaches the soil, it can continue downward by gravity to recharge groundwater, evaporate through contact with air in soil pores, or be taken up by tree roots and transpired into the atmosphere.

Typical Model

Many modeling studies model trees simply as a storage value, or "initial abstraction". Once this storage is exceeded, any excess stormwater flows immediately to a sewer inlet or receiving water.

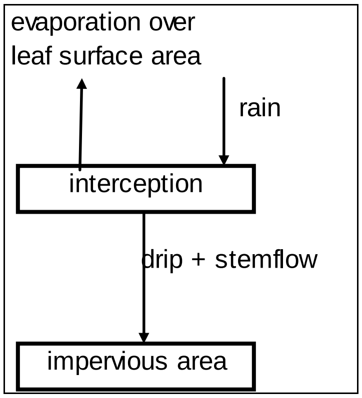


Figure v4.3.10 Typical simplistic model setup to represent tree canopy interception

Compromise Model

The model developed for this study is a good compromise between the ideal and typical models and can be implemented in SWMM. A strong basis for distinguishing between throughfall, drip and stemflow cannot be built without a lot more research. Therefore, a simplifying assumption was made that when canopy storage over pervious cover is exceeded, the excess will drip to pervious cover and vice versa. The dynamics of the unsaturated soil zone are not simulated for the LTCPU.

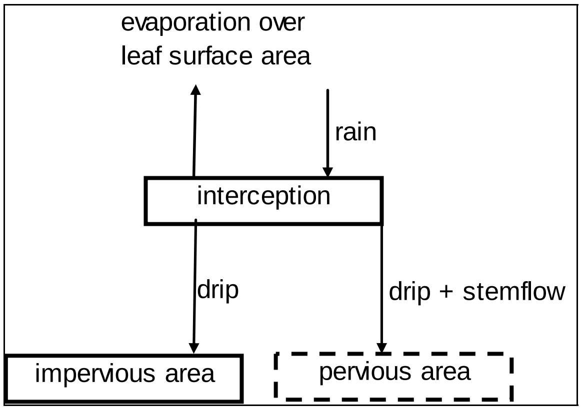


Figure v4.3.11 Visualization of the model setup for the LTCPU to represent tree canopy dynamics.

Model Assumptions and Setup

- Model a hypothetical acre of impervious cover equal to the leaf area.
- Canopy storage = 0.10 inches. This value is conservative compared to the Vanaskie and Xiao (2002) studies and roughly equivalent to the Xiao (2000) study. The CaseyTrees/Limno-Tech value of 0.032 inches seems overly conservative (see additional discussion below).
- Divide into 5 subsheds. Use SWMM 4 subshed routing options to route flows as shown in the diagram.
  - Two impervious sheds representing the leaf area and canopy storage (change SWMM default of 25% area with no depression storage); shed area = leaf area (tree canopy area times mean leaf area index (LAI) from Vanaskie study); divide rainfall and canopy storage (0.10 inches) by LAI; one drains to the impervious shed and one drains to the pervious shed
  - one shed representing pervious area under trees; no rainfall
  - one shed representing impervious area under trees; no rainfall
- Calculate and use the median and mode of the soil properties over the entire CSO area for the pervious area soil shed properties.
- Assuming mean crown diameter from the Vanaskie study, determine how many trees can be planted on the hypothetical acre if all canopies are touching.
- Assume each tree has a 16 sq.ft. (4 ft x 4 ft) tree well.
- A leaf on period of April 1 to October 31 is proposed. During the leaf off period, no canopy storage will be simulated.

Interpreting model results:

- Determine an equivalent acreage of green stormwater infrastructure that will result in the same reduction of uncontrolled runoff volume as the acre of trees. For example, "1.0 ac of impervious cover covered by street trees results in the same runoff volume reduction as 0.X ac draining to an infiltration bed meeting the level of performance defined by PWD's stormwater regulations."
- This approach assumes tree canopy covers all impervious cover on the site.

- With street trees, an added complication is that a fair level of implementation already exists; The resulting ratio will be adjusted based on an estimate of existing tree canopy and available area to implement new tree canopy.

Research/Previous Studies of Leaf Area and Canopy Storage

The CaseyTrees/LimnoTech Green Buildout study assumed a canopy storage volume of 0.032 inches over the ground projection. They conducted a literature review of twelve sources. CDM reviewed some of these sources and the results of an unpublished internal study by Matt Vanaskie. All storage depths are expressed over the tree's ground projection ("crown projection", "footprint"), not over the leaf area. Key results are summarized below:

Table v4.3.8 Literature review summary table for urban tree canopy research

Source	Study	Storage Min (in)	Storage Max (in)	Reviewed?	Urban/Open Grown	Deciduous	Species in Philadelphia "Top 30"?
Agricultural Runoff Manual, 1978	Casey Trees	0.138	0.197	No	No	?	?
Aston, 1979	Casey Trees	0.008	0.031	Yes	No	No	No
Blyth, 2002	Casey Trees	0.027	0.027	No	?	?	?
Crockford and Richardson, 1990	Casey Trees	0.067	0.079	No	?	No	No
Keim, 2006	Casey Trees	0.038	0.038	No	No	No	No
Link et al., 2004	Casey Trees	0.140	0.140	No	?	?	?
Pypker, 2005	Casey Trees	0.055	0.131	No	No	No	No
Schellekens, 1999	Casey Trees	0.045	0.045	No	?	?	?
Liu, 1998	Casey Trees	0.017	0.037	No	No	No	No
Wang, 2006	Casey Trees	0.027	0.027	No	?	?	?
Xiao, 2002	Casey Trees	0.340	0.563	Yes	Yes	Yes	Yes
Xiao, 2000	Casey Trees	0.106	0.106	Yes	Yes	Yes	Yes (similar)
Nowak/Von Hoyningen-Huene/USDA	Vanaskie	0.070	0.348	Yes	Yes	Yes	Yes

Green – results should apply to Philadelphia street trees
Yellow – unknown/not reviewed by CDM
Red – results do not apply to Philadelphia street trees

- Summary statistics on range of canopy storage in CaseyTrees literature review:
    - range: 0.008-0.563 in
    - median: 0.042 in
    - mean: 0.089 in
    - 95% confidence interval: (0.035, 0.143)

- CaseyTrees chose to simulate canopy storage at 0.032 inches. They arrived at this value based on assumptions in USDA's UFORE model, referenced in Wang 2006 above. According to CaseyTrees, UFORE assumes a value of 0.2 mm (0.0079 inches) over the leaf area. Using a leaf area index of 4.10 for District of Columbia street trees, this value works out to 0.032 inches over the ground projection.
- Many of CaseyTrees' sources are based on evergreen species, which are not commonly used as street trees on the east coast.
- Studies of interception in forest canopy may be useful, but the two recent studies by Xiao specifically consider urban, open grown, deciduous trees. These studies also report some of the highest values in the literature review.
- The unpublished Vanaskie study uses data from USDA specifically on trees in Philadelphia. It estimates leaf area and storage depths using regression approaches in the literature.
  - The USDA Forest Service provides data on species, sizes, condition and age of trees in Philadelphia (some documentation on data set in USDA Forest Service, 2007). Of the 31 most common types of trees, Matt found sufficient information to estimate storage for 14 of them.
  - Matt applied a regression approach reported by Nowak (1996) to estimate leaf area for species specific to Philadelphia. Leaf area is related to diameter at breast height and to shading factor. Nowak's study was specifically for urban, open grown, deciduous trees with species and sizes similar to Philadelphia street trees.
  - Matt applied a regression approach reported by Von Hoyningen-Huene (1981, reported in Schulze and George 1987, original reference available only in German). Storage is related to leaf area index. This equation is also applied by USDA's UFORE model and was used by Casey Trees.
  - After applying this regression approach to species and size data specific to Philadelphia, trees in the Vanaskie study had a mean LAI of 11.29 and a storage volume of 0.23 inches. Mean crown diameter was 24.5 ft.
  - Estimated LAIs were higher in the Vanaskie study than the mean found by Casey Trees of 4.10. Applying the Von Hoyningen-Huene regression with an LAI of 4.10 yields canopy storage of 0.113 inches.

Table v4.3.9 Summary of Unpublished Vanaskie Study Results

Common name	Genus	Species	% Population (% of trees)	Height (ft)	Crown Diameter (ft)	Shading factor	Ground Projection (ft^2)	Leaf Area (ft^2)	Leaf Area Index	Canopy Storage (in)
Crabapple	*Malus*	*species*	7.5	16.5	16.0	0.85	201	926	4.61	0.122
Red Maple	*Acer*	*rubrum*	6.6	43.3	22.5	0.83	396	4,880	12.31	0.244
Boxelder	*Acer*	*negundo*	5.6	21.6	12.6	0.86	125	870	6.98	0.163
White Ash	*Fraxinus*	*americana*	5.1	43.4	18.6	0.82	271	3,957	14.60	0.275
Norway Maple	*Acer*	*plantanoides*	2.6	31.3	19.8	0.88	307	3,338	10.86	0.223
Red Oak	*Quercus*	*rubra*	2.2	63.0	29.7	0.81	695	8,101	11.66	0.235
London Planetree	*Plantanus*	*x acerifolia*	1.5	63.2	46.4	0.86	1,691	2,954	1.75	0.070
American Beech	*Fagus*	*grandifolia*	1.4	58.7	32.1	0.88	811	9,913	12.22	0.243
Silver Maple	*Acer*	*saccharinum*	1.3	42.4	28.7	0.83	648	5,352	8.26	0.183
Siberian Elm	*Ulmus*	*pumila*	1.3	29.0	20.4	0.85	327	2,642	8.08	0.180
Eastern Cottonwood	*Populus*	*deltoides*	1.2	58.9	24.9	0.85	488	10,217	20.92	0.348
Black Walnut	*Juglans*	*nigra*	1.1	45.8	24.6	0.91	477	8,972	18.82	0.326
Green Ash	*Fraxinus*	*pennsylvanica*	0.9	32.3	15.4	0.83	187	1,880	10.06	0.211
American Sycamore	*Plantanus*	*occidentalis*	0.9	59.9	30.9	0.91	752	12,702	16.89	0.303
Total			39.2							
Minimum				16.5	12.6	0.81	125	870	1.75	0.070
Median				43.4	23.6	0.85	437	4,419	11.26	0.229
Mean				43.5	24.5	0.85	527	5,479	11.29	0.223
Max				63.2	46.4	0.91	1,691	12,702	20.92	0.348
St. Dev.				15.7	8.8	0.03	401	3,823	5.33	0.077
95% C.I. Lower Bound				35.3	19.9	0.84	317	3,476	8.49	0.183
95% C.I. Upper Bound				51.7	29.1	0.87	737	7,481	14.08	0.264
Leaf Area-Weighted Ave.										0.260

v4.3.9 Tree Canopy Coverage Adjustment Methodology

Street Tree Planting Research

A short literature review of Philadelphia and other cities' documents addressing street tree planting provided an outline of important restrictions for tree placement. A summarized outline of these documents is included in this memorandum following the results section. A list of specific considerations produced from this literature review affecting the city-wide tree canopy analysis is below.

- Distance from intersection to tree centerlines
- Distance between tree centerlines
- Distance from street lighting
- Distance from curb edge
- Distance from buildings

Other factors listed in the attachment were assumed to have minimal if any significance on calculating the amount of possible tree canopy coverage. For example, distances from parking meters or fire hydrants were assumed to have no affect on tree canopy coverage because 1) the objects do not impair tree canopy size and 2) the required distance from the tree is less than the mean tree canopy radius and does not limit the available area.

Distances from intersections, however, do limit available tree canopy area because the required distance may be greater than the mean tree canopy radius. The distance in this particular situation is the limiting factor, not the tree canopy (as in the parking meter and hydrant scenario). Figures v4.3.12 and v4.3.13 below are visual representations of these concepts. These figures also show a comparison of tree centerlines and the edge of tree canopy, which is a significant point for calculations that follow. Distance requirements (Table v4.3.10) are measured from the tree centerline and not the edge of tree canopy. When distance calculations are being performed, however, the edge of tree canopy is taken into account and therefore having an understanding of the distinction between the two is necessary.

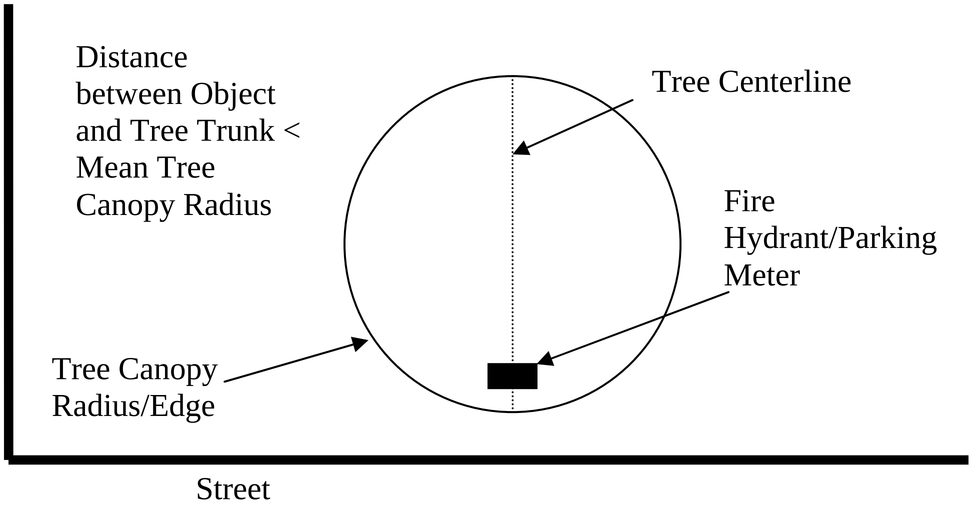


Figure v4.3.12 Visualization of the physical placement of an object with a required distance less than the mean tree canopy radius that does not obstruct the tree canopy area coverage.

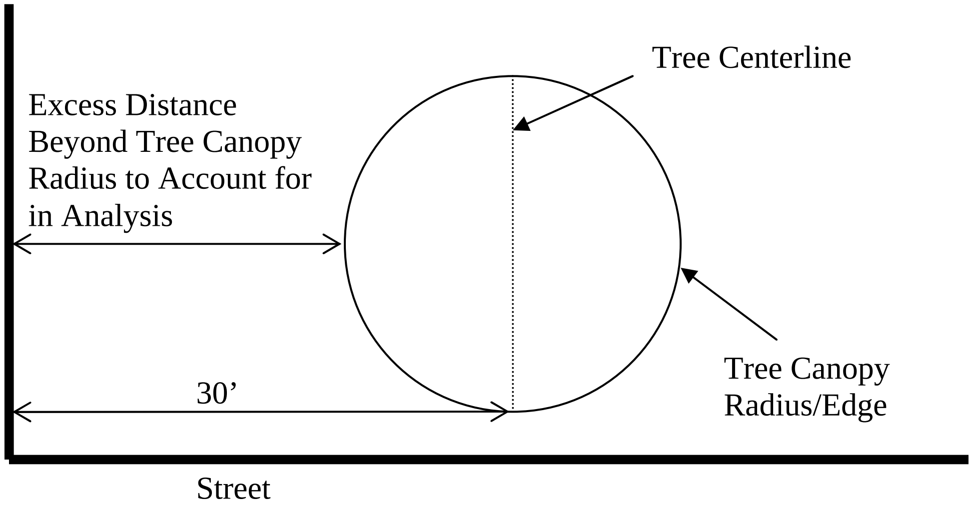


Figure v4.3.13 Excess distance to subtract from available tree canopy coverage area to fulfill distance requirements for tree center to the intersection.

In Figure v4.3.13, the area beyond the mean tree canopy perimeter needs to be subtracted from the available area for street tree canopy coverage. Based on the required distance from the tree center and height of the object, any distance less than the mean tree canopy radius will not affect the coverage of the tree canopy. Table v4.3.10 summarizes the final distance ranges found during the literature review used to calculate an adjusted equivalency ratio for the Philadelphia LTCPU.

Table v4.3.10 Distance Ranges for Specific Urban Elements Measured from Tree Center Line Based on Literature Review.

Distance from Intersection to Tree Center (ft)	30
Distance from Street Lighting (ft)	25
Distance between Tree Centerlines (ft)	30
Distance from Building Face to Edge of Canopy (ft)	5
Distance from Curb Face to Tree Center (ft)	1
Distance between Street Lights (ft)	150

Derivation of Available Coverage Area

It is inappropriate to extrapolate the unadjusted runoff reduction equivalency ratio to the entire city because it assumes an unrestricted availability of area for tree canopy coverage. Street tree canopy is limited by distance requirements due to such things as street lighting, buildings and intersections, as described previously. An adjustment based on these limitations is necessary. A ratio of the allowable area of tree canopy within the city versus the total city-wide sidewalk and street area is calculated and then adjusted to account for the limitations listed above. This value is multiplied with the preliminary equivalency ratio to determine the relative city-wide runoff benefit of street trees as compared to the runoff reduction from the model representing the city meeting the stormwater regulations.

Assumptions and Input Data

Assumptions were required in order to calculate an estimate of available urban area for tree canopy coverage. The main assumptions are as follows:

- Mean Tree Canopy Area = 527 square feet
- Total City-Wide Sidewalk and Street Area = 10,774.34 acres
- Required Distances affecting Available Area (found in Table v4.3.10)

These and other input data were produced from the literature review discussed in the previous section, the impervious cover master table spreadsheet (ImperviousAnalysis_071107_SKR.xls) and the tree canopy simulation results table and database (Parameter_adjmts_071102_SKR.xls, TREE_CANOPY_DATA_071119_932.mdb).

GIS sidewalk data provided by the Impervious_Surfaces_PHILA_2004 shapefile was used to estimate the total sidewalk area for the city. This data contained the area and perimeter length of sidewalk per square block and was the foundation from which all subsequent calculations were created. For the purposes of this analysis and the duration of this memo, the definition of a square block encompasses the length of sidewalk existing on all four sides of a block and does not include street length or width.

Calculations

The data from the Impervious_Surfaces_PHILA_2004 shapefile was imported into a database where all length, width and area calculations were performed. Within the database, each record represents a square block. The perimeter length of each square block was reduced by half to estimate the total sidewalk length. The given sidewalk area for each square block was divided by its respective calculated total sidewalk length to determine a width. The data was filtered to include only sidewalk widths greater than or equal to 6 feet (d_{smin}). Sidewalk widths less than 6 feet do not offer enough space to fulfill the building and curb edge distance requirements (required distances are listed in Table v4.3.10).

For the remaining data records, the distance between street lights was divided into the total square block length to determine the number of street lights per square block. Because the intersection distance requirement will compensate for street lighting at the corners of each square block, the total number of street lights per square block (n_{SL}) was reduced by 4. The length to remove to account for street lighting (L_{SL}) was determined using the equation below with the calculated number of lights per square block ($n_{SL} - 4$). Basically, the length to subtract for street lighting consists of the excess sidewalk area existing between the street light and the mean tree canopy perimeter. Each light will have two occurrences of this situation, assuming a tree exists on either side of the light and then it must be multiplied by the calculated number of street lights minus the occurrences on the corners ($n_{SL} - 4$).

$$L_{SL} = 2(d_{SL} - r)(n_{SL} - 4)$$

The sidewalk length to remove to fulfill the distance from an intersection requirement (d_I) was calculated as 240 feet. This was based on the required distance from an intersection (30 feet) and the number of instances (2 lengths per corner) of subtraction for a square block.

If the total calculated sidewalk length for a square block was less than the total length to subtract calculated from summing the excess street light (L_{SL}) and intersection (d_I) distance, the total distance to remove was set equal to the total sidewalk length for that square block. In these situations, the square block does not have enough space to allow for street tree coverage. Otherwise, the total distance to subtract was equal to the sum of the two calculated lengths (L_{SL} and d_I). The preliminary available length of sidewalk ($L_{Available}$) for tree canopy coverage was calculated by subtracting the summed distance requirement lengths (L_{SL} and d_I) from the total calculatedsidewalk length per square block.

Oftentimes, the tree canopy is obstructed by building interfaces. Therefore, only a portion of the tree canopy is active in intercepting rainfall. For each square block, the amount of tree canopy affected by the building interface was calculated using the equations that follow. The equations were taken from the Equv-pipes-RR-GM (version 3c) spreadsheet.

$$d_s = (Width + r) - d_{curb}$$

$$Width\ of\ Active\ Tree\ Canopy\ (W_{ATC}) = diameter - d_s$$

$$Angle\ Subtended = 2(Acos(r-W_{ATC}))\ /\ r$$

$$Active\ Tree\ canopy\ Area\ per\ Tree = (1/8(Angle\ Subtended - Sin(Angle\ Subtended)))*\ diameter^2$$

Where *diameter* = The Diameter of the Tree Canopy (feet)
r = The Radius of the Tree Canopy (feet)
d_s = The Length of Tree Canopy Unobstructed by Objects (feet)
d_{curb} = The Distance Required to the Curb Edge Measured from Tree Center Point (feet)

For larger sidewalk widths that do not impede the tree canopy the average tree canopy area of 527 square feet was applied.

The number of trees feasible per square block (n_B) was calculated by dividing the eligible length of sidewalk ($L_{Available}$) by the distance between tree center points requirement. For each square block the number of trees was multiplied by the active tree canopy area per tree to determine the estimated total tree canopy area available for each square block. The values for each square block were summed to determine the eligible city-wide tree canopy area. The ratio of calculated tree canopy area to total city-wide street and sidewalk area was calculated and then applied to the preliminary tree canopy total runoff reduction equivalency ratio of 0.875.

Results

A final runoff reduction equivalency ratio was developed based on required distances found in Table v4.3.10. Tables v4.3.11 and v4.3.12 contain all input parameters, assumptions and calculated values. The final ratio may be found in Table 3 and represents the percent city-wide tree canopy total runoff reduction as compared to the total runoff reduction produced from the model meeting the required stormwater regulations requirements. Ultimately, the ratio states that 1 acre of impervious surface covered by tree canopy results in the same total runoff volume reduction as approximately 0.287 acres of impervious surface draining to an infiltration bed meeting the stormwater regulations requirements.

Table v4.3.11 Static Input Variables used in Calculating Adjusted Tree Canopy Equivalency Ratios.

Variable Description	Values	Units
Total Combined Shed Area	43414.05	acres
Mean Tree Canopy Ground Projection Area	527	sq.ft
Percent of Combined Area without Trees	85%	
Runoff Reduction Equivalency Ratio	87.5%	
Diameter of Mean Tree Canopy Ground Projection Area	25.90	ft
Radius of Mean Tree Canopy Ground Projection Area	12.95	ft

Table v4.3.12 Varying Calculated Inputs and Outputs Used to Determine the Adjusted Equivalency Ratio.

Variable Description	Values	Units
Required Distance from Tree Center point to Building Face	5	ft
Required Distance from Tree Center point to Curb Edge	1	ft
Distance from Intersection to Tree Center (from curb to tree center)	30	ft
Distance Between Tree Centerlines	30	ft
Distance from Street Lighting	150	ft
Minimum Sidewalk Width where Tree Canopy is not Affected by Building Face	13.95	ft
Total Street/Sidewalk Area	4.69E+08	sq.ft
Total Area of Available Tree Canopy Coverage	1.54E+08	sq.ft
Adjusted Total Area of Available Tree Canopy Coverage	1.31E+08	sq.ft
Percent of City Area Available for Tree Canopy	32.78%	
New Tree Canopy Equivalency Ratio	**28.68%**	

v4.3.10 Outlying Community Flow Timeseries Analysis

Background

The procedures described herein were used to create SWMM4 EXTRAN K3-line timeseries input data for selected outlying community sanitary sewer connections to the Philadelphia combined sewer system (CSS). The timeseries data are used to define wet weather flow response from these areas in continuous simulations performed for the 2005 representative year selected for LTCP project evaluations. Filling missing or errant data is required in order to generate continuous timeseries over the one-year simulation period. The outlying community areas chosen for direct timeseries input are DELCORA, Bucks County (MB-1) and Lower Southampton Township (MSH-1). These areas were selected based on the magnitude of the contributing flows and the availability of acceptable quality data for the period of interest.

Data Sources

Bucks County and Lower Southampton Township timeseries flow data source is the 2.5-minute permanent billing meter data obtained from the PWD real-time unit (RTU) database. Quality assurance and quality control procedures including inspection of monthly timeseries plots were used to flag errant or missing data. The accepted data is then averaged to 15-minute intervals.

DELCORA flow data is obtained from hourly Southwest WPCP influent flow data measured at the plant. Quality assurance and quality control procedures including inspection of monthly timeseries plots were used to flag errant or missing data. The accepted data is then interpolated to 15-minute intervals.

Data Gap Filling Procedures

Identification and filling of data gaps are required in order to generate continuous timeseries data needed for performing the one-year (2005) model simulations. First, all data gaps and their durations are identified. Next, each data gap is characterized as either wet weather or dry weather flow with the corresponding procedures used for gap filling as described below:

Dry Weather Flow
For small data gaps (< 1 hour), linear interpolation was performed. Missing or errant data over one or more hours was filled using the nearest previous day's dry weather flow (DWF) data.

Wet Weather Flow
For small data gaps (< 1 hour), linear interpolation was performed. Wet weather events with missing or errant data periods of one or more hour duration were filled for the entire wet weather event with model simulation results using RDII RTK shape parameters previously calibrated for these areas. The model generated wet weather flow, obtained by subtracting the constant model baseflow from the simulated response, is added to the nearest previous day's DWF data.

Wet Weather Flow Separation

The continuous flow timeseries generated for the year 2005, as described above, contain diurnal and seasonal time varying baseflow patterns. In contrast, RUNOFF model generated hydrographs used for all other model areas simply have wet weather hydrograph responses added to a constant average baseflow. In order to represent the wet weather responses from the timeseries input areas more consistently with the Runoff modeled areas, hydrograph separations were performed on the timeseries data using CDM SHAPE software to extract the wet weather response hydrograph. The final timeseries was constructed by adding a constant average baseflow to the separated wet weather response timeseries.

v4.3.11 Capture Methodology

Capture calculations are performed in two steps. In the baseline condition, captured volume is the volume of combined sewer flow that is sent to the WPCPs during wet weather. In the LTCPU baseline wet weather is defined as when the flow in the dry weather pipe, connecting the regulator to the interceptor, increases more than 5 percent of the dry weather baseflow. In alternatives with CSO controls in place captured volume includes volume sent to the WPCPs and the volume prevented from reaching the CSS by source controls. Percent capture is calculated as the ratio of the captured volume to the sum of captured volume and volume overflowed to receiving waters.

The capture calculations are performed at each regulator. Each of the regulators is assigned to an interceptor system and the capture results from each regulator can be aggregated for that interceptor system. These results from the interceptors can be further aggregated by WPCP drainage district and by watershed

Capture calculation steps

For the Baseline capture calculations the following approach is used.

Requirements to calculate capture.

1. The capture formula is "Percentage Capture at a given regulator = 100 * [Total Volume through the dry weather pipe at the regulator / (Total Volume through the dry weather pipe at the regulator + Total volume that overflows to receiving water from the regulator)]".
2. For each regulator in the CSS, the dry weather flow pipe (DWO) and wet weather overflow pipe (SWO) is identified.
3. Flow for all the pipes identified in the last step is generated from the SWMM models. Another set of flow for the same pipes as above are generated for the same period as the wet weather simulation except using 0 (zero) precipitation. The zero precipitation simulation is performed to obtain the dry weather flows for the period of interest.
4. Using each of the regulators' DWO and SWO pipe flows calculations are performed.
    a. A tolerance is set for the baseflow for all the regulators which when exceeded indicates the regulator is in wet weather conditions (This tolerance is set at 5% for the LTCPU, when flow in the DWO pipe exceeds above 5% of baseflow, regulator is assumed to be in wet weather). Based on the baseflow tolerance the wet weather events are identified for the regulator. Capture calculations are performed for the wet weather events (using formula in step 1).
    b. If overflows from one regulator (Regulator "A") are re-regulated at another regulator (Regulator "B"), the overflow from A will be ignored when the capture result is aggregated to interceptor system.
    c. If a regulator (Regulator "C") re-regulates flow from upstream regulator's DWO (Regulator "D", Regulator "E"), all the DWO flows from D and E are ignored and only DWO flow from C is used when capture result is aggregated to the interceptor system.
    d. Negative flow through DWO (flow being relieved) pipes is subtracted when the capture calculation is performed. This accounts for regulators relieving other regulators.
5. The result from the CAPTURE program is summarized for yearly totals and aggregated by interceptor systems.

v4.3.12 Alternative Capture Calculation Methodology: Green Stormwater Infrastructure, Traditional Infrastructure and Large Scale Centralized Storage

Capture calculations for the alternatives that have been analyzed in the LTCPU – Green Stormwater Infrastructure, Traditional Infrastructure (Transmission to the WPCP) and Large Scale Centralized Storage (Tunnel) – are performed using the baseline model capture values as the foundation. The approach described below assumes that the overflow volume reduction, as compared to the baseline values, due to implementation of the alternatives is captured.

Steps included in alternative capture calculation

1. The overflow volume (SWO_0) to the receiving waters and treated volume (DWO_0) from the baseline models are obtained. This may be aggregated to the interceptor level or further aggregated to the WPCP drainage district level or the watershed level depending on the alternative for which effective capture calculations need to be performed.
2. The alternative scenario's overflow volume (SWO_1) aggregated to the interceptor level or further aggregated to the WPCP drainage district level or the watershed level depending on the alternative (representing Green Stormwater Infrastructure, Traditional Infrastructure or Large Scale Centralized Storage) are obtained.
3. The treated flow that accounts for reduction in volume that overflows to the receiving water due to implementation of the alternatives when compared to the baseline is inferred by the water balance to be: $[(SWO_0 + DWO_0) - (SWO_1)]$
4. The alternative capture formula is: $100*[(SWO_0 + DWO_0) - (SWO_1)] / (SWO_0 + DWO_0)$

v4.3.13 References

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Supplemental Documentation
Volume 5

Precipitation Analysis

Updated: September 1, 2009

Table of Contents

VOLUME 5 PRECIPITATION ANALYSES

v5.1 METEOROLOGIC CHARACTERIZATION

The United States Environmental Protection Agency (US EPA) CSO Control Policy (1994) requires the characterization of the CSS area and evaluation of control measure performance in terms of system-wide average annual hydrologic conditions. The identification of an average annual precipitation record, therefore, is critical for the evaluation of CSS performance.

v5.1.1 Long-Term Meteorologic Conditions

The hydrologic conditions over the Philadelphia CSS area are characterized using the long-term historic hourly precipitation record, 59-year period (1948-2006), for the National Weather Service Cooperative Station located at the Philadelphia International Airport (PIA) (WBAN#13739). Statistical analyses of the long-term record are performed to determine the average frequency, volume, and peak intensity of rainfall events.

Identification of long-term average hydrologic conditions over the CSS is based primarily upon average annual and monthly precipitation volumes determined from the long-term record at the PIA. Comparisons are made between the individual annual precipitation volumes and the long-term average to identify relatively 'wet' and 'dry' years.

Figure v5-1 presents total annual precipitation volumes at the PIA for the years 1948-2006 along with one standard deviation from the mean. By this measure, 1983 and 1922 are the wettest and driest years on record, respectively. Furthermore, it is seen that during the past 15-years (since 1990) one year, 1996, is characterized as being wet and five individual years are characterized as being dry by having a total annual precipitation volume greater than one standard deviation from the mean.

Figure v5-2 shows the average monthly precipitation volumes relative to a range of plus and minus one standard deviation from the mean based upon the PIA historical record. Table v5-1 presents accompanying historical monthly precipitation volume statistics. Long term seasonal variation in monthly precipitation volumes can readily be seen between summer and winter.

The PIA long-term empirical cumulative distribution function of hourly rainfall intensity is presented in Figure v5-3.

Event Based Precipitation Analyses

Event based analysis of the long term precipitation record is used to best represent average annual CSO frequency and volume statistics needed for presumptive measurement of collection system performance. These event statistics are specific for a given minimum inter-event time (MIT) used for event definition.

A minimum inter-event time (MIT) is chosen for event definition so that the coefficient of variation (the ratio of the standard deviation to the mean) of inter-event times most closely approximates unity. This follows an exponential distribution of inter-event times for which the mean equals the standard deviation, and is based on the results of National Urban Runoff Program (EPA 1993). A six-hour minimum inter-event time is selected on this basis for the PIA using hourly precipitation data for the period 1948-2006 as seen in Table v5-2.

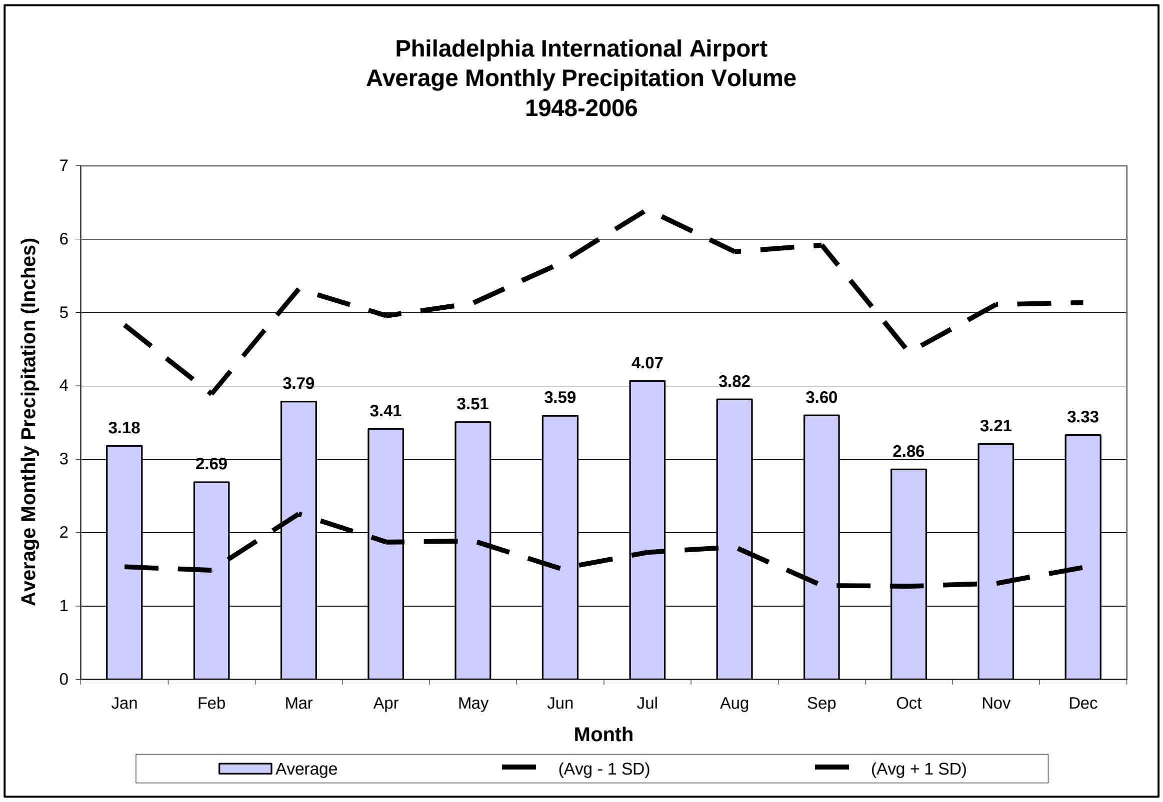

Figure v5-1 PIA Total Annual Precipitation Volume (1948-2006)

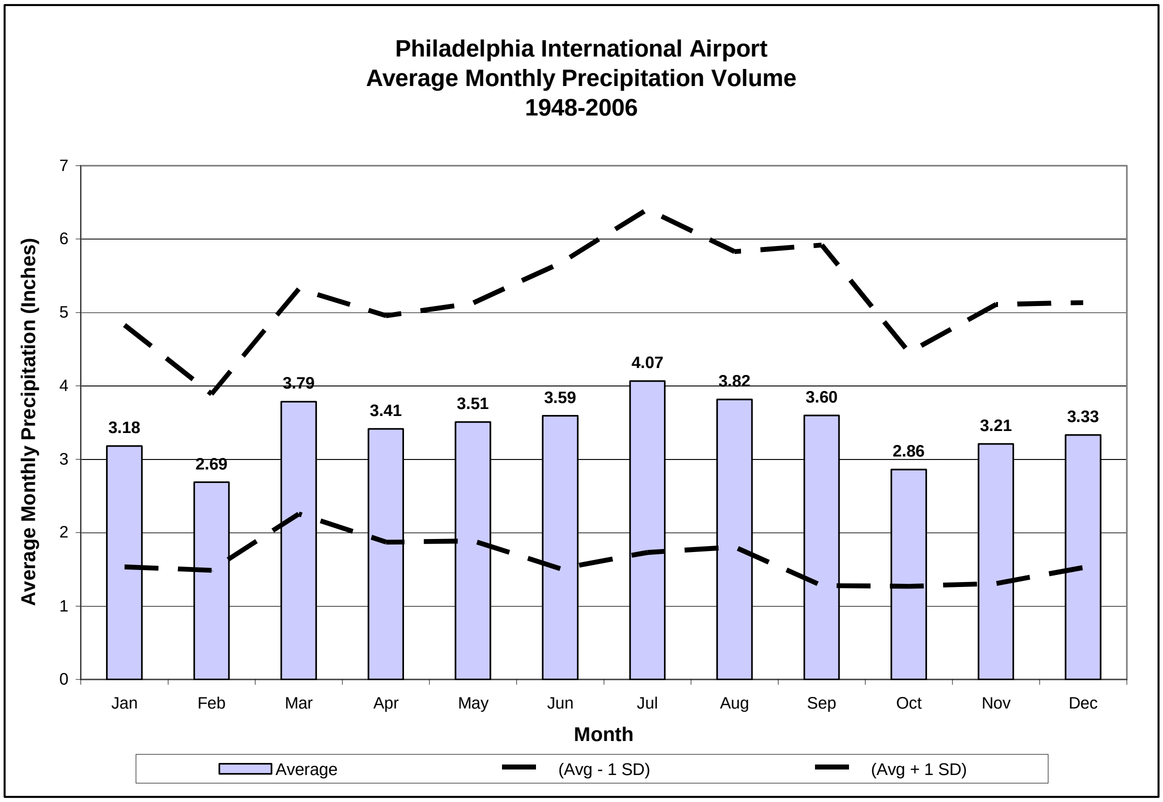

Figure v5-2 PIA Average Monthly Precipitation Volume (1948-2006).

Table v5-1 Monthly Precipitation Inches Statistics for PIA Historical Record (1948-2006)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Average	3.18	2.69	3.79	3.41	3.51	3.59	4.07	3.82	3.60	2.86	3.21	3.33	41.05
Avg +1SD	4.83	3.89	5.32	4.95	5.13	5.67	6.40	5.83	5.92	4.46	5.11	5.14	47.71
Avg - 1SD	1.54	1.49	2.26	1.87	1.89	1.51	1.73	1.80	1.28	1.27	1.31	1.53	34.39
Std. Dev.	1.65	1.20	1.53	1.54	1.62	2.08	2.34	2.01	2.32	1.59	1.90	1.80	6.66
Maximum	8.86	6.44	6.89	8.12	7.03	8.08	10.42	9.70	13.07	8.68	9.05	8.09	54.41
Minimum	0.45	0.46	0.69	0.61	0.48	0.11	0.37	0.49	0.21	0.09	0.32	0.25	29.34

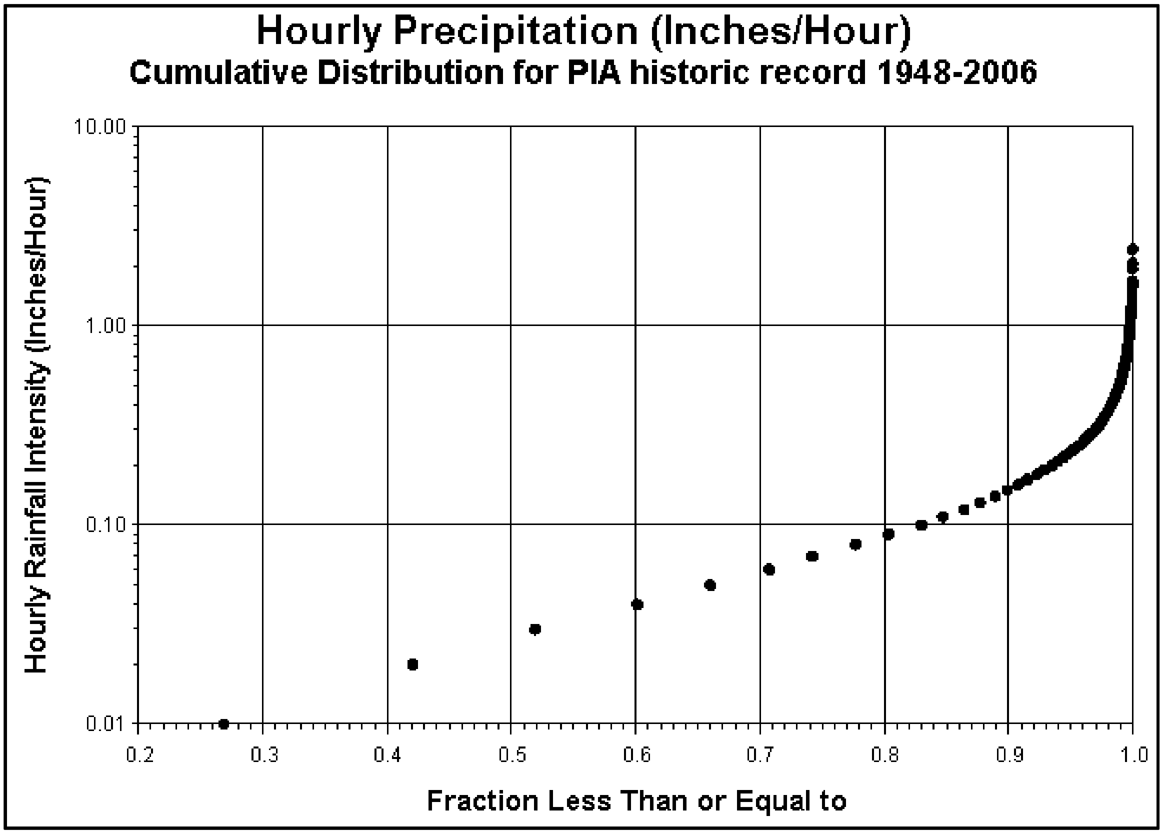

Figure v5-3 PIA Empirical Cumulative Distribution Function of Hourly Rainfall Intensity (1948-2006)

A minimum total event volume of 0.10 inches is selected as the minimum storm depth needed for precipitation events to significantly increase wastewater flows potentially contributing to CSO discharges. Table v5-3 presents event-based summary statistics for the PIA long-term precipitation record.

Table v5-2 Inter-event Time (IET) Statistics Determined for a Range of Minimum Inter-Event Times (MIT) using PIA Hourly Precipitation (1948-2006)

MIT (Hours)	Mean IET (Hours)	Std. Dev.IET (Hours)	CV IET
2	48.2	70.7	146.5
4	66.2	76.2	115.1
6	75.5	77.5	**102.7**
8	81.4	78.0	95.8
10	85.6	78.2	91.3
12	89.5	78.2	87.4
14	92.7	78.2	84.4
16	95.2	78.2	82.1
18	97.5	78.1	80.1
20	99.5	78.1	78.4
22	101.8	78.0	76.6
24	104.0	77.9	74.9

Table v5-3 Philadelphia International Airport Average Annual Wet Weather Event Statistics (1948-2006)

Month	Event Size Class	Average Number of Events	Average Total Rainfall (Inches)	Average Event Peak Hourly Intensity (In / hour)	Average Event Duration (hours)	Average Inter-Event Time (hours)
1	>= 0.05 in	6.4	3.04	0.11	11.2	83.2
2	>= 0.05 in	5.9	2.66	0.11	11.1	82.0
3	>= 0.05 in	7.1	3.81	0.14	10.9	83.6
4	>= 0.05 in	7.1	3.27	0.15	9.4	66.5
5	>= 0.05 in	7.6	3.46	0.18	7.9	73.5
6	>= 0.05 in	7.3	3.51	0.25	5.8	79.5
7	>= 0.05 in	7.2	4.02	0.29	5.6	83.7
8	>= 0.05 in	6.7	3.77	0.32	6.0	90.3
9	>= 0.05 in	5.7	3.58	0.26	8.1	95.7
10	>= 0.05 in	4.9	2.82	0.19	9.3	115.1
11	>= 0.05 in	5.7	3.16	0.16	9.9	100.1
12	>= 0.05 in	6.0	3.31	0.13	11.9	89.4
All	>= 0.05 in	77.6	40.39	0.19	8.7	77.1
All	< 0.05 in	30.3	0.62	0.02	1.7	74.6
All	**All**	**107.9**	**41.05**	**0.14**	**6.7**	**76.4**
* Events defined based on 6 hour Minimum Inter-Event Time (MIT)						

v5.1.2 Local Meteorologic Conditions

The average spatial distribution of precipitation over the CSS areas is characterized using the 17-year rainfall record for the PWD 24-raingage network collected over the period 1990-2006, along with 15 months of gage calibrated radar rainfall data. Extensive analyses of non-climatic gage biases based on inter-gage comparison and radar rainfall data are performed leading to the creation of a bias adjusted rainfall dataset for the PWD 24-raingage network over the 17-year period of record (1990-2006). The detailed analyses are presented in Section v5.2 Normalizing Rain Gage Network Biases Using Calibrated Radar Rainfall Estimates.

v5.1.3 Identifying a Representative 12-Month Period in Precipitation Record

The characterization of long-term system-wide average hydrologic conditions across the CSS is necessary in order to identify a continuous short–term period contained within the PWD 24-gage fifteen-minute rainfall record (1990-present) that simulates long-term average annual CSO statistics needed for performance evaluation of CSO control measures.

CSO occurrence is considered to be a complex function of storm-event characteristics such as total volume, duration, peak intensity, and length of antecedent dry period or inter-event time (IET). In order to identify short-term continuous periods likely to generate CSO statistics representative of the long-term record, continuous 12-month periods selected from the recent 17-year PWD 24-raingage record (1990-2006) were evaluated against the long-term record based on the following storm-event characteristics:

- Annual number of storm events
- Total annual rainfall volume
- Best fit cumulative distribution function (CDF) plot of event peak hourly rainfall intensity

Manipulation of the rainfall data is performed using Statistical Analysis System (SAS) code. SAS is a high-level programming language that is particularly well suited to processing large amounts of data with relatively simple programming code.

The first step in the analyses is to parse the bias adjusted and inverse distance-squared weight (IDW) filled 17-year precipitation record (1990-2006) for each gage location into continuous 12-month periods beginning with January 1, 1990 and progressing with 1-month increments to the final continuous 12-month period beginning on January 1, 2006. Each continuous 12-month period is thereby identified by the starting year and month.

Next, event statistics, including total volume, average duration, average peak intensity, and average inter-event time (IET) are determined, based on a minimum inter-event time (MIT) of 6 hours, for each 12-month period. Small events, defined as events with total volumes less than 0.05 inches, are removed from further analysis. Similarly, average annual event statistics are determined for each gage location over the s17-year period of record (1990-2006). The differences in average event statistics between each continuous 12-month period and the period of record are determined for each gage location. The absolute value of the average difference across all gage locations is then determined for each continuous 12-month period, and the result is then ranked in order of ascending magnitude as a measure of goodness of fit to the long term average for each event statistic.

The cumulative frequency distribution of event peak rainfall intensity is considered to be a critical measure for identifying rainfall periods that produce average long-term CSO statistics. Event peak hourly rainfall intensities are ranked and a left-continuous empirical CDF is generated with fractional ranks computed by dividing each rank by the denominator n+1, where n is the number of events. In this manner empirical cumulative distribution functions are generated for each continuous 12-month period and the 17-year period of record for each rain gage. The sum of the absolute differences in peak hourly rainfall intensity between the 12-month period and the 17-year period of record, determined for each event within the 12-month period based on its fractional rank, is used to measure the goodness of fit for each rain gage and 12-month period. This measure, referred to here as the total deviation, is averaged across all rain gages for each 12-month period and ranked in ascending order.

A final ranking is performed based on total deviation of peak hourly rainfall intensity, average annual rainfall volume, and average annual number of rain events. The top results from this ranking are presented in Table v5-4. The 12-month period beginning January 1, 2005 is chosen to represent long-term average hydrologic conditions for Long Tern Control Plan CSO performance evaluations based on the additional criteria that it is a recent calendar year.

Table v5-4 Ranking of Recent Representative Continuous 12-month Periods Based on the Best-Fit Distribution of Event Peak Hourly Rainfall Intensity, Average Annual Rainfall Volume, and Annual Number of Events

Start Year	Start Month	Average Event Peak (in/hr)	Annual Rainfall Volume (in)	Average IET (hrs)	Average Event Duration (hrs)	Annual Number of Events	Rank
1990 - 2006		0.11	42.80	76.54	9.74	76	
1992	3	0.10	43.57	74.48	10.33	79	1
1996	11	0.09	41.66	81.47	10.57	69	2
1992	8	0.10	44.08	76.52	9.95	78	3
1995	7	0.10	41.45	77.67	9.06	80	4
2004	12	0.11	43.51	77.27	10.63	76	5
1992	2	0.10	42.32	76.16	10.04	81	5
1992	1	0.10	41.36	78.87	10.15	79	5
2003	4	0.10	43.17	62.09	9.98	83	8
2005	3	0.11	43.02	82.31	10.00	75	9
2005	**1**	**0.11**	**44.06**	**78.76**	**10.26**	**79**	**10**
2000	8	0.11	41.43	77.65	9.34	73	11
1998	11	0.09	43.20	83.60	9.42	69	12
2002	7	0.08	41.67	72.39	11.85	76	13
1998	12	0.09	43.93	79.20	9.43	70	13
1997	7	0.09	43.09	71.39	11.92	80	15
1994	3	0.12	43.11	73.77	9.01	79	16
1997	8	0.09	41.87	71.42	11.77	80	17

* Only continuous periods with annual rainfall volumes within +/- 1.5 inches of the 17-year average annual rainfall volume (41.30 to 44.30 inches) were considered. Only rainfall events with total volume >= 0.05 inches, based on a 6-hour M.I.T. are included in the analysis

Table v5-5 compares selected PIA precipitation event statistics for the calendar year 2005 to PIA long-term historic median values. Events with total volumes less than 0.05 inches were excluded from the analysis because they are not expected to significantly influence CSO statistics.

Table v5-5 Seasonal Precipitation Event Statistics Comparing Long-Term Historic Record to Calendar Year 2005[*]

Statistic	2005		1948-2006	
	Recreation Season **	Annual	Recreation Season ** Median	Annual Median
Number of Events	41	78	40	76
Mean Event Volume (in)	0.53	0.53	0.52	0.53
Maximum Event Volume (in)	6.05	6.05	2.54	3.07
Mean Event duration (hr)	7.28	8.58	6.69	8.58
Mean Event Average Rainfall Intensity (in/hr)	0.09	0.08	0.10	0.07
Mean Event Peak Rainfall Intensity (in/hr)	0.24	0.19	0.25	0.19
Std. Dev. of the Mean Event Peak Rainfall Intensity (in/hr)	0.27	0.22	0.26	0.21
Maximum Event Peak Rainfall Intensity (in/hr)	1.55	1.55	1.17	1.17
Total Rainfall (in)	21.80	41.69	20.94	40.50

[*] Only rainfall events with total volume >= 0.05 inches, based on a 6-hour M.I.T. are included in the analysis

** Recreation season includes months May - October

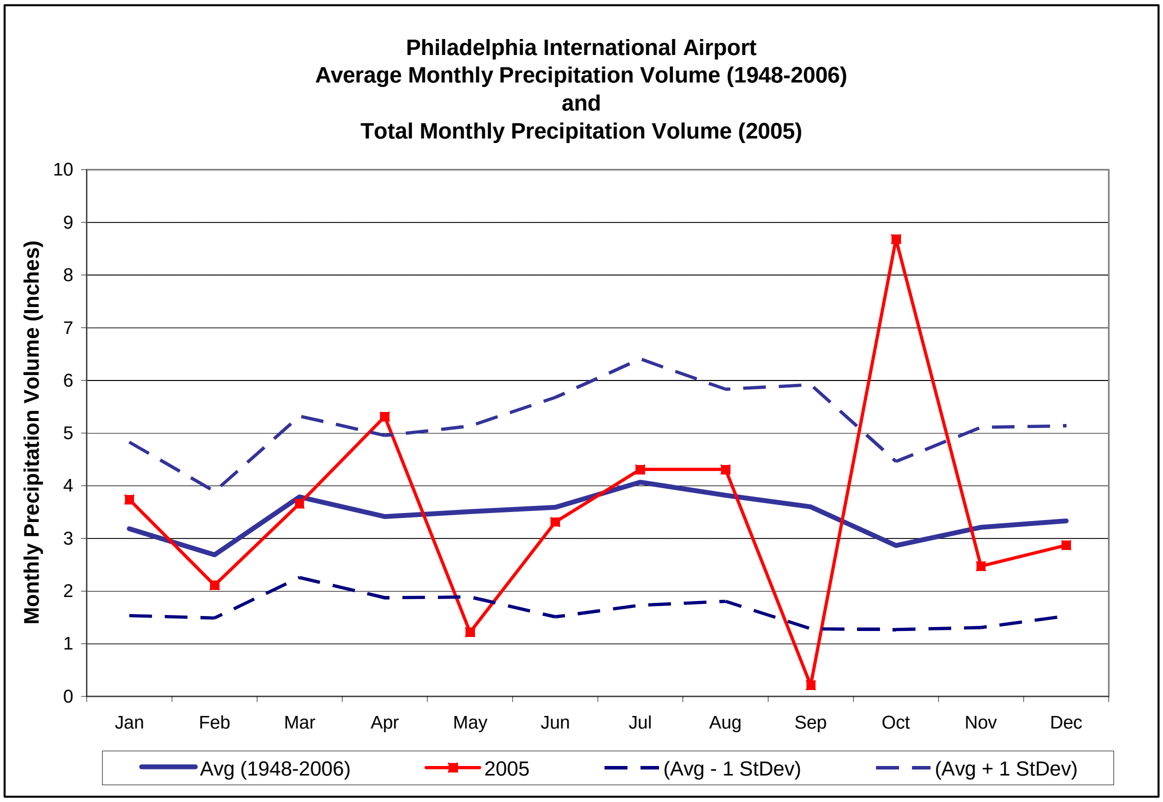

Figure v5-4 PIA Average Monthly Precipitation Volume Comparing the Long-Term Record (1948 – 2006) and Calendar year 2005

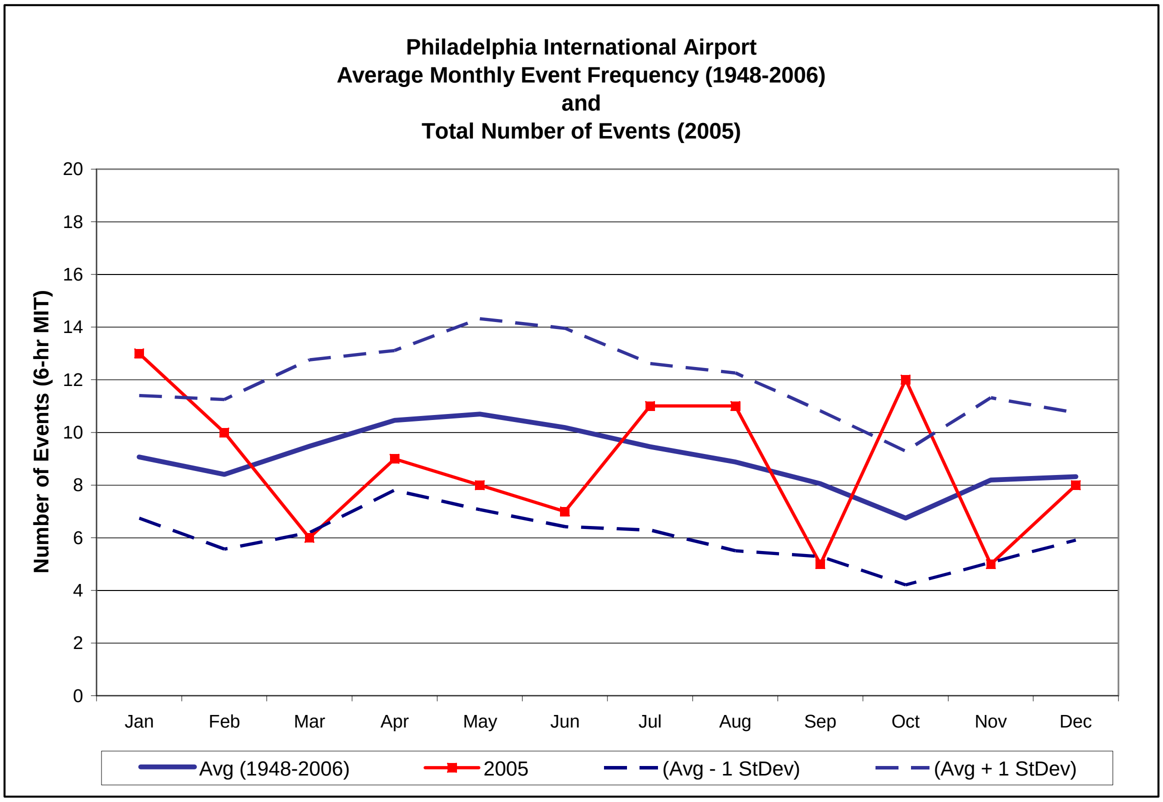

Figure v5-5 PIA Average Monthly Number of Events Comparing the Long-Term Record (1948 – 2006) and Calendar year 2005

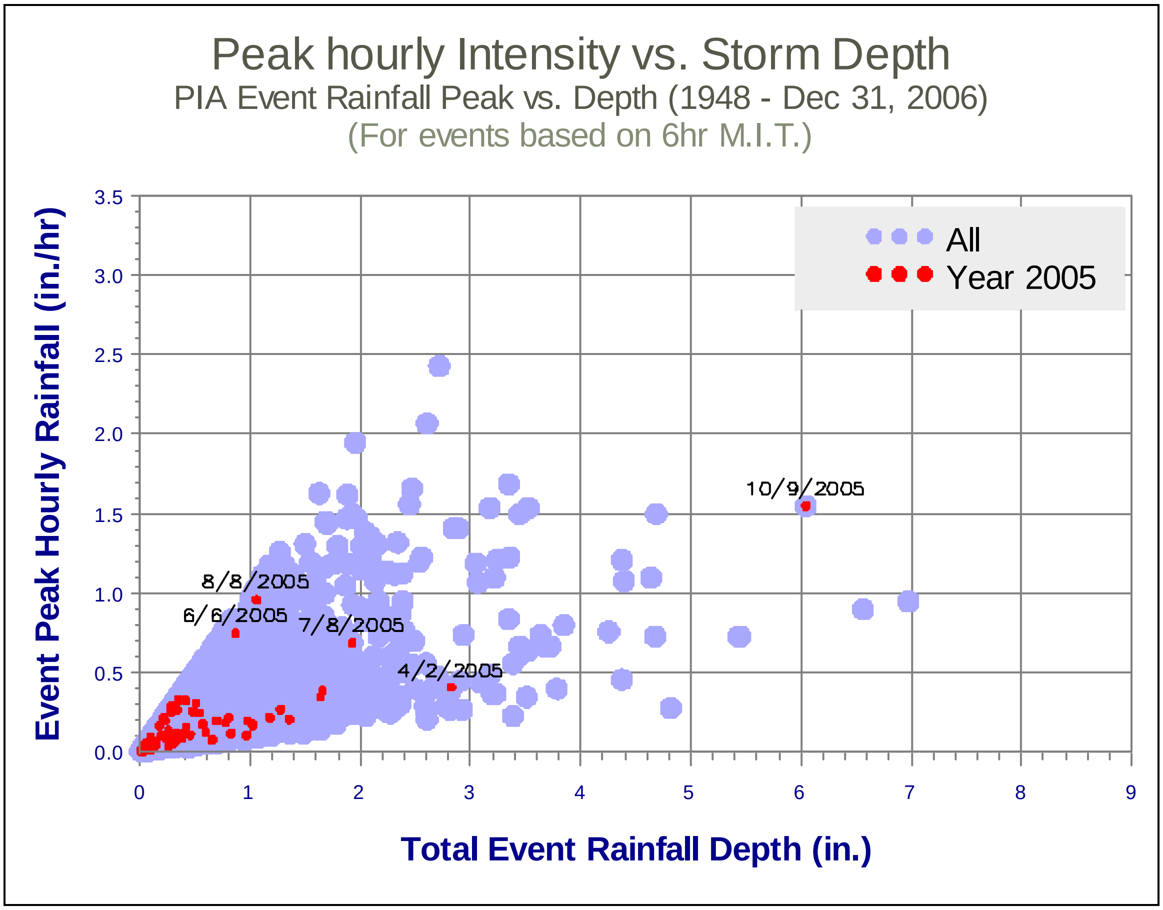

Figure v5-6 PIA Event Peak Hourly Rainfall Intensity Plotted and Rainfall Volume Comparing the Long-Term Record (1948 – 2006) and Calendar Year 2005

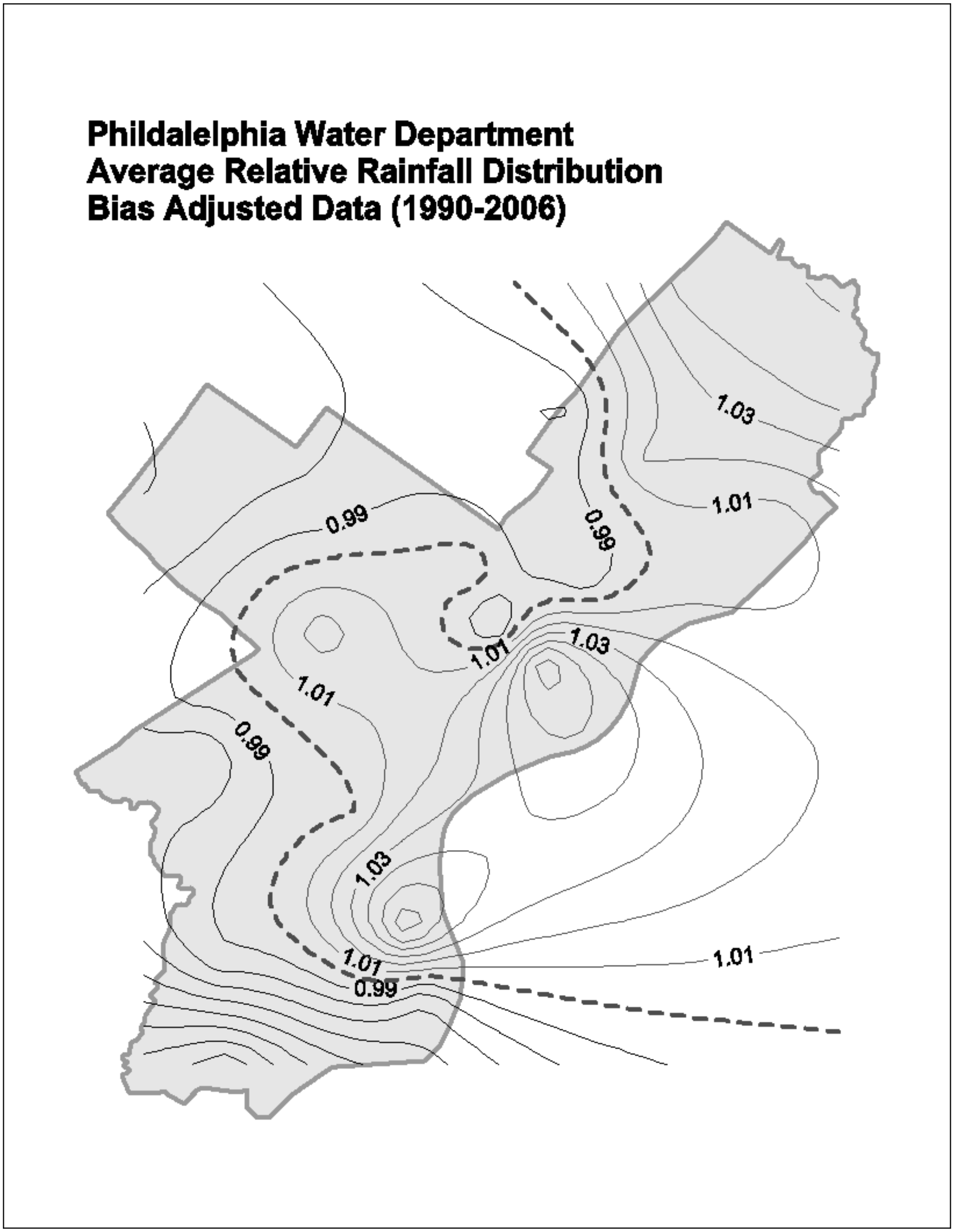

Figure v5-7 Relative Rainfall Distribution Map for PWD 24-raingage Network Bias Adjusted Data for the 17-year Period (1990-2006)

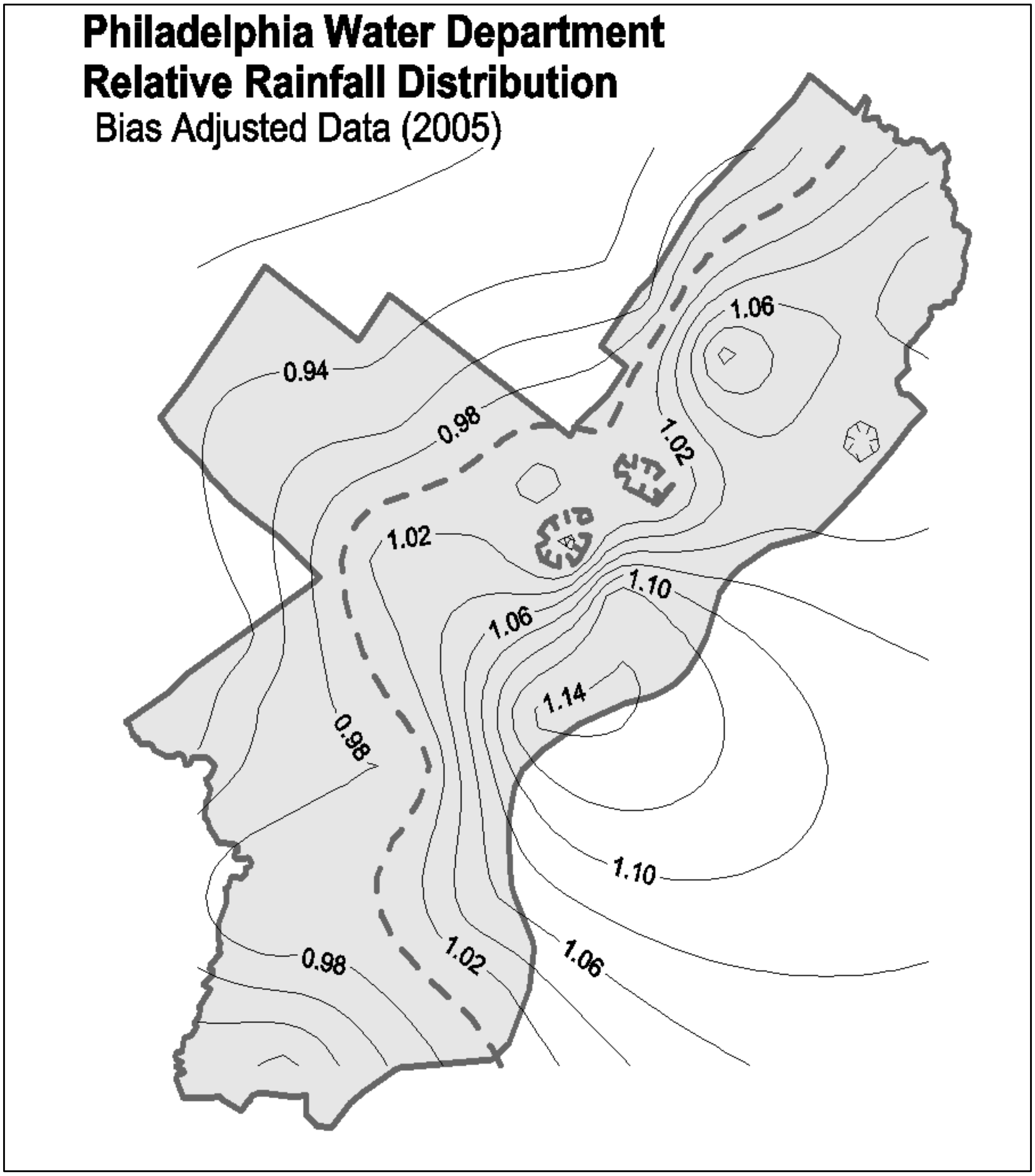

Figure v5-8 Relative Rainfall Distribution Map for PWD 24-raingage Network Bias Adjusted Data for Calendar Year 2005

v5.1.4 Modifying the Selected 12-month Precipitation Record

Initial selection of the calendar year 2005 to represent long-term average hydrologic conditions for CSO LTCP project evaluations was based on the annual number of storm events, the total annual rainfall volume, and the best fit CDF plot of event peak hourly rainfall intensity, with preference given to more recent calendar years to better represent current conditions.

The calendar year 2005, however, contains the extreme event of October 8, 2005 which recorded an average rainfall volume across the PWD 24-gage network of 5.40 inches between October 7 at 12:15 PM and October 9 at 8:45 AM. This rainfall event has the third largest annual peak rainfall volume recorded at the Philadelphia International Airport (PIA) station over the long-term period of 1948-2006. Because the extreme rainfall event of October 8, 2005 accounts for a disproportionately large fraction of the total annual overflow volume the results of CSO LTCP project evaluations may be unintentionally skewed to minimize the long-term effectiveness of certain alternatives in favor of others.

In response to these concerns, a decision was made to adjust the rainfall record for the calendar year 2005 to better represent long-term average hydrologic conditions by scaling down the October 8 rainfall event so that the average rainfall volume across the PWD 24-gage network for this event is equal to the median peak annual rainfall volume estimated for the network over the long-term period of 1948-2006.

After scaling down the October 8 event, several other events are selected to be scaled up so that the average total rainfall volume across the PWD 24-raingage network is equal to the long-term average annual rainfall volume estimated across the network for the long-term period 1948-2006.

Time Series Modification Procedures

Median Peak Annual Rainfall Volume

The median peak annual rainfall volume is estimated for the PWD 24-raingage network over the long-term period of 1948-2006 by scaling the PWD median peak annual rainfall event volume for the 17-year period of 1990-2006 by the ratio of PIA median peak annual rainfall event volume for the long-term period of 1948-2006 to that for the period 1990-2006. The result is an estimated average peak annual rainfall event volume across the PWD 24-gage network of 3.40 inches based on a 6-hr Minimum Inter-event Time (MIT) as presented in Table v5-6.

Table v5-6 Median Annual Peak Rainfall Event Volumes (MIT = 6 hrs)

	1948-2006	1990-2006
	(inches)	(inches)
PIA	3.18	2.78
PWD	**3.40**	2.97

October 8, 2005 Rainfall Event Scaling

The October 8, 2005 extreme rainfall event is scaled down by multiplying the time series data for each of PWD rain gages by the factor 0.630. This scaling factor is determined as the ratio of the average median peak annual rainfall volume estimated for PWD 24-raingage network over the long-term period of 1948-2006 (3.40 inches), to the average rainfall volume for PWD 24-raingage network during the October 8, 2005 event (5.40 inches).

Average Annual Rainfall Volume

The average annual rainfall volume across the PWD 24-raingage network for the recent period 1990-2006 is scaled up by a factor of 1.03 to estimate the average for the long-term period (1948-2006) based on the ratio of averages at the PIA for these periods. Simply stated, the PIA long-term average annual rainfall (1948-2006) is 3% greater than that for the more recent period 1990-2006.

Average annual rainfall volumes for the PIA and the PWD 24-raingage network are presented for each time period in Table v5-7. The long-term average annual rainfall volume across the PWD network is estimated to be approximately 44.79 inches.

Table v5-7 Average Annual Rainfall Volume Comparison

Rainfall Dataset	Average Annual Rainfall (inches)
PIA (1948-2006)	41.05
PIA (1990-2006)	39.84
PWD (1990-2006)	43.48
PWD (1948-2006) estimated	**44.79**
PWD 2005	44.53
PWD 2005 w/ Oct 8 Scaled Down	42.53
PWD Oct 8 Event	5.40
PWD Oct 8 Event Scaled Down	3.40

Scaling Representative Year to Match Long-Term Average Annual Rainfall Volume

The average annual rainfall volume across the PWD network for the year 2005, after scaling down the October 8 event, is 42.533 inches - approximately 2.25 inches less than the long-term average annual rainfall estimated for the PWD network of 44.785 inches. The 2.25 inches of rainfall are distributed back into the annual time series by selecting events to scale up based on the CDF of total event rainfall volumes.

The CDF plots of total event rainfall volume for each gage are considered in order to identify a range of event frequencies that have lower event volumes in the calendar year than in the long-term record (17-yrs).

The first step in this process is to generate a master event list based on the sum of the rainfall from all 24 PWD raingages using a 6-hr MIT. This allows the rainfall time series data for all rain gages to be scaled within the same selected set of event boundaries. The 18 events selected for distributing the 2.25 inches of rainfall needed on average to match the long-term average annual rainfall volume are presented in Table v5-8.

Table v5-8 Event Boundaries Selected for Scaling Up

Master Event No.	Start Time	End Time
2189	1/7/05 21:30	1/9/05 0:00
2190	1/11/05 15:00	1/12/05 1:15
2195	1/25/05 13:00	1/25/05 18:15
2204	2/4/05 9:00	2/4/05 16:00
2214	3/1/05 11:15	3/1/05 18:30
2215	3/8/05 4:15	3/8/05 14:15
2217	3/20/05 3:00	3/21/05 4:15
2228	4/23/05 6:30	4/24/05 1:45
2252	6/10/05 11:15	6/10/05 16:15
2257	7/1/05 16:00	7/1/05 19:00
2259	7/5/05 16:15	7/5/05 18:00
2280	8/8/05 6:30	8/9/05 11:15
2283	8/16/05 12:30	8/17/05 8:15
2287	8/27/05 8:15	8/27/05 19:30
2307	10/12/05 23:00	10/15/05 7:15
2328	12/9/05 7:45	12/10/05 0:00
2335	12/25/05 13:00	12/26/05 12:00
2337	12/29/05 7:00	12/29/05 23:30

A scaling factor is determined so that when multiplied by the time series data within the selected event boundaries for each gage then the average annual rainfall volume across all gages is equal to the long-term average. This factor for each gage is one plus the ratio of the total volume being added to the sum of the volumes of all events being selected for scaling. The total volume to be added for each gage is determined as the total annual volume for the gage excluding the volume for the October 8 event multiplied by the ratio of the average volume added to the average annual volume excluding the average volume for the October 8 event. The ratio of average volume added to average annual volume excluding the October 8th event is shown to be equal to (2.25 inches) / (44.53 inches – 5.4 inches) = 0.0576. Therefore, the scaling factor for each gage is determined by the formula:

$$\left[1 + 0.0576 \times \left(\mathrm{V}^{RG}_{\mathrm{Annual}} - \mathrm{V}^{RG}_{Oct8}\right) \Big/ \sum \mathrm{V}^{RG}_{SelectedEvents}\right]$$

The scaling factors applied to the selected events are presented for each gage in Table v5-9.

Results

The final results of the modification of the calendar year 2005 rainfall record is illustrated through the CDF plots of event rainfall volume produced for PWD RG-5 comparing the PWD period of record (1990-2006) and one of the following: calendar year 2005; modified calendar the year 2005. The two CDF plots produced for PWD RG-5 are presented in Figure v5-9 and Figure v5-10.

Table v5-9 Factors for Scaling Selected Rainfall Events for Each Raingage

RG	Factor	RG	Factor
1	1.32	13	1.348
2	1.304	14	1.35
3	1.362	15	1.337
4	1.331	16	1.347
5	1.334	17	1.364
6	1.329	18	1.348
7	1.354	19	1.372
8	1.359	20	1.351
9	1.313	21	1.384
10	1.356	22	1.325
11	1.344	23	1.301
12	1.335	24	1.383

In addition, Philadelphia International Airport (PIA) hourly rainfall data were used to generate CDF plots of total event rainfall (for events greater than or equal to 0.05 inches with MIT = 6hrs). These plots are presented in Figure v5-11 through Figure v5-13 comparing the following three time periods: 59-year period (1948-2006); 17-year period (1990-2006); calendar year 2005.

Comparing the CDF plots for each PWD gage indicates that event volumes corresponding to percentiles between 40% and 70% are generally lower for the calendar year 2005 before modification than for the 17-year average. Although these event volumes are increased after modification, they appear to be generally lower than the 17-year average. The same general relationship between calendar year 2005 and the 17-year average is seen at the PIA in Figure-4. Furthermore, PWD rain gage event volumes corresponding to percentiles between 70% and 90% are generally higher than the 17-year average before modification, and are increased further above the average after modification. A similar pattern is observed for the PIA.

Figure v5-14 and Figure v5-15 present cumulative frequency distribution plots of 15-minute rainfall intensities pooled for all 24 PWD rain gages over the period 1990-2006 for frequencies of occurrence less than or equal to 50% and greater than or equal to 50%, respectively .

Figure v5-16 presents a relative rainfall distribution map based on Inverse Distance Squared (IDS) weighting of 1-km square grid cells from bias adjusted PWD 24-raingage Network data for the modified representative year 2005. This IDS grid rainfall record is basin averaged and used as input for all hydrologic models as part of the LTCPU as described in Section v5.3.

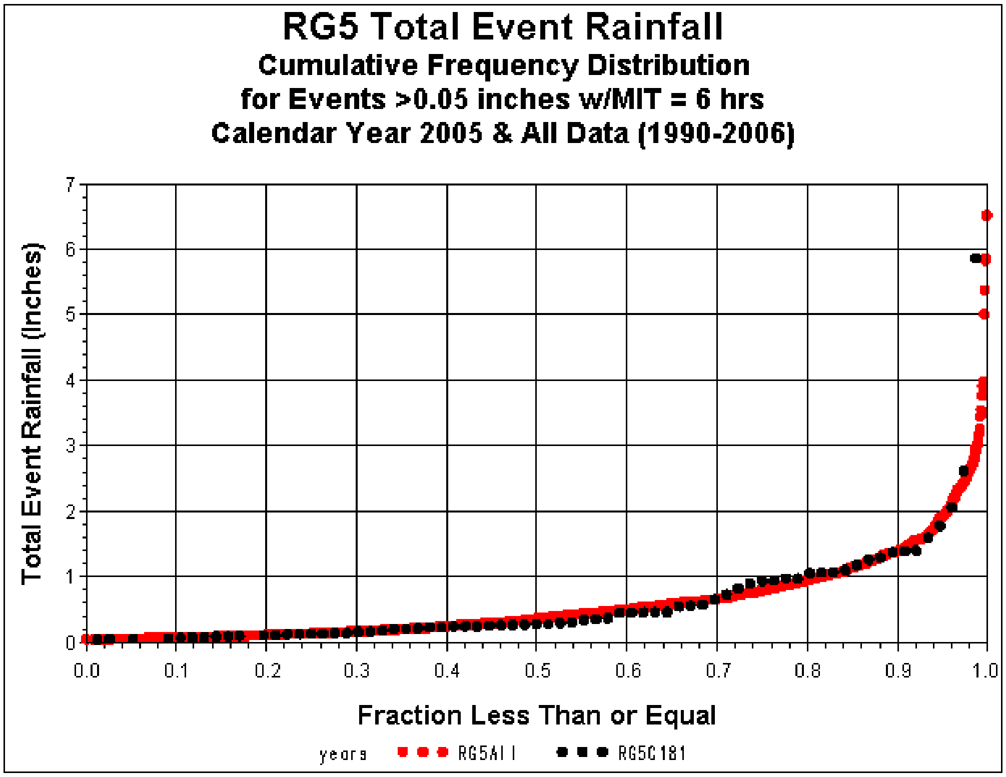

Figure v5-9 CDF Plot of RG-5 Rainfall Event Volumes Comparing the 17-year Period (1990-2006) and Calendar Year 2005

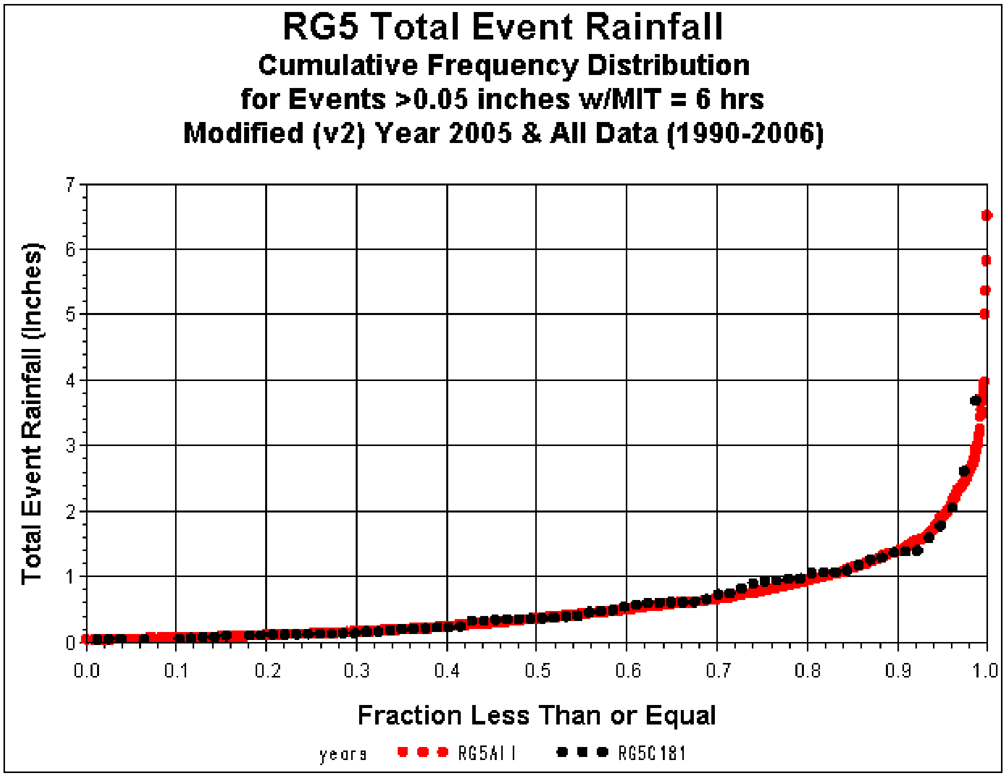

Figure v5-10 CDF Plot of RG-5 Rainfall Event Volumes Comparing the 17-year Period (1990-2006) and Modified Calendar Year 2005

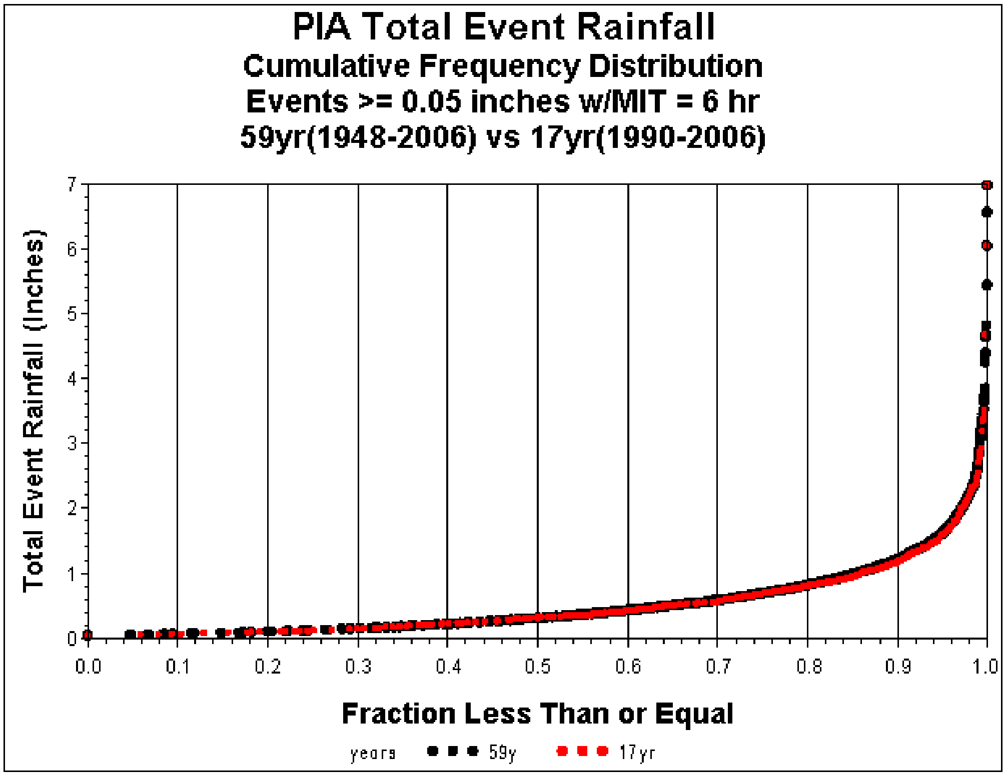

Figure v5-11 CDF Plot of Event Rainfall Volume at the PIA Comparing the 17-year Period (1990-2006) to the 59-year Period (1948-2006)

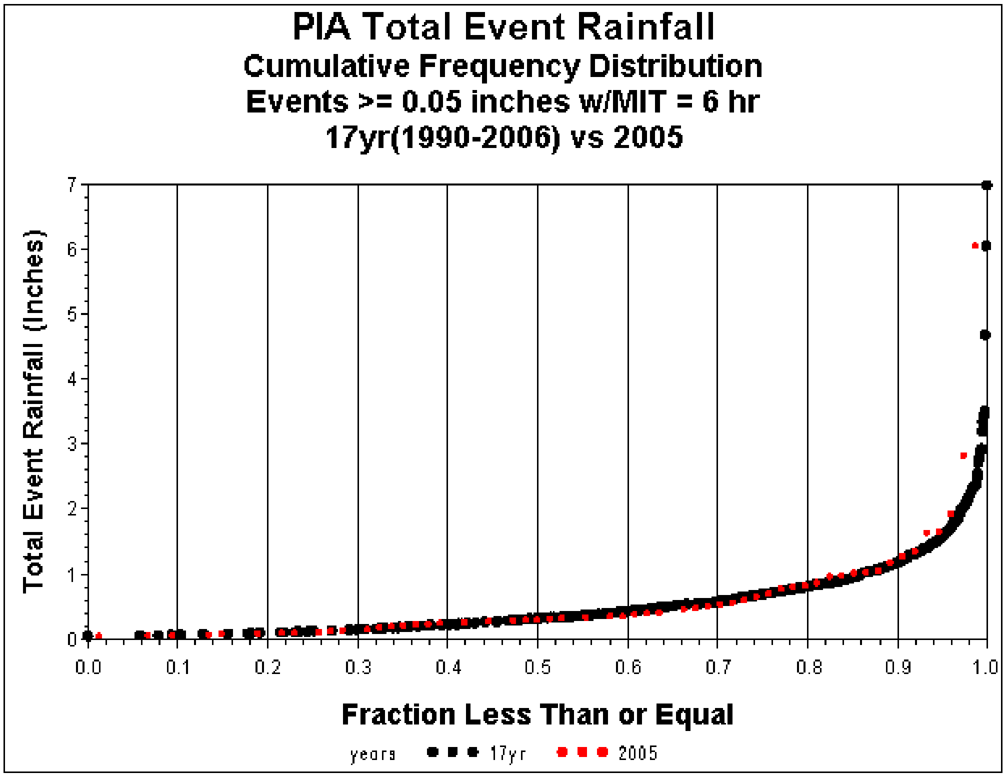

Figure v5-12 CDF Plot of Event Rainfall Volume at the PIA Comparing the 17-year Period (1990-2006) to the Calendar Year 2005

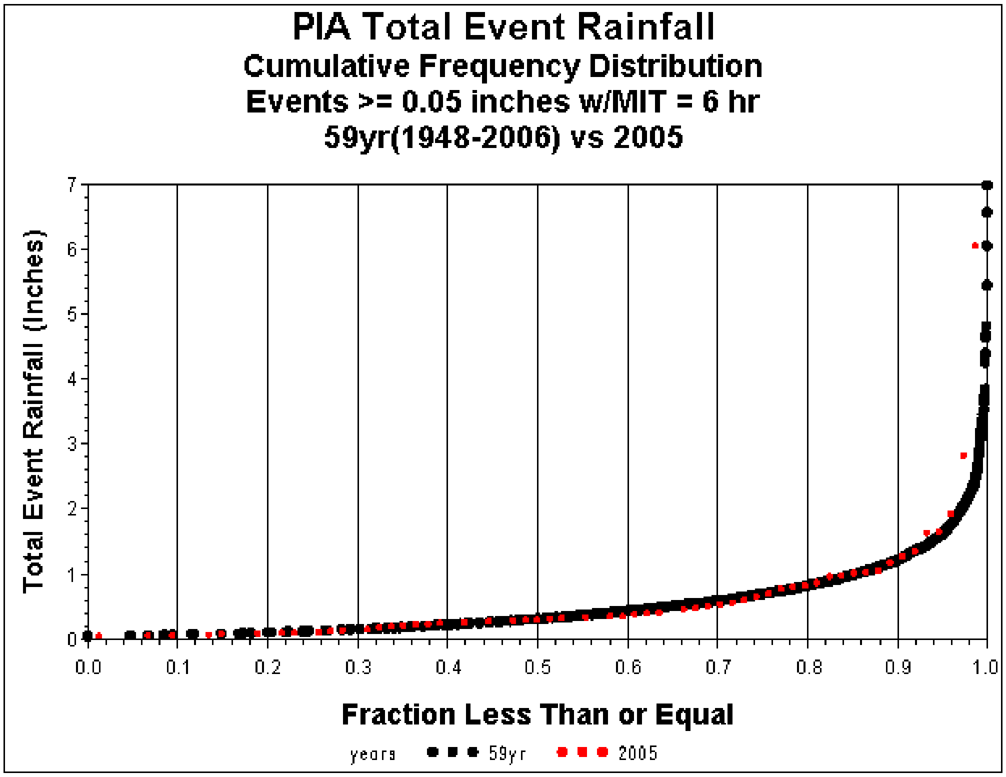

Figure v5-13 CDF Plot of Event Rainfall Volume at the PIA Comparing the 59-year Period (1948-2006) to the Calendar Year 2005

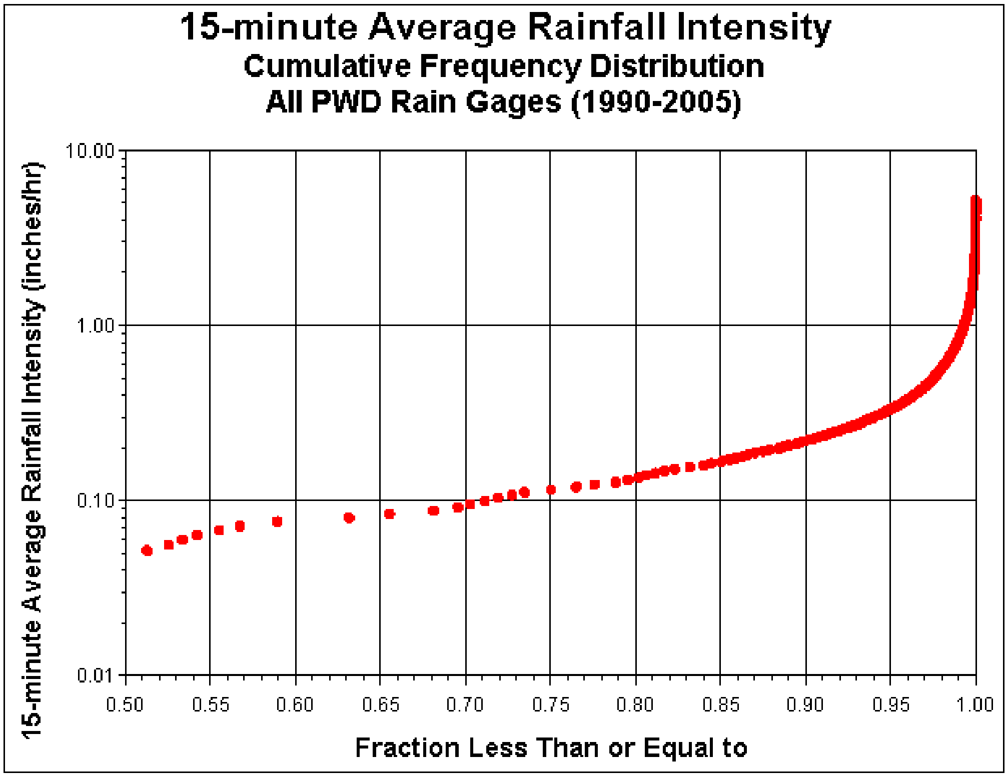

Figure v5-14 CDF Plot of 15-minute Rainfall Intensity for All 24 PWD Rain Gages (1990-2005) Less than or Equal to 50%

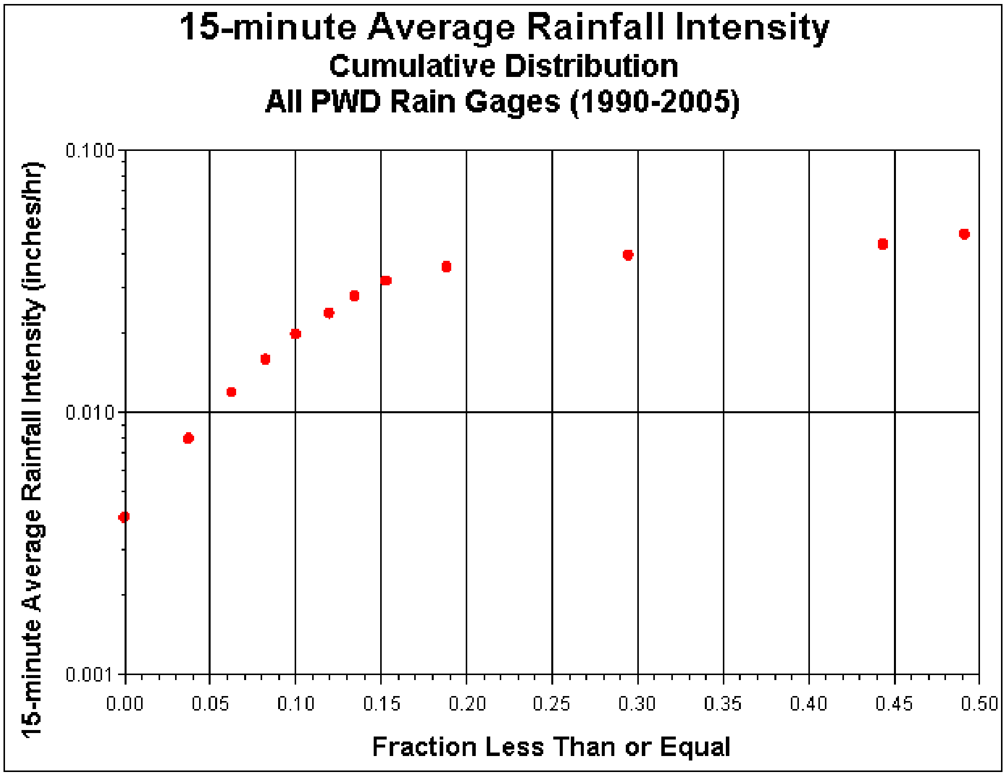

Figure v5-15 CDF Plot of 15-minute Rainfall Intensity for All 24 PWD Rain Gages (1990-2005) Greater than or Equal to 50%

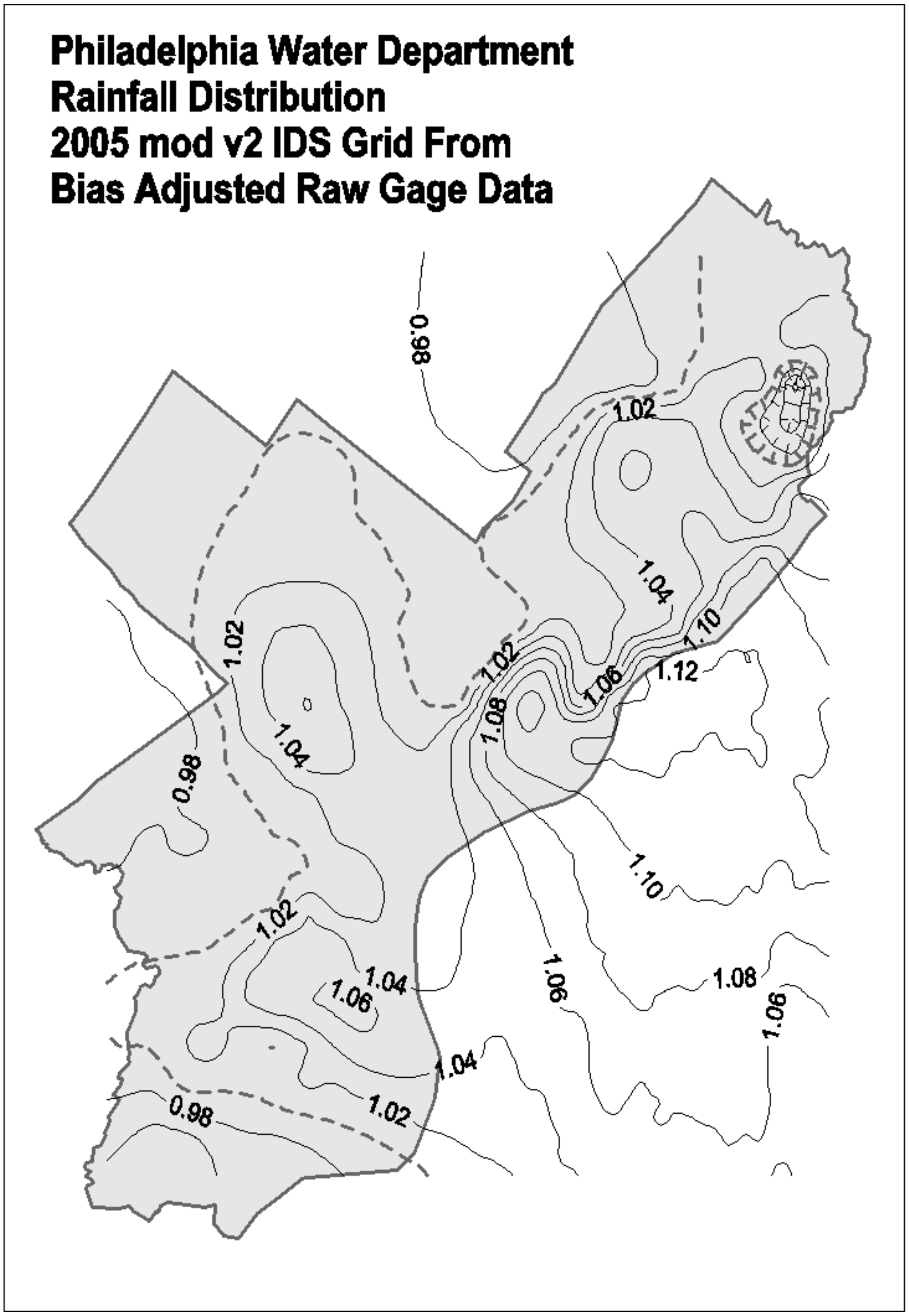

Figure v5-16 Relative Rainfall Distribution Map of Inverse Distance Squared (IDS) Weighting 1-km square Grid Bias Adjusted PWD Rain Gage Network Data for Modified Year 2005

v5.2 NORMALIZING RAIN GAGE NETWORK BIASES USING CALIBRATED RADAR RAINFALL ESTIMATES

The identification and adjustment of precipitation time series data for non-climatic changes in recording bias among rain gages can be instrumental in controlling uncertainty in hydrologic models. Hydrologic models depend upon the reliability of precipitation and flow monitoring data sets used for calibration and simulation. Consistent precipitation and flow monitoring measurements clearly can be important when attempting to characterize rainfall runoff relationships over time. Hydrologic models require rain gage networks to represent the spatial distribution of precipitation across a drainage basin and benefit from the normalization of relative rain gage biases across the network.

Calibration of large urban sewer system models, using a moderately-dense basin-wide rain gage network and continuous flow monitoring data, is improved by creating continuous homogeneous rainfall records with normalized spatial biases.

Double-mass regression and cumulative residual time series analysis techniques are used to evaluate and adjust historical rain gage network data to correct for non-homogeneity of individual rainfall records and to normalize spatial bias across the network. Homogeneity of rainfall time series data is evaluated and adjusted by comparison to the rain gage network mean over a 13-year period of record. Spatial bias across the network, then, is normalized by comparison to continuous calibrated radar rainfall estimates obtained over a 15-month period. Cumulative residual time series analysis techniques also are applied to evaluate the homogeneity of flow monitoring data used in model calibration. The benefits of normalizing the rain gage network biases to model calibration are illustrated by comparing model results using gage data with and without bias correction.

v5.2.1 Introduction

v5.2.1.1 Homogeneity of Rain Gage Station Records

Hydrologic model calibration of lumped runoff parameter estimates depends on consistent rather than precise absolute precipitation and flow monitoring measurement over time. Homogeneity of a rain gage record refers to the consistency of non-climatic bias in precipitation measurements at a gage location over its period of record. Changes in the method of measurement, location of the gage, or conditions immediately surrounding the gage, can cause the readings to differ systematically from prior readings and are indications of a need for correction (Easterling *et al.*, 1995). Homogeneity adjustment of rain gage data is performed to create a consistently scaled rainfall record at each gage location.

Adjustment of gage data to form homogeneous time series depends upon the ability to identify times when changes in measurement conditions may have occurred (Alexandersson 1986). Meta-data, a gage history record documenting changes in equipment and site conditions, often is used as the primary means for identifying changes in rain gage measurement conditions (Guttman 1998). Meta-data alone, however, is often insufficient for identifying non-homogeneity of gage records. Major reported equipment or station location changes can have little if any effect on the gage record, whereas seemingly minor adjustments and undocumented changes in site conditions may result in profound changes in the rainfall record as identified by analytic methods (Peterson *et al.*, 1998).

Time series analysis methods used for evaluating homogeneity and adjusting rain gage records depend upon comparison of gage data to a homogeneous reference time series. An appropriate reference time series is created by averaging measurements from several highly correlated nearby gages (Guttman 1998, Peterson *et al.*, 1998). It is also found valuable to include gages with short and incomplete data series in the reference value (Alexandersson 1986).

v5.2.1.2 Normalizing Rain Gage Network Biases

Representing precipitation spatially across a water or sewer-shed depends upon consistent recording among gages in a rain gage network. Once homogeneous rain gage records are created, it is important that all gages in the network be scaled to combine data for use in filling missing records. The goal is to develop a continuous rainfall record for each gage location, and to determine spatial bias adjustment factors to consistently represent the spatial distribution of rainfall across the network.

Normalizing rain gage network biases in this manner depends upon a reliable reference precipitation data set that represents spatial variation across the region with a uniform bias over a sufficiently long period of record. Calibrated radar rainfall estimates are used for this purpose.

v5.2.1.3 Background

The Philadelphia Water Department (PWD), as part of the City of Philadelphia's combined sewer overflow (CSO) permit compliance program, developed system hydraulic models of its separate sanitary and combined sewer systems that contribute flows to each of its three water pollution control plants, draining nearly 140 square miles of the city. The City maintains a network of 24 tipping bucket rain gages as part of this program. In addition, the City has obtained 18 months of largely continuous historical gage calibrated radar rainfall estimates provided by NEXRAIN Corporation, in order to further refine calibration of its large complex hydraulic system models. A map of Philadelphia showing approximate locations of PWD rain gages, radar rainfall grid, as well as, the combined and sanitary sewer service areas is presented in Figure v5-17.

Comparison of long term rainfall accumulations at neighboring gages revealed potentially significant systematic differences in non-climatic biases. Double mass and cumulative residual analyses of gage station records against the gage network mean value have further revealed non-homogeneity of station records due to changes in equipment operation or site conditions. Adjustment of rain gage data, therefore, was applied to create a consistently scaled precipitation record at each gage location. In addition to creating consistent (homogeneous) gage records over time, it also is important to scale all the gages consistently within the network to one another in order to combine data from different gages, for use in filling missing records, and representing spatial variation.

The goals of this investigation are to develop procedures to evaluate and adjust the historic PWD rain gage network record to produce homogeneous rain gage records at each gage location and to normalize rain gage network biases using radar rainfall estimates.

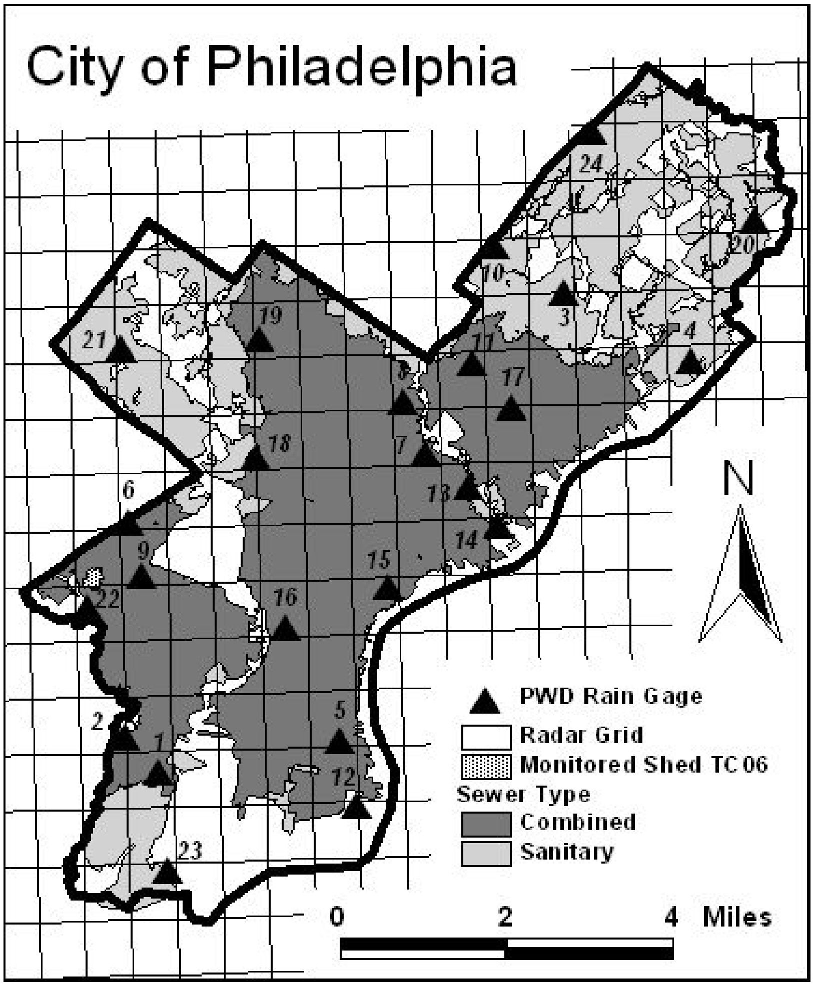

Figure v5-17 City of Philadelphia Showing the Approximate Locations of PWD Rain Gages, Radar Rainfall Grid, as Well as in City Combined and Sanitary Sewer Service Areas

v5.2.2 Homogeneity of PWD Rain Gage Station Records

This section describes the methods used to evaluate and adjust PWD rain gage records to create continuous homogeneous rainfall records at each location in the network for use as hydrologic model input.

v5.2.2.1 Data Set

The PWD maintains a database of 15-minute accumulated precipitation totals collected from its 24 tipping bucket rain gage network for the period 1990 to the present. The uncorrected, 2.5-minute accumulated, 0.01 inch tip count, rain gage data are subjected to preliminary quality assurance and quality control procedures. Identification and flagging of bad or missing data are performed for each rainfall event on a monthly basis by visual inspection of 15-minute accumulated data comparing measurements at nearby gages and looking for patterns of obvious gage failures, including plugged gages and erratic tipping. Flagged data for each gage subsequently are filled with data from the five nearest gages using inverse distance squared weighting. Neighboring gage data that are flagged are removed prior to weighting.

Daily rainfall volumes were totaled for each gage. Daily gage totals containing any filled data were removed from further analysis. A daily mean total was calculated for each gage as the average of all daily gage totals excluding the total at the gage itself. The resulting dataset consisted of daily gage totals, and daily mean totals (mean of all the other gages) for each gage.

v5.2.2.2 Double Mass Regression and Cumulative Residual Time Series Analysis

Double mass regression and cumulative residual time series analysis methods were used for evaluating the homogeneity and adjusting PWD rain gage records. These methods, like other reliable analytical methods of homogenizing rainfall time series, depend upon comparison of gage data to a homogeneous reference series. A reference series can be created using the average of a collection of nearby gages, or a homogeneous record at a single nearby gage (Allen *et al.*, 1998). The rain gage network mean value, calculated as described above, was selected as the reference series for homogenization of PWD rain gage data.

Evaluating the homogeneity of PWD rain gage records, and identifying dates when apparent changes in measurement conditions may have occurred, was performed using double mass and cumulative residual time series analysis techniques. A series of graphs was produced comparing gage to mean daily rainfall totals for each gage in the network. An example of the output generated is presented for PWD rain gage 22 in Figures v5-18 and v5-19.

A double mass plot of gage to mean cumulative daily rainfall totals was produced for each gage. The slope of the linear regression line passing through the origin is referred to as the double mass regression slope, DMRS, as shown in Figure v5-18. Potential heterogeneities are identified by visual inspection of the double mass plot as seen by systematic departures from the trend line. These departures can be identified more easily by plotting the accumulated residual from the simple linear regression of gage against mean daily rainfall totals over time (Craddock 1979) as shown in the cumulative residual plot in Figure v5-19.

Evaluation of potentially significant gage record non-homogeneity was aided by the addition of an objective graphic analytic tool to the cumulative residual plot. An ellipse was drawn on the plot to contain the residual of a homogeneous time series for a given probability of the standard normal variate (Allen *et al.*, 1998, Henriques et al 1999). The 80% probability level, commonly used by others according to Allen *et al.*, 1998, was chosen for this data evaluation program. Because the cumulative residual time series plot in Figure v5-19 is not contained within the ellipse, we reject at the 80% confidence level the hypothesis that the rainfall record at PWD rain gage 22 is homogeneous with respect to the mean. The parametric equation defining the probability ellipse is given by (Allen *et al.*, 1998)

$$x = \alpha Cos(\theta) + \alpha$$
$$y = \beta Sin(\theta)$$

with

$$\alpha = n/2$$
$$\beta = nZ_p S_{y,x} / \sqrt{(n-1)}$$
$$S_{y,x} = S_y \sqrt{(1-r^2)}$$

where:

n = the number of observations
S_y = the sample standard deviation
r = the Pearson correlation coefficient
Z_p = the standard normal variate at 80% probability
θ = an angle in radians varying from 0 to 2π

Cumulative residual analysis reveals even subtle change in gage bias often undetected by routine inspection of precipitation data and gage history records. Furthermore, subjective evaluation of the cumulative residual plot enables effective identification of the approximate dates abrupt changes in the relationship between the gage and its neighbors occur (Craddock 1979). In this manner, a set of adjustment periods are determined that contain continuous, relatively homogeneous segments of each gage record. Objective statistical methods are used by others to identify significant break points in gage record homogeneity (Peterson *et al.*, 1998). These methods have not been used here, however, like the subjective method of defining homogeneous periods used in this data homogenization program, they rely on comparative evaluation of time series data from a moderately dense and highly correlated gage network.

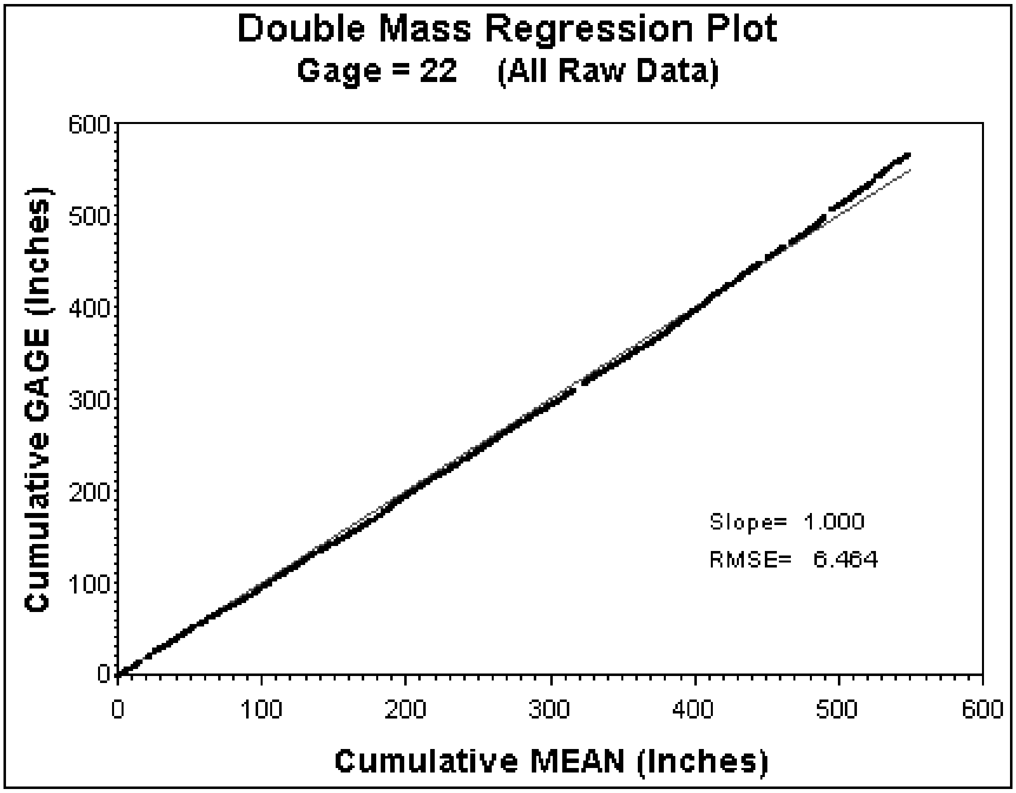

Figure v5-18 Double Mass Regression Plot of Cumulative Daily Rainfall at PWD Rain Gage 22 Against Mean Using All Raw Data for the 1990-2006 Period of Record

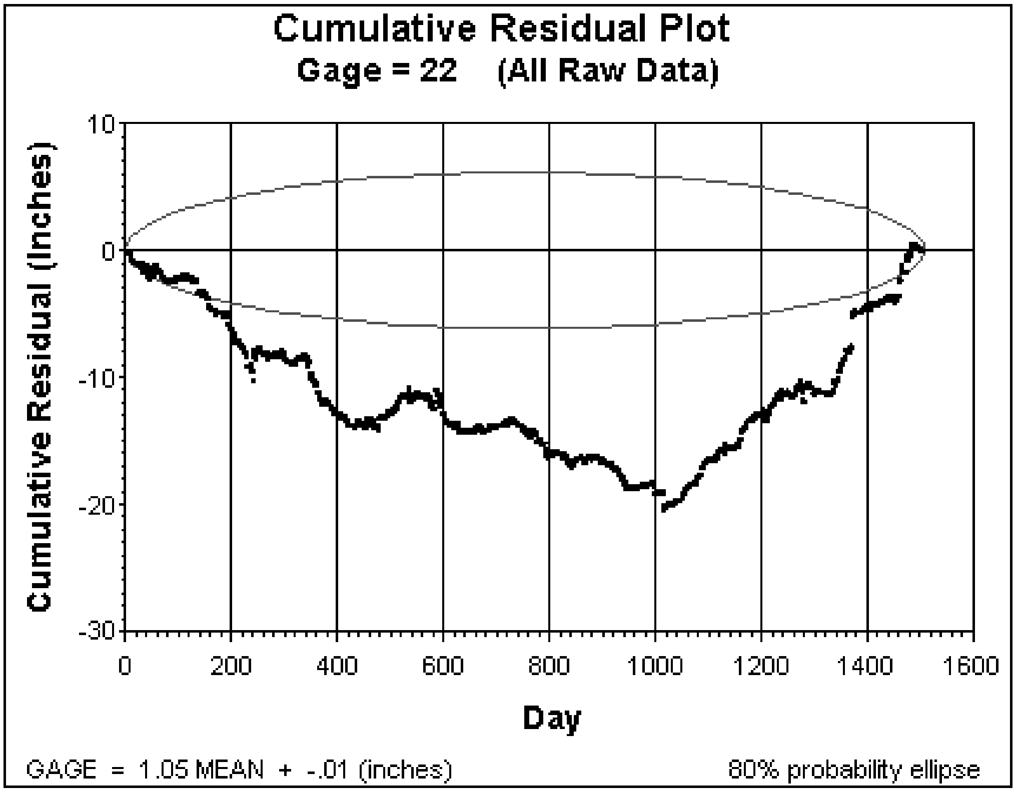

Figure v5-19 Cumulative Residual Time Series Plot from the Linear Regression of Daily Gage Against Mean Rainfall Totals at PWD Rain Gage 22 Using All Raw Data for the Period 1990-2006

v5.2.2.3 Adjusting Heterogeneous Gage Records

Once significant non-homogeneity of the gage record is determined, and the limits of homogeneous adjustment periods have been identified, adjustment factors are computed for these periods to form a homogeneous data record.

Homogeneity adjustment factors are viewed as the ratio of the average gage biases between a reference period and the period to be adjusted (Guttman 1998). Several methods of calculating adjustment factors are investigated. Each method employs a different form of expressing the average bias at the gage relative to the mean. Three methods of estimating average biases for a gage period considered are:

1. Average Daily Ratio of rain gage value to the mean (high influence of small event outliers)
2. Double mass linear regression slope (most stable with respect to outliers)
3. Linear regression slope (high influence of large event outliers)

The double mass linear regression slope with y-intercept = 0 was found to be the most stable with respect to outliers and was chosen for this study to determine homogeneity adjustment factors for selected periods of the rain gage record.

Rain gage record homogeneity adjustment factors were calculated for each interval by dividing the double mass regression slope (DMRS) of the entire unadjusted data record (Figure v5-18) by the DMRS for the adjustment period. This calculation is performed for each adjustment period identified and all raw data within the adjustment periods then is multiplied by these factors to generate the corrected rain gage record.

The results of homogeneity adjustment are presented for PWD rain gage 22 with the double mass regression plot in Figure v5-20 and the cumulative residual plot in Figure v5-21. Comparison of these plots to those presented in Figures v5-18 and v5-19 for the raw data reveal a significant improvement in homogeneity of rain gage bias relative to the network mean over the period of record for this gage.

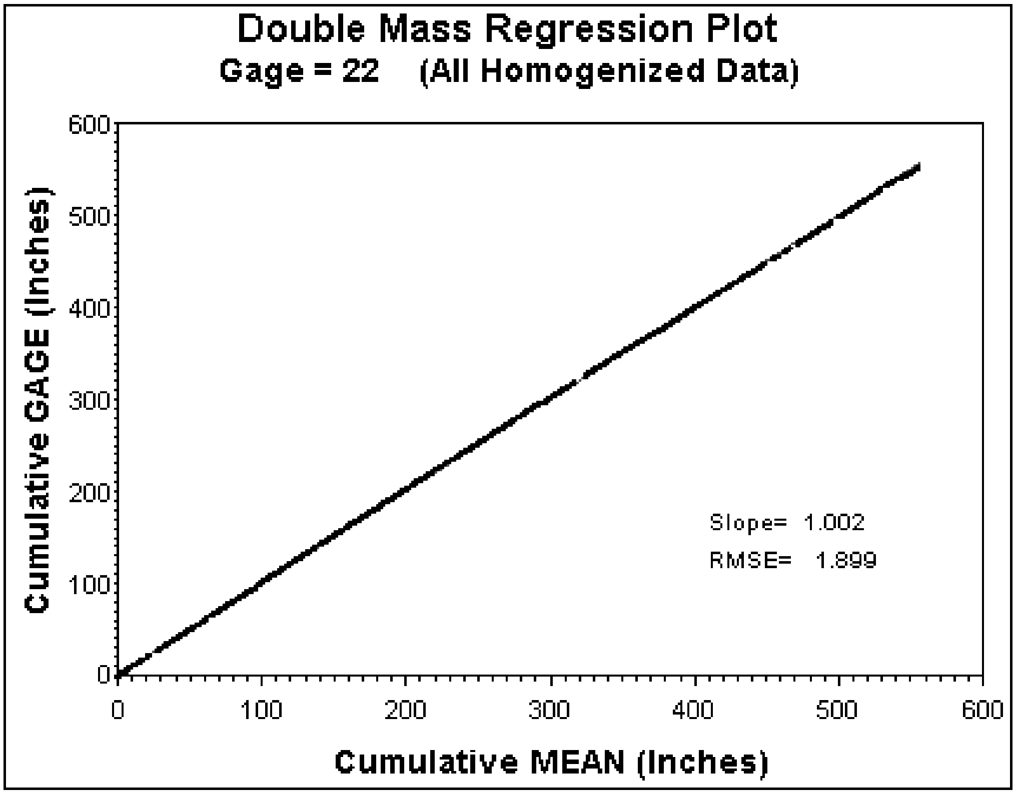

Figure v5-20 Double Mass Regression Plot of Cumulative Daily Rainfall at PWD Rain Gage 22 Against Mean Using Homogenized Data for the 1990-2006 Period of Record

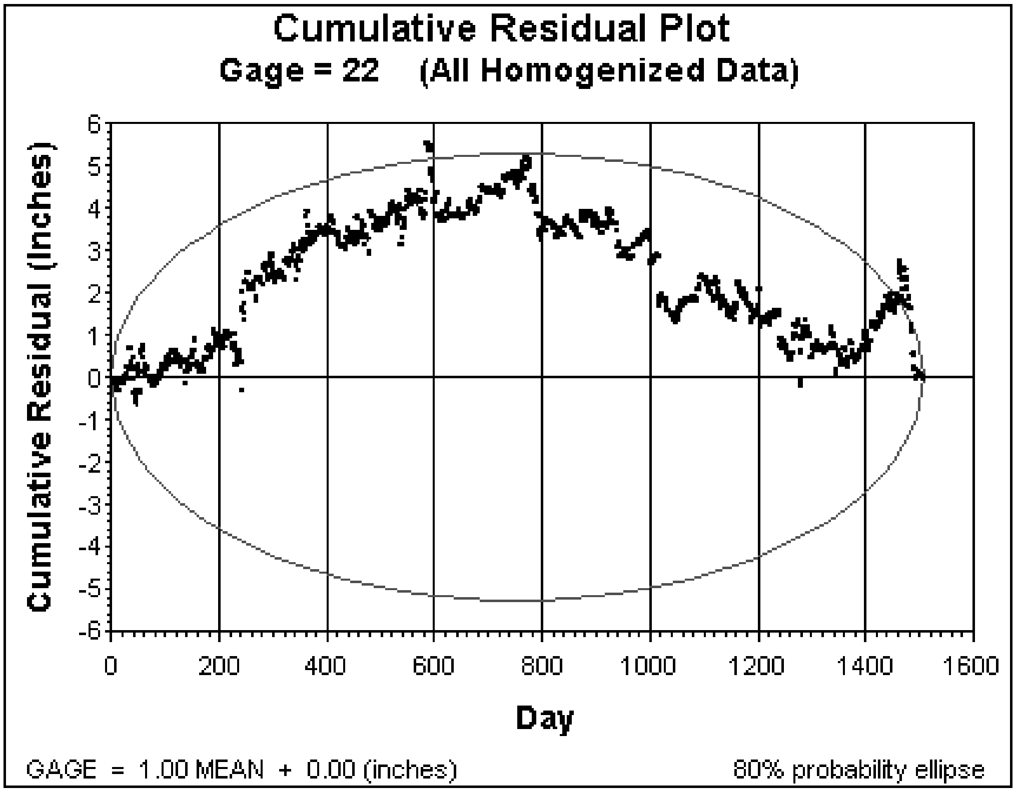

Figure v5-21 Time Series Plot of the Cumulative Residual from the Linear Regression of Daily Gage Against Mean Rainfall Totals at PWD Rain Gage 22 Using Homogenized Data for the Period 1990-2006

v5.2.3 Normalizing Spatial Biases in Rain Gage Data Using Calibrated Radar Rainfall Estimates

Once homogeneous gage records are created, all gages then are adjusted for consistent net systematic biases resulting from differences in gage equipment, gage site conditions, and previous homogeneity adjustments.

The second major goal of this investigation is to adjust all the gages in the PWD network to the same average bias, so the gage network more reliably represents spatial variation across the region. To achieve this goal a reliable reference series is needed to represent spatial variation of rainfall across region with a uniform bias, over a sufficiently long and homogeneous period of record. Calibrated radar rainfall estimates are used for this purpose.

v5.2.3.1 Data Set

Radar rainfall estimates provided by NEXRAIN Corporation are derived from a 2km x 2km National Weather Service level 3 radar mosaic product, corrected for ground clutter and other anomalies, and calibrated to the PWD 24 rain gage network using a mean field bias adjustment. The 15-minute calibrated radar rainfall estimates for a 15-month period including two relatively recent intervals: October, 1999 through August, 2000 and March, 2002 through June, 2002 are used for this analysis. The radar rainfall estimates are calibrated to the PWD rain gage network using a mean field bias adjustment method where the mean event accumulation for the radar pixels containing the

PWD rain gages is set equal to the mean event accumulation measured at the gages. In this way the total volume of rainfall reported within the network is conserved, while the spatial variation represented by radar data is retained.

v5.2.3.2 Bias Adjustment Using Double Mass Regression

Double mass regression analysis is used to correlate PWD rain gage measurements to calibrated radar rainfall data. In this way, overall spatial bias adjustment factors are determined that best represent the spatial distribution of rainfall over the full period of record for each rain gage in the network.

Before determining the overall bias of a rain gage record relative to the calibrated radar rainfall estimates, the homogeneity of the data sets is verified. The verification is performed by examining the time series plots of the cumulative residual from the linear regression of daily radar against rain gage rainfall totals, as shown for PWD rain gage 22 in Figure v5-22. Once an acceptable degree of homogeneity between the datasets is determined for the 15-month radar study period, the spatial bias adjustment factor is calculated for the complete gage record. The program developed for determining overall site bias factors at each gage is a two-part process using the same techniques developed for homogenization of the gage record.

The first step in determining the overall spatial bias adjustment factor, once the homogeneity of all datasets is established, is to determine the bias at each gage using the double mass regression slope,of radar to rain gage daily rainfall totals for the 15-month radar study period as presented in Figure v5-23 for PWD rain gage 22.

Next, the gage bias for the radar study period is related to the overall bias of the gage record to determine spatial bias adjustment factors that are applied to adjust the entire period of record for the gage, not just the 15-month radar period. This is done by determining the average gage bias for the 15-month radar period using the DMRS of the daily gage versus the mean rainfall for this period as shown by Figure v5-24. The DMRS for the entire period of record was previously determined using all homogenized data as shown by Figure v5-20. Then the ratio of the DMRS for the entire period of record (all data) to that of the radar study period (15-month) is calculated. This ratio is multiplied by the DMRS radar to rain gage bias from Figure v5-23, to yield the overall spatial bias adjustment factor for each gage.

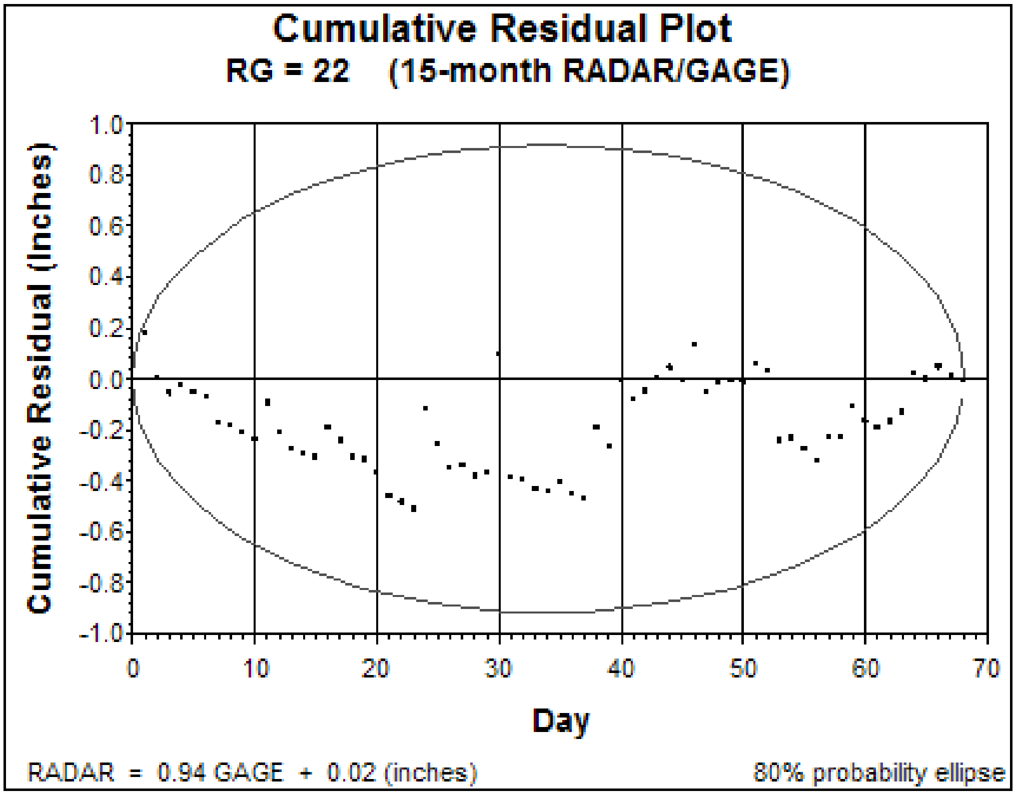

Figure v5-22 Cumulative Residuals: Linear Regression of Daily Radar Rainfall Estimates Against Rain Gage Totals at PWD Rain Gage 22 for the 15-Month Radar Study Period

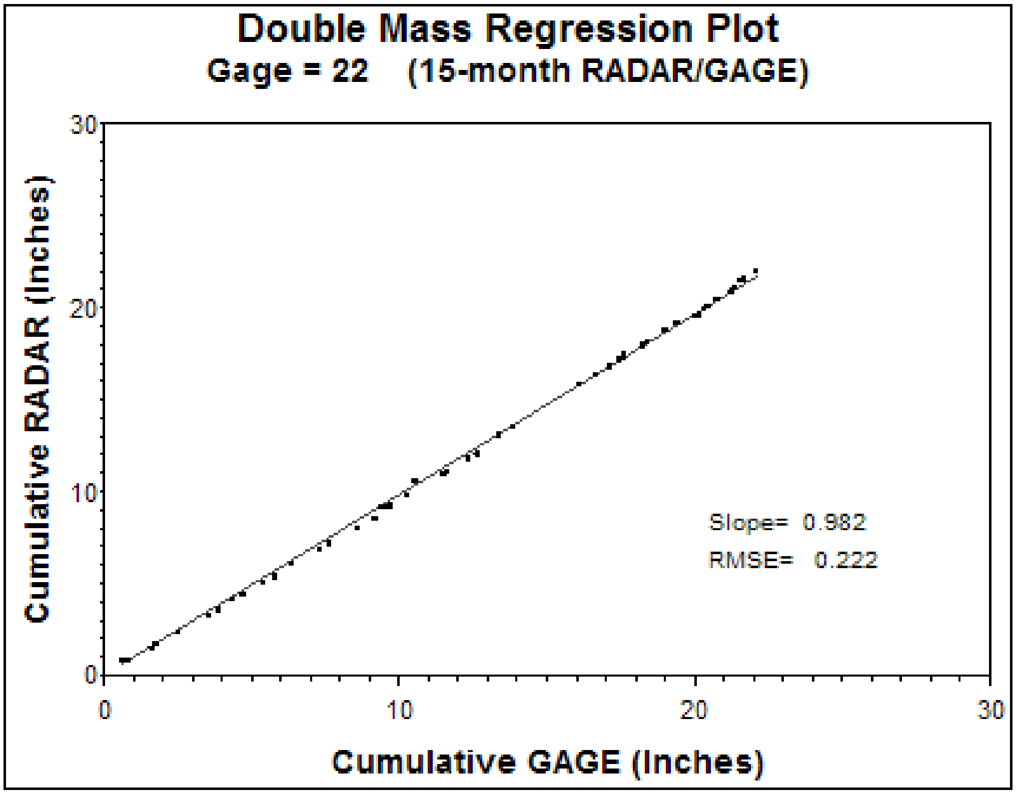

Figure v5-23 Double Mass Regression Plot of Cumulative Daily Radar Against Gage Rainfall Totals at PWD Rain Gage 22 for the 15-Month Radar Study Period

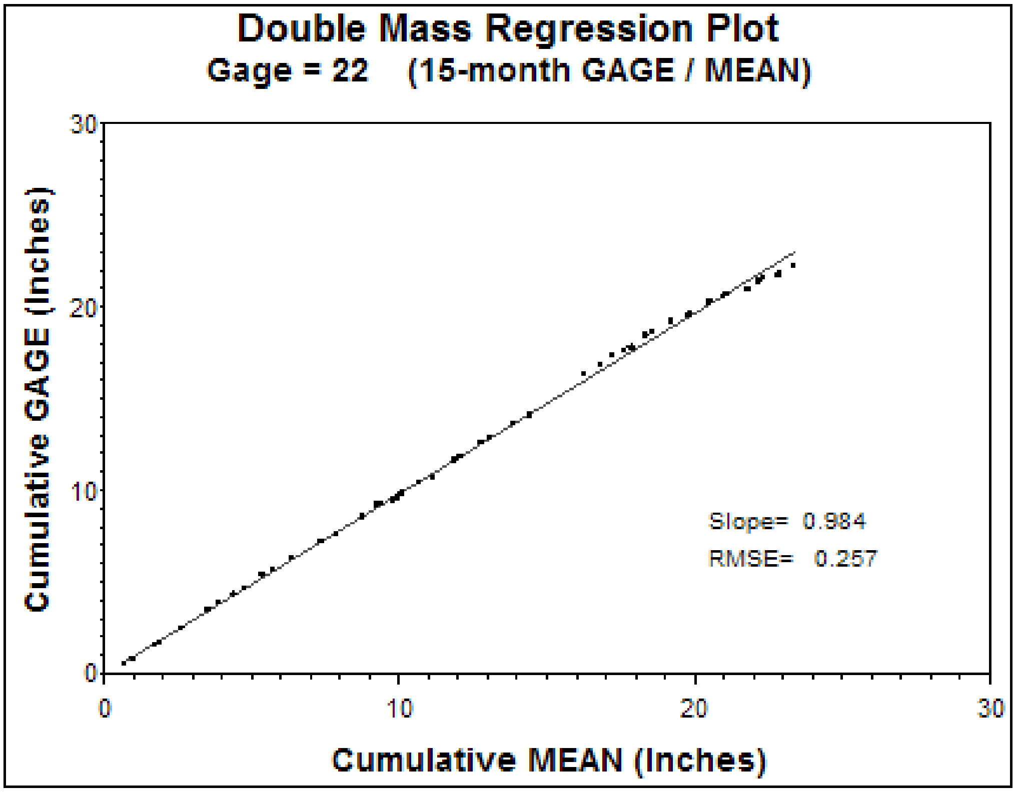

Figure v5-24 Double Mass Regression Plot of Cumulative Gage to Mean Daily Rainfall Totals at PWD Rain Gage 22 for the 15-Month Radar Study period

v5.2.3.3 Results

The overall spatial bias adjustment factors determined for each of the PWD rain gages is presented in column 8 of Table v5-10. PWD rain gage 14 is removed from the analysis because it lacks a sufficient number of daily measurements corresponding to the 15-month radar rainfall study period.

Inspection of column 3 in Table v5-10 reveals that across the network PWD rain gages 18 and 21 exhibit the greatest overall biases in raw gage data relative to the mean with overall biases of negative 8% and positive 9% respectively. These two rain gages are located among five PWD stations covering an approximately four square mile region of North West Philadelphia. This represents an average difference in rainfall between these two gages of approximately 15% over approximately a two mile distance.

The spatial distribution represented by radar rainfall data in column 10 of Table v5-10, however, reveals an average bias relative to the mean at gages 18 and 21 of positive and negative 3%, respectively. The spatial bias adjustment factors for PWD gages 18 and 21 are the greatest in the network. The final results of homogenization and spatial bias adjustment, given by the gage to mean double mass regression slopes presented in column 9 of Table v5-10, represent the long term average relative rainfall distribution across the region.

To better visualize the spatial distribution of rainfall represented by the final and intermediate results presented in Table v5-10, surface contour plots were generated using the DMRS for all rain gage locations relative to the network mean. The long term average distribution of rainfall over the Philadelphia area illustrated in Figure v5-25 is determined from the double mass linear regression slope, column 3 of Table v5-10, using all raw data for the 1990-2006 period of record.

Isometric contours lines are generated from this data using the kriging method of spatial interpolation provided by Surfer™ for Windows Notes V6 ©Golden Software Incorporated, 1993-97.

The average rainfall distribution relative to the network mean over the 15-month radar study period is presented in Figure v5-26 for raw, homogenized but not spatial bias adjusted, rain gage data. This figure reveals gage locations with significant long and short term differences in rainfall from nearby gages, as well as the regional average.

The final overall spatial bias adjustment factors for all homogenized PWD rain gage data over the 1990-2006 period of record are given in column 8 of Table v5-10 expressed as differences from the mean. These factors are graphically presented in Figure v5-27. Note that bias adjustment factors range from plus-to-minus seven percent.

The average relative distribution of rainfall observed from the radar rainfall data over the 15-month study period (Figure v5-28) compares favorably to that of the final adjusted PWD rain gage data determined over the 1990-2006 period of record (Figure v5-7).

Table v5-10 Final Spatial Bias Adjustment of PWD 24-Raingage Network Data with NEXRAIN Calibrated Radar Rainfall Data

1	2	3	4	5	6 = 5 / 4	7	8 = 6 x 7	9	10
PWD Rain Gage	Days with Radar Data	DMRS (Gage / Mean) Raw Data	DMRS (Gage / Mean) Homogenized Data		Ratio DMRS 15-month to DMRS All Data	DMRS (Radar / gage)	Overall Spatial Bias Adjustment Factor (Radar/All Data)	DMRS Final Adjusted Data	DMRS (Gage / Mean) Radar Data
			All Data	15-month					
1	136	1.00	0.99	1.00	1.01	0.96	0.97	0.99	0.98
2	136	0.98	0.99	1.00	1.01	0.97	0.98	0.98	0.97
3	120	0.96	0.97	0.98	1.01	1.02	1.02	1.02	1.01
4	46	0.98	1.00	1.00	1.00	0.98	0.98	1.00	0.96
5	123	0.99	1.00	1.03	1.03	1.01	1.04	1.07	1.06
6	151	1.03	1.03	1.03	1.00	0.95	0.94	0.99	0.98
7	132	1.04	1.04	1.04	1.00	0.92	0.92	0.97	0.98
8	75	0.97	0.98	0.96	0.98	1.03	1.01	1.01	0.98
9	122	1.03	1.03	1.07	1.04	0.89	0.92	0.97	0.98
10	106	1.02	1.02	1.01	0.99	0.95	0.94	0.98	0.99
11	37	1.01	1.01	1.06	1.05	0.91	0.95	0.98	1.00
12	41	0.91	0.92	0.93	1.01	1.03	1.04	0.97	0.98
13	13	0.96	0.96	1.19	1.24	0.88	1.09	1.07	1.04
14	NA	NA	NA	NA	NA	NA	NA	NA	NA
15	147	1.02	1.01	1.00	0.99	1.00	0.99	1.02	1.02
16	57	1.00	1.00	0.97	0.97	1.00	0.98	1.00	1.00
17	144	1.04	1.03	1.03	1.00	0.93	0.94	0.98	0.97
18	147	0.92	0.92	0.95	1.03	1.05	1.08	1.03	1.03
19	99	0.99	0.99	1.01	1.02	0.96	0.97	0.98	0.98
20	112	1.01	0.99	0.94	0.95	1.09	1.04	1.05	1.06
21	70	1.09	1.09	1.07	0.98	0.89	0.88	0.97	0.97
22	68	1.00	1.00	0.98	0.98	0.98	0.96	0.98	0.97
23	44	0.95	0.93	0.96	1.03	0.93	0.96	0.91	0.91
24	43	0.97	0.99	0.97	0.99	1.05	1.04	1.04	1.06

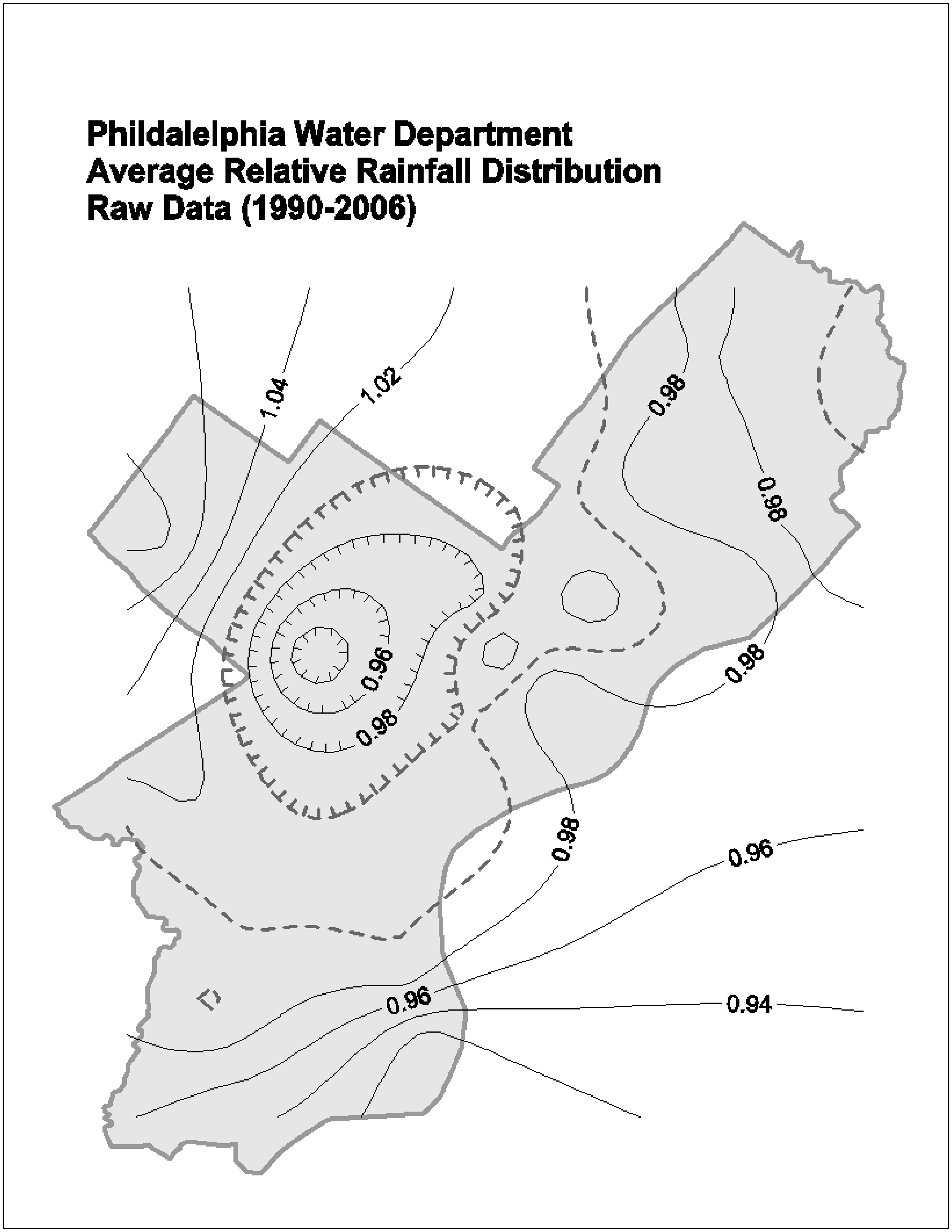

Figure v5-25 Relative Rainfall Distribution Map of the Philadelphia Area Showing Double Mass Regression Slopes of PWD Gage to Mean Daily Rainfall Totals Using Raw Data for the Period 1990-2006

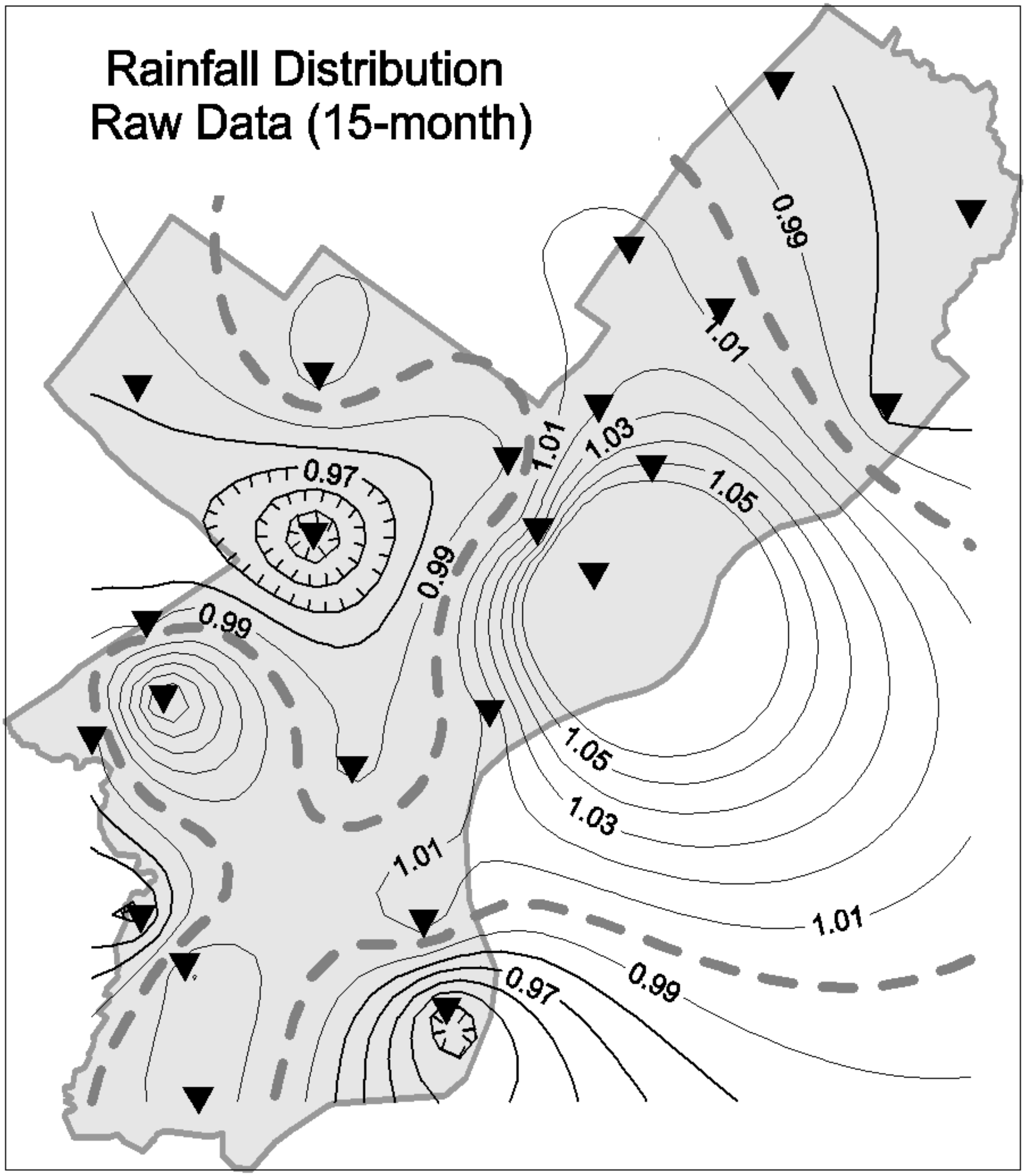

Figure v5-26 Relative Rainfall Distribution Map of the Philadelphia Area Showing Double Mass Regression Slopes of PWD Gage to Mean Daily Rainfall Totals for the 15-Month Radar Study Period

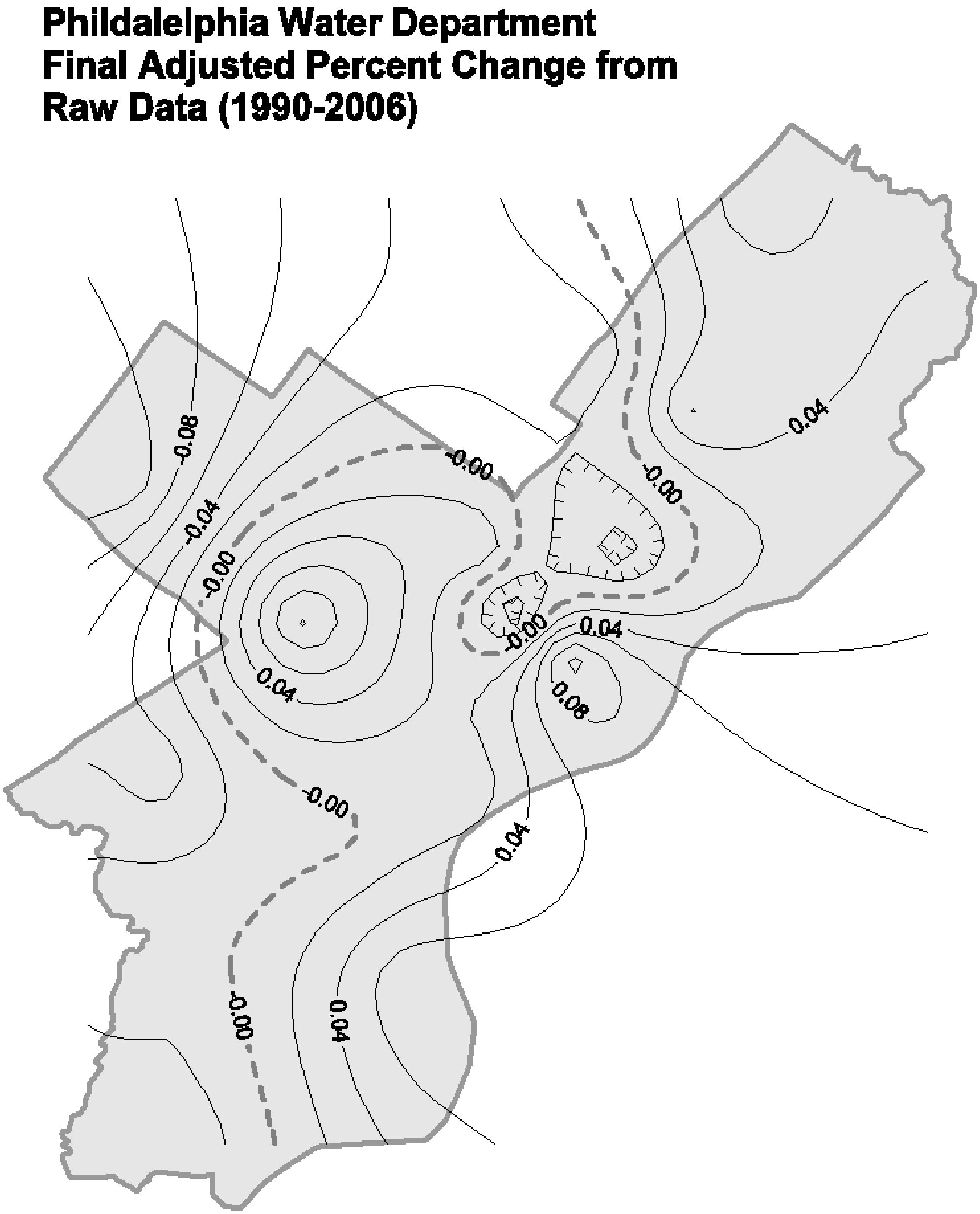

Figure v5-27 Map of Philadelphia Area Showing Final Bias Adjusted Data Percent Change from Raw Data for the Period 1990-2006

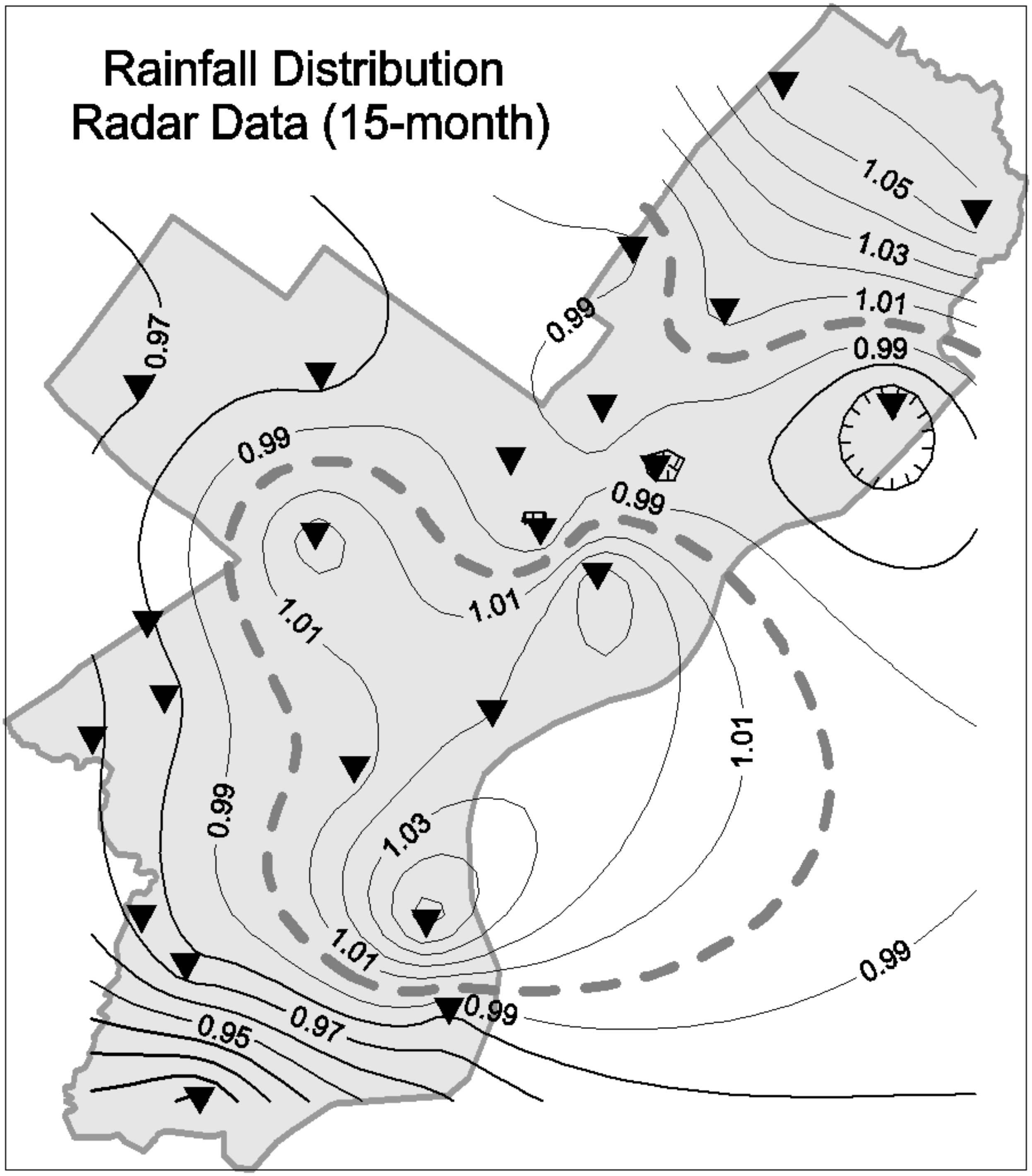

Figure v5-28 Rainfall Distribution Map of the Philadelphia Area Using Radar Data Over the 15-Month Study Period. Contours are Double Mass Regression Slopes at Gage Locations Relative to the Mean

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v5.3 INVERSE DISTANCE SQUARED WEIGHTING AND BASIN AVERAGE RAINFALL CALCULATIONS

Much of the uncertainty in a carefully constructed hydrologic and hydraulic model is derived from uncertainty in the rainfall record. Therefore, increasing the level of detail of the rainfall input, both spatially and temporally, increases the accuracy and precision of the model results. Careful attention to rainfall collection and analysis is critical to the modeling effort.

The Runoff module of US EPA's Storm Water Management Model (SWMM) is used to simulate the hydrology of the separate and combined sewersheds in the service area. The service area is subdivided into a number of smaller sewersheds that each drain to a particular point in the collection system. Input data, including imperviousness, slope, and precipitation data, are entered for each sewershed. A rainfall value is required for each sewershed at each date and time for which a simulation will be run. These values must be derived from some combination of rain gage rainfall data and a method of estimating rainfall at points where no gages exist.

Bias adjusted 15-minute accumulated rainfall data for the PWD 24-raingage network are used for the weighting analysis. No filling of missing data is performed prior to the inverse-distance-square weighting. Bias adjustments are performed on the data as documented in Section v5.2.

There are a number of methods of estimating rainfall in areas between rainfall gages, including Thiesson polygons and inverse distance-squared weighting. An inverse distance-squared weighting procedure is chosen as described below.

A one-square-kilometer grid is imposed over the PWD service area, and the results of the weighting calculations are applied to this grid. Thus, each of the cells on the grid is assigned a rainfall value at each date and time. These grid values are later used to provide area-weighted average 15-minute rainfall values for each individual sewershed.

Manipulation of the rainfall data is performed by Statistical Analysis System (SAS) code. SAS is a high-level programming language that is particularly well suited to processing large amounts of data with relatively simple programming code. The algorithm includes five steps that apply to each date and time. These steps are listed and discussed in further detail below.

1. Read in gage rainfall data, areas, and coordinates
2. Populate the grid center points with rainfall values
3. Area-weight cell data to create a rainfall value for each sewershed
4. Output the results

Step 1: Read in raw data, areas, and coordinates.
Data input to the program include the following:

- Raw (bias-adjusted) rainfall data
- Results of GIS intersect between grid cells and sewersheds
- Rain gages assigned to each grid cell by earlier GIS analysis
- State plane coordinates of rain gage locations and grid cell centroids

Rain gages are assigned using the following logic:

- For grid cells other than those close to the edge of the service area, the three closest gages surrounding the cell are identified, forming a triangle that contains the grid cell centroid
- For some grid cells close to the edge of the service area, only two gages are assigned. For example, cell centroids contained in triangular polygon "010203" in Figure v5-29 are assigned gages 1, 2, and 3; cell centroids in irregular polygon "0102" are assigned gages 1 and 2
- Each assigned rain gage is assigned a backup gage to be used in cases where measurements at the primary gage do not pass quality assurance. In this case, data from the backup gage replace data from the primary gage. However, since the backup gage is further from the cell centroid, its data ultimately get a lower weight than data from the primary gage would have

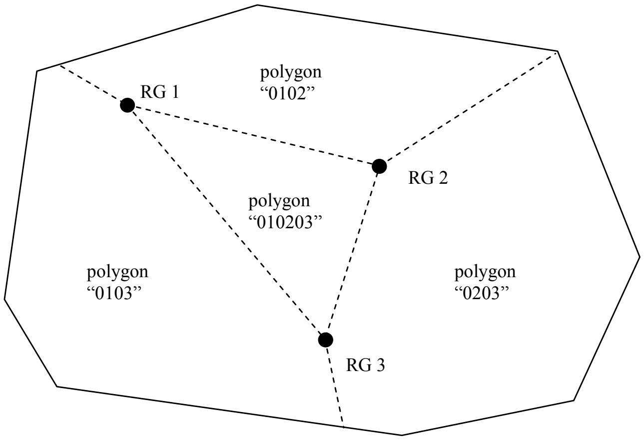


Figure v5-29 Schematic Diagram of Gauge Assignment Process

Step 2: Populate the grid center points with rainfall values.
After reading in the necessary data, the program uses it to populate the radar grid with rainfall values. Each point on the grid is assigned a value by inverse distance-squared weighting of 2 to 3 nearby rain gages. This process is depicted in Figure v5-30.

Rainfall for cell *j*, at a particular date and time, is given by the following equation:

$$P_j = \sum_{i=1}^{n} (f_{i,j} P_i)$$

Where P_j is the calculated precipitation at cell j,
j is the cell number,
i is the rain gage number,
n is the number of rain gages assigned to the cell (3 in the example),
$f_{i,j}$ is the rainfall weighting factor give by

$$f_{i,j} = \frac{(D_{i,j})^{-2}}{\sum_{i=1}^{n} (D_{i,j})^{-2}}$$

$D_{i,j}$ is the distance between gage i and cell j (by the Pythagorean Theorem), and P_i is the measured precipitation at rain gage i

Rules for missing data are as follows:

- A careful distinction is made between zero values and missing data due to quality control. Zero values are treated as zeros in the mathematical equations
- When a value is flagged as missing due to quality assurance, a value from a backup gage is substituted. If the backup gage data is also flagged, data assigned to the grid cell are based on data from the remaining 1-2 assigned gages, with backup gage values substituted as necessary. There were no instances in which none of the primary or secondary gages assigned had quality-assured data

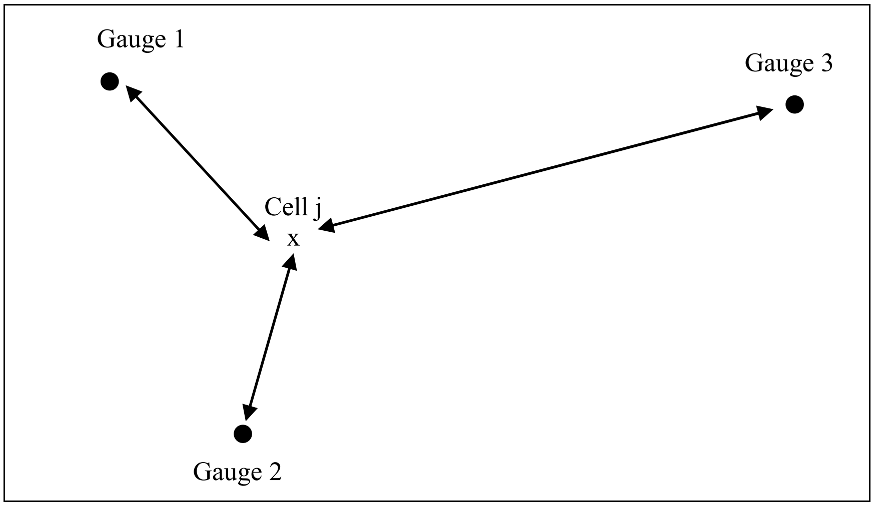


Figure v5-30 Conceptual Diagram Showing Gage Cell Assignments

Step 3: Area-weight cell data to create a rainfall value for each sewershed.
The final step in the calculations is the area-weighting of cell data to derive rainfall values for all sewersheds at all dates and times. This process is described by Figure v5-31.

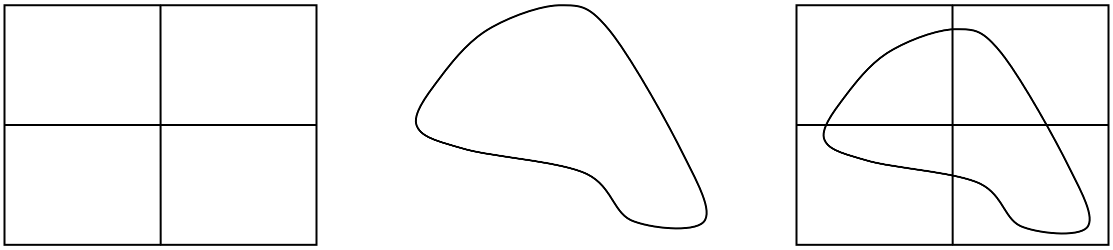


Figure v5-31 Conceptual Diagram of the Cell-Sewershed Relationship

At a given date and time, the precipitation for a sewershed is given by the following equation:

$$P_k = \sum_{j=1}^{n} \left(\frac{A_{j,k} P_j}{\sum_{j=1}^{n} A_{j,k}} \right)$$

Where P_k is the calculated rainfall for sewershed k,

j is the cell number,

n is the number of cells contained all or partially within sewershed k,

$A_{j,k}$ is the area of cell j within sewershed k, and

P_j is the calculated rainfall at cell j.

Step 4: Output the results.

The results of the calculations, consisting of rainfall at every sewershed, date, and time, are output in format that can readily be read by a SWMM model.

Quality assurance consists of verification of input parameters and verification of output with spreadsheet calculations. Scenarios for verification include some chosen at random and some chosen as special cases. Special cases include situations in which only one to two assigned gages provide usable data at a particular sewershed and time. Errors found through this process have been corrected, and it has been repeated until the project team has a high level of confidence that the results are accurate.

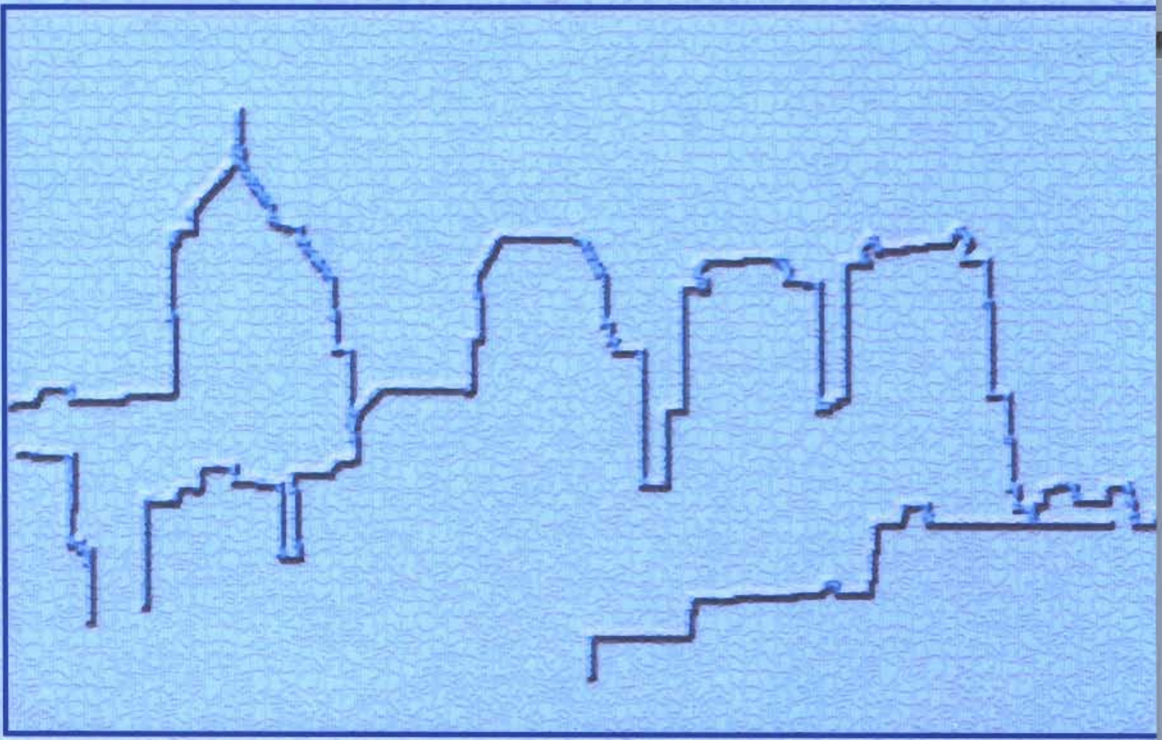
Philadelphia Combined Sewer Overflow Long Term Control Plan Update

Supplemental Documentation
Volume 6

Stress Testing of the Northeast WPCP

Updated: September 1, 2009

FINAL REPORT



Stress Testing of the Northeast WPCP

Stress Testing of the Northeast WPCP

Prepared for

Philadelphia Water Department

Prepared by

CH2MHILL

December 2001

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SECTION 1

INTRODUCTION

1. Introduction

1.1 Project Objectives and Methodology

As part of its obligations under the Federal Clean Water Act and the Pennsylvania Clean Streams Law, the City of Philadelphia Water Department (PWD) has initiated a program with an objective to minimize the impact of combined sewer overflows (CSOs) on local receiving waters. One of the proposed strategies for reducing the CSO volume is to maximize flow to be treated by the water pollution control plants (WPCPs) during periods of wet weather. To implement this strategy effectively, the PWD needs to have a clear understanding of the factors that affect how much flow each of the three WPCPs can effectively treat. With this knowledge, the PWD will be able to identify and prioritize plant upgrades and other system modifications that will allow it to meet their CSO minimization objectives in the most environmentally-sound and cost-effective manner.

The PWD contracted CH2M HILL to conduct stress testing at the three wastewater treatment plants that are owned and operated by the City. The objective of the stress testing was to determine the reliable maximum capacity of the existing facilities and identify cost-effective methods of increasing the ability of these facilities to treat peak hydraulic flows associated with wet weather conditions. The major tasks performed during the project are briefly described below.

Historical Data and Operations Review. The objective of the historical data and operations review was to evaluate the physical condition, current loading, and treatment efficiency provided by the existing unit processes. A tour of the plant was conducted, and the process equipment and facilities were examined. Operating records, design information, and engineering drawings were studied to develop a strong understanding of the operations and constraints. Technical Memorandum 1 – Historical Data Review was produced to summarize the results of the site visit and historical data analysis.

Short-Term Stress Test. CH2M HILL performed a series of capacity and diagnostic tests to determine the loading versus performance characteristics of specific unit processes at each facility. The short-term stress testing focused on determining the response of the primary and secondary clarifiers to increased hydraulic loading under different operating conditions. The short-term stress testing at the Northeast WPCP (NEWPCP) included primary clarifier stress tests, secondary clarifier stress tests, secondary clarifier dye tests, and flow meter calibration. The results of each test are summarized in a test description report in Technical Memorandum 2 – Short-Term Test Results.

Long-Term Stress Test (Online Monitoring). Online monitoring equipment was installed to quantify the dynamic load/response characteristics of the secondary treatment system to naturally-occurring storm events. The equipment was also used to monitor the effect that increased flows had on the solids inventory in the system and the secondary effluent quality. Online monitoring included total plant flow, return activated sludge (RAS) flow, mixed liquor suspended solids (MLSS) concentration, sludge blanket levels, and secondary effluent total suspended solids (TSS) concentration. The equipment was in place from March

1 to June 30, 1999 and recorded data on a 10-minute interval. The results of the long-term stress test are summarized in Technical Memorandum 3 – Long-Term Online Monitoring Results. The detailed online monitoring data and instrument calibration records are provided under separate cover.

Hydraulic Throughput Capacity Assessment. WinHYDRO, a computer model that facilitates complex analysis of plant hydraulics, was used to evaluate the hydraulic throughput capacity of the Northeast WPCP. Hydraulic and energy grade lines from the headworks to the plant outfall were developed for the average and peak flow conditions. Hydraulic bottlenecks, which limit the hydraulic throughput capacity of the existing facilities, and flow distribution problems were identified and evaluated. The hydraulic throughput capacity of each unit process was determined. The results of the hydraulic modelling performed are summarized in Technical Memorandum 4 – Hydraulic Throughput Capacity of Existing Facilities.

Evaluation of Potential Improvements. Based upon results on stress testing and hydraulic modeling, major bottlenecks that limit plant capacity were identified and potential solutions developed to increase peak instantaneous capacity. Budgetary cost estimates were developed for each potential solution. The results of this analysis are summarized in Technical Memorandum 5 – Budgetary Cost Estimates for Potential Plant Improvements.

1.2 Report Organization

The project notebook consists of a final report and a series of attachments. The main body of the report contains a summary of the results from the stress testing, plant data analysis, and the evaluation of process improvements and upgrade options. The detailed results from the historical data review, short-term testing (stress tests, dye tests and flow meter calibration), online monitoring, and hydraulic throughput capacity assessment are included in the project notebook as attachments. Tables describing the design criteria, scope of work, estimated capital costs for the potential process modifications and capital upgrades, and the current National Pollution Discharge Elimination System (NPDES) discharge permit for the site are also included as attachments.

SECTION 2

CURRENT PERFORMANCE

2. Current Performance

2.1 Description of Facilities

Figure 2.1 presents a flow schematic and Table 2.1 summarizes the existing unit processes at the NEWPCP.

TABLE 2.1
NORTHEAST WPCP - SUMMARY OF UNIT PROCESSES

Unit Process	Number	Description
Bar Screens	7 1	Width = 8 ft, single-rake front cleaned, 1-in. opening Width = 8 ft, multiple-rake front cleaned, 5/8-in. opening
Low-Level Pumps	6	Centrifugal pumps Q = 85 mgd, at 55-ft head
Grit Removal	4	Rectangular detritors Length = 55 ft, width = 55 ft, SWD = 7.5 ft, volume = 22,690 ft^3 (each)
Influent Flow Meter	2 1	Venturi – 48 inch – Set 1 primary clarifiers Venturi – 66 inch – Set 2 primary clarifiers
Primary Clarifiers	8 (Set 1)	Length = 240 ft, width = 65 ft, SWD = 10 ft Surface area = 15,600 ft^2, weir length = 450 ft (each) C and F sludge mechanism, influent end hopper
	4 (Set 2)	Length = 250 ft, width = 125 ft, SWD = 10 ft Surface area = 31,250 ft^2, weir length = 900 ft (each) C and F sludge mechanism, influent end hopper
Aeration Basin	7	Four-pass – through flow only Length = 371 ft, width = 87 ft, SWD = 15 ft, volume = 3.286 mg (each) Operate with selector
Aeration System		
Blowers	4 2	Centrifugal Q = 35,000 acfm Centrifugal Q = 27,000 acfm
Diffusers	Fine bubble	Ceramic; 12,000 per tank
Secondary Settling Tanks	8 (Set 1)	Length = 214 ft, width = 75 ft, SWD = 11 ft Surface area = 16,100 ft^2, weir length = 860 ft (each) Gould-type central hopper, C&F sludge mechanism
	8 (Set 2)	Length = 231 ft, width = 70 ft, SWD = 13 ft Surface area = 16,200 ft^2, weir length = 860 ft (each) Gould-type central hopper, C and F sludge mechanism
Chlorine Contact Chamber	2	Three-pass serpentine flow Length = 300 ft, width = 84 ft, SWD = 11 ft, volume = 2.06 mg Chlorine gas solution feed
Sludge Thickening	12	Dissolved air flotation Length = 90 ft, width = 20 ft, SWD = 12 ft
Anaerobic Digesters	8 (Set 1) 2	Digesters - Diameter = 110 ft, SWD = 30 ft, volume = 300,000 ft^3 (each) Sludge transfer tanks Volume = 1.5 mg (each) Diameter = 96 ft, SWD = 26 ft

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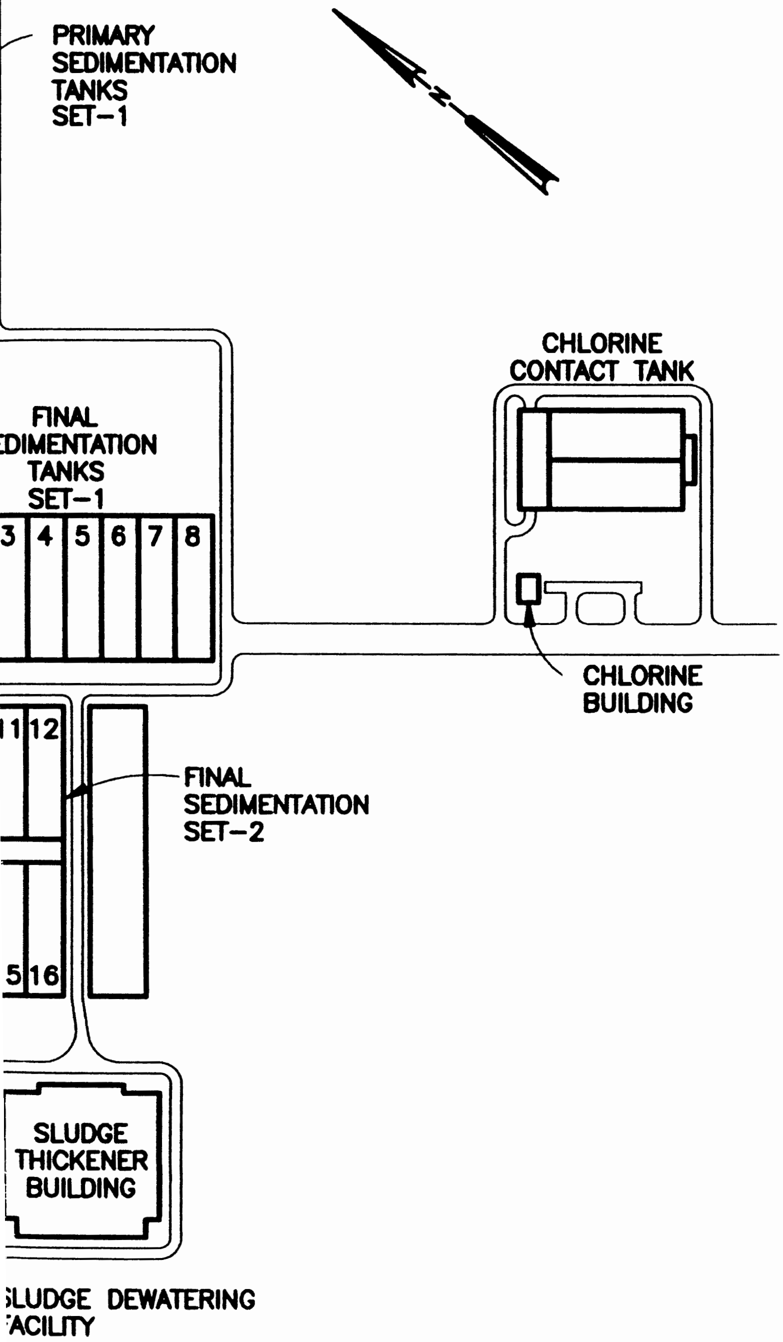

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WATERLOO ONTARIO
PROJECT No. *100U60689.01*

FIGURE 2-1
FLOW SCHEMATIC
NORTHEAST WPCP

CITY OF PHILADELPHIA WATER DEPARTMENT

2.1.1 Preliminary Treatment

The NEWPCP receives wastewater from the Frankford high-level sewer and the Frankford, Somerset, and Delaware low-level sewers. The Frankford high-level sewer flows by gravity through the high-level screens to preliminary treatment and provides approximately 28 percent of the raw sewage flow to the facility. The remaining 72 percent of the raw sewage flows via gravity through the low-level screens into the raw sewage pump station where it is pumped to detritor tanks. The low-level screens are susceptible to blinding during high loadings (autumn leaf litter) due largely to the long travel time of the single rake mechanism. A new screen, with multiple rakes, has been installed and is not performing satisfactorily.

There are six raw sewage pumps with a rated capacity of 85 mgd at 55 of feet head, each equipped with variable speed drive. The pump operation is manually controlled based on the level in the pump station wet well. The maximum water surface level (WSL) in Junction Chamber "A" (before overflows could occur in the collection system) is 18.5 ft. Operators control the raw sewage pump operations to ensure the pump wet well remains below this level. The level in Junction Chamber "A" is maintained between 8 to 10 feet with the influent gate in the fully open position. Either modifying the influent gate position or allowing the water surface level in Junction Chamber "A" to increase above 18.5 feet is considered a flow restriction or flow throttling action. Flow restriction or throttling incidences when the total flow is less than 420 mgd must be reported under the current NPDES requirements. THIS REPORTING MECHANISM IS TIED TO INFLUENT HGL NOT FLOW

The NEWPCP has four rectangular detritor grit removal tanks. Under certain flow conditions the WSL can back up into the grit tanks causing the tanks to overflow and recirculate back through the plant drain system. The hydraulic bottleneck is associated with the piping to the primary clarifiers and is discussed in more detail in Section 3.2.

2.1.2 Primary Treatment

There are two sets of primary clarifiers. The south (Set 2 or old) primary clarifiers consist of four 250 by 125 feet rectangular basins with a side wall depth of 10 feet. Each tank has seven chain and flight mechanisms that move the primary sludge to the influent end of the basin. The tank influent channel has openings at the bottom of the channel. A venturi meter located between the grit tanks and clarifiers measures flow to the south clarifiers. Due to a hydraulic restriction, the maximum flow to the south primary clarifiers is approximately 180 mgd.

The north (Set 1 or new) primary clarifiers consist of eight 240 by 65 feet rectangular basins with a side wall depth of 10 feet. Each tank has four chain and flight mechanisms that move the sludge to the influent end of the basin. There are four gates into each clarifier from the common influent channel located at the bottom of the influent channel. Two venturi meters located between the grit tanks and clarifiers measure flow to the north clarifiers. Due to a hydraulic restriction, the maximum flow to the north primary clarifiers is approximately 240 mgd.

420MGD
TO SECONDARY

2.1.3 Secondary Treatment

The NEWPCP has seven four-pass step-feed aeration basins. The original design of the facility was based on the SURFACT process that used a combination of suspended and attached growth by mounting a series of rotating biological contractor (RBC) units on top of each aeration basin. The RBCs are plagued with mechanical and operational problems and have been taken out of service.

The four-pass aeration basins can be operated in sludge re-aeration or step-feed mode. In addition, the NEWPCP has incorporated a selector zone at the beginning of B and C passes to improve the settling characteristics of the mixed liquor. The facility has been operating in re-aeration mode for several years. However, starting in mid-December 1998, the operations staff observed an increase in the final effluent five-day biochemical oxygen demand (BOD_5) concentration and a resultant decrease in the facility BOD_5 removal efficiency. The cause of the increased final BOD_5 was an inefficiency of the selector caused by an excessively high dissolved oxygen level in the zone. Modifications to the selector zone were made and the problem has been resolved.

The mixed liquor from the seven aeration basins flow into a common mixed liquor channel which feeds three sets of secondary clarifiers. The flow distribution between the sets of secondary clarifiers is not measured and therefore cannot be adequately controlled. There are a total of 16 rectangular secondary clarifiers. Each clarifier has chain and flight mechanisms that transport the sludge to a central hopper located at approximately the mid-length of the clarifier. The RAS rate is flow-paced and is currently operating at approximately 15 percent of the through flow based on the RAS flow meters output. Plant operations staff believe the existing RAS meters underestimate the RAS flow. Based on the measured ratio between the mixed liquor and RAS TSS concentration, the plant operations staff believe RAS is approximately 30 percent of the through flow.

Set 1 consists of eight 75 by 214 feet rectangular clarifiers, with a side wall depth of 11 feet and a common aerated influent (mixed liquor) channel. The flow distribution between the clarifiers in Set 1 is not measured and the operations staff suspects there are some hydraulic and solids loading imbalances between the eight clarifiers, with the downstream clarifiers receiving a larger portion of the overall flow.

Set 2 consists of eight 70 by 231 feet rectangular clarifiers, with a sidewall depth of 13 feet, and the set arranged into two banks of four clarifiers each. Each set of four clarifiers has a common non-aerated mixed liquor and a common final effluent channel. The common effluent channel for the Set 2 clarifiers is a hydraulic bottleneck and under high flow conditions the clarifier launders become flooded.

2.1.4 Disinfection

Disinfection is provided by chlorine solution injected at the upstream end of the chlorine contact chamber. Each basin provides a three-pass serpentine flow pattern and an overflow weir located at the end of the third-pass controls the WSL. The outfall conduits provide additional chlorine contact time for disinfection.

2.1.5 Solids Handling

The NEWPCP has twelve dissolved air floatation tanks (DAFs) to thicken the waste-activated sludge (WAS). The thickened sludge is pumped to the sludge-mixing chamber where it is combined with the primary sludge. The underflow from the DAF units is used as dilution water. Excess underflow is recycled to the head of the plant. Occasionally the DAF units are not able to float the WAS and the underflow from the DAF units has a very high solids concentration. Fortunately this does not occur very often.

The NEWPCP has eight anaerobic digesters with a total volume of 17.9 million gallons. The combined primary sludge and WAS is pumped to the anaerobic digesters sequentially. The digested solids are transported to the Biosolids Recycling Center for composting, beneficial reuse and landfilling.

2.2 Regulatory Requirements

The NEWPCP National Pollution Discharge Elimination System (NPDES) permit limits include effluent BOD_5 and TSS concentrations, mass discharges, and percent removal for daily, weekly (calendar), and monthly averages. Table 2.2 summarizes the NPDES permit criteria for the facility in effect during testing. Compliance is based on the flow measured by the three venturi flumes located upstream of the primary tanks and a 24-hour composite sample collected daily at the chlorine contact chamber outfall.

TABLE 2.2
NORTHEAST WPCP – NPDES PERMIT REQUIREMENTS

Parameter	Units	Monthly Average	Weekly Average	Maximum Day	Peak Instantaneous
BOD_5					
Concentration	mg/L	30	45	-	60
Mass Loading	lbs/day	42,000	63,600		
Percent Removal	%	86			
TSS					
Concentration	mg/L	30	45		60
Mass Lading	lbs/day	52,540	78,810	-	
Percent Removal	%	85			
Flow	mgd	210		315	420

PWD has negotiated a new NPDES permit for this facility effective July 2000. The modifications to the NPDES permit are summarized below. As part of PWD's long-term combined sewer overflow (CSO) control program, PWD will be reducing the frequency and volume of untreated sewage discharges through the CSOs. In order to account for the increased loading due to the combined sewage flows that exceed the treatment plant's rated hydraulic capacity, the following methods may be used for calculating and reporting mass loadings and effluent concentrations on the monthly discharge monitoring reports.

- If a calendar month includes one or more days where flow exceed 315 mgd, a value of 85 percent may be used for those days for the purpose of calculating average monthly TSS percent removal. The actual TSS percent removal associated with those days shall be reported on the appropriate space provided on the DMR.

- If a calendar month includes one or more days where flow exceed 315 mgd, a value of 86 percent may be used for those days for the purpose of calculating average monthly $cBOD_5$ percent removal. The actual $cBOD_5$ percent removal associated with those days shall be reported on the appropriate space provided on the DMR.
- When daily flows exceed 315 mgd, the average monthly and average weekly TSS and $cBOD_5$ mass loadings for those days may be calculated by using the lesser of the actual load or the permit's allowable average monthly and average weekly limit, respectively. The actual TSS and BOD_5 loadings associated with those days shall be reported on the appropriate space provided on the DMR.

PWD has requested that $cBOD_5$ data be used to establish compliance with permit requirements. Analysis of the data collected over the previous permit cycle indicated that there is relatively little variation in the $cBOD_5/BOD_5$ ratio in the plant influent. Therefore, calculating the theoretical $cBOD_5$ loading based on historical BOD_5 data can be used to develop $cBOD_5$ limits for the site. The suggested $cBOD_5$ permit requirements for NEWPCP are:

	Concentration mg/L	Mass Loading lbs/day	Percent Removal %
Average Monthly	25	36,430	86
Average Weekly	40	54,645	
Instantaneous Maximum	50		

A copy of the new NPDES is located in the project notebook.

2.3 Current Loading and Performance Achieved

2.3.1 Unit Process Loading

Table 2.3 presents a summary of the current unit process loading over a three-year period from July 1995 to July 1998. The average and maximum daily flows were 199 mgd and 380 mgd, respectively. The maximum instantaneous flow was 430 mgd.

On September 16, 1999, the total plant flow was greater than 315 mgd from 4:30 a.m. to 10:00 a.m. the following morning. The peak flow was greater than 420 mgd for approximately 13 hours over that timeframe. The water surface level in Junction Chamber "A" was greater than 12 feet starting at 7:00 a.m. on September 16. However, the influent sluice gate was not throttled to restrict the flow to the plant.

TABLE 2.3
NORTHEAST WPCP – SUMMARY OF CURRENT UNIT PROCESS LOADINGS

Unit Process	Units	Current Loadings		Typical Values	Notes
		Average	Maximum		
Loading					
Hydraulic	mgd	199	430		1
Organic					
BOD	lbs/day	217,682	291,207		2
TSS	lbs/day	291,855	442,469		2
Grit Tanks					
Volume (total)	ft^3	90,760			
Area (total)	ft^2	12,100			
HRT	minutes	4.9	2.3	3 – 5	3
Primary Clarifiers					
Area (total)	ft^2	249,800			
Weir Length (total)	ft	7,200			
Surface Overflow Rate	gpd/ft^2	797	1,721	1,000 – 3,000	3
Removal Efficiency					
BOD	%	37		35	
TSS	%	62		60	
Aeration Basins					
Volume (total)	mg	23			
BOD Loading	lbs/day/1,000 ft^3	46	59	20 – 40	2, 3
HRT	hours	2.8	1.3		4, 3
MLSS	mg/L	1,126	2,379		
SVI	mL/g	99		100 – 150	
ISV	ft/hr	15	25		
SRT	day	1.86			3
F/M	1/day	0.82			3
Secondary Clarifiers					
Area (total)	ft^2	258,400			
Weir Length	ft	13,760			
Surface Overflow Rate	gpd/ft^2	770	1,664	600 – 1,500	3
Solids Loading Rate	$lbs/hr/ft^2$	8.8	19.6	20 – 40	3, 5
Chlorination					
Volume	mg	4.12			
HRT	minutes	30	14	15	6

Notes:
[1] Maximum hydraulic loading based on instantaneous flow
[2] Maximum loading based on 95th percentile
[3] Based on all units in service
[4] Based on through flow only
[5] Based on RAS flow rated of 34 percent
[6] Including volume of outfall

The average raw sewage TSS and BOD_5 concentrations are 177 mg/L and 133 mg/L, respectively. The average organic loading to the treatment plant, calculated based on the raw sewage TSS and BOD_5 concentrations and the average flow for each day was 291,855 lbs/day and 217,282 lbs/day, respectively.

2.3.2 Primary Treatment Performance

The average and peak surface overflow rates (SORs) for the primary clarifiers were approximately 800 gpd/ft^2 and 1,700 gpd/ft^2, respectively. Typical overflow rates for rectangular clarifiers are between 1,000 gpd/ft^2 to 3,000 gpd/ft^2. The primary clarifiers at the NEWPCP are operating below their expected capacity based on typical surface overflow rates.

The removal efficiencies are slightly lower than expected considering the low hydraulic loading. The average TSS removal efficiency in the primary clarifiers was 61 percent and 63 percent, respectively for Sets 1 and 2. The Set 2 clarifiers performed slightly better than the Set 1 clarifiers given the hydraulic loading on Set 1 clarifiers was higher due to the hydraulic restriction between the Set 1 clarifiers and the preliminary treatment building. This difference in performance can be attributed to this hydraulic restriction. The BOD_5 removal efficiency in the primary clarifiers was 37 percent and 40 percent, respectively for Sets 1 and 2.

2.3.3 Secondary Treatment Performance

The average primary effluent TSS and BOD_5 concentrations were 87 mg/L and 96 mg/L, respectively. The average and 95th percentile total BOD_5 loadings to the secondary treatment system, calculated based on the primary effluent BOD_5 concentration and the average flow for each day were 142,600 lbs/day and 180,825 lbs/day, respectively.

The aeration basins are currently operating with a solids residence time (SRT) of 1.9 days. The food to microorganisms (F:M) ratio in the aeration basins averaged 0.82 day^{-1}. The F:M is slightly lower in the late summer/early fall due to a higher mixed liquor suspended solids (MLSS) concentration over this period. The average sludge volume index (SVI) between January 1998 and January 1999 was 99 mL/g. This is low for an activated sludge plant, indicating there are few filamentous organisms in the biomass. Operations created a selector zone in the beginning of B and C passes by controlling the air supply. The target SVI during the transition was 80 to 100 mL/g. Typically, the mixed liquor values for a well-settled activated sludge are between 100 mL/g and 150 mL/g. The aeration basin selector reduces the number of filamentous organisms in the mixed liquor and thereby improves the settling characteristics of the sludge. Operational staff reported that the effluent has been turbid in the winter months because of the absence of the "sweeping action" associated with filaments. Improvements to the selector zone being operated has not resulted in a reoccurrence of these turbid events. Current SVI's range from 80 to 100 mL/g.

Using average values, a mass balance around the secondary clarifiers was performed to check the reliability of the solids inventory data. The measured RAS flow was approximately 15 percent of the total plant flow. The error difference between the measured solids in, and the measured solids out of the secondary clarifier was approximately 194 percent. The expected level of accuracy for this type of analysis is +/- 10 percent. Based on the mass balance calculation, the RAS flow is approximately 34 percent of the flow into the aeration basin.

The average and peak SORs for the secondary clarifiers were approximately 770 gpd/ft^2 and 1,660 gpd/ft^2, respectively. Typical SORs for rectangular Gould-type clarifiers are between 800 gpd/ft^2 to 1,500 gpd/ft^2. The secondary clarifiers at the NEWPCP are operating at or beyond the expected maximum hydraulic capacity based on typical SORs.

The average and peak solids loading rates (SLRs) for the secondary clarifiers were approximately 9 lbs/day/ft^2 and 20 lbs/day/ft^2 based on RAS flows of 34 percent (result of mass balance calculation). Typical peak SLRs for rectangular Gould-type clarifiers are between 20 lbs/day/ft^2 and 40 lbs/day/ft^2. The secondary clarifiers at the NEWPCP are operating below the expected maximum hydraulic capacity based on typical solids loading rates.

The secondary clarifiers at the NEWPCP achieve a very good quality final effluent even though the hydraulic loading rates are close to the expected maximum capacity. The daily TSS and BOD$_5$ concentrations were below the NPDES criteria of 60 mg/L except for one day in October 1995 and three days in January 1996 when the TSS concentrations exceeded the discharge limit. Based on a 30-day running average, the final effluent TSS load to the receiving water and percent removal did not exceed the NPDES criteria of 52,540 lbs/day and 85 percent removal. However, the BOD$_5$ load to the receiving water and percent removal did exceed the NPDES criteria on one occasion in January 1996. The NPDES permit is based on the calendar month.

SECTION 3

CURRENT CAPACITY

3. Current Capacity

3.1 Treatment Capacity

The reliable treatment capacity of the unit processes at the NEWPCP was estimated using a combination of manufacturers information, standard engineering design loading and performance criteria, operations staff observations of previous performance, and field testing of specific unit processes.

The field testing conducted at the NEWPCP included the following:

Online Monitoring Data

- Secondary clarifier 7
- Plant flow, RAS flow, mixed liquor TSS, sludge blanket level, and effluent TSS from March 1 to June 30, 1999

Primary Clarifier Stress Tests

- Primary clarifier 12 – Set 2 clarifiers
- Primary clarifier 1 – Set 1 clarifiers normal sludge pumping operation
- Primary clarifier 1 – increased sludge pumping

Secondary Clarifier Stress Tests

- Secondary clarifier 2 – current mixed liquor concentration (approximately 1,000 mg/L)
- Secondary clarifier 2 – increased mixed liquor concentration (approximately 2,000 mg/L)

Secondary Clarifier Dye Tests

- Secondary clarifier 2 – Set 1 clarifiers
- Secondary clarifier 12 – Set 2 clarifiers
- Secondary clarifier 15 – installed longitudinal baffle and sludge hopper hat
- Secondary clarifier 16 – installed longitudinal baffle

Table 3.1 summarizes the estimated treatment capacity for each unit. The basis of the estimated capacity is discussed below. The detailed field test results are presented in Technical Memorandum 2 – Short-Term Test Results and Technical Memorandum 3 – Long-Term Online Monitoring Results.

TABLE 3.1
NORTHEAST WWTP TREATMENT CAPACITY ASSESSMENT

Unit Process	Estimated Capacity (mgd)	Criteria
Pumping and Screening	500 mgd – screening and raw sewage pumping capacity	
	Low-level interceptor[1] – 375 mgd	Observed capacity of pumps
	High-level interceptor – 125 mgd	Observed maximum flow
Grit Removal	525 mgd – grit removal [2]	SOR – 58,000 gpd/ft^2
Primary Treatment	460 mgd – existing	Based on allowable SOR
	505 mgd – modified inlet baffle	SOR – 2,500 gpd/ft^2
	567 mgd – improved sludge pumping	SOR – 2,800 gpd/ft^2
	710 mgd – potential	SOR – 3,500 gpd/ft^2
	Set 1[3] – 273 mgd (existing)	2,500 gpd/ft^2 – test results
	Set 2[3] – 187 mgd (existing)	2,000 gpd/ft^2 – test results
	Set 2 – 235 mgd (modified inlet baffle)	2,500 gpd/ft^2 – test results
Aeration Basins	N/A – no change to organic loading patterns	
Secondary Clarifiers	270 – 380 mgd – existing condition	Long-term monitoring results
	440 mgd – improved flow/solids distribution between clarifiers	Based on allowable SOR – 1,800 gpd/ft^2
	322 mgd – mixed liquor concentration 2,000 mg/L	Based on allowable SLR – 30 lbs/day/ft^2
Chlorine Contact Chamber	430 mgd – meeting disinfection requirements at current flows	
	800 mgd – volume of chlorine basin and plant outfall	HRT – 15 minutes

[1] Based on one pump and one screen out of service
Rated capacity of raw sewage pumps – 85 mgd at 55 feet TDH, Observed maximum capacity 75 mgd
Channel velocity of screens – 0.41 ft/s at 5 ft channel depth

[2] Based on removal of 60 mesh (0.25 mm) particles

[3] Based on one clarifier out of service

3.1.1 Preliminary Treatment

The estimated treatment capacity of the preliminary treatment system is 500 mgd. This is based on the observed capacity of 75 mgd of the existing pumps with five of the six pumps in service, plus an estimated capacity of 125 mgd for the Frankford high-level sewer. For peak flow conditions, the face velocity for the bar screens will vary from 0.2 ft/s to 0.4 ft/s. The face velocity is determined by the pump wet well level that controls the water depth through the bar screen channel.

The estimated treatment capacity of the grit removal tanks is 525 mgd. This is based on three of the four grit detritors being in service, with an allowable SOR of 58,000 gpd/ft^2. The expected removal efficiency of the grit removal system under peak flow conditions is 90 percent of particles greater than 60 mesh (25 mm).

3.1.2 Primary Treatment

Six primary stress tests were conducted at the three wastewater treatment plants owned and operated by the PWD. Table 3.2 summarizes the physical characteristics of the clarifiers at each site and the stress tests performed. The primary clarifiers at all three plants are hydraulically similar. Differences in behaviour are the result of differences in influent characteristics and minor differences in influent and effluent structures.

TABLE 3.2
PRIMARY CLARIFIERS STRESS TEST PERFORMED

Site	SEWPCP	SWWPCP	NEWPCP	
Clarifier dimension			**Set 1**	**Set 2**
# of clarifiers	4	5	8	4
Type	Rectangular	Rectangular	Rectangular	Rectangular
Length (ft)	250	250	240	250
Width (ft)	125	125	65	125
SWD (ft)	12	12	10	10
Sludge Removal				
Hopper location	Influent end	Influent end	Influent end	
Sludge collection	Chain & flight	Chain & flight	Chain & flight	
Pumping freq.	Once every two days	Once per day	Three times per day	
Influent structure				
Channel	Common	Common	Common	Common
Clarifier openings	Orifice and weirs	Orifice	Orifice	Orifice
Openings/clarifier	8 Orifices and 14 weirs	8	4	12
Location	Surface and mid-level	mid SWD	Bottom SWD	Surface and Bottom SWD
Baffling	Yes	Yes	yes	Yes
Effluent structure				
Type	Lateral launders	Finger launders	Finger launders	Finger launders
Orientation	Cross flow	Longitudinal	Longitudinal	Longitudinal
Weir length (ft)	193	307	137	274
Launders	3	21	12	24
Test performed	1	2	2	1
Target SOR (range) gpd/ft^2	1,000-2,400	1,000-3,500	1,000-3,000	750-2,800

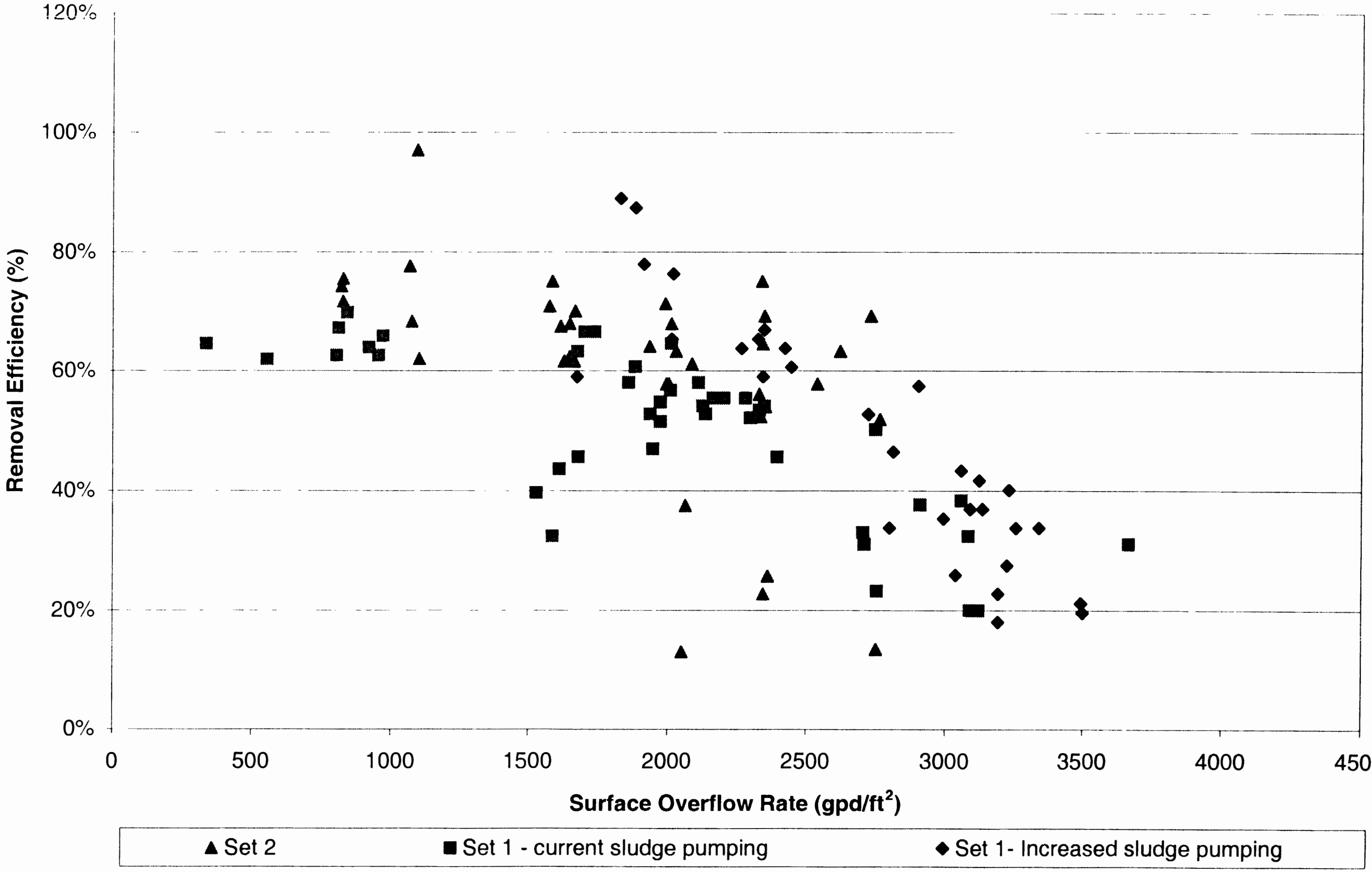
Three stress tests were performed on the primary clarifiers at NEWPCP. Figure 3-1 presents the measured TSS removal efficiency as a function of the SOR observed during the three stress tests. The test procedures and detailed results are described in Technical Memorandum 2; the main findings are summarized below.

Set 2 Primary Clarifiers. The stress test on primary clarifier 12 indicated that the clarifier performance began to deteriorate at a SOR of 2,000 gpd/ft^2, with an increase in effluent suspended solids and removal efficiency of less than 60 percent. At a SOR of 2,400 gpd/ft^2, the solids in the cross-collection channel were re-suspended, resulting in a short-term catastrophic failure of the clarifier. Clouds of black solids were observed in the influent end of the clarifier and the primary effluent TSS concentrations were greater than 100 mg/L for approximately 45 minutes. Catastrophic failure occurred again at a SOR of 2,700 gpd/ft^2. The sludge blanket in the clarifier rose throughout the test.

Set 1 Primary Clarifiers. The stress test on primary clarifier 1 indicated that the clarifier performance began to deteriorate at a SOR of 2,500 gpd/ft^2, with a TSS removal efficiency of less than 50 percent. The sludge blanket in the clarifier remained relatively constant through the test, rising slightly at the effluent end of the clarifier at the end of the test period. The re-suspension of solids from the cross-collection channel was not observed during this test. A second stress test on primary clarifier 1 was performed to quantify the improvement that could be achieved by increasing the primary sludge removal rate. The primary sludge pumps were operated for five out of every 20 minutes to simulate an underflow rate of 250 gpm for the test period. The TSS removal efficiency improved at all SORs tested. The removal efficiency was greater than 60 percent for a SOR of up to 2,800 gpd/ft^2. The clarifier performance deteriorated significantly at a SOR of 3,200 gpd/ft^2. The sludge blanket level remained below one foot throughout the test.

The estimated treatment capacity of the primary clarifiers is 460 mgd. This is based on two clarifiers being out of service (one clarifier in each set) and an allowable SOR of 2,500 gpd/ft^2 and 2,000 gpd/ft^2 for the Set 1 and Set 2 clarifiers, respectively. Modifications to the Set 2 clarifier inlet openings to direct the flow upward and away from the influent sludge hopper would result in an increase in primary treatment capacity of 505 mgd. Increasing the primary sludge pumping rate from the clarifiers would increase the primary treatment capacity to over 550 mgd. The primary stress test at SWWPCP indicated that these clarifiers are able to achieve 60 percent TSS removal efficiency at a SOR of 3,500 gpd/ft^2 with modifications to the inlet structures and improved solids removal. The potential maximum capacity of the primary clarifiers at the NEWPCP is 710 mgd with two clarifiers out of service based on an allowable SOR of 3,500 gpd/ft^2.

Figure 3-1
Comparison of Primary Clarifier Performance
TSS Removal Efficiency versus Surface Overflow Rate (SOR)



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3.1.3 Secondary Treatment

Six secondary clarifier stress tests were conducted at the three wastewater treatment plants owned and operated by the PWD. Table 3.3 summarises the physical characteristics of the clarifiers at each site and the secondary clarifier stress tests performed. The secondary clarifiers at all three plants are very similar and performed similarly. Differences in performance were largely the result of differences in mixed liquor settling characteristics and solids loading during the tests.

TABLE 3.3
PHYSICAL CHARACTERISTICS OF THE SECONDARY CLARIFIERS TESTED

Site	SEWPCP	SWWPCP	NEWPCP	
Clarifier dimension			**Set 1**	**Set 2**
# of clarifiers	12	20	8	8
Type	Gould	Gould	Gould	Gould
Length (ft)	214	260	214	231
Width (ft)	68	75	75	70
SWD (ft)	11	11	11	13
Sludge Removal				
Hopper location	mid length	mid length	mid length	
Sludge collection	Chain & flight	Chain & flight	Chain & flight	
RAS removal	Gravity to sump	Pump per clarifier	Common pump	
RAS rate	30%	35%	15-30%	
MLSS	1,300	2,100	1,100	
Influent structure				
Channel	Common to 6	Common to 10	Common to 8	Common to 4
Clarifier openings	Adjustable weir	Orifice	Overflow Weir	Overflow Weir
Number per clarifier	4	4	4	4
Location	Top	Surface	Surface	Surface
Baffling	Yes	Yes	No	Yes
Effluent structure				
Type	Finger Launders	Finger Launders	Finger Launders	Finger Launders
Orientation	Longitudinal	Longitudinal	Longitudinal	Longitudinal
Weir length (m)	784	816	850	850
Number of Launders/	24	12	24	24

TABLE 3.3
PHYSICAL CHARACTERISTICS OF THE SECONDARY CLARIFIERS TESTED

Site	SEWPCP	SWWPCP	NEWPCP	
Test performed				
Stress test	2	1	0	3
Target SOR (range) gpd/ft^2	860-2,000	600-2,100		1,000-2,100
Dye tests	1	0	3	1

Three stress tests were performed on the Set 1 secondary clarifiers. The test procedures and results are described in Technical Memorandum 2; the main findings are summarized below. Stress tests were not performed on the Set 2 clarifiers because of the difficulty in measuring flow to the test tank.

Four dye tests were performed on the secondary clarifiers. The dye tests included secondary clarifier 2 (Set 1), secondary clarifier 12 (Set 2), secondary clarifier 15 (with longitudinal baffle), and secondary clarifier 16 (longitudinal baffle plus sludge hopper hat). The test procedures and results are described in Technical Memorandum 2; the main findings are summarized below.

The performance of the secondary clarifier 7 was monitored over a four-month period using online instrumentation to quantify the dynamic performance of the clarifiers to naturally-occurring storm events. The online instrumentation recorded total plant flow, set 1 RAS flow, mixed liquor TSS concentration, sludge blanket levels, and effluent TSS concentration. The results of the online monitoring are summarized below; more detailed results are presented in Technical Memorandum 3.

Stress Test Results. Three stress tests were conducted on secondary clarifier 2. Figure 3-2 presents the effluent TSS concentration as a function of the SOR. The first test was conducted in the summer at current mixed liquor concentration. The second and third stress tests were conducted in September at current and elevated mixed liquor concentrations. The mixed liquor concentration of the Set 1 clarifiers was increased by modifying the RAS distribution to the aeration basins. Aeration basins 6 and 7 preferentially feed the Set 1 secondary clarifiers.

The stress tests conducted at current mixed liquor concentrations (Tests 1 and 2) indicated that the clarifier performance began to deteriorate at a SOR of 1,800 gpd/ft^2. The effluent TSS concentration remained below 25 mg/L throughout the test and catastrophic failure of the clarifier was not observed. The mixed liquor concentration and SVI during test 1 was 890 mg/L and 151 mL/g. The mixed liquor concentration and SVI during Test 2 were 970 mg/L and 103 mL/g, respectively. The clarifier performed slightly better during the second test. The SVI range corresponds to the range normally experienced at the facility. The mixed liquor concentrations were approximately 20 percent lower than the average mixed liquor for the facility.

The stress tests conducted at elevated mixed liquor concentrations (Test 3) indicated that the clarifier deteriorates rapidly at a SOR of 1,600 gpd/ft^2. Catastrophic failure of the clarifier was observed and the sludge blanket increased under the effluent launders and started to washout. The failure mechanism was a solids-flux-type failure and the test was terminated once failure was achieved. The mixed liquor concentration and SVI during Test 1 were 1,930 mg/L and 95 mL/g. The mixed liquor concentration was approximately 70 percent higher than the average mixed liquor for the facility.

Figure 3-3 presents the effluent TSS concentration as a function of solids loading rate (SLR) for the three stress tests conducted. The secondary clarifier failed at a SLR of approximately 30 lb/ft^2 per day. The estimated capacity of the secondary clarifiers will decrease with increasing mixed liquor concentrations.

Dye Test Results. Dye tests were used to evaluate the hydraulic efficiency of the secondary clarifiers. Four clarifier dye tests were performed; one dye test for each clarifier type and baffling configuration used at the facility. The test results from clarifiers 2 and 12 indicated that the hydraulic characteristics of the Set 1 and Set 2 clarifiers are very similar. The stress test results from clarifier 2 can be used to estimate the performance of the Set 2 clarifiers.

The test results from clarifiers 15 and 16 indicated that the longitudinal baffle does not improve the hydraulic characteristics of the clarifier. A more pronounced sludge density current was observed in the baffled clarifiers than in the unbaffled clarifiers.

Online Monitoring Results. The online monitoring recorded the response of secondary clarifier 7 to six storm events. Table 3.4 summarizes results of the online monitoring program. The secondary clarifier TSS concentration exceeded 60 mg/L for short periods of time during each storm. The effluent TSS concentration rose significantly at plant flow rates between 270 mgd to 380 mgd. The maximum SOR based on total plant flow and number of clarifiers in service during the storm events ranged from 1,310 gpd/ft^2 to 1,700 gpd/ft^2. This is significantly lower than the maximum allowable SOR observed during the secondary clarifier stress test. The difference between the stress test and long-term monitoring results indicates a significant imbalance in the flow and solids distribution between the secondary clarifiers.

TABLE 3.4
RESULTS OF THE ONLINE MONITORING PROGRAM

Date	SVI	MLSS	Q	Q Peak	SOR	SOR Peak	TSS Effluent Peak
March 3	95	998	270	340	1,040	1,310	80
March 6[1]	2*	1,643	300	388	1,160	1,500	93
March 6 and 7[1]	2*	1,240	325	370	1,250	1,430	93
March 21	94	1,219	300	410	1,240	1,700	153
April 9	133	1,117	360	394	1,490	1,630	191
April 11	2*	1,406	380	390	1,570	1,610	195
April 16	137	1,081	330	400	1,370	1,660	70

* Measurements were not taken on these days

[1] Same measured storm with difference in MLSS measured values

Figure 3-2
Northeast WPCP Secondary Clarifier 2 Stress Tests
Effluent Concentration versus Surface Overflow Rate (SOR)

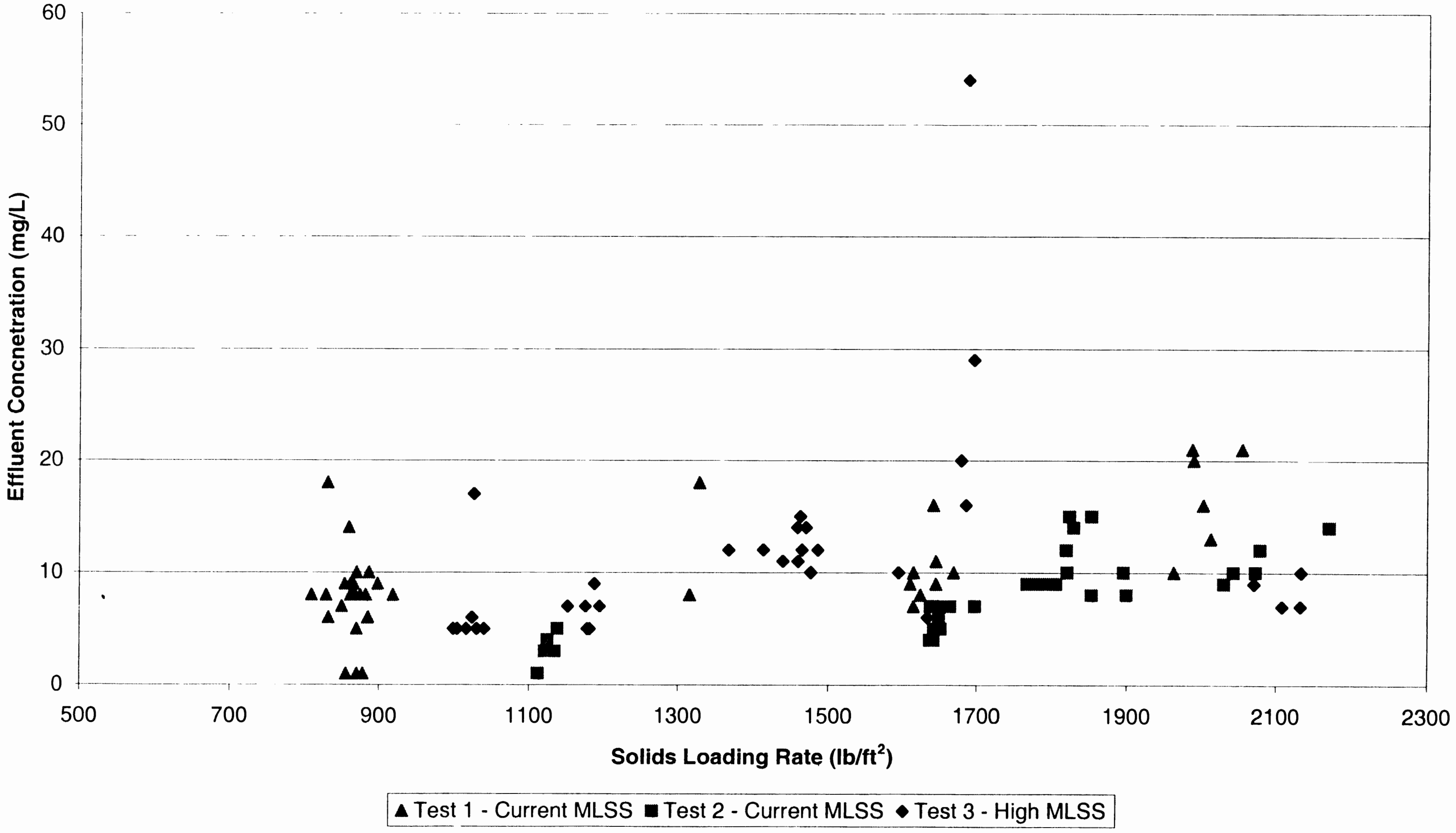

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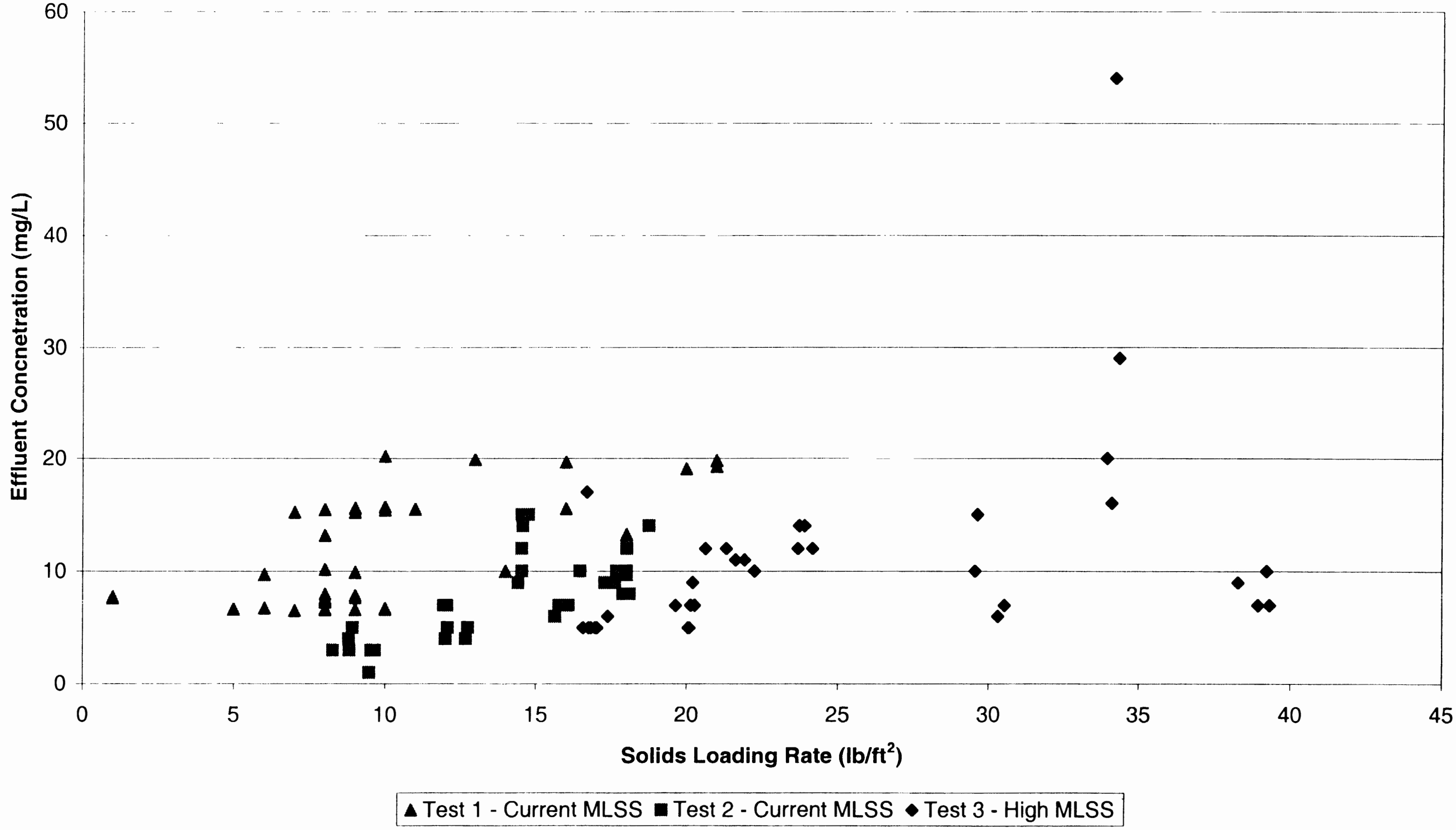
Figure 3-3
Northeast WPCP Secondary Clarifier 2 Stress Tests
Effluent Concentration versus Solids Loading Rate (SLR)



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3.2 Hydraulic Throughput Capacity

The hydraulic throughput capacity of the unit processes at the NEWPCP was estimated using WinHYDRO, a computer model that facilitates complex analysis of plant hydraulics. Hydraulic and energy gradelines from the headworks to the plant outfall were developed for a number of flow rates. The hydraulic throughput capacity of each unit process was developed based on the assumption that the downstream hydraulic bottlenecks had been resolved. Table 3.3 summarizes the estimated hydraulic throughput capacity for each unit process. The detailed hydraulic modelling results are presented in Technical Memorandum 4 – Hydraulic Throughput Capacity of Existing Facilities.

TABLE 3.3
NORTHEAST WWTP CURRENT HYDRAULIC THROUGHPUT CAPACITY

Unit Process	Estimated Capacity (mgd)	Basis of Capacity Estimate
Chlorine Contact Basin	>800	• Flow path – from the chlorine contact basin weir to the chlorine contact flow distribution chamber • Hydraulic control section – chlorine contact chamber weir • Both chlorine contact basins in service with the flow control gates fully open • Hydraulic exceedance – secondary clarifier overflow weir elevation
Secondary Effluent Channel – Set 1	300	• Flow path – from the chlorine contact basin weir to the secondary clarifier 1 overflow weir • Hydraulic control section – chlorine contact chamber weir • Both chlorine contact basins in service with the flow control gates fully open, 50/50 flow split between Set 1 and Set 2 secondary clarifiers; all secondary clarifiers in service • Hydraulic exceedance – secondary clarifier overflow weir elevation
Secondary Effluent Channel – Set 2	190	• Flow path – from the chlorine contact basin weir to the secondary clarifier 9 through 16 overflow weir • Hydraulic control section – chlorine contact chamber weir • Both chlorine contact basins in service with the flow control gates fully open, 50/50 flow split between Set 1 and Set 2 secondary clarifiers; all secondary clarifiers in service • Hydraulic exceedance – secondary clarifier overflow weir elevation
Primary Effluent Channel – Set 1	330	• Flow path – from the secondary clarifier overflow weir to the primary clarifier 1 overflow weir • Hydraulic control section – secondary clarifier overflow weir • A 50/50 flow split between Set 1 and Set 2 secondary clarifiers, 50/50 flow split between Set 1 and Set 2 primary clarifiers; six aeration basins in service • Hydraulic exceedance – primary secondary clarifier overflow weir elevation
Primary Effluent Channel – Set 2	250	• Flow path – from the secondary clarifier overflow weir to the primary clarifier 12 overflow weir • Hydraulic control section – secondary clarifier overflow weir • A 50/50 flow split between Set 1 and Set 2 secondary clarifiers, 50/50 flow split between Set 1 and Set 2 primary clarifiers: six aeration basins in service • Hydraulic exceedance – primary clarifier overflow weir elevation
Primary Clarifier – Set 1	250	• Flow path – from the primary clarifier overflow weir to the grit chamber collection channel • Hydraulic control section – primary clarifier overflow weir • All primary clarifiers in Set 1 in service, four detritors in service • Hydraulic exceedance – top of concrete in the grit removal building

TABLE 3.3
NORTHEAST WWTP CURRENT HYDRAULIC THROUGHPUT CAPACITY

Unit Process	Estimated Capacity (mgd)	Basis of Capacity Estimate
Primary Clarifier – Set 2	180	• Flow path – from the primary clarifier overflow weir to the grit chamber collection channel • Hydraulic control section – primary clarifier overflow weir • All primary clarifiers in service, four detritors in service, butterfly gate valve in the fully open position • Hydraulic exceedance – top of concrete in the grit removal building
Raw Sewage Pump Station Discharge Channel	Version A – 410 Version B – 440	• Flow path – from the Set 1 primary clarifier overflow weirs to the raw sewage pump station discharge channel • Hydraulic control section – primary clarifier Set 1 overflow weir • Version A – flow to Set 2 clarifiers limited to 180 mgd Version B – 50/50 flow split between Set 1 and Set 2 clarifiers • Hydraulic exceedance – top of concrete in the raw sewage pump station

The hydraulic throughput capacity of the NEWPCP is greater than 500 mgd except in the following locations:

- **Primary Clarifier Influent** – The hydraulic throughput capacity of the channel between the preliminary treatment building (grit tanks) and primary clarifiers set 2 is limited to 180 mgd. The headlosses occur in the 5 ft by 7 ft channel section between the set 2 flume (venturi meter) and the primary clarifier influent channel. The hydraulic throughput capacity of the channels between the preliminary treatment building (grit tanks) and the primary clarifiers set 1 is limited to 250 mgd. Therefore, the total hydraulic throughput capacity between the preliminary treatment and primary treatment is 430 mgd. At flow rates above 430 mgd the detritor floor and walkways become flooded. Additionally, at times, the detritor floor has flooded at flows less than 430 mgd for unknown reasons.

- **Secondary Clarifier Set 2 Effluent Channels** – The hydraulic throughput capacity of the set 2 secondary effluent channel is limited to 190 mgd with all secondary clarifiers in service. Excessive headlosses occur in the clarifier discharge channel and common effluent channel due to entrained air escaping through the bottom slots which connect the upper and lower channel sections. The hydraulic restriction contributes to the hydraulic imbalance between the set 1 and set 2 secondary clarifiers. The hydraulic restriction also contributes to flooding of the set 2 secondary clarifier weirs and premature failure of the clarifiers due to localized velocity gradients at the effluent weir.

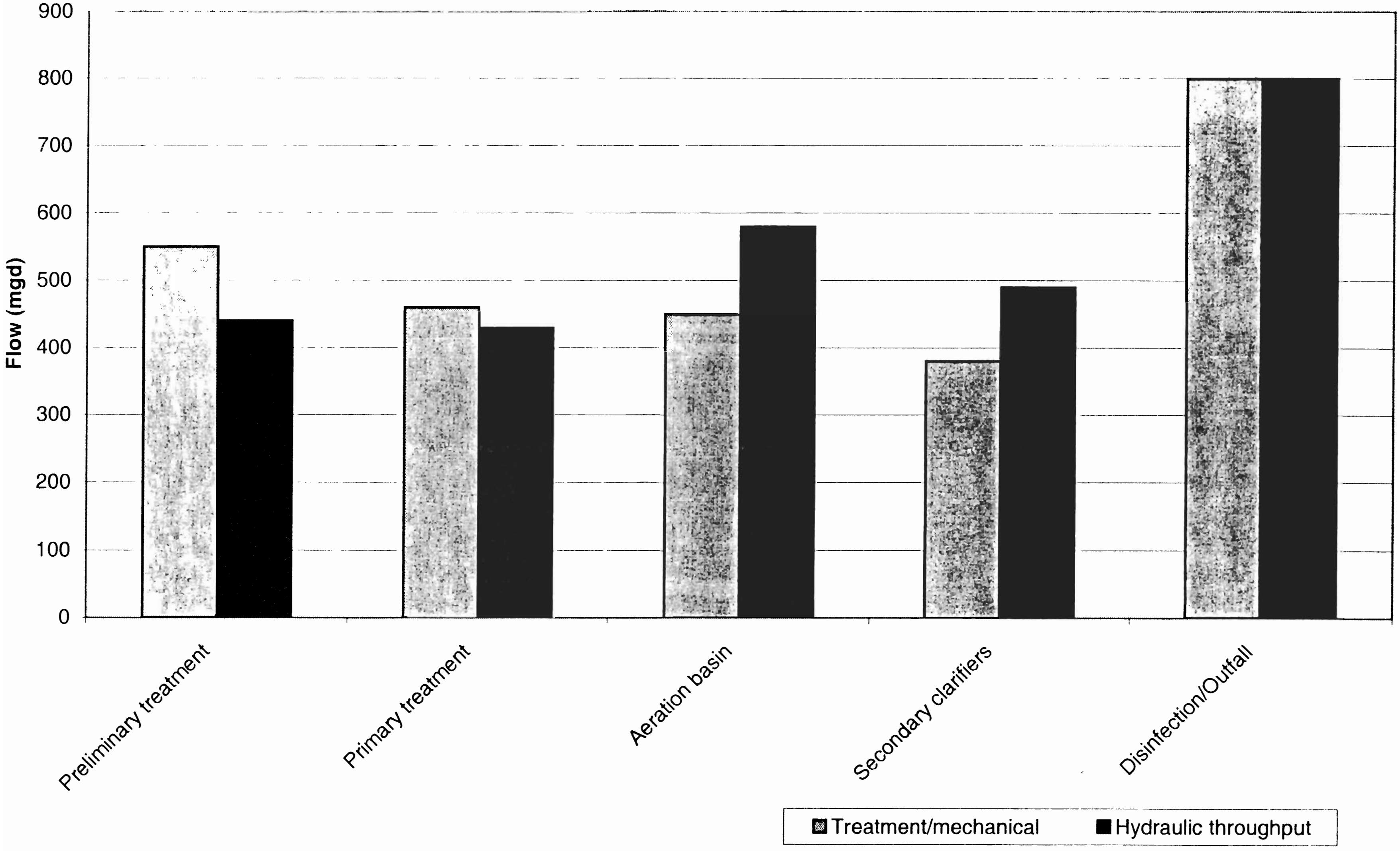
3.3 Capacity Limiting Factors

Figure 3-4 presents a summary of the estimated current capacity on a unit process basis for NEWPCP. The major capacity bottlenecks for the facility are:

- **Secondary Clarifiers** – The treatment capacity of the secondary clarifiers at the NEWPCP is reduced by the difficulties in controlling the hydraulic distribution between the set 1 and set 2 clarifiers and the hydraulic and solids loading between the clarifiers in each set.

- **Primary Clarifiers** – The hydraulic throughput capacity to the primary clarifiers limits the hydraulic throughput of the facility to 430 mgd. The hydraulic restriction between the set 2 primary clarifiers and the preliminary treatment building has a negative impact on the flow distribution between set 1 and set 2 primary clarifiers.
- **Primary Treatment** – The treatment capacity of the set 2 primary clarifiers is limited to 185 mgd due to high velocities caused by the inlet baffle resuspending solids in the clarifier cross collector channel.

Figure 3-4
Northeast WPCP - Estimated Current Capacity



SECTION 4

CURRENT SUSTAINABLE TREATMENT CAPACITY

4. Current Sustainable Treatment Capacity

4.1 Sustainable Treatment

The estimated treatment capacities summarized in section 3 of this report utilise maximum instantaneous limits currently in PWD's NPDES permits as the goal for the effluent quality. Since the maximum instantaneous and maximum daily limits are the same values, a process operation whose final effluent quality will meet the instantaneous maximum limits will also meet the daily maximum limits. However the current NPDES permits, based on expected performance for plants that intake substantial quantities of storm water, include maximum weekly and monthly limits which are significantly more stringent than the daily/instantaneous limits. Furthermore, strict compliance with maximum monthly concentration limits will not guarantee monthly compliance with other quality limits in the permit such as average monthly and weekly loading limits and percent removal requirements.

An important but difficult question remains regarding how long a facility (or process) can sustain high flows which allow effluent quality to meet all the permit effluent quality requirements.

The performance of the secondary clarifiers determines the final effluent quality from the NEWPCP. The data collected during the field-testing was used to predict final effluent quality as a function of flow rate. The predicted final effluent TSS and BOD_5 concentration for a given flow rate was used to determine the maximum flow which could be maintained for an infinite period of time with effluent quality meeting the monthly and weekly loading and percent removal requirements in the NPDES permit.

Secondary clarifier capacity is defined by either the clarification capacity, which is a function of surface overflow rate (SOR), or the solids flux capacity which is a function of solids loading rate (SLR). Clarifier performance as a function of both SOR and SLR was collected during the testing for a range of operating conditions. Data from the six secondary clarifier stress test was used to quantify the secondary clarifier performance as a function of hydraulic loading and to identify the maximum allowable solids loading rate for the clarifiers.

The historical data was used to determine the yield and mixed liquor concentrations required as a function of primary effluent quality. The data from the primary clarifier stress tests was used to determine the expected primary effluent quality as a function of flow rate. The mixer liquor required for the expected primary effluent quality determines the solids loading rate for the secondary clarifier.

4.2 Analysis Methodology

4.2.1 Predicting Secondary Effluent Quality as a Function of the SOR

In the stress tests of the secondary clarifiers, the TSS and BOD_5 concentrations in the secondary effluent were measured as a function of the surface overflow rate applied to the clarifiers. A linear regression was performed on the field testing data to establish the relationship between SOR and TSS and BOD_5 concentrations in the effluent. The intercept and slope values obtained for the regression were statistically analyzed to find the 95% confidence level associated with these two coefficients. Using the upper 95% confidence level interval provides a conservative description of the relationship between the SOR and effluent quality. The model is used to predict TSS or BOD_5 for a given SOR, the value generated using the linear regression will be lower than the actual value observed 95 out of 100 times.

The estimated effluent concentrations and discharge loads (which are equal to the effluent flow rate multiplied by the effluent concentration) can then be compared to permit levels to determine the sustainable treatment capacity of the facility on a SOR basis.

4.2.2 Effect of the SLR on Secondary Clarifier Performance

Failure of the secondary clarifiers may occur either due to clarification or thickening. An increase in the hydraulic loading to the primary clarifiers will result in an increase in organic loading to the aeration basin due to an increase in the amount of organic material entering the plant and deterioration in the primary clarifier performance. An increase in the organic loading to the aeration tanks results in an increase in the mixed liquor concentrations and therefore an increase in he solids loading for a given flow. Therefore the analysis done in terms of the SOR must be complemented with an analysis of the effect of influent flow rate versus SLR.

Stress tests were performed on the primary clarifiers and removal efficiencies as a function of the surface overflow rate in the primary clarifiers were documented. The data was used to predict the quality of the primary effluent as a function of the influent flow rate. This analysis, combined with analysis of historical data on solids production, was used to estimate the SLR as a function of flow, taking into account both the performance of the primary clarifiers and the increase in the organic loading associated with augmented flows.

The stress tests on the secondary clarifiers indicated that the maximum SLR that could be maintained before thickening failure occurs is 35 lb/(ft^2.day). The flow at which these solids loading rates are achieved are the maximum sustained flow that can be maintained in the plant before thickening failure occurs.

4.3 Analysis Results

4.3.1 Predicting Maximum Flows as a Function of the SOR

Figure 4.1 is a plot of the TSS in the secondary effluent and the SOR applied in the secondary clarifier from the six secondary clarifier stress tests conducted at the facilities owned and operated by PWD. The data from all six secondary clarifier stress tests were used in the preparation of this plot. Figure 4.2 presents the same analysis was done for the BOD_5 concentration in the secondary effluent.

The amount of TSS and BOD_5 discharged results from the product of the flow rate and the concentrations predicted by the 95% confidence level regressions. The discharge values were compared to the NPDES Permit values at the time of the test for the NEWPCP. The results of this analysis are presented in Table 4.1.

TABLE 4.1 NORTHEAST WPCP – TEST PERIOD NPDES PERMIT REQUIREMENTS AND RESULTS OF THE SUSTAINABLE FLOW ANALYSIS[1]

Parameter	Units	NPDES Limit	Maximum Sustainable Flow based on SOR		Maximum Sustainable Flow based on SLR
			TSS Limit	BOD5 Limit	
Maximum Day Limits	Mgd	420			375
Maximum Week Limits	Mgd		320	305	
BOD_5 Concentration	mg/L	45			
BOD5 Mass Loading	lbs/day	63,600			
TSS Concentration	mg/L	45			
TSS Mass Loading	lbs/day	78,810			
Maximum Monthly Limits	Mgd	210	260	235	
BOD_5 Concentration	mg/L	30			
BOD_5 Mass Loading	lbs/day	42,000			
BOD_5 Percent Removal	%	86			
TSS Concentration	mg/L	30			
TSS Mass Loading	lbs/day	52,540			
TSS Percent Removal	%	85			

[1] BOD_5 limits based on old permit, plant now monitors $cBOD_5$ for compliance.

The maximum sustainable flow at which the NEWPCP can meet the monthly NPDES TSS and BOD_5 effluent mass loading requirements are 260 and 235 mgd respectively. The maximum month sustainable capacities are slightly higher than the average design capacity of the facility.

Figure 4-1
Secondary Clarifier Stress Test - Effluent TSS Concentration as a Function of SOR

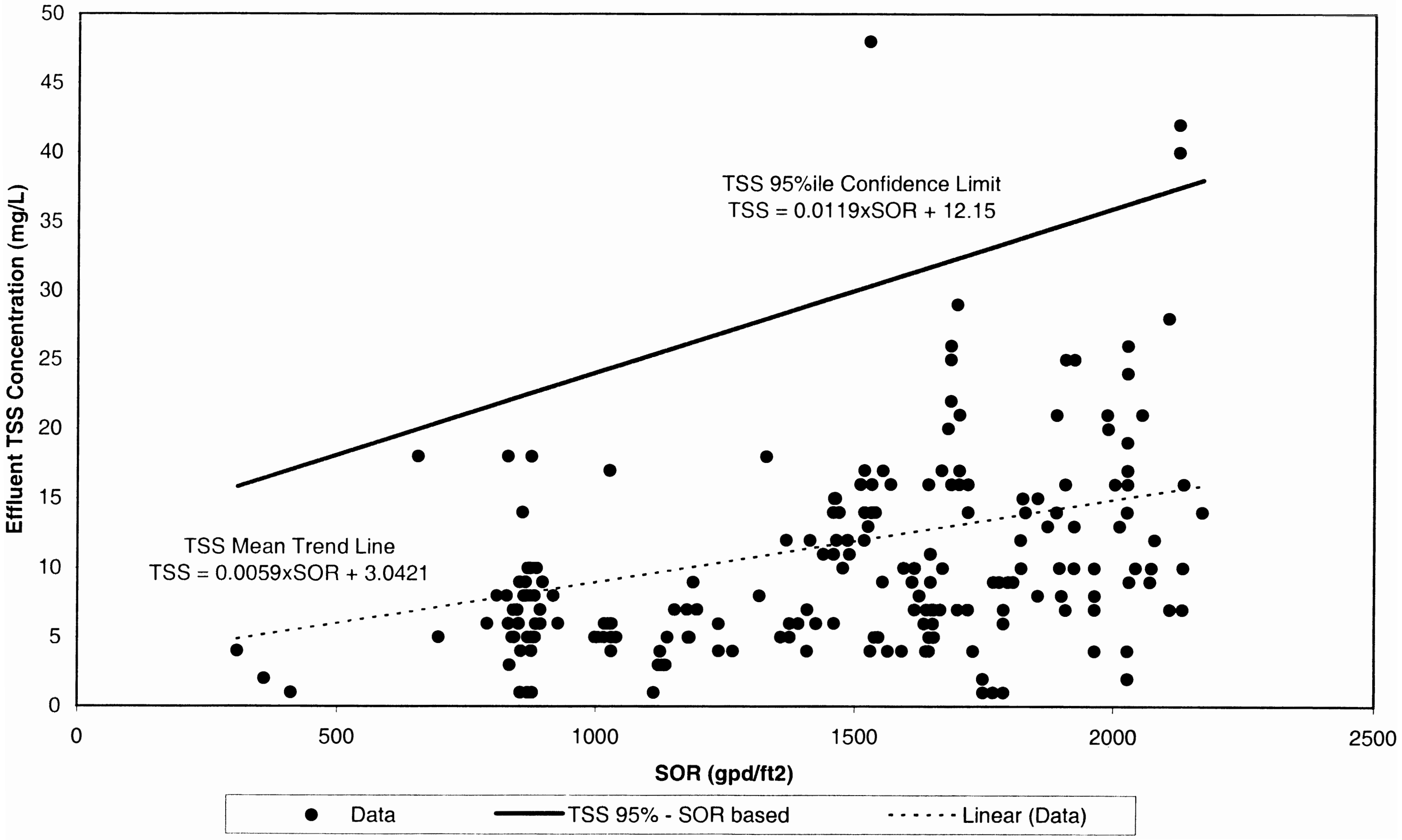
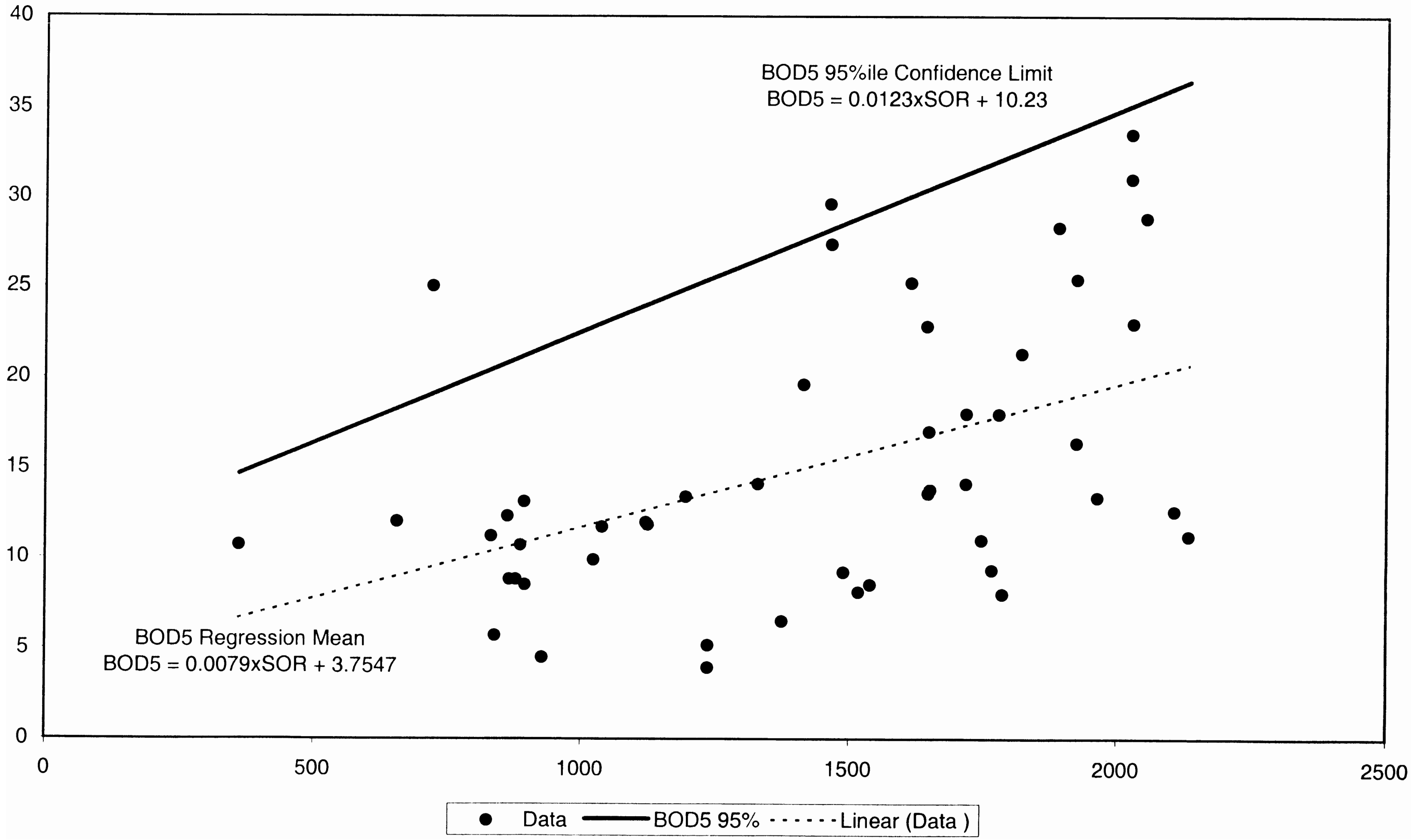


Figure 4-2
Secondary Clarifier Stress Test - Effluent BOD5 Concentration as a Function of SOR



4.3.2 Predicting Maximum Flows as a Function of SLR

The stress tests of the secondary clarifiers indicated that the maximum solids loading rate that could be sustained by the secondary clarifiers was 35 lb/(ft^2.day). The solids loading rate is a function of the MLSS concentration in the aeration basin and the influent and RAS flow rates. The MLSS concentration is dependent on the loading to the aeration basins, which in turn is dependent on the performance of the primary clarifiers as a function of the flow. The objective is to develop an overall correlation between the flow coming into the plant and the resulting solids loading rate into the secondary clarifiers.

The primary clarifier stress test results were used to determine the TSS percent removal in the primary clarifiers as a function of influent flow rate. A regression analysis of all stress test results performed in the primary clarifiers, except the test performed at the Southeast plant where the clarifier failed prematurely due to the hydraulic limitations of the launders, was performed and the lower 95% confidence levels associated with the regression parameters were calculated. Figure 4.3 presents the results of this analysis.

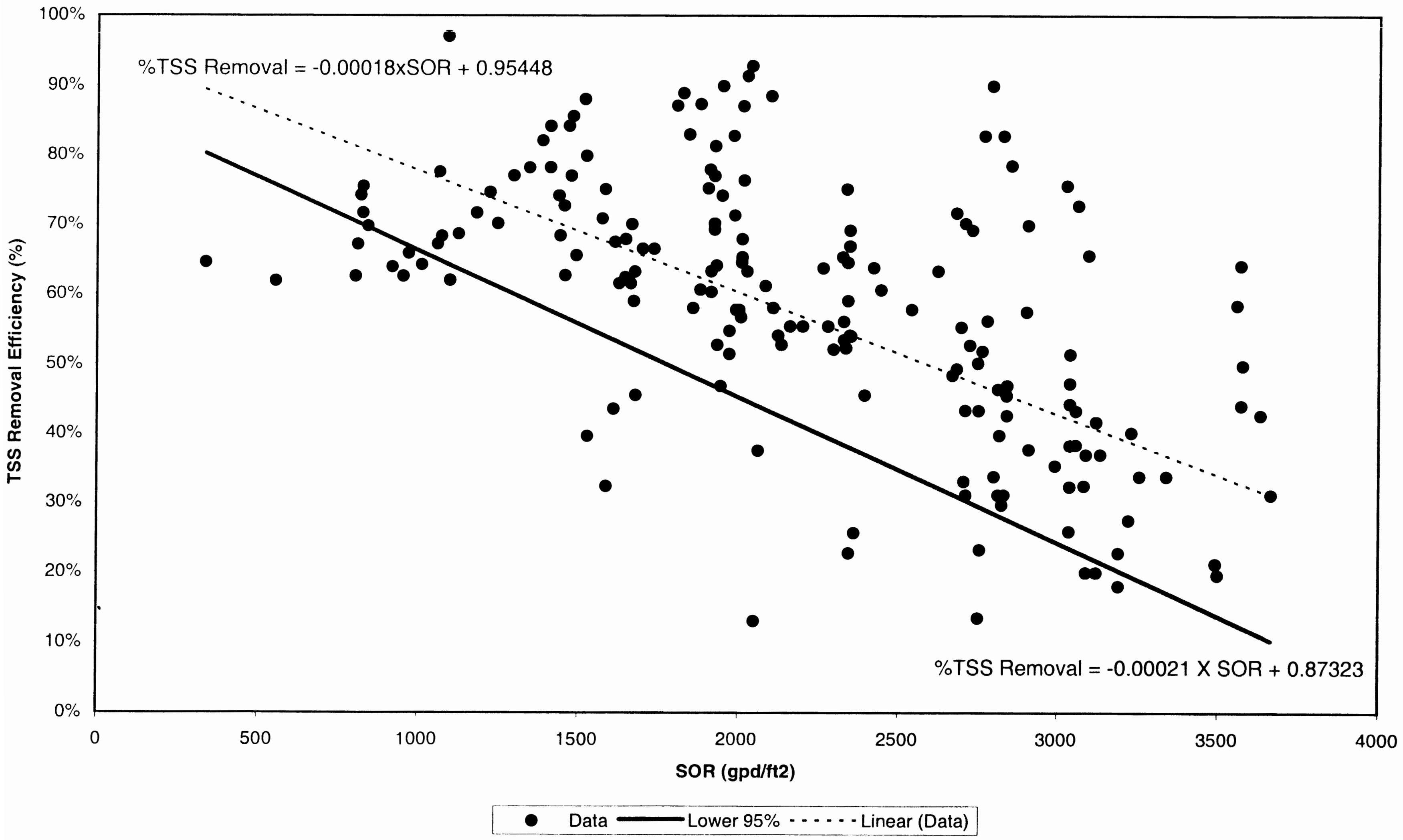
The yield for the NEWPCP was estimated based on the historical data of waste activated produced and the TSS and BOD$_5$ concentrations in the primary effluent. For the determination of the SLR limiting flow it was assumed that all of the primary clarifiers, secondary clarifiers and aeration basins are in service. This corresponds to current operating practice at the site.

The SLR becomes 35 lb(ft^2.day) at the NEWPCP when the sustained flow is equal to 375 mgd. At flow rates greater than 375 mgd thickening failure will occur unless measures are taken to reduce the solids loading rate to the secondary clarifiers. Preventative measures which can be readily implemented at the NEWPCP include modifing the step feed gate postions based on influent flow.

Improving the primary clarifier performance by providing "out of clarifier" primary sludge thickening or enhanced primary clarifier performance through chemical addition would also reduce the solids loading to the secondary clarifiers. These alternatives would require capital expenditure for additional facilities.

Improving the solids removal efficiency of the secondary clarifiers would effectively increase the allowable solids loading rate to the clarifier. This would require modifications to the existing RAS system.

Figure 4-3
Primary Clarifier Stress Test – Percent TSS Removal Efficiency as a Function of SOR



Upgrades to Increase Capacity of Secondary Treatment to 450 MGD

Currently NEWPCP secondary system capacity is limited to 430 mgd. A slight increase to this secondary treatment capacity could be achieved by modifying the Set 2 secondary effluent channel "double decker" structure to improve hydraulics and some modifications to the existing RAS collection and pumping system. Capital costs for these improvements are estimated at $2,410,000.

Increase Wet Weather Treatment Capacity

The NEWPCP has four unused secondary clarifiers on site. These tanks could be modified to provide stormwater treatment equivalent to primary treatment for an additional 100 mgd of flow. The estimated capital cost to modify these tanks is between $5,000,000 and $10,000,000. The estimated capital cost to increase the raw sewage pumping and preliminary treatment by 150 mgd is between $20,000,000 and $24,000,000.

The potential primary treatment capacity at the NEWPCP is 710 mgd. Increased primary sludge pumping would be required to achieve the additional primary treatment capacity. The estimated capital cost for primary sludge thickeing is $12,254,000. The estimated capital cost to increase the raw sewage pumping from 500 to 800 mgd to take advantage of all available tankage on site is between $36,000,000 and $40,000,000.

COST TO TAKE THICKENING/SLUDGE CAPACITY TO 550 MGD = ?

4.4 Control of High Flow Duration

Discussions with PWD managers directing PWD 's CSO program indicated that current CSO in line storage and draw down plans expect that stored combined sewerage would be released to the plant over a 12 hour period following a storm event. This is a volume of combined sewerage that PWD's plants have not received in the past. Furthermore, there is flexibility in the draw down strategy since the primary objective of the effort would be to return the storing sewer back to its original condition prior to the next storm event. It was clear that this is only a current plan and it would change should PWD be required in the future to provide additional combined sewerage storage to meet receiving water quality objectives.

From the wastewater treatment plants perspective, there are a number of factors that influence the ability of a plant to achieve weekly or monthly limits when the plant is being stressed by storm induced high influent flows. The number and distribution of rain events during the week/month together with plant effluent quality during non-rain event periods rank high on the list of influences. PWD's revised permit language provides effluent quality relief but only when the daily plant flow exceeds the permitted maximum daily flows currently stated in the permits. No such relief occurs for flows below the maximum daily flow limits.

Since the impact of stored combined sewerage on the NEWPCP performance is an unchartered experience, it is recommended that the duration of storage be no greater than a 24-hour period for each storm event. Should the CSO program's strategy for stored combined sewerage change beyond this 24 hour period, the issue of plant compliance for all monthly and weekly effluent quality requirements should be reviewed.

SECTION 5

POTENTIAL UPGRADES

5. Potential Upgrades

A list of potential upgrades was developed to increase the capacity or improve the performance of the NEWPCP. The potential improvements are based on the results of stress tests on unit process, long-term monitoring of the plant, and hydraulic modelling.

Each upgrade option has been prioritized based upon the following criteria:

- **Priority A – Existing Facilities Optimization.** Improvements that are easily implemented, low cost, high benefit, and will have an immediate positive impact upon normal operations. These are options that can be included in short-term capital budgets.
- **Priority B – Proactive Improvements.** Improvements that are moderate in cost and will have a small impact on plant capacity. This category also includes improvements that are necessary to maintain existing capacity for increased mixed liquor suspended solids (MLSS) in the aeration tanks. These are options that should be included in a long-term improvement plan.
- **Priority C – Improvements to Increase the Solids Handling Capacity of the Secondary Clarifier.** The stress tests identified that the solids handling capacity of the secondary clarifiers is very limited. This category includes improvements that are necessary to increase the secondary clarifier capacity with current mixed liquor concentration and/or to maintain exisitng capacity if increased mixed liquor suspended solids are required in the future.
- **Priority D - Capacity De-bottlenecking.** Improvements that have large costs associated with them and will greatly increase capacity above the current permitted peak flow. These options should be considered in an overall long-term wet-weather flow control program and in the long-term improvement plan if significantly more treatment capacity is required at the facility.

The list of potential upgrades, budgetary cost estimate, and their associated prioritization are summarized in Table 5.1 below. Detailed descriptions of each upgrade are presented in Technical Memorandum 5 – Budgetary Cost Estimates for Potential Plant Improvements.

The cost estimates shown here are based on preliminary costs and are for use as "budgetary" values only. The cost estimates are Class "C" cost estimates (order of magnitude costs) as defined by the American Association of Cost Engineers. The level of accuracy of the Class "C" cost estimates is +50 percent to –30 percent of the actual cost of construction. These costs can be used for decision-making to select those options that are most feasible from both a design and cost perspective for more detailed analysis.

Table 5.1
Potential Upgrade Options at Northeast WPCP

Option No.	Description	Priority Classification	Estimated Conceptual Cost
1	Improve mixing in mixed liquor channel to secondary clarifiers 9 through 16	A	$472,000
2	Polymer addition on Set 1 secondary clarifiers to maintain effluent quality	B	$22,000
3	Separate flow measurement of secondary effluent from sets 1 and 2	C	Currently undetermined
4	Automation of step feed operation for aeration tanks	A/B	$161,000
5	Modify Set 2 secondary effluent channels to reduce hydraulic restrictions under high flow conditions	B/D	$223,000
6	Modify the existing RAS system in the secondary clarifiers	C	$2,183,000
7	Provide a second conduit to the Set 2 primary clarifiers to convey additional flow to Set 2 Primary tanks	D	$3,312,000
8	Reduce losses and increase capacity between the grit tanks and Set 1 clarifiers by installing another conduit and venturi meter	D	$707,000
9	Provide a bypass from the primary effluent channels to the chlorine contact chamber	D	$8,291,000
10	Provide separate primary sludge thickening	D	$12,254,000
11	Reuse abandoned ABCD tanks as wet weather treatment facility	C	$5.0 – 10.0 million
12	Increase raw sewage pumping and screening	D	
	A - by 50 mgd	D	$10.0 – 12.0 million
	B - by 150 mgd		$20.0 – 24.0 million
	C - by 300 mgd		$36.0 – 40 million

Table 5.1 includes the final estimated cost for each improvement. Table 5.2 below presents a summary of the overall cost for improvements at the Northeast plant, broken down into alternatives that are dependant upon one another for an increase in capacity at the plant.

TABLE 5.2
SUMMARY OF BUDGETARY COSTS FOR POTENTIAL IMPROVEMENTS AT NORTHEAST WPCP

Improvement Alternatives	Total Costs for Improvements (Million $)	Cumulative Costs for Improvements (Million $)	Plant Peak Capacity (mgd)	New Plant Peak Capacity (MGD)		
				Primary	Secondary	Stormwater
Process optimization (Options 1,2, 4)	0.64	0.64	430	430	430	0
Upgrades required to increase capacity of the primary treatment to 550 mgd with secondary bypassing (Options 7, 8, 9, 12A)	23.31	23.95	550	550	430	0
Upgrades required to increase capacity of secondary treatment to 450 mgd (Options 5, 6)	2.41	26.36	550	550	450	0
Increase wet weather treatment capacity						
(Options 11, 12B)	34.00	49.36	650	550	450	100
(Options 10, 12C)	52.25	77.61	800	700	450	100

Process Optimization

The objective of this plan is to improve the performance of the NEWPCP under current wet weather flow conditions by implementing modest capital imrovements and operational changes.

The secondary clarifiers at the NEWPCP are susceptible to solids loading failure under high flow conditions. This project identified upgrades that improve the hydraulic and solids loading distribution between the clarifiers by improving the mixing in the mixed liquor channel and improving flow measurement between sets of clarifiers. Implementing step feed during high flow conditions will reduce the solids loading on the secondary clarifiers and therfore improve performance. The estimated capital cost of these upgrades is $640,000.

Upgrades to Increase Primary Capacity to 550 MGD with Secondary Bypassing

The NEWPCP has additional primary treatment capacity that is unavailable because of hydraulic limitations between the preliminary treatment building and the primary clarifiers. This bottleneck can be resolved by adding a new conduit and venturi meter, as well as a new conduit to the Set 2 primary clarifiers. A bypass channel from the primary effluent to ? WHY the chlorine contact chamber will be required for the additional flow. The estimated capital cost to increase the primary treatment capacity from 430 to 550 mgd, including secondary bypassing and upgrade to the raw sewage pumping, is $23,310,000.

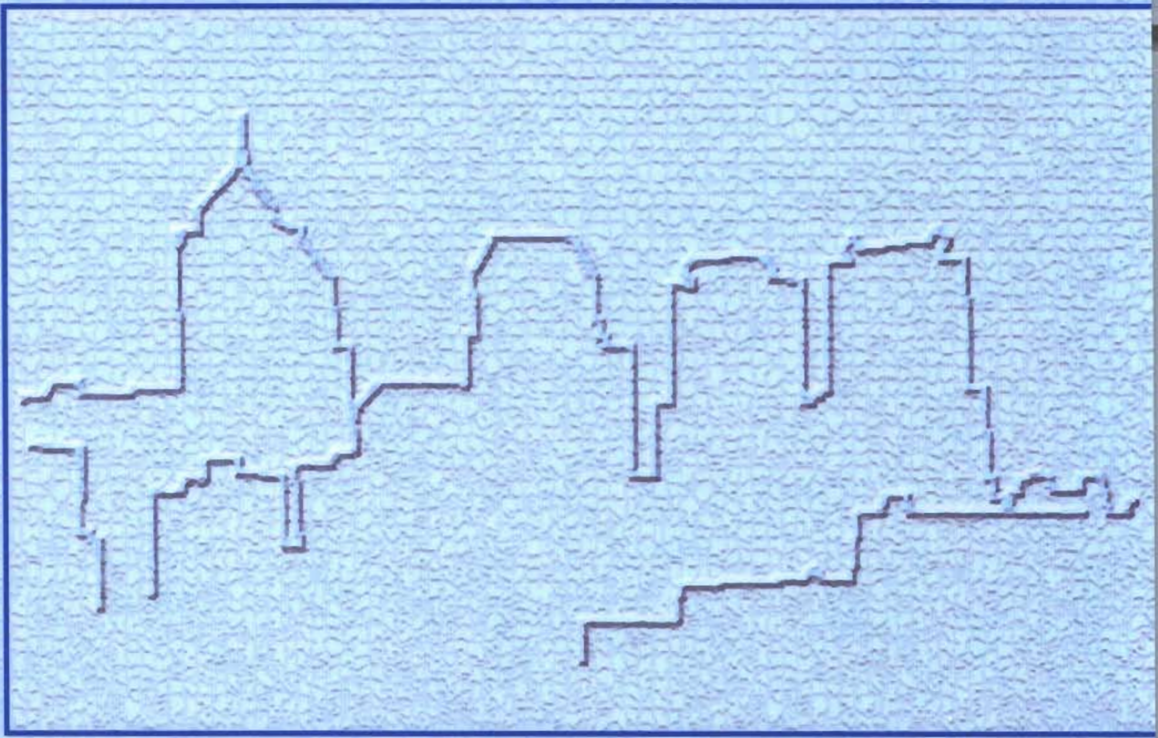
Philadelphia Combined Sewer Overflow Long Term Control Plan Update

Supplemental Documentation
Volume 7

Stress Testing of the Southeast WPCP

Updated: September 1, 2009

FINAL REPORT



Stress Testing of the Southeast WPCP

Stress Testing of the Southeast WPCP

Prepared for

Philadelphia Water Department

Prepared by

CH2MHILL

December 2001

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SECTION 1

INTRODUCTION

1. Introduction

1.1 Project Objectives and Methodology

As part of its obligations under the Federal Clean Water Act and the Pennsylvania Clean Streams Law, the City of Philadelphia Water Department (PWD) has initiated a program with an objective to minimize the impact of Combined Sewer Overflows (CSO) on local receiving waters. One of the proposed strategies for reducing the CSO volume is to maximize flow to be treated by the water pollution control plants (WPCP) during periods of wet weather. To implement this strategy effectively, the PWD needs to have a clear understanding of the factors that affect how much flow each of the three WPCPs can effectively treat. With this knowledge, the PWD will be able to identify and prioritize plant upgrades and other system modifications that will allow it to meet the CSO minimization objectives in the most environmentally sound and cost-effective manner.

The PWD contracted CH2M HILL to conduct stress testing at the three wastewater treatment plants that are owned and operated by the City. The objective of the stress testing was to determine the reliable maximum capacity of the existing facilities and identify cost-effective methods of increasing the ability of these facilities to treat peak hydraulic flows associated with wet weather conditions. The major tasks performed during the project are briefly described below.

Historical Data and Operations Review. The objective of the historical data and operations review was to evaluate the physical condition, current loading, and treatment efficiency provided by the existing unit processes. A tour of the plant was conducted, and the process equipment and facilities were examined. Operating records, design information, and engineering drawings were studied to develop a strong understanding of the operations and constraints. Technical Memorandum 1 – Historical Data Review was produced to summarize the results of the site visit and historical data analysis.

Short-Term Stress Test. CH2M HILL performed a series of capacity and diagnostic tests to determine the loading versus performance characteristics of specific unit processes at each facility. The short-term stress testing focused on determining the response of the primary and secondary clarifiers to increased hydraulic loading under different operating conditions. The short-term stress testing at the Southeast WPCP (SEWPCP) included primary clarifier stress tests, secondary clarifier stress tests, secondary clarifier dye tests, and flow meter calibration. The results of each test are summarized in a test description report in Technical Memorandum 2 – Short-Term Test Results.

Long-Term Stress Test (Online Monitoring). Online monitoring equipment was installed to quantify the dynamic load/response characteristics of the secondary treatment system to naturally-occurring storm events. The equipment was also used to monitor the effect increased flows had on the solids inventory in the system and secondary effluent quality. Online monitoring included total plant flow, return activated sludge (RAS) flow, mixed liquor suspended solids (MLSS) concentration, sludge blanket levels, and secondary effluent total suspended solids (TSS) concentration. The equipment was in place from March 1 to June 30, 1999 and recorded data on a 10-minute interval. The results of the long-term stress test are summarized in Technical Memorandum 3 – Long-Term Online Monitoring Results. The detailed online monitoring data and instrument calibration records are provided under separate cover.

Hydraulic Throughput Capacity Assessment. WinHYDRO, a computer model that facilitates complex analysis of plant hydraulics, was used to evaluate the hydraulic throughput capacity of the SEWPCP. Hydraulic and energy grade lines from the headworks to the plant outfall were developed for the average and peak flow conditions. Hydraulic bottlenecks, which limit the hydraulic throughput capacity of the existing facilities, and flow distribution problems were identified and evaluated. The hydraulic throughput capacity of each unit process was determined. The results of the hydraulic modelling performed are summarized in Technical Memorandum 4 – Hydraulic Throughput Capacity of Existing Facilities.

Evaluation of Potential Improvements. Based upon stress testing and hydraulic modeling results, major bottlenecks that limit plant capacity were identified and potential solutions were developed to increase peak instantaneous capacity. Budgetary cost estimates were developed for each potential solution. The results of this analysis are summarized in Technical Memorandum 5 – Budgetary Cost Estimates for Potential Plant Improvements.

1.2 Report Organization

The project notebook consists of a final report and a series of attachments. The main body of the report contains a summary of the results from the stress testing, plant data analysis, and the evaluation of process improvements and upgrade options. The detailed results from the historical data review, short-term testing (stress tests, dye tests, and flow meter calibration), online monitoring, and hydraulic throughput capacity assessment are included in the project notebook as attachments. Tables describing the design criteria, scope of work, estimated capital costs for the potential process modifications and capital upgrades, and the current National Pollution Control Discharge Elimination System (NPDES) discharge permit for the site are also included as attachments.

SECTION 2

CURRENT PERFORMANCE

2. Current Performance

2.1 Description of Facilities

Figure 2-1 presents a site plan and Table 2.1 summarizes the existing unit processes at the SEWPCP.

TABLE 2.1
SOUTHEAST WPCP – SUMMARY OF UNIT PROCESSES

Unit Process	Number	Description
Coarse Screens	2	Width = 6.5 ft, single-rake front cleaned
Low-Level Pumps	6	Centrifugal pumps; 3 VSD, 3 constant speed Design Q = 70 mgd, at 45-ft head
Bar Screens	6	Width = 6.5 ft, 75 percent inclined, 1-inch opening
Grit Removal	6	Grit channels Length = 140 ft, width = 10 ft, SWD = 10 ft, volume = 14,000 ft^3 (each)
Flocculation Pre-aeration	2	Aerated channel Length = 225 ft, width = 28 ft, SWD = 13 ft, volume = 81,900 ft^3 (each)
Primary Clarifiers	4	Length = 250 ft, width = 125 ft, SWD = 12 ft Surface area = 31,250 ft^2, weir length = 635 ft (each) C&F sludge mechanism, influent end hopper
Flow Spit Chamber	24	Gates at 60-inch weir length 6 gates for 2 aeration basins
Aeration Basin	8	Four-pass – through flow only Length = 210 ft, width = 52.5 ft, SWD = 14.3 ft, volume = 1.18 mg (each) Operate with first pass as selector
Aeration System	4	1@ 40 Hp , 3@ 30 Hp (per basin)
Secondary Settling Tanks	12	Length = 214 ft, width = 68 ft, SWD = 11 ft Surface area = 14,552 ft^2 Weir length = 784 ft (each) Gould-type central hopper, C&F mechanism
Effluent Pumps	5	Q = 70 mgd at 11 head, VSD 3 units

2.1.1 Preliminary Treatment

The SEWPCP receives wastewater from the Lower Delaware low-level interceptor through an 11-foot-diameter gravity sewer. Mechanically-cleaned bar racks provide coarse screening before the raw sewage pump station. The pump station wet well is separated into two hydraulically-isolated chambers, each of which is serviced by three raw sewage pumps with a rated capacity of 70 mgd each. The pump station operation is controlled manually based on the level in the wet well. Under high flow conditions the pumps are susceptible to

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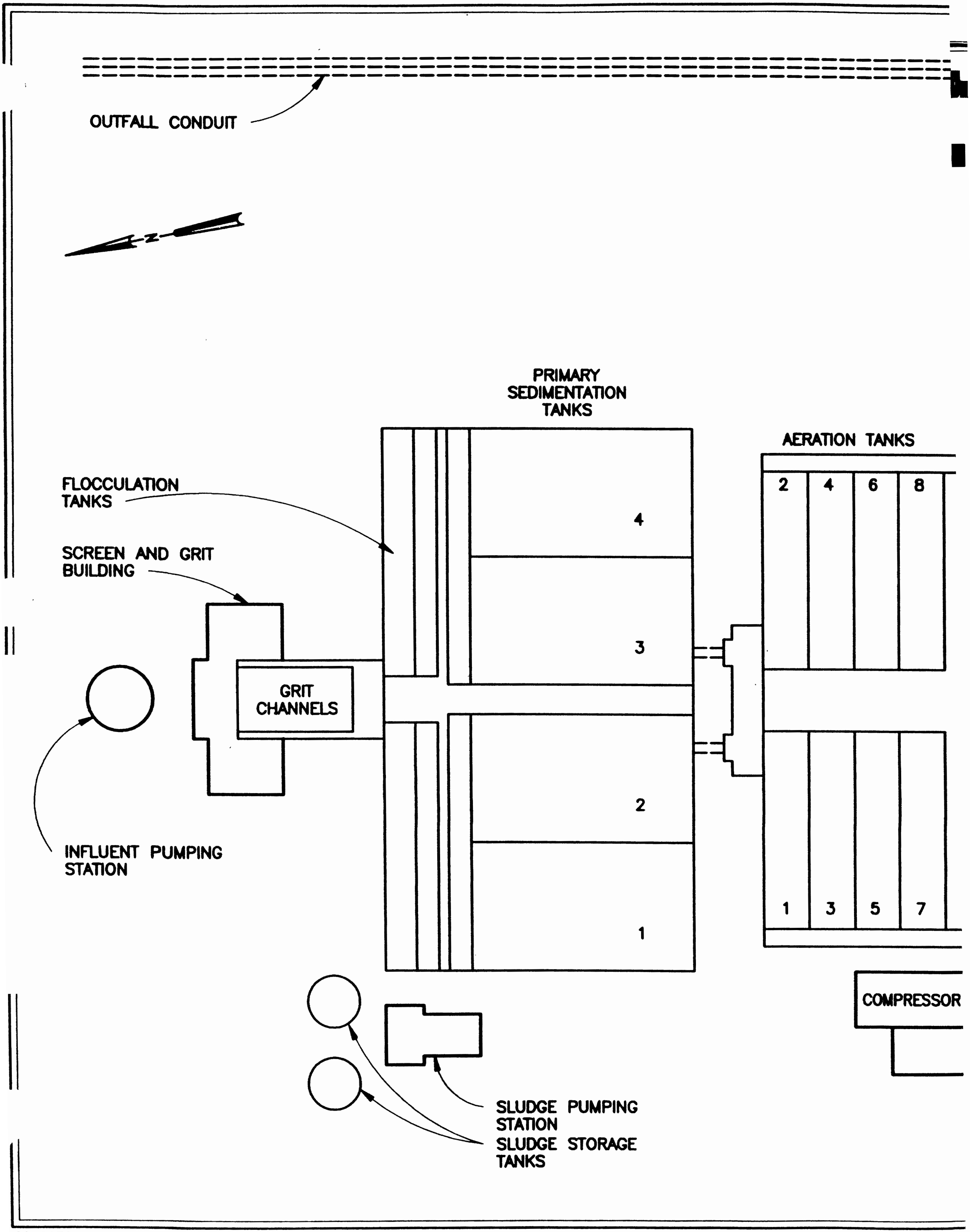

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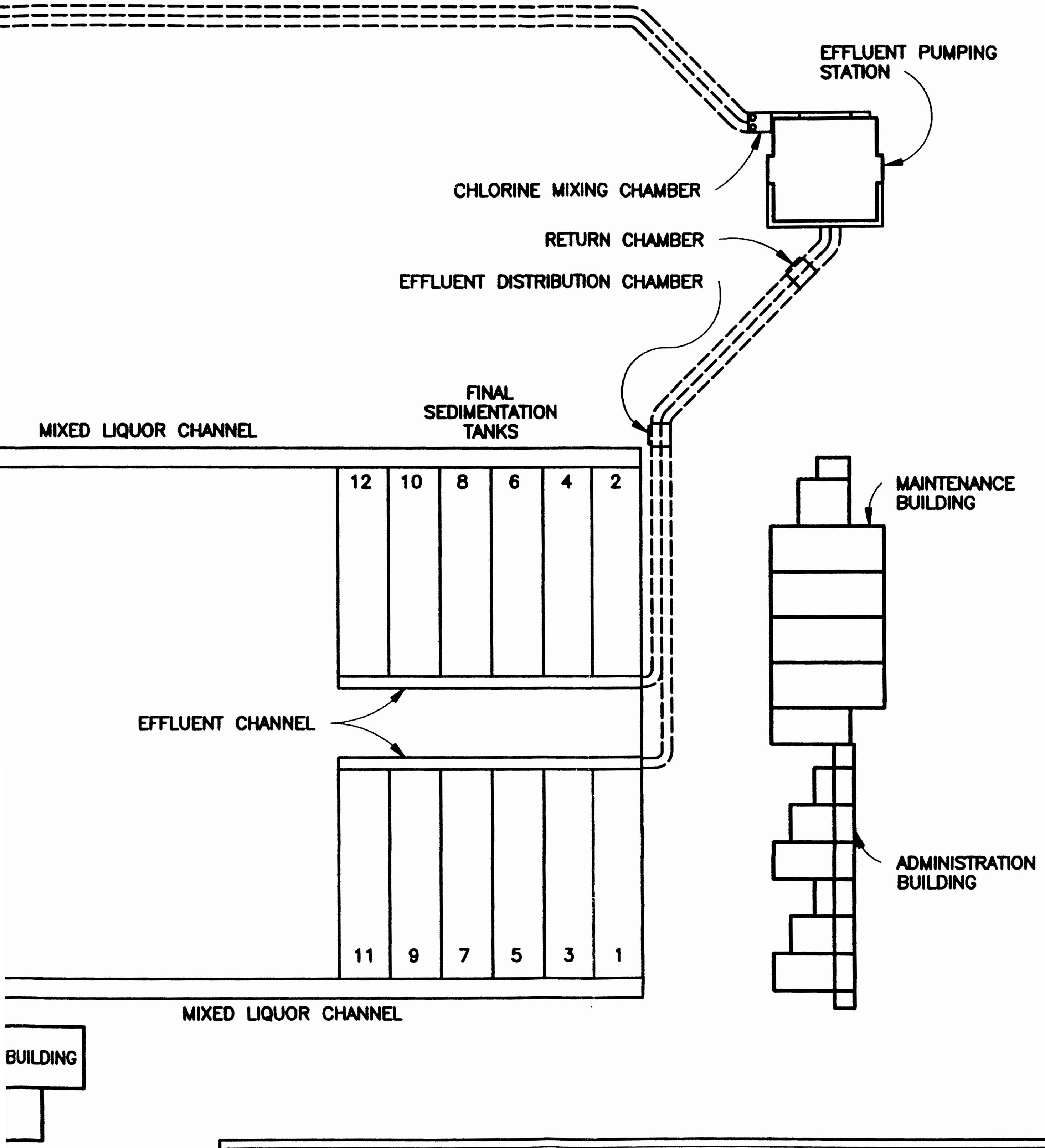

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FIGURE 2-1
SITE PLAN
SOUTHEAST WATER POLLUTION
CONTROL PLANT
CITY OF PHILADELPHIA WATER DEPARTMENT

vortexing, resulting in a sudden deterioration in the measured pump output (flow). Pump capacity is restored by temporarily shutting down the pump and allowing the wet well levels to rise. The maximum flow measured at the raw sewage pump station is approximately 286 mgd with both wet wells in service and 200 mgd with only one wet well in service.

The pump risers discharge into a common channel that leads to six mechanically-cleaned bar screens. The bar screens are located in the influent channel to the grit chambers with one bar screen per grit chamber. The grit chambers consist of six 10 by 140 feet channels with chain and flight collection mechanisms and screw conveyors to remove the grit. Under normal flow conditions, two out of six grit tanks are in service. The accumulated grit is pumped from the grit tanks, washed, and hauled offsite for disposal. The wastewater from the grit tanks flows into a common channel that leads to two flocculation tanks. The flocculation tanks are two-pass aerated tanks, which provide a total flow path length of 450 feet. The flocculation tanks discharge into a common primary influent channel.

Under high flow conditions, the grit chambers flood into the lower basement area through the grit conveyor wall notch. The hydraulic restriction is associated with the primary clarifier launders and the piping between the primary tanks and aeration basins. This issue is discussed in greater detail in Section 3.2.

2.1.2 Primary Treatment

The SEWPCP has four 250 by 125 feet rectangular primary clarifiers with a side wall depth of 12 feet. Each tank has seven chain and flight mechanisms that move the sludge to the influent end of the basin. The flow from the flocculation tanks enters the common influent channel between Primary Clarifiers 2 and 3. Each clarifier has 14 inlet weirs from the common influent channel. The primary sludge is pumped from two tanks every other day. The primary sludge is pumped to the sludge holding tank and then is pumped directly to the SWWPCP for treatment. There are no recycle streams returning to the SEWPCP headworks associated with this process. The primary effluent discharges into a common effluent channel that leads to two flow splitter boxes that control the flow distribution to the aeration basins.

The SEWPCP receives a significant quantity of ferric sludge from the Queen's Lane Water Treatment Plant. The water treatment plant sludge has very good settling characteristics and therefore enhances the performance of the primary treatment system.

However, in 1998, Queen's Lane Water Treatment Plant changed the coagulation procedures used at the facility. The chemical characteristics of the water treatment plant sludge changed, increasing the impact of the Queen's Lane sludge on the treatment processes at the SEWPCP.

The Queen's Lane sludge has exhibited the ability to remove phosphate from the wastewater stream, resulting in periodic incidences of severe nutrient deficiency in the secondary treatment process. Periods of nutrient deficiency encourage the growth of filamentous microorganisms in the activated sludge system, causing bulking sludge and premature failure of the secondary clarifiers.

2.1.3 Secondary Treatment

The SEWPCP has eight 4-pass aeration basins. The basins were originally designed as UNOX pure oxygen. They are currently operating with air. Under current loading conditions, six of the eight aeration basins are in service. Each basin is 52.5 by 210 feet, with a side wall depth of 14.3 feet. The aeration basin consists of four cells operating in series; the primary effluent follows a serpentine flow pattern through the basin, and the RAS is pumped to the upstream end of Cell A. There are no structures to allow step-feed in the basin. The water surface level (WSL) in the basin is controlled by the basin effluent weir structure.

Each cell has a single-paddle, submerged aerator/mixer located in the center of the tank. The SEWPCP operates the first cell as an anoxic selector in the summer months to improve the settling characteristics of the mixed liquor by turning off the first aerator/mixer. During high flow conditions, operations staff also turn off the aerators/mixers in the first and fourth cells to reduce the energy demand. This retains more solids in the aeration basin through settling, which reduces the solids loading on the secondary clarifiers.

The east and west secondary treatment processes are operated as separate systems. The mixed liquor from the east aeration basins flows to the east secondary clarifiers, and the RAS from the east secondary clarifiers is pumped to the east aeration basins. The RAS is flow-paced at approximately 30 percent of the flow through the plant. The mixed liquor from each set of aeration basins flows through a common mixed liquor channel to a set of six secondary clarifiers.

There are twelve 68 by 214 feet rectangular secondary clarifiers with a sidewall depth of 11 feet. Each clarifier has four chain and flight mechanisms that transport the sludge to a central hopper located at approximately the mid-length of the clarifier. The waste activated sludge (WAS) is pumped from the RAS system 24 hours per day. The target WAS flow rate is established based on a target solids retention time of 1.5 days and current mixed liquor concentration in the aeration basins.

2.1.4 Effluent Pumping and Disinfection

The secondary effluent flow from the east and west secondary treatment processes flows through a common conduit to the effluent pump station wet well and chlorine contact chamber. Under dry weather flow conditions, the secondary effluent flows by gravity through the outfall to the Delaware River. The outfall conduit provides contact time for disinfection.

The SEWPCP has five effluent pumps, each with a rated capacity of 70 mgd. The effluent pumps are operated based on the WSL in the effluent pump station wet well and, under wet weather flow and/or high tide conditions, will operate automatically. Three 24-hour composite samples are collected at the end of the facility outfall.

2.2 Regulatory Requirements

The SEWPCP NPDES permit limits include effluent BOD_5 and TSS concentrations; mass discharges; and percent removal for daily, weekly (calendar), and monthly averages. Table

2.2 summarizes the NPDES permit criteria for the facility in effect during testing. Compliance is based on the flow measured by the raw sewage flow meters located in the influent pump station and two 24-hour composite samples collected daily at the facility outfall.

PWD has negotiated a new NPDES permit for this facility effective August 1st, 2000. The modifications to the NPDES permit are summarized below.

As part of PWD's long-term combined sewer overflow (CSO) control program, PWD will be reducing the frequency and volume of untreated sewage discharges through the CSOs; in order to account for the increased loading due to the combined sewage flows that exceed the treatment plant's rated hydraulic capacity, the following methods may be used for calculating and reporting mass loadings and effluent concentrations on the monthly discharge monitoring reports:

- If a calendar month includes one or more days where flows exceed 168 mgd, a value of 85 percent may be used for those days for the purpose of calculating average monthly TSS percent removal. The actual TSS percent removal associated with those days shall be reported on the appropriate space provided on the DMR.
- If a calendar month includes one or more days where flow exceed 168 mgd, a value of 86 percent may be used for those days for the purpose of calculating average monthly BOD_5 percent removal. The actual BOD_5 percent removal associated with those days shall be reported on the appropriate space provided on the DMR.
- When daily flows exceed 168 mgd, the TSS and BOD_5 mass loadings for those days may be omitted from the average monthly and average weekly mass loading calculations, in accordance with the requirements of the Delaware River Basin Commission for Zone 3 of the Delaware Estuary. The actual TSS and BOD_5 loadings associated with those days shall be reported on the appropriate space provided on the DMR.

The BOD_5 in the raw wastewater shall be reduced by at least 86 percent as a monthly average. The percent removal shall be calculated from daily 24-hour composite samples of the influent and effluent. The BOD_5 percent removal requirement may be relaxed to 85 percent when the influent BOD_5 concentration is less than 75 mg/L on a monthly average basis, as long as the $CBOD_{20}$ allocation, equivalent mass BOD_5 limitation, and effluent BOD_5 concentration of 15 mg/L are not exceeded on a monthly average basis. At all other times, the 86 percent removal equipment would apply.

A copy of the new NPDES permit is located in the project notebook.

TABLE 2.2
SOUTHEAST WPCP – NPDES PERMIT REQUIREMENTS

Parameter	Units	Monthly Average	Weekly Average	Maximum Day	Peak Instantaneous
BOD_5					
Concentration	mg/L	30	45	–	60
Mass loading	lbs/day	19,650	29,475		
Percent removal	%	86			
TSS					
Concentration	mg/L	30	45	–	60
Mass loading	lbs/day	28,025	42,035		
Percent removal	%	85			
Flow	mgd	112		168	224

2.3 Current Loading And Performance Achieved

2.3.1 Unit Process Loading

Table 2.3 presents a summary of the current unit process loading over a three-year period from July 1995 to July 1998. The average and maximum daily flows were 106 mgd and 212 mgd, respectively. The maximum instantaneous flow was 286 mgd.

On September 16, 1999, during Hurricane Floyd, the maximum instantaneous flow was 274 mgd. The flow remained above 200 mgd for over 14 hours. During that period, the maximum WSL in the raw sewage wet well was 19.5 feet. During the five years from July 1995 to present, SEWPCP has not exceeded the CSO action level established for the facility.

The average raw sewage TSS and BOD_5 concentrations were 143 mg/L and 87 mg/L, respectively. The average organic loadings to the treatment plant, calculated based on the raw sewage TSS and BOD_5 concentration and the average flow for each day, were 126,281 lbs/day and 75,834 lbs/day, respectively.

TABLE 2.3
SOUTHEAST WPCP - SUMMARY OF CURRENT UNIT PROCESS LOADINGS (JULY 1995- JULY 1998)

Unit Process	Units	Current Loadings		Typical Values	Notes
		Average	Maximum		
Loading					
Hydraulic	Mgd	106	286		1
Organic					
BOD	lb/d	75,834	111,743		2
TSS	lb/d	126,281	222,378		2
Grit Tanks					
Volume (total)	ft^3	84,000			
Area (total)	ft^2	8,400			
HRT	Minutes	8.5	3.2	3 – 5	3
Primary Clarifiers					
Area (total)	ft^2	125,000			
Weir Length (total)	Ft	2,540			
Surface Overflow Rate	gpd/ft^2	848	2,288	1,000 – 3,000	3
Removal Efficiency					

TABLE 2.3
SOUTHEAST WPCP - SUMMARY OF CURRENT UNIT PROCESS LOADINGS (JULY 1995- JULY 1998)

Unit Process	Units	Current Loadings		Typical Values	Notes
		Average	Maximum		
BOD	%	49		35	
TSS	%	73		60	
Aeration Basins					
Volume (total)	Mg	7.08			4
BOD Loading	lbs/d/1,000 ft^3	29.6	48.9	20 – 40	4,2
HRT	Hours	2.6	0.8		4
MLSS	mg/L	1,357			
SVI	mL/g	144		100 – 150	
ISV	ft/hr	11			
SRT	Day	0.7			4
F/M	1/day	East 0.47 West 0.48			4
Secondary clarifiers					
Area (total)	ft^2	174,624			
Weir length	Ft	9,408			
Surface overflow rate	gpd/ft^2	607	1,638	600 – 1,500	3
Solids loading rate	lb/ft^2 per day	9.05	20	20 – 40	3

Notes:
[1] Maximum hydraulic loading based on instantaneous flows
[2] Maximum loading based on 95th percentile
[3] Based on all units in service
[4] Based on six aeration basins in service

2.3.2 Primary Treatment Performance

The average and peak surface overflow rates (SOR) for the primary clarifiers were approximately 850 gpd/ft^2 and 2,286 gpd/ft^2, respectively. Typical overflow rates for rectangular clarifiers are between 1,000 gpd/ft^2 and 3,000 gpd/ft^2. The primary clarifiers at the SEWPCP are operating slightly below their expected capacity based on typical SORs.

The removal efficiencies achieved in the primary clarifiers are very good. This is due to the low hydraulic loading rate and the relatively high proportion of ferric solids from Queen's Lane Water Treatment Plant. The average TSS and BOD$_5$ removal efficiencies in the primary clarifiers were 73 percent and 49 percent, respectively.

2.3.3 Secondary Treatment Performance

The average primary effluent TSS and BOD$_5$ concentrations were 34 mg/L and 43 mg/L, respectively. The average and 95th percentile total BOD$_5$ loadings to the secondary treatment system, calculated based on the primary effluent BOD$_5$ concentration and the average flow for each day, were 37,293 lbs/day and 61,629 lbs/day, respectively.

The aeration basins are currently operating with a solids residence time (SRT) of 0.7 days. The food to microorganisms (F:M) ratio in the aeration basins averaged 0.5 day^{-1}. The F:M ratio generally peaked in March each year, mainly due to an increase in food (BOD$_5$ loading) during the early spring periods. The average sludge volume index (SVI) between

July 1995 and December 1998 was 144 mL/g. The SVI was more than 200 mL/g approximately 5 percent of the time, indicating that the facility experiences occasional bulking incidents.

During January through March of 1999, the SEWPCP experienced a major sludge bulking incident. A microscopic examination of the mixed liquor indicated severe nutrient (phosphorus) deficiency in the biomass. Phosphoric acid was added to the return sludge, and the SVI dropped to levels typical for the facility.

The average and peak SORs for the secondary clarifiers were approximately 800 gpd/ft^2 and 1,640 gpd/ft^2, respectively. Typical SORs for rectangular Gould-type clarifiers are between 800 gpd/ft^2 and 1,500 gpd/ft^2. The secondary clarifiers at the SEWPCP are operating at their expected maximum hydraulic capacity based on typical SORs.

The average and peak solids loading rates (SLRs) for the secondary clarifiers were approximately 9 lbs/day/ft^2 and 20 lbs/ft^2 per day based on RAS flows of 30 percent. Typical peak SLRs for rectangular Gould-type clarifiers are between 20 lbs/day/ft^2 and 40 lbs/ft^2 per day. The secondary clarifiers at the SEWPCP are operating below the expected maximum hydraulic capacity based on typical SLRs.

The secondary clarifiers at the SEWPCP achieve a very good quality final effluent. The daily TSS and BOD$_5$ concentrations were consistently below the NPDES criteria of 60 mg/L. The average effluent TSS and BOD concentrations were 5.7 and 7.5 mg/L, respectively.

SECTION 3

CURRENT CAPACITY

3. Maximum Instantaneous Capacity

3.1 Maximum Treatment Capacity

The current maximum instantaneous treatment capacity of the unit processes at the SEWPCP was estimated using a combination of manufacturers information, standard engineering design loading and performance criteria, operations staff observations of previous performance, and field testing of specific unit processes.

The field testing conducted at the SEWPCP included the following:

Online Monitoring Data

- Secondary Clarifier 12
- Plant flow, RAS flow, mixed liquor TSS, sludge blanket level, and effluent TSS from March 1 to June 30, 1999

Primary Clarifier Stress Tests

- Primary Clarifier 4

Secondary Clarifier Stress Tests

- Secondary Clarifier 1 – gradual increase in hydraulic loading
- Secondary Clarifier 1 – sudden increase in hydraulic loading (spike loading)

Secondary Clarifier Dye Tests

- Secondary Clarifier 11

Table 3.1 summarizes the estimated treatment capacity for each unit. The basis of the estimated capacity is discussed below. The detailed field test results are presented in Technical Memorandum 2 – Short-Term Test Results and Technical Memorandum 3 – Long-Term Online Monitoring Results.

3.1.2 Preliminary Treatment

The estimated treatment capacity of the preliminary treatment system is 200 mgd. This is based on operators' observations for the maximum pumping capacity of the raw sewage pump station with one side of the wet well out of service because of partial blockage or failure of the coarse bar screens. The bar screen can be put back into service quickly. However the potential of permanently damaging the screen and pumps increases at flow rates greater than 240 mgd. With both sides of the raw sewage pump station wet well in service, the maximum capacity of the raw sewage pump station is 286 mgd. Maintaining the maximum flow rate requires manual control of the pumps, with four of the six pumps in operation at one time. The pumps are rotated into service as the pump output is reduced due to vortexing/cavitation. The capacity is limited by the wet well configuration.

TABLE 3.1
SOUTHEAST WWTP TREATMENT CAPACITY ASSESSMENT

Unit Process	Estimated Capacity (mgd)	Criteria
Pumping and Screening	286 240[1] – 1 coarse screen partialy blocked 200[2] – 1 wet well out of service	Observed maximum flow Observed maximum flow Observed maximum flow
Grit Removal	350[3] – 1 channel out of service	
Primary Treatment	225 mgd[4] – existing condition (hydraulic limitations) 260 mgd[4] – new launders 330 mgd[4] – improved sludge pumping	2,400 gpd/ft² – test results 2,800 gpd/ft² – SW test results 3,500 gpd/ft² – potential
Aeration Basins	N/A No change in organic loading pattern	
Secondary Clarifiers	200 mgd[4] – existing (sludge bulking incidence) 330 mgd[4] – current mixed liquor concentration	Long-term monitoring results Based on allowable SOR of 1,800 gpd/ft²
	236 mgd[4] – mixed liquor concentration 2,000 mg/L	Based on allowable SLR of 30 lbs/day
Effluent Pump Station	280 mgd[5] (1 pump out of service)	70 mgd per pump
Disinfection	395 mgd – volume of plant outfall	HRT - 15 minutes

[1] Based on one screen partially blocked
[2] Based on one screen (1/2 of the wet well) out of service
[3] Based on removal of 60 mesh (0.25mm) particles
[4] Based on one clarifier out of service
[5] Based on 1 pump out of service rated capacity of pumps 70 mgd

The estimated treatment capacity of the bar screens and grit removal tanks is 350 mgd. This is based on five of the six channels in service, with an allowable average velocity in the grit channel of 1 ft/sec. The theoretical removal efficiency of the grit removal system is 90 percent of particles greater than 60 mesh (25 mm) under peak flow conditions.

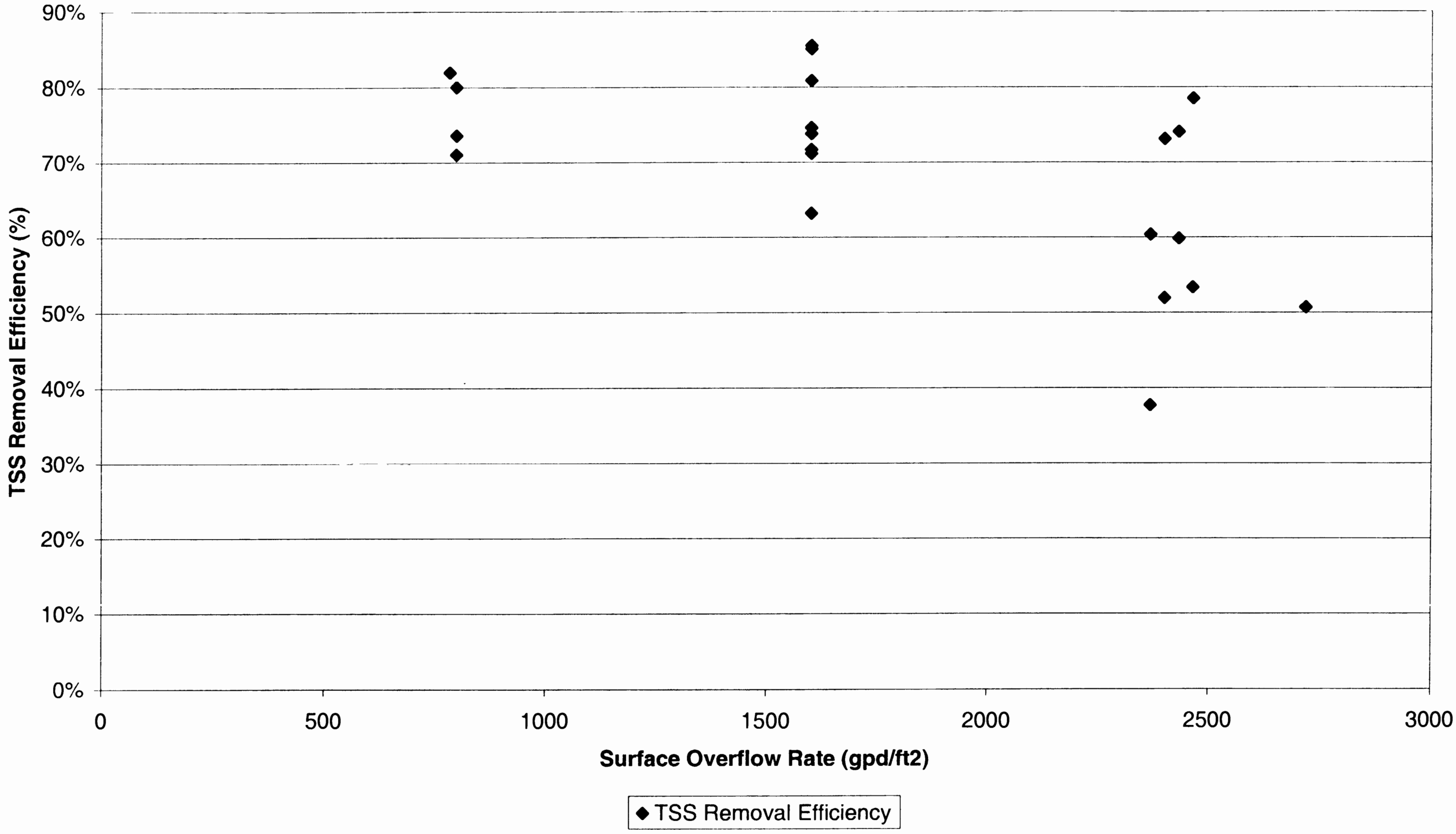
3.1.3 Primary Treatment

Six primary stress tests were conducted at the three wastewater treatment plants owned and operated by the PWD. Table 3.2 summarizes the physical characteristics of the clarifiers at each site and the stress tests performed. The primary clarifiers at all three plants are hydraulically similar. Differences in behaviour are the result of differences in influent characteristics and minor differences in influent and effluent structures.

One stress test was performed on the primary clarifiers at the SEWPCP. Figure 3.1 presents the measured TSS removal efficiency as a function of SOR observed during the test. The test procedures and detailed results are described in Technical Memorandum 2.

The performance of the primary clarifier at SEWPCP deteriorated at a SOR of 2,400 gpd/ft². Clarifier deterioration was due to hydraulic throughput failure of the launders, resulting in unbalanced flow distribution over the length of the effluent weir. At 75 mgd, the center half of the launder was submerged. The velocity at the outside ends of the weirs increased, resulting in increased upward velocities in these locations. Throughout the test, the clarifier

Figure 3-1
SEWPCP Primary Clarifier Stress Test
TSS Removal Efficiency versus Surface Overflow Rate (SOR)



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launders had a free discharge into the clarifier collection channel (the WSL in the collection channel was not impacting the hydraulic throughput capacity of the launders). The estimated treatment capacity of the primary clarifiers is 225 mgd with three clarifiers in service. The capacity-limiting factor was the hydraulic throughput capacity of the clarifier launders. The primary clarifiers at the SEWPCP are virtually identical to the primary clarifiers at the SWWPCP, except for the configuration of the effluent launders. If the effluent launders on the SEWPCP primary clarfiers were replaced, the expected performance of these clarifiers would be similar to the measured performance of the SWWPCP primary clarifiers (allowable SOR of 2,800 gpd/ft^2). The estimated capacity of the primary clarifiers would increase to 260 mgd with three clarifiers in service or 350 mgd with all four clarifiers is service.

TABLE 3.2
PRIMARY CLARIFIERS STRESS TEST PERFORMED

Site	SEWPCP	SWWPCP	NEWPCP	
Clarifier dimension			**Set 1**	**Set 2**
# of clarifiers	4	5	8	4
Type	Rectangular	Rectangular	Rectangular	Rectangular
Length (ft)	250	250	240	250
Width (ft)	125	125	65	125
SWD (ft)	12	12	10	10
Sludge Removal				
Hopper location	Influent end	Influent end	Influent end	
Sludge collection	Chain & flight	Chain & flight	Chain & flight	
Pumping freq.	Once every two days	Once per day	Three times per day	
Influent structure				
Channel	Common	Common	Common	Common
Clarifier openings	Orifice and weirs	Orifice	Orifice	Orifice
Openings/clarifier	8 Orifices and 14 weirs	8	4	12
Location	Surface and mid-level	mid SWD	Bottom SWD	Surface and Bottom SWD
Baffling	Yes	Yes	yes	Yes
Effluent structure				
Type	Lateral launders	Finger launders	Finger launders	Finger launders
Orientation	Cross flow	Longitudinal	Longitudinal	Longitudinal
Weir length (ft)	193	307	137	274
Launders	3	21	12	24
Test performed	1	2	2	1
Target SOR (range) gpd/ft^2	1,000-2,400	1,000-3,500	1,000-3,000	750-2,800

The capacity of the primary clarifiers at the SEWPCP could be further increased by improving the sludge removal procedures for the primary clarifiers. This modification would require removing the primary sludge from the clarifiers more frequently. Allowable surface overflow rates of up to 3,500 gpd/ft^2 were observed at the SWWPCP for the test conducted on Primary Clarifier 4. The test was conducted without BRC solids and with no sludge blanket in the clarifier.

Based on an allowable SOR of 3,500 gpd/ft^2, the theoretical maximum treatment capacity of the existing primary clarifiers is 330 mgd with three clarifiers in service or 440 mgd with all four clarifiers in service.

3.1.4 Secondary Treatment

Six secondary clarifier stress tests were conducted at the three wastewater treatment plants owned and operated by the PWD. Table 3.3 summarizes the physical characteristics of the clarifiers at each site and the secondary clarifier stress tests performed. The secondary clarifiers at all three plants are very similar and performed similarly. Differences in performance were largely the result of differences in mixed liquor settling characteristics and solids loading during the tests.

TABLE 3.3
PHYSICAL CHARACTERISTICS OF THE SECONDARY CLARIFIERS TESTED

Site	SEWPCP	SWWPCP	NEWPCP	
Clarifier dimension			**Set 1**	**Set 2**
# of clarifiers	12	20	8	8
Type	Gould	Gould	Gould	Gould
Length (ft)	214	260	214	231
Width (ft)	68	75	75	70
SWD (ft)	11	11	11	13
Sludge Removal				
Hopper location	mid length	mid length	mid length	
Sludge collection	Chain & flight	Chain & flight	Chain & flight	
RAS removal	Gravity to sump	Pump per clarifier	Common pump	
RAS rate	30%	35%	15-30%	
MLSS	1,300	2,100	1,100	
Influent structure				
Channel	Common to 6	Common to 10	Common to 8	Common to 4
Clarifier openings	Adjustable weir	Orifice	Overflow Weir	Overflow Weir
Number per clarifier	4	4	4	4
Location	Top	Surface	Surface	Surface
Baffling	Yes	Yes	No	Yes

TABLE 3.3
PHYSICAL CHARACTERISTICS OF THE SECONDARY CLARIFIERS TESTED

Site	SEWPCP	SWWPCP	NEWPCP	
Effluent structure				
Type	Finger launders	Finger launders	Finger launders	Finger launders
Orientation	Longitudinal	Longitudinal	Longitudinal	Longitudinal
Weir length (m)	784	816	850	850
Number of Launders/	24	12	24	24
Test performed				
Stress test	2	1	0	3
Target SOR (range) gpd/ft^2	860-2,000	600-2,100		1,000-2,100
Dye tests	1	0	3	1

Two stress tests and one dye test were performed on the SEWPCP secondary clarifiers. The test procedures and results are described in Technical Memorandum 2; the main findings are summarized below.

Two stress tests were conducted on Secondary Clarifier 11 at the SEWPCP. Figures 3-2a and 3-2b present the flow and effluent TSS concentration as a function of time for each test. Figure 3-3 presents the effluent TSS concentration as a function of SOR for both tests. The first test was conducted by increasing the hydraulic loading on the clarifier gradually, in incremental steps. The second test was conducted by increasing the hydraulic loading suddenly from normal dry weather flow to peak flow within approximately five minutes. In both tests, the effluent TSS concentration remained well below 60 mg/L. The maximum SOR achieved during the tests was 2,100 gpd/ft^2.

Dye tests are used to evaluate the hydraulic efficiency of the secondary clarifiers. A clarifier dye test was performed on Secondary Clarifier 1. The test results indicated that there is relatively even flow distribution throughout the clarifier body, with only small areas of the tank not utilized for clarification. The slight short-circuiting observed is considered normal for a clarifier of this design.

Figure 3-2a
SEWPCP Secondary Clarifier Stress Test - Gradual Increase in Flow
Effluent TSS Concentration versus Time

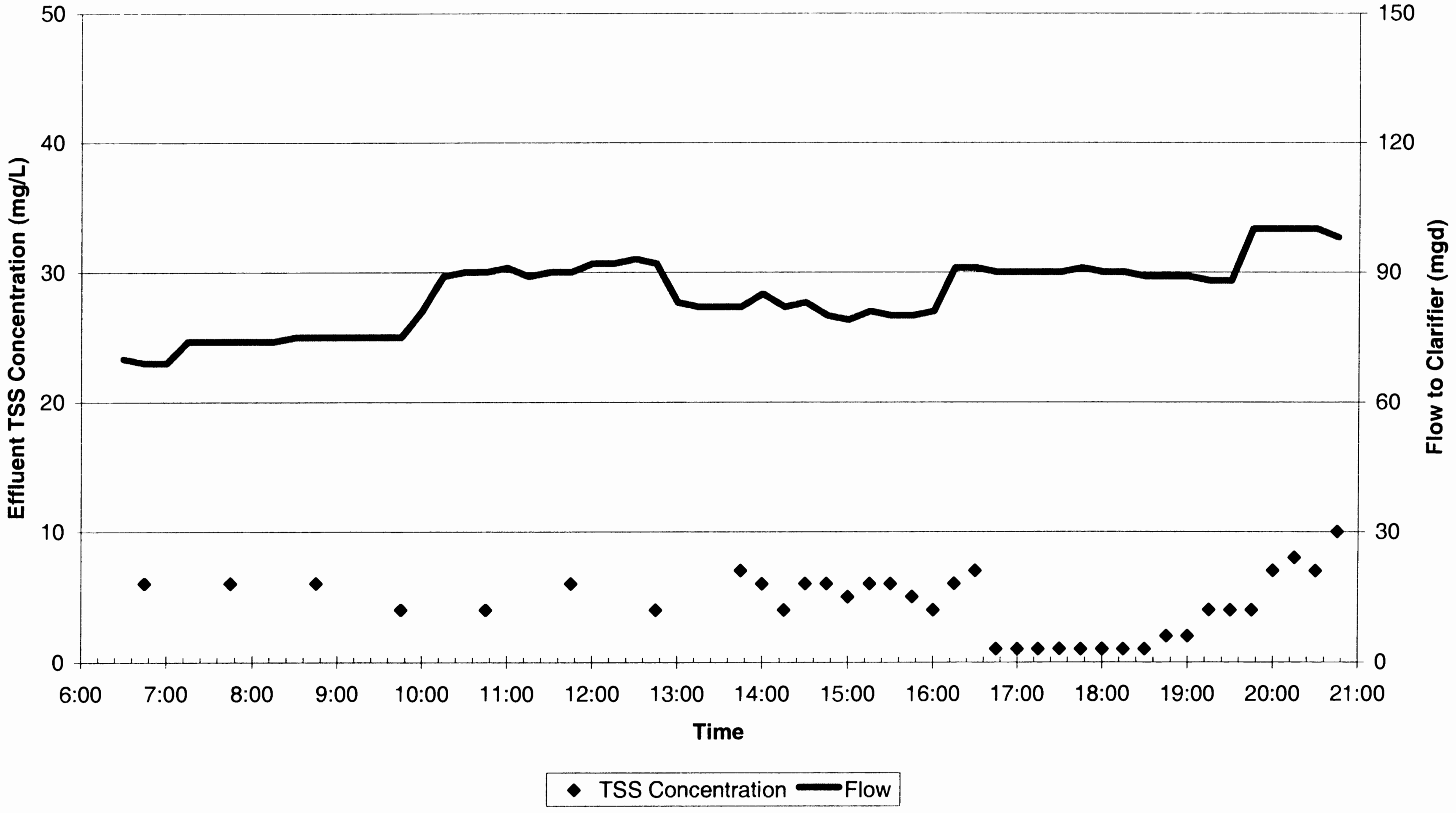

Figure 3-2b
SEWPCP Secondary Clarifier 11 Stress Test - Sudden Increase in Flow
Effluent TSS Concentration versus Time

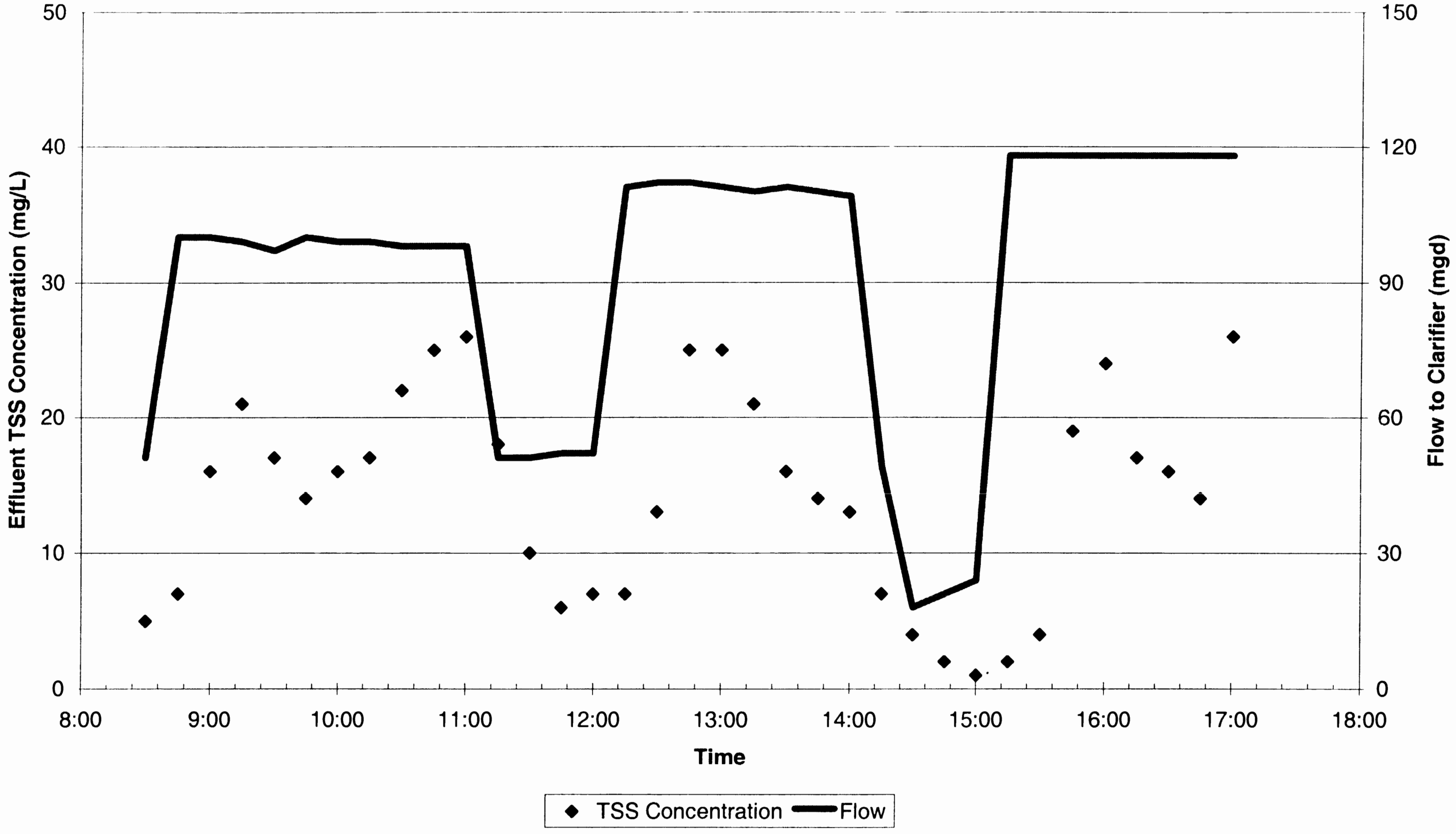

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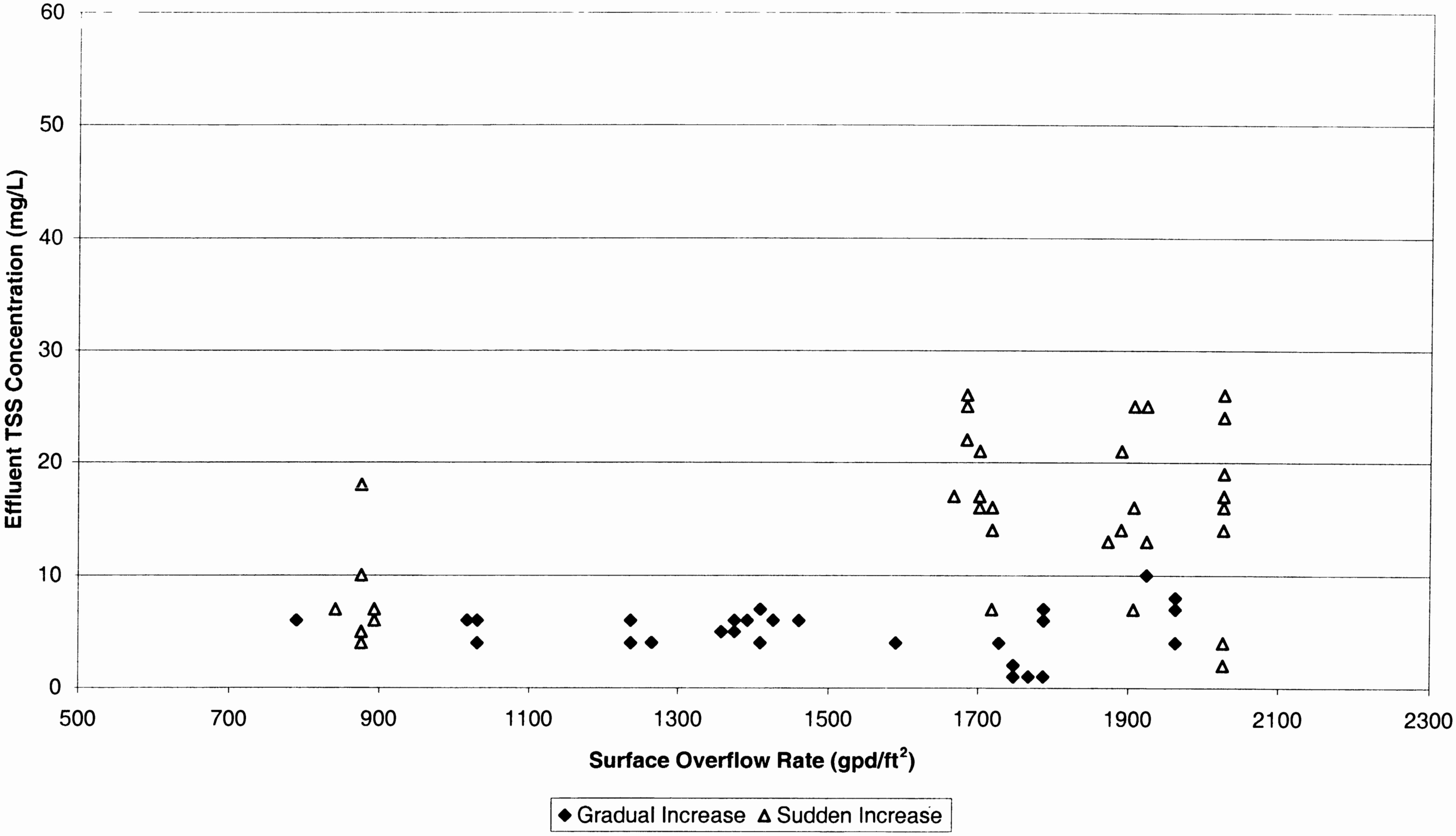
Figure 3-3
SEWPCP Secondary Clarifier Stress Test
Effluent TSS Concentration versus Surface Overflow Rate (SOR)



The performance of Secondary Clarifier 2 was monitored over a four-month period using online instrumentation to quantify the dynamic performance of the clarifiers to naturally-occurring storm events. The online instrumentation recorded total plant flow, RAS flow, mixed liquor TSS concentration, sludge blanket levels, and effluent TSS concentration. The online monitoring recorded the response of Secondary Clarifier 2 to seven storm events. Table 3.4 summarizes results of the online monitoring program; more detailed results are presented in Technical Memorandum 3.

The secondary clarifier TSS concentration exceeded 60 mg/L for short periods of time during the first three storms. The effluent TSS concentration rose significantly at plant flow rates between 120 to 220 mgd. The maximum SOR based on total plant flow and number of clarifiers in service during the storm events ranged from 1,250 to 1,300 gpd/ft^2. This is significantly lower than the maximum allowable SOR observed during the secondary clarifier stress test.

TABLE 3.4
RESULTS OF THE ONLINE MONITORING PROGRAM

Date	SVI ml/g	MLSS mg/L	TSS >60 mg/L		Peak Achieved	
			Q mgd	SOR gpd/ft^2	Q mgd	SOR gpd/ft^2
March 14	217	1,357	220	1,260	220	1,260
March 21	383	1,340	116	660	227	1,300
April 9	214	967	190	1,088	218	1,250
April 11	186	1,203	~	~	220	1,230
April 23	190	1,077	~	~	214	1,230
May 19	155	683	~	~	230	1,580
May 24	141	1,067	~	~	226	1,290

The secondary clarifier effluent TSS concentration did not exceed 60 mg/L for the remaining four storms, even though the maximum flow rate was similar to the first three storms. The main reason for the difference in performance between the first month of the online monitoring period and the remaining three months was the settling characteristics of the mixed liquor.

During February and March 1999, the SEWPCP experienced a severe sludge bulking incident. Samples of the mixed liquor were sent to Dr. David Jenkins at the University of California for microbial species identification. The results indicated that the overabundance of filamentous organisms that were causing the bulking incidence were associated with nutrient deficiency in the activated sludge system.

A sampling program was initiated to track the ortho-phosphate concentration at various points in the collection system and WPCP to identify the cause of the deficiency, and a temporary chemical feed system was installed to add phosphoric acid upstream of the aeration basin. It was determined that the ferric sludge from Queen's Lane Water Treatment Plant was absorbing the ortho-phosphate in the raw sewage before it arrived at the SEWPCP. The ortho-phosphate in the plant influent was less than the detection limit for most of the samples collected. The settling characteristics of the activated sludge improved after the nutrient deficiency was corrected.

The estimated capacity of the secondary clarifiers is 330 mgd with one clarifier out of service. This is based on the observed performance of the secondary clarifiers during the stress tests and on allowable SOR of 1,800 gpd.ft^2. Under bulking sludge conditions, the estimated capacity is less than 200 mgd. The secondary clarifiers at the three facilities are very similar, and therefore the results from stress testing at the other facilities can be used to predict the performance of the secondary clarifiers at the SEWPCP. The secondary clarifier stress test at the NEWPCP indicated that the clarifiers were susceptible to solids flux failure at solids loading rates of approximately 30 lbs/day. The solids flux failure was due to inefficiencies in the solids removal systems. Based on the stress test results from NEWPCP, the estimated capacity of the secondary clarifiers will be reduced if the mixed liquor concentration is increased.

At a mixed liquor concentration of 2,000 mg/L, the capacity of the secondary clarifiers would be reduced to 236 mgd. Modifications to the solids removal systems will be required to maintain current treatment capacity if higher mixed liquor concentrations are required in the future. Higher mixed liquor concentrations would be required if there were a significant change in the raw sewage quality due to changes in the industrial contributions or reduction in the ferric sludge.

3.1.5 Disinfection and Effluent Pump Station

The estimated capacity of the SEWPCP effluent pump station is 280 mgd. This is based on the rated capacity of the existing pumps with one pump out of service. The rated capacity of the disinfection is 395 mgd. This is based on 15 minute HRT in the existing outfall under peak flow conditions.

3.2 Hydraulic Throughput Capacity

The hydraulic throughput capacity of the unit processes at the SEWPCP was estimated using WinHYDRO, a computer model that facilitates complex analysis of plant hydraulics.

Hydraulic and energy gradelines from the headworks to the plant outfall were developed for a number of flow rates. The hydraulic throughput capacity of each unit process was developed based on the assumption that the downstream hydraulic bottlenecks had been resolved. Table 3.5 summarizes the estimated hydraulic throughput capacity for each unit process. The detailed hydraulic modeling results are presented in Technical Memorandum 4 – Hydraulic Throughput Capacity of Existing Facilities.

TABLE 3.5
SOUTHEAST WWTP CURRENT HYDRAULIC THROUGHPUT CAPACITY

Unit Process	Estimated Capacity (mgd)	Basis of Capacity Estimate
Outfall	450	• Flow path – Delaware River to the effluent pump station • Hydraulic control section – mean high tide 97.75 feet • Two outfall channels in service • Hydraulic exceedance – pump station discharge weir
Secondary effluent channel	Version A – 250 Version B >330	• Flow path – effluent PS wet well to secondary clarifier overflow weir • Hydraulic control section – wet well water surface level Version A – wet well level at maximum WSL 100.75 feet Version B – wet well level at WSL 97 feet • Ten secondary clarifiers in service • Hydraulic exceedance – clarifier overflow weir elevation
Mixed liquor channel	Version B > 330	• Flow path – effluent PS wet well to aeration basin overflow weir • Hydraulic control section – secondary clarifier weir The secondary clarifier weir has a free discharge • Hydraulic exceedance – aeration basin overflow weir
Aeration basin and primary flow split box	Capacity 1 – 235 Capacity 2 – 250 Capacity 3 – 330	• Flow path – aeration basin overflow weir to the primary clarifier overflow weir • Hydraulic control section – aeration basin overflow weir • 50/50 flow split between east and west side, six aeration basins in service • Hydraulic exceedance 1 – flow split weir elevation Hydraulic exceedance 2 – primary clarifier overflow weir Hydraulic exceedance 3 – top of concrete
Preliminary treatment	>330	• Flow path – primary clarifier overflow weir to the common influent channel downstream of the raw sewage pump station • Hydraulic control section – primary clarifier overflow weir • Four primary clarifiers and five grit channels and bar screens in service • Hydraulic exceedance – raw sewage pump station discharge weir

The hydraulic throughput capacity of the SEWPCP is greater than 330 mgd, except for the following locations:

- **Primary Clarifier Launders** - The primary clarifier launder capacity is exceeded at less than 75 mgd per clarifier. The launder becomes flooded and the water surface in the clarifier increases and backs up into the flocculation basins and grit tanks. This hydraulic limitation is the result of the small collection channel into which the launders discharge prior to discharging into the main primary effluent channels.

- **Aeration Basin Overflow Weir** - Under high flow conditions, the WSL in the aeration basin increases and submerges the primary effluent flow split weirs. The primary effluent flow split weirs become submerged at approximately 235 mgd. The primary clarifier effluent weirs become submerged at approximately 250 mgd. The WSL in the flocculation tanks and grit chambers is impacted by the increase in the WSL in the primary clarifiers. The hydraulic limitation is the aeration basin outfall weirs. The weir discharge is restricted to keep oxygen in the enclosed aeration tanks.

3.3 Capacity Limiting Factors

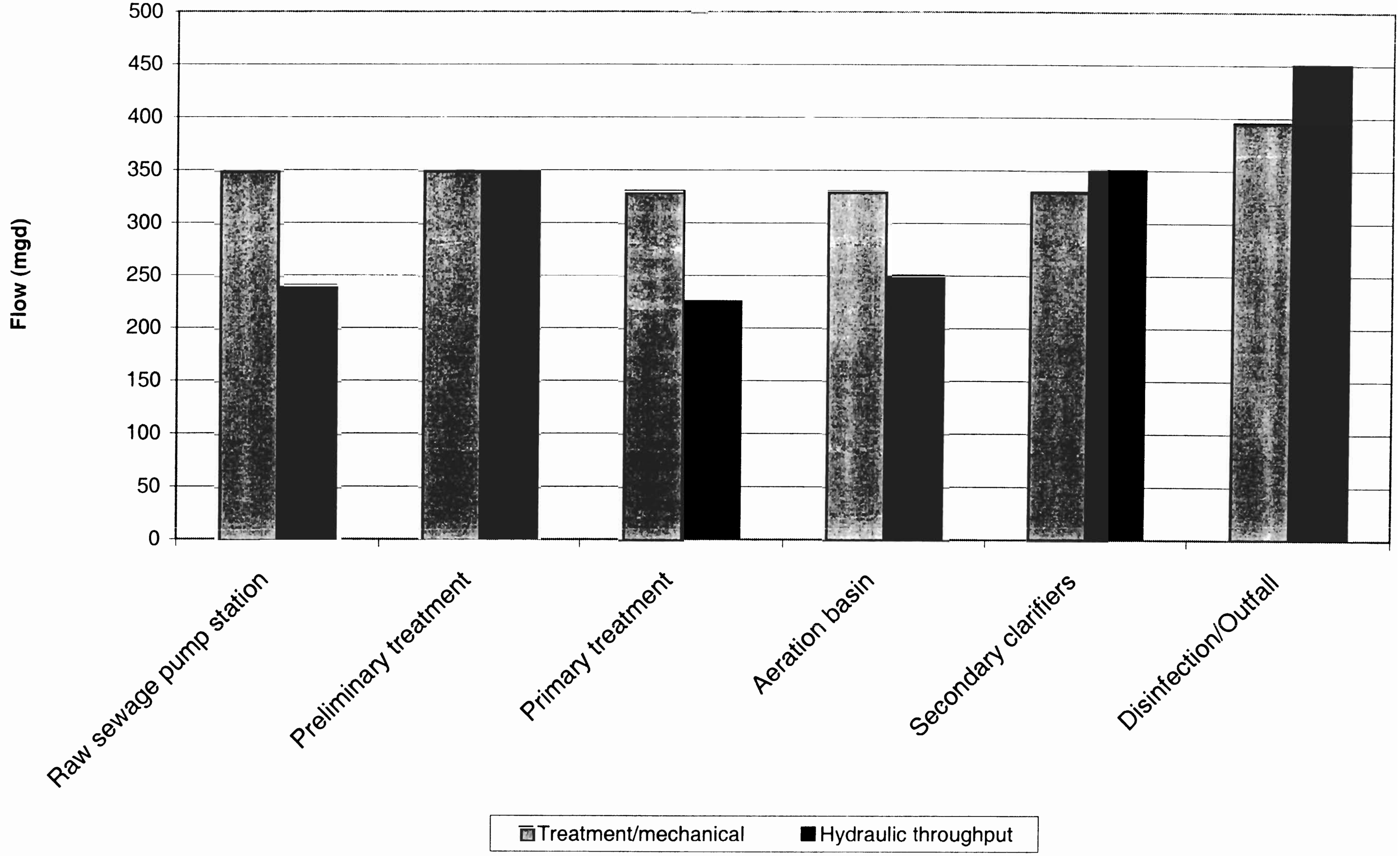
Figure 3-4 presents a summary of the estimated current peak instantaneous capacity on a unit process basis for the SEWPCP. The major capacity bottlenecks for the facility follow:

- **Raw Sewage Pump Station** - Estimated capacity of 200 mgd with one bar rack out of service. The bar rack can be put back into service quickly. However, the potential of permanently damaging the screens and pumps increases. The maximum capacity of the raw sewage pump station with both sides of the wet well in service is 286 mgd. Modifications to the pump station wet well and inlet structure are required to resolve this bottleneck.

- **Primary Clarifier Launders** - Estimated hydraulic throughput capacity of the primary clarifier launders is 225 mgd with three clarifiers in service. Replacing the clarifier launders would increase the primary treatment capacity to 260 mgd. Improved primary sludge pumping would increase the capacity to 300 mgd.

- **Aeration Basin Influent** - Estimated hydraulic throughput capacity of the aeration basin and primary effluent channels is 235 mgd before submerging the aeration basin influent weir. The facility will continue to operate but there will be deterioration in process control under these circumstances. The estimated hydraulic throughput capacity of the aeration basin and primary effluent channels is 250 mgd before flooding occur of the primary clarifier effluent weir. Secondary effluent pumping or aeration basin by-pass (extreme step feed) is required to resolve this bottleneck.

Figure 3-4
Southeast WPCP - Estimated Current Capacity



SECTION 4

CURRENT SUSTAINABLE TREATMENT CAPACITY

4. Current Sustainable Treatment Capacity

4.1 Sustainable Treatment

The estimated treatment capacities summarized in section 3 of this report utilize maximum instantaneous limits currently in PWD's NPDES permits as the goal for the effluent quality. Since the maximum instantaneous and maximum daily limits are the same values, a process operation whose final effluent quality will meet the instantaneous maximum limits will also meet the daily maximum limits. However, the current NPDES permits, based on expected performance for plants that intake substantial quantities of stormwater, include maximum weekly and monthly limits that are significantly more stringent than the daily/ instantaneous limits. Furthermore, strict compliance with maximum monthly concentration limits will not guarantee monthly compliance with other quality limits in the permit, such as average monthly and weekly loading limits and percent removal requirements.

An important but difficult question remains regarding how long a facility (or process) can sustain high flows that allow effluent quality to meet all the permit effluent quality requirements.

The performance of the secondary clarifiers determines the final effluent quality from the SEWPCP. The data collected during the field-testing was used to predict final effluent quality as a function of flow rate. The predicted final effluent TSS and BOD_5 concentration for a given flow rate was used to determine the maximum flow that could be maintained for an infinite period of time with effluent quality meeting the monthly and weekly loading and percent removal requirements in the NPDES permit.

Secondary clarifier capacity is defined by either the clarification capacity, which is a function of SOR, or the solids flux capacity, which is a function of solids loading rate (SLR). Clarifier performance as a function of both SOR and SLR was collected during the testing for a range of operating conditions. Data from the six secondary clarifier stress test was used to quantify the secondary clarifier performance as a function of hydraulic loading and to identify the maximum allowable solids loading rate for the clarifiers.

The historical data was used to determine the yield and mixed liquor concentrations required as a function of primary effluent quality. The data from the primary clarifier stress tests was used to determine the expected primary effluent quality as a function of flow rate. The mixer liquor required for the expected primary effluent quality determines the solids loading rate for the secondary clarifier.

4.2 Analysis Methodology

4.2.1 Predicting Secondary Effluent Quality as a Function of the SOR

In the stress tests of the secondary clarifiers, the TSS and BOD_5 concentrations in the secondary effluent were measured as a function of the surface overflow rate applied to the clarifiers. A linear regression was performed on the field testing data to establish the relationship between SOR and TSS and BOD_5 concentrations in the effluent. The intercept and slope values obtained for the regression were statistically analyzed to find the 95% confidence level associated with these two coefficients. Using the upper 95% confidence level interval provides a conservative description of the relationship between the SOR and effluent quality. The model is used to predict TSS or BOD_5 for a given SOR; the value generated using the linear regression will be lower than the actual value observed 95 out of 100 times.

The estimated effluent concentrations and discharge loads (which are equal to the effluent flow rate multiplied by the effluent concentration) can then be compared to permit levels to determine the sustainable treatment capacity of the facility on a SOR basis.

4.2.2 Effect of the SLR on Secondary Clarifier Performance

Failure of the secondary clarifiers may occur due either to clarification or thickening. An increase in the hydraulic loading to the primary clarifiers will result in an increase in organic loading to the aeration basin due to an increase in the amount of organic material entering the plant and deterioration in the primary clarifier performance. An increase in the organic loading to the aeration tanks results in an increase in the mixed liquor concentrations and therefore an increase in he solids loading for a given flow. Therefore the analysis done in terms of the SOR must be complemented with an analysis of the effect of influent flow rate versus SLR.

Stress tests were performed on the primary clarifiers, and removal efficiencies as a function of the surface overflow rate in the primary clarifiers were documented. The data was used to predict the quality of the primary effluent as a function of the influent flow rate. This analysis, combined with analysis of historical data on solids production, was used to estimate the SLR as a function of flow, taking into account both the performance of the primary clarifiers and the increase in the organic loading associated with augmented flows.

The stress tests on the secondary clarifiers indicated that the maximum SLR that could be maintained before thickening failure occurs is 35 lb/(ft^2.day). The flow at which these solids loading rates are achieved is the maximum sustained flow that can be maintained in the plant before thickening failure occurs.

4.3 Analysis Results

4.3.1 Predicting Maximum Flows as a Function of the SOR

Figure 4.1 is a plot of the TSS in the secondary effluent and the SOR applied in the secondary clarifier from the six secondary clarifier stress tests conducted at the facilities owned and operated by PWD. The data from all six secondary clarifier stress tests were used in the preparation of this plot. Figure 4.2 presents the same analysis was done for the BOD_5 concentration in the secondary effluent.

Figure 4-1
Secondary Clarifier Stress Test - Effluent TSS Concentration as a Function of SOR

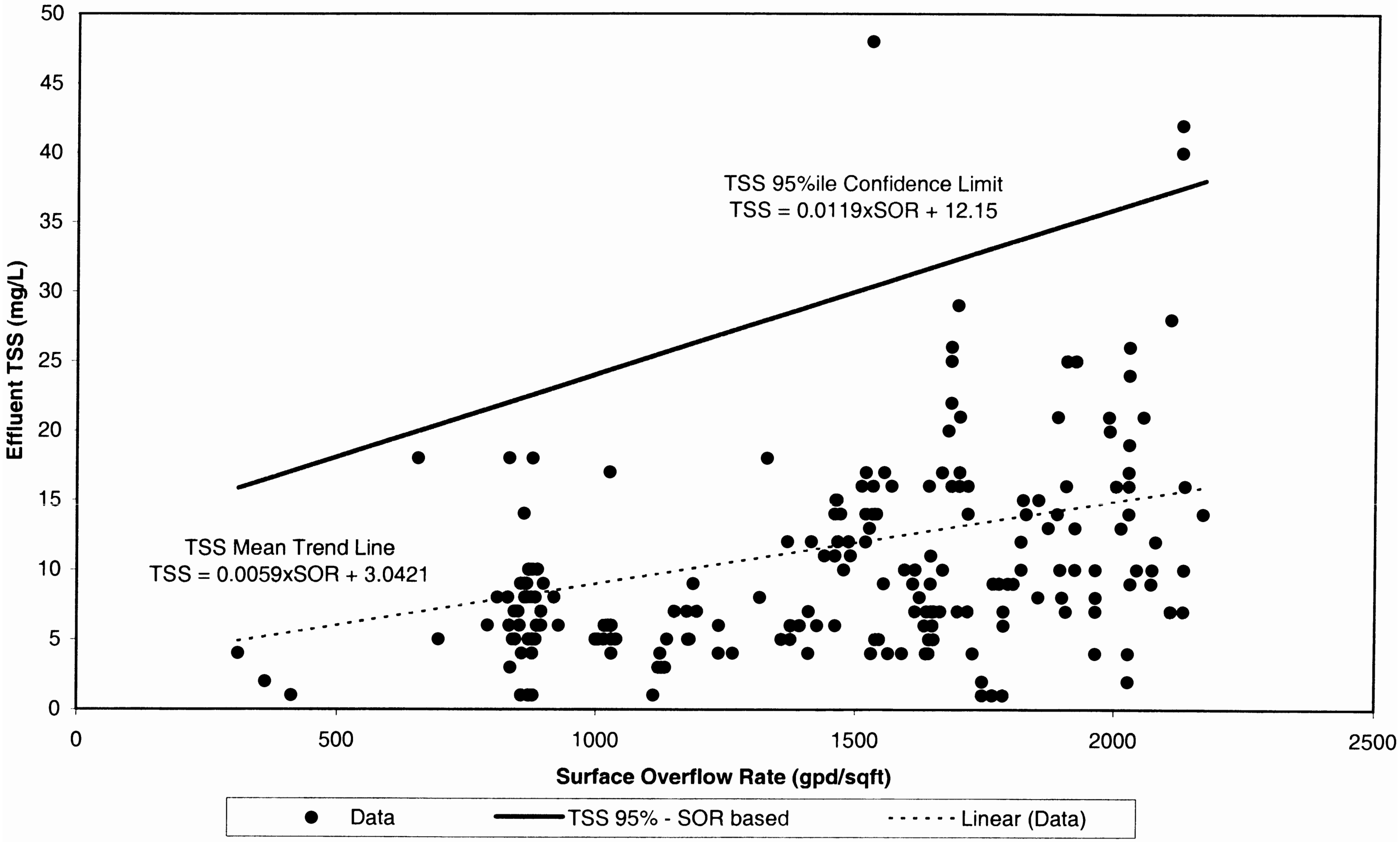
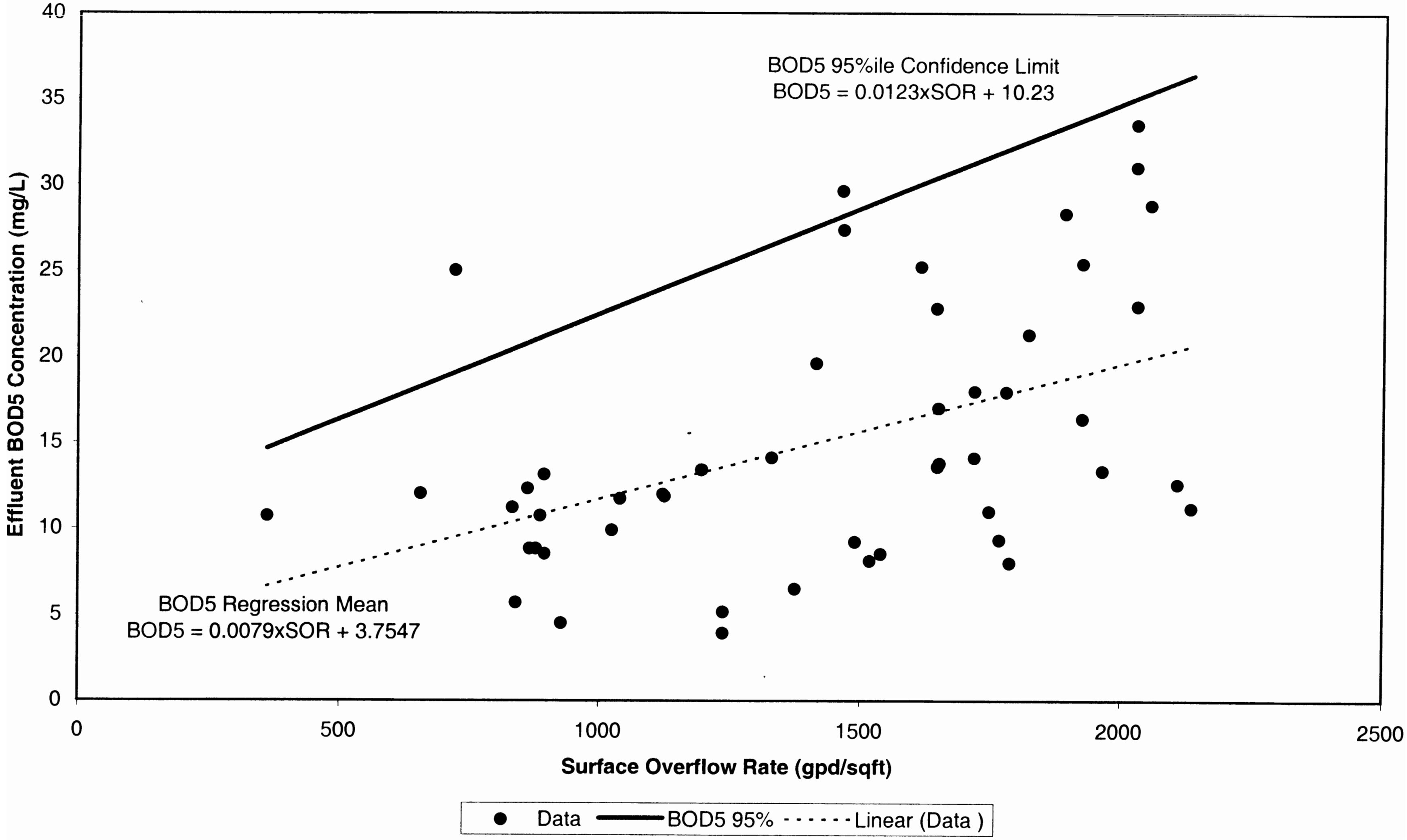


Figure 4-2
Secondary Clarifier Stress Test - Effluent BOD5 Concentration as a Function of SOR



The amount of TSS and BOD$_5$ discharged results from the product of the flow rate and the concentrations predicted by the 95% confidence level regressions. The discharge values were then compared to the NPDES Permit values for the SEWPCP. The results of this analysis are presented in Table 4.1.

TABLE 4.1 SOUTHEAST WPCP – NPDES PERMIT REQUIREMENTS AND RESULTS OF THE SUSTAINABLE FLOW ANALYSIS

Parameter	Units	NPDES Limit	Maximum Sustainable Flow based on SOR		Maximum Sustainable Flow based on SLR
			TSS Limit	BOD$_5$ Limit	
Maximum Day Limits	mgd	168			190
Maximum Week Limits	mgd		195	165	
BOD$_5$ Concentration	mg/L	45			
BOD5 Mass Loading	lbs/day	29,475			
TSS Concentration	mg/L	45			
TSS Mass Loading	lbs/day	42,035			
Maximum Monthly Limits	mgd	112	150	125	
BOD$_5$ Concentration	mg/L	30			
BOD$_5$ Mass Loading	lbs/day	19,650			
BOD $_5$ Percent Removal	%	86			
TSS Concentration	mg/L	30			
TSS Mass Loading	lbs/day	28,025			
TSS Percent Removal	%	85			

The maximum sustainable flows at which the SEWPCP can meet the weekly NPDES TSS and BOD$_5$ effluent mass loading requirements are 195 and 165 mgd, respectively. The BOD$_5$ weekly mass loading is the limiting criteria because the allowable effluent BOD$_5$ mass loading is significantly lower. The maximum daily flow in the NPDES permit is 168 mgd. This is very similar to the predicted maximum sustainable flow at which the facility can meet the weekly mass loading limits.

The maximum sustainable flows at which the SEWPCP can meet the monthly NPDES TSS and BOD$_5$ effluent mass loading requirements are 150 and 125 mgd, respectively. The maximum month sustainable capacity is slightly higher than the average design capacity of the facility.

4.3.2 Predicting Maximum Flows as a Function of SLR

The stress tests of the secondary clarifiers indicated that the maximum solids loading rate that could be sustained by the secondary clarifiers was 35 lb/(ft^2.day). The solids loading rate is a function of the MLSS concentration in the aeration basin and the influent and RAS flow rates. The MLSS concentration is dependent on the loading to the aeration basins, which in turn is dependent on the performance of the primary clarifiers as a function of the flow. The objective is to develop an overall correlation between the flow coming into the plant and the resulting solids loading rate into the secondary clarifiers.

The primary clarifier stress test results were used to determine the TSS percent removal in the primary clarifiers as a function of influent flow rate. A regression analysis of all stress test results performed in the primary clarifiers (except the test performed at the Southeast Plant where the clarifier failed prematurely due to the hydraulic limitations of the launders) was performed, and the lower 95% confidence levels associated with the regression parameters were calculated. Figure 4.3 presents the results of this analysis.

The yield for the SEWPCP was estimated based on the historical tonnage of waste activated sludge pumped to the SWWPCP and the TSS and BOD_5 concentrations in the primary effluent. The SEWPCP is operated at an SRT of 1.9 days, the RAS flow rate is about 30% of the influent flow rate, and the raw wastewater has an average TSS concentration of 142 mg/L. For the determination of the SLR limiting flow, it was assumed that all of the primary and secondary clarifiers are online, but that only six out of the eight aeration basins are in use. This corresponds to current operating practice at the site.

The SLR becomes 35 lb (ft^2.day) at the SEWPCP when the sustained flow is equal to 190 mgd. At flow rates greater than 190 mgd, thickening failure will occur unless measures are taken to reduce the solids loading rate to the secondary clarifiers. Preventative measures that are currently implemented at the SEWPCP include reducing the mixing in the aeration basin to allow solids to settle in Cells 1 and 4 and using the two aeration basins that are out of service as RAS storage for the duration of the storm.

Alternatively, step feed could be implemented at the SEWPCP by constructing an "in basin" primary effluent conduit along the length of the basin. The conduit would operate as a submerged diffusor and would require structural modifications to existing tanks. Improving the primary clarifier performance by providing "out of clarifier" primary sludge thickening or enhanced primary clarifier performance through chemical addition would also reduce the solids loading to the secondary clarifiers. However, these alternatives would require capital expenditure for additional facilities. Improving the solids removal efficiency of the clarifiers would effectively increase the allowable solids loading rate to the clarifier. This would require modifications to the existing RAS system.

4.4 Control of High Flow Duration

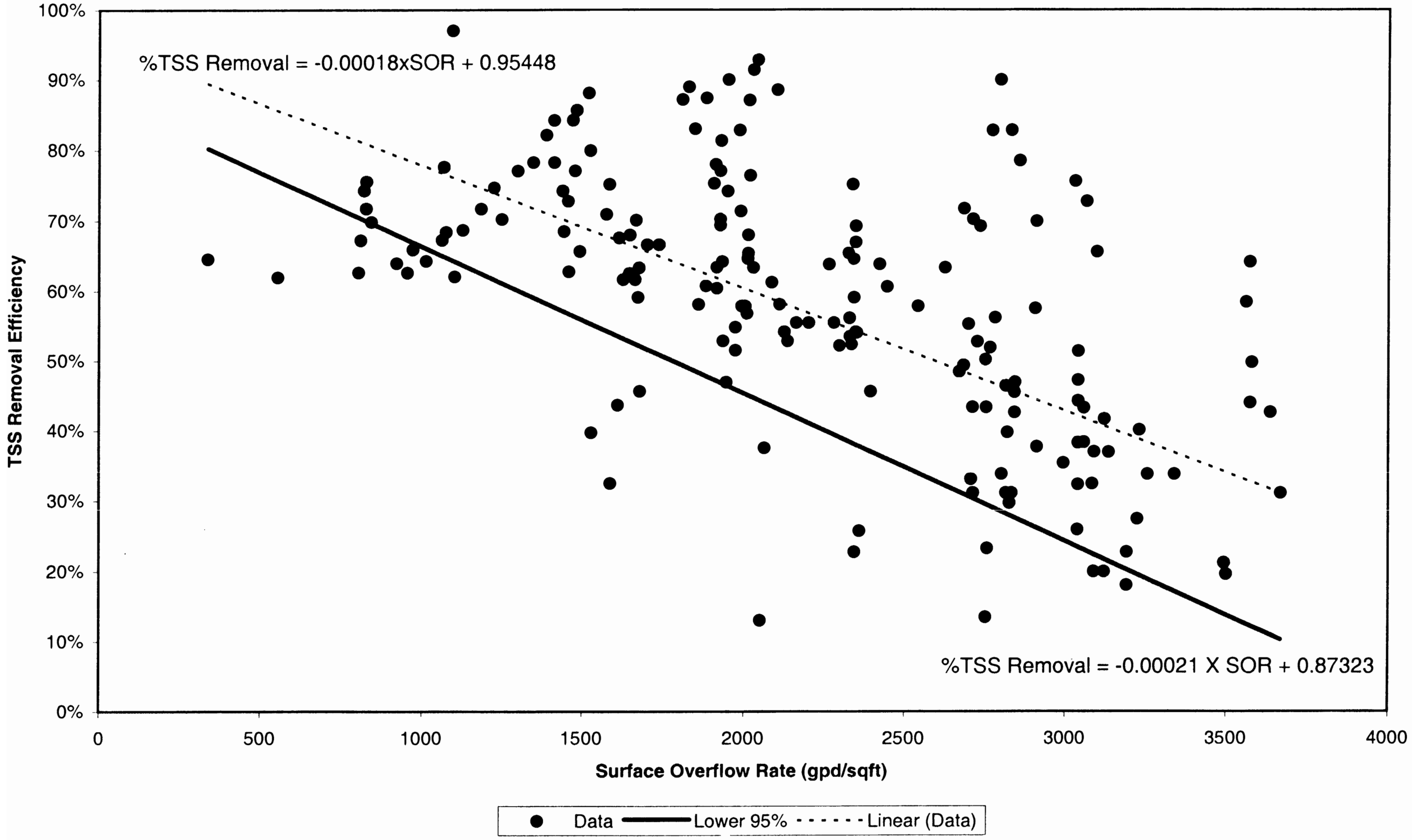
Discussions with PWD managers directing PWD 's CSO program indicated that current CSO inline storage and draw-down plans expect that stored combined sewerage would be released to the plant over a 12-hour period following a storm event. This is a volume of combined sewerage that PWD's plants have not received in the past. Furthermore, there is flexibility in the draw-down strategy since the primary objective of the effort would be to return the storing sewer back to its original condition prior to the next storm event. It was clear that this is only a current plan and it would change should PWD be required in the future to provide additional combined sewerage storage to meet receiving water quality objectives.

From the wastewater treatment plant perspective, a number of factors can influence the ability of a plant to achieve weekly or monthly limits whenever the plant is being stressed by storm-induced, high influent flows. The number and distribution of rain events during the week/month, together with plant effluent quality during non-rain event periods, rank high on the list of influences. PWD's revised permit language provides effluent quality relief, but only when the daily plant flow exceeds the permitted maximum daily flows currently stated in the permits. No such relief occurs for flows below the maximum daily flow limits.

Since the impact of stored combined sewerage on the SEWPCP performance is an unchartered experience, it is recommended that the duration of storage be no greater than a 24-hour period for each storm event. Should the CSO program's strategy for stored combined sewerage change beyond this 24-hour period, the issue of plant compliance for all monthly and weekly effluent quality requirements should be reviewed.

Figure 4-3

Primary Clarifier Stress Test – Percent TSS Removal Efficiency as a Function of SOR



SECTION 5

POTENTIAL UPGRADES

5. Potential Upgrades

A list of potential improvements was developed to increase the capacity or improve the performance of the SEWPCP; the potential improvements are based on the results of stress tests on unit processes, long-term monitoring of the plant, and hydraulic modelling

Each upgrade option has been prioritized based upon the following criteria:

- **Priority A – Existing Facilities Optimization.** Improvements that are easily implemented, low cost, high benefit, and will have an immediate positive impact upon normal operations. These are options that can be included in short-term capital budgets.
- **Priority B – Proactive Improvements.** Improvements that are moderate in cost and will have a positive impact on plant capacity. This category also includes improvements that are necessary to maintain existing capacity for increased mixed liquor suspended solids in the aeration tanks. These are options that should be included in a long-term improvement plan.
- **Priority C - Capacity De-bottlenecking.** Improvements that have large costs associated with them and will greatly increase capacity above the current permitted peak flow. These options should be considered in an overall long-term, wet-weather flow control program and in the long-term improvement plan if significantly more treatment capacity is required at the facility.

The list of potential upgrades, budgetary cost estimates, and their associated prioritization is summarized below. The detailed descriptions of each upgrade are presented in Technical Memorandum 5 - Budgetary Cost Estimates for Potential Plant Improvements.

The cost estimates are based on preliminary costs and are for use as "budgetary" values only. The cost estimates are Class "C" cost estimates (order-of-magnitude costs) as defined by the American Association of Cost Engineers. The level of accuracy of the Class "C" cost estimates is +50 percent to –30 percent of the actual cost of construction. These costs can be used for decisionmaking to select options for more detailed analysis that are most feasible from both a design and cost perspective.

Table 5.1 includes the final estimated cost for each improvement. Table 5.2 presents a summary of the overall cost for improvements at the SEWPCP, which are broken down into alternatives that are dependant upon one another for an increase in capacity at the plant.

TABLE 5.1
POTENTIAL UPGRADE OPTIONS AT SOUTHEAST WPCP

Option No.	Description	Priority Classification	Estimated Conceptual Cost
1	Provide permanent facilities for phosphorous addition if influent phosphorous deficiency remains	A	$200,000
2	Resolve capacity limitation in existing pump station by adding a new bar rack	C	$8-10M, if feasible
3	New influent pump station (Includes adding new bar rack)	C	$24,140,000
4	Replace existing primary clarifier effluent launders with new launders running parallel to flow to increase hydraulic capacity	C	$1,265,000
5	Provide separate primary sludge thickening	C	$3,645,000
6	Provide an additional effluent pump at the effluent pumping station	C	$319,000
7	Provide primary effluent bypass to secondary clarifiers	C	$644,000
8	Resolve hydraulic limitation between primary clarifiers and aeration basin	C	$3,600,000

TABLE 5.2
SUMMARY OF BUDGETARY COSTS FOR POTENTIAL IMPROVEMENTS AT SOUTHEAST WPCP

Improvement Alternatives	Total Costs for Improvements (Million $)	Cumulative Costs for Improvements (Million $)	Peak Treatment Capacity (MGD)			
			Plant	Preliminary	Primary	Secondary
All process improvements (Option 1)	0.2	0.2	240	240	240	240
Increase in raw pumping capacity (Option 2/3)	24.14	24.34	240	330	240	240
Increase primary capacity, bypass aeration basins (Options 4, 5, 6, 7)	5.87	30.21	330	330	330	240
Increase primary and secondary treatment capacity (Options 4, 6, 8)	5.18	33.81	330	330	330	330

Process Improvements. The capacity of the SEWPCP is determined by the solids settling characteristics of the mixed liquor TSS. As discussed in Section 3.1.4, the solids received from Queen's Lane WTP cause a nutrient imbalance in the aeration basin, and phosphorus addition is required to correct this imbalance. Permanent facilities for phosphorus addition address the nutrient deficiency and are currently in use at the plant.

Increase in Raw Pumping Capacity. The capacity of the raw sewage pumping station limits the capacity of the SEWPCP. The objective of Improvement Alternative 2 is to increase the raw sewage pumping capacity. This is required before any other alternatives can be considered for increasing plant flow. The current raw water pumping station is limited to a flow of 200 mgd with one bar rack out of service because of hydraulic limitations in the raw water pump station wet well area.

The facility can operate up to a maximum capacity of 240 mgd with one bar rack partially obstructed. However, there is a greater potential for causing permanent damage to the bar rack or raw sewage pumps operating in this fashion. In the past ten years, a bar rack has been taken out of service for maintenance only once. In the past five years, the hydraulic throughput capacity has never been less than required as a result of maintenance activities. If more CSO flow is brought to the facility, the frequency of the hydraulic throughput being limited by a bar rack out of service will increase.

The hydraulic limitation of the raw sewage pump station is a result of the configuration of the inlet structures. The estimated capital cost of providing a new influent pump station is $24,140,000. A detailed hydraulic evaluation of the pump station inlet structure may identify a more cost-effective method of increasing the hydraulic throughput capacity. Potential retrofits include installing an additional bar rack, additional or larger inlet conduit and/or sluice gates, and modifications to the pump suction channels. However, due to the depth of the pump suction, any modification that requires changes to the inlet structure footprint will be expensive. A new influent pump station may be the preferred alternative.

Increase Primary Treatment Capacity with Aeration Bypass. The estimated primary treatment capacity is 225 mgd with three primary tanks in service. The capacity is limited by the hydraulic capacity of the effluent launders. Replacing the effluent launders will increase the primary treatment capacity to 260 mgd with three tanks in service. The estimated capital cost to replace the clarifier launders is $1,265,000.

The potential primary treatment capacity of the SEWPCP is 330 mgd. Increased primary sludge pumping would be required to achieve the additional primary treatment capacity. The estimated cost of providing a gravity sludge thickening facility at the SEWPCP is $3,645,000.

A bypass between the primary clarifier effluent channel and the mixed liquor channel/secondary clarifier influent will be required to circumvent the hydraulic bottleneck between the primary clarifiers and the aeration basins. One aproach would be to construct the primary effluent channel to the mixed liquor channel. The estimated cost for this potential upgrade is $644,000. The primary effluent would be added to the upstream end of the mixed liquor channel and pass through the secondary clarifiers before discharge. The estimated peak hydraulic capacity of the secondary clarifiers is 330 mgd at current mixed liquor concentrations. The primary effluent will increase the hydraulic loading on the secondary clarifiers without increasing the solids loading. Therefore, the secondary clarifiers have sufficient hydraulic capacity to treat the additional load.

The advantage of this approach is that the primary effluent will receive some additional treatment due to contact with the mixed liquor and the "sweeping" action of the activated sludge in the secondary clarifiers. The final effluent will be of higher quality than the blended effluent from the secondary clarifier and bypass stream combined after the secondary clarifier. However, the contact time between the activated sludge and primary effluent bypass will be very small and therefore BOD_5 removal from the primary effluent will be minimal. A relaxation in the permit requirements on days when aeration tank bypassing occurs is recommended. Additionally, to get the flow out of the plant, a new effluent pump would need to be added at a cost of $319,000.

Increase Primary and Secondary Treatment Capacity. The objective of this plan is to increase the secondary treatment capacity by eliminating the hydraulic bottlenecks at the influent end of the aeration basins. Offline sludge thickening would not be required because the primary effluent would receive full secondary treatment and no bypass arrangement of the aeration basins would be used. The estimated capital cost to provide intermittent pumping between the primary clarifiers and the aeration basin is $3,600,000. Additionally, a new effluent pump would need to be added to increase the capacity of the effluent pumping station from 280 mgd to 350 mgd. The capital cost would be $319,000 for the new pump. The hydraulic residence time of the outfall is greater than 15 minutes at this flowrate, therefore no additional chlorine contact time would be required.

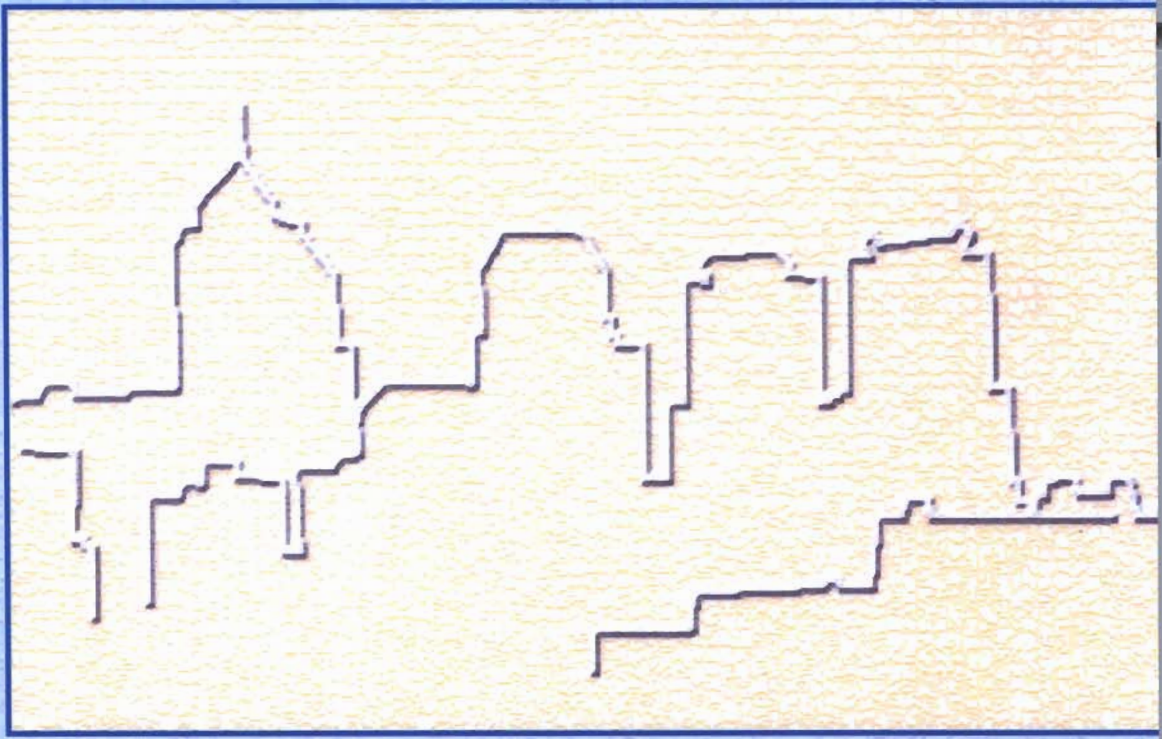
Philadelphia Combined Sewer Overflow Long Term Control Plan Update

Supplemental Documentation
Volume 8

Stress Testing of the Southwest WPCP

Updated: September 1, 2009

FINAL REPORT



Stress Testing of the Southwest WPCP

Stress Testing of the Southwest WPCP

Prepared for

Philadelphia Water Department

Prepared by

CH2MHILL

December 2001

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SECTION 1

INTRODUCTION

1. Introduction

1.1 Project Objectives and Methodology

As part of its obligations under the Federal Clean Water Act and the Pennsylvania Clean Streams Law, the City of Philadelphia Water Department (PWD) has initiated a program with an objective to minimize the impact of Combined Sewer Overflows (CSO) on local receiving waters. One of the proposed strategies for reducing the CSO volume is to maximize flow to be treated by the water pollution control plants (WPCP) during periods of wet weather. To implement this strategy effectively, the PWD needs to have a clear understanding of the factors that affect how much flow each of the three WPCPs can effectively treat. With this knowledge, the PWD will be able to identify and prioritize plant upgrades and other system modifications that will allow it to meet the CSO minimization objectives in the most environmentally-sound and cost-effective manner.

PWD contracted CH2M HILL to conduct stress testing at the three wastewater treatment plants that are owned and operated by the City. The objective of the stress testing was to determine the reliable maximum capacity of these facilities and identify cost-effective methods of increasing the ability of the existing facilities to treat peak hydraulic flows associated with wet weather conditions. The major tasks performed during the project are briefly described below.

Historical Data and Operations Review. The objective of the historical data and operations review was to evaluate the physical condition, current loading, and treatment efficiency provided by the existing unit processes. A tour of the plant was conducted, and the process equipment and facilities were examined. Operating records, design information, and engineering drawings were studied to develop a strong understanding of the operations and constraints. Technical Memorandum 1 – Historical Data Review was produced to summarize the results of the site visit and historical data analysis.

Short-Term Stress Testing. CH2M HILL performed a series of capacity and diagnostic tests to determine the loading versus performance characteristics of specific unit processes at each facility. The short-term stress testing focused on determining the response of the primary and secondary clarifiers to increased hydraulic loading under different operating conditions. The short-term stress testing at the Southwest WPCP (SWWPCP) included primary clarifier stress tests, secondary clarifier stress tests, secondary clarifier dye tests, and flow meter calibration. The results of each test are summarized in a test description report in Technical Memorandum 2 – Short-Term Test Results.

Long-Term Stress Test (Online Monitoring). Online monitoring equipment was installed to quantify the dynamic load/response characteristics of the secondary treatment system to naturally-occurring storm events. The equipment was also used to monitor the effect increased flows had on the solids inventory in the system and secondary effluent quality. Online monitoring included total plant flow, return activated sludge (RAS) flow, mixed liquor suspended solids (MLSS) concentration, sludge blanket levels, and secondary effluent total suspended solids (TSS) concentration. The equipment was in place from March 1 to June 30, 1999 and recorded data on a 10-minute interval. The long-term monitoring period was extended to include the fall and winter period from October 1, 1999 to January 31, 2000. The results of the long-term stress test are summarized in Technical Memorandum 3 – Long-Term Online Monitoring Results. The detailed online monitoring data and instrument calibration records are provided under separate cover.

Hydraulic Throughput Capacity Assessment. WinHYDRO, a computer model that facilitates complex analysis of plant hydraulics, was used to evaluate the hydraulic throughput capacity of the SWWPCP. Hydraulic and energy grade lines from the headworks to the plant outfall were developed for the average and peak flow conditions. Hydraulic bottlenecks, which limit the hydraulic throughput capacity of the existing facilities, and flow distribution problems were identified and evaluated. The hydraulic throughput capacity of each unit process was determined. The results of the hydraulic modelling performed are summarized in Technical Memorandum 4 – Hydraulic Throughput Capacity of Existing Facilities.

Evaluation if Potential Improvements. Based upon stress testing and hydraulic modeling results, major bottlenecks that limit plant capacity were identified and potential solutions were developed to increase peak instantaneous capacity. Budgetary cost estimates were developed for each potential solution. The results of this analysis are summarized in Technical Memorandum 5 – Budgetary Cost Estimates for Potential Plant Improvements.

1.2 Report Organization

The project notebook consists of a final report and a series of attachments. The main body of the report contains a summary of the results from the stress testing, plant data analysis, and the evaluation of process improvements and upgrade options. The detailed results from the historical data review, short-term testing (stress tests, dye tests and flow meter calibration), online monitoring, and hydraulic throughput capacity assessment are included in the project notebook as attachments. Tables describing the design criteria, scope of work, and estimated capital costs for the potential process modifications and capital upgrades, and the current National Pollution Discharge Elimination System (NPDES) discharge permit for the site are also included as attachments.

SECTION 2

CURRENT PERFORMANCE

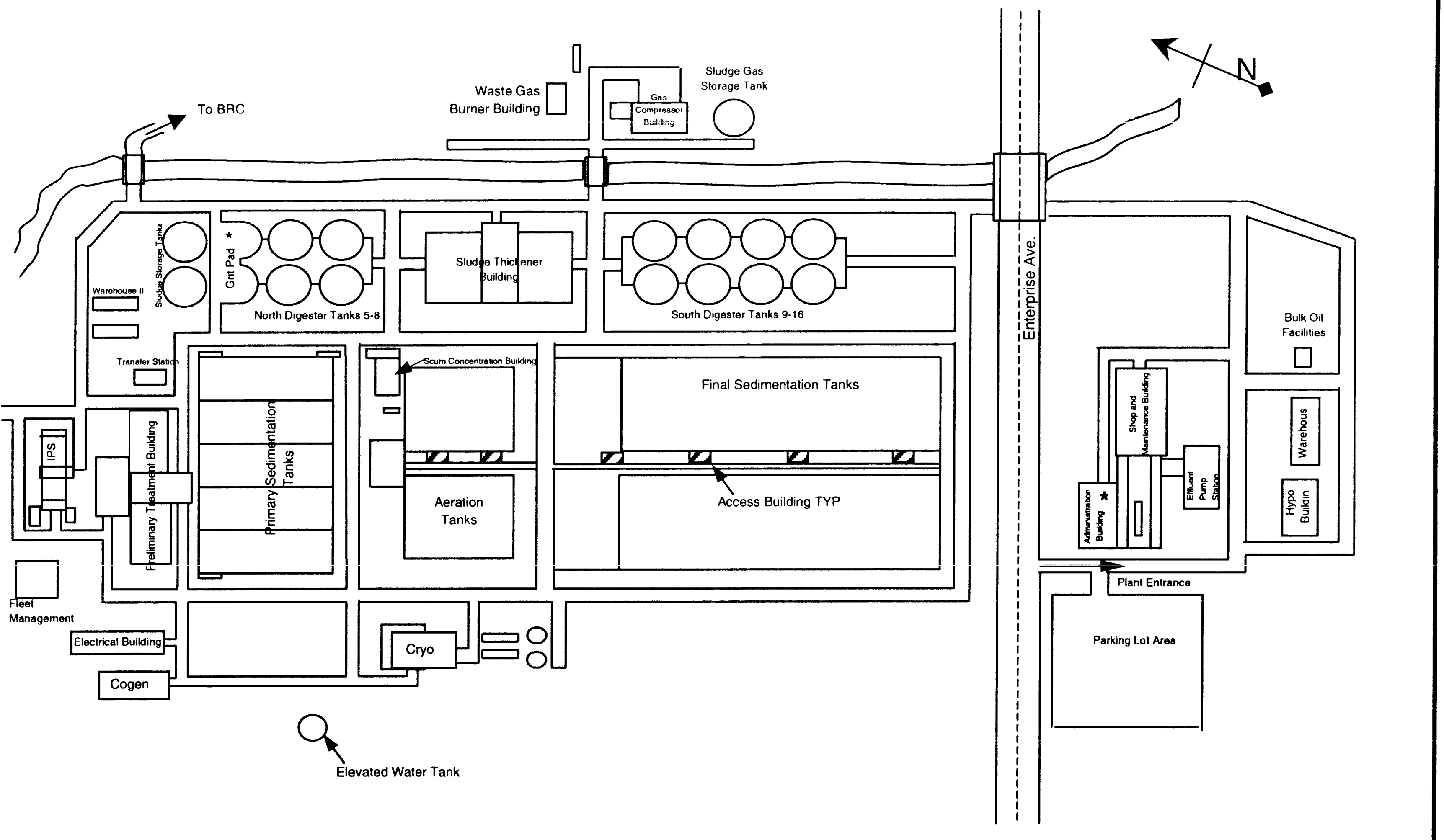
2. Current Performance

2.1 Description of Facilities

Figure 2.1 presents a site plan and Table 2.1 summarizes the existing unit processes at the SWWPCP.

TABLE 2.1
SOUTHWEST WPCP – SUMMARY OF UNIT PROCESSES

Unit Process	Number	Description
Influent Flow Meter	1 3 1	Parshall flume – low-level gravity sewer Venturi –high-level gravity sewer Venturi –DELCORA forcemain
Low-Level Pumps	6	Archimedes screw (operating 2 in series) Q = 32 mgd, diameter = 8.5 ft, head = 22 ft (each), 42 ft total
Bar Screens	5 1	Width = 6 ft, 84° incline, front cleaned, 1-in. opening Width = 6 ft, 84° incline, front cleaned, 5/8-in. opening
Grit Removal	4	Rectangular Detritor Length = 60 ft, width = 60 ft, SWD = 8 ft
Flocculation (Pre-aeration)	1 (west) 1 (east)	Length = 127.25 ft, width = 28.75 ft, SWD = 12 ft, Volume = 43,900 ft^3 Length = 127.25 ft, width = 28.75 ft, SWD = 12 ft, Volume = 43,900 ft^3
Primary Clarifiers	5	Length = 250 ft, width = 125 ft, SWD = 12 ft Area = 31,250 ft^2, weir length = 1,008 ft (each) C and F sludge mechanism, influent end hopper
Flow Split Chamber	36	Gates at 86-in. weir length 6 gates for 2 aeration basins
Aeration Basin	10	Four-pass – through flow only Length = 160 ft, width = 40 ft, SWD = 17 ft Operate with first pass as selector – seasonally
Aeration System	2 40	Cryogenic, 90 lbs O_2 per day 125 hp, 100 hp, 75 hp, 60 hp (per basin)
Secondary Settling Tanks	20	Length = 260 ft, width = 76 ft, SWD = 11 ft Weir length = 816 ft (each) Chain and flight sludge mechanism
RAS Pumps	30	Q = 6.2 mgd, 3 pumps for 2 clarifiers
Effluent Pumps	5	Q = 115 mgd, hp = 500, VSD 3 units
DAF	8	Length = 70 ft, width = 18 ft, SWD = 12 ft
Anaerobic Digesters	12 1	Diameter = 110 ft, SWD=30 ft, volume = 2.1 mg (each) Sludge storage tanks



CH2MHILL

FIGURE 2-1
SITE PLAN
SOUTHWEST WATER POLLUTION CONTROL PLANT
CITY OF PHILADELPHIA WATER DEPARTMENT

2.1.1 Preliminary Treatment

The SWWPCP receives wastewater from a triple-barrel, high-level gravity sewer; a low-level gravity sewer; and the DELCORA forcemain. The triple-barrel, high-level sewer provides approximately 68 percent of the flow to the facility. Three venturi flumes, one for each line in service, measure the flow. The DELCORA forcemain provides approximately 23 percent of the flow to the facility and is measured by a separate venturi flume. Flow from the Biosolids Recycling Center (BRC) is combined with the low-level gravity sewer discharges upstream of the low-level pump wet well. The plant drain system, which includes the recycle flow from the sludge thickening processes onsite, also flows to the low-level pump wet well. The BRC and plant drain flows are measured separately and provide a significant solid and organic loading to the facility. The flow from the low-level pump is measured by a Parshall flume and represents less than 10 percent of the flow to the facility.

The low-level flow discharges on the east side of the common raw sewage channel. Inadequate mixing of the combined raw sewage flow is a concern because the low-level sewer flow travels preferentially to the east side of the SWWPCP facility. The inadequate mixing results in higher organic loadings to the east primary clarifiers (Clarifiers 1 and 5) and the east secondary treatment system.

The SWWPCP has six mechanically-cleaned bar screens. Five of the six screens have 1-inch bar openings, while the sixth screen has 5/8-inch openings. In general, the bar screens operate satisfactorily. However, the 5/8-inch screen experiences grit accumulation upstream of the screen. The screenings are collected and are hauled offsite for disposal. The SWWPCP is able to pass the current peak flow with five of the six screens in service.

The SWWPCP has four rectangular detritor grit removal tanks. Under dry weather flow conditions, two of the four grit tanks are in service. The standby grit tanks are brought into service under high flow conditions. The grit is removed from the detritors and is pumped to the hydrogritters. The washed grit is then removed from the site for disposal. The recycle stream from the hydrogritters discharges into the flocculation basin. A significant volume of grit passes through the existing grit removal system and is deposited in the flocculation tanks downstream. The flocculation tanks must be drained so that the accumulated grit can be removed on a periodic basis. The grit removal process requires one tank to be out of service for approximately two weeks. The hydraulic throughput capacity of the flocculation basins is very limited during this cleaning process.

There are two flocculation tanks at the SWWPCP. Under high flow conditions, the water surface level (WSL) in the flocculation tanks is very close to the top of the wall. Splashing and periodic, short-term overtopping of the walls can occur under high flow conditions when either one primary clarifier and/or one flocculation tank is out of service. The hydraulic restriction is associated with the primary clarifier collection channel and the piping between the primary tanks and aeration basins. This issue is discussed in greater detail in Section 3.2.

2.1.2 Primary Treatment

The SWWPCP has five 250 by 125 feet rectangular primary clarifiers with a side wall depth of 12 feet. Each tank has seven chain and flight mechanisms that move the sludge to the influent end of the basin. The flow from the flocculation tanks enters the common influent channel between Primary Clarifiers 2 and 3. The flow is unequally distributed between tanks, with the east clarifiers receiving approximately 20 percent more flow. The sludge blanket level in Primary Tank 5 is higher than the sludge blanket levels in the other clarifiers because of the higher solids loading associated with the BRC flows. The primary sludge is pumped sequentially from each tank once per day. The primary sludge is pumped to the mixing chamber where it is combined with the thickened waste activated sludge (WAS) and the sludge pumped from the Southeast WPCP (SEWPCP).

Primary effluent discharges into a common effluent channel. Two flow splitter boxes control the flow distribution to the aeration basins. The 20 percent flow imbalance between the east and west primary clarifiers is also seen in the flow distribution to secondary treatment.

The SWWPCP collects a 24-hour composite primary effluent sample from the east and west flow splitter boxes. The primary effluent TSS and five-day biochemical oxygen demand (BOD_5) concentrations are approximately 10 percent higher in the east flow splitter box. Therefore, the loading to the east secondary system is higher due to both a hydraulic imbalance as well as an organic loading imbalance.

2.1.3 Secondary Treatment

The SWWPCP has ten 4-pass UNOX pure oxygen aeration basins. Under current loading conditions, eight of the ten aeration basins are in service. Each basin is 160 by 40 feet with a side wall depth of 17 feet. The aeration basins consist of four cells operating in series. The primary effluent follows a serpentine flow pattern through the basin, and the return activated sludge (RAS) is pumped to the upstream end of Cell A. There are no structures to allow step-feed in the basin.

Each cell has a single, two-paddle submerged aerator/mixer located in the center of the tank. The SWWPCP operates the first cell as an anoxic selector by turning off the first aerator/mixer in the summer months to combat Nocardia and thereby improve the settling characteristics of the mixed liquor. During the winter months, the SWWPCP turns off the aerator mixer in the second cell as part of its ongoing energy management efforts. The first mixer is placed back in service when the second mixer is turned off.

The east and west secondary treatment processes are operated as separate systems. The mixed liquor from the east aeration basins flows to the east secondary clarifiers, and the RAS from the east secondary clarifiers is pumped to the east aeration basins. The mixed liquor suspended solids concentration is approximately 2,270 mg/L and 1,940 mg/L for the east and west secondary systems, respectively. The difference in mixed liquor concentration is due to the difference in loading. The RAS is flow-paced at approximately 32 percent of the flow through the plant.

The mixed liquor from each set of four aeration basins flows through a common mixed liquor channel to a set of ten secondary clarifiers. The caulking on some of the clarifier launders is missing, resulting in a large volume of flow in the launders that is not controlled by the clarifier weir elevation. This results in a flow imbalance between clarifiers that is difficult to predict or control.

Each set of secondary clarifiers consists of ten 76 by 260 foot rectangular clarifiers with a sidewall depth of 11 feet. Each clarifier has eight chain and flight mechanisms that transport the sludge to a central hopper located at approximately the mid-length of the clarifier. The RAS flow rate is measured separately for each clarifier. The maximum RAS per clarifier is limited to 6.2 mgd.

2.1.4 Disinfection

Secondary effluent from the east and west secondary treatment processes flows through the secondary effluent channel to the effluent pump station wet well. The conduit is separated for approximately 200 feet before it is combined upstream of the common wet well. Under dry weather flow conditions, the secondary effluent flows by gravity through a triple-barrel outfall to the Delaware River. The outfall conduit provides contact time for disinfection.

The SWWPCP has five effluent pumps, four of which are in service. Three of the effluent pumps are equipped with variable speed drives, two pumps are single speed only. The effluent pumps are operated based on the WSL in the effluent pump station wet well. Under wet weather flow and/or high tide conditions, the pumps are controlled automatically based on wet well level, but they must be placed into service manually.

2.1.5 Solids Handling

The waste activated and primary sludge generated at the SEWPCP is treated at the SWWPCP. The WAS from the SEWPCP and SWWPCP is pumped to the sludge thickeners. The SWWPCP has eight 18 by 70 feet dissolved air floatation (DAF) sludge thickeners. All attempts are made to keep the eight tanks in service, because additional sludge thickening capacity is often required. The thickened WAS sludge is pumped to the sludge-mixing chamber where it is combined with the primary sludge. The underflow from the DAF sludge thickeners flows to the plant drain and therefore to the wet well of the low-level sewage pump station. However, when the sludge volume index (SVI) of the WAS is high, the DAF units are not able to separate the WAS, and the underflow from the DAF units has a very high solids concentration. The sludge thickening process can become limiting, depending on the quality and quantity of sludge pumped from the SEWPCP, BRC centrate loadings, and/or if one or more units is out of service.

The SWWPCP has 12 anaerobic digesters with an average hydraulic residence time (HRT) of 18 days. The combined primary and waste activated sludge is pumped to the anaerobic digesters sequentially, with each digester receiving solids for nine minutes on each sequence. The digested solids are transported to the BRC for composting and beneficial reuse. The recycle streams from the BRC facility are returned to the SWWPCP headworks for treatment.

2.2 Regulatory Requirements

The SWWPCP NPDES permit limits include effluent BOD_5 and TSS concentrations; mass loading discharges; and percent removal for daily, weekly averages and monthly averages. Table 2.2 summarizes the NPDES permit criteria for the facility in effect during testing. Compliance is based on the flow measured by the four venturi meters and one Parshall flume located upstream of the preliminary treatment and 24-hour composite samples collected daily at the influent and outfall station.

TABLE 2.2
SOUTHWEST WPCP – NPDES PERMIT REQUIREMENTS

Parameter	Units	Monthly Average	Weekly Average	Maximum Day	Peak Instantaneous
BOD_5					
Concentration	mg/L	30	45		60
Mass loading	lbs./day	21,650	32,475	--	
Percent removal	%	89.25			
TSS					
Concentration	mg/L	30	45	--	60
Mass loading	lbs./day	50,040	75,060		
Percent removal	%	85			
Flow	mgd	200		300	400

PWD has negotiated a new NPDES permit for the facility effective July 2000. The modifications to the NPDES permit are summarized below.

As part of PWD's long-term combined sewer overflow (CSO) program, PWD will be reducing the frequency and volume of untreated sewage discharges through the CSOs. In order to account for the increased loading due to the combined sewage flows that exceed the treatment plant's rated hydraulic capacity, the following methods may be used for calculating and reporting mass loadings and effluent concentrations on the monthly discharge monitoring report.

- If a calendar month includes one or more days where flows exceed 300 mgd, a value of 85 percent may be used for those days for the purpose of calculating average monthly TSS percent removal. The actual TSS percent removal associated with those days shall be reported on the appropriate space provided on the DMR.
- If a calendar month includes one or more days where flows exceed 300 mgd, a value of 89.25 percent may be used for those days for the purpose of calculating average monthly BOD_5 percent removal. The actual BOD_5 percent removal associated with those days shall be reported on the appropriate space provided on the DMR.
- When daily flows exceed 300 mgd, the TSS and BOD_5 mass loadings for those days may be omitted from the average monthly and average weekly mass loading calculations. The actual TSS and BOD_5 loadings associated with those days shall be reported on the appropriate space provided on the DMR.

PWD has requested that $cBOD_5$ data be used to establish compliance with permit requirements. Analysis of the data collected over the previous permit cycle indicated that there is relatively little variation in the influent ratios of $cBOD_5/BOD_5$. Therefore, calculating the theoretical influent $cBOD_5$ loadings based on historic BOD_5 data can be used to develop recommended $cBOD_5$ limits for this facility.

The new NPDES $cBOD_5$ permit requirements for SW WPCP are:

	Concentration (mg/L)	Mass Loading (lbs/day)	Percent Removal (%)
Average monthly	25	19,800	89.25
Average weekly	40	29,700	
Instantaneous maximum	50		

The $cBOD_5$ in the raw wastewater shall be reduced by at least 89.25 percent as a monthly average. The percent removal shall be calculated from daily 24-hour composite samples of the influent and effluent. The $cBOD_5$ percent removal requirement will be relaxed to 86 percent when the influent $cBOD_5$ concentration is less than 103 mg/L on a monthly average basis as long as the $cBOD_{20}$ allocation, equivalent mass BOD_5 limitation, and an effluent $cBOD_5$ concentration of 14 mg/L are not exceeded on a monthly basis.

A copy of the new NPDES permit is located in the Project Notebook.

2.3 Current Loading and Performance Achieved

2.3.1 Unit Process Loading

Table 2.3 presents a summary of the current unit process loading over a three-year period from July 1995 to July 1998. The average and maximum daily flows were 176 mgd and 384 mgd, respectively. The maximum instantaneous flow was 439 mgd. On September 16, 1999, during Hurricane Floyd, the maximum instantaneous flow at the plant reached 486 mgd.

The average raw sewage TSS and BOD_5 concentrations were 154 mg/L and 108 mg/L, respectively. The average organic loadings to the treatment plant, calculated based on the raw sewage TSS and BOD_5 concentration and the average flow for each day, were 224,434 lbs/day and 156,642 lbs/day, respectively. Approximately 30 percent of the TSS loading to the SWWPCP is from the BRC recycle streams.

2.3.2 Primary Treatment Performance

The average and peak SORs for the primary clarifiers were approximately 1,126 gpd/ft^2 and 2,810 gpd/ft^2, respectively. Typical overflow rates for rectangular clarifiers are between 1,000 gpd/ft^2 and 3,000 gpd/ft^2. The primary clarifiers at the SWWPCP are operating at close to the expected maximum capacity based on typical SORs.

The removal efficiencies are lower than expected based on current hydraulic loading. The expected TSS and BOD_5 removal efficiencies are 60 and 35 percent, respectively. The average TSS removal efficiencies in the primary clarifiers were 47 and 43 percent for the east and west sides of the plant, respectively.

Based on solids removal efficiency, the east clarifiers performed slightly better than the west clarifiers. This is due to the higher solids concentration in the primary influent on the east side of the plant. Based on primary effluent solids concentration, the west primaries performed significantly better than the east primaries. The average TSS concentrations in the primary effluent were 125 mg/L and 95 mg/L for the east and west, respectively. The BOD_5

removal efficiencies in the primary clarifiers were 28 and 38 percent for east and west primary clarifiers, respectively. The BOD_5 removal efficiencies were closer to the expected values.

2.3.3 Secondary Treatment Performance

The average primary effluent TSS and BOD_5 concentrations were 110 mg/L and 75 mg/L, respectively. The average and 95th percentile total BOD_5 loading to the secondary treatment system, calculated based on the primary effluent BOD_5 concentration, and the average flow for each day were 104,720 lbs/day and 153,0455 lbs/day, respectively.

TABLE 2.3
SOUTHWEST WPCP – SUMMARY OF CURRENT UNIT PROCESS LOADINGS (JULY 1995 – JULY 1998)

Unit Process	Units	Current Loadings		Typical Values	Notes
		Average	Maximum		
Loading					
Hydraulic	mgd	176	439		1
Organic					
BOD	lb/d	156,642	196,449		2
TSS	lb/d	224,434	337,762		2
Grit Tanks					
Volume (total)	ft^3	133,200			
Area (total)	ft^2	14,400			
HRT	minutes	4.1	3.3	3 – 5	3
Primary Clarifiers					
Area (total)	ft^2	156,250			
Weir Length (total)	ft	5,040			
Surface Overflow Rate	gpd/ft^2	1,126	2,810	1,000 – 3,000	4
Removal Efficiency					
BOD	%	33		35	
TSS	%	45		60	
Aeration Basins					
Volume (total)	mg	13.6			5
BOD loading	$lb/d/1000\ ft^3$	52	79		2
HRT	hours	2.0	0.80		5
MLSS	mg/L	2,265 (east) 1,947 (west)			
SVI	mL/g	103		100 – 150	
ISV	ft/hr	9.4			
SRT	day	2.0			5
F/M	1/day	0.41 (east) 0.45 (west)			5
Secondary Clarifiers					
Area (total)	ft^2	395,200			4
Weir length (total)	ft	16,320			4,1
Surface overflow rate	gpd/ft^2	445	1,111	600 – 1,500	4,2
Solids loading rate	lb/ft^2	12.1 (east) 9.6 (west)	19.5 (east) 14.7 (west)		
Chlorination					
Volume	mg	8.68			
HRT	minutes	71	28	15	4

Notes:
1. Maximum hydraulic loading based on instantaneous flow
2. Maximum loading based on 95th percentile
3. Based on two units in service for average day flow and four units in service for maximum flow
4. Based on all units in service
5. Based on eight aeration basins in service

The Southwest WPCP has three sources that provide flow to the plant. The high level interceptor can deliver up to 540 mgd to the plant. The DELCORA interceptor can deliver up to 110 mgd. The low level gravity sewer delivered capacity is limited to the pumping capacity at the headworks, which is 96 mgd with all three pumps running.

The estimated treatment capacity of the preliminary treatment system is 475 mgd. This is based on two of the three low level pumps in service (64 mgd) and the remainder of flow provided by the interceptors. Treatment capacity is based upon acceptable bar screen face velocities and one bar screen out of service. Under peak flow conditions, the face velocity on the bar screens will vary between 0.2 to 0.4 ft/sec.

The design of the SWWPCP allows the east and west secondary treatment processes to be operated as different systems. The organic loading to the east secondary treatment system is approximately 20 percent higher. The average mixed liquor concentrations in the east and west secondary treatment systems were 2,265 mg/L and 1,947 mg/L, respectively. The east and west aeration basins are currently operating with a solids residence time (SRT) of 2.0 days. The food to microorganisms (F:M) ratio in the aeration basins averaged 0.4 day^{-1}.

The average SVIs were 111 mL/g and 94 mL/g for the east and west systems, respectively, indicating a well-settled sludge. Typically, SVI values for a well-settled activated sludge are between 100 mL/g and 150 mL/g. During the summer months, the SWWPCP experiences occasional episodes of Norcardia infestations. Plant operations is able to control the filamentous growth by creating an anoxic selector in the first cell of the aeration basin by turning off the first aerator/mixer.

The average and peak SORs for the secondary clarifiers were approximately 445 gpd/ft^2 and 1,110 gpd/ft^2, respectively. Typical SORs for rectangular Gould-type clarifiers are between 800 gpd/ft^2 to 1,500 gpd/ft^2. The secondary clarifiers at the SWWPCP are operating well below their expected maximum hydraulic capacity based on typical SORs.

The average and peak solids loading rates (SLRs) for the secondary clarifiers were approximately 12 and 19 lbs/day/ft^2 on the east clarifiers and 10 and 15 lbs/day/ft^2 on the west clarifiers. Typical peak SLRs for rectangular Gould-type clarifiers are between 20 and 40 lbs/day/ft^2. The secondary clarifiers at the SWWPCP are operating at lower than typical SLRs.

The secondary clarifiers at the SWWPCP achieve a very good quality final effluent. The daily TSS and BOD_5 concentrations were consistently below the NPDES criteria of 60 mg/L. The average effluent TSS and BOD_5 concentrations were 6.4 and 9.1 mg/L, respectively.

SECTION 3

CURRENT CAPACITY

3. Maximum Instantaneous Capacity

3.1 Maximum Treatment Capacity

The current maximum instantaneous treatment capacity of the unit processes at the SWWPCP was estimated using a combination of manufacturers information, standard engineering design loading and performance criteria, operations staff observations of previous performance, and field testing of specific unit processes.

The field testing conducted at the SWWPCP included the following:

Online Monitoring Data

- Secondary Clarifier 2
- Plant flow, RAS flow, mixed liquor TSS, sludge blanket level, and effluent TSS from March 1 to June 30 1999, and from October 1, 1999, to January 31, 2000

Primary Clarifier Stress Tests

- Primary Clarifier 5 with BRC solids
- Primary Clarifier 4 without BRC solids

Secondary Clarifier Stress Tests

- Secondary Clarifier 20

Flow Distribution Dye Tests

- East and west mixed liquor channel
- Primary clarifiers

Table 3.1 summarizes the estimated treatment capacity for each unit. The basis of the estimated capacity is discussed below. The detailed field test results are presented in Technical Memorandum 2 – Short-Term Test Results and Technical Memorandum 3 – Long-Term Online Monitoring Results

3.1.2 Preliminary Treatment

The estimated treatment capacity of the preliminary treatment system is 475 mgd. This is based on the rated capacity of 32 mgd of the existing pumps with two of the three pumps in service, plus an estimated capacity of 475 mgd for the high-level interceptor.

For peak flow conditions, the face velocity for the bar screens will vary from 0.2 to 0.4 ft/s. The face velocity is determined by the water surface level through the bar screen channel.

The theoretical treatment capacity of the grit removal tanks is 625 mgd. This is based on three of the four grit detritors in service, with an allowable SOR of 58,000 gpd/ft^2. The theoretical removal efficiency of the grit removal system is 90 percent of particles greater than 60 mesh (25 mm) under peak flow conditions.

TABLE 3.1
SOUTHWEST WPCP TREATMENT CAPACITY ASSESSMENT

Unit Process	Estimated Capacity (mgd)	Criteria
Preliminary Treatment	540 mgd – screening and raw sewage pumping capacity	
	Low level interceptor[1] – 64 mgd	Rated capacity of pumps
	High level interceptor – 475 mgd	Observed maximum flow
Grit Removal	625 mgd – grit removal [2]	SOR – 58,000 gpd/ft^2
Primary Treatment	250 mgd[3] – with BRC solids	Based on allowable SOR – 2,000 gpd/ft^2
	350 mgd[3] – with BRC solids	Based on allowable SOR – 2,800 gpd/ft^2
	440 mgd[3] – without BRC solids	Based on allowable SOR – 3,500 gpd/ft^2
Aeration Basins	N/A no change to organic loading patterns.	
Secondary Clarifiers	675 mgd [3] – existing	Based on allowable SOR – 1,800 gpd/ft^2
	550 mgd [3] – mixed liquor concentration 2,000 mg/L	Based on allowable SLR – 30 lbs/day/ft^2
	350 mgd [3] – mixed liquor concentration 3,000 mg/L	Based on allowable SLR – 30 lbs/day/ft^2
ES station	460 mgd [4] (1 pump out of service)	115 mgd rated capacity
Chlorination	830 mgd – volume of plant outfall	HRT – 15 minutes

[1] Based on design capacity of 32 mgd for each pump, with one pump out of service
[2] Based on unit out of service
[3] Based on one clarifier out of service
[4] Based on one pump out of service

3.1.3 Primary Treatment

Six primary stress tests were conducted at the three wastewater treatment plants owned and operated by the PWD. Table 3.2 summarizes the physical characteristics of the clarifiers at each site and the stress tests performed. The primary clarifiers at all three plants are hydraulically similar. Differences in behaviour are the result of differences in influent characteristics and minor differences in influent and effluent structures.

TABLE 3.2
PRIMARY CLARIFIERS STRESS TEST PERFORMED

Site	SEWPCP	SWWPCP	NEWPCP	
Clarifier dimension			**Set 1**	**Set 2**
# of clarifiers	4	5	8	4
Type	Rectangular	Rectangular	Rectangular	Rectangular
Length (ft)	250	250	240	250
Width (ft)	125	125	65	125
SWD (ft)	12	12	10	10
Sludge Removal				
Hopper location	Influent end	Influent end	Influent end	
Sludge collection	Chain & flight	Chain & flight	Chain & flight	

TABLE 3.2
PRIMARY CLARIFIERS STRESS TEST PERFORMED

Site	SEWPCP	SWWPCP	NEWPCP	
Pumping freq.	Once every two days	Once per day	Three times per day	
Influent structure				
Channel	Common	Common	Common	Common
Clarifier openings	Orifice and weirs	Orifice	Orifice	Orifice
Openings/clarifier	8 Orifices and 14 weirs	8	4	12
Location	Surface and mid-level	mid SWD	Bottom SWD	Surface and Bottom SWD
Baffling	Yes	Yes	yes	Yes
Effluent structure				
Type	Lateral launders	Finger launders	Finger launders	Finger launders
Orientation	Cross flow	Longitudinal	Longitudinal	Longitudinal
Weir length (ft)	193	307	137	274
Launders	3	21	12	24
Test performed	1	2	2	1
Target SOR (range) gpd/ft^2	1,000-2,400	1,000-3,500	1,000-3,000	750-2,800

Two stress tests were performed on the primary clarifiers at the SW WPCP. Figure 3-1 presents the measured TSS removal efficiency as a function of SOR and Figure 3-2 presents the measured effluent TSS concentration as a function of SOR. The test procedures and detailed results are described in Technical Memorandum 2; the main findings are summarized below.

Primary Clarifier 5 – With BRC Recycle. The stress test on the SWWPCP Primary Clarifier 5 indicated that the clarifier performance deteriorated at a SOR of 2,800 gpd/ft^2 with a removal efficiency less than 60 percent. However, the primary effluent TSS concentration was consistently greater than 80 mg/L at SOR greater than 2,300 gpd/ft^2. The apparently high solids removal efficiency was associated with the high solids concentration in the primary influent. The sludge blanket in the clarifier was greater than four feet and rose steadily through the test. The solids in the primary effluent were black.

Primary Clarifier 4 – Without BRC Recycle Stream. The stress test on the SWWPCP Primary Clarifier 4 indicated that the clarifier performance deteriorated at a SOR of 3,100 gpd/ft^2 with a TSS removal efficiency of less than 60 percent. The sludge blanket in the clarifier remained relatively constant through the test, rising slightly at the effluent end of the clarifier at the end of the test period. The primary effluent TSS concentration remained below 80 mg/L throughout the test.

Figure 3-1
SWWPCP Primary Clarifier Stress Test
TSS Removal Efficiency as a Function of Hydraulic Loading

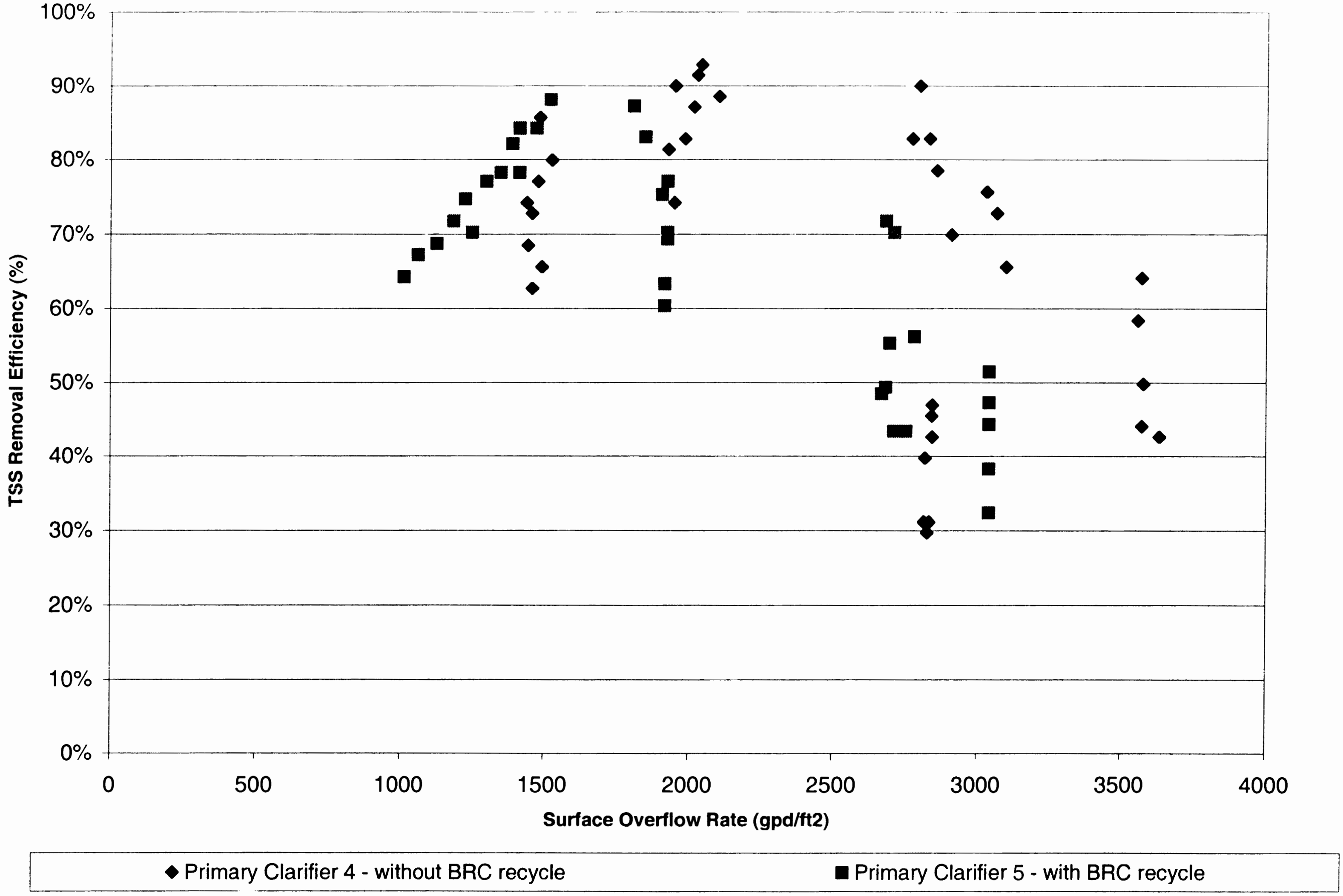
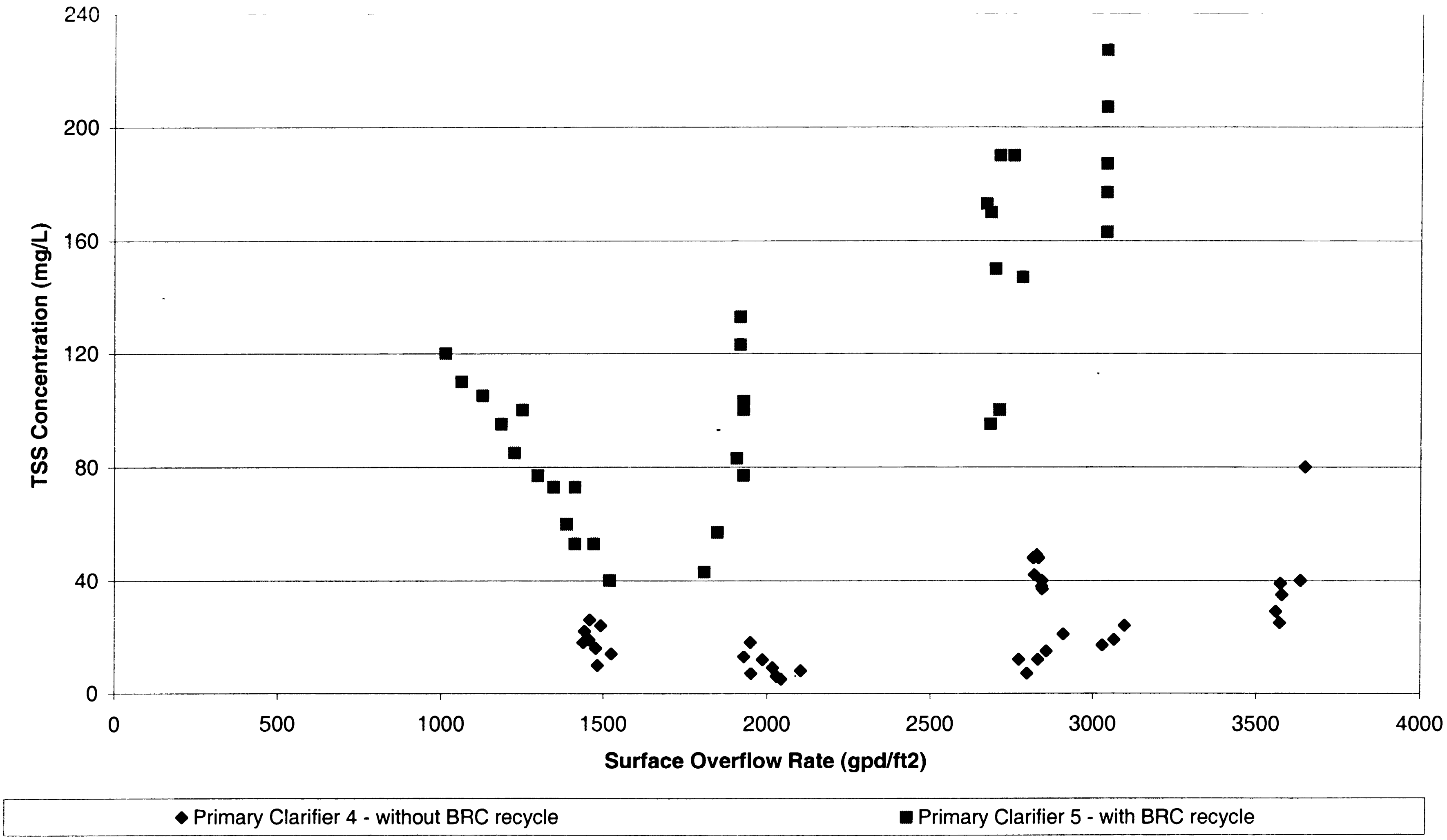


Figure 3-2
SWWPCP Primary Clarifier Stress Test
TSS Concentration as a Function of Hydraulic Loading



The estimated treatment capacity of the SWWPCP primary clarifiers is between 250 and 350 mgd with four clarifiers in service. This is based on the results of the Primary Clarifier 5 stress test. The clarifier performance deteriorated at an SOR of 2,000 and 2,800 gpd/ft^2, respectively. The BRC recycle stream has a negative impact on the primary clarifier performance. The BRC solids impact the east primary clarifiers, but have a less significant impact on the west primary clarifiers. Under high flow conditions, the TSS removal efficiency of Primary Clarifier 5 is poor at overflow rates greater than 2,000 gpd/ft^2. More significantly, the primary effluent TSS concentration is more than four times higher for Primary Clarifier 5. This results in a significant increase in organic loading to the east secondary treatment system.

The estimated treatment capacity of the primary clarifiers without BRC loading is 440 mgd with four clarifiers in service. This is based on the results of the Primary Clarifier 4 stress test performed at the SWWPCP. The clarifier performance deteriorated at an SOR of 3,500 gpd/ft^2, and the primary effluent TSS concentration remained below 80 mg/L throughout the test.

3.1.4 Secondary Treatment

Six secondary clarifier stress tests were conducted at the three wastewater treatment plants owned and operated by the PWD. Table 3.3 summarizes the physical characteristics of the clarifiers at each site and the secondary clarifier stress tests performed. The secondary clarifiers at all three plants are very similar and performed similarly. Differences in performance were largely the result of differences in mixed liquor settling characteristics and solids loading during the tests.

TABLE 3.3
PHYSICAL CHARACTERISTICS OF THE SECONDARY CLARIFIERS TESTED

Site	SEWPCP	SWWPCP	NEWPCP	
Clarifier dimension			**Set 1**	**Set 2**
# of clarifiers	12	20	8	8
Type	Gould	Gould	Gould	Gould
Length (ft)	214	260	214	231
Width (ft)	68	75	75	70
SWD (ft)	11	11	11	13
Sludge Removal				
Hopper location	mid length	mid length	mid length	
Sludge collection	Chain & flight	Chain & flight	Chain & flight	
RAS removal	Gravity to sump	Pump per clarifier	Common pump	
RAS rate	30%	35%	15-30%	
MLSS	1,300	2,100	1,100	

TABLE 3.3
PHYSICAL CHARACTERISTICS OF THE SECONDARY CLARIFIERS TESTED

Site	SEWPCP	SWWPCP	NEWPCP	
Influent structure				
Channel	Common to 6	Common to 10	Common to 8	Common to 4
Clarifier openings	Adjustable weir	Orifice	Overflow Weir	Overflow Weir
Number per clarifier	4	4	4	4
Location	Top	Surface	Surface	Surface
Baffling	Yes	Yes	No	Yes
Effluent structure				
Type	Finger launders	Finger launders	Finger launders	Finger launders
Orientation	Longitudinal	Longitudinal	Longitudinal	Longitudinal
Weir length (m)	784	816	850	850
Number of Launders/	24	12	24	24
Test performed				
Stress test	2	1	0	3
Target SOR (range) gpd/ft^2	860-2,000	600-2,100		1,000-2,100
Dye tests	1	0	3	1

One stress test was performed on the SWWPCP secondary clarifiers. The test procedures and results are described in Technical Memorandum 2; the main findings are summarized below.

The stress test was conducted on Secondary Clarifier 20. Figure 3-3 presents the flow and effluent TSS concentration as a function of time for the test. Figure 3-4 presents the effluent TSS concentration as a function of SOR. The test was conducted by increasing the hydraulic loading on the clarifier in incremental steps. The effluent TSS concentration remained below 60 mg/L. The maximum SOR achieved during the tests was 2,100 gpd/ft^2. The blanket in the clarifier began to rise at an SOR of 2,100 gpd/ft^2.

Dye dilution was used to measure the flow in the mixed liquor channel for the east and west secondary treatment system. The testing indicated that the east side received approximately 20 percent more primary effluent flow.

The operators' experience indicates that the secondary clarifiers will fail at a total plant flow rate of less than indicated by the stress test results and that the east clarifiers are more susceptible to failure. The mixed liquor concentration is approximately 17 percent higher in the east secondary treatment system and the hydraulic loading is approximately 20 percent greater. The combination of increased flow and increased mixed liquor concentration results in an increase of 35 to 40 percent in the solids loading to the east clarifiers. The operators use the two empty aeration tanks to store RAS, thereby reducing the solids loading on the clarifiers during high flow conditions.

The caulking on the secondary clarifier effluent launders is in poor condition. A large volume of flow was observed coming up through the launder joints and connections after rather than over the clarifier effluent weirs. This results in an uneven flow distribution between clarifiers that is difficult to control or predict. Replacing the caulking in the clarifiers affected will improve the flow distribution between clarifiers and prevent premature failure.

The performance of the secondary clarifier was monitored over two 4-month periods using online instrumentation to quantify the dynamic performance of the clarifiers to naturally-occurring storm events. The online instrumentation recorded total plant flow, RAS flow, mixed liquor TSS concentration, sludge blanket levels, and effluent TSS concentration. The online monitoring recorded the response of the secondary clarifier to 15 storm events. Table 3.4 summarizes results of the online monitoring program; more detailed results are presented in Technical Memorandum 3.

TABLE 3.4
RESULTS OF THE ONLINE MONITORING PROGRAM

Date	SVI ml/g	MLSS mg/L	Online TSS Concentration		24 h Average Effluent TSS	Peak Achieved	
			Average mg/L	Peak mg/L	(mg/L)	Q mgd	SOR gpd/ft^2
March 6	NA	1,240	NA	NA	2.5	334	845
March 14	131	1,750	NA	NA	3.6	382	967
March 21	98.5	1,340	NA	NA	16.8	425	1,075
April 9	106	1,420	NA	NA	19	381	964
April 11	100	1,400	NA	NA	9.2	392	992
April 23	136	1,580	NA	NA	4	339	858
May 19	111	2,250	NA	NA		349	883
May 24	136	1,890	NA	NA		408	1,032
November 1	110	1,270	6.8	28	3.6	450	1,139
November 25	116	1,720	11.5	16	7.6	370	936
December 6	92	1,410	15.6	40	21	345	873
December 10	105	1,240	34.9	59	22	344	870
December 13	100	1,300	17.2	34	23	414	1,048
December 20	78	1,540	14.2	22	11.2	337	853
Jan 10, 2000	138	1,380	14.1	19	11.3	354	896

The secondary clarifier TSS concentration did not exceed 60 mg/L during the online monitoring period. During the storm events of December 6, December 10, and December 13, 1999, the online effluent TSS monitor indicated that the effluent TSS concentration reached peaks of 40, 59 and 34 mg/L, respectively. During the storm event of December 10, 1999, the effluent TSS concentration increased dramatically under relatively low hydraulic loading conditions. The plant flow data indicates that, during the storm, the return activated sludge pump was operating erratically. The inconsistent pumping during the storm likely resulted in elevated effluent TSS concentration in the final effluent.

Figure 3-3
SWWPCP Secondary Clarifier Stress Test
Effluent TSS Concentration Versus Time

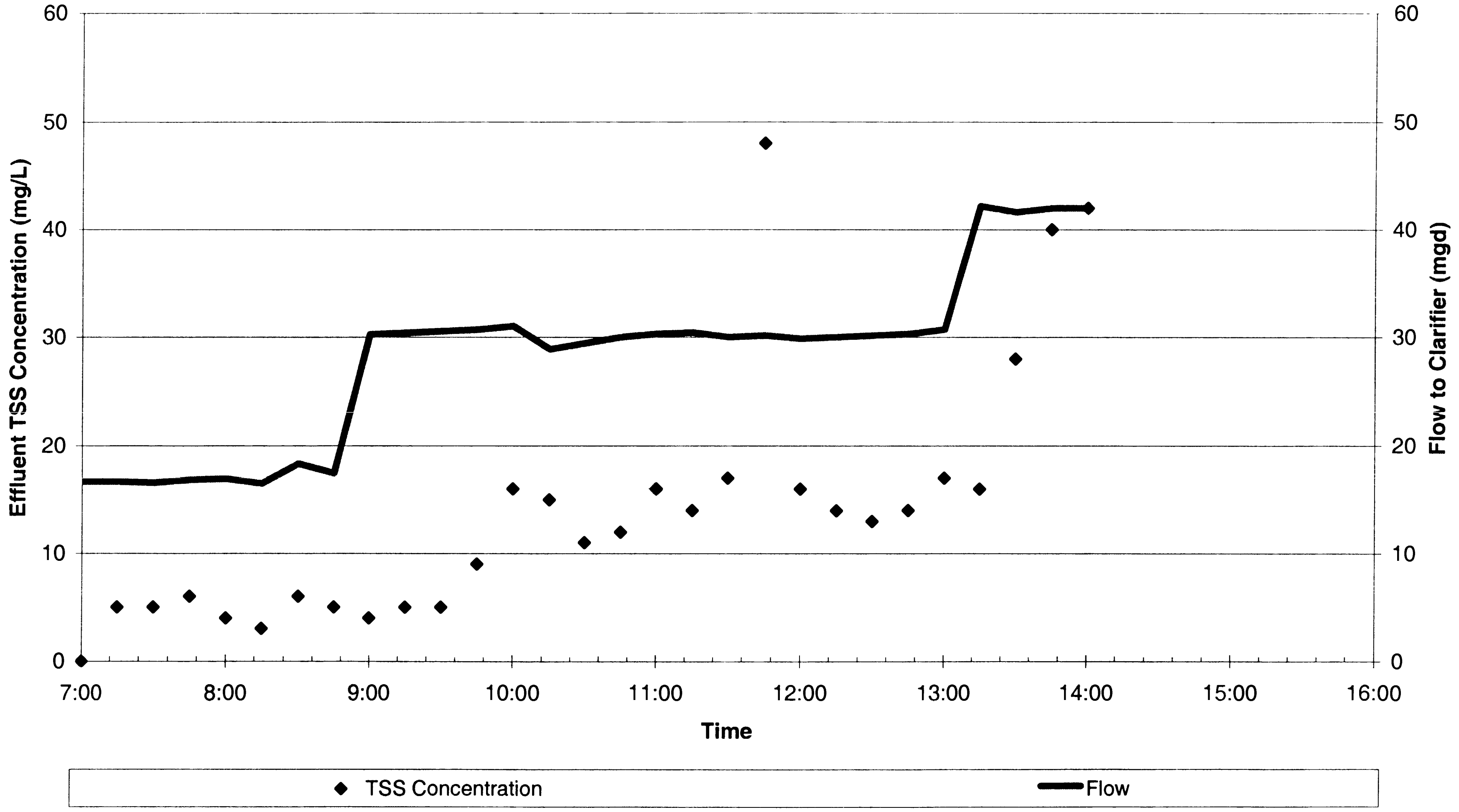
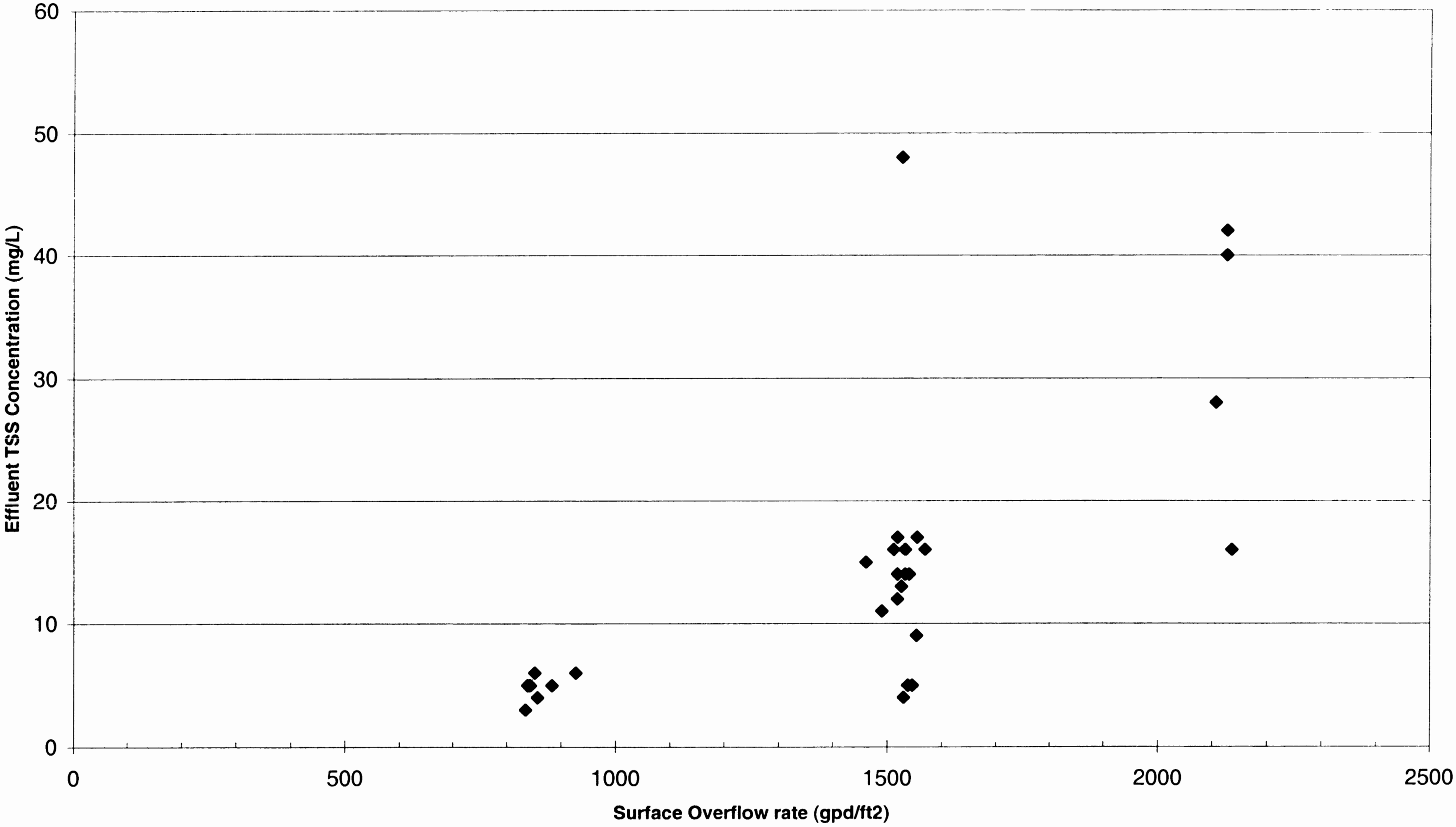


Figure 3-4
SWWPCP - Secondary Clarifier Stress Test
Effluent TSS Concentration as a Function of Hydraulic Loading



3.1.5 Disinfection and Effluent Pump Station

The estimated capacity of the SWWPCP effluent pump station is 460 mgd. This is based on the rated capacity of the existing pumps with one pump out of service. The rated capacity of the disinfection is 830 mgd. This is based on 15-minute HRT in the existing outfall under peak flow conditions.

3.2 Hydraulic Throughput Capacity

The hydraulic throughput capacity of the unit processes at the SWWPCP were estimated using WinHYDRO, a computer model that facilitates complex analysis of plant hydraulics. Hydraulic and energy gradelines from the headworks to the plant outfall were developed for a number of flow rates. The hydraulic throughput capacity of each unit process was developed based on the assumption that the downstream hydraulic bottlenecks had been resolved. Table 3.2 summarizes the estimated hydraulic throughput capacity for each unit process. The detailed hydraulic modelling results are presented in Technical Memorandum 4 – Hydraulic Throughput Capacity of Existing Facilities.

TABLE 3.2
SOUTHWEST WWTP CURRENT HYDRAULIC THROUGHPUT CAPACITY

Unit Process	Estimated Capacity (mgd)	Basis of capacity estimate
Outfall	>800 mgd	• Flow path – from the Delaware River to the effluent pump station • Hydraulic control section – mean high tide of 97.75 feet • Two outfall channels in service • Hydraulic exceedance – pump station discharge weir elevation
Secondary effluent channel	Version A – 410 Version B – >800	• Flow path – effluent PS wet well to the secondary clarifier weir • Hydraulic control section – PS wet well water surface level Version A – wet well level at maximum WSL - 99 ft feet Version B – wet well level at WSL – 96 feet • Twenty secondary clarifiers in service • Hydraulic exceedance – secondary clarifier overflow weir elevation
Mixed liquor channel	790	• Flow path – secondary clarifier effluent weir to the aeration basin overflow weir • Hydraulic control section – secondary clarifier weir • The secondary clarifier weir has a free discharge Hydraulic exceedance – aeration basin overflow weir elevation
Aeration basin and primary flow split box	Capacity 1 - 340 Capacity 2 - 410 Capacity 3 > 500	• Flow path – aeration basin overflow weir to the primary clarifier overflow weir • Hydraulic control section – aeration basin overflow weir • 50/50 flow split between east and west side, eight aeration basins in service • Hydraulic exceedance [1] – primary effluent flow split weir elevation Hydraulic exceedance [2] – primary clarifier overflow weir elevation Hydraulic exceedance [3] – top of concrete

TABLE 3.2
SOUTHWEST WWTP CURRENT HYDRAULIC THROUGHPUT CAPACITY

Unit Process	Estimated Capacity (mgd)	Basis of capacity estimate
Preliminary treatment	520 – Parshall flume 680 – top of concrete	• Flow path – primary clarifier overflow weir to influent channel downstream of the Parshall flume • Hydraulic control section – primary clarifier overflow weir • Five primary clarifiers, two flocculation tanks, four detritors, and five bar screens in service • Hydraulic exceedance – Parshall flume flooded Hydraulic exceedance – top of concrete at bar screens

The hydraulic throughput capacity of the SWWPCP is greater than 600 mgd, except for the following locations:

- **Aeration Basin Overflow Weir** - Under high flow conditions, the water surface level in the aeration basin increases and submerges the primary effluent flow split weirs. The primary effluent flow split weirs become submerged at approximately 340 mgd with eight aeration basins in service. The primary clarifier effluent weirs become submerged at approximately 410 mgd. The water surface level in the flocculation tanks and grit chambers are impacted by the increase in water surface level in the primary clarifiers. The hydraulic limitation is the aeration basin outfall weirs. The weir discharge is restricted to keep oxygen in the enclosed aeration tanks.

- **Parshall Flume** - At flow rates greater than 520 mgd, the water surface level downstream of the parshall flume will impact the flow measurement.

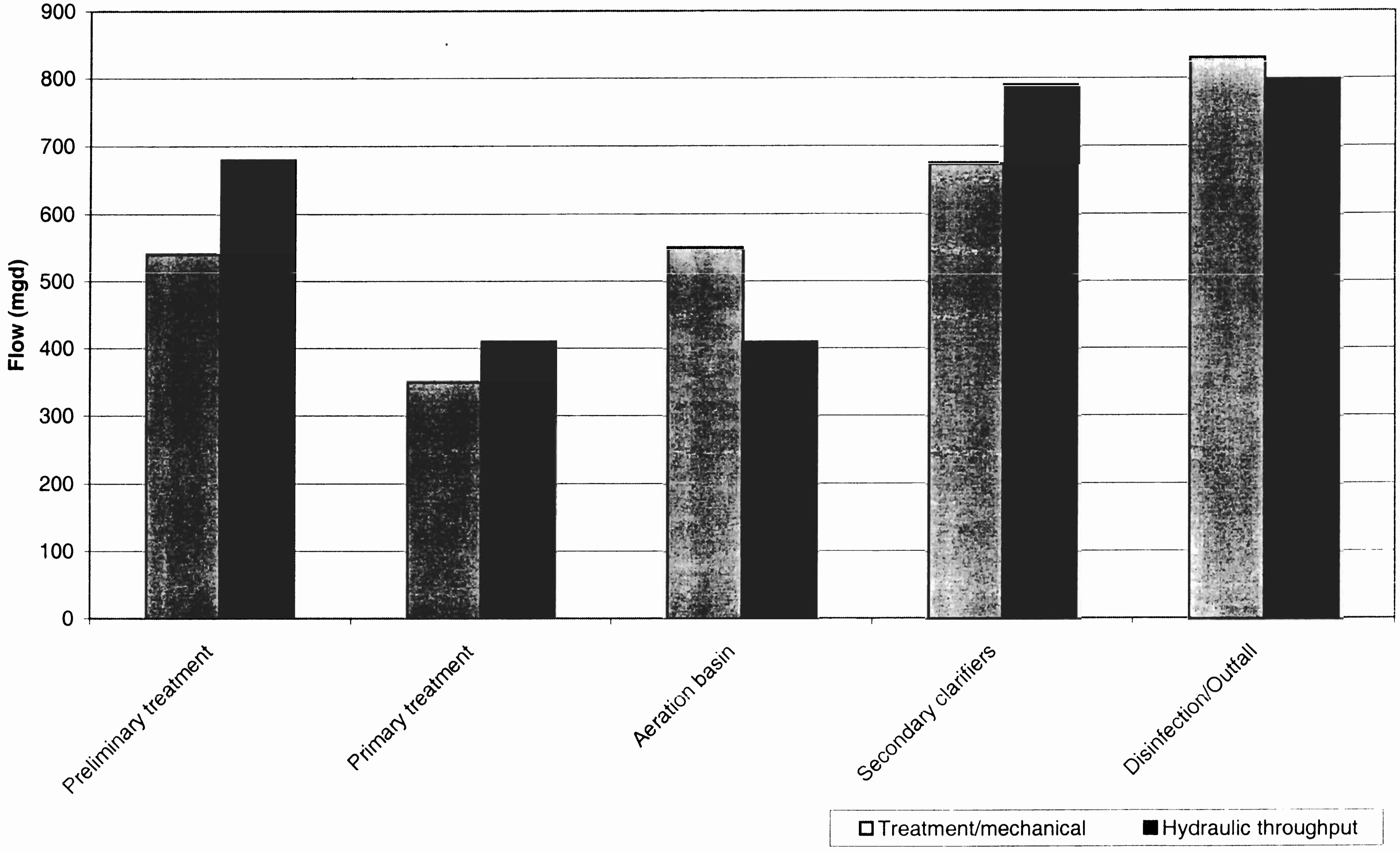
3.3 Capacity Limiting Factors

Figure 3-5 presents a summary of the estimated current capacity on a unit process basis for the SWWPCP. The major capacity bottlenecks for the facility follow:

- **Aeration Basin** - The hydraulic throughput capacity of the aeration basins is limited to 340 mgd with eight basins in service. At flow rates greater than 340 mgd, the weirs in the flow distribution box become flooded, resulting in loss of control over the flow distribution between aeration basins. The facility will continue to operate, but there will be a deterioration in process control under these circumstances. At flow rates greater than 410 mgd, the primary clarifier weirs are impacted. Loss of control of the flow distribution will not result in an immediate failure of the treatment system. However, there will be a negative impact on treatment efficiency if the flows remain greater than 340 mgd over an extended period of time. Secondary effluent pumping or aeration basin bypass (extreme step feed) is required to resolve this bottleneck.

- **Primary Treatment** - The estimated treatment capacity of the primary clarifiers is 350 mgd based on an allowable SOR of 2,800 gpd/ft^2 and four clarifiers in service. The capacity of the primary clarifiers could be increased to 440 mgd if the recycle stream from the BRC facilities is not treated at the SWWPCP.

Figure 3-5
Southwest WPCP - Estimated Current Capacity



SECTION 4

CURRENT SUSTAINABLE TREATMENT CAPACITY

4. Current Sustainable Treatment Capacity

4.1 Sustainable Treatment

The estimated treatment capacities summarized in Section 3 of this report utilize maximum instantaneous limits currently in PWD's NPDES permits as the goal for the effluent quality. Since the maximum instantaneous and maximum daily limits are the same values, a process operation whose final effluent quality will meet the instantaneous maximum limits will also meet the daily maximum limits. However, the current NPDES permits, based on expected performance for plants that intake substantial quantities of stormwater, include maximum weekly and monthly limits that are significantly more stringent than the daily/ instantaneous limits. Furthermore, strict compliance with maximum monthly concentration limits will not guarantee monthly compliance with other quality limits in the permit, such as average monthly and weekly loading limits and percent removal requirements.

An important but difficult question remains regarding how long a facility (or process) can sustain high flows that allow effluent quality to meet all the permit effluent quality requirements.

The performance of the secondary clarifiers determines the final effluent quality from the SWWPCP. The data collected during the field-testing was used to predict final effluent quality as a function of flow rate. The predicted final effluent TSS and BOD_5 concentration for a given flow rate was used to determine the maximum flow that could be maintained for an infinite period of time with effluent quality meeting the monthly and weekly loading and percent removal requirements in the NPDES permit.

Secondary clarifier capacity is defined by either the clarification capacity, which is a function of SOR or the solids flux capacity which is a function of solids loading rate (SLR). Clarifier performance as a function of both SOR and SLR was collected during the testing for a range of operating conditions. Data from the six secondary clarifier stress tests was used to quantify the secondary clarifier performance as a function of hydraulic loading and to identify the maximum allowable solids loading rate for the clarifiers.

The historical data was used to determine the yield and mixed liquor concentrations required as a function of primary effluent quality. The data from the primary clarifier stress tests was used to determine the expected primary effluent quality as a function of flow rate. The mixer liquor required for the expected primary effluent quality determines the solids loading rate for the secondary clarifier.

4.2 Analysis Methodology

4.2.1 Predicting Secondary Effluent Quality as a Function of the SOR

In the stress tests of the secondary clarifiers, the TSS and BOD_5 concentrations in the secondary effluent were measured as a function of the surface overflow rate applied to the clarifiers. A linear regression was performed on the field testing data to establish the relationship between SOR and TSS and BOD_5 concentrations in the effluent. The intercept and slope values obtained for the regression were statistically analyzed to find the 95% confidence level associated with these two coefficients. Using the upper 95% confidence level interval provides a conservative description of the relationship between the SOR and effluent quality. The model is used to predict TSS or BOD_5 for a given SOR; the value generated using the linear regression will be lower than the actual value observed 95 out of 100 times.

The estimated effluent concentrations and discharge loads (which are equal to the effluent flow rate multiplied by the effluent concentration) can then be compared to permit levels to determine the sustainable treatment capacity of the facility on a SOR basis.

4.2.2 Effect of the SLR on Secondary Clarifier Performance

Failure of the secondary clarifiers may occur either due to clarification or thickening. An increase in the hydraulic loading to the primary clarifiers will result in an increase in organic loading to the aeration basin due to an increase in the amount of organic material entering the plant and deterioration in the primary clarifier performance. An increase in the organic loading to the aeration tanks results in an increase in the mixed liquor concentrations and therefore an increase in he solids loading for a given flow. Therefore, the analysis done in terms of the SOR must be complemented with an analysis of the effect of influent flow rate versus SLR.

Stress tests were performed on the primary clarifiers, and removal efficiencies as a function of the surface overflow rate in the primary clarifiers were documented. The data was used to predict the quality of the primary effluent as a function of the influent flow rate. This analysis, combined with analysis of historical data on solids production, was used to estimate the SLR as a function of flow, taking into account both the performance of the primary clarifiers and the increase in the organic loading associated with augmented flows.

The stress tests on the secondary clarifiers indicated that the maximum SLR that could be maintained before thickening failure occurs is 35 lb/(ft^2.day). The flow at which these solids loading rates are achieved is the maximum sustained flow that can be maintained in the plant before thickening failure occurs.

4.3 Analysis Results

4.3.1 Predicting Maximum Flows as a Function of the SOR

Figure 4.1 is a plot of the TSS in the secondary effluent and the SOR applied in the secondary clarifier from the six secondary clarifier stress tests conducted at the facilities owned and operated by PWD. The data from all six secondary clarifier stress tests was used in the preparation of this plot. Figure 4.2 presents the same analysis was done for the BOD_5 concentration in the secondary effluent.

The amount of TSS and BOD_5 discharged results from the product of the flow rate and the concentrations predicted by the 95% confidence level regressions. The discharge values were compared to the NPDES Permit values for the SWWPCP. The results of this analysis are presented in Table 4.1.

Table 4.1 Southwest WPCP – NPDES Permit Requirements and Results of the Sustainable Flow Analysis[1]

Parameter	Units	NPDES Limit	Maximum Sustainable Flow based on SOR		Maximum Sustainable Flow based on SLR
			TSS Limit	BOD$_5$ Limit	
Maximum Day Limits	Mgd	400			320
Maximum Week Limits	Mgd		380	225	
BOD$_5$ Concentration	mg/L	45			
BOD$_5$ Mass Loading	lbs/day	32,475			
TSS Concentration	mg/L	45			
TSS Mass Loading	lbs/day	75,060			
Maximum Monthly Limits	Mgd	200	288	175	
BOD$_5$ Concentration	mg/L	30			
BOD$_5$ Mass Loading	lbs/day	21,650			
BOD$_5$ Percent Removal	%	89.25			
TSS Concentration	mg/L	30			
TSS Mass Loading	lbs/day	50,040			
TSS Percent Removal	%	85			

1 – BOD$_5$ limits based on old permit, plant now monitors cBOD$_5$ for compliance.

The maximum sustainable flows at which the model predicts the SWWPCP can meet the weekly NPDES TSS and BOD$_5$ effluent mass loading requirements are 380 and 225 mgd, respectively. The BOD$_5$ weekly mass loading is the limiting criteria because the allowable effluent BOD$_5$ mass loading is significantly lower than the weekly concentration limit. The maximum weekly flow in the NPDES permit is 300 mgd. The model predicts that the facility will not be able to meet the BOD$_5$ weekly mass loading at a sustained flow of 300 mgd.

The maximum sustainable flows at which the model predicts the SWWPCP can meet the monthly NPDES TSS and BOD$_5$ effluent mass loading requirements are 288 and 175 mgd, respectively. The maximum month sustainable capacity for BOD$_5$ is lower than the average design capacity of the facility. This corresponds reasonably well to the historical performance of the facility. The SWWPCP is currently operating at 88 percent of its rated capacity. A 30-day running average of the effluent BOD$_5$ data was within 95 percent of its monthly average BOD$_5$ mass loading requirements on two occasions over the three-year period from July 1995 to July 1998.

The sustainable capacity values for weekly and monthly flows based on BOD$_5$ limits as estimated by the model are low due to several factors that influence the model in relation to the SW WPCP. First, an analysis for the SWWPCP plant operations versus the other two plants indicates that the SW plant normally runs its secondary clarifiers at lower surface overflow rates (SORs). Observing the trend in data in Figure 4.2 for lower SOR values, it is apparent that the model is conservative in SORs below 1000 gpd/sf, which is where under high flow conditions the SW WPCP will operate. Additionally, the model predicted sustainable flow at the plant is developed assuming two secondary clarifiers out of service.

The most significant influence on the SWWPCP ability to sustain high flows is the difference in the operation of the plant during these events as compared to what is done at the other PWD treatment plants. Operational changes that cannot be reflected in the model results, such as the ability to store solids in tanks that are off-line, significantly increases the ability of the plant to sustain adequate treatment during high flow events. SWWPCP has been able to treat over 300 mgd of flow for a sustained period of time (almost a week) during unusual storm events without any significant deterioration of the effluent quality.

Figure 4-1
Secondary Clarifier Stress Test - Effluent TSS Concentration as a Function of SOR

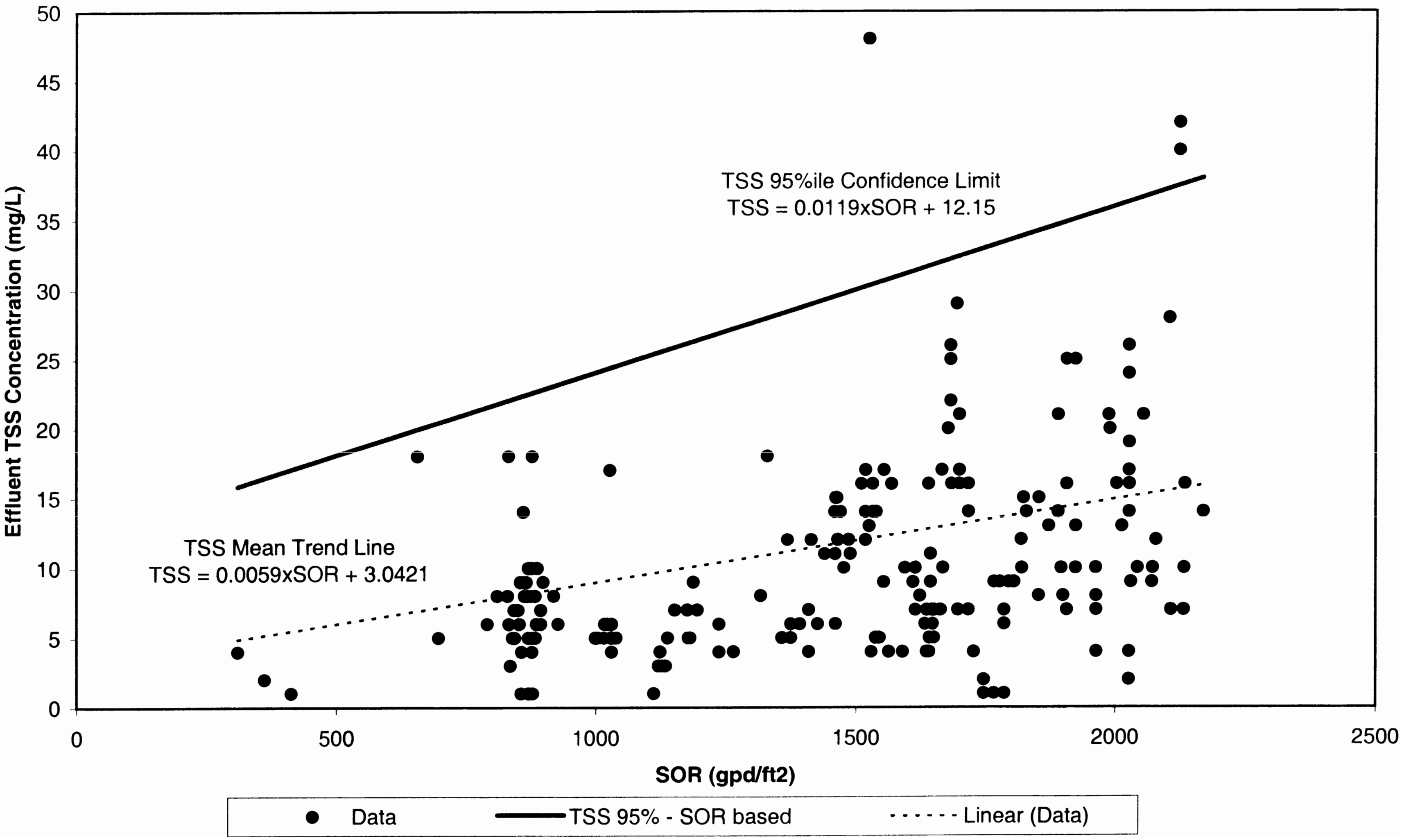
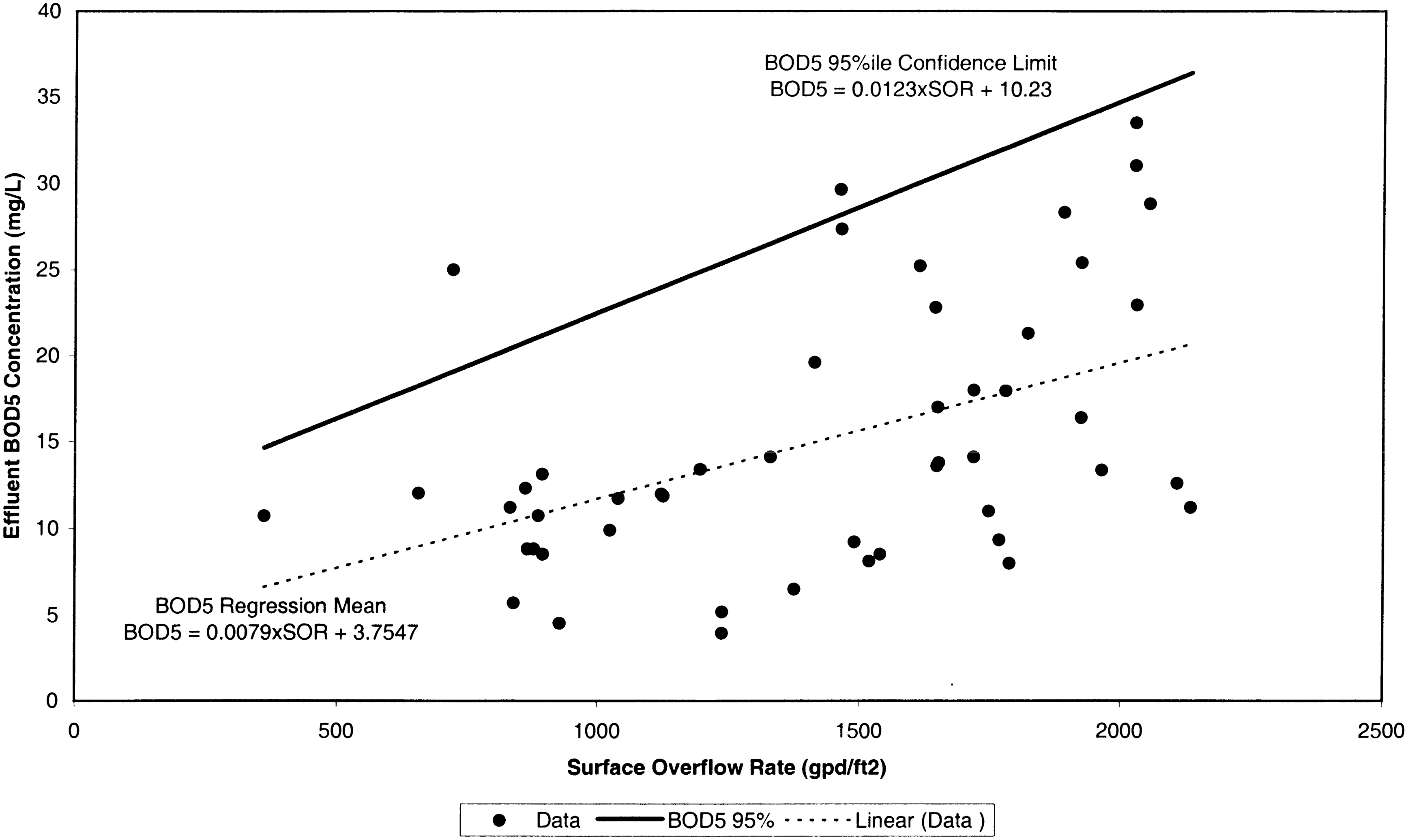


Figure 4-2
Secondary Clarifier Stress Test - Effluent BOD5 Concentration as a Function of SOR



4.3.2 Predicting Maximum Flows as a Function of SLR

The stress tests of the secondary clarifiers indicated that the maximum solids loading rate that could be sustained by the secondary clarifiers was 35 lb/(ft^2.day). The solids loading rate is a function of the MLSS concentration in the aeration basin and the influent and RAS flow rates. The MLSS concentration is dependent on the loading to the aeration basins, which in turn is dependent on the performance of the primary clarifiers as a function of the flow. The objective is to develop an overall correlation between the flow coming into the plant and the resulting solids loading rate into the secondary clarifiers.

The primary clarifier stress test results were used to determine the TSS percent removal in the primary clarifiers as a function of influent flow rate. A regression analysis of all stress test results performed in the primary clarifiers (except the test performed at the Southeast Plant where the clarifier failed prematurely due to the hydraulic limitations of the launders) was performed, and the lower 95% confidence levels associated with the regression parameters were calculated. Figure 4.3 presents the results of this analysis.

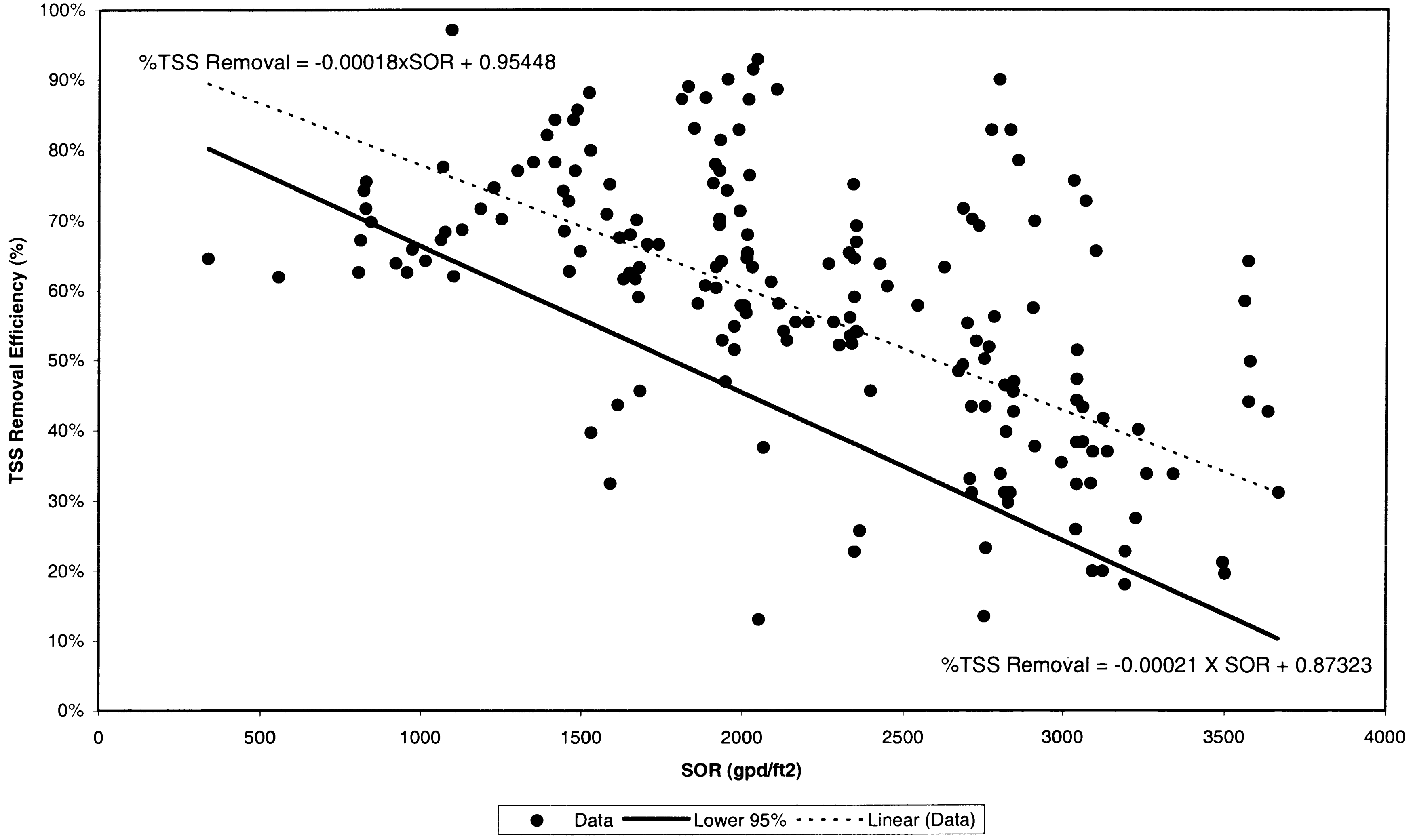
The yield for the SWWPCP was estimated based on the historical data of waste activated produced and the TSS and BOD_5 concentrations in the primary effluent. The SWWPCP is operated at an SRT of 1.9 days, the RAS flow rate is about 35 percent of the influent flow rate, and the raw wastewater has an average TSS concentration of 154 mg/L. For the determination of the SLR limiting flow, it was assumed that all of the primary and secondary clarifiers are in service, but that only eight of the ten aeration basins are in use. This corresponds to current operating practice at the site.

The SLR becomes 35 lb (ft^2.day) at the SWWPCP when the sustained flow is equal to 320 mgd. At flow rates greater than 320 mgd, thickening failure will occur unless measures are taken to reduce the solids loading rate to the secondary clarifiers. Preventative measures that are currently implemented at the SWWPCP include reducing the mixing in the aeration basin to allow solids to settle in Cells 3 and 4 and using the two aeration basins that are out of service as RAS storage for the duration of the storm.

Alternatively, step feed could be implemented at the SWWPCP by constructing an "in basin" primary effluent conduit along the length of the basin. The conduit would operate as a submerged diffusor and would require structural modifications to existing tanks. Improving the primary clarifier performance by providing pretreatment of the BRC centrate would significnatly improve the primary clarifier performance. Providing "out of clarifier" primary sludge thickening or enhanced primary clarifier performance through chemical addition would also reduce the solids loading to the secondary clarifiers. These alternatives would require capital expenditure for additional facilities.

Improving the solids removal efficiency of the secondary clarifiers would effectively increase the allowable solids loading rate to the clarifier. This would require modifications to the existing RAS system.

Figure 4-3
Primary Clarifier Stress Test – Percent TSS Removal Efficiency as a Function of SOR



4.4 Control of High Flow Duration

Discussions with PWD managers directing PWD's CSO program indicated that current CSO inline storage and draw-down plans expect that stored combined sewerage would be released to the plant over a 12-hour period following a storm event. This is a volume of combined sewerage that PWD's plants have not received in the past. Furthermore, there is flexibility in the draw-down strategy since the primary objective of the effort would be to return the storing sewer back to its original condition prior to the next storm event. It was clear that this is only a current plan and it would change should PWD be required in the future to provide additional combined sewerage storage to meet receiving water quality objectives.

From the wastewater treatment plants' perspective, a number of factors can influence the ability of a plant to achieve weekly or monthly limits when the plant is being stressed by storm-induced, high influent flows. The number and distribution of rain events during the week/month, together with plant effluent quality during non-rain event periods, rank high on the list of influences. PWD's revised permit language provides effluent quality relief, but only when the daily plant flow exceeds the permitted maximum daily flows currently stated in the permits. No such relief occurs for flows below the maximum daily flow limits.

Since the impact of stored combined sewerage on the SWWPCP performance is an unchartered experience, it is recommended that the duration of storage be no greater than a 24-hour period for each storm event. Should the CSO program's strategy for stored combined sewerage change beyond this 24-hour period, the issue of plant compliance for all monthly and weekly effluent quality requirements should be reviewed.

SECTION 5

POTENTIAL UPGRADES

5. Potential Upgrades

A list of potential upgrades was developed to increase the capacity or improve the performance of the SWWPCP. The potential improvements are based on the results of stress tests on unit process, long-term monitoring of the plant, and hydraulic modelling.

Each upgrade option has been prioritized based upon the following criteria:

- **Priority A – Existing Facilities Optimization.** Improvements that are easily implemented, low cost, high benefit, and will have an immediate positive impact upon normal operations. These are options that can be included in short-term capital budgets.
- **Priority B – Proactive Improvements.** Improvements that are moderate in cost and will have a positive impact on plant capacity. These are options that should be included in a long-term improvement plan.
- **Priority C – Improvements to Increase the Solids Handling Capacity of the Secondary Clarifier.** The stress tests identified that the solids handling capacity of the secondary clarifiers is very limited. This category includes improvements that are necessary to increase the secondary clarifier capacity with current mixed liquor concentration and/or to maintain existing capacity if increased mixed liquor suspended solids are required in the future.
- **Priority D - Capacity De-bottlenecking.** Improvements that have large costs associated with them and will greatly increase capacity above the current permitted peak flow. These options should be considered in an overall long-term, wet-weather, flow-control program and in the long-term improvement plan if significantly more treatment capacity is required at the facility.

The list of potential upgrades, budgetary cost estimate, and their associated prioritization is summarized below. Detailed descriptions of each upgrade are presented in Technical Memorandum 5 – Budgetary Cost Estimates for Potential Plant Improvements.

The cost estimates shown here are based on preliminary costs and are for use as "budgetary" values only. The cost estimates are Class "C" cost estimates (order-of-magnitude costs) as defined by the American Association of Cost Engineers. The level of accuracy of the Class "C" cost estimates is +50 percent to –30 percent of the actual cost of construction. These costs can be used for decisionmaking to select those options for more detailed analysis that are most feasible from both a design and cost perspective.

Table 5.1 includes the final estimated cost for each improvement. Table 5.2 presents a summary of the overall cost for improvements at the SWWPCP, which are broken down into alternatives that are dependant upon one another for an increase in capacity at the plant.

TABLE 5.1
POTENTIAL UPGRADE OPTIONS AT SOUTHWEST WPCP

Option No.	Description	Priority Classification	Estimated Conceptual Cost
1	Replace caulking on secondary clarifier launders to improve flow distribution [1]	A	$1,640,000
2	Provide preliminary treatment for the BRC centrate that is recycled to the plant	B/C	$8,585,000
3	Modify existing RAS system in the secondary clarifiers	C	$4,256,000
4	Provide primary effluent bypass to secondary clarifiers	D	$902,000
5	Provide separate facilities for primary sludge thickening	D	$9,892,000
6	Resolve hydraulic limitations between primary clarifiers and aeration basin	D	$5,429,000
7	Provide an additional effluent pump at the effluent pumping station	D	$806,000

[1] Complete or in progress.

TABLE 5.2
SUMMARY OF BUDGETARY COSTS FOR POTENTIAL IMPROVEMENTS AT SOUTHWEST WPCP

Plan	Total Costs for Improvements (Million $)	Cumulative Costs for Improvements (Million $)	Peak Treatment Capacity (mgd)			
			Facility	Preliminary	Primary	Secondary
Process improvements (Option 1)	1.64	1.64	340[1]	540	350	340
Increase primary treatment capacity w/ aeration bypassing (Options 2, 4, 5)	19.4	21.0	440	540	440	340[2]
Increase secondary treatment capacity (Options 2, 3, 6, 7)	19.1	31.5	540	540	540[3]	540

1. Existing facility is able to treat peak instantaneous flows of 440 mgd for a short period of time
2. Capacity of secondary is limited by hydraulic restriction into the aeration basin, however bypass will allow plant to increase overall capacity.
3. Deterioration of primary clarifier performance is offset by maintaining aeration basins in service

Process Improvements. The performance of the secondary clarifiers at the SWWPCP is negatively affected by an uneven flow distribution between individual clarifiers due to deterioration of the grouting in the effluent launders. The objective of this plan is to improve the performance of the SWWPCP under high flow conditions by improving the flow distribution. These improvements will not increase the peak hydraulic capacity of the facility beyond its current capabilities.

Increase Primary Treatment Capacity with Aeration Bypassing. The primary treatment capacity is limited at the SWWPCP. A significant portion of capacity is being used to treat the BRC recycle stream. Poor primary clarifier performance under current loading conditions requires a higher mixed liquor concentration, which has a negative impact on the secondary clarifier capacity. The objective of Options 2, 4, and 5 is to increase the peak capacity of the primary treatment to 440 mgd and to improve primary clarifier performance under all flow conditions.

The work would include providing pretreatment of the BRC recycle stream at the BRC facility, increased sludge removal from the primary tanks, and a bypass conduit from the primary effluent channel to the mixed liquor channel.

The estimated cost of providing pretreatment of the BRC recycle stream is $8,585,000. This includes chemical addition, coagulation, flocculation, and sedimentation facilities. However, based on recent jar testing work performed by PWD, the cost of chemical addition may be reduced if the recycle stream can be treated immediately.

A bypass between the primary clarifier effluent channel and the plant outfall will be required to circumvent the hydraulic bottleneck between the pimary clarifiers and the aeration basins. One approach would be to construct the primary effluent channel to the mixed liquor channel. The estimated cost for this potential upgrade is $902,000. The primary effluent would be added to the upstream end of the mixed liquor channel and pass through the secondary clarifiers before discharge. The estimated peak hydraulic capacity of the secondary clarifiers is 695 mgd at current mixed liquor concentrations. The primary effluent will increase the hydraulic loading on the secondary clarifiers without increasing the solids loading. Therefore, the secondary clarifiers have sufficient hydraulic capacity to treat the additional load.

The advantage of this approach is that the primary effluent will receive some additional treatment due to contact with the mixed liquor and the "sweeping" action of the activated sludge in the secondary clarifiers. The final effluent will be of higher quality than the blended effluent from the secondary clarifier and the bypass stream combined after the secondary clarifier. However, the contact time between the activated sludge and primary effluent bypass will be very small, and therefore BOD_5 removal from the primary effluent will be minimal. A relaxation in the permit requirements on days when aeration tank bypassing occurs is recommended. An alternative approach would be to bypass both the aeration basin and the secondary clarifiers. The primary effluent would flow directly to the secondary effluent channel. This approach would not provide the benefit of additional treatment as the primary effluent passes through the aerated mixed liquor channel and secondary clarifiers.

The potential primary treatment capacity of the SWWPCP is 540 mgd with five clarifiers in service. Increased primary sludge pumping may be required to achieve the additional primary treatment capacity. The estimated cost of providing a gravity sludge thickening facility at the SWWPCP is $9,892,000.

Increase Secondary Treatment Capacity. The objective of the remaining improvements is to increase the secondary treatment capacity to 540 mgd by eliminating the hydraulic bottlenecks at the influent end of the aeration basins. Offline sludge thickening would not be required because the primary effluent would receive full secondary treatment and no bypass arrangement of the aeration basins would be used. The estimated capital cost to provide intermittent pumping between the primary clarifiers and the aeration basin is $5,429,000. The capacity of the effluent pump station will also need to be increased. The estimated capital cost of providing an additional effluent pump is $806,000. In addition, to achieve this full plant capacity of 540 mgd, BRC pretreatment (Option 2) and modifications to the existing RAS system (Option 3) would have to be implemented.

Supplemental Documentation
Volume 9

Analysis of Wet Weather Treatment Alternatives for Northeast WPCP

Updated: September 1, 2009

Final Tech Memo

Wet Weather Treatment Alternatives at Northeast, Southeast and Southwest WPCPs

NE2: Analysis of Wet Weather Treatment Alternatives for Northeast WPCP

Prepared for

Philadelphia Water Department

Philadelphia, PA

March 2009

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Executive Summary

Background and Project Summary

As part of the series of memoranda prepared for the Philadelphia Water Department's (PWD) Combined Sewer Overflow (CSO) Long Term Control Plan (LTCP) update, this report presents the conceptual design and cost analyses for four wet weather treatment alternatives for the Northeast Water Pollution Control Plant (NE WPCP). The wet weather treatment technologies for the NE WPCP evaluated in this report are as follows:

1. Vortex Swirl Concentrators
2. Conventional Clarifiers
3. Chemically Enhanced Primary Treatment (CEPT) with Conventional Clarifiers
4. Ballasted Flocculation (includes fine screening)

Conceptual treatment trains were developed for each treatment technology at various wet weather flows ranging from 69 million gallons per day (mgd) to 1100 mgd and cost curves for capital, operations and maintenance (O&M), and lifecycle costs were generated for each treatment train alternative.

Currently, the NE WPCP has a flow capacity of 435 mgd. With several process and hydraulic modifications, as identified in the 2001 Stress Testing Report and the NE WPCP Flow Study, the capacity of the existing plant can potentially reach 650 mgd (CH2M HILL, 2001; CH2M HILL, 2008a, d). This work includes the construction of a 250-mgd secondary bypass from the existing primary sedimentation tanks to the chlorine contact chamber. In sizing the wet weather treatment trains, it was assumed that these upgrades, costing $98.1M, will have been completed, increasing the plant's capacity to a minimum of 650 mgd (Section 2). Any wet weather flow in excess of 650 mgd would be diverted to the new wet weather facility.

To expand the flow capacity of NE WPCP beyond 650 mgd for the treatment of wet weather flows, a separate wet weather treatment train will be required. Wet weather flows in excess of 650 mgd will be diverted to one of the new treatment trains, listed above, eventually blending with effluent from both the secondary system and the bypass from the existing plant. Conceptual designs and cost estimates were performed for each treatment train at various design flows.

Flow Scenarios

Conceptual designs and cost estimates were developed at several design flows for each wet weather treatment train under evaluation (Exhibit ES-1). These flows were selected based on the ability to meet permit requirements, the land area available onsite, and the maximum expected flow from the upgraded collection system, as described in Section 4. The Vortex/Swirl and Conventional Clarification trains were both flow-limited by permit requirements.

EXHIBIT ES-1
Design Flows Evaluated for each Wet Weather Treatment Train

Treatment Train	Design Flows Evaluated (mgd)
#1) Vortex/Swirl Concentrators	69, 183
#2) Conventional Clarifiers	160, 376
#3) CEPT w/ Conventional Clarifiers	150, 300, 1000
#4) Ballasted Flocculation	150, 500, 1100

Comparison of Treatment Alternatives

Effluent Water Quality

While each flow scenario for each treatment train evaluated is sized to produce blended effluent concentrations compliant with permit limits, the resulting water quality differs widely between different scenarios. The TSS and BOD concentrations of the blended effluent for each treatment train and flow scenario is presented under Section 9 in Exhibits 9-1 and 9-2, respectively. In general, ballasted flocculation achieves the lowest TSS and BOD concentrations after treatment and can operate an unlimited number of times during the month while allowing the NE WPCP to continue to meet permit limits.

Capital and O&M Costs

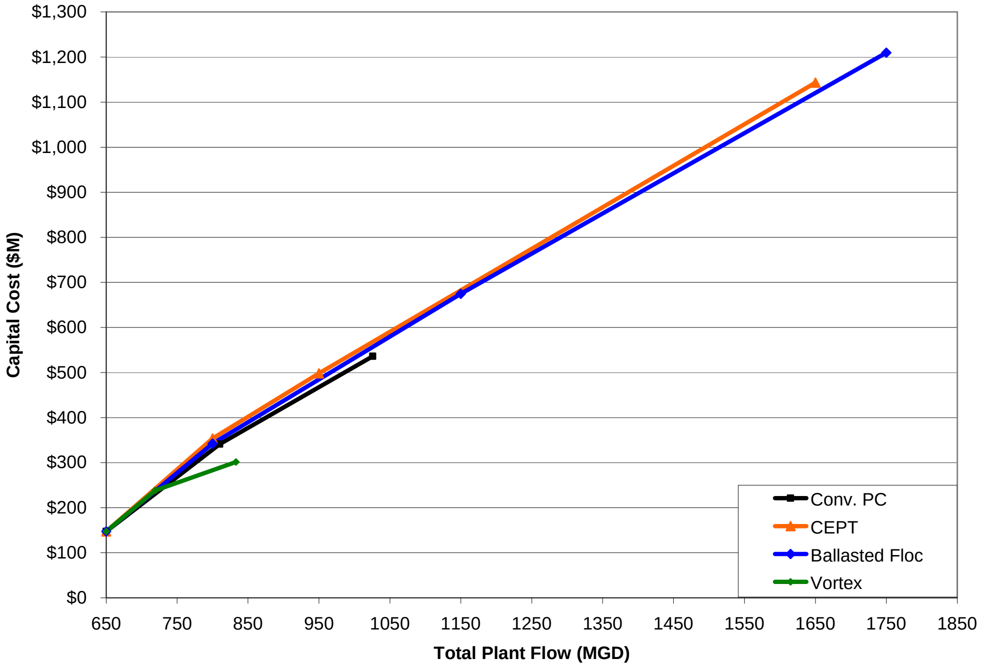
As shown in Exhibit ES-2, the capital costs for Trains #2 - #4 track each other very closely, with CEPT being slightly more expensive. Train #1, the vortex/swirl, appears least expensive and most cost effective as flows increase (Exhibit ES-3). Train #3, CEPT, appears slightly less cost-effective than Train #4, Ballasted Flocculation, due to greater cost for piles due to its larger footprint.

The comparison of O&M costs for each treatment train is shown in Exhibit ES-4. As expected, the O&M costs for vortex swirls and conventional clarifiers, which do not require chemical settling aids, are the lowest. Ballasted Flocculation has the highest O&M costs due to the use of chemicals and the complexity of its system.

Taking construction, non-construction, and O&M costs into consideration, Exhibit ES-5 shows the present value of the total cost of each wet weather treatment train. This graph suggests that there is negligible cost difference between Train #3, CEPT, and Train #4, Ballasted Flocculation at this plant. As expected, Trains #1 and #2 are least expensive due to its low chemical usage and minimal O&M costs.

EXHIBIT ES-2

Comparison of Capital Costs for All Treatment Trains



Note: Capital cost presented includes cost of improvements recommended in the Stress Testing Report ($147 M). Total plant flow includes flow from both the conventional plant and the wet weather treatment facility.

EXHIBIT ES-3

Comparison of Capital Cost Effectiveness for all Treatment Trains

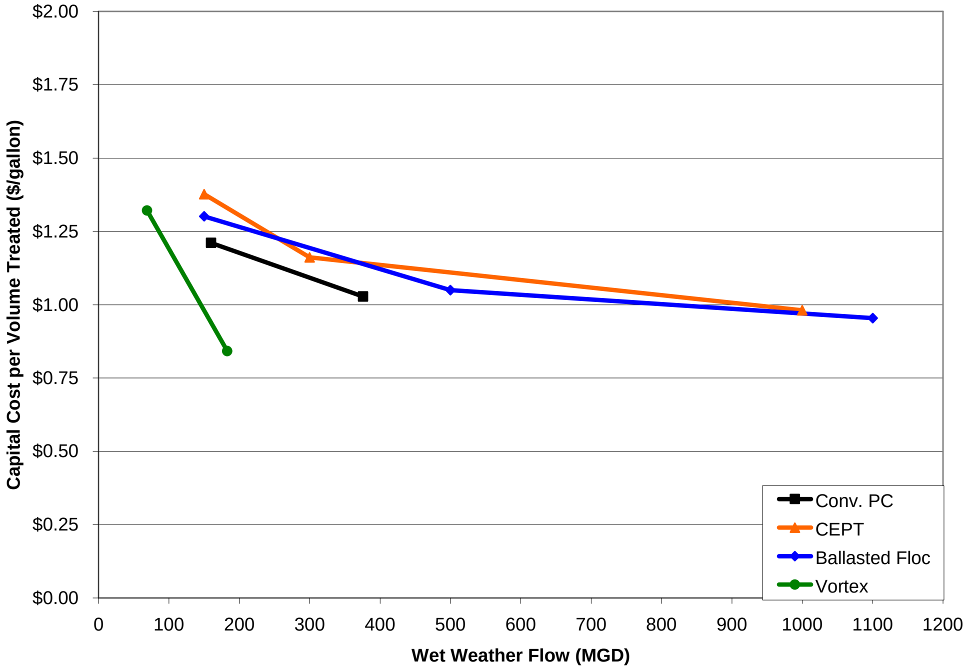


EXHIBIT ES-4
Comparison of Operations and Maintenance Costs for all Treatment Trains

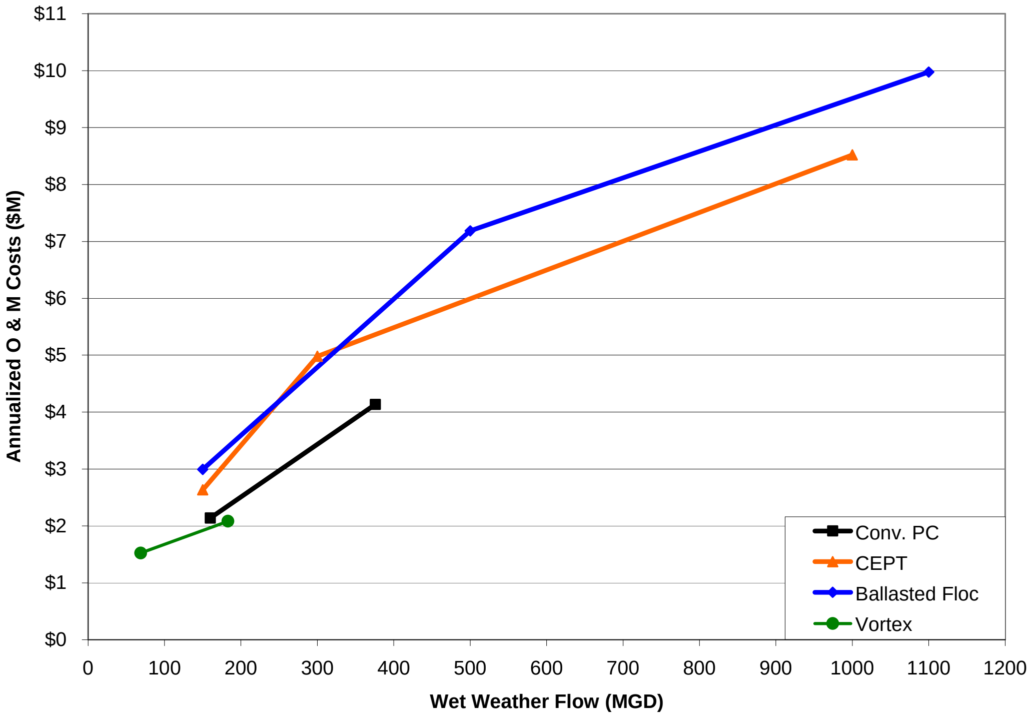
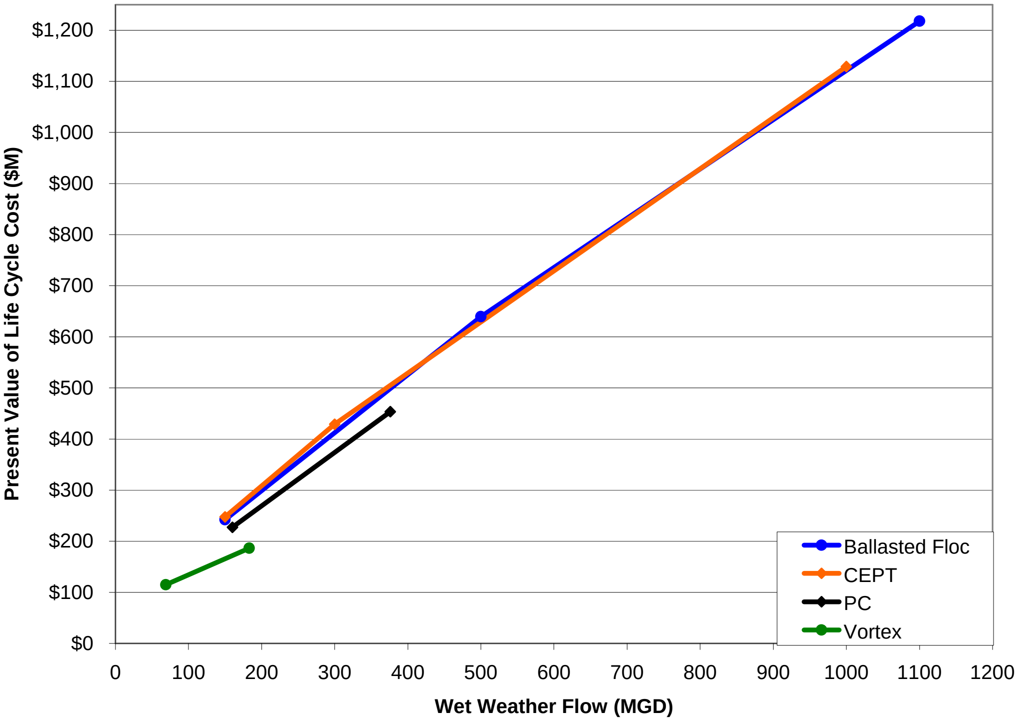


EXHIBIT ES-5
Comparison of Life-Cycle Costs for all Treatment Trains



Overall Comparison

Aside from capital, O&M, and lifecycle costs, there are numerous other criteria by which the treatment trains should be evaluated, including system reliability, community impacts, the ability to handle large variations in flow, land requirements, constructability, requirements for maintenance and operator attention, and sustainability. The main advantages and disadvantages for Treatment Trains #1 - #4, as evaluated in this report, are described in Exhibit ES-6.

EXHIBIT ES-6
Summary of Pros and Cons for Each Wet Weather Treatment Train

Treatment Train	Pros	Cons
Train #1: Vortex/Swirl Concentrators	• Simple operation • Low maintenance requirements – no moving parts	• Only cost competitive at high loading rates and low removal efficiencies. • Maximum design flow may decrease if the assumed number of operating days is greater than 7.
Train #2: Conventional Clarifiers	• Simple operation • Same technology as existing plant – operators familiar with equipment	• Space limited • Maximum design flow may decrease if the assumed number of operating days is greater than 7.
Train #3: CEPT	• Lower chlorine dose possible due to high TSS removal efficiencies • May be operated as Conventional Clarifiers if chemicals found to be unnecessary	• Operators unfamiliar with technology • Space limited • Uses two additional chemical systems for coagulation and flocculation • Maximum design flow may decrease if the assumed number of operating days is greater than 9.
Train #4: Ballasted Flocculation	• Can treat up to 1500 mgd with available land on site • Highest removal efficiencies • Unlimited number of operating days per month • Lower chlorine dose possible due to high TSS removal efficiencies	• Operators unfamiliar with technology • Most labor intensive and complex system • Uses two additional chemical systems for coagulation and flocculation

The costs for wet weather treatment at the NE WPCP should be analyzed with the costs of other wet weather treatment alternatives, such as improvements in the collection system, to determine which treatment train alternatives and flow regimes should be evaluated further. Treatment trains that are selected for further evaluation should undergo more detailed design and costing methods, water quality sampling, and bench and pilot scale testing, so that removal efficiencies, land requirements, capital costs, and O&M costs can be further refined.

Contents

Exhibits

Attachment

1.0 Introduction

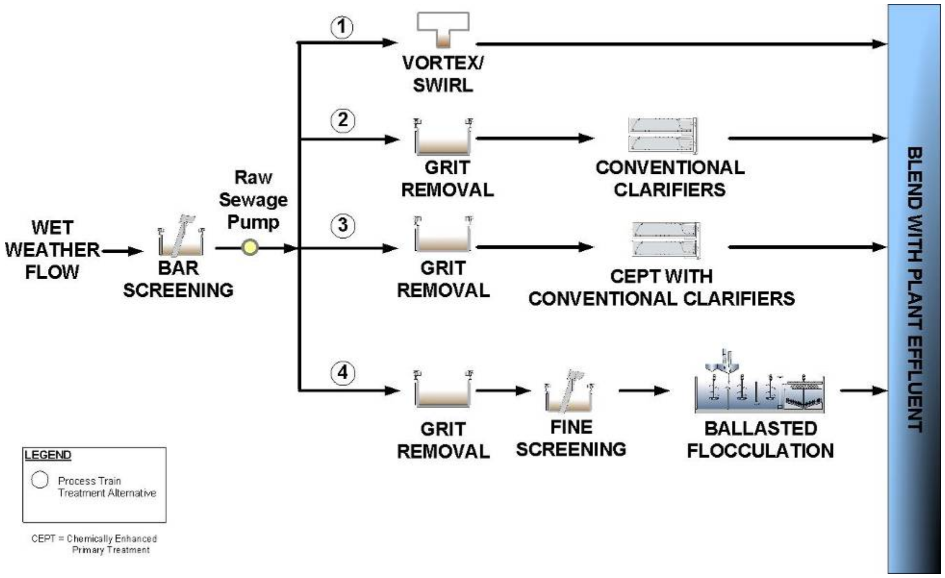
As part of the series of memoranda prepared for the Philadelphia Water Department's (PWD) Combined Sewer Overflow (CSO) Long Term Control Plan (LTCP) update, this report presents the conceptual design and cost analyses for four wet weather treatment alternatives for the Northeast Water Pollution Control Plant (NE WPCP). These treatment alternatives were short listed from previous evaluations by the LTCP team (PWD, CDM, and CH2M HILL) based on information from: water quality data analysis and review of available land for NE WPCP; survey of various potential wet weather treatment technologies; and site visits to three existing wet weather treatment facilities in Ohio (CH2M HILL, 2007b; CH2M HILL, 2008b). A treatment train utilizing CEPT with Plate Settlers was evaluated for the Southeast WPCP, but was subsequently eliminated due to its extremely high cost (CH2M HILL, 2008c).

The wet weather treatment technologies for the NE WPCP evaluated in this report are as follows:

1. Vortex Swirl Concentrators
2. Conventional Clarifiers
3. Chemically Enhanced Primary Treatment (CEPT) with Conventional Clarifiers
4. Ballasted Flocculation (includes fine screening)

Conceptual treatment trains were developed for each treatment technology at various wet weather flows ranging from 69 million gallons per day (mgd) to 1100 mgd (Exhibit 1-1). Cost curves for both capital and operations and maintenance (O&M) costs were generated for each treatment train alternative. This report presents the conceptual design parameters, site layouts, cost estimates, and potential issues of each treatment train alternative.

EXHIBIT 1-1
Schematic View of Treatment Trains Evaluated



2.0 Improvements to Existing Plant

In order to increase the flow capacity of the NE WPCP for wet weather conditions, the potential of maximizing flow through the existing plant must first be evaluated. From 2004 to 2007, the NE WPCP treated an average daily flow of 185 mgd with an instantaneous peak flow of 417 mgd (CH2M HILL, 2008b). Historically, plant operation has demonstrated that the secondary system can treat 435 mgd without experiencing catastrophic failure in the secondary clarifiers.

Since 2001, PWD has been actively planning to evaluate and implement options to increase the capacity of the NE WPCP to treat wet-weather flows. The 2007 Flow Study for the plant presented various options for hydraulic and process improvements that would increase plant capacity from 435 mgd to 535 mgd by incorporating a 100-mgd secondary bypass during wet weather events (CH2M HILL, 2007a). Subsequent studies indicated that it is possible to pass 650 mgd through the existing primary treatment system using a 215-mgd secondary bypass without exceeding permit limits (CH2M HILL, 2008d). A conceptual design project is currently underway for a pretreatment facility to treat an additional 250 mgd of flow (CH2M HILL, 2008e).

The improvements necessary to achieve a plant capacity of 650-mgd are presented in Exhibit 2-1. The majority of these improvements were identified in the 2001 Stress Testing Report and are based on results of stress tests on unit processes, long-term monitoring of the plant, hydraulic modeling, and input from NE WPCP plant staff (CH2M HILL, 2001). These improvements were also evaluated in further detail in the NE WPCP Flow Study (CH2M HILL, 2007a).

In sizing the wet weather treatment trains, it was assumed that the upgrades presented in Exhibit 2-1 will have been completed, increasing the plant's capacity to a minimum of 650 mgd. Thus, the baseline cost that is used in the wet weather treatment train cost estimates is $147.3 million (Exhibit 2-1). This is reflected in the cost curves for each treatment train, presented in latter sections of the report.

EXHIBIT 2-1
Cost Summary of Potential Improvements for Existing NE WPCP

	Improvement Description	**Cost**[(1)]
1	Frankford grit chamber bypass replacement to reduce hydraulic restriction	$3,057,279
2	Rehabilitation of Frankford high level second barrel	$11,421,413
3	New conduits between preliminary treatment building and the Set-1 primary sedimentation tanks	$2,500,000 (2)
4	Construction of new diversion chamber, conduit and new pretreatment system (screening, grit removal) upstream of Set 2 Primaries	$70,050,000 (3)
5	Installation of new influent baffles in Set-2 primary sedimentation tanks	$384,332
6	Removal of double-deck effluent channel in Set-2 final sedimentation tanks	$590,954
7	Construction of 215-mgd bypass conduit from Set-1 primary sedimentation tanks to the existing chlorine contact chamber	$26,347,571 (4)
8	Construction of four new gravity thickeners for thickening of primary sludge (tentative location north of existing digesters- NE-1.8 on Figure 3-4)	$32,895,246 (5)
	TOTAL	**$147,246,795**

(1) Assume escalation factor of 19.8% - based on 9/1/2009 start date and 2-year construction duration.

(2) Based on PWD design cost estimates.

(3) See Northeast WPCP Pretreatment Facility Conceptual Design Report (CH2M HILL, 2008e)

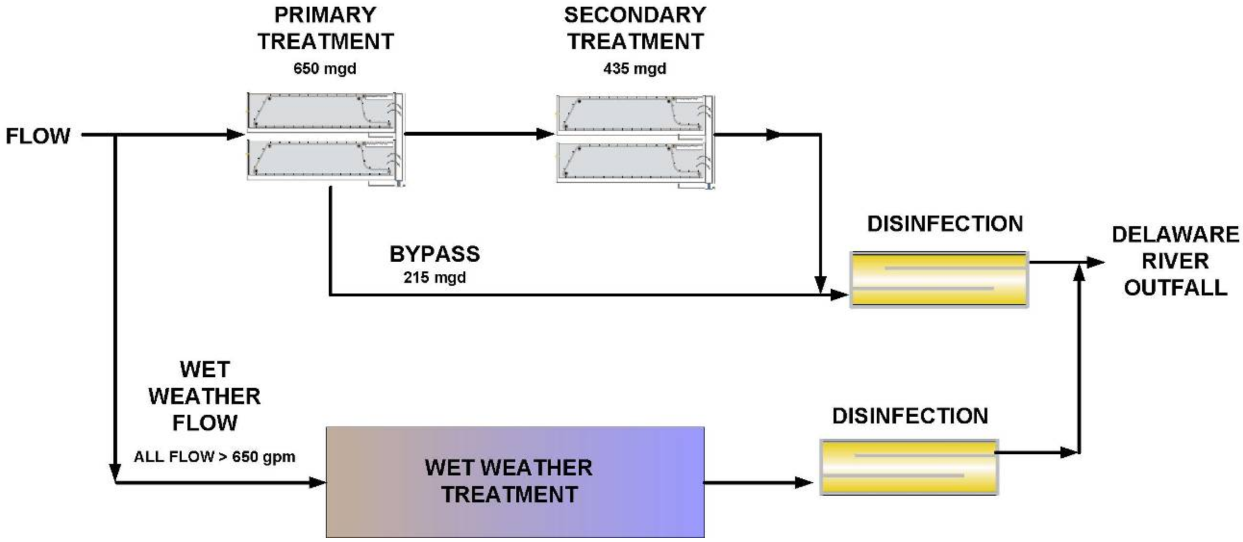
(4) Costs for these line-items were approximated by scaling the costs found in the Flow Study report for upgrades to 535 mgd only. More definitive costs for upgrades to 650 mgd can be substituted once they become available.

(5) See Flow Study Update memo (CH2M HILL, 2008d). New thickeners for the existing primaries will be located in the area of the abandoned digesters. This cost does not include remediation/demolition of the abandoned digesters.

3.0 Wet Weather Treatment Alternatives: Evaluation Methodology

To expand the flow capacity of NE WPCP beyond 650 mgd for the treatment of wet weather flows, a separate wet weather treatment train will be required. Wet weather flows in excess of 650 mgd will be diverted to this new treatment train, eventually blending with both secondary effluent and the secondary bypass effluent (Exhibit 3-1).

EXHIBIT 3-1
Anticipated Wet Weather Flow Pattern in NE WPCP



As depicted in Exhibit 1-1, the four wet weather treatment trains under evaluation for the new wet weather treatment facility are:

1. Vortex Swirl Concentrators
2. Conventional Clarifiers
3. Chemically Enhanced Primary Treatment (CEPT) with Conventional Clarifiers
4. Ballasted Flocculation (includes fine screening)

Conceptual designs and cost estimates were performed for each treatment train at different design flows. This section describes the development of the various design flows and the key assumptions for design and cost estimating.

3.1 Design Flows

The design flows that were selected for evaluation for each treatment train in the new wet weather facility are shown in Exhibit 3-2 and are described below in further detail.

EXHIBIT 3-2
Design Flows Evaluated for each Wet Weather Treatment Train

Treatment Train	Design Flows Evaluated (mgd)
#1) Vortex/Swirl Concentrators	69, 183
#2) Conventional Clarifiers	160, 376
#3) CEPT w/ Conventional Clarifiers	150*, 300, 1000
#4) Ballasted Flocculation	150*, 500, 1100

*The 150 MGD flow point for Trains #3 and #4 was selected arbitrarily to widen the range of the cost curves.

3.1.1 Design Flows by Permit Limits

The maximum allowable flow through each wet weather treatment train is a function of its removal efficiency, the achievable effluent concentration after blending, and the plant's continued ability to meet NPDES permit limits for weekly and monthly TSS and BOD concentrations. The data analysis performed for NE WPCP determined that the monthly TSS limit was the most stringent, and were thus used to determine the maximum allowable flow through each train, as shown in Exhibit 3-3 (CH2M HILL, 2008d).

EXHIBIT 3-3
Maximum Allowable Flow of Wet Weather Treatment Trains to Meet NPDES Permit Requirements

Treatment Train	TSS Removal Efficiency(1) (%)	Achievable Effluent TSS Concentration of Wet Weather Train(2) (mg/l)	Maximum Allowable Flow Through Wet Weather Train Assuming 215-mgd Secondary Bypass(3) (mgd)	Maximum Allowable Flow Through Wet Weather Train Assuming No Bypass (3) (mgd)
#1) Vortex/Swirl Concentrators	30%	221	69	183
#2) Conventional Clarifiers	55%	142	161	376
#3) CEPT w/ Conventional Clarifiers	80%	63	Unlimited*	Unlimited*
#4) Fine Screening -> Ballasted Floc	91%	30	Unlimited*	Unlimited*

*The flow for Train #3 is unlimited assuming the wet weather treatment train operates for no more than seven days per month, an estimate provided by CDM (CH2M HILL, 2008). Since the effluent water quality for Train #4 exceeds permit requirements, it is truly unlimited in flow and frequency of operation. See Section 9.1.

(1) TSS removal efficiencies are based on industry standards. Specific references are provided in TM-SE2 (CH2M HILL, 2008a).

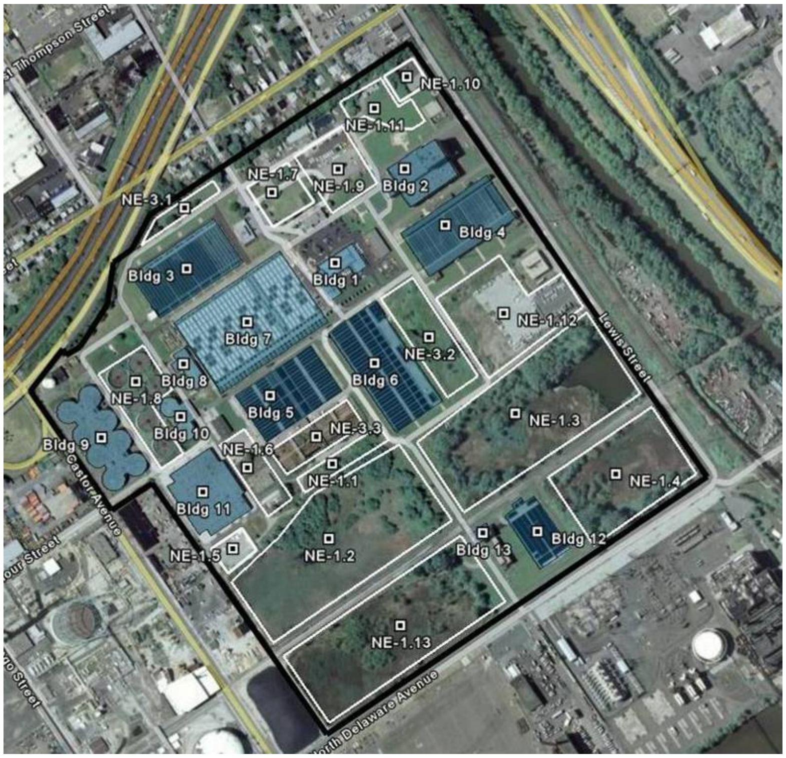
(2) Achievable effluent concentrations based on 95th percentile influent wet weather TSS concentration (316 mg/L)

(3) Maximum flow determined by NPDES Monthly TSS Limit. The allowable daily blended effluent TSS concentration during wet weather was calculated to be 99 mg/L (CH2M HILL, 2008b).

Both the vortex/swirl and conventional clarification trains are limited by permit requirements for this plant. The permitted flows are largely affected by the 215-mgd bypass, which undergoes only primary treatment, reducing the effluent quality of the conventional plant. Since the bypass has not been constructed yet, Exhibit 3-3 also includes the maximum allowable flow assuming no bypass. The permitted flows under both scenarios are used as design points for the vortex/swirl and conventional clarification trains in this report.

The trains with chemical addition obtain higher removal efficiencies and are considered unlimited by permit requirements. For CEPT, the flows are only unlimited if the wet weather treatment facility operates for no more than seven days per month. For the Ballasted Flocculation train, whose effluent quality exceeds that of permit requirements, both the flow and frequency of operation is unlimited (See Section 9.1). The design flow points for these "unlimited" trains were primarily based on the available land area on the existing plant site, as discussed below.

EXHIBIT 3-4
Available Land Areas Within NE WPCP Site



3.1.2 Design Flows by Available Land - Fleet Auction Lot: 300 MGD, 500 MGD

During discussions of land utilization at the existing site, it was agreed that the existing Fleet auction lot north of the lagoons would be the optimal location for the new wet weather facility (NE -1.12 in Exhibit 3-4). It was found that a 300-mgd CEPT facility, or a 500-mgd ballasted flocculation facility, could fit on this existing lot. This assumes that, if needed, the existing cogeneration building at the corner of the lot could be demolished to increase the land area available.

3.1.3 Design Flows by Available Land - Fleet Auction Lot and Sludge Lagoon: 1000 MGD

To expand beyond 300 and 500 mgd flow capacities, it was decided that only one section of the sludge lagoons would be utilized (NE-1.3 in Exhibit 3-4). This serves to minimize disturbance of the sludge lagoons, which would require remediation if used for construction. A small section in the NE-1.4 sludge lagoon was also set aside for the new chlorine contact chamber for the wet weather treatment train. The combination of the fleet auction lot and the NE-1.3 sludge lagoon provide sufficient area for a 1000-mgd CEPT facility or a 1500-mgd ballasted flocculation facility. Since 1500 mgd exceeds the expected collection system capacity, it is not evaluated as a design point (see following section).

3.1.4 Design Flows by Collection System Capacity Assumptions: 1100 MGD

According to CDM's assumptions on the capacity of the upgraded collection system, the collection system capacity for the NE WPCP could reach 1,740 mgd after transmission improvements, which is equivalent to three times the existing collection system capacity (Myers, 2007a). Assuming the existing plant will be able to handle 650 mgd, the maximum flow to the new wet weather facility would be 1090 mgd. The maximum design flow point used for the ballasted flocculation was thus 1100 mgd.

3.2 Key Design Assumptions

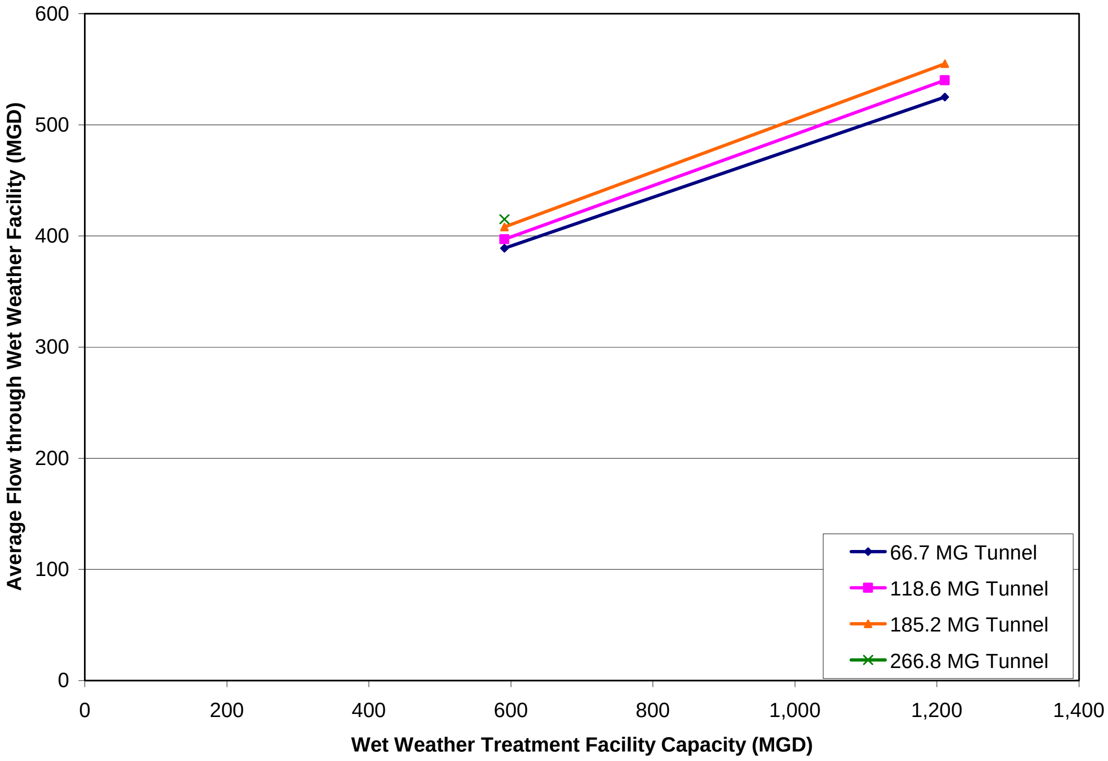
3.2.1 Average Design Flow

In the previous section, the design flow capacities were identified for each treatment train based on permit limits, available land area, and collection system capacity. These flows are the peak flows that the wet weather facilities are designed to treat under each scenario.

The average flow that the wet weather facility will receive, however, depends on conditions in the collection system. Preliminary model simulations have been performed for the Northeast Drainage district (NEDD) under several deep tunnel and plant expansion scenarios (CDM, 2008). Simulation results suggest that the average flow delivered to the wet weather facility increases as the capacity of the facility increases, and is not highly sensitive to the volume of storage in the collection system (Exhibit 3-5).

Model runs for a 591-mgd and a 1,211-mgd wet weather facility generated an average flow of 415-mgd and 555-mgd, respectively, assuming the largest storage tunnel scenario. Based on these model results, the maximum average design flow assumed for the new wet weather treatment trains evaluated in this report is 555-mgd. For the Ballasted Flocculation 500-mgd scenario, an average flow of 415-mgd was assumed. For trains with peak capacities less than 415 mgd, the average flow is assumed to be equivalent to the peak flow of the facility (Exhibit 3-6).

EXHIBIT 3-5
Average Annual Wet Weather Treatment Rates Under Various Deep Tunnel and Plant Expansion Scenarios



*This plots the average wet weather treatment rates using data from the high flow scenario hydrologic model (CDM, 2008).

EXHIBIT 3-6
Average Design Flows

Maximum Design Flow (mgd)	Average Design Flow (mgd)
69	69
150	150
160	160
183	183
300	300
376	376
500	415(1)
1000, 1100	555(2)

(1) Model runs with a 591-mgd facility generated an average flow of 415-mgd.

(2) Model runs with a 1,211-mgd facility generated an average flow of 555-mgd.

3.2.2 Process

The process design described herein is based on conceptual design parameters and will require refinement as the planning and design efforts progress. For the purposes of developing capital costs, sizing of most facilities was based on maximum design flows. The average design flow, as described above, was used for sizing chemical storage facilities, storage for screenings and grit, and sludge handling facilities.

Preliminary Treatment

Each wet weather train evaluated in this report was sized to treat influent flow in excess of the plant's flow capacity of 650 mgd. For each case, the head of the new wet weather facility is located in the existing Fleet auction lot, southeast of the Set-1 primaries. A new influent conduit running south along Lewis Street will divert excess wet weather flow to the new preliminary treatment building (PTB) of the wet weather treatment facility. The new PTB will contain an influent wet well at a similar elevation to the existing low level wet well, bar screens, influent pumps, and screenings and grit handling systems. The influent pumps were designed to increase the hydraulic grade line so that the wet weather flow can discharge to the river outfall by gravity from the wet weather treatment facilities. The screenings and grit handling systems include screenings washers and compactors, as well as grit concentrators and classifiers. This system will handle screenings from both the bar screens and the fine screens when required.

From the PTB, the wet weather flow will continue on to further treatment through processes dependent on each treatment train. These are described in further detail in Sections 4 through 7.

Disinfection

The final process of all treatment trains is chlorination and dechlorination. The wet weather flow will be dosed with sodium hypochlorite at the head of the new chlorine contact chamber. The chlorine contact chamber is sized to provide a 20-minute detention time at peak flow, with the exception of the 1,000 mgd and 1,100 mgd flow scenarios. In these scenarios, the chamber is sized for a 10-minute detention time at peak flow, and it is assumed that the chlorine dosage will be increased correspondingly to provide adequate disinfection. Sodium bisulfite is then used for dechlorination at the end of the chlorine contact chamber.

Chemical Feed

For Treatment Trains #3 and #4, which provide chemically-enhanced clarification, a coagulant and flocculant are added as settling aids. For Train #3, CEPT, these chemicals are added to a rapid mixer and flocculation basin upstream of the sedimentation tank. In the ballasted flocculation train (#4), the settling aids are added to mixing zones that are part of the ballasted flocculation unit.

Ferric chloride was selected as the coagulant for all trains since it is currently used at PWD's water treatment plants. However, if there are concerns with the iron affecting the digestion process downstream, aluminum sulfate (alum) can be used as a substitute.

Polymer is used as the flocculant and is stored in liquid form to allow immediate startup of the wet weather system.

Ten-day storage at average flow was assumed for all chemicals.

Sludge Handling

Primary sludge from all treatment trains is pumped to new gravity thickeners, where the solids concentration is expected to increase to a minimum of 3 percent. The thickeners are sized to handle the average wet weather flow (as presented in Exhibit 3-6) with a 95 percentile influent solids concentration (316 mg/L) for a continuous period of 24 hours.

The thickened sludge will be pumped to the plant's anaerobic digesters for further treatment. The sludge will be screened through StrainPress® sludge cleaners to remove inert solids before entering the digesters. PWD is currently conducting a study of the existing digesters and expects that proposed improvements will generate capacity equivalent to two extra digesters. Capital costs for each treatment train include the cost of new digesters that may be required beyond this improved capacity. The digesters were sized to provide 20-day storage for solids, assuming average flow, a 95 percentile influent solids concentration (316 mg/L), an average wet weather event duration of five hours, and five events in 20 days.

Along with the four new thickeners for the existing plant, these new digesters will be located in the area of the abandoned digesters (Figure 3-4, NE-1.8). The cost of demolishing the abandoned digesters and removing the sludge contained is not included in the capital cost estimates. The design parameters that were assumed for all the treatment train processes are summarized in Exhibit 3-7. The process flows are described in further detail in each of the treatment train sections.

EXHIBIT 3-7
Key Process Design Assumptions for Wet Weather Treatment Trains(1)

Preliminary Treatment			
Bar Screens	Opening Size	15	mm (0.59 in)
	Screenings Production(2)	3.5	cf/mg
Influent Pumps	Type	Vertical End-Suction	
	Total Dynamic Head (TDH)	45	ft (match existing wet well elevations)
Fine Screens	Opening Size	6	mm (0.24 in)
	Screenings Production(2)	2.5	cf/mg
	Screenings Compaction Factor	2	
Grit Removal	Type	Vortex Grit Unit	
	Grit Production(2)	4	cf/mg
Screenings and Grit	Number of Days Storage	1	Day
Primary Clarifiers	Type	Rectangular Basin	
	Sludge Collection Mechanism	Chain-and-flight	
Flocculation Tank	Detention Time (at max flow)	10	Min
	Number of Stages	3	
Wet Weather Treatment Technology	**Surface Overflow Rate (gpd/sf)**		

EXHIBIT 3-7
Key Process Design Assumptions for Wet Weather Treatment Trains(1)

Vortex/Swirl	36,000 (25 gpm/sf)		
Conventional Clarifiers	2,400 (3)		
CEPT	3,000		
Ballasted Flocculation	84,600 (60 gpm/sf)		
Chlorine Contact			
Chlorine Contact Chamber	Detention Time	10 -20	Min
Chemical Feed			
Chemical	**Purpose**	**Concentration**	**Storage (at avg flow)**
Ferric Chloride	Coagulation	60 mg/L	10 days
Liquid Polymer	Flocculation	2 mg/L	10 days
Sodium Hypochlorite	Chlorination	5 mg/L	10 days
Sodium Bisulfite	De-chlorination	1.5 mg/L(4)	10 days
Primary Sludge Generation(5)			
Train	**% TSS Removal**	**% Solids in Sludge**	
#1: Vortex/Swirl	30%	0.07%(6)	
#2: Conventional Clarifiers	55%	0.5%	
#3: CEPT	80%	0.5%	
#4: Ballasted Floc	90%	0.3%	
Sludge Thickening			
Gravity Thickeners	Max Hydraulic Loading Rate (limiting factor for Trains #1 and #4)	900	gal/sf/day
	Max Solids Loading Rate (limiting factor for Trains #2, #3)	30.7	lb/sf/day
	% Solids of Thickened Sludge	3	% minimum
StrainPress® Sludge Screens	Sludge Throughput	200 – 400	gpm
Digesters			
Anaerobic Digesters	Detention Time	20	days
	Diameter	115	ft
	Side Water Depth	25	ft
	Volatile Solids Destruction	50	%

(1) Unless otherwise noted, all design parameters are based on standard textbook values.

(2) Estimated from 2004-2005 grit and screenings disposal records from the SE WPCP. It is assumed that

EXHIBIT 3-7
Key Process Design Assumptions for Wet Weather Treatment Trains(1)

the difference in grit and screenings quantities between the plants are negligible.

(3) Based on stress testing results on existing primary clarifiers

(4) Assumes 1 mg/L residual chlorine concentration at the end of the chlorine contact chamber

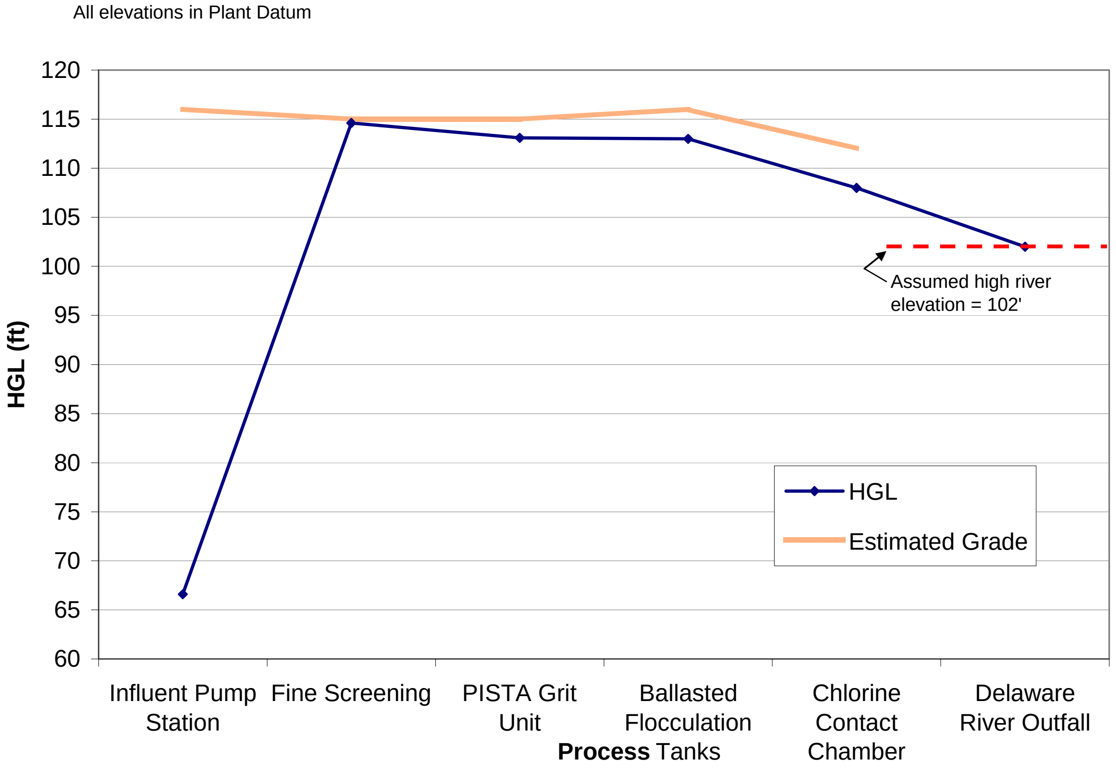
(5) Assumes 95 percentile influent TSS concentration of 316 mg/L, and volatile solids percentage of 70%

(6) Based on a 10% underflow from the vortex/swirl concentrator

3.2.3 Hydraulics

To eliminate the need for an effluent pump station, the elevations of the new wet weather treatment trains were set to allow gravity flow to the Delaware River outfall. A preliminary hydraulic profile for the ballasted flocculation train at 1100 mgd is shown in Exhibit 3-8 as an example of a maximum head loss scenario.

EXHIBIT 3-8
Preliminary Hydraulic Gradeline for the Ballasted Flocculation Treatment Train at 1100 MGD



As an initial condition, the high river elevation was assumed to be 102 feet. This is similar to the assumption made for the Delaware River in the Southeast WPCP memo (CH2M HILL, 2008c).

The water surface level of the chlorine contact chamber was assumed to be 2 feet higher than the top of the existing chlorine contact chamber (108 feet). The contact chamber was elevated from the existing chamber to avoid flooding of the chamber and the final sedimentation tank weirs, which the current plant occasionally experiences during high river level conditions. The estimated head-loss through the new outfall conduit is 3.2 ft (using Manning’s Equation).

The elevation of the chlorine contact chamber sets the elevations of the upstream unit processes. As shown in Exhibit 3-8, the water surface elevations are slightly beneath the existing grade elevation. The hydraulic grade-line of the wet weather facility is higher than the existing plant due to its location on the east side, which is higher in elevation than the rest of the site. Capital cost estimates assume complete burial of all tanks.

3.2.4 Existing Site

In developing conceptual layouts of the wet weather treatment trains, several assumptions were made about the existing site:

- The cogeneration building in the Fleet auction lot (NE-1.12 of Exhibit 3-4) can be demolished to increase the land area available for the wet weather facility.
- The existing outfall pier (approximately 600-ft long) needs to be expanded to support the new outfall conduit. Pier expansion is included in the capital cost estimates.

3.2.5 Site Conditions

The site and soil conditions in the Fleet auction lot and the sludge lagoons were assumed to be similar to the rest of the NE WPCP. Two main assumptions were made based on existing plant drawings:

- Piles will be needed for foundations of all structures. A pile density and depth of 0.069 piles/sf and 30 feet were used for all water-bearing structures on site. A pile density and depth of 0.089 piles/sf and 50 feet were used for the outfall conduit to the Delaware River. T A pile density and depth of 0.0043 piles/sf and 30 feet were used for all other structures. These numbers were based on existing pile plans for the Northeast WPCP.
- Dewatering will be required for some buried structures. According to plant drawings, the groundwater elevation ranges from approximately 5-ft to 20-ft below grade at the NE WPCP.

3.3 Cost Estimating Assumptions

CH2M HILL’s costing model was used to develop conceptual level estimates of both capital and life-cycle costs for each of the treatment trains and flows. This tool was supplemented by budgetary quotes from vendors for all major pieces of equipment. These estimates are defined as Class 4 estimates by the Association for the Advancement of Cost Engineers (AACE) and have an expected level of accuracy of +50 to -30 percent.

3.3.1 Capital Costs

Construction Costs

Construction costs were developed using the costing model for each building or unit process of a treatment train, and were based on estimated materials, labor, equipment, and installation costs. Contractor markups applied to the construction subtotal costs are presented in Exhibit 3-9. The percentages used are industry standards and are in agreement with CDM’s assumptions. The escalation factors applied are based on a construction start-date of September 1, 2009, and the estimated construction duration of each scenario (Exhibit 3-10). This start-date was chosen since PWD's LTCP Update must be submitted by this date. A location adjustment factor of 15.2 percent was applied to the escalated construction cost, which is in agreement with the ENR 20-city Construction Cost Index (CCI).

Lastly, a market adjustment factor of 15 percent was applied to account for: busy contractors; contractors selectively bidding jobs; contractors selectively choosing which Owners they want to do jobs for; premium wages to keep skilled workers and management staff; availability of crafts/trades; immigration impacts and uncertainty; abnormal fuel impacts and uncertainty; and abnormal material impacts of the last two years.

EXHIBIT 3-9
Contractor Markups Assumed in Capital Cost Estimates

Contractor Markups	%	Applied to:
Overhead (OH)	10%	Subtotal of Construction Cost
Profit (P)	5%	Subtotal of Construction Cost + OH
Mobilization, Bonds, and Insurance (MOB)	5%	Subtotal of Construction Cost + OH&P
Contingency	25%	Subtotal of Construction Cost + OH&P + MOB

EXHIBIT 3-10
Escalation Factors for Various Construction Scenarios

Flow Capacity of Wet Weather Treatment Train (mgd)	Estimated Construction Duration (months)(1)	Escalation Factor(2)
69	24	19.8%
150, 160	26	20.5%
183	27	21.2%
300	30	21.8%
376	32	22.5%
500	36	23.9%
1000, 1100	48	28.2%

(1) Escalation factors are based on mid-point of construction with a construction start-date of 9/1/2009.

(2) Construction durations were estimated based on facilities of similar size, and need to be refined through each stage of design.

Non-Construction Costs

A factor of 30 percent was applied to the total construction costs to estimate non-construction costs related to the project. The breakdown of these factors is shown in Exhibit 3-11.

EXHIBIT 3-11
Non-Construction Cost Factors

Non-Construction Expenditure	Factor*

EXHIBIT 3-11
Non-Construction Cost Factors

Non-Construction Expenditure	Factor*
Permitting	2%
Engineering	10%
Services During Construction	10%
Commissioning and Startup	3%
Legal/Administration	5%

*Each factor was applied to the total construction cost of the project, including all markups and escalation.

Land Remediation

Under certain high-flow scenarios, the new chlorine contact chamber will be located next to the existing chamber, in an abandoned sludge lagoon. This capped sludge lagoon will need remediation before construction can begin. For the higher flows of 1000 and 1100 mgd, an additional 11.4 acres of abandoned sludge lagoons must also be utilized to provide enough space for the new facility.

The estimated cost of remediation is $1.14 M per acre, as estimated by PWD. This assumes a relatively low hazard level of the material being removed.

3.3.2 O&M and Life Cycle Cost Analysis

Life cycle and O&M costs of each treatment train at each flow were also estimated using CH2M HILL's costing model and were based on financial and operational assumptions as listed in Exhibit 3-12. The O&M costs cover labor, power for equipment and buildings, chemicals, sludge and trash disposal, and repair, maintenance and replacement of structures and equipment. O&M costs are mainly based on average flows through the plant, as described in Section 3.2.1 and shown in Exhibit 3-6.

The additional labor required for each treatment train is dependent on the flow capacity of the train, as shown in Exhibit 3-13. It was assumed that new maintenance workers and operators would be hired for the new wet weather facility, working full time throughout the year. For some flow scenarios, it was assumed that a portion of the labor requirements during wet weather events could be met by increasing the number of shifts for existing operators, who would work overtime at a rate of 1.5 times their normal wage. It was assumed that the operators on overtime would work one 8-hour shift per wet weather event.

A detailed break down of the O&M costs and the energy requirements for each train are presented in Attachment NE-2.1. It should be noted that all O&M costs presented for the treatment trains are annualized O&M costs that include escalation over the 30-year period.

Life cycle costs were calculated using the total capital cost, including construction and non-construction costs, and O&M costs. The present value of the life cycle costs are presented in the cost summary section of each train.

EXHIBIT 3-12
Assumed Factors for Life Cycle Cost Estimates

Factor	Value	
Financial		
Annual Discount Rate	4.875	%
Life-Cycle Calculation Period	30	Years
Inflation Rate	4	%(1)
Operation		
Days of operation of wet weather treatment train	51	days(2)
Duration of wet weather event	5	Hours(2)
Labor		
Hourly wage for plant operator	$50.44	including fringe benefits
Hourly wage for plant operator on overtime	$75.65	including fringe benefits
Hourly wage for maintenance worker	$52.35	including fringe benefits
Fringe benefits and overhead multiplier	2.7	applied on top of raw hourly rate
Number of working hours for full time operators at wet weather facility	2,080	hours per year per operator
Number of working hours for operators on overtime at wet weather facility	408	hours per year per operator (8 hours per event)
Number of working hours for maintenance workers at wet weather facility	2,080	hours per year per worker
Power for Buildings		
Building Electrical Cost Assumed	$0.10	$/kwh
Building Electrical Requirements	2	watts/sf of building area
Building Heating Requirements	1.2	BTU/hr/surface area of building
Natural gas cost assumed	$14	per MBTU
Power for Equipment(3)	$0.10	$/kwh
Chemicals(4)		
Ferric Chloride	$310	$/dry ton
Liquid Polymer	$3983	$/dry ton
Sodium Hypochlorite	$1450	$/dry ton
Sodium Bisulfite	$1000	$/dry ton
Repair, Maintenance, and Replacement		
	Percentage assumed for annual O&M cost	
Finishes	2%	of finishes cost during construction

EXHIBIT 3-12
Assumed Factors for Life Cycle Cost Estimates

Factor	Value	
Equipment	1%	of capital cost of equipment
Instrumentation and Controls	5%	of capital cost of I&C
Mechanical	0.1%	of capital cost of mechanical work (incl. valves)
Electrical	1%	of capital cost of electrical equipment
Disposal		
Grit and Screenings Disposal and Hauling Costs	$100	per cubic yard
Final Sludge Disposal Costs(5)	$75	per wet ton
Other		
Other O&M Costs (including vehicles, lab tests, office equipment and other miscellaneous costs)	$10,000	per additional full-time operator and maintenance worker
Contingency		
Contingency applied to O&M costs	20	%

(1) Based on CCI Index

(2) The maximum average annual number of wet weather events with flows higher than 650 MGD is 51 under scenarios modeled by CDM. Similarly, the maximum average annual wet weather duration is 219 hours (CDM, 2008). The duration of each event is then assumed to be 5 hours.

(3) Equipment power costs estimated by PWD.

(4) Based on existing costs at the plant (McKeon, 2008)

(5) Final sludge mass assumes 30% dewatered cake.

EXHIBIT 3-13
Additional Labor Requirements for each Flow Scenario

Treatment Train Flow Capacity	Number of Additional Full-Time Operators(1)	Number of Existing Operators on Overtime(2)	Number of Additional Maintenance Workers(1)
69, 150, 160, 183	1	1	2
300, 376, 500	2	0	4
1000, 1100	2	1	4

(1) Full-time operators and maintenance workers are new hires who work 2080 hours per year. Maintenance workers include different trades required for the facility (e.g. electricians, instrument technicians, mechanics, etc.) (2) Existing operators on overtime work 8 hours per wet weather event, or 408 hours per year.

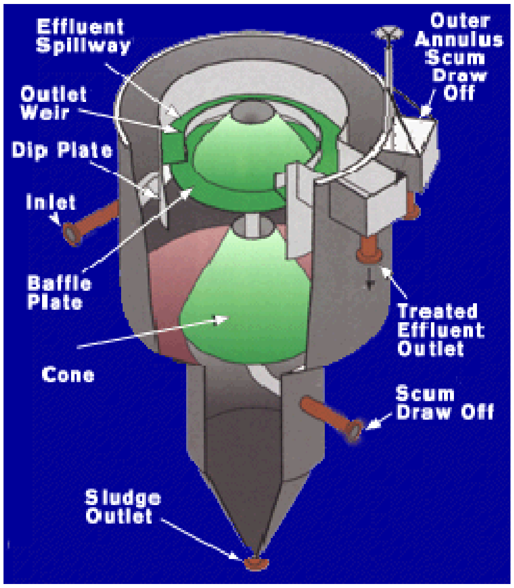
4.0 Treatment Train #1- Vortex/Swirl Concentrators

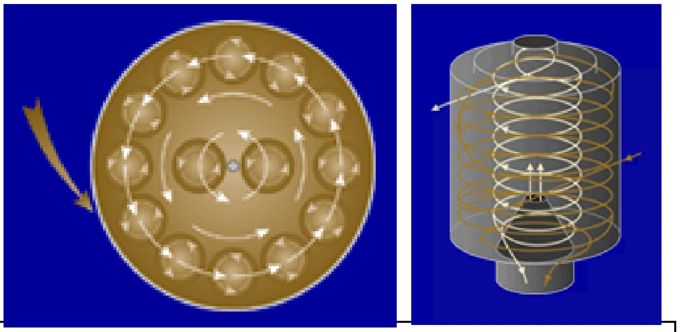
4.1 Process Flow Diagram

The first treatment train under evaluation utilizes the vortex separation technology as its main treatment process. After passing through bar screens and influent pumping at the PTB, the wet weather flow will enter the primary vortex/swirl concentrators. Vortex/swirl concentrators are flow-through structures with no moving parts. The wet weather flow enters the cylindrical structure tangentially, producing a swirling motion that concentrates the solids in the center (Exhibit 4-1). An underflow drain in the center of the unit continually draws the solid materials out of the flow.

The treated effluent flows out of the top of the vessel, continuing on to the chlorine contact chamber. The solids underflow, typically 10 percent of the influent, undergoes grit removal through a vortex grit unit before settling and thickening in gravity thickeners. The conceptual process flow diagram for this treatment train is shown in Exhibit 4-2.

EXHIBIT 4-1
Diagrammatic Cutaway of Vortex/Swirl Device (Storm King®, H.I.L. Technologies)

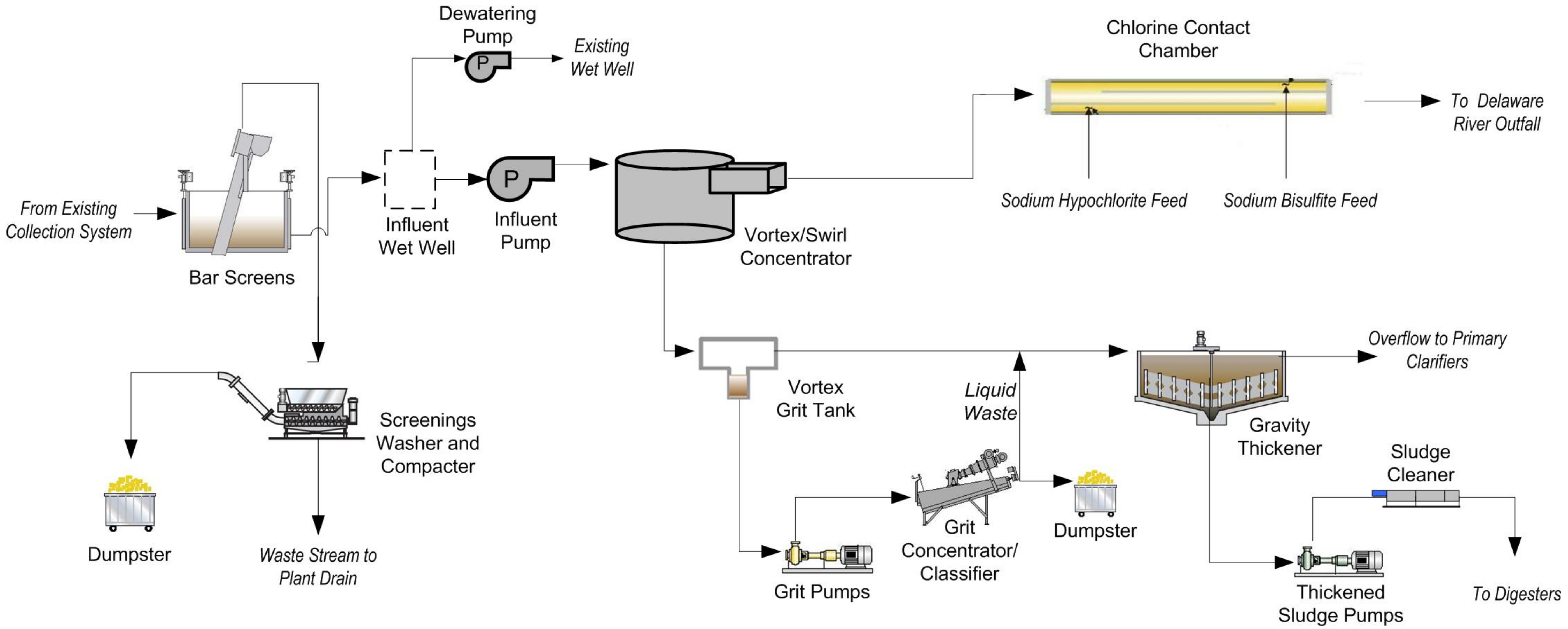




Flow Pattern Plan and Profile Views (H.I.L. Technologies)
The flow in vortex/swirl devices initially follows a path around the perimeter of the unit and is then directed into an inner swirl pattern with a lower velocity than the outer swirl. Solids separation is achieved by both centrifugal force and gravity because of the long flow path and inertial separation due to the circular flow pattern. The concentrated underflow passes through an outlet in the bottom of the vessel while the treated effluent flows out of the top of the vessel.

EXHIBIT 4-2

Process Flow Diagram and Key Process Design Parameters for Treatment Train #1: Vortex/Swirl Concentrators



Flow	Bar Screens	Influent Pumps	Vortex/Swirl Concentrators		Vortex Grit Tank		Screenings Washer/ Compactor	Grit Pumps		Grit Concentrator	Grit Classifier	Screenings and Grit Prod.	Sodium hypochlorite			Sodium Bisulfite			Gravity Thickeners & Sludge Cleaners	Primary Sludge Pumps		Thickened Sludge Pumps		Sludge Prod.	Digesters
(mgd)	# units	# units	# primary units	Loading rate on primary unit (gpm/sf)	# units	Dia (ft)	# units	# duty	# standby	# units	# units	Compacted volume (cf/day)	Total storage vol (gal)	# duty pumps	# standby pumps	Total storage vol (gal)	# duty pumps	# standby pumps	# Units	# Duty	# Standby	# Duty	# Stand by	lb/day	# Units
69	1	2	2	19.1	1	10	1	1	1	1	1	397	34,255	1	1	6,226	1	1	2	4	1	2	1	54,554	0
183	2	3	4	25.3	1	16	2	1	1	1	1	1,052	91,115	1	1	6,226	1	1	4	8	2	4	1	144,686	0

EXHIBIT 4-3

Conceptual Layout and Footprint for Treatment Train #1: Vortex/Swirl Concentrators

69 MGD (left), 183 MGD (right)

FLOW (mgd)	PTB	GRIT UNITS	VORTEX SWIRLS	CHEMICAL BUILDING	CCC	GRAVITY THICKENERS*	TOTAL FOOTPRINT (acres)	REMEDIATION FOOTPRINT (acres)
69	41' x 27' & 39' x 39'	10' (1 unit)	40' (2 units)	61' x 45'	67' x 114' (3 passes)	80' (2 units)	0.6 acres	NONE
183	54' x 42' & 56' x 39'	16' (1 unit)	40' (4 units)	101' x 47'	109' x 177' (5 passes)	80' (4 units)	1.3 acres	NONE

4.2 Conceptual Design and Site Layouts

A conceptual design and site layout was developed for a flow of 69 mgd, the maximum allowable flow to meet permit requirements assuming the 215-mgd secondary bypass, and for 183 mgd, the maximum allowable flow assuming no bypass. The main design parameters are shown in Exhibit 4-2 and the conceptual site layouts and footprints are shown in Exhibits 4-3. Since the entire facility can fit on the existing Fleet auction lot, no land acquisition or remediation will be required.

4.3 Operational and Technology-Specific Issues

The effectiveness of vortex/swirl concentrators greatly depends on the hydraulic loading rate on the unit and the characteristics of the solids entering the unit. The optimal loading rate must be determined through pilot or operational testing. In order to operate the vortex/swirl at its optimal operating rate or “sweet spot”, the vortex/swirl units can be brought online one by one as the influent flow increases. Alternatively, an equalization basin can be constructed to maintain a specific flow-rate into the units. An equalization basin was not included in the cost estimates, but conservative hydraulic loading rates were assumed for facility sizing.

4.3.1 Startup and Shutdown

The pretreatment processes (bar screens, influent pumps, and grit removal) can be brought online quickly at the start of a wet weather event. Vortex/ swirl concentrators would be empty at the start of a wet weather event. At small flows, the wet weather flow will exit through the underflow. As flows increase, the vessel will fill due to the increased hydraulic load and begin discharging treated effluent to the outfall.

During shutdown, the vortex/swirl and grit units will be emptied by pumping from the underflow sections to the main plant’s influent wet well. The influent wet well in the new PTB would also be pumped down to the plant’s existing wet well using dewatering pumps (Exhibit 4-2).

For long term shutdown, the chlorine contact chamber could be pumped down, with the flow recycled to the head of the main plant.

4.3.2 Interaction with Main Plant

The waste streams generated by the screenings washer/compactor and the grit classifiers are sent to the gravity thickeners of the wet weather treatment train and will not affect the main plant.

The overflow from the gravity thickeners is conveyed to the head of the entire plant. The estimated overflow range from wet weather thickeners is 6 to 18 mgd. To minimize the effect of this volume, the overflow is recycled back to the head of the entire plant so that it can be distributed across all units in operation.

4.3.3 Impact on plant operations

Since the vortex/swirl unit has no moving parts, it is expected to have little operations and maintenance requirements. However, operators’ attention may be necessary to monitor the hydraulic loading rates into the vortex/swirls to ensure that the "sweet spot" is maintained. The treatment train also includes grit pumps, concentrators, and classifiers, as well as sludge pumps and other equipment, all of which require maintenance. In addition, the new chemical building will include storage of sodium hypochlorite and bisulfite, which are fed to the new chorine contact chamber. Storage of hypochlorite will need to be monitored, since it degrades over time. In addition, the hypochlorite feed-lines should be flushed or degassed periodically.

4.4 Cost Analyses

The estimated capital, O&M, and lifecycle costs are shown in Exhibit 4-4. Total capital costs and the capital costs per volume treated for all scenarios are shown in Exhibits 4-5 and 4-6. The estimated O&M costs by category are also presented in Exhibits 4-7. A more detailed breakdown of these costs is presented in Attachment NE-2.1.

EXHIBIT 4-4
Cost Summary for Vortex/Swirl Treatment Train #1

	Wet Weather Flow (mgd)	
Cost	**69**	**183**
Capital Cost ($M)	$91	$154
Annual Operations and Maintenance Cost ($M)	$1.5	$2.1
Present Value of the Cost ($M)	$115	$186

EXHIBIT 4-5
Capital Costs for Treatment Train #1: Vortex/Swirl
Includes cost of upgrading existing plant capacity to 650 mgd

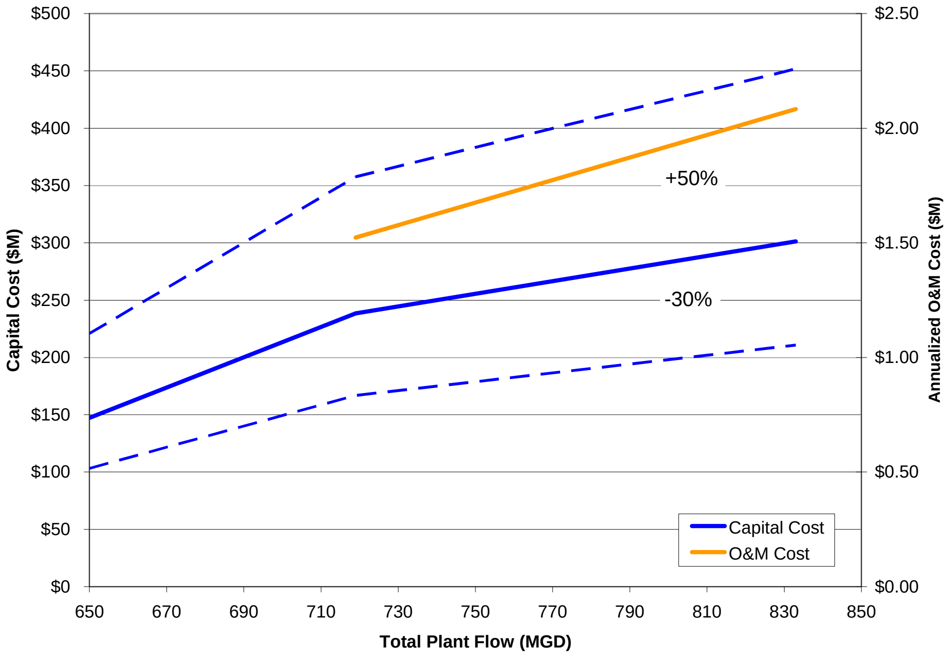


EXHIBIT 4-6
Capital Costs per Gallon Treated for Treatment Train #1: Vortex/Swirl

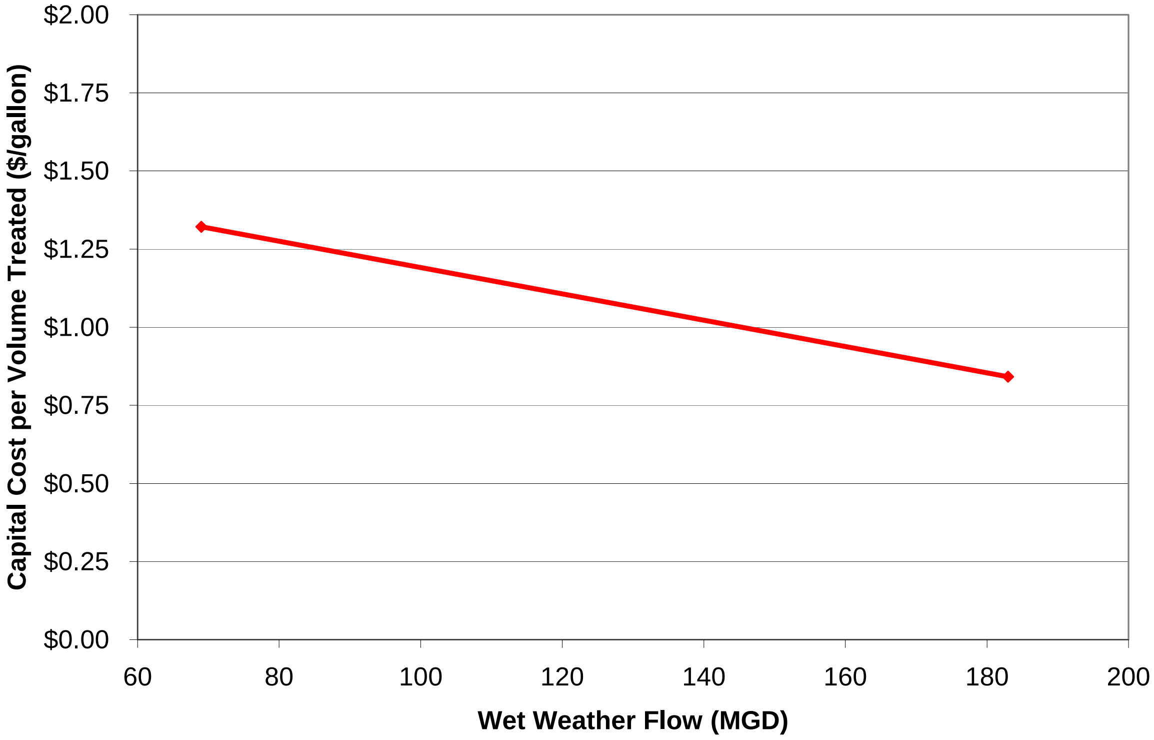
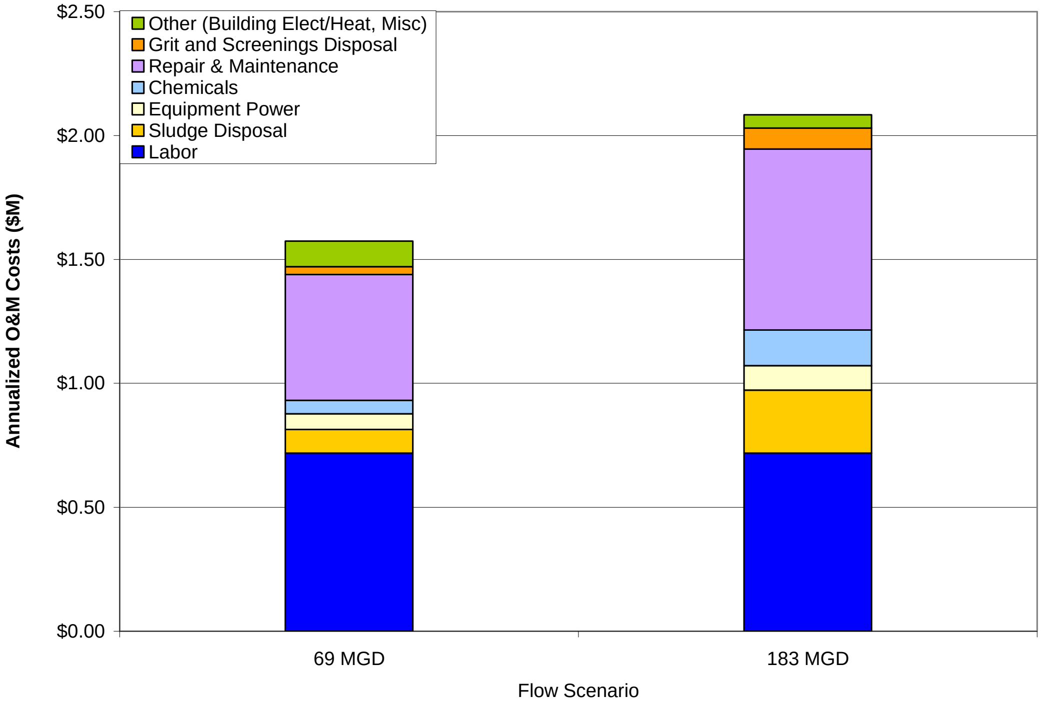


EXHIBIT 4-7
Operations and Maintenance by Category for Treatment Train #1: Vortex/Swirl



5.0 Treatment Train #2 - Conventional Clarifiers

5.1 Process Flow Diagram

Through treatment train #2, the wet weather flow undergoes essentially the same level of primary treatment as the flow through the existing NE WPCP. After preliminary treatment through the bar screens and grit removal, the wet weather flow passes through conventional primary clarifiers at a maximum loading rate of 2400 gpd/sf. This is the overflow rate achievable by the plant's existing primary clarifiers, as shown through stress testing (CH2M HILL, 2001). Primary sludge is collected by chain and flights in the clarifier tanks and is pumped to the gravity thickeners for thickening. The process flow diagram for this treatment train is shown in Exhibit 5-1.

5.2 Conceptual Design and Site Layouts

Conceptual designs were developed for a flow of 160 mgd, the maximum allowable flow to meet permit requirements assuming a 215-mgd secondary bypass, and 376 mgd, the allowable flow assuming no bypass. Key design parameters at these flows are shown in Exhibit 5-1 and conceptual layouts are shown in Exhibit 5-2. No remediation will be required for the 160-mgd flow scenario since the entire facility can fit on the existing Fleet auction lot. For the 376 mgd flow scenario, remediation will be required to site the new chlorine contact chamber.

5.3 Operational and Technology-Specific Issues

5.3.1 Startup and Shutdown

When the wet weather facility is initially put into service, it will take 2-3 hours before the conventional clarifiers begin to discharge treated wet weather flow. This is equivalent to the time needed to displace the existing wastewater in the tanks, or to fill the tanks if they are empty.

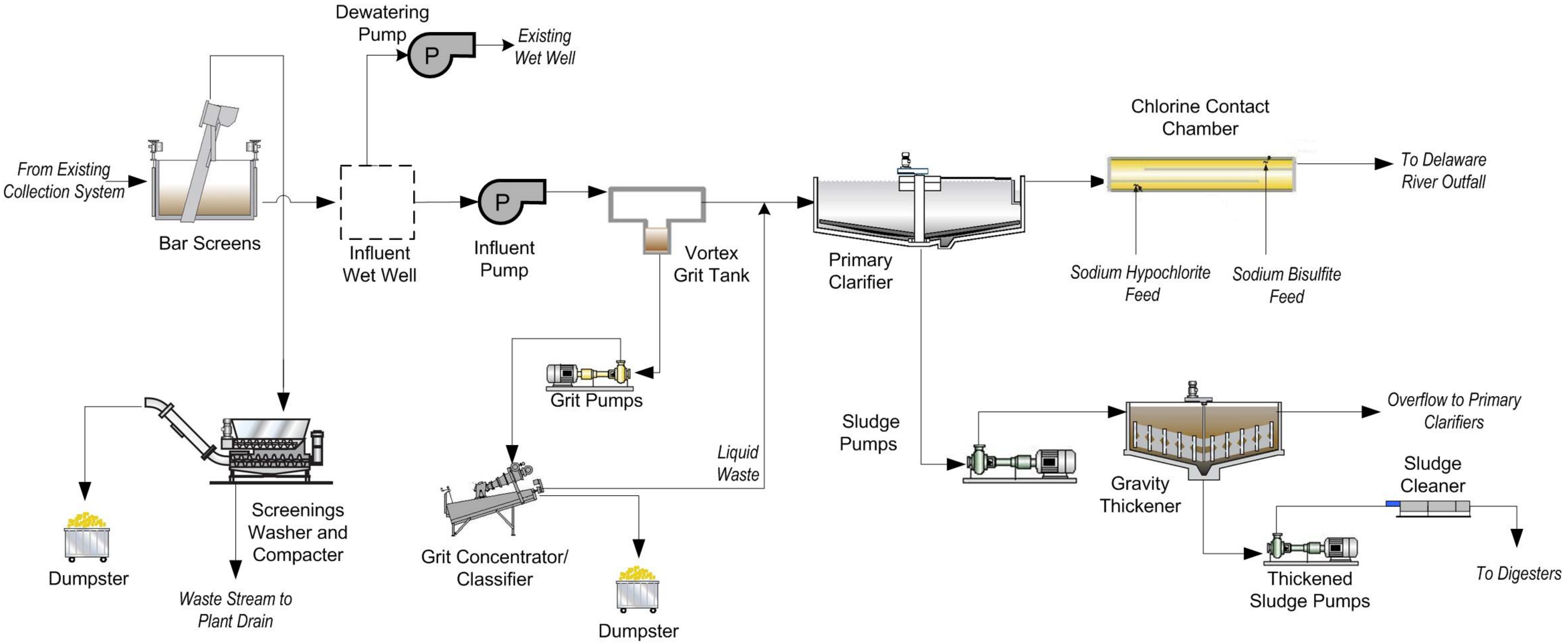
For shut down, the tank may be filled with treated effluent, or pumped down to the existing plant if freezing becomes an issue.

5.3.2 Interaction with Main Plant

Since the existing plant uses primary clarifiers, the new primary clarifiers for wet weather treatment can provide redundancy on primary treatment for the entire plant. If connected to the influent to the existing aeration basins, the new clarifiers could be used for treatment of dry weather flows.

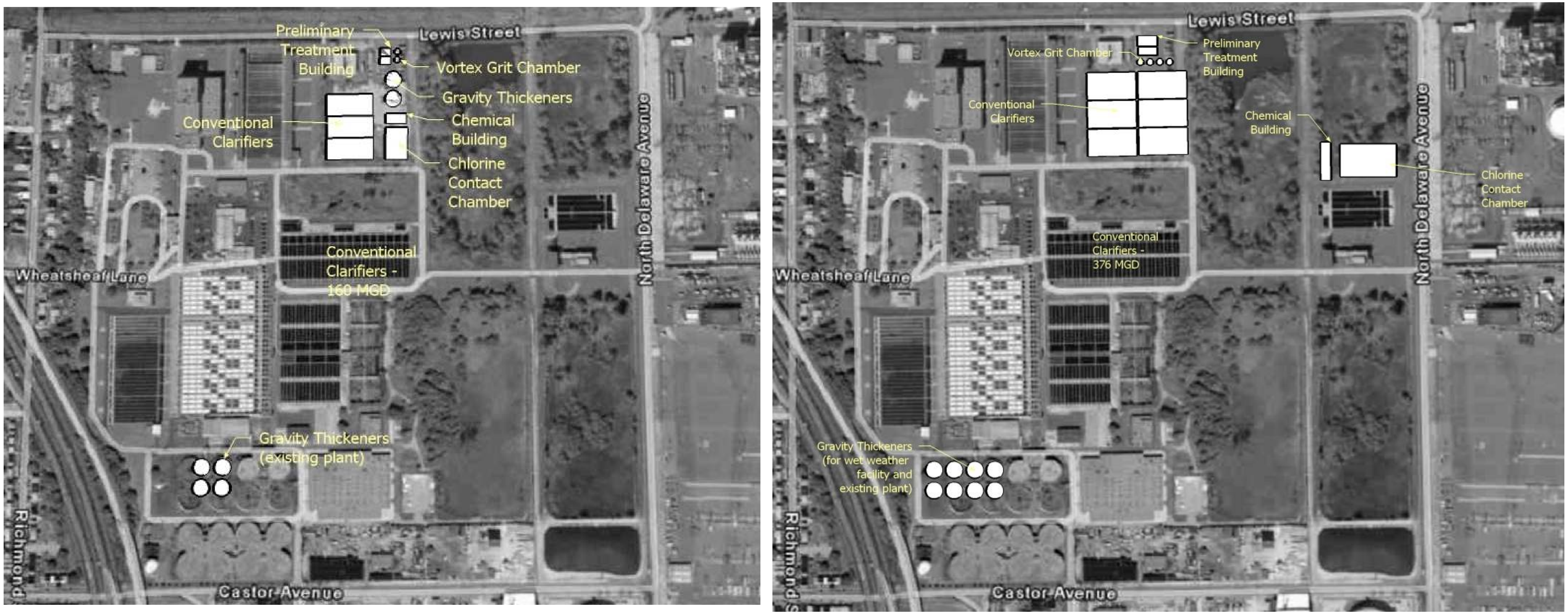
The waste streams generated by the screenings washer/compactor and the grit classifiers are sent to the primary clarifiers of the wet weather treatment train and will not affect the main plant. As with the other treatment trains, the overflow from the gravity thickeners will be conveyed to the head of the entire plant. The estimated overflow range from wet weather

EXHIBIT 5-1
Process Flow Diagram and Key Process Design Parameters for Treatment Train #2: Conventional Clarifiers



	Bar Screens	Influent Pumps	Vortex Grit Tank		Screenings Washer/ Compactor	Grit Pumps		Grit Concentrator	Grit Classifier	Screenings and Grit Prod.	Sodium Hypochlorite			Sodium Bisulfite			Clarification	Gravity Thickeners & Sludge Cleaners	Primary Sludge Pumps		Thickened Sludge Pumps		Sludge Prod.	Digesters
Flow (mgd)	# Units	# Units	# Units	DIA (ft)	# Units	# Duty	# Standby	# Units	# Units	Compacted Volume (cf/day)	Total Storage Vol (gal)	# Duty Pumps	# Standby Pumps	Total Storage Vol (gal)	# Duty Pumps	# Standby Pumps	# Trains	# Units	# Duty	# Standby	# Duty	# Standby	lb/day	# Units
160	2	3	2	32	2	2	1	2	1	920	79,663	1	1	6,226	1	1	3	2	3	1	2	1	231,919	0
376	4	6	6	32	4	4	1	4	1	2,185	187,208	1	1	10,847	1	1	6	4	6	2	4	1	545,009	0

EXHIBIT 5-2
Conceptual Layouts and Footprints for Treatment Train #2: Conventional Clarifiers 160 MGD
160 MGD (left), 376 MGD (right)



Flow (mgd)	PTB	Grit Units	Clarifier Tanks	Chemical Building	CCC	Gravity Thickeners	Digesters	TOTAL FOOTPRINT (acres)	REMEDIATION FOOTPRINT (acres)
160	54’ x 39’ & 56’ x 39’	32' (2 units)	104’ x 226’ (3 tanks)	101' x 47'	109’ x 156’ (5 passes)	80' (2 units)	-	2.6	NONE
376	93’ x 49’ & 102’ x 39’	32’ (4 units)	129’ X 231’ (4 tanks)	177’ x 47’	151’ x 259’ (7 passes)	80’ (4 units)	-	6.3	2.3

thickeners only is 4 to 11 mgd. To minimize the effect of this volume, the overflow is recycled back to the head of the entire plant so that it can be distributed across all units in operation.

5.3.3 Impact on Plant Operations

The operations and maintenance requirements for this treatment train should be similar to those needed for corresponding processes at the existing plant.

5.4 Cost Analyses

The estimated capital, O&M, and lifecycle costs are shown in Exhibit 5-3. Total capital costs and the capital costs per volume treated are also shown in Exhibits 5-4 and 5-5. Estimated O&M costs by category are presented in Exhibit 5-6. A more detailed breakdown of these costs is presented in Attachment NE-2.1.

EXHIBIT 5-3
Cost Summary for Conventional Clarifiers: Treatment Train #2

	Wet Weather Flow (mgd)	
Cost	**160**	**376**
Capital Cost ($M)	$194	$389
Annual Operations and Maintenance Cost ($M)	$2.1	$4.1
Present Value of the Cost ($M)	$227	$453

EXHIBIT 5-4
Capital Costs for Treatment Train #2: Conventional Clarifiers
Includes cost of upgrading plant capacity to 650 MGD

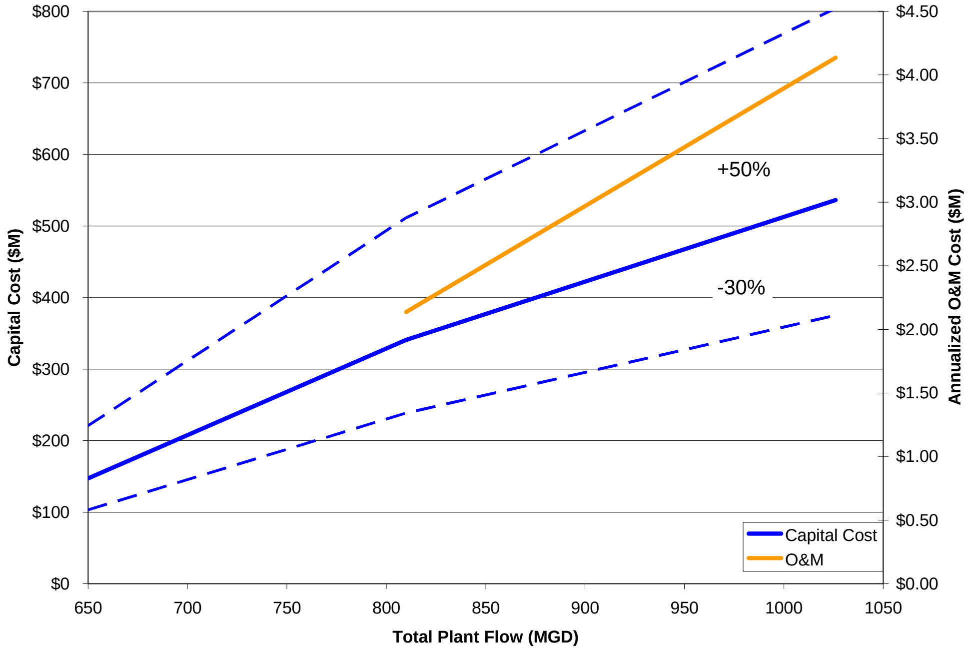


EXHIBIT 5-5
Capital Costs per Gallon Treated for Treatment Train #2: Conventional Clarifiers

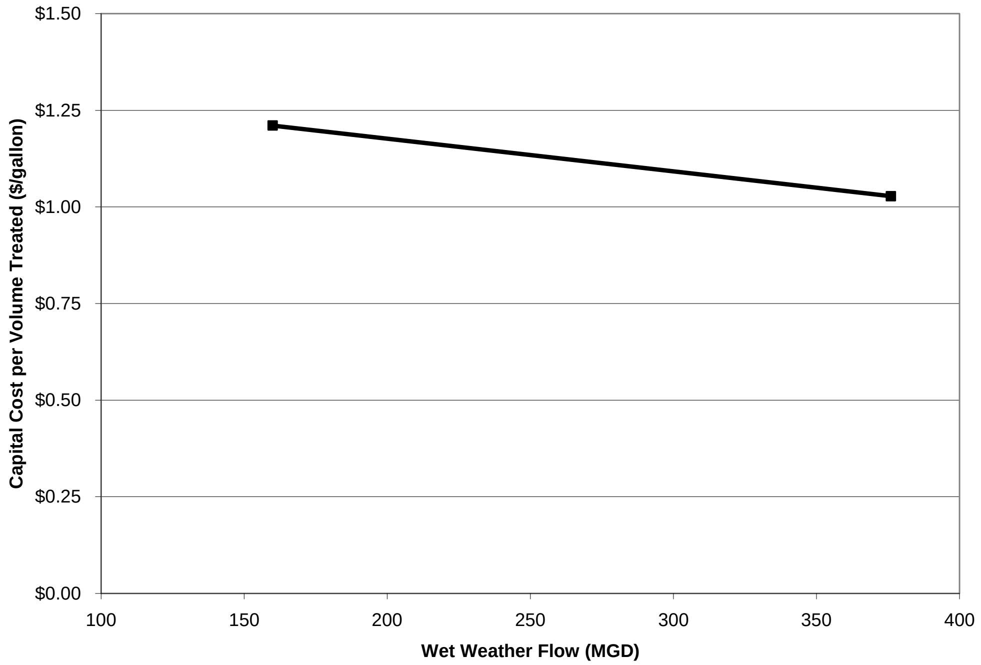
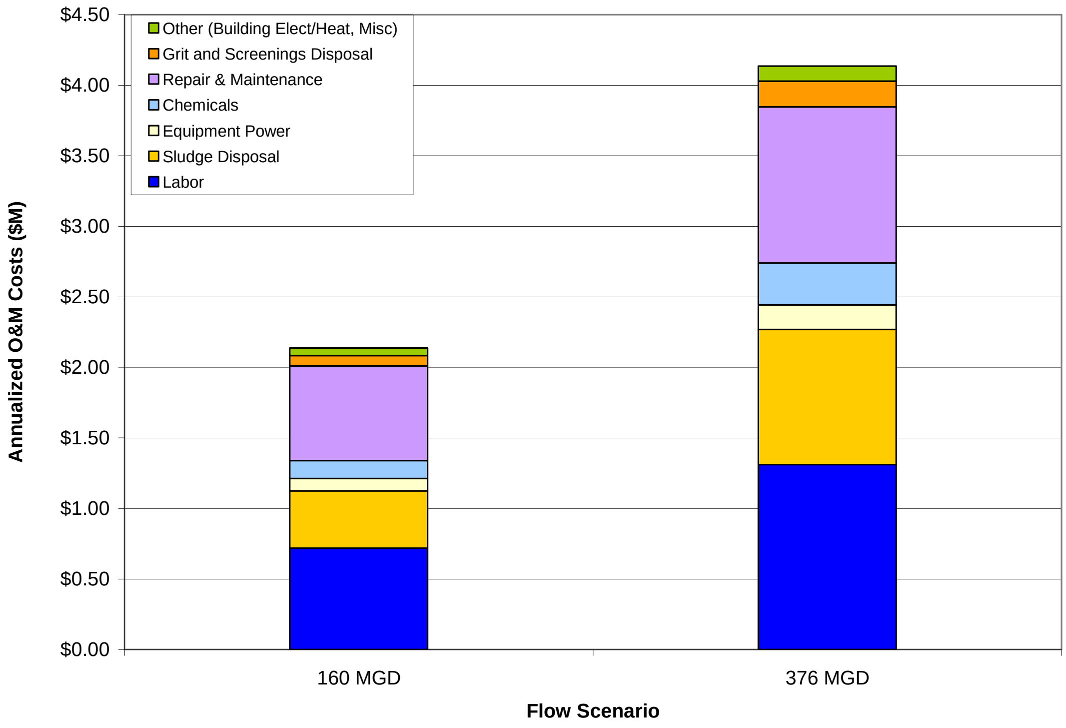


EXHIBIT 5-6
Operation and Maintenance Costs by Category for Treatment Train #2: Conventional Clarifiers



6.0 Treatment Train #3 - Chemically Enhanced Primary Treatment (CEPT)

6.1 Process Flow Diagram

Chemically enhanced primary treatment (CEPT) improves the removal efficiency of TSS and BOD through the addition of coagulants and flocculants to primary clarifiers. With chemical enhancement, the surface overflow rate of the primary clarifier is expected to increase from 2400 gpd/sf to 3000 gpd/sf, and the removal efficiency from 55 percent to 80 percent. As shown in the process flow diagram in Exhibit 6-1, the flow path is similar to Treatment Train #2. The only difference is the addition of rapid mixers and flocculation basins upstream of the primary clarifiers, along with their associated chemical feed and storage systems.

6.2 Conceptual Design and Site Layouts

Conceptual designs were developed for three different flow scenarios for this train: 150, 300 and 1000 mgd. Key design parameters at these flows are shown in Exhibit 6-1. As shown in Exhibit 6-2, there is adequate space on the Fleet auction lot to treat up to 300 mgd of wet weather flow. Utilizing the adjacent sludge lagoon area allows an increased flow capacity to 1000 mgd. This sludge lagoon, as well as the lagoon area for the new chlorine contact chamber, will need remediation.

6.3 Operational and Technology-Specific Issues

6.3.1 Startup and Shutdown

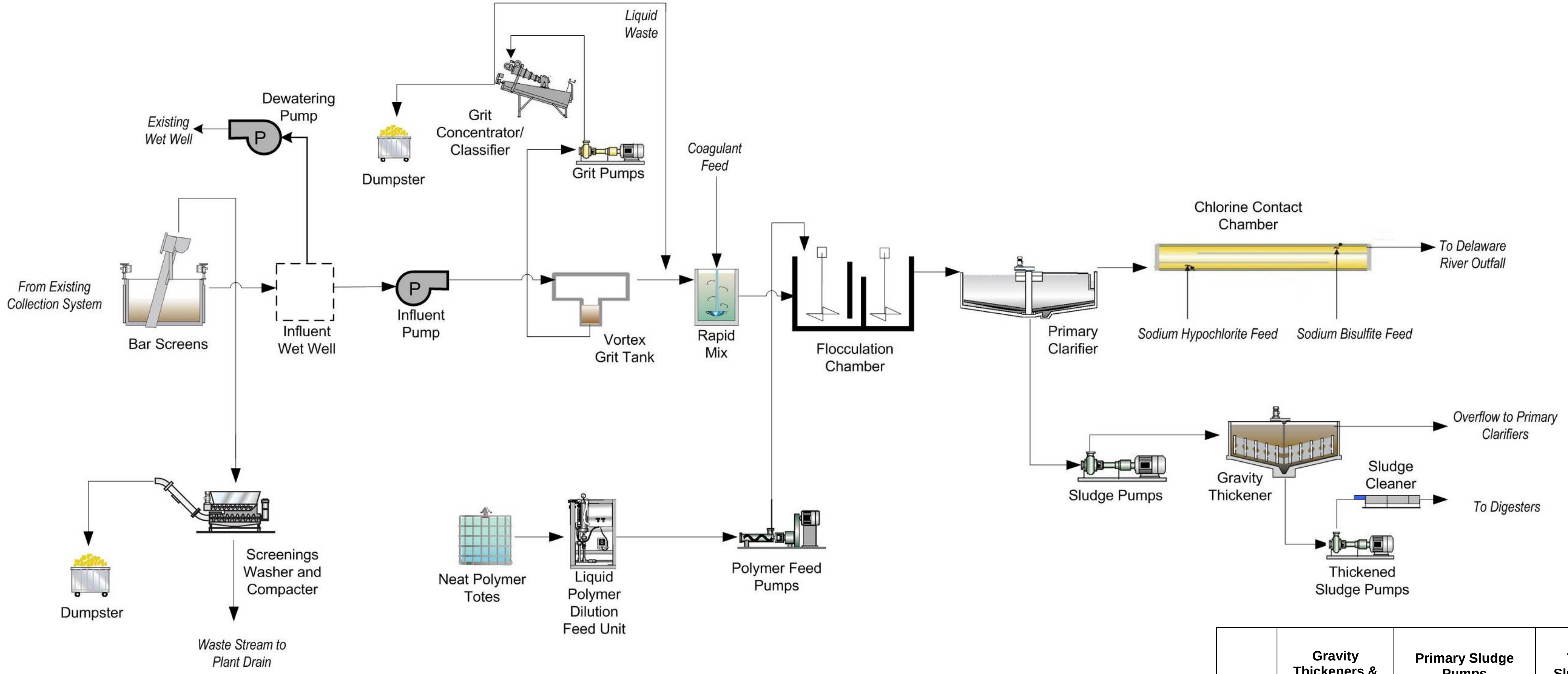
When the wet weather facility is initially put into service, it will take 2-3 hours before the clarifiers begin to discharge treated wet weather flow. This is equivalent to the time needed to displace the existing wastewater in the tanks, or to fill the tanks if they are empty.

For shut down, the tanks may be filled with treated effluent, or drained down to the existing plant if freezing becomes an issue.

The other processes in the system are physical or physical/chemical treatment systems that are easily and quickly brought online and will achieve normal levels of treatment efficiency quickly.

EXHIBIT 6-1

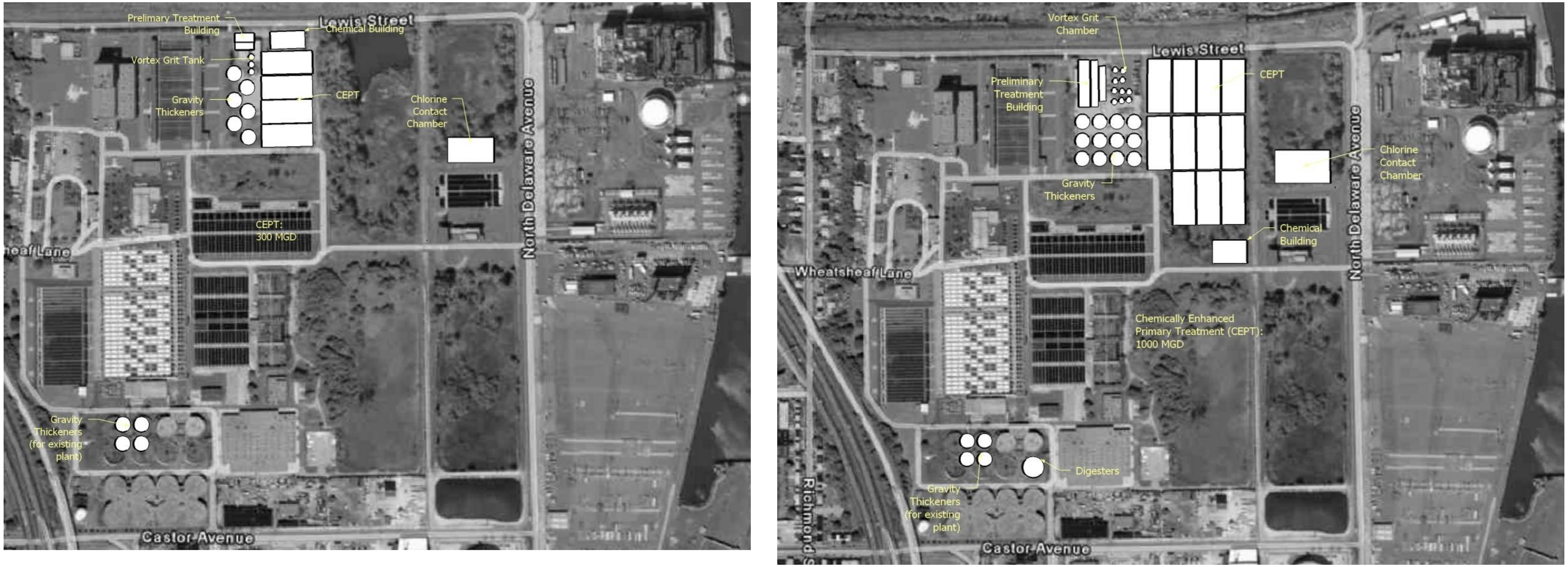
Process Flow Diagram and Key Process Design Parameters for Treatment Train #3: CEPT



Flow (mgd)	Gravity Thickeners & Sludge Cleaners # Units	Primary Sludge Pumps		Thickened Sludge Pumps		Sludge Prod. (lb/day)	Digesters
		# Duty	# Standby	# Duty	# Standby		# units
150	3	3	1	3	1	355,168	0
300	6	4	1	6	2	724,905	0
1000	12	11	3	12	3	1,341,075	1

Flow (mgd)	Bar Screens # Units	Influent Pumps # Units	Vortex Grit Tank		Screenings Washer/ Compactor # Units	Grit Pumps		Grit Concentrator # Units	Grit Classifier # Units	Screenings and Grit Prod. Compacted Volume (cf/day)	Ferric Chloride			Liquid Polymer			Sodium Hypochlorite			Sodium Bisulfite			Flocculation # Trains	Clarification # Trains
			# Units	DIA (ft)		# Duty	# Standby				Total Storage Vol (gal)	# Duty Pumps	# Standby Pumps	Total Storage Vol (gal)	# Duty Pumps	# Standby Pumps	Total Storage Vol (gal)	# Duty Pumps	# Standby Pumps	Total Storage Vol (gal)	# Duty Pumps	# Standby Pumps		
150	2	2	2	32	2	2	1	2	1	863	157,388	3	1	7,358	1	1	74,684	1	1	6,226	1	1	3	3
300	3	4	3	32	3	3	1	3	1	1,725	314,776	4	1	13,637	4	1	149,638	1	1	8,654	1	1	4	4
1000	10	14	10	32	10	10	3	10	3	3,191	582,335	11	3	25,229	11	3	276,331	1	1	16,.011	1	1	11	11

EXHIBIT 6-2
Conceptual Layouts and Footprints for Treatment Train #3: CEPT
300 MGD Layout (left), 1000 MGD (right)



Flow (Mgd)	PTB	Grit Units	Flocculation Tanks	Clarifier Tanks	Chemical Building	CCC	Gravity Thickeners	Digesters	TOTAL FOOTPRINT (acres)	Remediation Footprint (acres)
150	41’ x 45’ & 56’ x 39’	32’ (2 units)	107’ x 51’ (3 units)	107’ x 164’ (3 units)	101’ x 100’	88’ x 181’ (4 passes)	80’ (3 units)	-	2.7	0
300	67’ x 53’ & 80’ x 39’	32' (3 units)	127' x 55' (4 units)	127' x 213' (4 units)	201' x 100'	130’ x 239’ (6 passes)	80' (6 units)	-	5.3	2.3
1000	197’ x 58’ & 188’ x 39’	32' (10 units)	126’ x 27’ (11 units)	126’ x 257’ (11 units)	259' x 100'	172' x 297' (8 passes)	80' (12 units)	115’ (1 unit)	13.3	13.5

6.3.2 Interaction with Main Plant

As described in the previous treatment trains, the overflow from the thickeners, ranging from 7 to 48 mgd depending on the flow scenario, is recycled back to the head of the plant for distribution across the main plant and the wet weather treatment train.

6.3.3 Impact on Plant Operations

CEPT requires the addition of chemicals, ferric chloride and polymer, that are not currently used at the NE WPCP. Storage of these new chemicals will need to be monitored to ensure that they are not degraded over time, especially during long periods of shutdown. The system effluent may need to be recycled to the head of the existing plant until the unit process is stabilized.

6.4 Cost Analyses

The estimated capital, O&M, and lifecycle costs for each flow scenario are shown in Exhibit 6-3. Total capital costs and the capital costs per volume treated are also shown in Exhibits 6-4 and 6-5. Estimated O&M costs by category are shown in Exhibit 6-6. A breakpoint in the O&M costs can be seen after a flow of 300-mgd. This is because O&M costs such as for chemical and sludge disposal are dependent on the average flow of the plant, not the peak. For example, while the 1000-mgd facility can treat a peak of 1000-mgd, the average flow through the facility is only 555 mgd, so the O&M (Section 3.2.1). Thus, facilities with peak flows greater than the average wet weather flow will experience a relatively smaller increase in O&M costs.

A more detailed breakdown of these costs is presented in Attachment NE-2.1.

EXHIBIT 6-3
Cost Summary for CEPT Train #3

	Wet Weather Flow (mgd)		
Cost	**150**	**300**	**1000**
Capital Cost ($M)	$207	$351	$996
Annual Operations and Maintenance Cost ($M)	$2.6	$5.0	$8.5
Present Value of the Cost ($M)	$248	$429	$1,129

EXHIBIT 6-4
Capital Costs for Treatment Train #3: CEPT
Includes cost to upgrade plant capacity to 650 MGD.

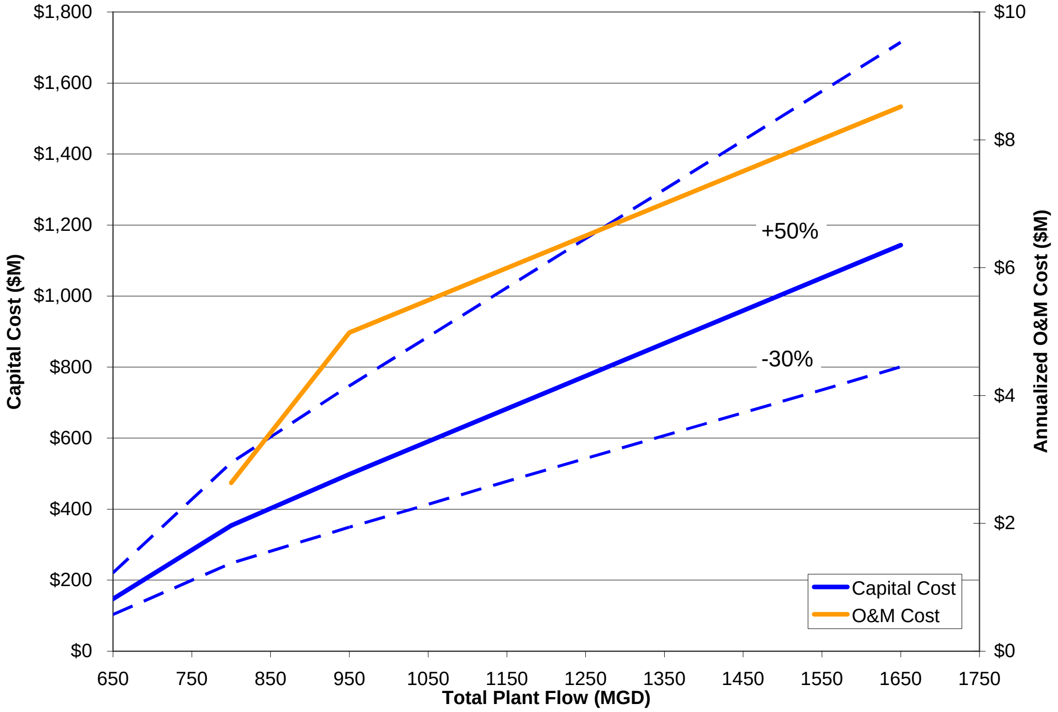


EXHIBIT 6-5
Capital Costs per Gallon Treated for Treatment Train #3: CEPT

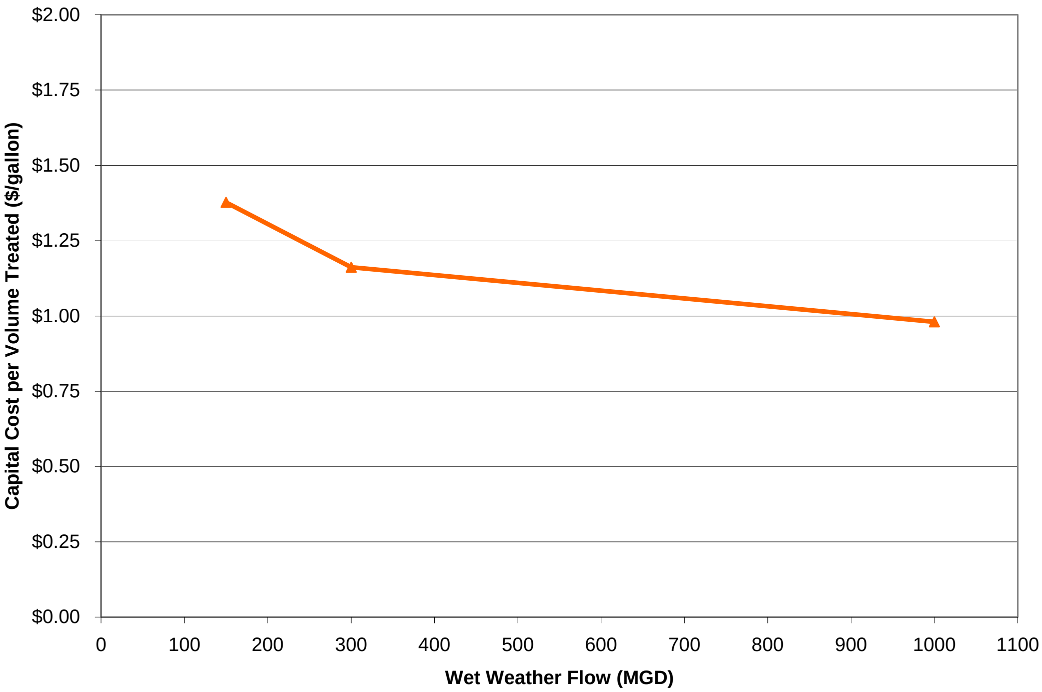
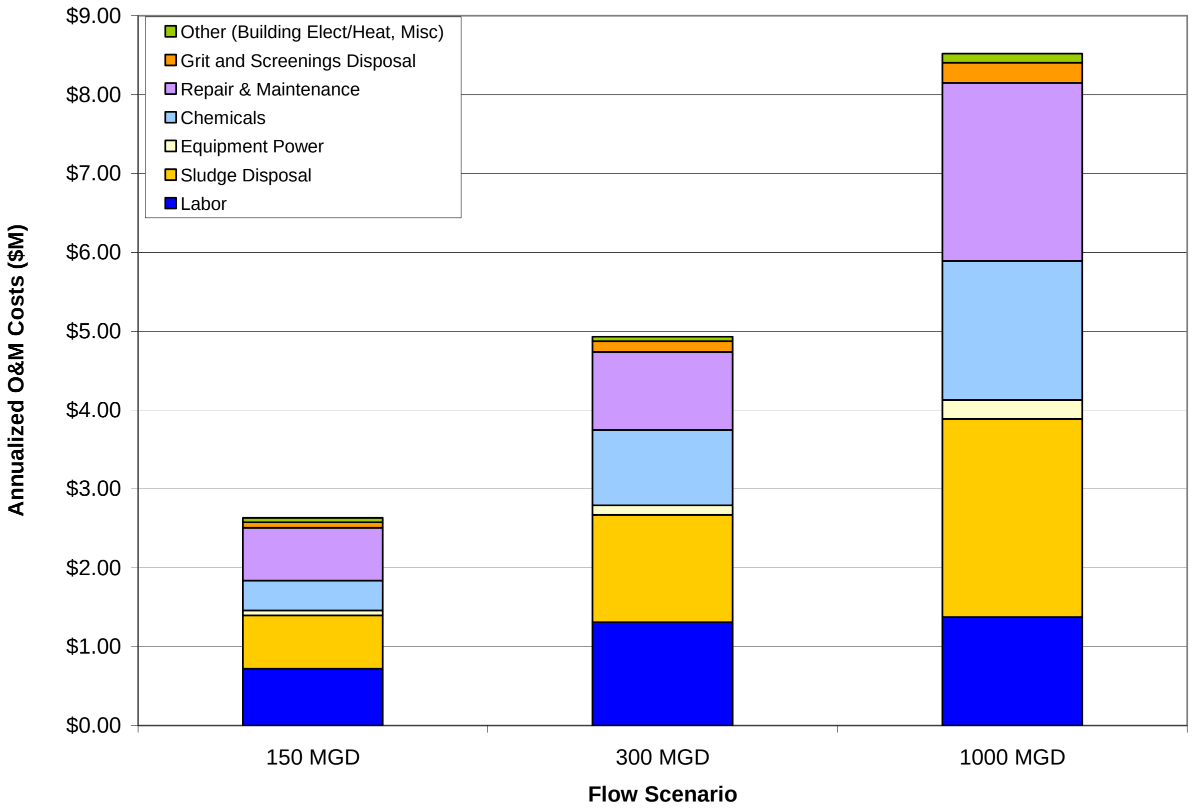


EXHIBIT 6-6
Operations and Maintenance Costs by Category for Treatment Train #3: CEPT



7.0 Treatment Train #4 - Ballasted Flocculation

The final treatment train uses ballasted flocculation to achieve removal efficiencies beyond that of CEPT. Ballasted flocculation, often referred to as "high rate treatment," creates extremely dense flocs with high settling velocities that can be removed efficiently even at very high surface overflow rates. Two proprietary systems that use ballasted flocculation are the DensaDeg and Actiflo systems. The DensaDeg system uses chemical sludge produced within it (recirculated from the clarifier underflow to the system influent) as a ballasting agent. The Actiflo system uses microsand as the ballasting agent. Both systems can achieve TSS removals in the range of 85 to 95 percent.

Actiflo requires separate gravity thickeners to process the sludge it generates, while Densadeg recirculates its sludge within its own process and therefore produces a thicker sludge not requiring thickening. The overall cost differential is not significant in most cases, however, since Densadeg has a lower overflow rate (40 gpm/sf compared with 60 gpm/sf) and larger footprint (CH2M HILL, 2007b). Since the overall cost of the Actiflo and DensaDeg systems have been found to be similar, only one system was chosen for evaluation for this treatment train. The Actiflo system was selected in order to show the possibility of adding gravity thickeners to the plant layout. Pilot testing should be performed to determine the system best suited for the plant, while providing other benefits such as:

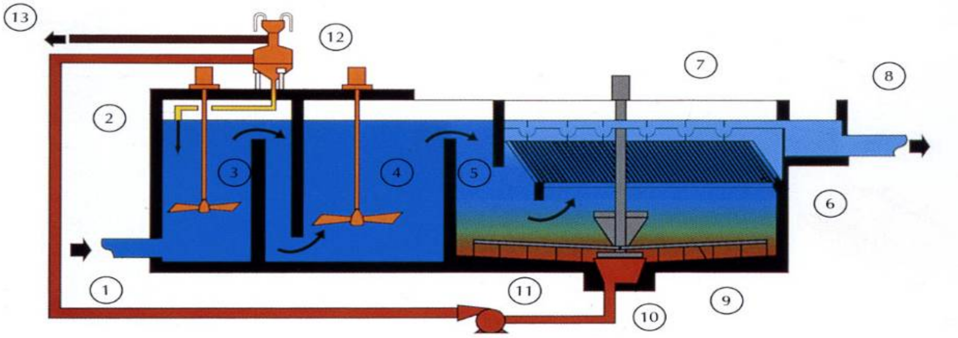
- Identification of influent wastewater constituents that may affect performance of either technology
- Determining suitable chemical dosages for the ballasted flocculation system
- Providing effluent quality information that can be used for design of downstream disinfection processes
- Assessing treatment performance at typical design overflow rates
- Providing better understanding of system operation through pilot testing.

7.1 Process Flow Diagram

In the ballasted flocculation treatment train, wet weather flow passes through bar screening, influent pumps, grit removal, and fine screening before entering the ballasted flocculation system (Exhibit 7-2). A schematic of the Actiflo system is shown in Exhibit 7-1.

Using the numbers in the Exhibit, the wastewater enters at point (1) along with the coagulant (ferric chloride) to the flash mixing zone (3) where microsand is also added (2). Addition of the coagulant enhances flocculation by destabilizing suspended solids in the wastewater. Compartment (4) is a gentle mixing zone where polymer is added to promote formation of strong flocs around the microsand. The flocculated solids flow to compartment (5), the clarification zone. Most of the solids settle at the bottom of this compartment, but this zone also has lamella settling modules (6) to enhance removal of suspended solids that may be present in the wastewater. The solids accumulated at the bottom of the clarification compartment (10) are recycled to a hydrocyclone (12), where the sludge is separated from the microsand. The microsand is recycled back to the flash mixing zone (3), and the sludge leaves the system by stream (13).

EXHIBIT 7-1
Schematic of the ACTIFLO High-Rate Primary Clarifier (scanned from vendor's brochure)



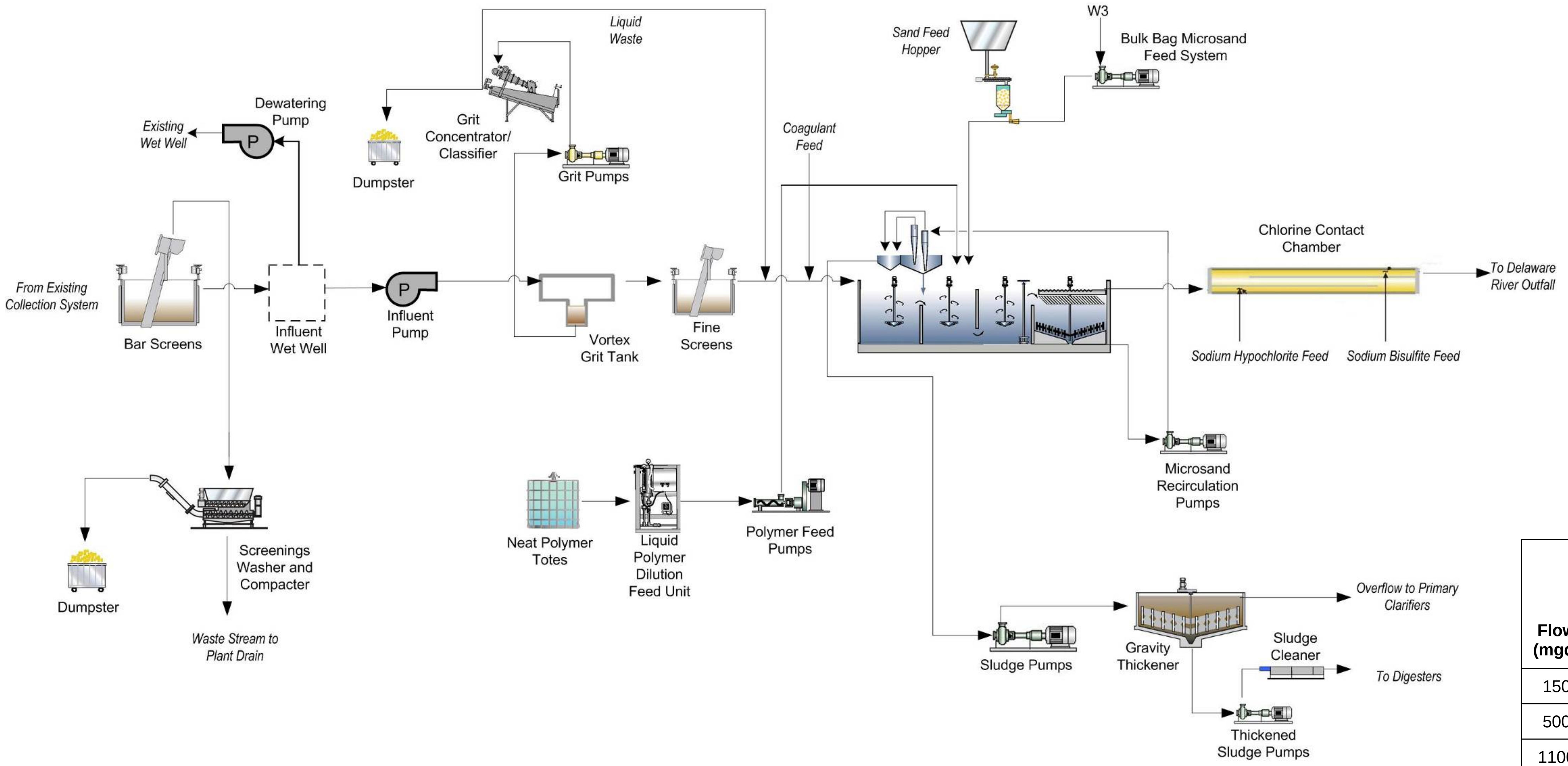
As shown in Exhibit 7-2, the sludge from the ballasted flocculation process is pumped to gravity thickeners to be thickened from 0.3 percent solids to 3-4 percent solids.

7.2 Conceptual Design and Site Layouts

Conceptual designs using the ballasted flocculation system were developed for flow capacities of 150, 500 and 1,100 mgd. The key design parameters are presented in Exhibit 7-2. As seen in the conceptual layouts in Exhibit 7-3, the Fleet auction lot provides adequate space for treating up to 500 mgd. With the adjacent sludge lagoon area, the flow capacity can reach 1500 mgd. However, since the upgraded collection system is not likely to convey more than 1100 mgd, the maximum design point for this train is 1100 mgd. Due to its extremely high surface overflow rate of 60 gpm/sf, ballasted flocculation has minimal space requirements compared to the other alternatives.

EXHIBIT 7-2

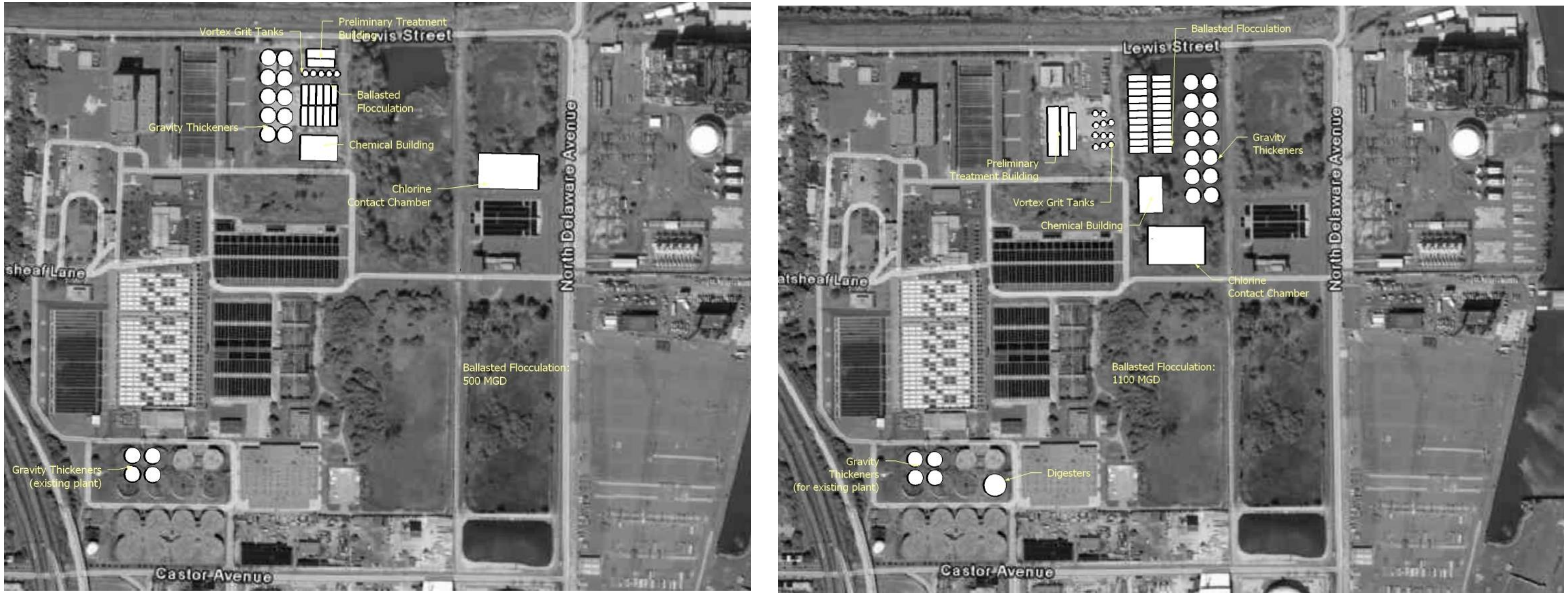
Process Flow Diagram and Key Process Design Parameters for Treatment Train #5: Ballasted Flocculation



Flow (mgd)	Primary Sludge Pumps		Thickened Sludge Pumps		Sludge Prod. (lb/day)	Digesters
	# Duty	# Standby	# Duty	# Standby		# units
150	3	1	4	1	407,759	0
500	10	3	10	3	1,128,134	0
1100	22	6	14	4	1,508,709	1

Flow (Mgd)	Bar Screens # Units	Influent Pumps # Units	Vortex Grit Tank		Fine Screening # Units	Screenings Washer/ Compactor # Units (for bar/fine screening)	Grit Pumps		Grit Concentrator # Units	Grit Classifier # Units	Screenings and Grit Prod. Compacted Volume (Cf/Day)	Ferric Chloride			Liquid Polymer			Sodium Hypochlorite			Sodium Bisulfite			Actiflo	Gravity Thickeners & Sludge Cleaners
			# Units	Dia (Ft)			# Duty	# Standby				Total Storage Vol (Gal)	# Duty Pumps	# Standby Pumps	Total Storage Vol (gal)	# Duty Pumps	# Standby Pumps	Total Storage Vol (Gal)	# Duty Pumps	# Standby Pumps	Total Storage Vol (Gal)	# Duty Pumps	# Standby Pumps	# Trains	# Units
150	2	2	2	32	2	4	2	1	2	1	1,033	157,388	3	1	7,.358	3	1	74,684	1	1	6,226	1	1	3	4
500	5	7	5	32	5	10	5	2	5	2	2,953	435,440	10	3	18,865	10	3	206,626	1	1	11,972	1	1	10	10
1100	11	15	11	32	11	22	11	4	11	4	3,822	582,335	22	6	225,229	22	6	276,331	1	1	16,011	1	1	22	14

EXHIBIT 7-3
Conceptual Layouts and Footprints for Treatment Train #5: Ballasted Flocculation
500 MGD Layout (left), 1100 MGD (right)



Flow (mgd)	PTB	Grit Units	Fine Screening	Actiflo Units	Chemical Building	CCC	Gravity Thickeners	Digesters	TOTAL FOOTPRINT (acres)	Remediation Footprint (acres)
150	41’ x 45’ & 56’ x 39’	32’ (2 units)	37’ x 38’	32’ x 86’ (3 units)	119’ x 100’	88’ x 181’ (4 passes)	80’ (4 units)	-	1.5	NONE
500	106’ x 55’ & 117’ x 39’	32' (5 units)	77’ x 38’	32’ x 86’ (10 units)	141’ x 118’	172’ x 297’ (8 passes)	80' (10 units)	-	4.2	2.3
1100	210’ x 60’ & 232’ x 39’	32' (11 units)	171’ x 38’	32’ x 86’ (22 units)	141’ x 118’	193’ x 291’ (9 passes)	80' (14 units)	115’ (1 unit)	6.4	11.4

7.3 Operational and Technology-Specific Issues

7.3.1 Startup and Shutdown

Ballasted flocculation systems stabilize quickly, with Actiflo taking less than 20 minutes and DensaDeg less than 45 minutes to start producing good quality effluent based on demonstration testing. Infilco Degremont indicated that the DensaDeg process will produce design effluent immediately if left filled with chlorinated plant effluent. However, based on piloting studies, a connection should be provided for discharging wet weather effluent to the head of the existing plant during startup or until ballasted flocculation system performance stabilizes. To facilitate startup, the ballasted flocculation system should also be underloaded initially.

Shutdown can occur at the operator's convenience. Typically, equipment will simply need to be switched off. The hydrocyclones should be pumped down before being turned off. The tanks themselves can either be filled with treated effluent, or drained down. To prevent freezing during cold weather, any system that is not totally enclosed should have a constant flow of water, or be drained down. The cost estimate does not include a building for the ballasted flocculation units since they are able to be effectively operated in an outdoor environment, and the inclusion of a building would add unnecessary capital costs to this alternative.

The advantage of leaving the basins filled with water is that the startup time is substantially reduced and the basins reach their design effluent quality much more quickly. This reduces the volume of partially treated water that must be returned to the existing treatment plant. Running a small flow through the tanks also helps in maintaining equipment, such as the tank mixers. Actiflo's manufacturer recommends leaving the sand in the tanks only if the tanks are filled with effluent. With sand readily available in the tanks, treatment can begin sooner. If the system were fully drained, the sand within the Actiflo system would require removal and disposal to prevent freezing. Upon startup, sand would have to be reintroduced into the treatment flow using the bulk sand feed system. Infilco Degremont indicates that solids should be removed from the DensaDeg system within six hours to prevent septicity. The DensaDeg system can then be left filled with chlorinated plant effluent.

7.3.2 Interaction with Main Plant

During startup, effluent from the ballasted flocculation system will be discharged to the head of the main plant until system performance stabilizes.

Similar to the other treatment trains, recycle flows from the screenings washer/compactor and grit classifier will be conveyed to the ballasted flocculation system with the wet weather treatment train. The overflow streams from the gravity thickeners, however, must be sent to the head of the main plant for distribution across both the wet weather treatment train and the existing plant. Since this treatment train has the highest removal efficiency, it generates the highest sludge and overflow volumes. In addition, the solids content of the sludge is thinner compared to primary clarifier sludge as a result of the cyclones used to separate the ballast from the sludge. The estimated overflow volume is 49 to 108 mgd, depending on the flow capacity of the treatment train.

7.3.3 Impact on plant operations

To simplify routine operation, Actiflo and Densadeg typically have automated routine startup and shutdown sequences with PLC programming and adjustable timers (service interval, tank fill, equipment run, shutdown, and tank drain). However, operator attention will be necessary to monitor or optimize performance, and to confirm successful facility startup. The operators will have the following responsibilities:

- Start the process train
- Monitor coagulant and polymer dose and perform jar tests to optimize chemical dosing.
- Manage the loading of screenings and grit dumpsters.
- Observe equipment operation and contact maintenance if equipment malfunctions.

7.3.4 Other Issues

Foaming – Foaming may occur due to the addition of coagulants and polymer settling aids, and should be investigated in pilot studies. For example, during startup of the Actiflo unit at Lawrence WWTP in Lawrence, Kansas, the observed foaming resulted from the reaction of ferric chloride with biodegradable surfactants in the incoming wastewater. Foaming can be controlled using silica-based defoamers such as Tramfloc 110, Chemco DF, and Neo Solutions NS-8454 at low dosages.

Floc Carryover and Microsand Loss – Floc carryover is an issue for the DensaDeg system that should be investigated through pilot tests. As flows approach the design SOR, sludge densities may decrease, sending large flocs of sludge out in the effluent. These large flocs not only affect effluent quality in terms of TSS and BOD levels, but may also decrease effectiveness of the disinfection process downstream.

Regarding the Actiflo system, a certain degree of microsand loss is expected from normal operation of the system. The manufacturer indicates that about 8 pounds of microsand are lost for each million gallons of wastewater treated. The sand must be replaced for optimal operation of the system. According to information gathered during the team's site visit to the Cincinnati Metropolitan Sewer District, the SSO 700 Facility loses 350 lbs of sand per 15 mg wet weather event. In the conceptual design of this treatment train, adequate storage space was provided in the chemical buildings for 10 day storage of sand. Additionally, the microsand needs to be maintained in the system in case rapid startup is required, and the sand must be prevented from freezing during the winter so that the unit can start up quickly if needed during the cold season. The DensaDeg unit is totally drained when the system is shut down, and no chemical sludge is maintained in the system when it is not in use.

Sludge Concentration - One important difference between Actiflo and Densadeg is the sludge concentration that they produce. Sludge from the DensaDeg system can be four to five times more concentrated than sludge from the Actiflo system. Since the two systems are expected to produce the same mass of sludge, because they operate with similar coagulant dosages, it is expected that the volume of sludge produced in the ACTIFLO system will be four to five times greater than that in the DensaDeg unit. Gravity thickeners have been included in the conceptual design for the Actiflo treatment train to thicken the sludge to 3-4 percent solids. These thickeners may not be necessary if the Densadeg system is chosen.

7.4 Cost Analyses

The estimated capital, O&M, and lifecycle costs for each flow scenario are shown in Exhibit 7-4. Total capital costs and the capital costs per volume treated are also shown in Exhibits 7-5 and 7-6. Estimated O&M costs by category are presented in Exhibit 7-7. As described in the CEPT section, the breakpoint in the O&M costs at 500-mgd is due to the dependence on average flow, rather than peak flow, of the chemical and sludge disposal costs.

A more detailed breakdown of these costs is presented in Attachment NE-2.1.

EXHIBIT 7-4
Cost Summary for Ballasted Flocculation: Treatment Train #4

	Wet Weather Flow (mgd)		
Cost	**150**	**500**	**1100**
Capital Cost ($M)	$195	$527	$1,062
Annual Operations and Maintenance Cost ($M)	$3.0	$7.2	$10.0
Present Value of the Cost ($M)	$242	$639	$1,218

EXHIBIT 7-5
Capital Costs for Treatment Train #4: Ballasted Flocculation
Includes cost to upgrade plant capacity to 650 MGD

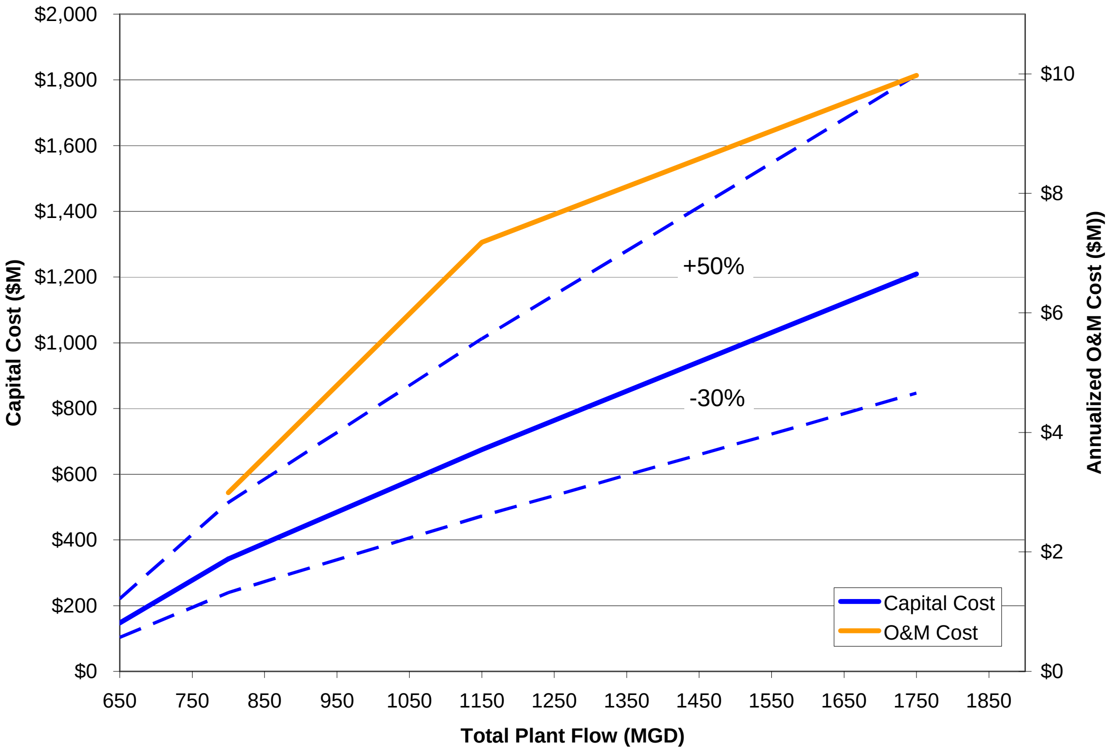


EXHIBIT 7-6
Capital Costs per Gallon Treated for Treatment Train #4: Ballasted Flocculation

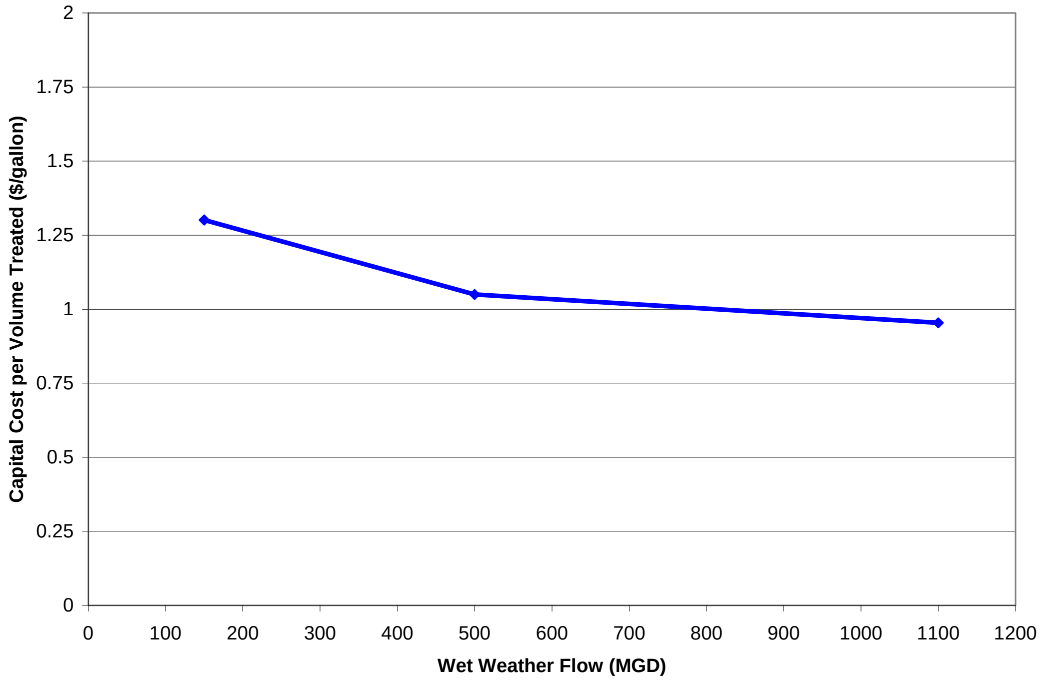
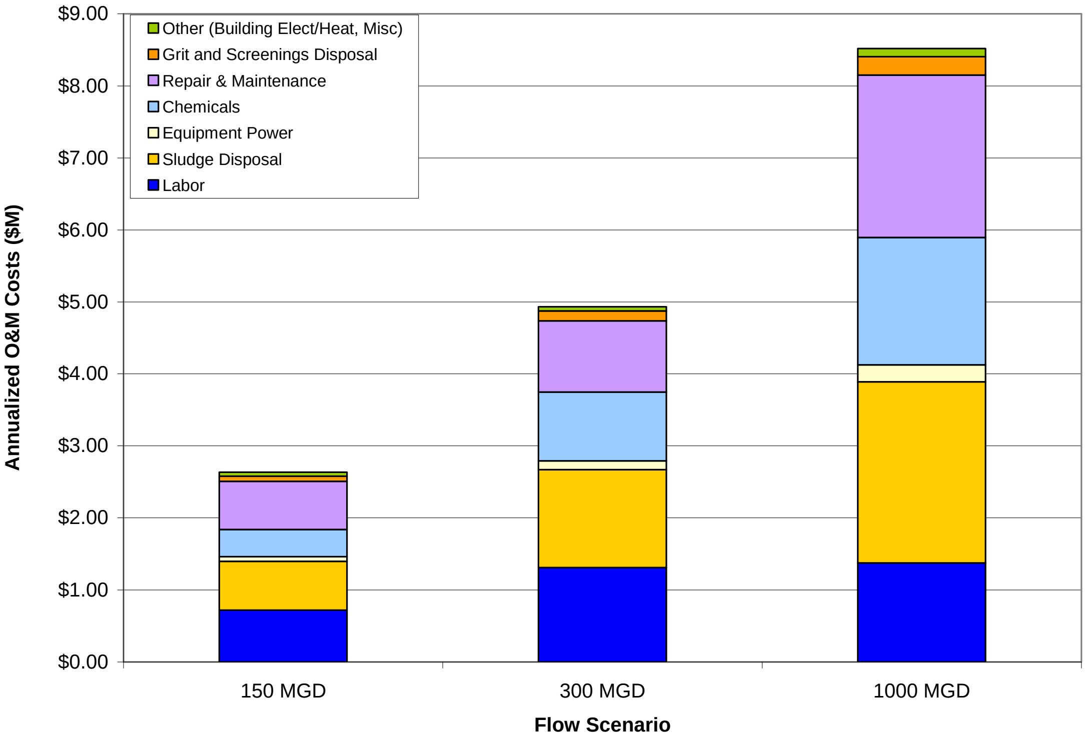


EXHIBIT 7-7
Operations and Maintenance Costs by Category for Treatment Train #4: Ballasted Flocculation



8.0 Alternatives for Optimizing Capital Costs

8.1 Ballasted Flocculation

As mentioned in Section 7, the costs presented for Treatment Train #4, Ballasted Flocculation, are based on the Actiflo system, which is similiar in cost to Densadeg, the other proprietary high rate treatment technology. If the ballasted flocculation treatment train is selected, a cost estimate for the Densadeg system should be developed to examine the cost differential. The main contributions to the cost differential will include:

- **Reduction in number of thickeners** - Densadeg maintains a 3-4 percent sludge thickness for its ballast, compared to the 0.3 percent sludge thickness in the Actiflo system.
- **Increase in footprint** – Densadeg has a 40 gpm/sf loading rate, compared to Actiflo's 60 gpm/sf loading rate.
- **Elimination of fine screening** – Actiflo requires fine screening to protect the hydrocyclones in the system, which separate sand from sludge. Since Densadeg uses sludge only as its ballast, it does not require fine screening upstream.

Implications to operations and maintenance should also be examined between the two systems. For example, Actiflo requires sand as the ballasting agent, which requires storage and maintenance.

8.2 Refined Design Assumptions via Influent Sampling

Influent sampling at the plant during wet weather events will shed light on the wastewater characteristics of the wet weather flow, as well as the flow regime during events. More concrete numbers for influent TSS, BOD, and flow can be used to refine process design parameters, which may lead to a reduction in the size and cost of the treatment trains.

9.0 Comparison of Treatment Alternatives

9.1 Effluent Water Quality

While each flow scenario for each treatment train evaluated above is capable of producing blended effluent concentrations that meet permit limits, the resulting water quality differs widely between different scenarios. The TSS and BOD concentrations of the blended effluent for each treatment train and flow scenario is presented in Exhibit 9-1 and 9-2, respectively.

EXHIBIT 9-1
Blended Effluent TSS Concentrations

		Blended Effluent TSS Concentration (mg/L)								
		Wet Weather Treatment Train Flow (mgd)								
Treatment Train	**Wet Weather Treatment Train Effluent Conc. (mg/L)**	***69***	***150***	***160***	***183****	***300***	***376****	***500***	***1000***	***1100***
#1) Vortex/Swirl Concentrators	221	83			87					
#2) Conventional Clarifiers	142			83			82			
#3) CEPT w/ Conventional Clarifiers	63		67			66			65	
#4) Ballasted Flocculation	30		61					51		44

Notes: Based on the 95th percentile wet weather TSS concentration of 68 mg/L and a maximum of 650 MGD through the existing plant. Allowable daily blended effluent TSS concentration on wet weather days is 99 mg/L to meet monthly TSS permit limits.

*As discussed in Section 3.1, the Vortex-183 mgd and CEPT-376 mgd flow scenarios are only allowable assuming no secondary bypass at the plant. Thus, these concentrations assume a 95th percentile wet weather TSS concentration of 31 mg/L and a maximum of 435 MGD through the existing plant.

EXHIBIT 9-2
Blended Effluent cBOD Concentrations

		Blended Effluent cBOD Concentration (mg/L)								
		Wet Weather Treatment Train Flow (mgd)								
Treatment Train	**Wet Weather Treatment Train Effluent Conc. (mg/L)**	***69***	***150***	***160***	***183****	***300***	***376****	***500***	***1000***	***1100***
#1) Vortex/Swirl Concentrators	117	37			49					
#2) Conventional Clarifiers	91			41			53			
#3) CEPT w/ Conventional Clarifiers	66		36			41			51	
#4) Ballasted Flocculation	55		34					40		45

Notes: Based on the 95th percentile wet weather cBOD concentration of 29 mg/L and a maximum of 650 MGD through the existing plant.

*As discussed in Section 3.1, the Vortex-183 mgd and CEPT-376 mgd flow scenarios are only allowable assuming no secondary bypass at the plant. Thus, these concentrations assume a 95th percentile wet weather cBOD concentration of 20 mg/L and a maximum of 435 MGD through the existing plant.

As described in Section 3.1, Trains #1 and #2, Vortex/Swirl and Conventional Clarification, are limited in flow by permit conditions. Trains #3 and #4, CEPT and Ballasted Flocculation, are considered unlimited in flow if the number of wet weather days is less than 7 days per month. To illustrate the risk of exceeding permit limits at each flow scenario, Exhibit 9-3 presents the maximum number of days that the wet weather treatment train can operate at its maximum capacity without exceeding monthly TSS permit limits. The ballasted flocculation train is unlimited in frequency of operation since its effluent quality (30 mg/L TSS) surpasses permit limits without blending. The CEPT train can operate more frequently at higher flows since its effluent quality (63 mg/L TSS) is slightly better than the quality from the conventional secondary treatment plant (68 mg/L TSS)

A frequency plot of the estimated number of wet weather events per month is shown in Exhibit 9-4 (Myers, 2008b). As shown, wet weather events have occurred at a historical maximum of 15 per month. It should be noted that the wet weather event referred to in this plot occurs whenever rainfall exceeds 0.1 inch, and does not necessarily correspond to operation of the new wet weather treatment train. If the flow does not exceed the capacity of the conventional plant, the wet weather treatment train will not come online. Thus, the new wet weather treatment train is expected to operate less than 15 times per month.

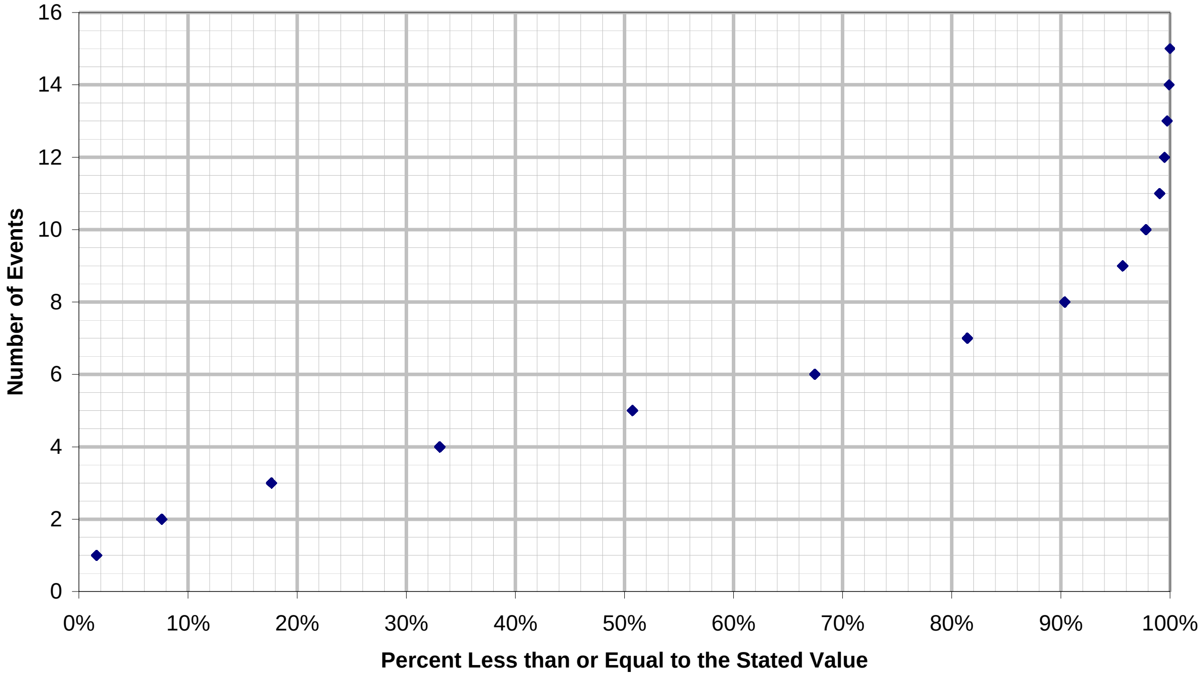
It should be noted that a continuous simulation-based approach would give a more accurate estimate of risk, and more detailed analyses should be performed during the facility planning and design phases.

EXHIBIT 9-3
Allowable Number of Operating Days of Wet Weather Treatment Train

	Maximum Allowable Number of Operating Days per Month(1)								
	Wet Weather Treatment Train Flow (mgd)								
Treatment Train	***69***	***150***	***160***	***183****	***300***	***376****	***500***	***1000***	***1100***
#1) Vortex/Swirl Concentrators	7			7					
#2) Conventional Clarifiers			7			7			
#3) CEPT w/ Conventional Clarifiers		7			8			9	
#4) Ballasted Flocculation	UNLIMITED								

Notes:
(1) Allowable number of operating days without exceeding permit limits for monthly TSS concentrations. Assumes entire plant operates at maximum capacity during every wet weather event.

EXHIBIT 9-4
Cumulative Frequency Plot of the Number of Wet Weather Events per Month



Notes: Based on Philadelphia International Airport NOAA Rain Gauge Hourly Data from1902-2000. Minimum Interevent Time = 4 hrs, Minimum Storm = 0.1 Inches (provided by CDM)

9.2 Capital, O&M and Life-Cycle Costs

As shown in Exhibit 9-5, the capital costs for Trains #2 - #4 track each other very closely, with CEPT being slightly more expensive. Train #1, the vortex/swirl, appears least expensive and most cost effective as flows increase (Exhibit 9-6). Train #3, CEPT, appears slightly less cost-effective than Train #4, Ballasted Flocculation, due to greater cost for piles for its larger footprint.

The comparison of O&M costs for each treatment train is shown in Exhibit 9-7. As expected, the O&M costs for vortex swirls and conventional clarifiers, which do not require chemical settling aids, are the lowest. Ballasted Flocculation has the highest O&M costs due to the use of chemicals and the complexity of its system.

Taking construction, non-construction, and O&M costs into consideration, Exhibit 9-8 shows the present value of the total cost of each wet weather treatment train. This graph suggests that there is negligible cost difference between Train #3, CEPT, and Train #4, Ballasted Flocculation at this plant. As expected, Trains #1 and #2 are least expensive due to its low chemical usage and minimal O&M costs.

EXHIBIT 9-5
Comparison of Capital Costs for All Treatment Trains
Includes cost to upgrade plant capacity to 650 MGD

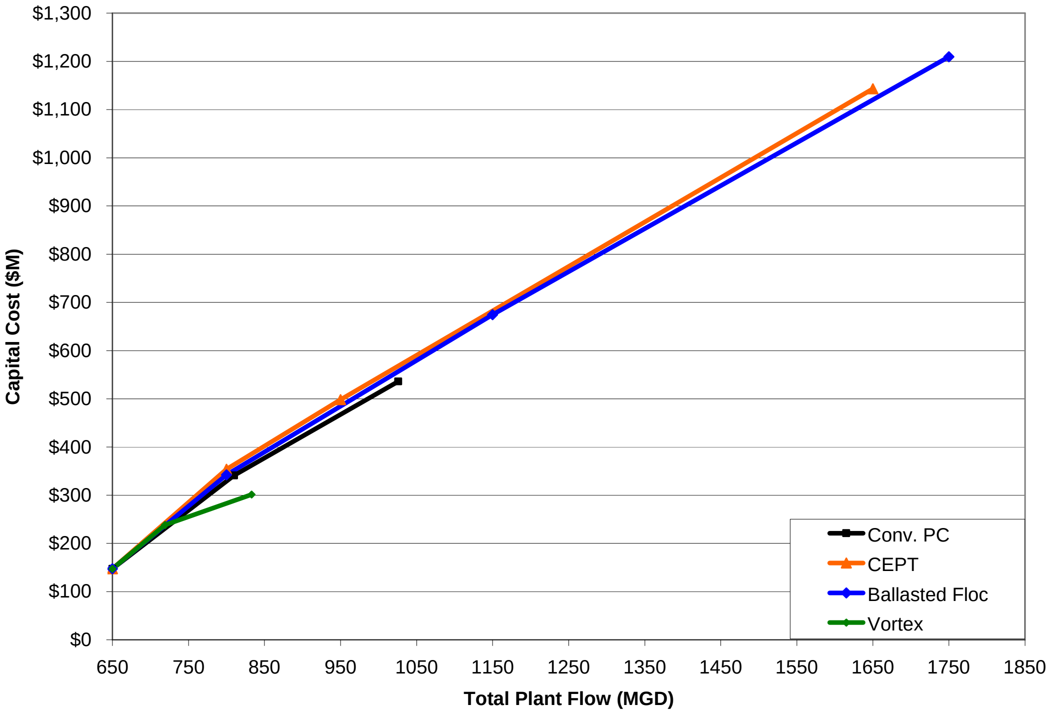


EXHIBIT 9-6
Comparison of Cost Effectiveness for all Treatment Trains

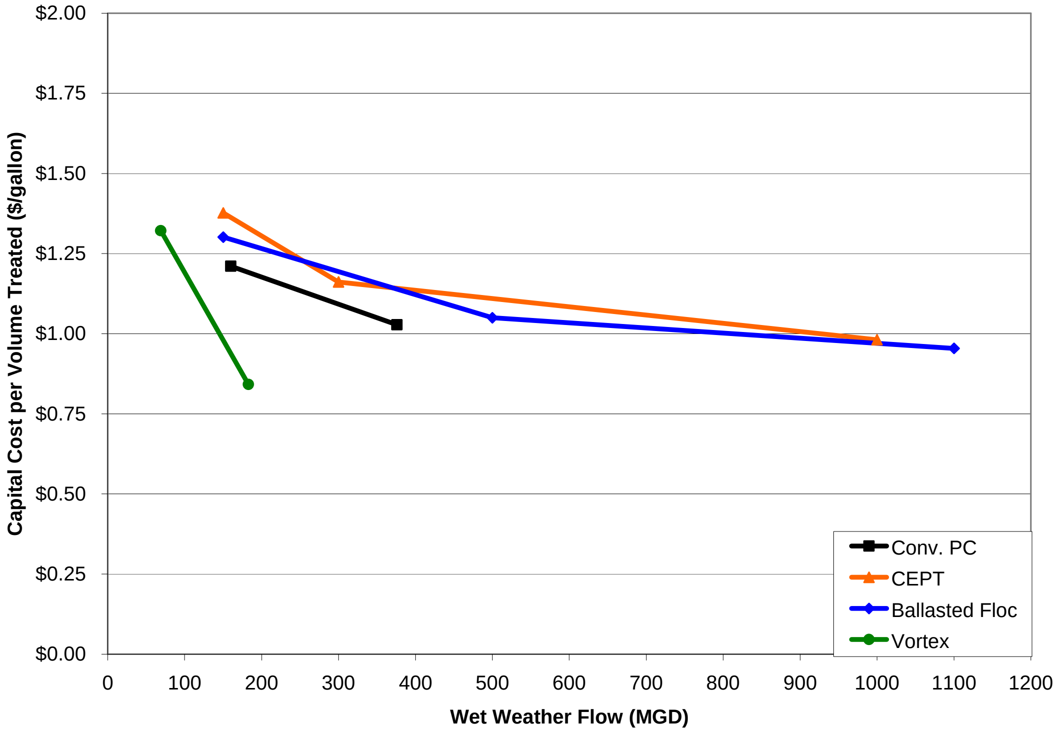


EXHIBIT 9-7
Comparison of Operations and Maintenance Costs for all Treatment Trains

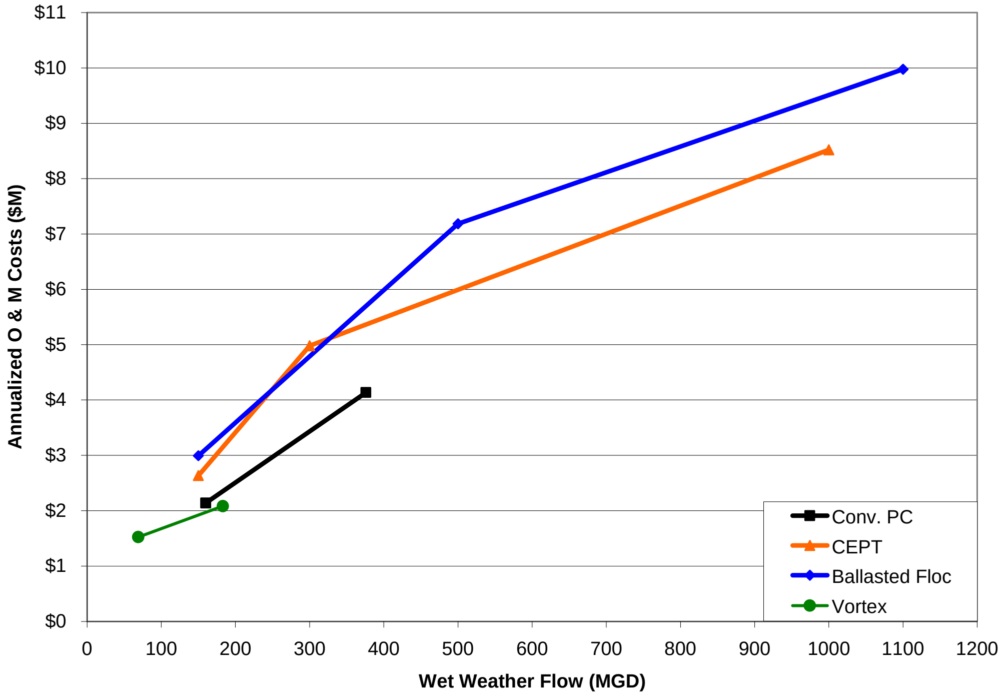
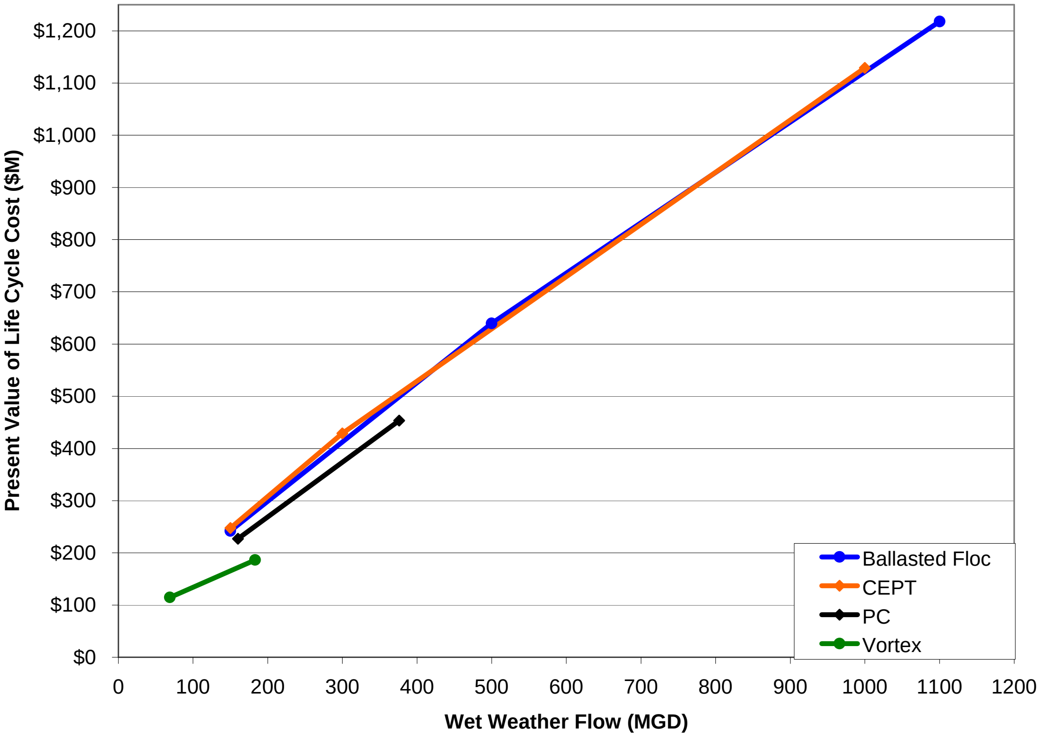


EXHIBIT 9-8
Comparison of Life-Cycle Costs for all Treatment Trains



9.3 Overall Comparison

Aside from capital, O&M, and lifecycle costs, there are numerous other criteria by which the treatment trains should be evaluated, including:

- Reliability of the system
- Community and environmental impacts or perception
- Ability to handle large variations in flow
- Land requirements
- Constructability
- Requirements for maintenance and operator attention
- Sustainability

These evaluation criteria were discussed in Workshop No. 2B, and are presented in TM-SE2 for various wet weather treatment technologies (CH2M HILL, 2008a). Several key advantages and disadvantages of Treatment Trains #1 - #4, as evaluated in this report, are described in Exhibit 9-9.

EXHIBIT 9-9
Summary of Pros and Cons for Each Wet Weather Treatment Train

Treatment Train	Pros	Cons
Train #1: Vortex/Swirl Concentrators	• Simple operation • Low maintenance requirements – no moving parts	• Only cost competitive at high loading rates and low removal efficiencies. • Maximum design flow may decrease if the assumed number of operating days is greater than 7.
Train #2: Conventional Clarifiers	• Simple operation • Same technology as existing plant –operators familiar with equipment	• Space limited • Maximum design flow may decrease if the assumed number of operating days is greater than 7.
Train #3: CEPT	• Lower chlorine dose possible due to high TSS removal efficiencies • May be operated as Conventional Clarifiers if chemicals found to be unnecessary	• Operators unfamiliar with technology • Space limited • Uses two additional chemical systems for coagulation and flocculation • Maximum design flow may decrease if the assumed number of operating days is greater than 9.
Train #4: Ballasted Flocculation	• Can treat up to 1500 mgd with available land on site • Highest removal efficiencies • Unlimited number of operating days per month • Lower chlorine dose possible due to high TSS removal efficiencies	• Operators unfamiliar with technology • Most labor intensive and complex system • Uses two additional chemical systems for coagulation and flocculation

The costs for wet weather treatment at the NE WPCP should be analyzed with the costs of other wet weather treatment alternatives, such as improvements in the collection system, to determine which treatment train alternatives and flow regimes should be evaluated further. Treatment trains that are selected for further evaluation should undergo more detailed design and costing methods, water quality sampling, and bench and pilot scale testing, so that removal efficiencies, land requirements, capital costs, and O&M costs can be further refined.

10.0 References

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Attachment NE-2.1

Breakdown of Capital and O&M Costs

NE WPCP Wet Weather Treatment Train Alternatives: Capital Cost Estimates

Train	Train #1: Vortex/Swirl		Train #2: Conventional Clarifiers		Train #3: CEPT			Train #4: Ballasted Flocculation		
Flow (mgd)	**69**	**183**	**160**	**376**	**150**	**300**	**1000**	**150**	**500**	**1100**
Influent Pump Station	$3,775,534	$5,825,465	$5,715,245	$11,155,330	$4,193,296	$7,848,029	$25,723,707	$4,193,296	$13,177,903	$27,627,105
Bar Screens, Grit Removal, and Fine Screens	$2,124,734	$3,518,520	$4,305,848	$7,963,022	$4,306,977	$6,027,362	$19,666,033	$6,805,293	$15,334,981	$34,703,082
Vortex Swirl	$4,544,219	$9,088,438	$0	$0	$0	$0	$0	$0	$0	$0
Flocculation Tanks	$0	$0	$0	$0	$3,044,901	$4,801,275	$10,067,713	$0	$0	$0
Primary Clarifiers	$0	$0	$8,593,891	$20,599,909	$7,205,748	$12,520,587	$41,843,098	$0	$0	$0
Actiflo System	$0	$0	$0	$0	$0	$0	$0	$10,562,312	$34,329,380	$75,008,712
Chemical Feed	$825,578	$1,315,461	$1,277,089	$2,268,957	$3,248,382	$5,093,207	$7,920,216	$3,457,211	$6,685,702	$8,641,618
Chlorine Contact Chamber (1)	$1,187,531	$2,764,885	$2,454,069	$5,350,790	$2,326,943	$4,314,045	$6,888,494	$2,326,943	$6,888,494	$7,525,878
Gravity Thickeners	$1,722,904	$3,491,350	$2,460,577	$4,035,149	$3,688,352	$7,347,645	$14,659,263	$4,720,858	$12,401,511	$17,179,717
Yard Piping (large)	$1,576,038	$1,608,050	$3,496,708	$5,681,538	$3,529,489	$5,502,651	$16,016,916	$3,516,500	$7,840,832	$18,796,161
Digesters	$0	$0	$0	$0	$0	$0	$6,501,580	$0	$0	$6,568,306
Subtotal Project Cost	$15,756,538	$27,612,169	$28,303,427	$57,054,695	$31,544,088	$53,454,801	$149,287,020	$35,582,413	$96,658,803	$196,050,579
Additional Project Costs:										
General Demolition	$157,565	$276,122	$283,034	$570,547	$315,441	$534,548	$1,492,870	$355,824	$966,588	$1,960,506
Overall Sitework	$1,260,523	$2,208,974	$2,264,274	$4,564,376	$2,523,527	$4,276,384	$11,942,962	$2,846,593	$7,732,704	$15,684,046
Plant Computer System	$1,339,306	$2,347,034	$2,405,791	$4,849,649	$2,681,247	$4,543,658	$12,689,397	$3,024,505	$8,215,998	$16,664,299
Yard Electrical	$1,260,523	$2,208,974	$2,264,274	$4,564,376	$2,523,527	$4,276,384	$11,942,962	$2,846,593	$7,732,704	$15,684,046
Yard Piping	$787,827	$1,380,608	$1,415,171	$2,852,735	$1,577,204	$2,672,740	$7,464,351	$1,779,121	$4,832,940	$9,802,529
Subtotal with Additional Project Costs	$20,562,282	$36,033,881	$36,935,972	$74,456,377	$41,165,035	$69,758,515	$194,819,561	$46,435,049	$126,139,738	$255,846,006
Subtotal with Contractor Markups (1)	$31,171,135	$54,625,111	$55,992,625	$112,871,214	$62,403,620	$105,749,549	$295,334,278	$70,392,632	$191,219,959	$387,846,554
Subtotal with Escalation (2)	$37,343,019	$66,205,634	$67,471,114	$138,267,237	$75,196,362	$128,802,951	$378,618,545	$84,823,122	$236,921,529	$497,219,282
Subtotal with Local Adjustment Factor (3)	$43,019,158	$76,268,891	$77,726,723	$159,283,857	$86,626,209	$148,381,000	$436,168,564	$97,716,236	$272,933,602	$572,796,613
Dewatering	$236,348	$414,183	$424,551	$855,820	$473,161	$801,822	$2,239,305	$533,736	$1,449,882	$2,940,759
Structural Piles	$17,721,821	$26,324,595	$51,392,989	$98,281,523	$51,073,762	$83,840,011	$217,557,438	$32,311,163	$76,635,890	$126,090,858
Subtotal - Construction Cost, including Market Adjustment Factor (4)	**$70,123,927**	**$118,458,818**	**$148,975,903**	**$297,184,381**	**$158,899,102**	**$267,976,257**	**$754,360,103**	**$150,145,305**	**$403,672,280**	**$807,102,464**
Remediation	$0	$0	$0	$2,591,727	$0	$2,591,727	$15,356,115	$0	$2,591,727	$13,000,000
Total Capital Cost (with non construction costs)	**$91,161,105**	**$153,996,464**	**$193,668,674**	**$388,931,422**	**$206,568,832**	**$350,960,861**	**$996,024,249**	**$195,188,897**	**$527,365,691**	**$1,062,233,203**
Total Capital Cost ($M)	$91	$154	$194	$389	$207	$351	$996	$195	$527	$1,062
.+50% Capital Cost ($M)	$137	$231	$291	$583	$310	$526	$1,494	$293	$791	$1,593
.-30% Capital Cost ($M)	$64	$108	$136	$272	$145	$246	$697	$137	$2	$744
Cost Efficiency ($/gallon)	**$1.32**	**$0.84**	**$1.21**	**$1.03**	**$1.38**	**$1.16**	**$0.98**	**$1.30**	**$1.05**	**$0.95**

Notes:
1. Contractor markups - use 1.516 multiplier (see TM-NE2 Section 3.3)
2. Escalation - multiplier depends on duration of construction (see Exhibit 4-7 in TM-NE2 Section 3.3)
3. Local Adjustment Factor - use 1.152 multiplier (see TM-NE2 Section 3.3)
4. Market Adjustment Factor - use 1.15 multiplier (see TM-NE2 Section 3.3)
5. Non-construction costs - use 1.3 multiplier (see TM-NE2 Section 3.3)

NE WPCP Wet Weather Treatment Train Alternatives: Operations and Maintenance Cost Estimates (1)

	Flow (mgd)	***Labor***	***Sludge Disposal***	***Equipment Power (2)***	***Building Electrical & Heating***	***Chemicals***	***Repair & Maintenance***	***Grit and Screenings Disposal***	***Other (3)***	***Total***	***Horsepower requirements (HP)***
Train #1: Vortex/Swirls	69	$718,712	$95,734	$63,064	$1,570	$54,376	$507,250	$31,737	$50,819	$1,523,263	1,632
	183	$718,712	$253,902	$98,567	$2,622	$144,216	$730,715	$84,173	$50,819	$2,083,727	2,550
Train #2: Conventional Clarifiers	160	$718,712	$406,984	$87,585	$2,562	$126,090	$670,820	$73,594	$50,819	$2,137,167	2,266
	376	$1,311,933	$956,412	$174,523	$4,440	$296,313	$1,106,862	$183,525	$101,639	$4,135,647	4,515
Train #3: CEPT	150	$718,712	$679,707	$63,365	$4,170	$378,458	$669,393	$68,994	$50,819	$2,633,619	1,639
	300	$1,311,933	$1,359,414	$121,720	$6,384	$954,216	$988,988	$137,989	$101,639	$4,982,284	3,149
	1000	$1,374,679	$2,514,917	$237,786	$11,614	$1,765,300	$2,256,985	$255,279	$101,639	$8,518,198	11,084
Train #5: Ballasted Flocculation	150	$718,712	$764,671	$84,081	$4,895	$478,742	$808,568	$82,642	$50,819	$2,993,130	2,175
	500	$1,311,933	$2,115,589	$289,565	$8,698	$1,324,519	$1,796,046	$236,194	$101,639	$7,184,182	7,491
	1100	$1,374,679	$2,829,281	$319,038	$13,667	$1,771,345	$3,260,931	$305,774	$101,639	$9,976,354	16,359

Notes:

1. All O&M costs are annualized costs based on escalation through a 30-year period. For average flows, see Section 3.2.1 in TM-NE2
2. Power costs are estimated based on the total horsepower requirements and the average-to-max flow ratio.
3. "Other" costs cover miscellaneous costs for vehicles, lab tests, office equipment, etc.

Percentage of Costs by Category

	Flow (mgd)	***Labor***	***Sludge Disposal***	***Equipment Power (2)***	***Building Electrical & Heating***	***Chemicals***	***Repair & Maintenance***	***Grit and Screenings Disposal***	***Other (3)***
Train #1: Vortex/Swirls	69	47.2%	6.3%	4.1%	0.1%	3.6%	33.3%	2.1%	3.3%
	183	34.5%	12.2%	4.7%	0.1%	6.9%	35.1%	4.0%	2.4%
Train #2: Conventional Clarifiers	160	33.6%	19.0%	4.1%	0.1%	5.9%	31.4%	3.4%	2.4%
	376	31.7%	23.1%	4.2%	0.1%	7.2%	26.8%	4.4%	2.5%
Train #3: CEPT	150	27.3%	25.8%	2.4%	0.2%	14.4%	25.4%	2.6%	1.9%
	300	26.3%	27.3%	2.4%	0.1%	19.2%	19.9%	2.8%	2.0%
	1000	16.1%	29.5%	2.8%	0.1%	20.7%	26.5%	3.0%	1.2%
Train #5: Ballasted Flocculation	150	24.0%	25.5%	2.8%	0.2%	16.0%	27.0%	2.8%	1.7%
	500	18.3%	29.4%	4.0%	0.1%	18.4%	25.0%	3.3%	1.4%
	1100	13.8%	28.4%	3.2%	0.1%	17.8%	32.7%	3.1%	1.0%

Supplemental Documentation
Volume 10

Analysis of Wet Weather Treatment Alternatives for Southeast WPCP

Updated: September 1, 2009

Final Tech Memo

Wet Weather Treatment Alternatives at Northeast, Southeast and Southwest WPCPs

SE3: Analysis of Wet Weather Treatment Alternatives for Southeast WPCP

Prepared for

Philadelphia Water Department

Philadelphia, PA

March 2009

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Suite 4400
Philadelphia, PA 1910

Executive Summary

Background and Project Summary

As part of the series of memoranda prepared for the Philadelphia Water Department's (PWD) Combined Sewer Overflow (CSO) Long Term Control Plan (LTCP) update, this report presents the conceptual design and cost analyses for five wet weather treatment alternatives for the Southeast Water Pollution Control Plant (SE WPCP). The wet weather treatment technologies for the SE WPCP evaluated in this report are as follows:

1. Vortex Swirl Concentrators (at low and high loading rates)
2. Conventional Clarifiers
3. Chemically Enhanced Primary Treatment (CEPT) with Conventional Clarifiers
4. CEPT with Plate Settlers (includes fine screening)
5. Ballasted Flocculation (includes fine screening)

Conceptual treatment trains were developed for each treatment technology at various wet weather flows ranging from 80 million gallons per day (mgd) to 1200 mgd and cost curves for capital, operations and maintenance (O&M), and lifecycle costs were generated for each treatment train alternative.

In order to increase the flow capacity of the SE WPCP for wet weather conditions, the potential of maximizing flow through the existing plant was evaluated. According to stress testing results, the SE WPCP currently has a firm capacity of 240 mgd (CH2M HILL, 2001). With several process and hydraulic modifications, the SE WPCP's firm capacity can potentially reach 330 mgd. The necessary improvements to achieve this flow were identified in the Stress Testing Report and are based on results of stress tests on unit processes, long-term monitoring of the plant, hydraulic modeling, and input from SE WPCP plant staff.

In sizing the wet weather treatment trains, it was assumed that the upgrades proposed in the Stress Testing Report and discussed in this report will have been completed, increasing the plant's capacity to a minimum of 330 mgd. Thus, the baseline cost that is used in the wet weather treatment train cost estimates is $48.1, which is reflected in the cost curves for each treatment train.

To expand the flow capacity of SE WPCP beyond 330 mgd for the treatment of wet weather flows, a separate wet weather treatment train will be required. Wet weather flows in excess of 330 mgd will be diverted to one of the new treatment trains, listed above, eventually blending with effluent from the existing plant. Conceptual designs and cost estimates were performed for each treatment train at various design flows.

Design Flows

The maximum allowable flow through each wet weather treatment train is a function of its removal efficiency, the achievable effluent concentration after blending, and the plant's continued ability to meet NPDES permit limits for weekly and monthly TSS and BOD concentrations. With the exception of the vortex/swirl train at high loading rates, the flows through the candidate wet weather treatment trains were unlimited by permit requirements, assuming that the wet weather treatment facility operates for no more than seven days per month. Other design flow points were selected based on the existing collection system capacity, the existing outfall conduit capacity, and limits of available land on site and are indicated in the Exhibit ES-1.

EXHIBIT ES-1
Design Flows Evaluated for each Wet Weather Treatment Train

Treatment Train	Design Flows Evaluated (mgd)
#1) Vortex/Swirl Concentrators	
High Loading Rate:	80, 200, 380
Low Loading Rate:	80, 200, 900
#2) Conventional Clarifiers	80, 200, 540, 900
#3) CEPT w/ Conventional Clarifiers	80, 200, 470, 900
#4) CEPT w/ Plate Settlers	80, 200, 900
#5) Ballasted Flocculation	80, 200, 900, 1200

Comparison of Treatment Alternatives

Effluent Water Quality

While each flow scenario for each treatment train evaluated is sized to produce blended effluent concentrations compliant with permit limits, the resulting water quality differs widely between different scenarios. The TSS and BOD concentrations of the blended effluent for each treatment train and flow scenario is presented under Section 10 in Exhibits 10-1 and 10-2, respectively. In general, ballasted flocculation achieves the lowest TSS and BOD concentrations after treatment and can operate an unlimited number of times during the month and continue to meet permit limits.

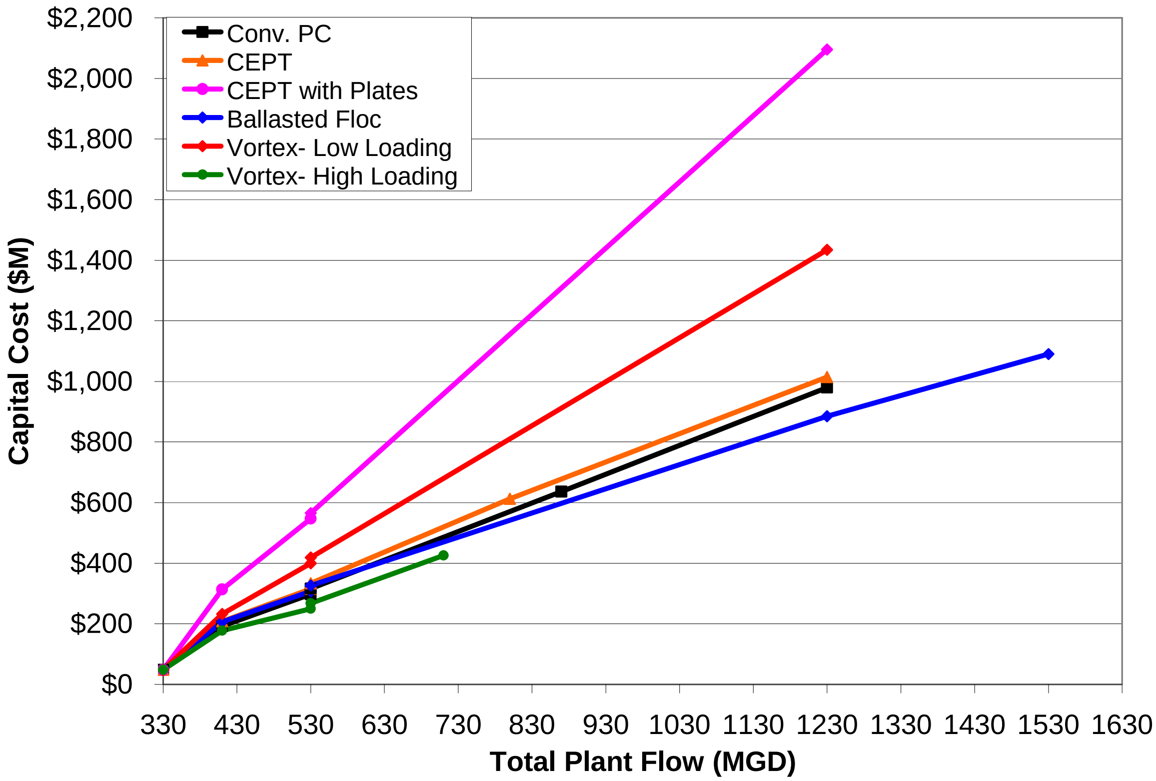
Capital and O&M Costs

The capital cost estimates for the five treatment trains are shown in Exhibit ES-2. Train #4, CEPT with Plates, is the most expensive, followed by Train #1, vortex/swirl at low loading rates. Trains #2, 3, and 5 appear to have similar costs throughout the entire flow range, with Train 5 being slightly less costly. Translated into a capital cost per volume treated, all trains appear to become more cost effective as flow capacity increases (Exhibit ES-3).

The comparison of O&M costs for each treatment train is shown in Exhibit ES-4. As expected, the O&M costs are lowest for vortex swirls at high loading and conventional clarifiers, which do not require chemical settling aids. Vortex swirls at low loading rates has the highest O&M costs for repair and maintenance of the large number of vortex units and gravity thickeners required.

Taking construction, non-construction, and O&M costs into consideration, Exhibit ES-5 shows the present value of the total cost of each wet weather treatment train. Train #4, CEPT with Plates, remains most costly since it requires the highest capital and O&M costs. Train #1, vortex/swirl concentrators, appears to be least costly from the life-cycle cost perspective, especially at lower flows. This is due to its low chemical usage and minimal operations and maintenance needs.

EXHIBIT ES-2
Comparison of Capital Costs for All Treatment Trains



Note: Capital cost presented includes cost of improvements recommended in the Stress Testing Report ($48.1M). Total plant flow includes flow from both the conventional plant and the wet weather treatment facility.

EXHIBIT ES-3
Comparison of Capital Cost Effectiveness for all Treatment Trains

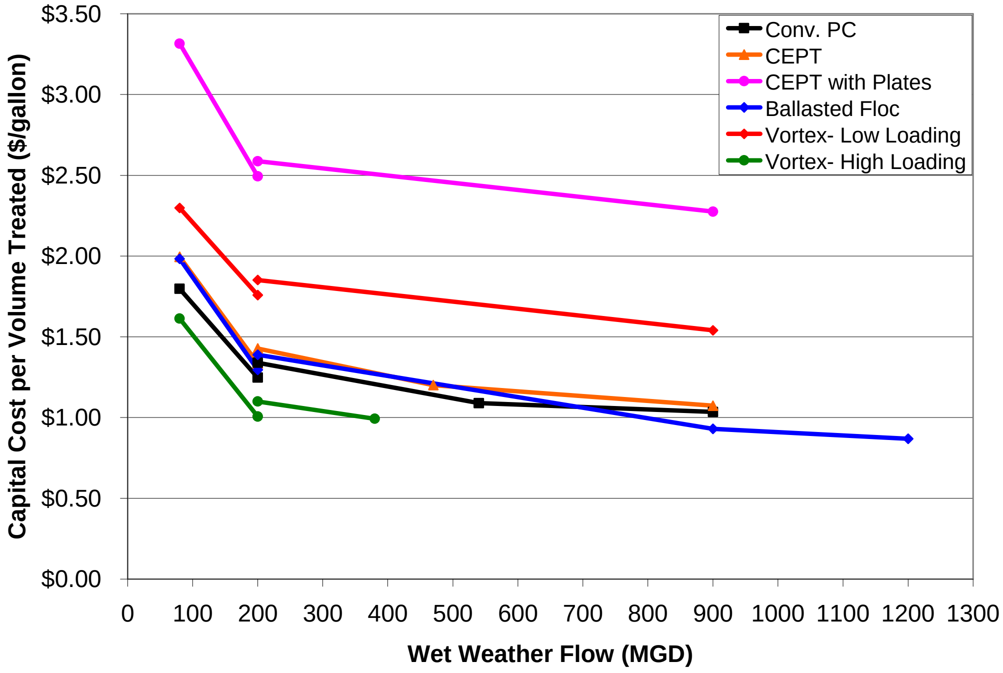


EXHIBIT ES-4
Comparison of Operations and Maintenance Costs for all Treatment Trains

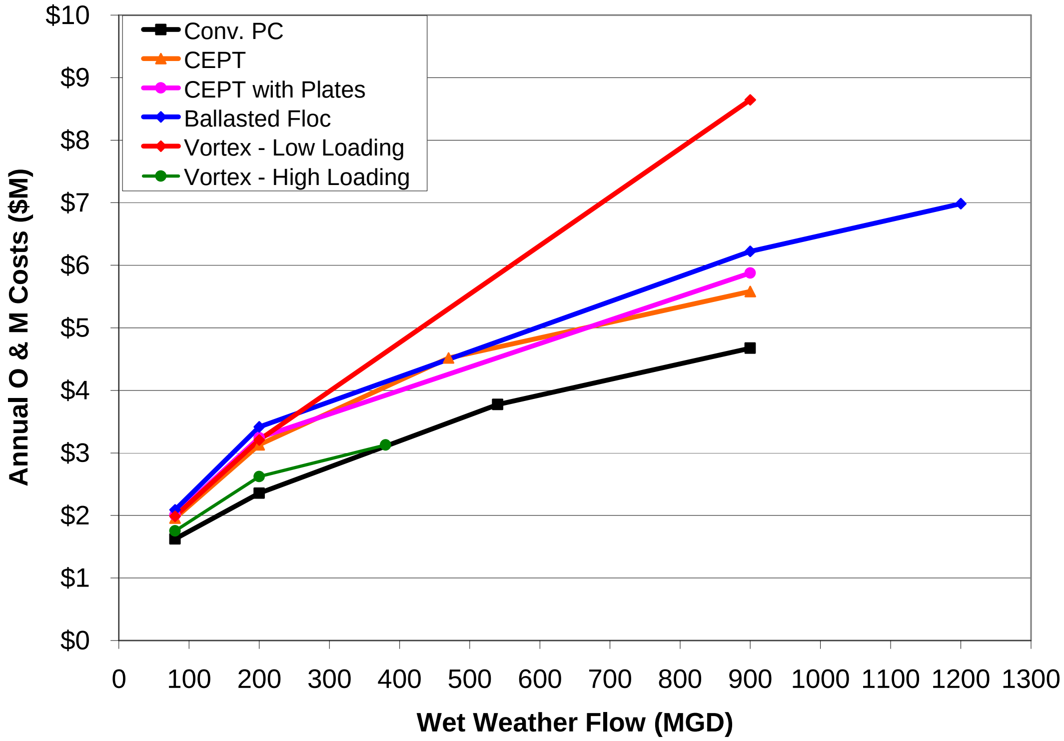
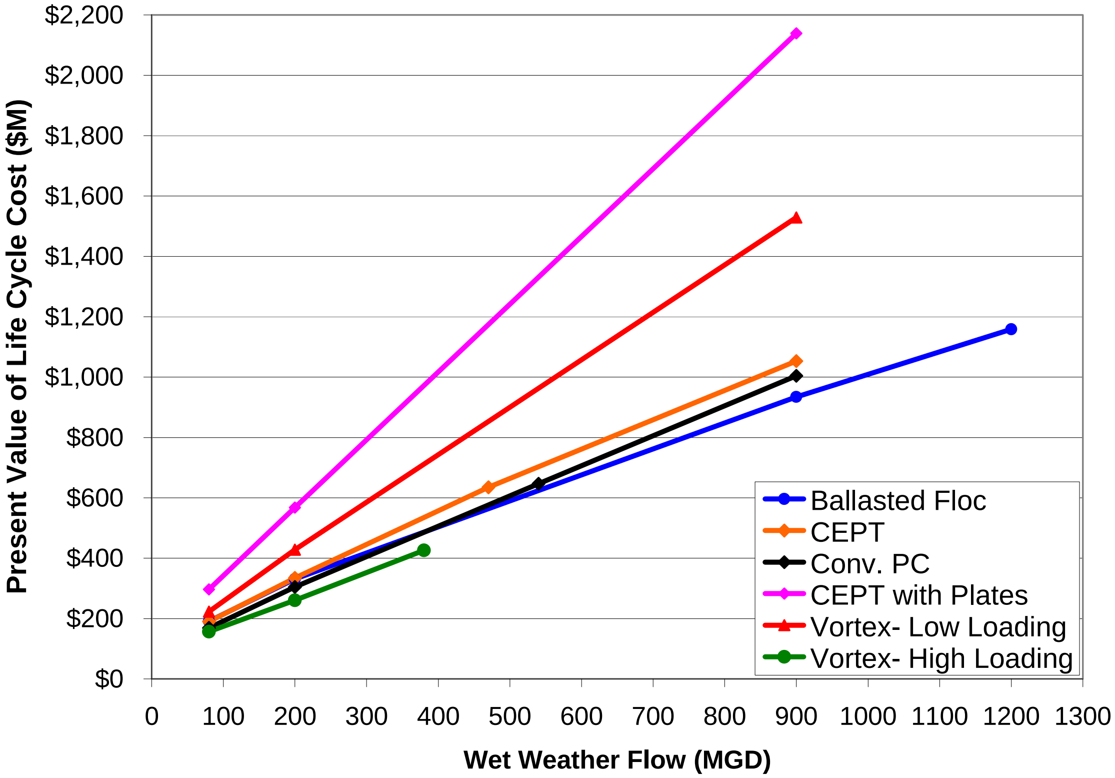


EXHIBIT ES-5

Comparison of Life-Cycle Costs for all Treatment Trains



Overall Comparison

Aside from capital, O&M, and lifecycle costs, there are numerous other criteria by which the treatment trains should be evaluated, including:

- Reliability of the system
- Community and environmental impacts or perception
- Ability to handle large variations in flow
- Land requirements
- Constructability
- Requirements for maintenance and operator attention
- Sustainability

These evaluation criteria were discussed in Workshop No. 2B, and are presented in TM-SE2 for various wet weather treatment technologies (CH2M HILL, 2008). The main advantages and disadvantages for Treatment Trains #1 - #5, as evaluated in this report, are described in Exhibit ES-6.

EXHIBIT ES-6
Summary of Pros and Cons for Each Wet Weather Treatment Train

Treatment Train	Pros	Cons
Train #1: Vortex/Swirl Concentrators	• Simple operation • Low maintenance requirements – no moving parts	• Only cost competitive at high loading rates and low removal efficiencies. • Maximum design flow may decrease if the assumed number of operating days is greater than 7.
Train #2: Conventional Clarifiers	• Simple operation • Same technology as existing plant –operators familiar with equipment	• Space limited • May exceed instantaneous blended effluent BOD concentration at high flows • Maximum design flow may decrease if the assumed number of operating days is greater than 7.
Train #3: CEPT	• Lower chlorine dose possible due to high TSS removal efficiencies	• Operators unfamiliar with technology • Space limited • Uses chemicals • Can treat less flow on existing site than conventional clarifiers • Operators unfamiliar with technology
Train #4: CEPT with Plates	• Can treat 900 mgd with available land on site • Lower chlorine dose possible due to high TSS removal efficiencies • Unlimited number of operating days per month	• High capital and O&M costs • Operators unfamiliar with technology • Labor intensive to clean plates • Uses chemicals
Train #5: Ballasted Flocculation	• Can treat up to 1200 mgd with available land on site • Highest removal efficiencies • Unlimited number of operating days per month • Lower chlorine dose possible due to high TSS removal efficiencies	• Operators unfamiliar with technology • Second most labor intensive • Uses chemicals

The costs for wet weather treatment at the SE WPCP should be analyzed with the costs of other wet weather treatment alternatives, such as improvements in the collection system, to determine which treatment train alternatives and flow regimes should be evaluated further. Treatment trains that are selected for further evaluation should undergo more detailed design and costing methods, water quality sampling, and bench and pilot scale testing, so that removal efficiencies, land requirements, capital costs, and O&M costs can be further refined.

Contents

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Exhibits

Attachment

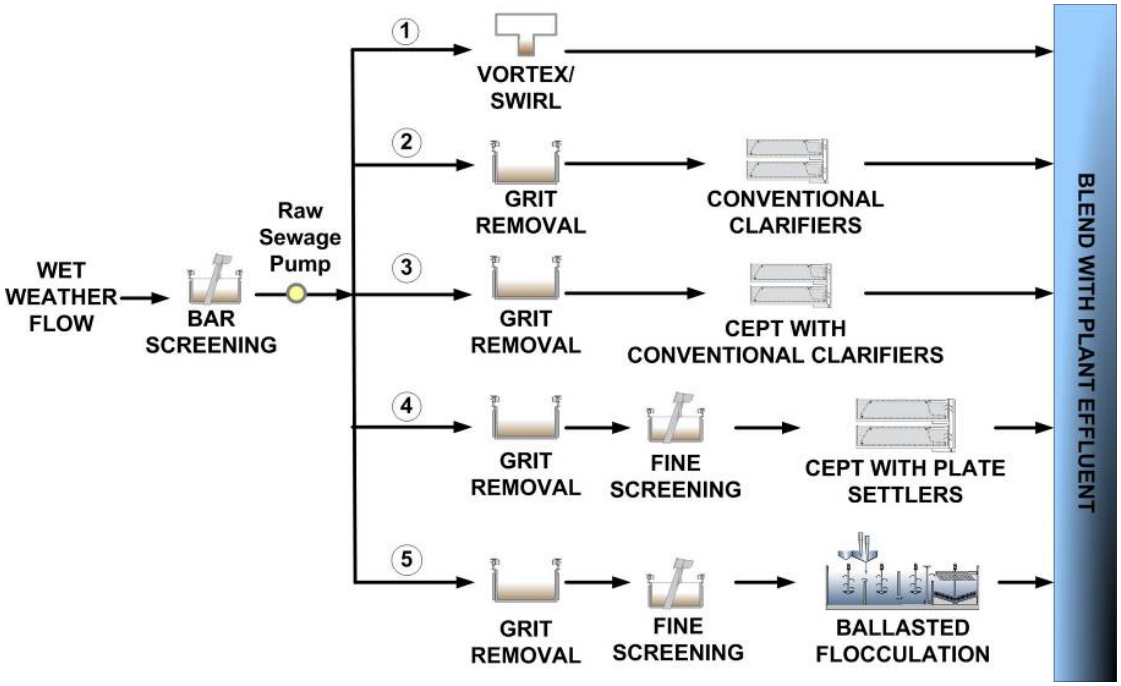
1.0 Introduction

As part of the series of memoranda prepared for the Philadelphia Water Department's (PWD) Combined Sewer Overflow (CSO) Long Term Control Plan (LTCP) update, this report presents the conceptual design and cost analyses for five wet weather treatment alternatives for the Southeast Water Pollution Control Plant (SE WPCP). These treatment alternatives were short listed from previous evaluations by the LTCP team (PWD, CDM, and CH2M HILL) based on information from: water quality data analysis and review of available land for SE WPCP; survey of various potential wet weather treatment technologies; and site visits to three existing wet weather treatment facilities in Ohio (CH2M HILL, 2007a; CH2M HILL, 2008). The wet weather treatment technologies for the SE WPCP evaluated in this report are as follows:

1. Vortex Swirl Concentrators (at low and high loading rates)
2. Conventional Clarifiers
3. Chemically Enhanced Primary Treatment (CEPT) with Conventional Clarifiers
4. CEPT with Plate Settlers (includes fine screening)
5. Ballasted Flocculation (includes fine screening)

Conceptual treatment trains were developed for each treatment technology at various wet weather flows ranging from 80 million gallons per day (mgd) to 900 mgd (Exhibit 1-1). Cost curves for both capital and operations and maintenance (O&M) costs were generated for each treatment train alternative. This report presents the conceptual design parameters, site layouts, cost estimates, and potential issues of each treatment train alternative.

EXHIBIT 1-1
Schematic View of Treatment Trains Evaluated



2.0 Improvements to Existing Plant

In order to increase the flow capacity of the SE WPCP for wet weather conditions, the potential of maximizing flow through the existing plant was evaluated. According to stress testing results, the SE WPCP currently has a firm capacity of 240 mgd (CH2M HILL, 2001). Firm capacity is defined as the treatment capacity when the largest unit process is out of service. With several process and hydraulic modifications, the SE WPCP's firm capacity can potentially reach 330 mgd (Exhibit 2-1). The necessary improvements to achieve this flow were identified in the Stress Testing Report and are based on results of stress tests on unit processes, long-term monitoring of the plant, hydraulic modeling, and input from SE WPCP plant staff.

In sizing the wet weather treatment trains, it was assumed that the upgrades proposed in the Stress Testing Report and identified in Exhibit 2-1 will have been completed, increasing the plant's capacity to a minimum of 330 mgd. Thus, the baseline cost that is used in the wet weather treatment train cost estimates is $48.1 million (Exhibit 2-1). This is reflected in the cost curves for each treatment train, presented in latter sections of the report.

EXHIBIT 2-1
Cost Summary of Potential Improvements for Existing SEWPCP

	Improvement Description	**Cost(1)**
1	Provide facilities for phosphorous addition to wastewater	Completed
2, 3	Resolve capacity limitations associated with having one coarse bar rack out of service and hydraulic bottleneck at existing influent pump station	$23,780,982
4	Replace existing primary clarifier effluent launders with new launders running parallel to flow to increase hydraulic capacity	$2,591,292
5	Provide two gravity thickeners to perform offline sludge thickening and improve performance of the primary clarifiers	$13,499,572
6	Provide an additional 71-MGD effluent pump at the effluent pumping station	$783,037
8	Resolve hydraulic limitation between primary clarifiers and the aeration basins by adding pumps to pass greater flow and increase available head.	$7,441,414
	TOTAL	**$48,096,297**

(1) See Section 3.3 for markups applied. Assume escalation factor of 19.8% - based on 9/1/2009 start date and 2-year construction duration.

Since Improvements # 2, 3, and 5 involve the addition of new structures on site, these improvements were examined more closely to see how they would interface with the new wet weather treatment trains.

2.1 Improvements #2 and #3

The current configuration of the influent wet wells limits the plant flow to 200 mgd when one coarse screen is out of service. To provide redundancy, Improvements #2 and 3 include the addition of two new bar screens and influent pumps with a capacity of 130 mgd. Due to the configuration and space limitations of the existing influent pump station, a new pump station will be needed for this new equipment. Since any new wet weather treatment facility will also require influent screening and pumping, a single building can be constructed to house all the new equipment. This new preliminary treatment building (PTB) will include the two new bar screens and influent pumps for the existing plant, as well as the additional units needed for the wet weather treatment train alternatives. A new conduit will be constructed from the new PTB to the head of the existing grit channels, carrying up to 130 mgd to the existing plant for treatment during either dry or wet weather conditions. The cost shown in Exhibit 2-1 for this improvement includes only the cost for a new PTB with the two bar screens and influent pumps for the existing plant. The additional cost of equipment for wet weather flows is included in the cost estimates for the separate wet weather treatment trains. The footprint of the entire PTB for dry and wet weather flows is shown in the conceptual layouts for each wet weather treatment train.

2.2 Improvement #5

To increase the capacity of the existing primary clarifiers, Improvement #5 provides for the addition of offline sludge thickening. Currently, primary sludge is thickened in the clarifiers. The thickened sludge is pumped from the clarifiers to sludge storage tanks, which store the sludge until it is pumped to the Southwest WPCP for further treatment. The addition of separate gravity thickeners on site will eliminate the need to carry a sludge blanket in the primary clarifiers. This will eliminate scour of the solids from the sludge blanket during high surface overflow rates, allowing the clarifiers to maintain removal efficiencies during peak flows.

The cost estimate for this improvement, shown in Exhibit 2-1, is based on the addition of two gravity thickeners, which would thicken the dilute sludge before it is pumped to the existing sludge storage tanks. The sizing of these gravity thickeners is based on a 55 percent removal efficiency in the existing clarifiers, a 0.5 percent solids concentration, and a solids loading rate of 30.7 lb/sf/day for the thickeners. These assumptions are consistent with those for the wet weather treatment trains (see Section 3.2). Cost estimates also include thickened sludge pumps and Strainpress sludge cleaners for pumping to the digesters. Since the majority of the proposed wet weather treatment trains require gravity thickening also, all gravity thickeners for both the existing plant and the wet weather treatment facility will be located in the same area on site.

3.0 Wet Weather Treatment Alternatives: Evaluation Methodology

To expand the flow capacity of SE WPCP beyond 330 mgd for the treatment of wet weather flows, a separate wet weather treatment train will be required. Wet weather flows in excess of 330 mgd will be diverted to this new treatment train, eventually blending with effluent from the existing plant. As depicted in Exhibit 1-1, the five wet weather treatment trains under evaluation are:

1. Vortex Swirl Concentrators (at low and high loading rates)
2. Conventional Clarifiers
3. Chemically Enhanced Primary Treatment (CEPT) with Conventional Clarifiers
4. CEPT with Plate Settlers (includes fine screening)
5. Ballasted Flocculation (includes fine screening)

Conceptual designs and cost estimates were performed for each treatment train at different design flows. This section describes the development of the various design flows and the key assumptions for design and cost estimating.

3.1 Design Flows

The maximum allowable flow through each wet weather treatment train is a function of its removal efficiency, the achievable effluent concentration after blending, and the plant's continued ability to meet NPDES permit limits for weekly and monthly TSS and BOD concentrations. The data analysis performed for SE WPCP determined that the monthly TSS limit was the most stringent, and were thus used to determine the maximum allowable flow through each train, as shown in Exhibit 3-1 (CH2M HILL, 2008).

EXHIBIT 3-1
Maximum Allowable Flow of Wet Weather Treatment Trains to Meet NPDES Permit Requirements

Treatment Train	TSS Removal Efficiency[1] (%)	Achievable Effluent TSS Concentration of Wet Weather Train[2] (mg/l)	Maximum Allowable Flow Through Wet Weather Train[3] (mgd)
#1) Vortex/Swirl Concentrators			
High Loading Rate:	30%	154	378
Low Loading Rate:	65%[4]	77	Unlimited*
#2) Conventional Clarifiers	55%	99	Unlimited*
#3) CEPT w/ Conventional Clarifiers	80%	44	Unlimited*
#4) Fine Screening -> CEPT w/ Plate Settlers	81%	42	Unlimited*
#5) Fine Screening -> Ballasted Floc	91%	21	Unlimited*

*These flows are unlimited assuming the wet weather treatment train operates for no more than seven days per month, an estimate provided by CDM (CH2M HILL, 2008).

(1) TSS removal efficiencies are based on industry standards. Specific references are provided in TM-SE2 (CH2M HILL, 2008).

(2) Achievable effluent concentrations based on 95th percentile influent wet weather TSS concentration (220 mg/L)

(3) Maximum flow determined by NPDES Monthly TSS Limit. The allowable daily blended effluent TSS concentration during wet weather was calculated to be 99 mg/L (CH2M HILL, 2008).

(4) Based on results of Wet Weather Demonstration Project in Columbus, Georgia (WERF, 2003)

With the exception of the vortex/swirl train at high loading rates, the flows through the candidate wet weather treatment trains were unlimited by permit requirements, assuming that the wet weather treatment facility operates for no more than seven days per month. For these "unlimited" trains, the maximum design flow was based on CDM's assumptions on the capacity of the upgraded collection system. Other design flow points were selected based on the existing collection system capacity, the existing outfall conduit capacity, and limits of available land on site. The design flows that were selected for evaluation for each treatment train are shown in Exhibit 3-2 and are described below in further detail.

EXHIBIT 3-2
Design Flows Evaluated for each Wet Weather Treatment Train

Treatment Train	Design Flows Evaluated (mgd)
#1) Vortex/Swirl Concentrators	
High Loading Rate:	80, 200, 380
Low Loading Rate:	80, 200, 900
#2) Conventional Clarifiers	80, 200, 540, 900
#3) CEPT w/ Conventional Clarifiers	80, 200, 470, 900
#4) CEPT w/ Plate Settlers	80, 200, 900
#5) Ballasted Flocculation	80, 200, 900, 1200

3.1.1 Minimum Design Flow: 80 MGD

The 80 mgd flow point reflects the capacity of the wet weather treatment train required to bring the treatment capacity of SE WPCP to the same level as the existing collection system capacity. In a technical memorandum provided by CDM, it was noted that the existing collection system can deliver 410 mgd to the SE WPCP assuming all process and hydraulic limitations in the plant are removed (Myers, 2007). With the assumption that 330 mgd can be treated by upgrading the existing plant, the new wet weather treatment train will need a minimum capacity of 80 mgd.

3.1.2 Maximum Design Flow: 380 or 900 MGD

The 900 mgd flow point is based on the maximum flow expected to be delivered to SE WPCP after improvements have been made to the collection system. In a technical memorandum provided by CDM, it was noted that collection system improvements could allow a flow of up to 1,230 mgd to the SE WPCP (Myers, 2007). Again, assuming a flow capacity of 330 mgd for the upgraded existing plant, the new wet weather treatment train will need to treat a maximum of 900 mgd. This excludes Train #1, Vortex /Swirl, which is capped at 380 mgd by permit limits.

3.1.3 200 MGD Design Flow

The 200 mgd flow point is the maximum flow that the new wet weather treatment train can discharge through the plant’s existing outfall conduits. The estimated capacity of the existing 7 feet by 9 feet twin outfall conduits is 530 mgd. This hydraulic capacity assumes gravity flow from the new chlorine contact chamber (CCC) of the wet weather treatment train (water surface level of 109.88 feet) to the Delaware River (assume maximum river level of 102 feet; see Section 3.2.3 on hydraulics). Under these assumptions, the 330 mgd from the main plant will be pumped from the existing effluent pump station to the head of the new CCC, blending with up to 200 mgd of the wet weather flow before chlorination. This will ensure that adequate chlorination contact time is maintained. (Currently, flow from the existing plant achieves chlorination contact through the outfall conduits alone. At 330 mgd, the contact time is 20 minutes.)

Wet weather flow in excess of 200 mgd (or 530 mgd for total plant flow) will require the construction of a new double barrel outfall conduit from the plant to the Delaware River. In this case, flow from the main plant will not be affected and will only blend with the wet weather flow at the river outfall.

3.1.4 Design Flows by Available Land

For Trains #2 and #3, Conventional Clarifiers and CEPT, design flows may be limited by the available land within the property boundaries of the SE WPCP. With the footprint of the wet weather treatment facility limited to the existing site, the maximum flow capacities of Trains #2 and #3 are 540 mgd and 470 mgd, respectively. Flow capacities exceeding these values will require acquisition of neighboring properties.

For Train #4, CEPT with Plates, a 900 mgd facility will require all the available land on site. Train #5, Ballasted Flocculation, occupies the smallest footprint and will be able to treat flows of up to 1200 mgd using the available land on site.

3.2 Key Design Assumptions

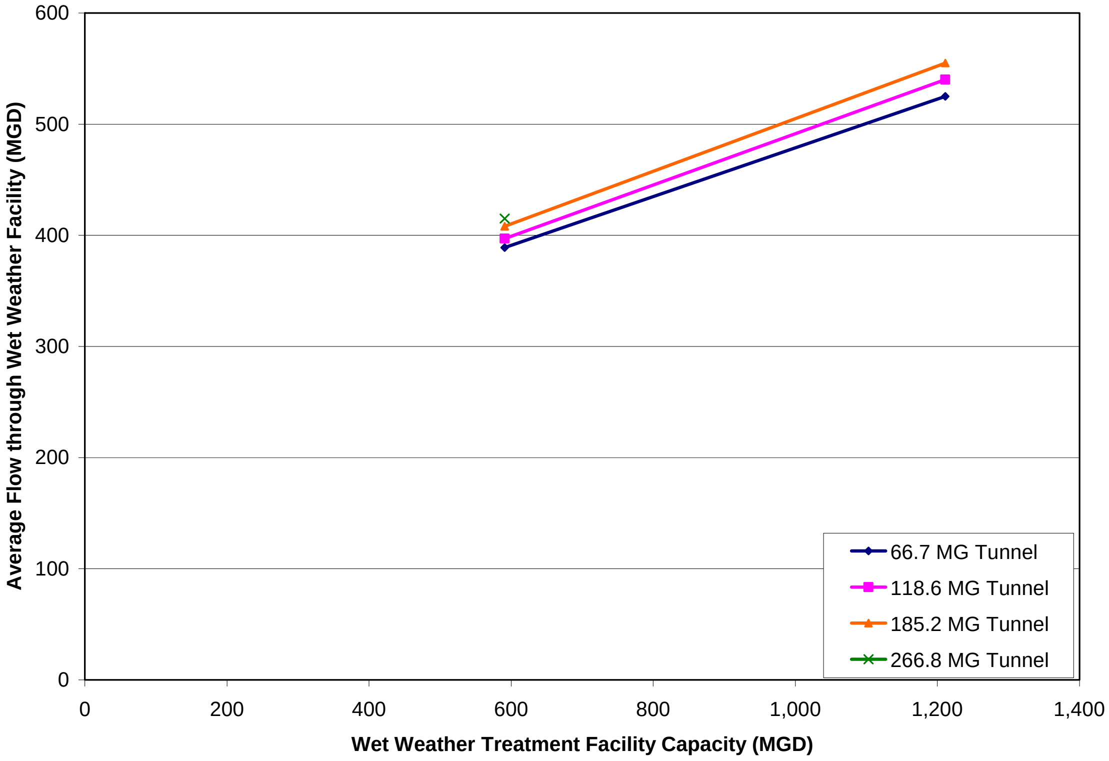
3.2.1 Average Design Flow

In the previous section, the design flow capacities were identified for each treatment train based on permit limits, available land area, and collection system capacity. These flows are the peak flows that the wet weather facilities are designed to treat under each scenario.

The average flow that the wet weather facility will receive, however, depends on conditions in the collection system. Preliminary model simulations have been performed for the Southeast Drainage district (SEDD) under several deep tunnel and plant expansion scenarios (CDM, 2008). Simulation results suggest that the average flow delivered to the wet weather facility increases as the capacity of the facility increases, and is not highly sensitive to the volume of storage in the collection system (Exhibit 3-3).

Model runs for a 490-mgd and a 900-mgd wet weather facility generated an average flow of 204-mgd and 229-mgd, respectively, assuming the largest storage tunnel scenario. Based on these model results, the maximum average design flow assumed for the new wet weather treatment trains evaluated in this report is 229-mgd. The average flows assumed for each of the treatment train scenarios is presented in Exhibit 3-4.

EXHIBIT 3-3
Average Annual Wet Weather Treatment Rates Under Various Deep Tunnel and Plant Expansion Scenarios



*This plots the average wet weather treatment rates using data from the high flow scenario hydrologic model (CDM, 2008).

EXHIBIT 3-4
Average Design Flows

Maximum Design Flow (mgd)	Average Design Flow (mgd)
80	80
200	200
380, 470, 540	204 (1)
900, 1200	229 (2)

(1) Model runs with a 490-mgd facility generated an average flow of 204-mgd.

(2) Model runs with a 900-mgd facility generated an average flow of 229-mgd.

3.2.2 Process

The process design described herein is based on conceptual design parameters and will require refinement as the planning and design efforts progress. For the purposes of developing capital costs, sizing of most facilities was based on maximum design flows. The average design flow was used for sizing the chlorine contact chamber, chemical storage facilities, screenings and grit storage, and sludge handling facilities.

Preliminary Treatment

Each wet weather train evaluated in this report was sized to treat influent flow in excess of the plant's flow capacity of 330 mgd. For each case, the main treatment train is located on the strip of vacant land to the east of the existing structures. A new influent conduit will divert excess wet weather flow to the new preliminary treatment building (PTB) of the wet weather treatment facility, to be located at the northeast corner of the plant. The new PTB will contain an influent wet well at a similar elevation to the existing wet well, bar screens, influent pumps, and screenings and grit handling systems. The influent pumps were designed to increase the hydraulic grade line so that the wet weather flow can discharge to the river outfall by gravity from the wet weather treatment facilities. The screenings and grit handling systems include screenings washers and compactors, as well as grit concentrators and classifiers. This system will handle screenings from both the bar screens and the fine screens when required.

From the PTB, the wet weather flow will continue on to further treatment through processes dependent on each treatment train. These are described in further detail in Sections 4 through 8.

Disinfection

The final process of all treatment trains is chlorination and dechlorination. The wet weather flow will be dosed with sodium hypochlorite at the head of the new chlorine contact chamber, which provides a minimum of 20 minutes detention time at average flow. At higher flows, it is assumed that the chlorine dosage will be increased correspondingly to provide adequate disinfection. Sodium bisulfite is then used for dechlorination at the end of the chlorine contact chamber.

For wet weather design flows of less than 200 mgd, the new CCC and the existing outfall conduits will be shared by the wet weather flow and the flow from the main plant. Under these scenarios, the CCC is sized for both the average design flow of the wet weather treatment facility and the maximum flow of 330 mgd from the plant.

Chemical Feed

For Treatment Trains #3, #4 and #5, which provide chemically-enhanced clarification, a coagulant and flocculant are added as settling aids. For Trains #3 and #4 that use CEPT, these chemicals are added to a rapid mixer and flocculation basin upstream of the sedimentation tank. In the ballasted flocculation train (#5), the settling aids are added to mixing zones that are part of the ballasted flocculation unit.

Ferric chloride was selected as the coagulant for all trains since it is currently used at PWD's water treatment plants. However, if there are concerns with the iron affecting the digestion process downstream, aluminum sulfate (alum) can be used as a substitute.

Polymer is used as the flocculant, and is stored in both liquid and dry form. Since preparation of dry polymer usually takes approximately 2 hours, a liquid polymer system is provided to allow immediate startup of the wet weather treatment system. With the exception of liquid polymer, a 10-day storage at average flow was assumed for all chemicals. The option of using liquid polymer only is discussed in Section 9.1.

Sludge Handling

Primary sludge from all treatment trains is pumped to gravity thickeners, where the solids concentration is expected to increase to a minimum of 3 percent. The thickeners are sized to handle the average wet weather flow (as presented in Exhibit 3-4) with a 95 percentile influent solids concentration (220 mg/L) for a continuous period of 24 hours.

The thickened sludge will be pumped to the plant's existing sludge storage tanks, from which it will be pumped to anaerobic digesters at the Southwest (SW) WPCP. The sludge will be screened through StrainPress® sludge cleaners to remove inert solids before entering the digesters. Since the maximum inlet pressure of the sludge cleaners is 14 psi, they will be located at the SW WPCP at the tail end of the sludge pump discharge.

Capital costs for each treatment train include the cost of extra digesters that may be required at the SW WPCP, assuming a maximum of seven wet weather days in one month. The digesters were sized to provide 20-day storage for solids, assuming average flow (as presented in Exhibit 3-4), a 95 percentile influent solids concentration (220 mg/L), an average wet weather event duration of seven hours, and five events in 20 days. The cost of an additional sludge pump and 8" force main to the SW WPCP ($7.7 M, including markups) was also added as a line-item to the overall cost of each scenario.

The design parameters that were assumed for all the treatment train processes are summarized in Exhibit 3-5. The process flows are described in further detail in each of the treatment train sections.

EXHIBIT 3-5
Key Process Design Assumptions for Wet Weather Treatment Trains(1)

Preliminary Treatment

Bar Screens	Opening Size	15	mm (0.59 in)
	Screenings Production(2)	3.5	cf/mg
Influent Pumps	Type	Vertical End-Suction	
	Total Dynamic Head (TDH)	45	ft (match existing wet well elevations)
Fine Screens	Opening Size	6	mm (0.24 in)
	Screenings Production(2)	2.5	cf/mg
	Screenings Compaction Factor	2	
Grit Removal	Type	Vortex Grit Unit	
	Grit Production(2)	4	cf/mg
Screenings and Grit	Number of Days Storage	1	day
Primary Clarifiers	Type	Rectangular Basin	
	Sludge Collection Mechanism	Chain-and-flight	
Flocculation Tank	Detention Time (at max flow)	10	min
	Number of Stages	3	

Wet Weather Treatment Technology	Surface Overflow Rate (gpd/sf)
Vortex/Swirl	High: 36,000 (25 gpm/sf)
	Low: 7,200 (5 gpm/sf)
Conventional Clarifiers	2,400 (3)
CEPT	3,000
CEPT with Plates	7,000
Ballasted Flocculation	84,600 (60 gpm/sf)

Chlorine Contact

Chlorine Contact Chamber	Detention Time (at avg flow)	20	min

Chemical Feed

Chemical	Purpose	Concentration	Storage (at avg flow)
Ferric Chloride	Coagulation	60 mg/L	10 days
Liquid Polymer	Flocculation	2 mg/L	20 hours(4)
Dry Polymer	Flocculation	2 mg/L	10 days
Sodium Hypochlorite	Chlorination	5 mg/L	10 days
Sodium Bisulfite	De-chlorination	1.5 mg/L(5)	10 days

EXHIBIT 3-5
Key Process Design Assumptions for Wet Weather Treatment Trains(1)

Primary Sludge Generation(6)

Train	**% TSS Removal**	**% Solids in Sludge**
#1: Vortex/Swirl	High Loading Rate: 30%	0.07%(7)
	Low Loading Rate: 65%	0.14% (7)
#2: Conventional Clarifiers	55%	0.5%
#3: CEPT	80%	0.5%
#4: CEPT with Plates	80%	0.5%
#5: Ballasted Floc	90%	0.3%

Sludge Thickening

Gravity Thickeners	Max Hydraulic Loading Rate (limiting factor for Trains #1 and #5)	900	gal/sf/day
	Max Solids Loading Rate (limiting factor for Trains #2, #3, and #4))	30.7	lb/sf/day
	% Solids of Thickened Sludge	3	% minimum
StrainPress® Sludge Screens	Sludge Throughput	200 – 400	gpm

Digesters (SW WPCP)

Anaerobic Digesters	Detention Time	20	days
	Diameter	115	ft
	Side Water Depth	25	ft
	Volatile Solids Destruction	50	%

(1) Unless otherwise noted, all design parameters are based on standard textbook values.

(2) Estimated from 2004-2005 grit and screenings disposal records from the SE WPCP.

(3) Based on stress testing results on existing primary clarifiers

(4) Liquid polymer required for startup only

(5) Assumes 1 mg/L residual chlorine concentration at the end of the chlorine contact chamber

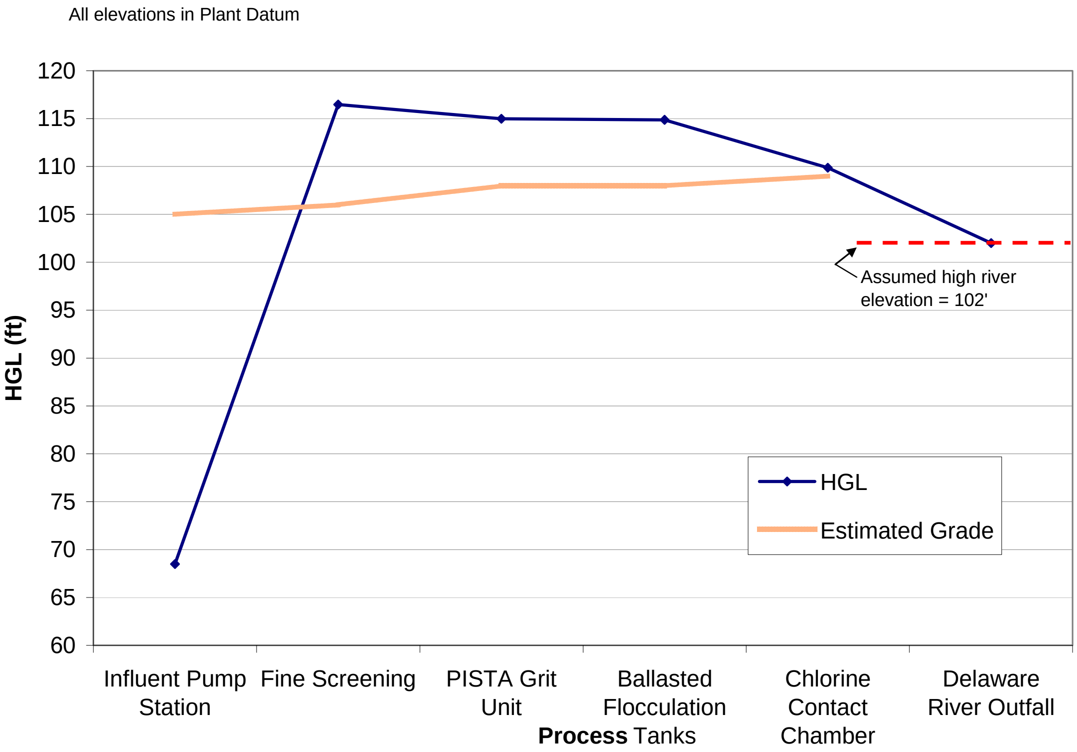
(6) Assumes 95 percentile influent TSS concentration of 220 mg/L, and volatile solids percentage of 70%

(7) Based on a 10% underflow from the vortex/swirl concentrator

3.2.3 Hydraulics

To eliminate the need for a new effluent pump station, the elevations of the new wet weather treatment trains were set to allow gravity flow to the Delaware River outfall. A preliminary hydraulic profile for the ballasted flocculation train at 900 mgd is shown in Exhibit 3-6 as an example of a maximum head loss scenario.

EXHIBIT 3-6
Preliminary Hydraulic Gradeline for the Ballasted Flocculation Treatment Train at 900 MGD



As an initial condition, the high river elevation was assumed to be 102 feet. The mean high tide level shown in SE WPCP plant drawings of the outlet structure is 97.75 feet. According to historic data, the peak river level in 2005 was 101.49 feet. Head loss through the outfall conduits at 900 mgd was estimated to be 7.88 feet using Manning's equation (assume new twin outfall conduits, 13.5 feet by 10 feet each; K factor of 3 for minor losses). As shown in the hydraulic profile, this sets the water surface level of the new chlorine contact chamber at 109.88 feet. This is only 0.7 feet lower than the high discharge level of the existing effluent pumps at the plant (110.58 feet), so is assumed to be a reasonable elevation.

The elevation of the chlorine contact chamber sets the elevations of the upstream unit processes. As shown in Exhibit 3-6, the tank walls may rise above grade by several feet. To be conservative, however, the capital cost estimates assume complete burial of all tanks.

3.2.4 Existing Site

In developing conceptual layouts of the wet weather treatment trains, it was assumed that the parking lot to the east of the existing Equipment Building (northeast corner of the plant) can be reduced in size if necessary to accommodate the new Preliminary Treatment Building.

3.2.5 Site Conditions

The site and soil conditions on the vacant land surrounding the plant were assumed to be similar to the SE WPCP. Two main assumptions were made based on existing plant drawings:

- Piles will be needed for foundations of all structures. A pile density and depth of 0.056 piles/sf and 30 feet were used for all structures on site. A pile density and depth of 0.062 piles/sf and 50 feet were used for the outfall conduits going out to the Delaware River. These numbers were based on existing pile plans for the SE WPCP.
- Dewatering will be required for all buried structures. According to plant drawings, the groundwater elevation is approximately 5-ft below grade at the SE WPCP.

3.3 Cost Estimating Assumptions

CH2M HILL's costing model was used to develop conceptual level estimates of both capital and life-cycle costs for each of the treatment trains and flows. This tool was supplemented by budgetary quotes from vendors for all major pieces of equipment. These estimates are defined as Class 4 estimates by the Association for the Advancement of Cost Engineers (AACE) and have an expected level of accuracy of +50 to -30 percent.

3.3.1 Capital Costs

Construction Costs

Construction costs were developed using the costing model for each building or unit process of a treatment train, and were based on estimated materials, labor, equipment, and installation costs. Contractor markups applied to the construction subtotal costs are presented in Exhibit 3-7. The percentages used are industry standards and are in agreement with CDM's assumptions. The escalation factors applied are based on a construction start-date of September 1, 2009, and the estimated construction duration of each scenario (Exhibit 3-8). This start-date was chosen since PWD's LTCP Update must be submitted by this date. A location adjustment factor of 15.2 percent was applied to the escalated construction cost, which is in agreement with the ENR 20-city Construction Cost Index (CCI).

Lastly, a market adjustment factor of 15 percent was applied to account for: busy contractors; contractors selectively bidding jobs; contractors selectively choosing which Owners they want to do jobs for; premium wages to keep skilled workers and management staff; availability of crafts/trades; immigration impacts and uncertainty; abnormal fuel impacts and uncertainty; abnormal material impacts of the last two years; and Katrina impacts.

EXHIBIT 3-7
Contractor Markups Assumed in Capital Cost Estimates

Contractor Markups	%	Applied to:
Overhead (OH)	10%	Subtotal of Construction Cost
Profit (P)	5%	Subtotal of Construction Cost + OH
Mobilization, Bonds, and Insurance (MOB)	5%	Subtotal of Construction Cost + OH&P
Contingency	25%	Subtotal of Construction Cost + OH&P + MOB

EXHIBIT 3-8
Escalation Factors for Various Construction Scenarios

Flow Capacity of Wet Weather Treatment Train (mgd)	**Estimated Construction Duration (months)**(1)	**Escalation Factor**(2)
80	24	19.8%
200	27	21.2%
380	30	21.8%
470	36	23.9%
540	36	23.9%
900	48	28.2%

(1) Escalation factors are based on mid-point of construction with a construction start-date of 9/1/2009.

(2) Construction durations were estimated based on facilities of similar size, and need to be refined through each stage of design.

Non-Construction Costs

A factor of 30 percent was applied to the total construction costs to estimate non-construction costs related to the project. The breakdown of these factors is shown in Exhibit 3-9.

EXHIBIT 3-9
Non-Construction Cost Factors

Non-Construction Expenditure	**Factor***
Permitting	2%
Engineering	10%
Services During Construction	10%
Commissioning and Startup	3%
Legal/Administration	5%

*Each factor was applied to the total construction cost of the project, including all markups and escalation.

Land Acquisition

For Trains #2 and 3, Conventional Clarifiers and CEPT, neighboring properties must be purchased in order to reach flow capacities beyond 540 mgd and 470 mgd, respectively. The cost of this land was estimated to be $784,000 per acre, based on cost information found in the Philadelphia parcelBase, relating to the 2007 purchase of a block directly east of the plant (Parcel block 88-4-3514-60).

For both cases, the estimated parcel of land that would need to be acquired is 11 acres (See Exhibits 5-2 and 6-2). The estimated cost of acquiring this block of land is $9.23M in 2009 dollars, which includes a 7 percent markup for permitting, legal and administration fees.

3.3.2 O&M and Life Cycle Cost Analysis

Life cycle and O&M costs of each treatment train at each flow were also estimated using CH2M HILL's costing model and were based on financial and operational assumptions as listed in Exhibit 3-10. The O&M costs cover labor, power for equipment and buildings, chemicals, and repair, maintenance and replacement of structures and equipment. O&M costs are based on average flows through the plant, as described in Section 3.2.1 and shown in Exhibit 3-4.

The additional labor required for each treatment train is dependent on the flow capacity of the train, as shown in Exhibit 3-11. It was assumed that new maintenance workers and operators would be hired for the new wet weather facility, working full time throughout the year. For some flow scenarios, it was assumed that a portion of the labor requirements during wet weather events could be met by increasing the number of shifts for existing operators, who would work overtime at a rate of 1.5 times their normal wage. It was assumed that the operators on overtime would work one 8-hour shift per wet weather event.

A detailed break down of the O&M costs and the energy requirements for each train are presented in Attachment SE-3.1. It should be noted that all O&M costs presented for the treatment trains are annualized O&M costs that include escalation over the 30-year period.

Life cycle costs were calculated using the total capital cost, including construction and non-construction costs, and O&M costs. The present value of the life cycle costs are presented in the cost summary section of each train.

EXHIBIT 3-10
Assumed Factors for Life Cycle Cost Estimates

Factor	Value	
Financial		
Annual Discount Rate	4.875	%
Life-Cycle Calculation Period	30	Years
Inflation Rate	4	%(1)
Operation		
Days of operation of wet weather treatment train	35	days(2)
Duration of wet weather event	7	Hours
Labor		
Hourly wage for plant operator	$50.44	including fringe benefits
Hourly wage for plant operator on overtime	$75.65	including fringe benefits
Hourly wage for maintenance worker	$52.35	including fringe benefits

EXHIBIT 3-10
Assumed Factors for Life Cycle Cost Estimates

Factor	Value	
Fringe benefits and overhead multiplier	2.7	applied on top of raw hourly rate
Number of working hours for full time operators at wet weather facility	2,080	hours per year per operator
Number of working hours for operators on overtime at wet weather facility	280	hours per year per operator (8 hours per event)
Number of working hours for maintenance workers at wet weather facility	2,080	hours per year per worker
Power for Buildings		
Building Electrical Cost Assumed	$0.10	$/kwh
Building Electrical Requirements	2	watts/sf of building area
Building Heating Requirements	1.2	BTU/hr/surface area of building
Natural gas cost assumed	$14	per MBTU
Power for Equipment$^{(3)}$	$0.10	$/kWh
Chemicals$^{(4)}$		
Ferric Chloride	$310	$/dry ton
Liquid Polymer	$3983	$/dry ton
Dry Polymer	$3400	$/dry ton
Sodium Hypochlorite	$1450	$/dry ton
Sodium Bisulfite	$1000	$/dry ton
Repair, Maintenance, and Replacement		
	Percentage assumed for annual O&M cost	
Finishes	2%	of finishes cost during construction
Equipment	1%	of capital cost of equipment$^{(5)}$
Instrumentation and Controls	5%	of capital cost of I&C
Mechanical	0.1%	of capital cost of mechanical work (incl. valves)
Electrical	1%	of capital cost of electrical equipment
Disposal		
Grit and Screenings Disposal and Hauling Costs	$100	per cubic yard
Final Sludge Disposal Costs$^{(6)}$	$75	per wet ton
Other		
Other O&M Costs (including vehicles, lab tests, office equipment and other miscellaneous costs)	$10,000	per additional full-time operator and maintenance worker
Contingency		

EXHIBIT 3-10
Assumed Factors for Life Cycle Cost Estimates

Factor	Value	
Contingency applied to O&M costs	20	%

(1) Based on CCI Index

(2) The maximum average annual number of wet weather events with flows higher than 330 MGD is 35 under scenarios modeled by CDM. Similarly, the maximum average annual wet weather duration is 222 hours (CDM, 2008). The duration of each event is then assumed to be 7 hours.

(3) Equipment power estimated by PWD.

(4) Based on existing costs at the plant (McKeon, 2008)

(5) For Train #4, CEPT with Plates, the equipment cost does not include that of the stainless steel plates.

(6) Final sludge mass assumes 30% dewatered cake.

EXHIBIT 3-11
Additional Labor Requirements for each Flow Scenario

Treatment Train Flow Capacity	Number of Additional Full-Time Operators(1)	Number of Existing Operators on Overtime(2)	Number of Additional Maintenance Workers(1)
80, 200, 380	1	1	2
470, 540	2	0	4
900, 1200	2	1	4

(1) Full-time operators and maintenance workers are new hires who work 2080 hours per year. Maintenance workers include different trades required for the facility (e.g. electricians, instrument technicians, mechanics, etc..)

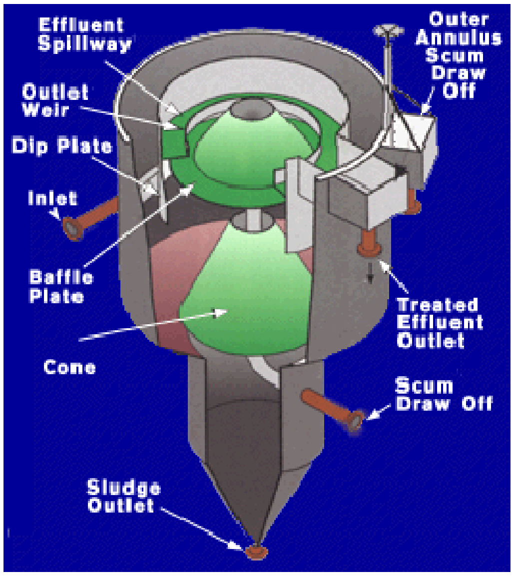
(2) Existing operators on overtime work 8 hours per wet weather event, or 280 hours per year.

4.0 Treatment Train #1- Vortex/Swirl Concentrators

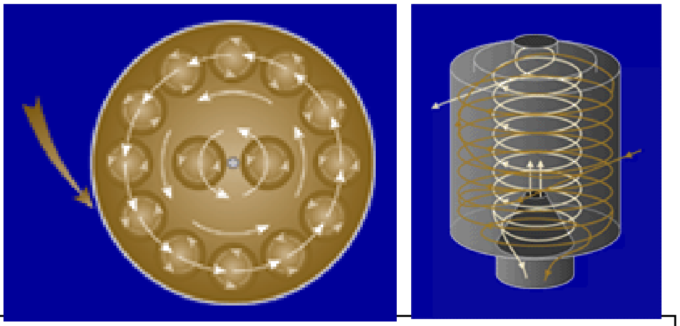
4.1 Process Flow Diagram

The first treatment train under evaluation utilizes the vortex separation technology as its main treatment process. After passing through bar screens and influent pumping at the PTB, the wet weather flow will enter the primary vortex/swirl concentrators. Vortex/swirl concentrators are flow-through structures with no moving parts. The wet weather flow enters the cylindrical structure tangentially, producing a swirling motion that concentrates the solids in the center (Exhibit 4-1). An underflow drain in the center of the unit continually draws the solid materials out of the flow.

EXHIBIT 4-1
Diagrammatic Cutaway of Vortex/Swirl Device (Storm King®, H.I.L. Technologies)

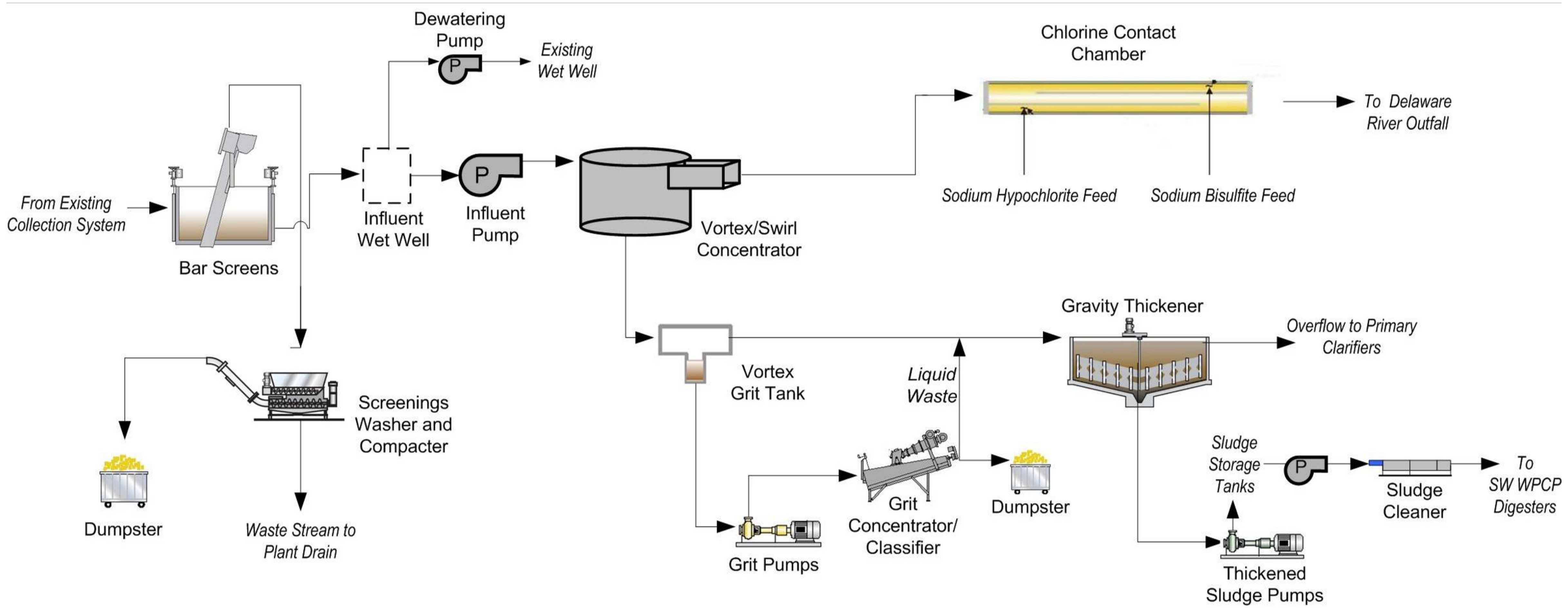


The treated effluent flows out of the top of the vessel, continuing on to the chlorine contact chamber. The solids underflow, typically 10 percent of the influent, undergoes grit removal through a vortex grit unit before settling and thickening in gravity thickeners. The conceptual process flow diagram for this treatment train is shown in Exhibit 4-2.



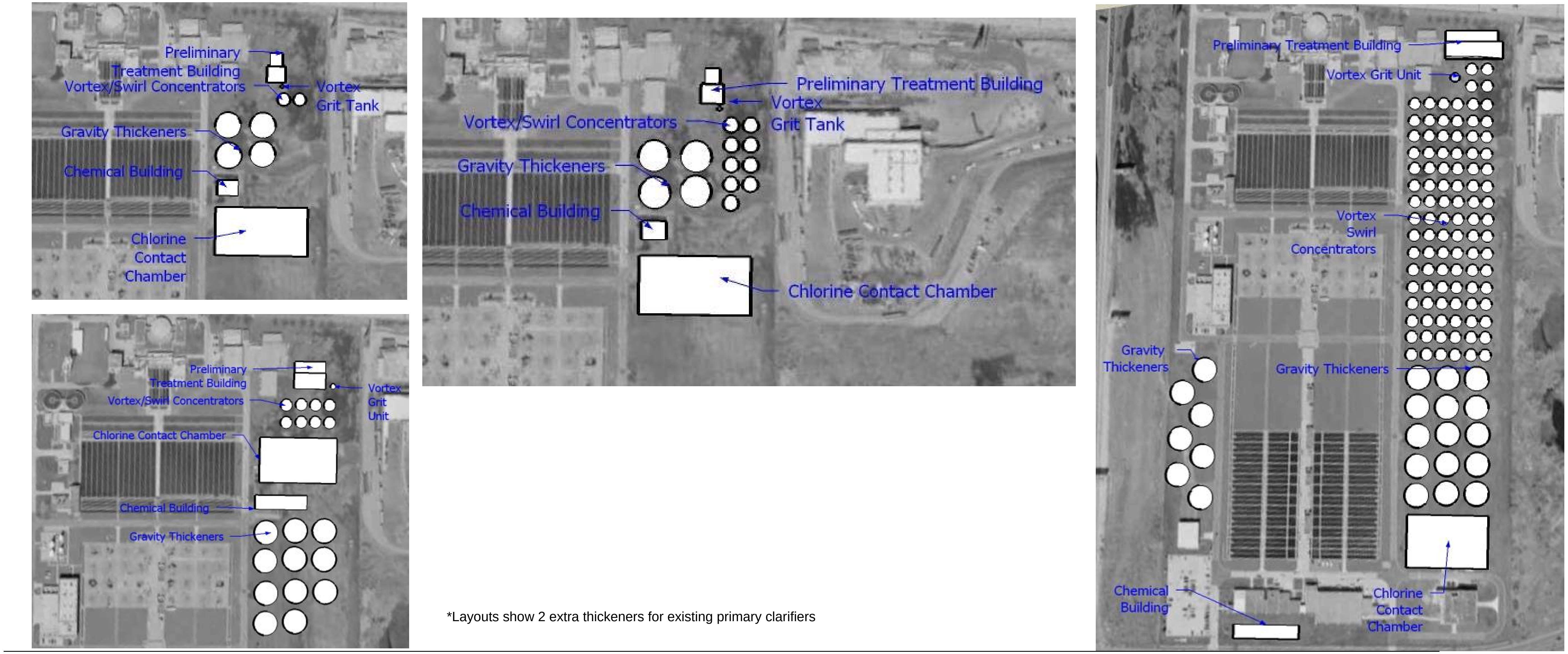
Flow Pattern Plan and Profile Views (H.I.L. Technologies)
The flow in vortex/swirl devices initially follows a path around the perimeter of the unit and is then directed into an inner swirl pattern with a lower velocity than the outer swirl. Solids separation is achieved by both centrifugal force and gravity because of the long flow path and inertial separation due to the circular flow pattern. The concentrated underflow passes through an outlet in the bottom of the vessel while the treated effluent flows out of the top of the vessel.

EXHIBIT 4-2
Process Flow Diagram and Key Process Design Parameters for Treatment Train #1: Vortex/Swirl Concentrators



	Bar Screens	Influent Pumps	Vortex/Swirl Concentrators		Vortex Grit Tank		Screenings Washer/ Compactor	Grit Pumps		Grit Concentrator	Grit Classifier	Screenings and Grit Prod.	Sodium hypochlorite			Sodium Bisulfite			Gravity Thickeners & Sludge Cleaners	Primary Sludge Pumps		Thickened Sludge Pumps		Sludge Prod.	Digesters (at SW WPCP)
Flow (mgd)	# units	# units	# primary units	Loading rate on primary unit (gpm/sf)	# units	Dia (ft)	# units	# duty	# standby	# units	# units	Compacted volume (cf/day)	Total storage vol (gal)	# duty pumps	# standby pumps	Total storage vol (gal)	# duty pumps	# standby pumps	# Units	# Duty	# Standby	# Duty	# Stand by	lb/day	# Units
HIGH LOADING:																									
80	1	1	2	22.1	1	12	1	1	1	1	1	460	39,831	1	1	6,226	1	1	2	4	1	2	1	44,035	1
200	2	3	4	27.6	1	18	2	1	1	1	1	1,150	99,579	1	1	6,226	1	1	5	8	2	5	2	110,088	1
380	4	5	8	26.2	1	18	4	1	1	1	1	1,173	101,570	1	1	6,226	1	1	9	16	5	9	3	112,290	1
LOW LOADING:																									
80	1	1	9	4.9	1	12	1	1	1	1	1	460	39,831	1	1	6,226	1	1	2	9	1	2	1	44,035	1
200	2	3	22	5.0	1	18	2	1	1	1	1	1,150	99,579	1	1	6,226	1	1	5	22	6	5	2	110,088	1
900	9	12	100	5.0	1	32	9	1	1	1	1	1,317	114,018	1	1	6,606	1	1	20	100	25	20	5	273,110	1

EXHIBIT 4-3
Conceptual Layouts and Footprints for Treatment Train #1: Vortex/Swirl Concentrators
High Loading: 80 MGD Layout (top left) and 380 MGD Layout (bottom left), Low Loading: 80 MGD Layout (center) and 900 MGD Layout (right)



*Layouts show 2 extra thickeners for existing primary clarifiers

FLOW (mgd)	PTB	GRIT UNITS	VORTEX SWIRLS	CHEMICAL BUILDING	CCC	GRAVITY THICKENERS*	TOTAL FOOTPRINT (acres)
80	54' x 47' & 39' x 39'	12' (1 unit)	40' (high loading: 2 units low loading: 9 units)	65' x 47'	147' x 287' (7 passes)	80' (2 units)	1.4
200	80' x 49' x 63' x 39'	18' (1 unit)	40' (high loading: 4 units low loading: 22 units)	101' x 47'	109' x 193' (5 passes) or 176' x 310' (9 passes)	80' (5 units)	1.4
380 (high loading)	106' x 56' & 101' x 39'	18' (1 unit)	40' (8 units)	111' x 45'	151' x 259' (7 passes)	80' (9 units)	2.7
900 (low loading)	197’ x 60’ & 180’ x 39’	32’ (1 unit)	40’ (100 units)	143’ x 45’	172’ x 268’ (8 passes)	80’ (20 units)	8.1

4.2 Conceptual Design and Site Layouts

Two different loading rates were assumed for this treatment train, as presented in Exhibit 4-4.

EXHIBIT 4-4
Design Assumptions for Treatment Train #1: Vortex/Swirl Concentrators

Loading Rate (gpm/sf)	Removal Efficiency (%)	Flows Evaluated (mgd)
25	30	80, 200, 380
5	65	80, 200, 900

As with clarification units, the performance of the vortex swirl concentrators varies widely depending on the loading rate. In typical installations where vortex swirls are used to treat combined sewer overflows in the collection system, the units are designed for a loading rate of approximately 25 gpm/sf. At this loading rate, manufacturers estimate that a TSS removal rate of 30 percent can be achieved.

According to a study performed in Columbus, Georgia, the vortex performs similarly to a primary clarifier at loading rates of 5 gpm/sf or less (7,200 gpd/sf). The study showed that removal efficiencies of up to 70 percent were achieved at a 5 gpm/sf loading rate (WERF, 2003). To be conservative, a 65 percent removal efficiency was assumed in this report. Actual performance of the units will need to be verified in pilot studies.

The main design parameters for each flow scenario of this treatment train are shown in Exhibit 4-2. The conceptual site layouts for the minimum and maximum flow scenarios are shown in Exhibits 4-3.

4.3 Operational and Technology-Specific Issues

The effectiveness of vortex/swirl concentrators greatly depends on the hydraulic loading rate on the unit and the characteristics of the solids entering the unit. The optimal loading rate must be determined through pilot or operational testing. In order to operate the vortex/swirl at its optimal operating rate or “sweet spot”, the vortex/swirl units can be brought online one by one as the influent flow increases. Alternatively, an equalization basin can be constructed to maintain a specific flow-rate into the units. An equalization basin was not included in the cost estimates, but conservative hydraulic loading rates were assumed for facility sizing.

4.3.1 Startup and Shutdown

The pretreatment processes (bar screens, influent pumps, and grit removal) can be brought online quickly at the start of a wet weather event. Vortex/ swirl concentrators would be empty at the start of a wet weather event. At small flows, the wet weather flow will exit through the underflow. As flows increase, the vessel will fill due to the increased hydraulic load and begin discharging treated effluent to the outfall.

During shutdown, the vortex/swirl and grit units will be emptied by pumping from the underflow sections to the main plant's influent wet well. The influent wet well in the new PTB would also be pumped down to the plant's existing wet well using dewatering pumps (Exhibit 4-2).

For long term shutdown, the chlorine contact chamber could be pumped down, with the flow recycled to the head of the main plant.

4.3.2 Interaction with Main Plant

The waste streams generated by the screenings washer/compactor and the grit classifiers are sent to the gravity thickeners of the wet weather treatment train and will not affect the main plant. However, there are two streams from the gravity thickeners that will interact with the main plant.

Thickened sludge from the gravity thickeners is pumped to the existing sludge storage tanks at a rate of 0.2 to 4.3 mgd, depending on the flow capacity of the treatment train. This does not include the two gravity thickeners needed for the existing plant. Since the thickened sludge can be pumped at any time, the thickeners themselves can serve as storage tanks for the sludge before it is pumped to the existing storage tanks.

The overflow from the gravity thickeners is conveyed to the head of the entire plant. The estimated overflow range from wet weather thickeners only is 8 to 86 mgd, depending on the treatment train capacity. To minimize the effect of this volume, the overflow is recycled back to the head of the entire plant so that it can be distributed across all units in operation.

4.3.3 Impact on plant operations

Since the vortex/swirl unit has no moving parts, it is expected to have little operations and maintenance requirements. However, operators' attention may be necessary to monitor the hydraulic loading rates into the vortex/swirls to ensure that the "sweet spot" is maintained. The treatment train also includes grit pumps, concentrators, and classifiers, as well as sludge pumps and other equipment, all of which require maintenance. In addition, the new chemical building will include storage of sodium hypochlorite and bisulfite, which are fed to the new chorine contact chamber. Storage of hypochlorite will need to be monitored, since it degrades over time. In addition, the hypochlorite feed-lines should be flushed or degassed periodically.

4.4 Cost Analyses

The estimated capital, O&M, and lifecycle costs for each flow scenario at low and high loading rates are shown in Exhibit 4-5 and 4-6, respectively. Total capital costs and the capital costs per volume treated for all scenarios are shown in Exhibits 4-7 and 4-8. The estimated O&M costs by category are also presented in Exhibits 4-9 and 4-10. A more detailed breakdown of these costs is presented in Attachment SE-3.1. As expected, the cost of this technology at low loading rates is significantly greater than the cost for high loading rates due to the greater number of units required for operation at lower loading rates.

EXHIBIT 4-5
Cost Summary for Vortex/Swirl Treatment Train #1 with Low Loading Rates

	Wet Weather Flow (mgd)		
Cost	**80**	**200**	**900**
Capital Cost ($M)	$192	$378	$1,394
Annual Operations and Maintenance Cost ($M)	$2.0	$3.2	$8.6
Present Value of the Cost ($M)	$223	$428	$1,529

EXHIBIT 4-6
Cost Summary for Vortex/Swirl Treatment Train #1 with High Loading Rates

	Wet Weather Flow (mgd)		
Cost	**80**	**200**	**380**
Capital Cost ($M)	$129	$220	$377
Annual Operations and Maintenance Cost ($M)	$1.8	$2.6	$3.1
Present Value of the Cost ($M)	$156	$261	$426

EXHIBIT 4-7
Capital Costs for Treatment Train #1: Vortex/Swirl

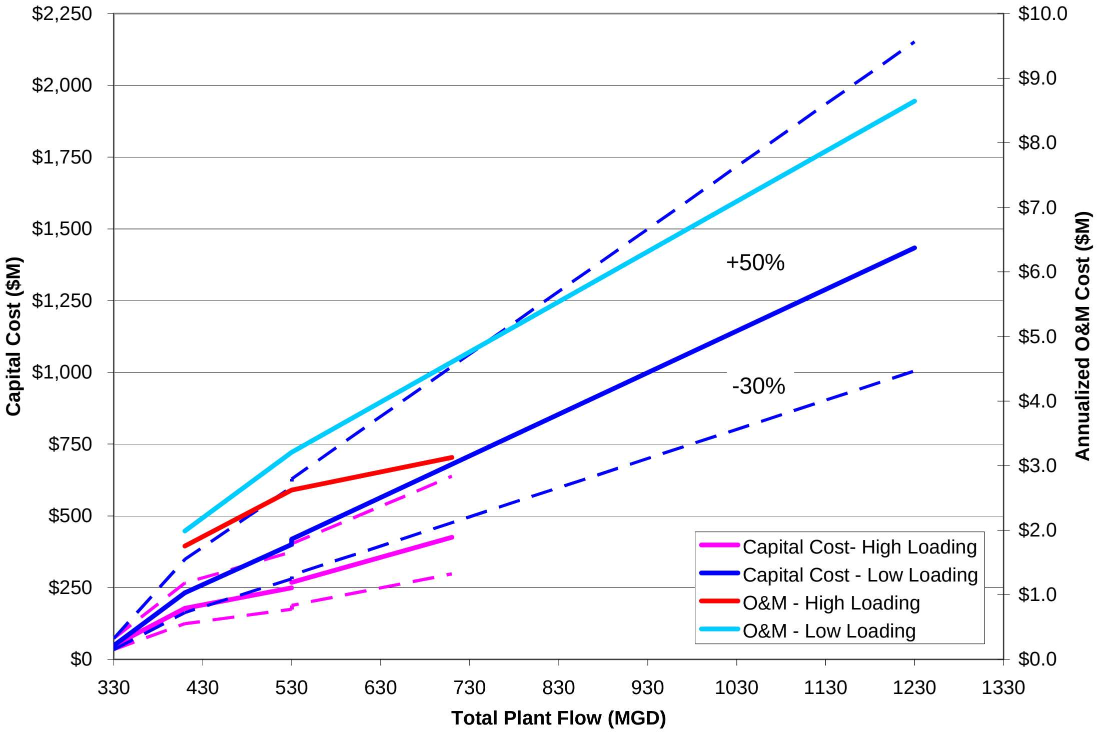


EXHIBIT 4-8
Capital Costs per Gallon Treated for Treatment Train #1: Vortex/Swirl

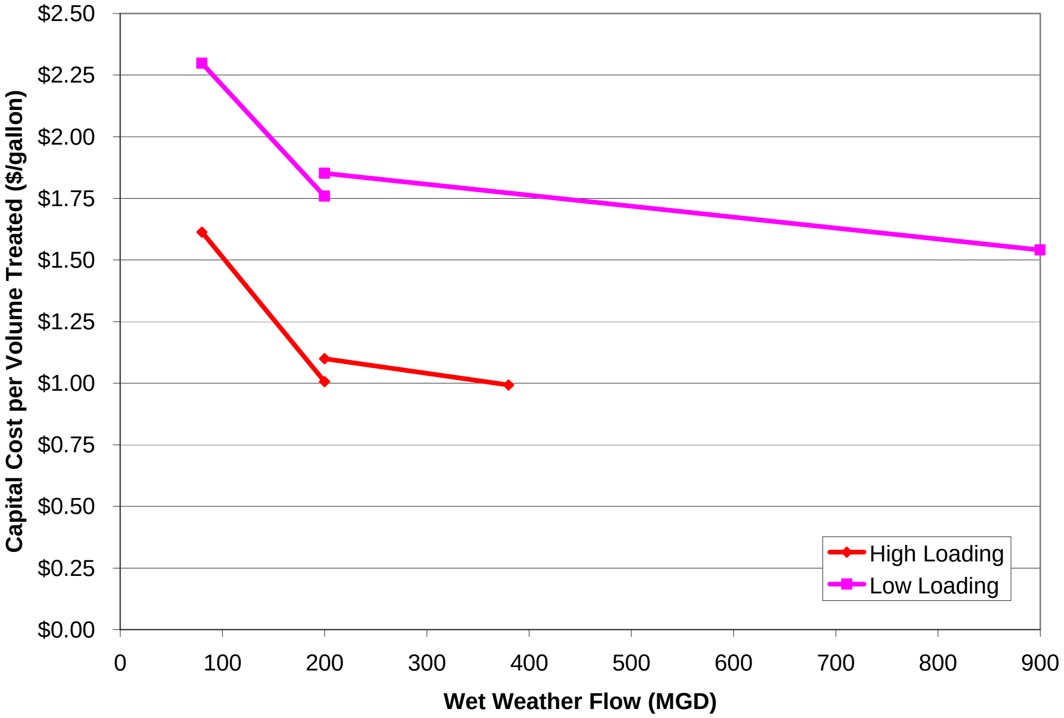


EXHIBIT 4-9
Operations and Maintenance by Category for Treatment Train #1: Vortex/Swirl at Low Loading Rates

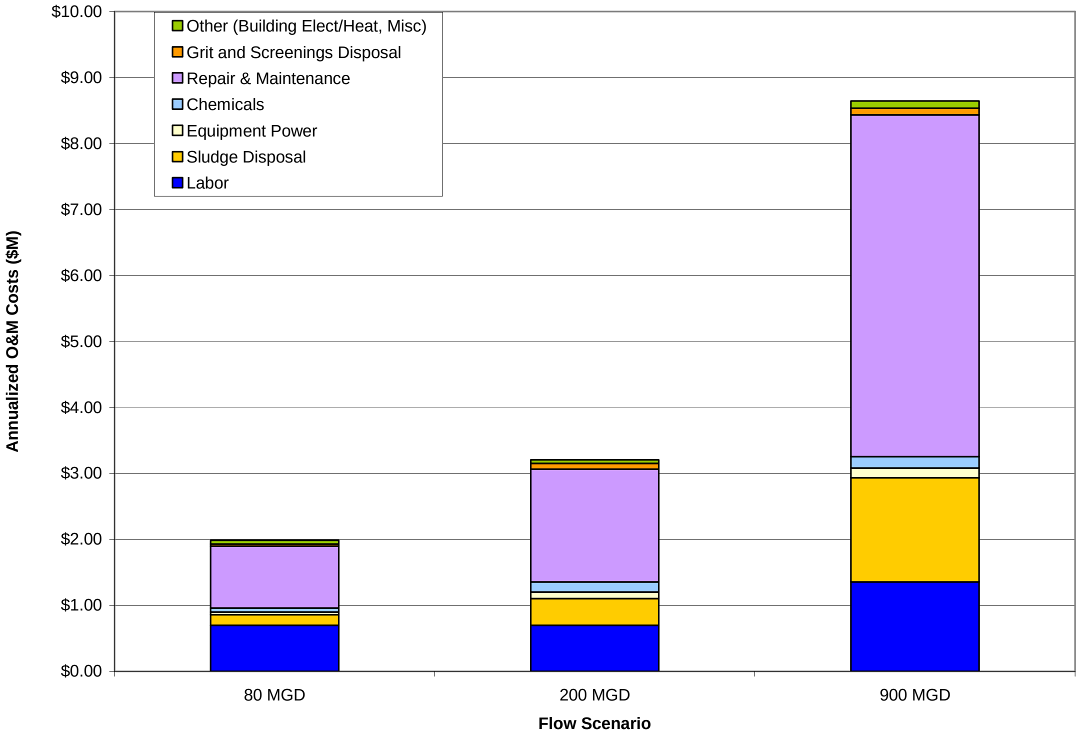
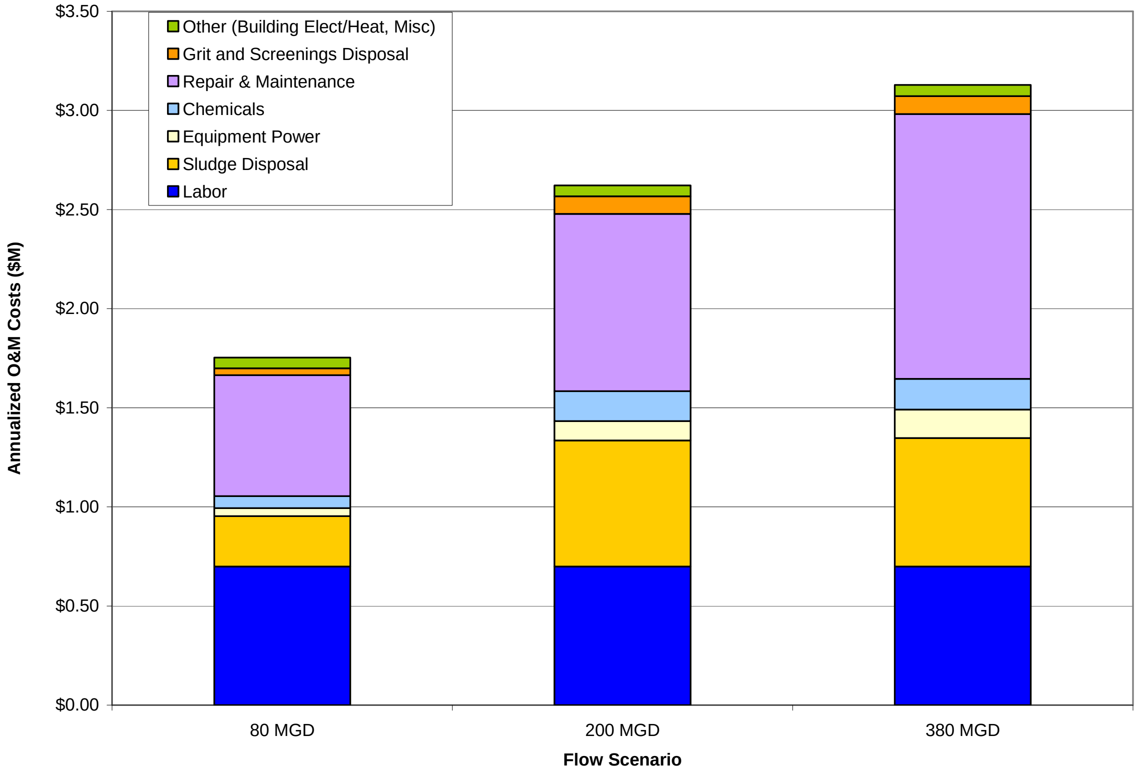


EXHIBIT 4-10
Operations and Maintenance by Category for Treatment Train #1: Vortex/Swirl at High Loading Rates



5.0 Treatment Train #2 - Conventional Clarifiers

5.1 Process Flow Diagram

Through treatment train #2, the wet weather flow undergoes essentially the same level of primary treatment as the flow through the existing SE WPCP. After preliminary treatment through the bar screens and grit removal, the wet weather flow passes through conventional primary clarifiers at a maximum loading rate of 2400 gpd/sf. This is the overflow rate achievable by the plant's existing primary clarifiers, as shown through stress testing (CH2M HILL, 2001). Primary sludge is collected by chain and flights in the clarifier tanks and is pumped to the gravity thickeners for thickening. The process flow diagram for this treatment train is shown in Exhibit 5-1.

5.2 Conceptual Design and Site Layouts

Conceptual designs were developed at four different flow scenarios for this train: 80, 200, 540, and 900 mgd. Key design parameters at these flows are shown in Exhibit 5-1. The conceptual layouts for the 80, 540, and 900 mgd scenarios are shown in Exhibit 5-2. At a flow of 900 mgd, 11 acres of land will need to be acquired to the east of the plant. The 540 mgd scenario can fit on the existing site.

5.3 Operational and Technology-Specific Issues

5.3.1 Startup and Shutdown

The startup time required for conventional clarifiers will be 2-3 hours, the duration needed to displace the wastewater in the existing tank. For shut down, the tank may be filled with treated effluent, or pumped down to the existing plant if freezing becomes an issue.

5.3.2 Interaction with Main Plant

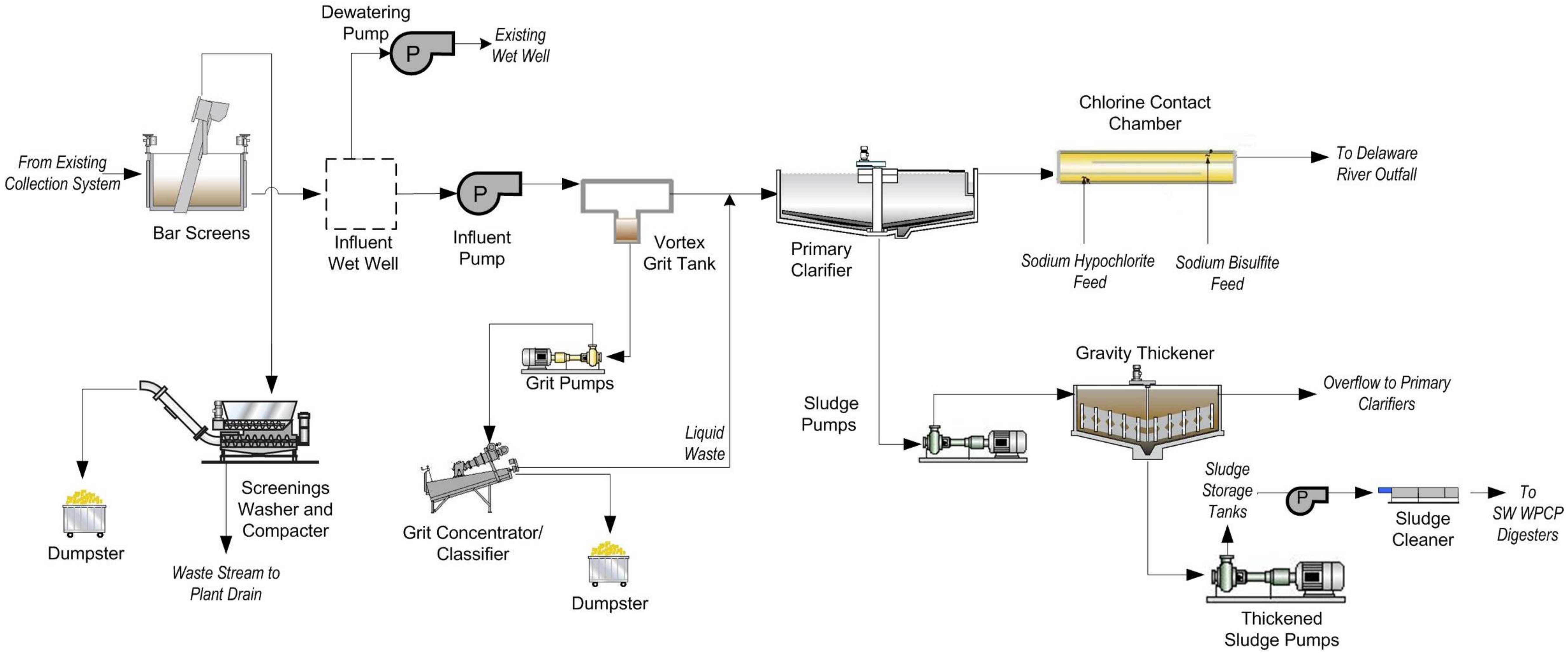
Since the existing plant uses primary clarifiers, the new primary clarifiers for wet weather treatment can provide redundancy on primary treatment for the entire plant. If connected to the influent of the existing aeration basins, the new clarifiers could be used for treatment of dry weather flows.

The waste streams generated by the screenings washer/compactor and the grit classifiers are sent to the primary clarifiers of the wet weather treatment train and will not affect the main plant. As with the other treatment trains, there are two streams from the gravity thickeners that will interact with the main plant.

Thickened sludge from the gravity thickeners is pumped to the existing sludge storage tanks at an estimated rate of 0.3 to 3.6 mgd, depending on the flow capacity of the treatment train. This does not include the two gravity thickeners needed for the existing plant. Since

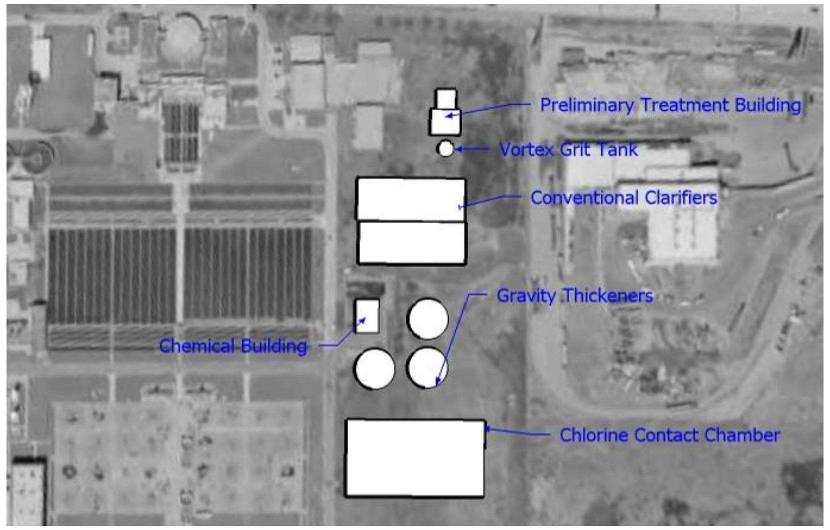
EXHIBIT 5-1

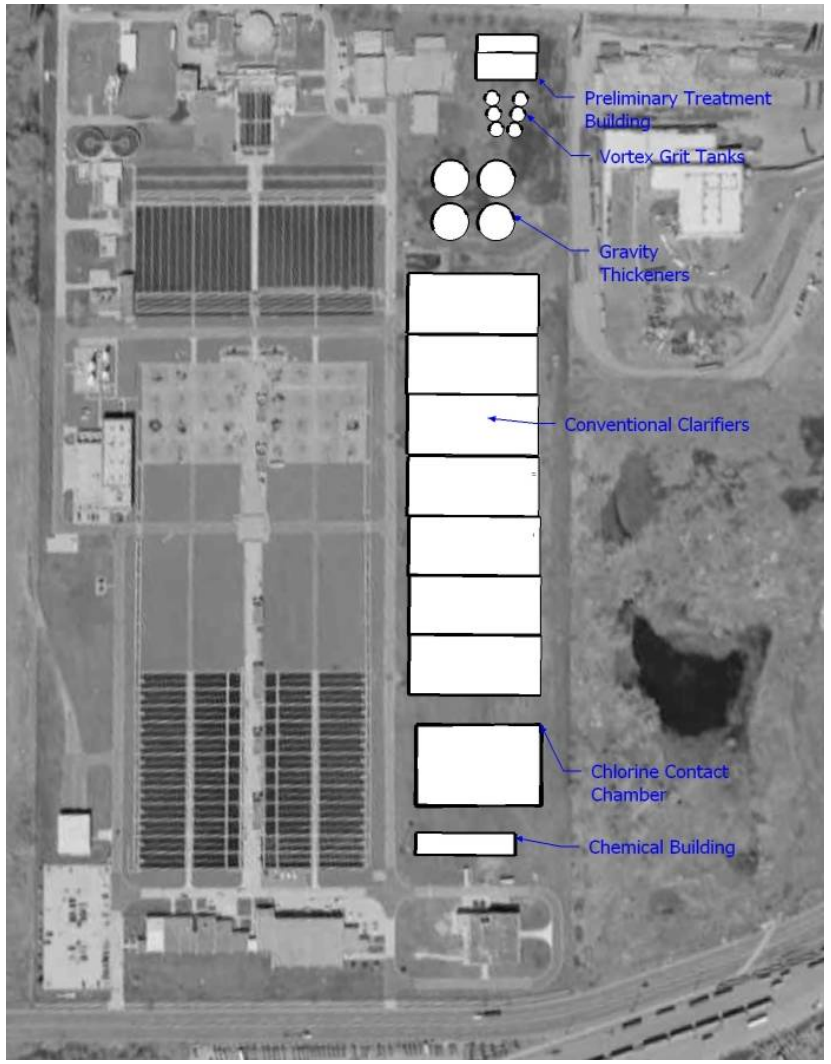
Process Flow Diagram and Key Process Design Parameters for Treatment Train #2: Conventional Clarifiers

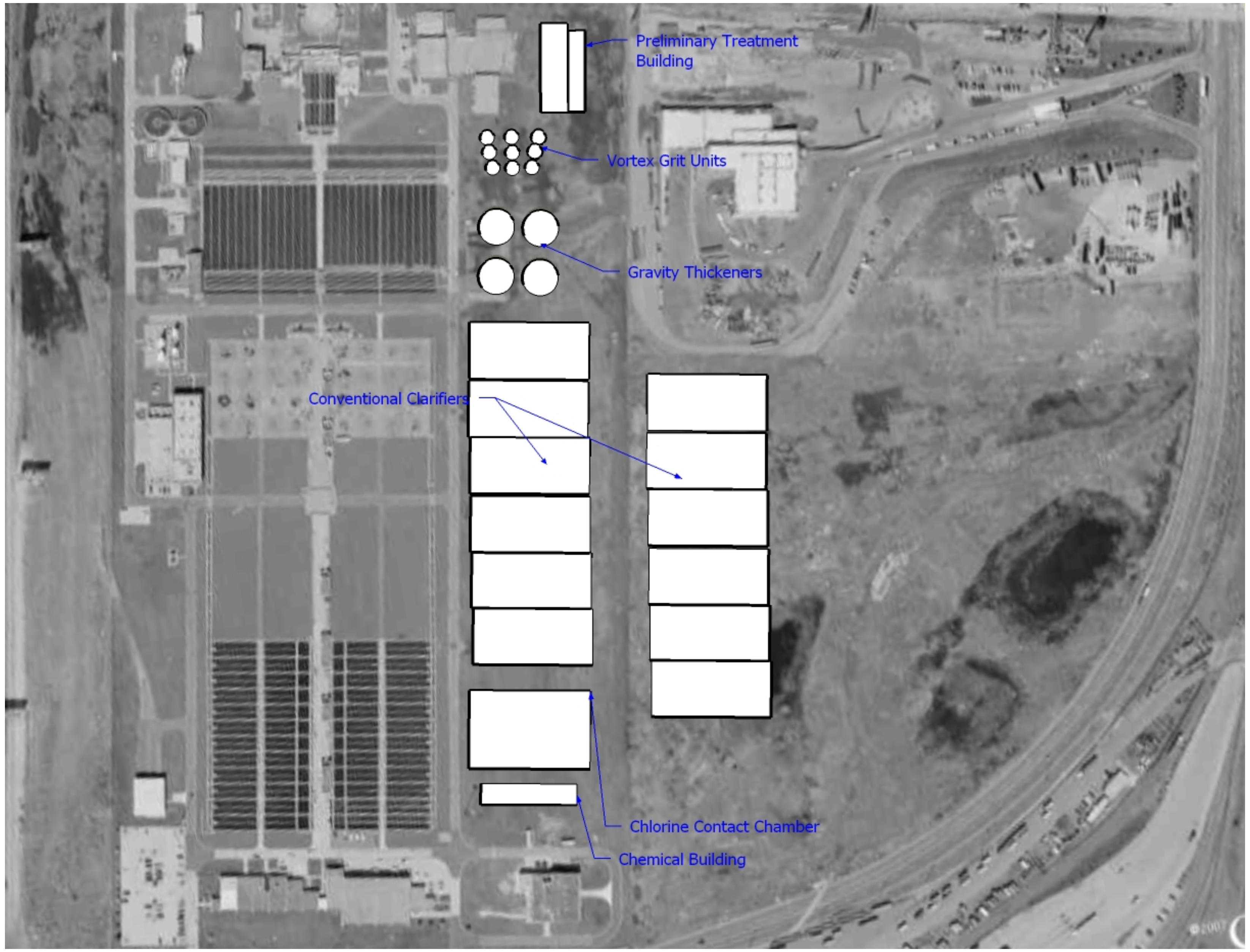


Flow (mgd)	Bar Screens	Influent Pumps	Vortex Grit Tank		Screenings Washer/ Compactor	Grit Pumps		Grit Concentrator	Grit Classifier	Screenings and Grit Prod.	Sodium Hypochlorite			Sodium Bisulfite			Clarification	Gravity Thickeners & Sludge Cleaners	Primary Sludge Pumps		Thickened Sludge Pumps		Sludge Prod.	Digesters (at SW WPCP)
	# Units	# Units	# Units	DIA (ft)	# Units	# Duty	# Standby	# Units	# Units	Compacted Volume (cf/day)	Total Storage Vol (gal)	# Duty Pumps	# Standby Pumps	Total Storage Vol (gal)	# Duty Pumps	# Standby Pumps	# Trains	# Units	# Duty	# Standby	# Duty	# Standby	lb/day	# Units
80	1	1	1	32	1	1	1	1	1	460	39,831	1	1	6,226	1	1	2	1	2	1	1	1	80731	1
200	2	3	2	32	2	2	1	2	1	1,150	99,579	1	1	6,226	1	1	3	2	3	1	2	1	201828	1
540	6	7	6	32	6	6	2	6	3	1,173	101,570	1	1	6,226	1	1	7	2	7	2	2	1	205865	1
900	9	12	9	32	9	9	3	9	5	1,317	114,018	1	1	6,606	1	1	12	2	12	4	2	1	231093	1

EXHIBIT 5-2
Conceptual Layouts and Footprints for Treatment Train #2: Conventional Clarifiers
80 MGD Layout (top left), 540 MGD Layout (bottom left), 900 MGD (right)







*Layouts show 2 extra thickeners for existing primary clarifiers

Flow (mgd)	PTB	Grit Units	Clarifier Tanks	Chemical Building	CCC	Gravity Thickeners*	Land Acquired	TOTAL FOOTPRINT (acres)
80	54' x 47' & 39' x 39'	32' (1 unit)	84' x 212' (2 units)	65' x 47'	147' x 287' (7 passes)	70' (1 unit)	NONE	2.1
200	80' x 49' x 63' x 39'	32' (2 units)	129' x 245' (3 units)	101' x 47'	109' x 193' (5 passes) or 176’ x 310’ (9 passes)	80' (2 units)	NONE	3.3
540	132' x 58' & 133' x 39'	32' (6 units)	129' x 283' (7 units)	127' x 45'	172' x 268' (8 passes)	80' (2 units)	NONE	8.4
900	197' x 60' & 180' x 39'	32' (9 units)	124' x 265' (12 units)	143' x 45'	172' x 268' (8 passes)	80' (2 units)	11 acres	12.6

the thickened sludge can be pumped at any time, the thickeners themselves can serve as storage tanks for the sludge before it is pumped to the existing storage tanks.

The overflow from the gravity thickeners is conveyed to the head of the entire plant. The estimated overflow range from wet weather thickeners only is 2 to 18 mgd, depending on the treatment train capacity. To minimize the effect of this volume, the overflow is recycled back to the head of the entire plant so that it can be distributed across all units in operation.

5.3.3 Impact on Plant Operations

The operations and maintenance requirements for this treatment train should be similar to those needed for corresponding processes at the existing plant.

5.4 Cost Analyses

The estimated capital, O&M, and lifecycle costs for each flow scenario are shown in Exhibit 5-3. Total capital costs and the capital costs per volume treated are also shown in Exhibits 5-4 and 5-5. Estimated O&M costs by category are presented in Exhibit 5-6. A more detailed breakdown of these costs is presented in Attachment SE-3.1.

EXHIBIT 5-3
Cost Summary for Conventional Clarifiers: Treatment Train #2

	Wet Weather Flow (mgd)			
Cost	**80**	**200**	**540**	**900**
Capital Cost ($M)	$144	$268	$588	$931
Annual Operations and Maintenance Cost ($M)	$1.6	$2.4	$3.8	$4.7
Present Value of the Cost ($M)	$169	$305	$647	$1,004

EXHIBIT 5-4
Capital Costs for Treatment Train #2: Conventional Clarifiers

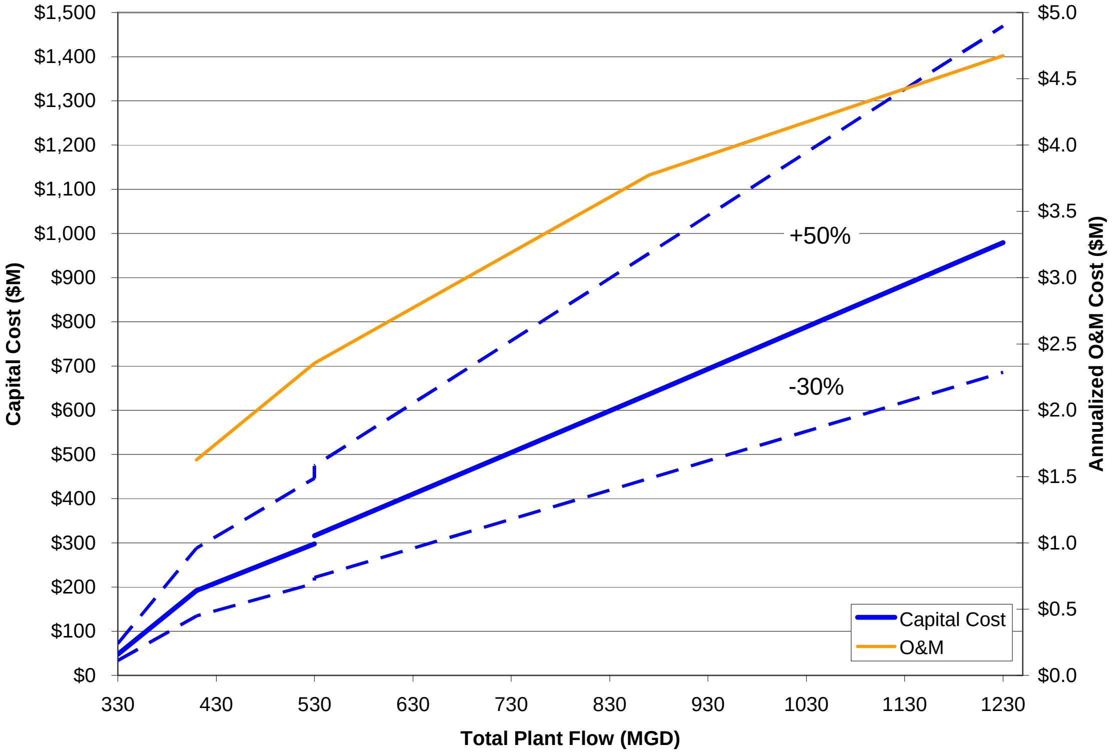


EXHIBIT 5-5
Capital Costs per Gallon Treated for Treatment Train #2: Conventional Clarifiers

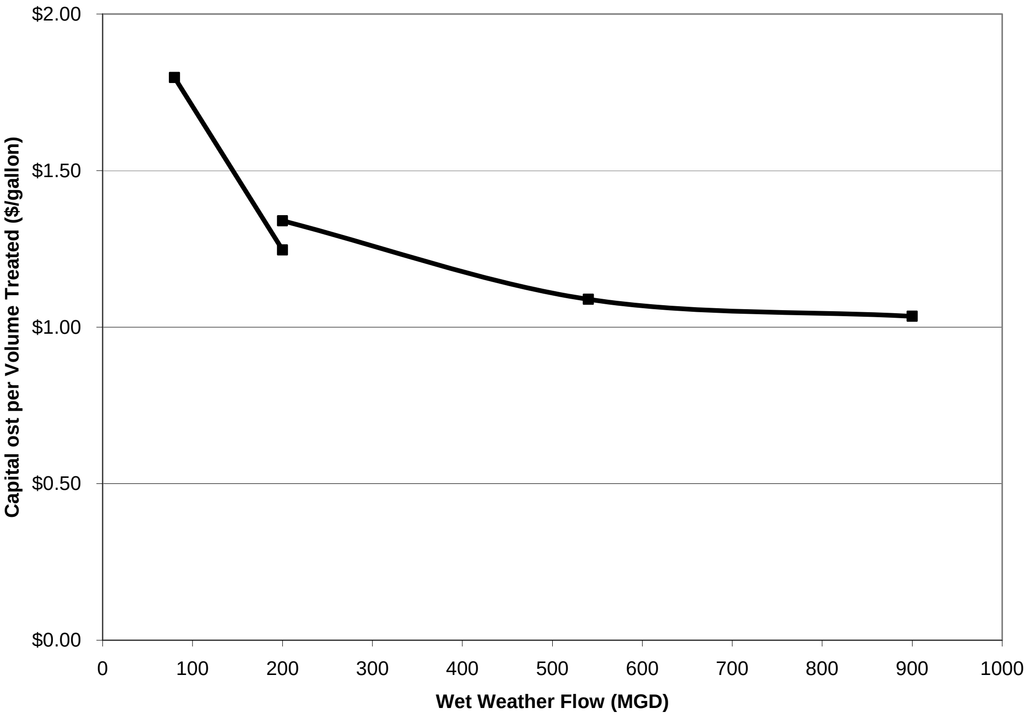
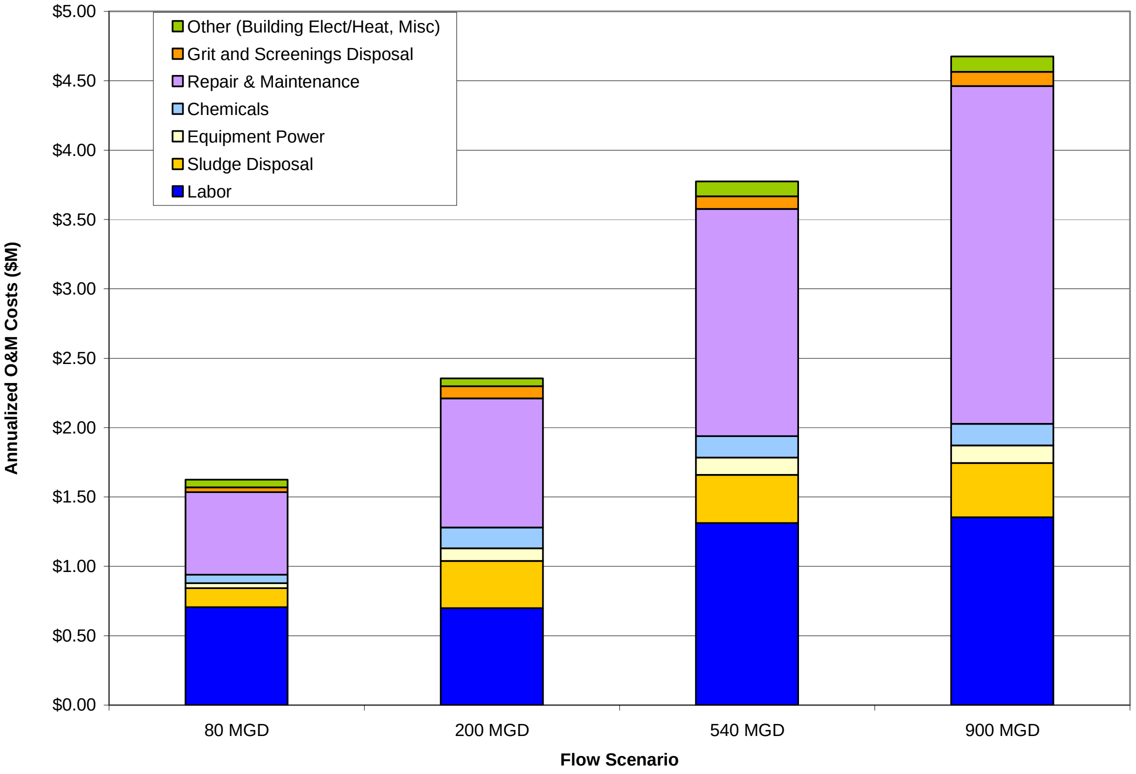


EXHIBIT 5-6
Operation and Maintenance Costs by Category for Treatment Train #2: Conventional Clarifiers



6.0 Treatment Train #3 - Chemically Enhanced Primary Treatment (CEPT)

6.1 Process Flow Diagram

Chemically enhanced primary treatment (CEPT) improves the removal efficiency of TSS and BOD through the addition of coagulants and flocculants to primary clarifiers. With chemical enhancement, the surface overflow rate of the primary clarifier is expected to increase from 2400 gpd/sf to 3000 gpd/sf, and the removal efficiency from 55 percent to 80 percent. As shown in the process flow diagram in Exhibit 6-1, the flow path is similar to Treatment Train #2. The only difference is the addition of rapid mixers and flocculation basins upstream of the primary clarifiers, along with their associated chemical feed and storage systems.

6.2 Conceptual Design and Site Layouts

Conceptual designs were developed at four different flow scenarios for this train: 80, 200, 470, and 900 mgd. Key design parameters at these flows are shown in Exhibit 6-1. As with Treatment Train #2, the 900 mgd flow scenario requires acquisition of neighboring property. As shown in Exhibit 6-2, there is adequate space on the existing site to treat up to 470 mgd of wet weather flow. Compared to Treatment Train #2, the CEPT primary clarifiers have a smaller footprint due to its slightly higher surface overflow rate, but the number of gravity thickeners required increases due to the higher removal efficiency of CEPT.

6.3 Operational and Technology-Specific Issues

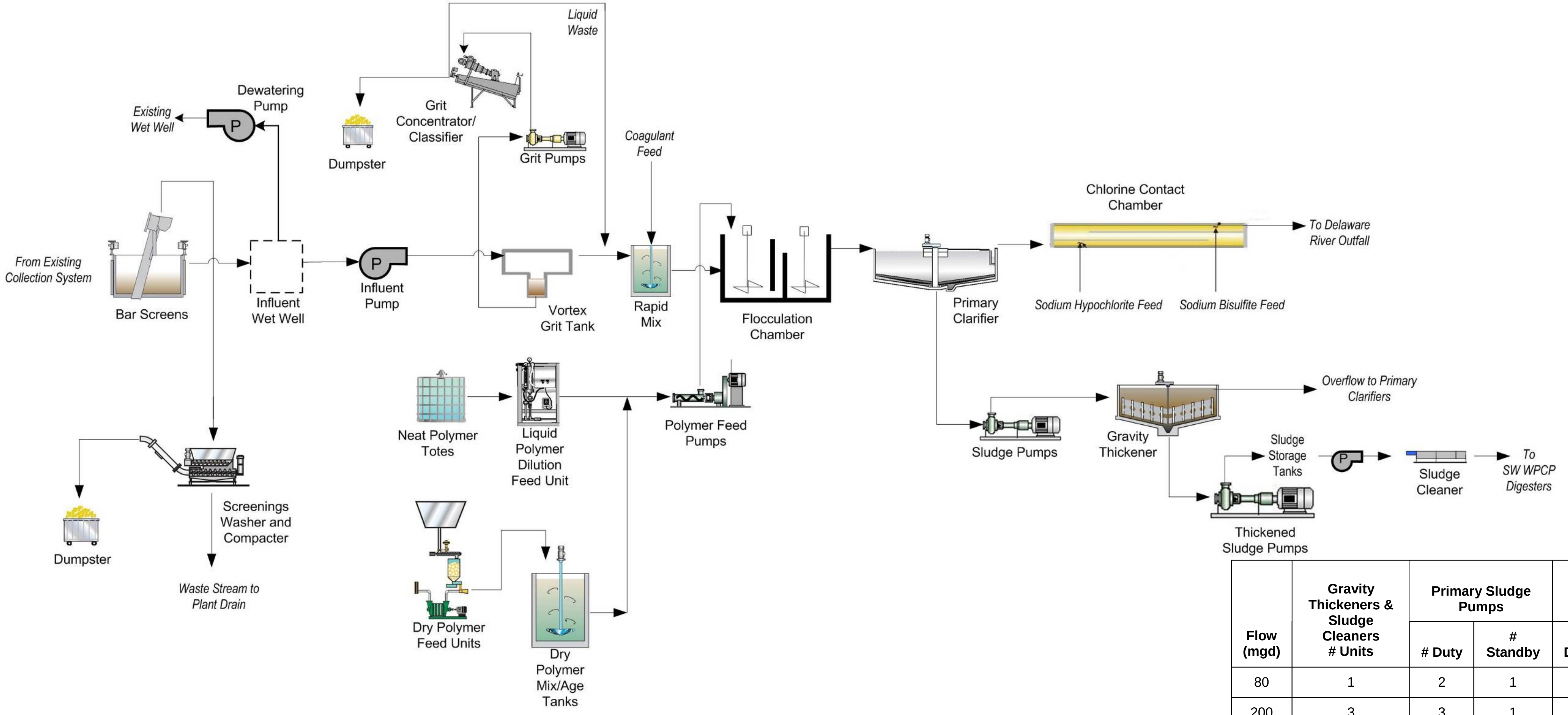
6.3.1 Startup and Shutdown

The startup time of the CEPT treatment train is approximately 2 to 3 hours, which is the time it takes to either fill up an empty clarifier tank, or to displace existing wastewater in a tank. As with the conventional primary clarifiers, the CEPT tanks can be filled with treated effluent or pumped down when taken out of service.

A liquid polymer system is provided to allow immediate start up of this wet weather treatment train, since dry polymer preparation and aging takes approximately 2 hours. Once the dry polymer has aged, it can be substituted for liquid polymer. Dry polymer has the benefit of taking up less space and having a somewhat longer shelf life than emulsion polymer. A well-designed neat polymer storage tank system provides a shelf life of about six months, while dry polymer generally has a shelf life of 12 months when properly stored in a clean, dry environment. A small liquid polymer system for startup and a dry polymer system following startup are both included in the cost and footprint estimates. For a cost estimate of using liquid polymer only, see Section 9-1.

EXHIBIT 6-1

Process Flow Diagram and Key Process Design Parameters for Treatment Train #3: CEPT



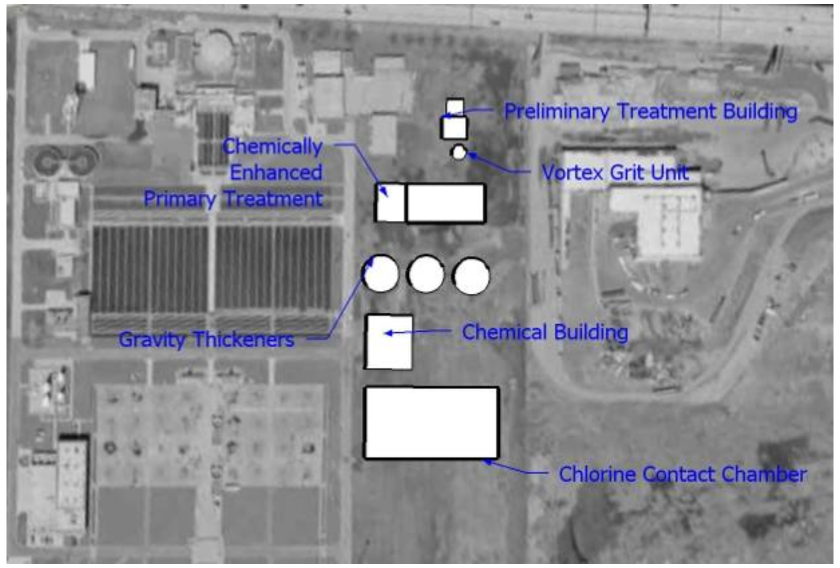
Flow (mgd)	Gravity Thickeners & Sludge Cleaners # Units	Primary Sludge Pumps		Thickened Sludge Pumps		Sludge Prod. lb/day	Digesters (SW WPCP)
		# Duty	# Standby	# Duty	# Standby		# units
80	1	2	1	1	1	142067	1
200	3	3	1	3	1	355168	1
470	3	6	2	3	1	362271	1
900	4	11	3	4	1	406667	1

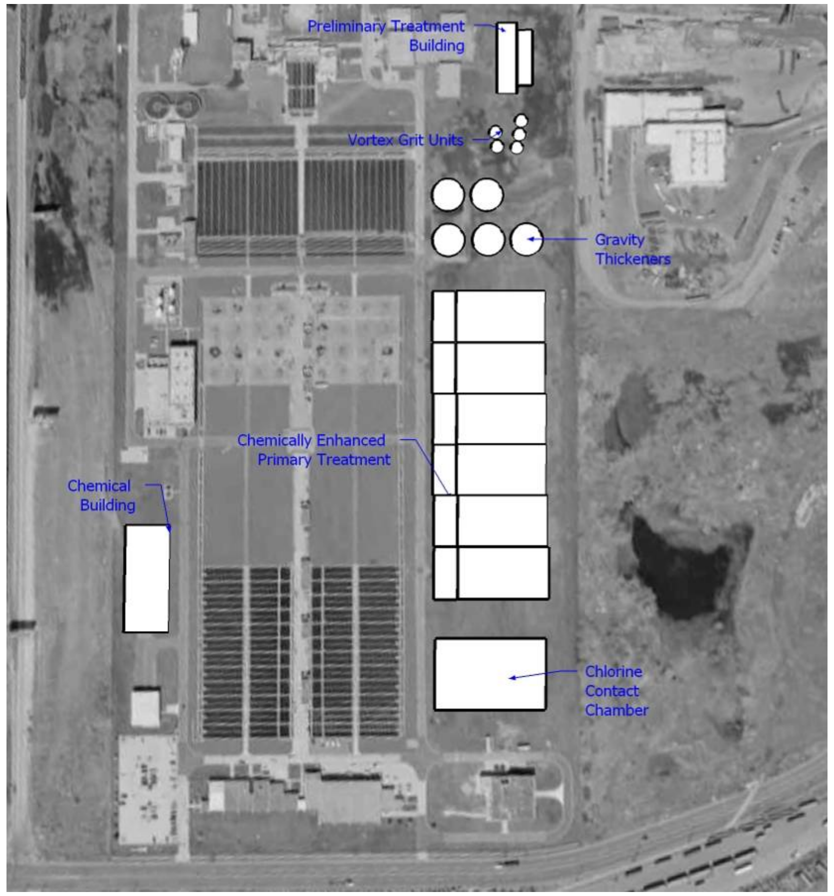
Flow (mgd)	Bar Screens # Units	Influent Pumps # Units	Vortex Grit Tank		Screenings Washer/ Compactor # Units	Grit Pumps		Grit Concentrator # Units	Grit Classifier # Units	Screenings and Grit Prod. Compacted Volume (cf/day)	Ferric Chloride			Liquid Polymer Total Storage Vol (gal)	Dry Polymer			Sodium Hypochlorite			Sodium Bisulfite			Flocculation # Trains	Clarification # Trains
			# Units	DIA (ft)		# Duty	# Standby				Total Storage Vol (gal)	# Duty Pumps	# Standby Pumps		Total Storage Vol (ton)	# Duty Pumps	# Standby Pumps	Total Storage Vol (gal)	# Duty Pumps	# Standby Pumps	Total Storage Vol (gal)	# Duty Pumps	# Standby Pumps		
80	1	1	1	32	1	1	1	1	1	460	83,940	2	1	300	7	2	1	39,831	1	1	6,226	1	1	2	2
200	2	3	2	32	2	2	1	2	1	1150	209,851	3	1	900	17	3	1	99,579	1	1	6,226	1	1	3	3
470	5	7	5	32	5	5	1	5	3	1173	214,048	6	2	900	17	6	2	101,570	1	1	6,226	1	1	6	6
900	9	12	9	32	9	9	1	9	5	1317	240,279	11	4	1200	19	11	4	114,018	1	1	6,606	1	1	11	11

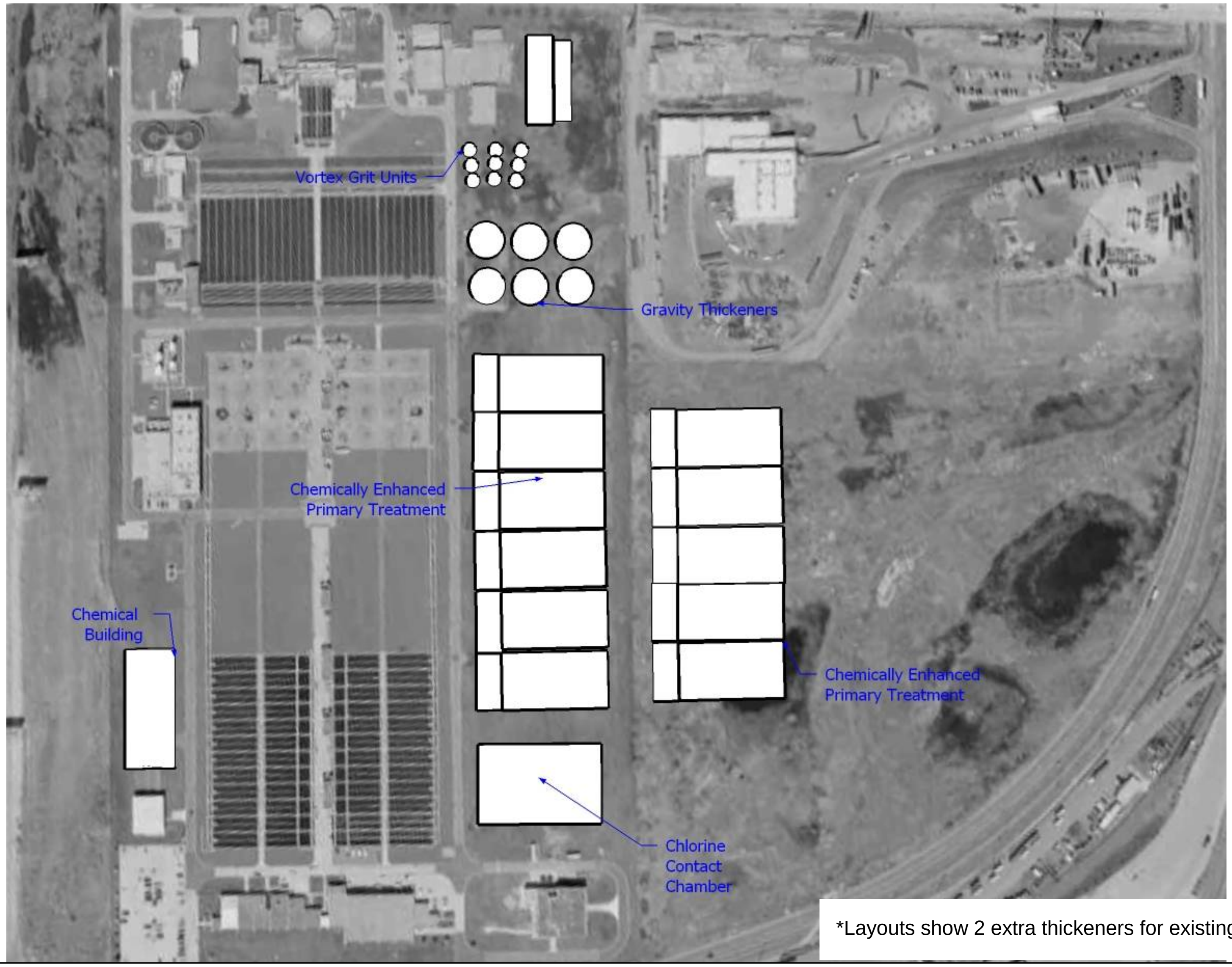
EXHIBIT 6-2

Conceptual Layouts and Footprints for Treatment Train #3: CEPT

80 MGD Layout (top left), 470 MGD Layout (bottom left), 900 MGD (right)







*Layouts show 2 extra thickeners for existing primary clarifiers

Flow (Mgd)	PTB	Grit Units	Flocculation Tanks	Clarifier Tanks	Chemical Building	CCC	Gravity Thickeners*	Land Acquired	TOTAL FOOTPRINT (acres)
80	54' x 47' & 39' x 39'	32' (1 unit)	84' x 51' (3 units)	84' x 171' (2 units)	116' x 106'	147' x 287' (7 passes)	80' (1 unit)	NONE	2.3
200	80' x 49' x 63' x 39'	32' (2 units)	84' x 62' (3 units)	104' x 226' (3 units)	165' x 106'	109' x 193' (5 passes) or 176' x 310' (9 passes)	80' (3 units)	NONE	3.4
470	132' x 53' & 140' x 39'	32' (5 units)	125' x 56' (6 units)	125' x 221' (6 units)	189' x 100'	172' x 168' (8 passes)	80' (3 units)	NONE	7.5
900	197' x 60' & 180' x 39'	32' (9 units)	125' x 57' (11 units)	124' x 231' (11 units)	205' x 100'	172' x 268' (8 passes)	80' (4 units)	11 acres	12.9

The other processes in the system are physical or physical/chemical treatment systems that are easily and quickly brought online and will achieve normal levels of treatment efficiency quickly.

6.3.2 Interaction with Main Plant

As described in the previous treatment trains, two waste streams from the gravity thickeners will interact with the existing plant. Thickened sludge will be pumped to the existing storage tanks at an estimated rate of 0.6 to 6.4 mgd, depending on the flow capacity of the treatment train. The overflow from the thickeners, ranging from 3 to 32 mgd, is recycled back to the head of the plant for distribution across the main plant and the wet weather treatment train.

6.3.3 Impact on Plant Operations

CEPT requires the addition of chemicals, ferric chloride and polymer, that are not currently used at the SE WPCP. Storage of these new chemicals will need to be monitored to ensure that they are not degraded over time, especially during long periods of shutdown. The system effluent may need to be recycled to the head of the existing plant until the unit process is stabilized.

6.4 Cost Analyses

The estimated capital, O&M, and lifecycle costs for each flow scenario are shown in Exhibit 6-3. Total capital costs and the capital costs per volume treated are also shown in Exhibits 6-4 and 6-5. Estimated O&M costs by category are shown in Exhibit 6-6. A more detailed breakdown of these costs is presented in Attachment SE-3.1.

EXHIBIT 6-3
Cost Summary for CEPT Train #3

	Wet Weather Flow (mgd)			
Cost	**80**	**200**	**470**	**900**
Capital Cost ($M)	$160	$286	$564	$966
Annual Operations and Maintenance Cost ($M)	$2.0	$3.1	$4.5	$5.6
Present Value of the Cost ($M)	$190	$334	$635	$1,053

EXHIBIT 6-4

Capital Costs for Treatment Train #3: CEPT

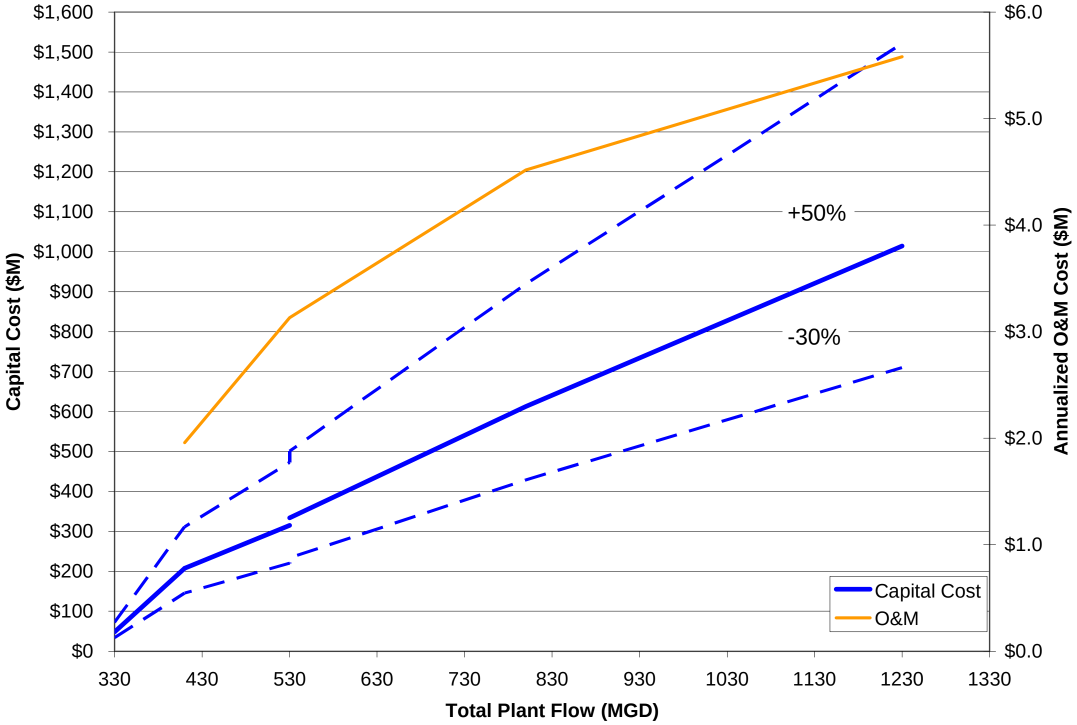


EXHIBIT 6-5

Capital Costs per Gallon Treated for Treatment Train #3: CEPT

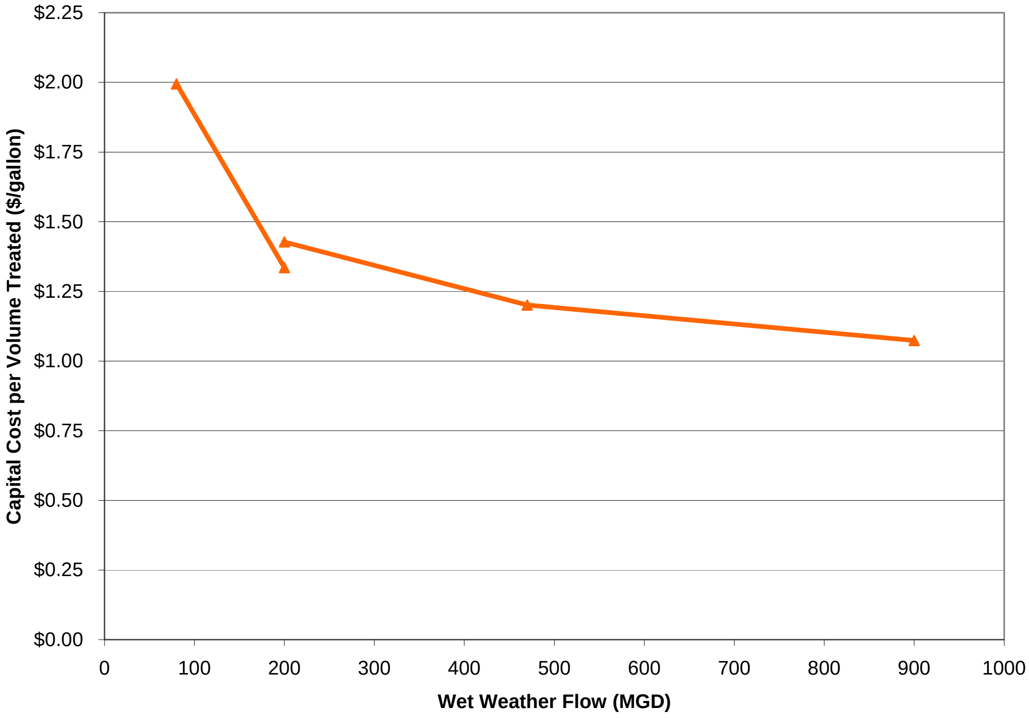
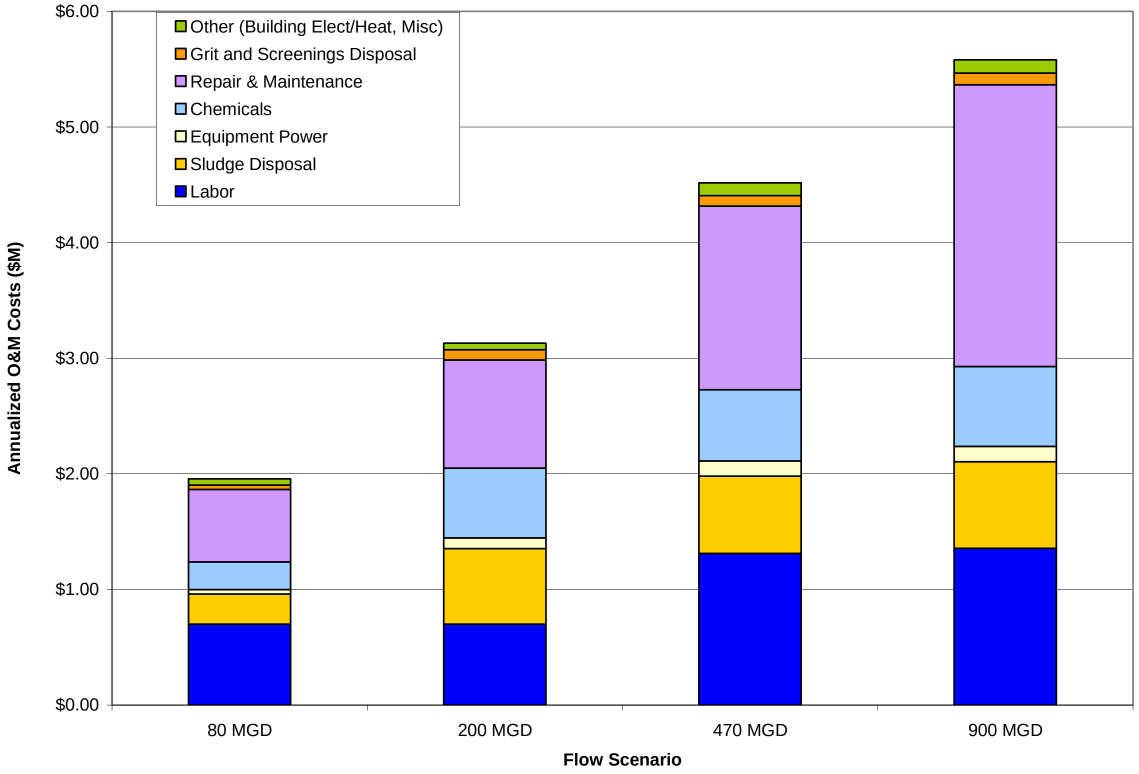


EXHIBIT 6-6
Operations and Maintenance Costs by Category for Treatment Train #3: CEPT



7.0 Treatment Train #4 - CEPT with Plate Settlers

7.1 Process Flow Diagram

Building upon Treatment Train #3, this train utilizes the addition of plate settlers in the primary clarifiers to increase the effective settling area of the tank. With chemical addition and the increased settling area, the surface overflow rate is estimated to increase from 3000 gpd/sf for CEPT only, to 7000 gpd/sf with the addition of plates. To prevent the plate settlers from clogging, fine screening is included as an additional process in this train (Exhibit 7-1).

7.2 Conceptual Design and Site Layouts

Conceptual designs were developed at three different flow scenarios for this train: 80, 200, and 900 mgd. Key design parameters at these flows are shown in Exhibit 7-1. Due to the higher surface loading rate of these tanks, a 900 mgd facility will be able to fit on the existing site (Exhibit 7-2).

7.3 Operational and Technology-Specific Issues

7.3.1 Startup and Shutdown

The requirements for startup and shutdown are similar to those for the CEPT treatment train.

7.3.2 Interactions with Main Plant

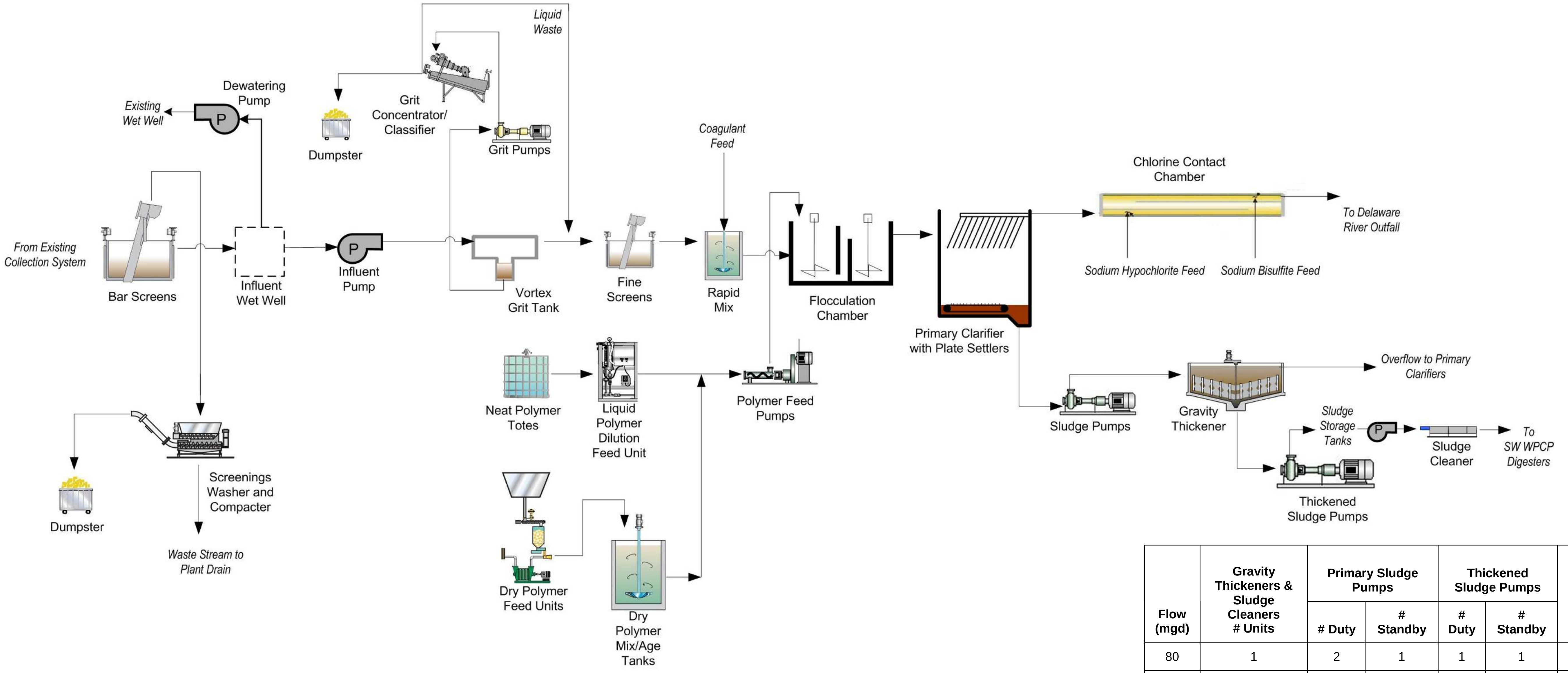
The waste streams from the gravity thickeners will be similar in flow to the CEPT treatment train. An estimated thickened sludge flow of 0.6 to 6.4 mgd, depending on the flow capacity of the treatment train, will be pumped to the existing sludge storage tanks. The overflow from the thickeners, ranging from 3 to 32 mgd depending on the flow capacity of the treatment train, will be recycled back to the head of the entire plant.

7.3.3 Impact on plant operations

In addition to the same impacts on plant operations associated with CEPT, plate settlers require regular cleaning to maintain performance, especially due to the sticky nature of the solids that are typically present in wastewater. There will also be additional maintenance associated with the set of fine screens as well.

EXHIBIT 7-1

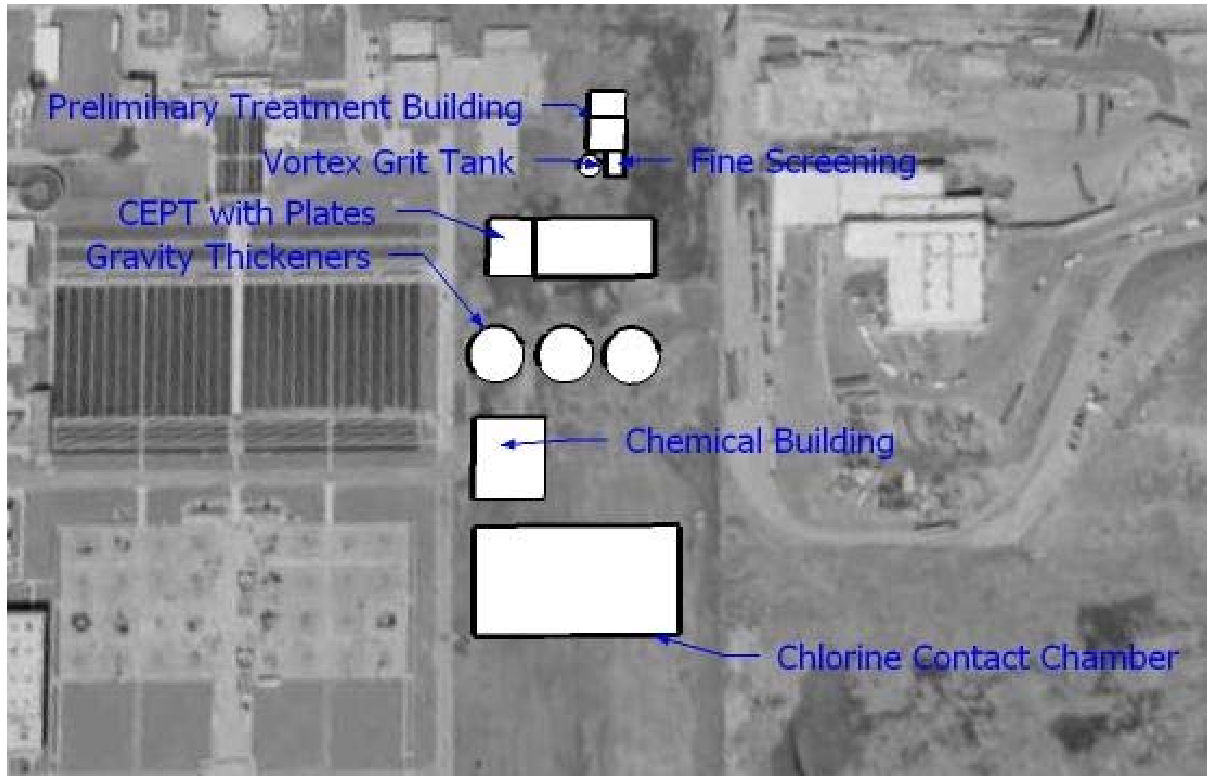
Process Flow Diagram and Key Process Design Parameters for Treatment Train #4: CEPT with Plates

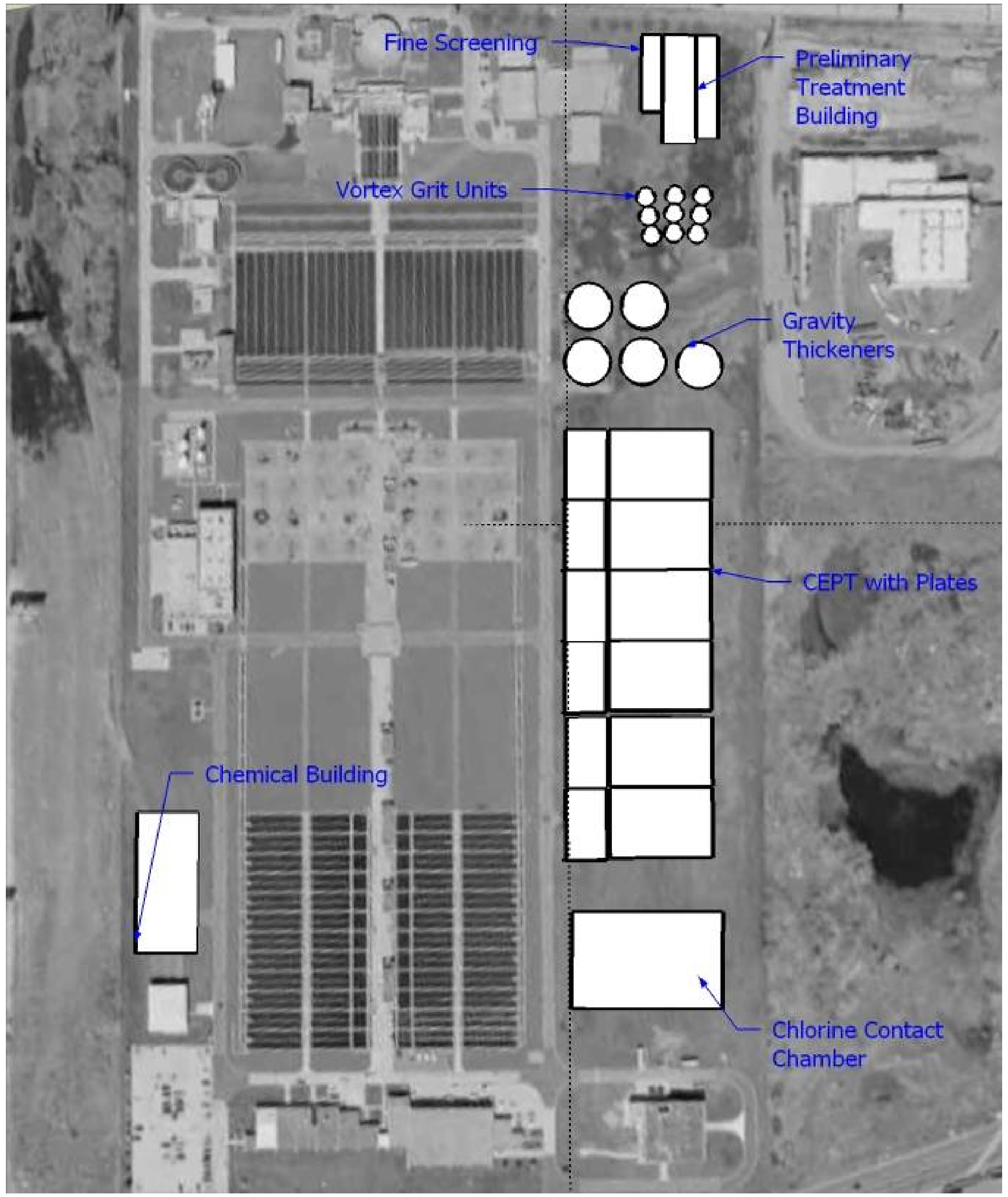


Flow (mgd)	Gravity Thickeners & Sludge Cleaners # Units	Primary Sludge Pumps		Thickened Sludge Pumps		Sludge Prod. lb/day	Digesters (SW WPCP)
		# Duty	# Standby	# Duty	# Standby		# units
80	1	2	1	1	1	142067	1
200	3	3	1	3	1	355168	1
900	3	12	4	3	1	406667	1

Flow (Mgd)	Bar Screens # Units	Influent Pumps # Units	Vortex Grit Tank		Fine Screening # Units	Screenings Washer/ Compactor # Units (for bar/fine screening)	Grit Pumps		Grit Concentrator # Units	Grit Classifier # Units	Screenings and Grit Prod. Compacted Volume (cf/day)	Ferric Chloride			Liquid Polymer	Dry Polymer			Sodium Hypochlorite			Sodium Bisulfite			Flocculation	Clarification
			# Units	Dia (Ft)			# Duty	# Standby				Total Storage Vol (Gal)	# Duty Pumps	# Standby Pumps	Total Storage Vol (Gal)	Total Storage Vol (Ton)	# Duty Pumps	# Standby Pumps	Total Storage Vol (Gal)	# Duty Pumps	# Standby Pumps	Total Storage Vol (Gal)	# Duty Pumps	# Standby Pumps	# Trains	# Trains
80	1	1	1	32	1	2	1	1	1	1	551	83,940	1	1	300	7	1	1	39,831	1	1	6,226	1	1	1	1
200	2	3	2	32	2	4	2	1	2	1	1377	209,851	2	1	900	17	2	1	99,579	1	1	6,226	1	1	2	2
900	9	12	9	32	9	18	9	1	9	5	1577	240,279	6	2	1200	19	6	2	114,018	1	1	6,609	1	1	6	6

EXHIBIT 7-2
Conceptual Layouts and Footprints for Treatment Train #4: CEPT with Plates
80 MGD Layout (left), 900 MGD (right)





*Layouts show 2 extra thickeners for existing primary clarifiers

Flow (mgd)	PTB	Grit Units	Fine Screening	Flocculation Tanks	Clarifier Tanks	Chemical Building	CCC	Gravity Thickeners*	TOTAL FOOTPRINT (acres)
80	54' x 47' & 46' x 39'	32' (1 unit)	27' x 38'	84' x 66' (1 unit)	84' x 147' (1 unit)	116' x 106'	147' x 287' (7 passes)	80' (1 unit)	1.9
200	80' x 49' x 63' x 39'	32' (2 units)	37' x 38'	84' x 72' (2 units)	84' x 183' (2 units)	165' x 106'	109' x 193' (5 passes) or 176' x 310' (9 passes)	80' (3 units)	2.4
900	197' x 60' & 187' x 39'	32' (9 units)	140' x 38'	124' x 73' (6 units)	124' x 183' (6 units)	259' x 104'	172' x 268' (8 passes)	80' (3 units)	7.8

7.4 Cost Analyses

The estimated capital, O&M, and lifecycle costs for each flow scenario are shown in Exhibit 7-3. Total capital costs and the capital costs per volume treated are also shown in Exhibits 7-4 and 7-5. Estimated O&M costs by category are presented in Exhibit 7-6. A more detailed breakdown of these costs is presented in Attachment SE-3.1.

EXHIBIT 7-3
Cost Summary for CEPT with Plates: Treatment Train #4

	Wet Weather Flow (mgd)		
Cost	**80**	**200**	**900**
Capital Cost ($M)	$265	$517	$2,047
Annual Operations and Maintenance Cost ($M)	$2.0	$3.2	$5.9
Present Value of the Cost ($M)	$296	$568	$2,139

EXHIBIT 7-4
Capital Costs for Treatment Train #4: CEPT with Plates

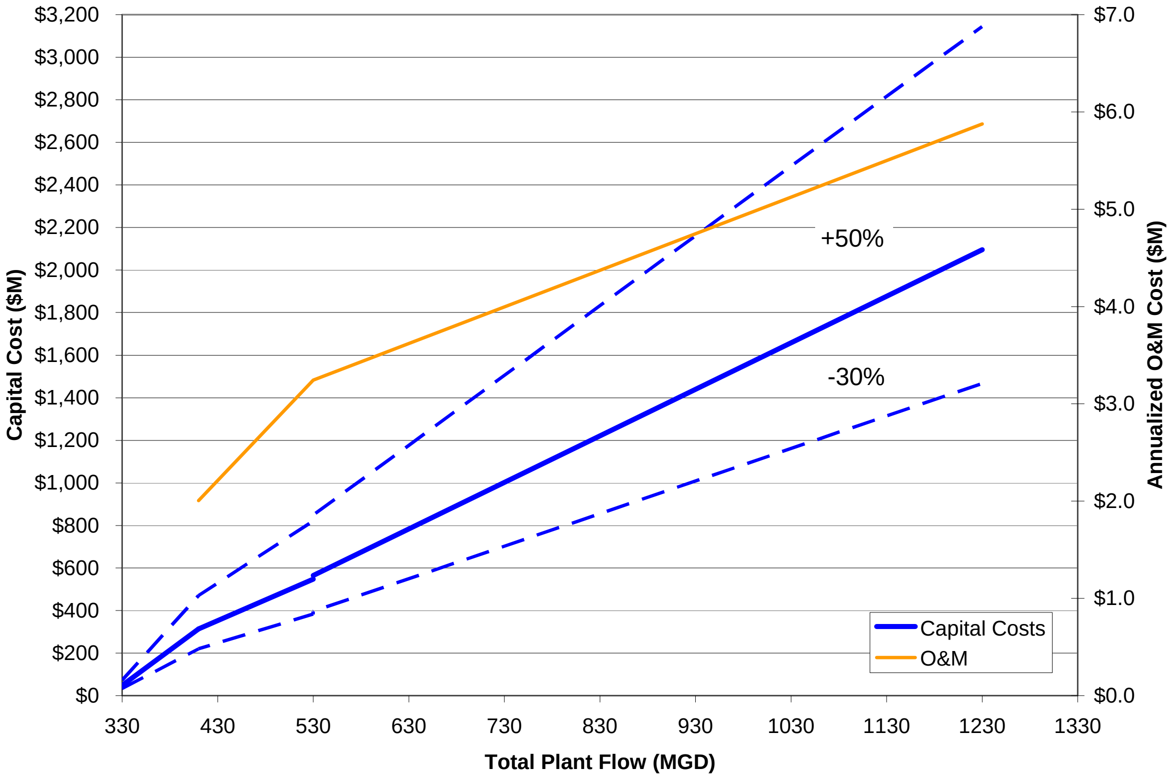


EXHIBIT 7-5
Capital Costs per Gallon Treated for Treatment Train #4: CEPT with Plates

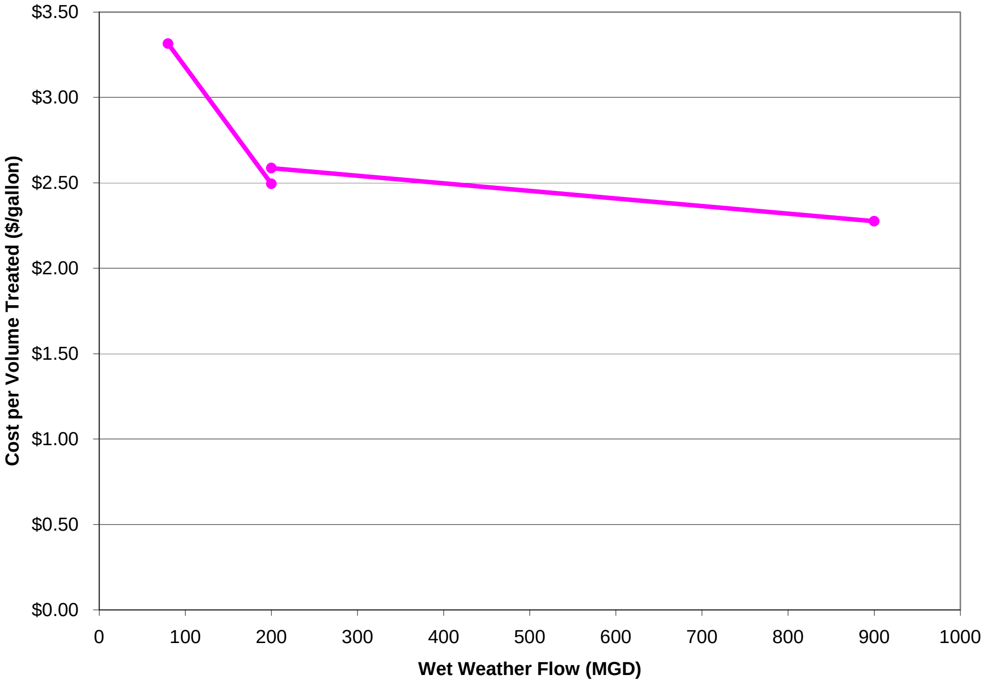
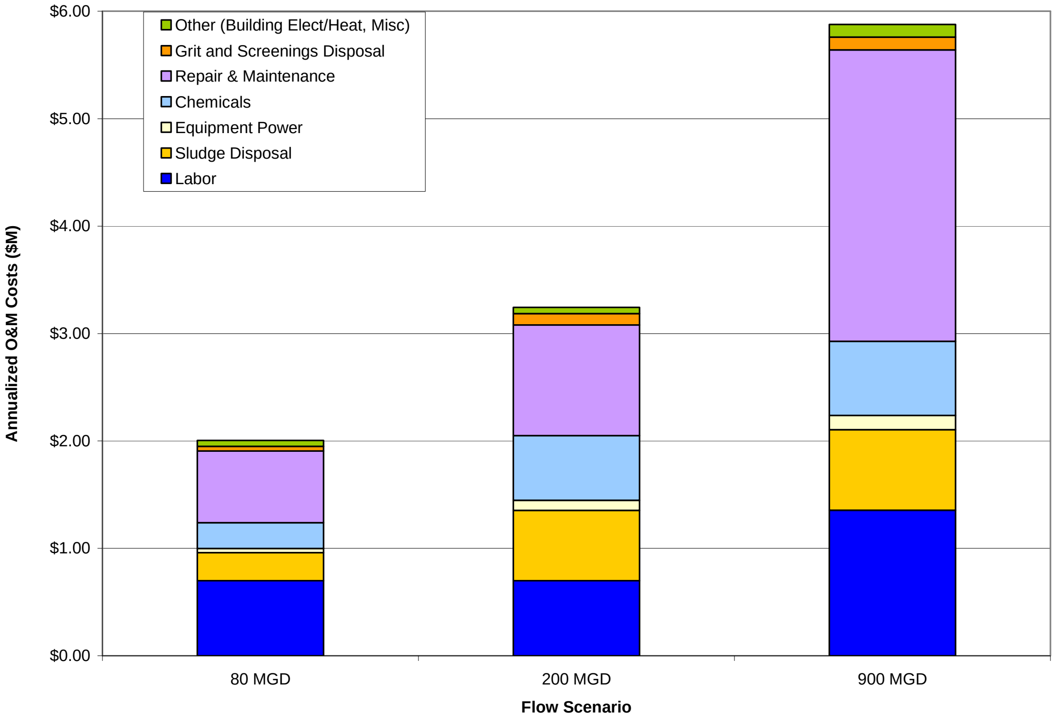


EXHIBIT 7-6
Operation and Maintenance Costs by Category for Train #4: CEPT with Plates



8.0 Treatment Train #5 - Ballasted Flocculation

The final treatment train uses ballasted flocculation to achieve removal efficiencies beyond that of CEPT. Ballasted flocculation, often referred to as “high rate treatment,” creates extremely dense flocs with high settling velocities that can be removed efficiently even at very high surface overflow rates. Two proprietary systems that use ballasted flocculation are the DensaDeg and Actiflo systems. The DensaDeg system uses chemical sludge produced within it (recirculated from the clarifier underflow to the system influent) as a ballasting agent. The Actiflo system uses microsand as the ballasting agent. Both systems can achieve TSS removals in the range of 85 to 95 percent.

Actiflo requires separate gravity thickeners to process the sludge it generates, while Densadeg recirculates its sludge within its own process and therefore produces a thicker sludge not requiring thickening. The overall cost differential is not significant in most cases, however, since Densadeg has a lower overflow rate (40 gpm/sf compared with 60 gpm/sf) and larger footprint (CH2M HILL, 2007b).

Since the overall cost of the Actiflo and DensaDeg systems have been found to be similar, only one system was chosen for evaluation for this treatment train. The Actiflo system was selected in order to show the possibility of adding gravity thickeners to the plant layout. Pilot testing should be performed to determine the system best suited for the plant, while providing other benefits such as:

- Identification of influent wastewater constituents that may affect performance of either technology
- Determining suitable chemical dosages for the ballasted flocculation system
- Providing effluent quality information that can be used for design of downstream disinfection processes
- Assessing treatment performance at typical design overflow rates
- Providing better understanding of system operation through pilot testing.

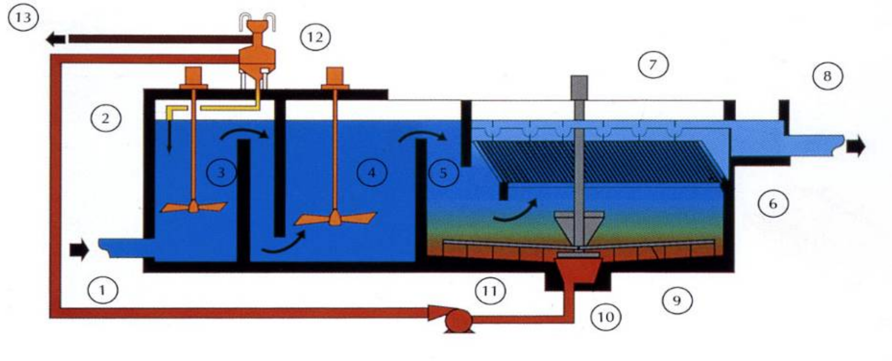
8.1 Process Flow Diagram

In the ballasted flocculation treatment train, wet weather flow passes through bar screening, influent pumps, grit removal, and fine screening before entering the ballasted flocculation system (Exhibit 8-2). A schematic of the Actiflo system is shown in Exhibit 8-1.

Using the numbers in the Exhibit, the wastewater enters at point (1) along with the coagulant (ferric chloride) to the flash mixing zone (3) where microsand is also added (2). Addition of the coagulant enhances flocculation by destabilizing suspended solids in the wastewater. Compartment (4) is a gentle mixing zone where polymer is added to promote formation of strong flocs around the microsand. The flocculated solids flow to compartment (5), the clarification zone. Most of the solids settle at the bottom of this compartment, but this zone also has lamella settling modules (6) to enhance removal of suspended solids that may be present in the wastewater. The solids accumulated at the bottom of the clarification compartment (10) are recycled to a hydrocyclone (12), where the sludge is separated from the microsand. The microsand is recycled back to the flash mixing zone (3), and the sludge leaves the system by stream (13).

As shown in Exhibit 8-2, the sludge from the ballasted flocculation process is pumped to gravity thickeners to be thickened from 0.3 percent solids to 3-4 percent solids.

EXHIBIT 8-1
Schematic of the ACTIFLO High-Rate Primary Clarifier (scanned from vendor's brochure)

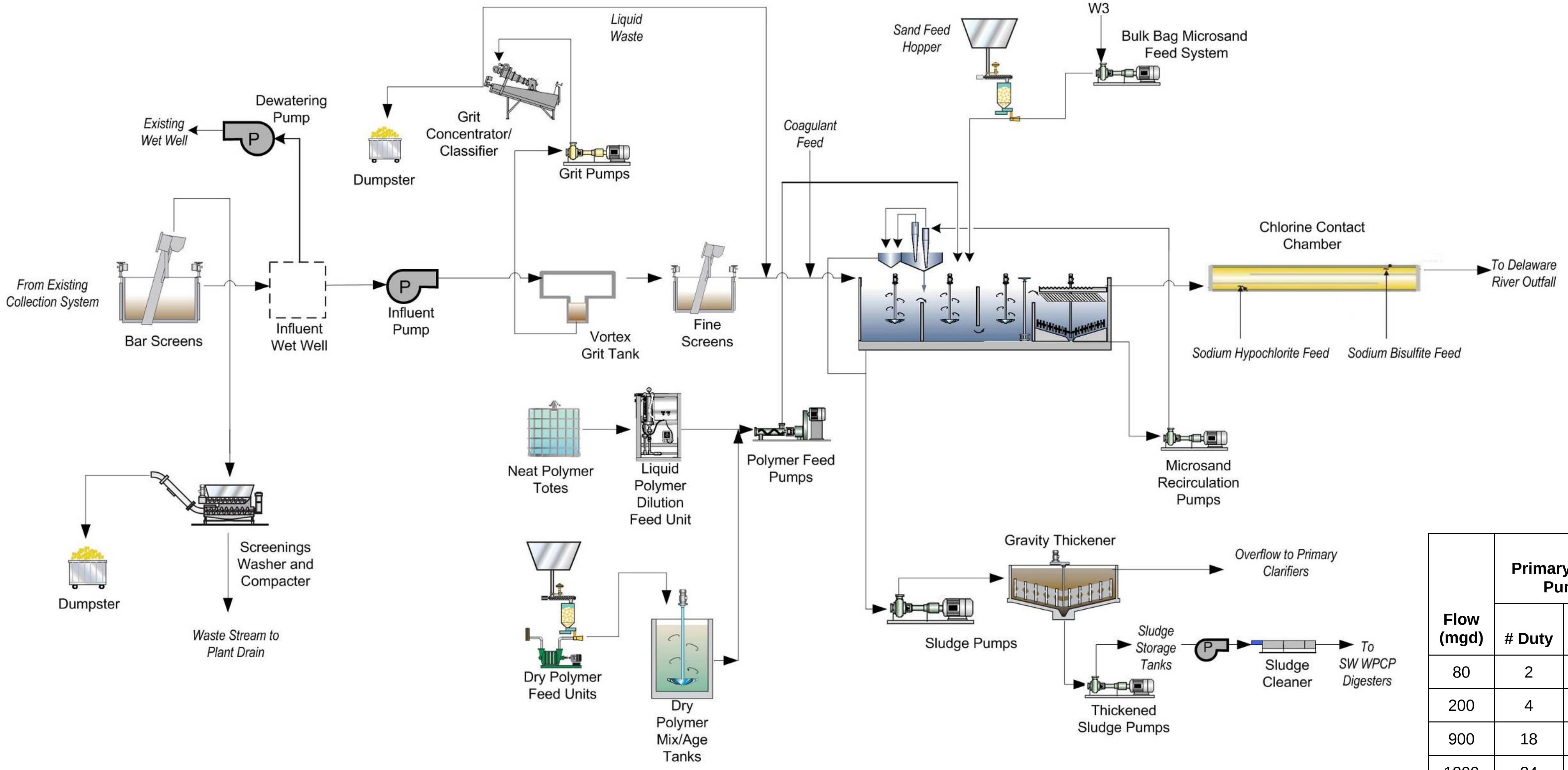


8.2 Conceptual Design and Site Layouts

Conceptual designs using the ballasted flocculation system were developed for flow capacities of 80, 200, 900, and 1,200 mgd. The 1,200 mgd scenario was developed to show the maximum flow that can be treated using the available land onsite. The key design parameters are presented in Exhibit 8-2. As seen in the conceptual layouts in Exhibit 8-3, the space requirements of this treatment train are minimal compared to the other alternatives. This is due to its extremely high surface overflow rate of 60 gpm/sf.

EXHIBIT 8-2

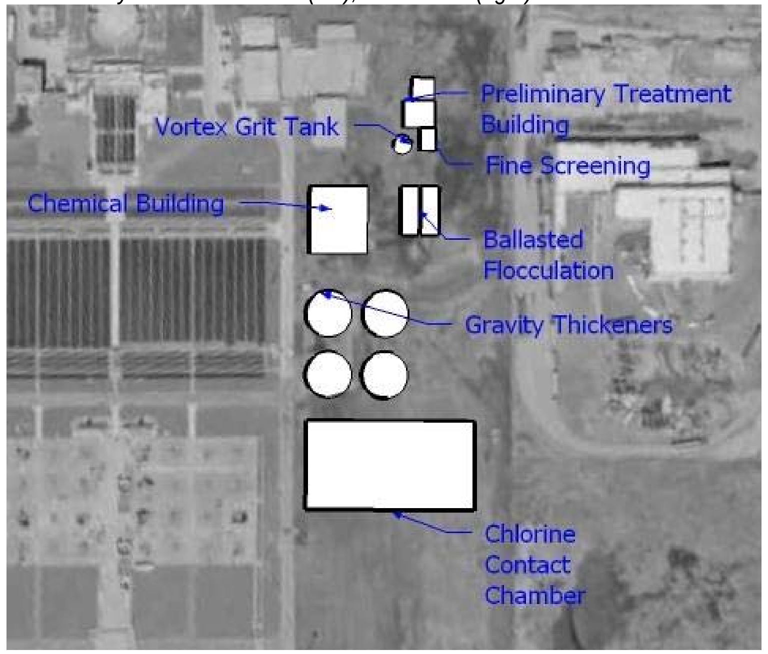
Process Flow Diagram and Key Process Design Parameters for Treatment Train #5: Ballasted Flocculation

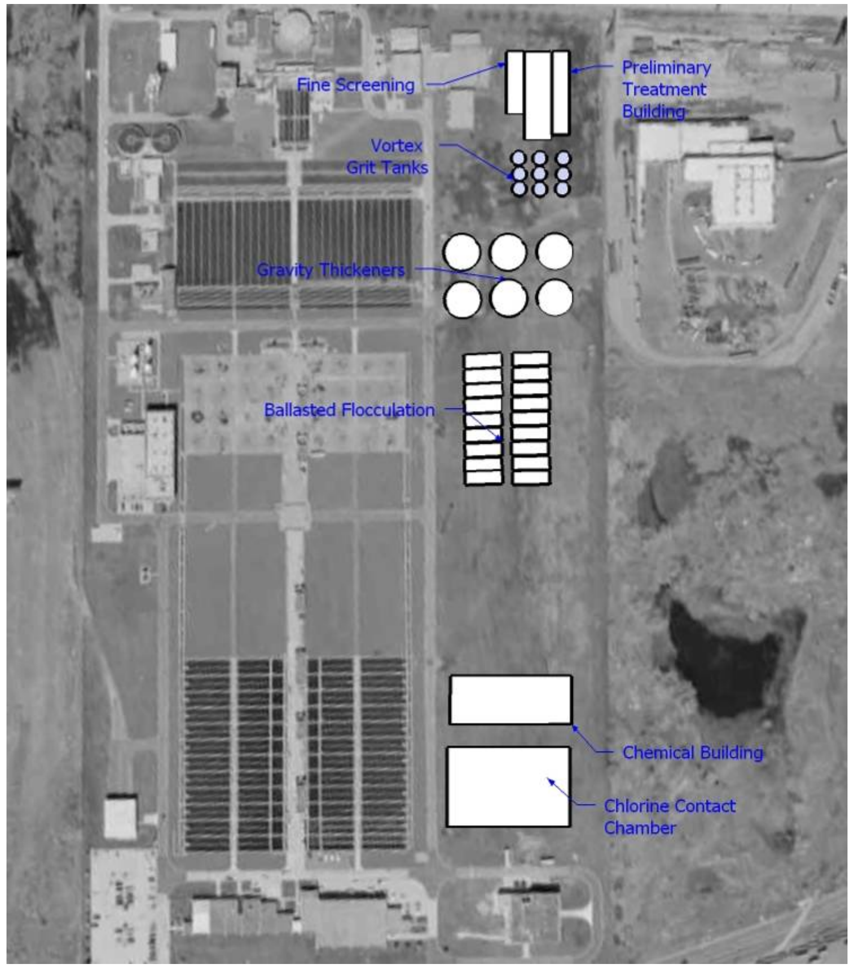


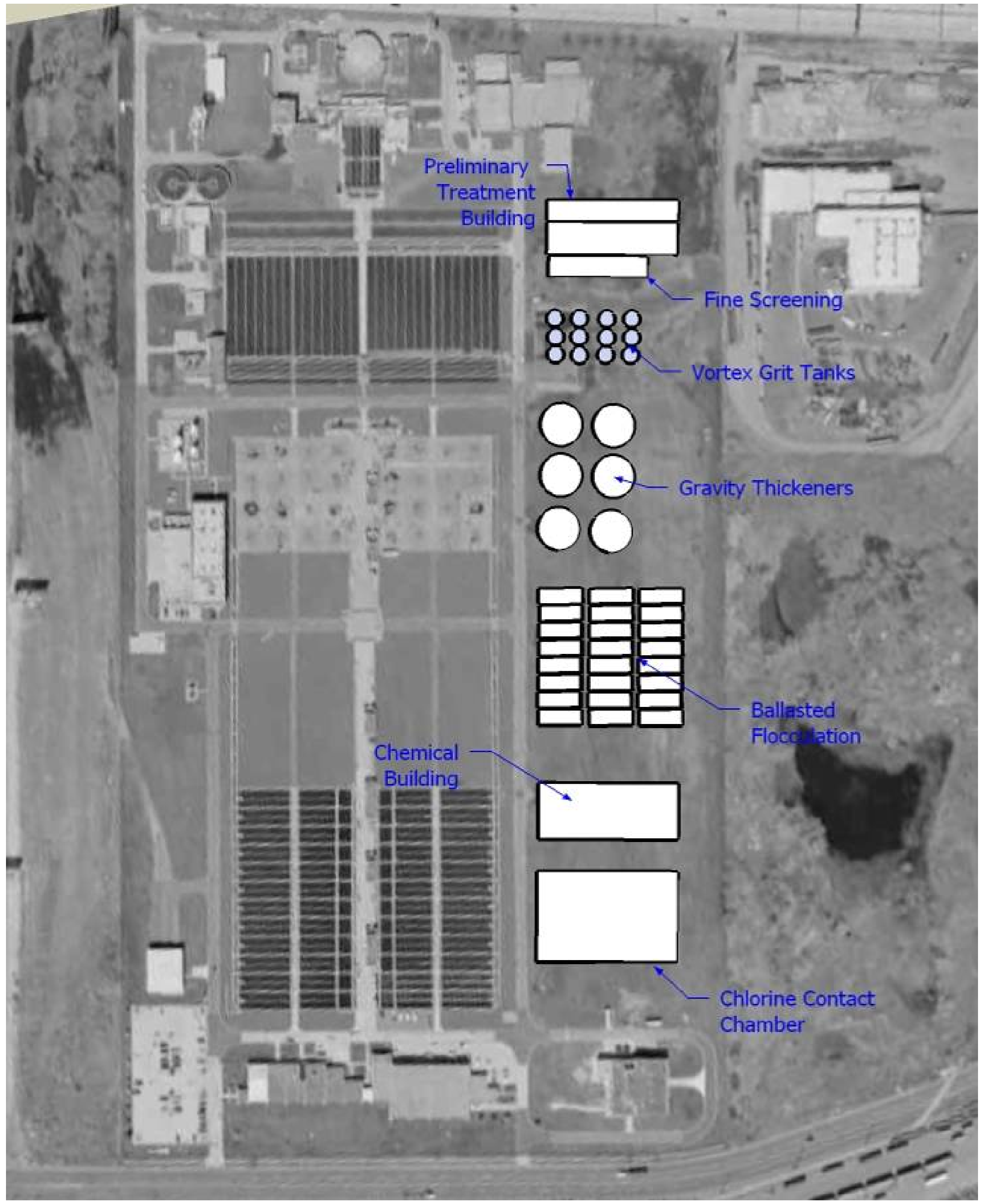
Flow (mgd)	Primary Sludge Pumps		Thickened Sludge Pumps		Sludge Prod. lb/day	Digesters (SW WPCP)
	# Duty	# Standby	# Duty	# Standby		# units
80	2	1	2	1	159,825	1
200	4	1	4	1	399,564	1
900	18	6	4	1	457,500	1
1200	24	8	4	1	457,500	1

Flow (Mgd)	Bar Screens # Units	Influent Pumps # Units	Vortex Grit Tank		Fine Screening # Units	Screenings Washer/ Compactor # Units (for bar/fine screening)	Grit Pumps		Grit Concentrator # Units	Grit Classifier # Units	Screenings and Grit Prod. Compacted Volume (Cf/Day)	Ferric Chloride			Liquid Polymer Total Storage Vol (Gal)	Dry Polymer			Sodium Hypochlorite			Sodium Bisulfite			Actiflo	Gravity Thickeners & Sludge Cleaners
			# Units	Dia (Ft)			# Duty	# Standby				Total Storage Vol (Gal)	# Duty Pumps	# Standby Pumps		Total Storage Vol (Ton)	# Duty Pumps	# Standby Pumps	Total Storage Vol (Gal)	# Duty Pumps	# Standby Pumps	Total Storage Vol (Gal)	# Duty Pumps	# Standby Pumps	# Trains	# Units
80	1	1	1	32	1	2	1	1	1	1	551	83,940	2	1	600	7	2	1	39,831	1	1	6,226	1	1	2	2
200	2	3	2	32	2	4	2	1	2	1	1377	209,851	4	1	900	17	4	1	99,579	1	1	6,226	1	1	4	4
900	9	12	9	32	9	18	9	3	9	5	1577	240,279	18	5	1200	19	18	5	114,018	1	1	6,606	1	1	18	4
1200	12	16	12	32	12	24	12	4	12	7	1577	240,279	24	6	1200	19	24	6	114,018	1	1	6,606	1	1	24	4

EXHIBIT 8-3
Conceptual Layouts and Footprints for Treatment Train #5: Ballasted Flocculation
80 MGD Layout and 900 MGD (left), 1200 MGD (right)







*Layouts show 2 extra thickeners for existing primary clarifiers

Flow (mgd)	PTB	Grit Units	Fine Screening	Actiflo Units	Chemical Building	CCC	Gravity Thickeners*	TOTAL FOOTPRINT (acres)
80	54' x 47' & 39' x 39'	32' (1 unit)	27' x 38'	32' x 86' (2 unit)	116' x 106'	147' x 287' (7 passes)	80' (2 unit)	1.6
200	80' x 49' x 63' x 39'	32' (2 units)	37' x 38'	32' x 86' (4 units)	165' x 106'	109' x 193' (5 passes) or 176' x 310' (9 passes)	80' (4 units)	1.8
900	197' x 60' & 187' x 39'	32' (9 units)	140' x 38'	32' x 86' (18 units)	187' x 106'	172' x 268' (8 passes)	80' (4 units)	4.0
1200	249' x 61' & 248' x 39'	32' (12 units)	187' x 38'	32' x 86' (24 units)	205' x 106'	172' x 268' (8 passes)	80' (4 units)	4.5

8.3 Operational and Technology-Specific Issues

8.3.1 Startup and Shutdown

Ballasted flocculation systems stabilize quickly, with Actiflo taking less than 20 minutes and DensaDeg less than 45 minutes to start producing good quality effluent based on demonstration testing. Infilco Degremont indicated that the DensaDeg process will produce design effluent immediately if left filled with chlorinated plant effluent. However, based on piloting studies, a connection should be provided for discharging wet weather effluent to the head of the existing plant during startup or until ballasted flocculation system performance stabilizes. To facilitate startup, the ballasted flocculation system should also be underloaded initially.

Shutdown can occur at the operator’s convenience. Typically, equipment will simply need to be switched off. The hydrocyclones should be pumped down before being turned off. The tanks themselves can either be filled with treated effluent, or drained down. To prevent freezing during cold weather, any system that is not totally enclosed should have a constant flow of water, or be drained down. The cost estimate does not include a building for the ballasted flocculation units since they are able to be effectively operated in an outdoor environment, and the inclusion of a building would add unnecessary capital costs to this alternative.

The advantage of leaving the basins filled with water is that the startup time is substantially reduced and the basins reach their design effluent quality much more quickly. This reduces the volume of partially treated water that must be returned to the existing treatment plant. Running a small flow through the tanks also helps in maintaining equipment, such as the tank mixers. Actiflo’s manufacturer recommends leaving the sand in the tanks only if the tanks are filled with effluent. With sand readily available in the tanks, treatment can begin sooner. If the system were fully drained, the sand within the Actiflo system would require removal and disposal to prevent freezing. Upon startup, sand would have to be reintroduced into the treatment flow using the bulk sand feed system. Infilco Degremont indicates that solids should be removed from the DensaDeg system within six hours to prevent septicity. The DensaDeg system can then be left filled with chlorinated plant effluent.

8.3.2 Interaction with Main Plant

During startup, effluent from the ballasted flocculation system will be discharged to the head of the main plant until system performance stabilizes.

Similar to the other treatment trains, recycle flows from the screenings washer/compactor and grit classifier will be conveyed to the ballasted flocculation system with the wet weather treatment train. The overflow streams from the gravity thickeners, however, must be sent to the head of the main plant for distribution across both the wet weather treatment train and the existing plant. Since this treatment train has the highest removal efficiency, it generates the highest sludge and overflow volumes. In addition, the solids content of the sludge is thinner compared to primary clarifier sludge as a result of the cyclones used to separate the ballast from the sludge. The estimated overflow volume is 6 to 86 mgd, depending on the flow capacity of the treatment train. Thickened sludge will be pumped to the existing sludge storage tanks at a rate of 0.6 to 9.6 mgd.

8.3.3 Impact on plant operations

To simplify routine operation, Actiflo and Densadeg typically have automated routine startup and shutdown sequences with PLC programming and adjustable timers (service interval, tank fill, equipment run, shutdown, and tank drain). However, operator attention will be necessary to monitor or optimize performance, and to confirm successful facility startup. The operators will have the following responsibilities:

- Start the process train
- Monitor coagulant and polymer dose and perform jar tests to optimize chemical dosing.
- Manage the loading of screenings and grit dumpsters.
- Observe equipment operation and contact maintenance if equipment malfunctions.

8.3.4 Other Issues

Foaming – Foaming may occur due to the addition of coagulants and polymer settling aids, and should be investigated in pilot studies. For example, during startup of the Actiflo unit at Lawrence WWTP in Lawrence, Kansas, the observed foaming resulted from the reaction of ferric chloride with biodegradable surfactants in the incoming wastewater. Foaming can be controlled using silica-based defoamers such as Tramfloc 110, Chemco DF, and Neo Solutions NS-8454 at low dosages.

Floc Carryover and Microsand Loss – Floc carryover is an issue for the DensaDeg system that should be investigated through pilot tests. As flows approach the design SOR, sludge densities may decrease, sending large flocs of sludge out in the effluent. These large flocs not only affect effluent quality in terms of TSS and BOD levels, but may also decrease effectiveness of the disinfection process downstream.

Regarding the Actiflo system, a certain degree of microsand loss is expected from normal operation of the system. The manufacturer indicates that about 8 pounds of microsand are lost for each million gallons of wastewater treated. The sand must be replaced for optimal operation of the system. According to information gathered during the team’s site visit to the Cincinnati Metropolitan Sewer District, the SSO 700 Facility loses 350 lbs of sand per 15 mg wet weather event. In the conceptual design of this treatment train, adequate storage space was provided in the chemical buildings for 10 day storage of sand. Additionally, the microsand needs to be maintained in the system in case rapid startup is required, and the sand must be prevented from freezing during the winter so that the unit can start up quickly if needed during the cold season. The DensaDeg unit is totally drained when the system is shut down, and no chemical sludge is maintained in the system when it is not in use.

Sludge Concentration - One important difference between Actiflo and Densadeg is the sludge concentration that they produce. Sludge from the DensaDeg system can be four to five times more concentrated than sludge from the Actiflo system. Since the two systems are expected to produce the same mass of sludge, because they operate with similar coagulant dosages, it is expected that the volume of sludge produced in the ACTIFLO system will be four to five times greater than that in the DensaDeg unit. Gravity thickeners have been included in the conceptual design for the Actiflo treatment train to thicken the sludge to 3-4 percent solids. These thickeners may not be necessary if the Densadeg system is chosen.

8.4 Cost Analyses

The estimated capital, O&M, and lifecycle costs for each flow scenario are shown in Exhibit 8-4. Total capital costs and the capital costs per volume treated are also shown in Exhibits 8-5 and 8-6. Estimated O&M costs by category are presented in Exhibit 8-7. A more detailed breakdown of these costs is presented in Attachment SE-3.1.

EXHIBIT 8-4
Cost Summary for Ballasted Flocculation: Treatment Train #5

	Wet Weather Flow (mgd)			
Cost	**80**	**200**	**900**	**1200**
Capital Cost ($M)	$159	$278	$837	$1,050
Annual Operations and Maintenance Cost ($M)	$2.1	$3.4	$6.2	$7.0
Present Value of the Cost ($M)	$191	$331	$934	$1,159

EXHIBIT 8-5
Capital Costs for Treatment Train #5: Ballasted Flocculation

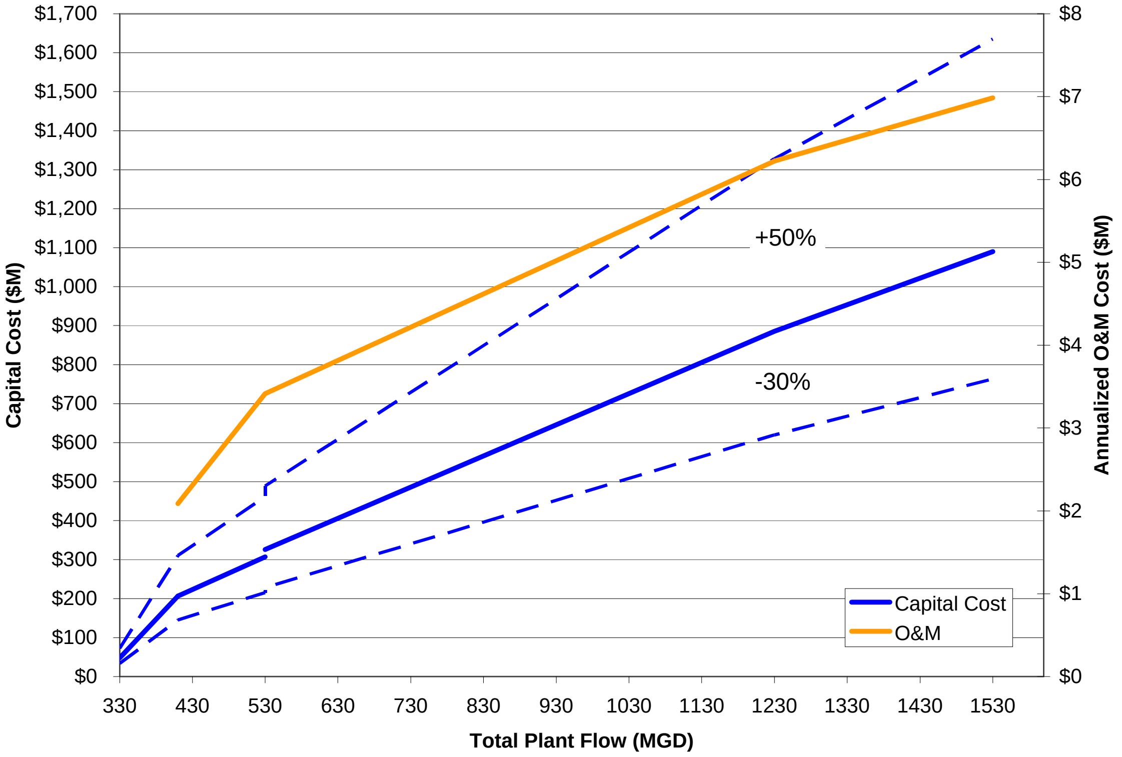


EXHIBIT 8-6
Capital Costs per Gallon Treated for Treatment Train #5: Ballasted Flocculation

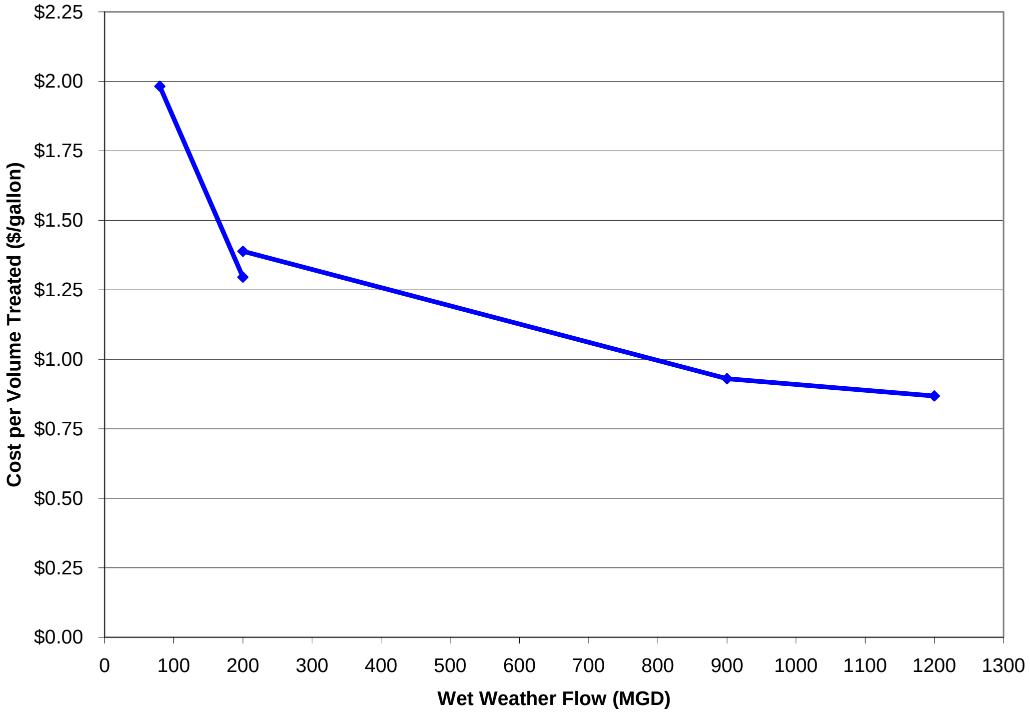
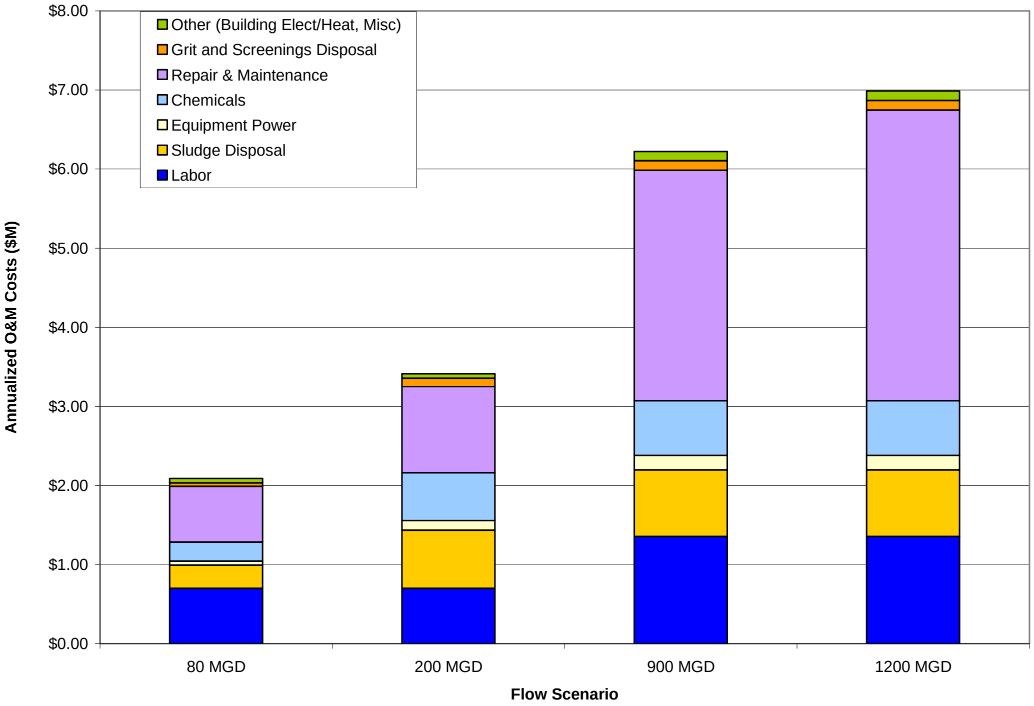


EXHIBIT 8-7
Operations and Maintenance Costs by Category for Treatment Train #5: Ballasted Flocculation



9.0 Alternatives for Optimizing Capital Costs

9.1 Polymer Usage

For Trains #3-#5, polymer is added as a flocculant to the wet weather flow. The capital costs presented for these trains include the cost for both a liquid polymer system and a dry polymer feed system. The liquid polymer system is sized for a 20-hour storage of 40 percent emulsion polymer, and would be used during the first two hours of start up of the wet weather treatment facility. This allows time for the dry polymer to be mixed and aged. The dry polymer system would include a hopper and solution tank(s) for mixing and aging. Ten day storage of dry polymer supersacks would be maintained on site.

An alternative to using dry polymer would be to maintain a 10-day storage of the liquid polymer in bulk storage tanks. The capital cost savings from using liquid polymer only for various flow scenarios is presented in Exhibit 9-1.

EXHIBIT 9-1
Capital Cost of Using Liquid Polymer Only

	Total Capital Cost ($)		
Flow (mgd)	**Liquid and Dry Polymer**	**Liquid Polymer Only**	**Cost Differential**
80	$2,142,080	$1,088,080	$1,054,000
200	$3,538,778	$1,424,771	$2,114,007
470	$5,085,895	$2,574,029	$2,511,866
900	$7,016,125	$3,355,787	$3,660,338

Note: 40% active liquid emulsion polymer assumed.

The capital cost savings are mostly due to the high cost of the dry polymer feed equipment. The main advantage of dry polymer systems is the reduction in chemical costs, which contribute significantly to the operations and maintenance costs of the plant. Dry polymer is $3400 per dry ton, which is approximately 15% cheaper than liquid polymer ($3983 per dry ton for 40 percent active emulsion). Dry polymer also has a 12-month shelf life, which is double that for liquid polymer. This is useful for systems where wet weather events occur less frequently or predictably.

Since the chemical cost of dry polymer is lower than liquid polymer, but the capital costs are higher for the dry polymer system, there is not a significant difference in the life cycle cost of the two alternatives. Thus, selection of the polymer system often depends on operational preferences. Liquid polymer systems are easier to maintain than dry polymer systems, which have the risk of clogging in the hopper and feed-lines. Having only one system to operate also reduces the complexity of the chemical feed system.

9.2 Digesters at the SW WPCP

The capital cost of one digester was included for each of the treatment trains and flow scenarios described in previous sections. Since sludge from the SE WPCP is currently transferred to the SW WPCP for treatment, the new digester is assumed to be located in the SW WPCP also.

According to PWD, as discussed in Workshop No. 3, the existing digesters at the SW WPCP may have adequate capacity to treat the wet weather flow. Since there will be gravity thickeners in the new wet weather treatment facility, the thickness and pumping rate of the sludge transferred to the SW WPCP can be controlled. Sludge can also be stored in the gravity thickeners and metered to the SW WPCP at the desired flow-rate.

The need to expand the digestion capacity of the SW WPCP for treatment of primary sludge from the SE WPCP will be determined after further analysis of the digesters and the wet weather treatment trains in SW WPCP. The costs of the digester (without markups) are included as separate line items in the detailed cost tables in Attachment SE-3.1 and can be subtracted from the total if necessary.

9.3 Ballasted Flocculation

As mentioned in Section 8, the costs presented for Treatment Train #5, Ballasted Flocculation, are based on the Actiflo system, which is similar in cost to Densadeg, the other proprietary high rate treatment technology. If the ballasted flocculation treatment train is selected, a cost estimate for the Densadeg system should be developed to examine the cost differential. The main contributions to the cost differential will include:

- **Reduction in number of thickeners** - Densadeg maintains a 3-4 percent sludge thickness for its ballast, compared to the 0.3 percent sludge thickness in the Actiflo system.
- **Increase in footprint** – Densadeg has a 40 gpm/sf loading rate, compared to Actiflo’s 60 gpm/sf loading rate.
- **Elimination of fine screening** – Actiflo requires fine screening to protect the hydrocyclones in the system, which separate sand from sludge. Since Densadeg uses sludge only as its ballast, it does not require fine screening upstream.

Implications to operations and maintenance should also be examined between the two systems. For example, Actiflo requires sand as the ballasting agent, which requires storage and maintenance.

9.4 Refined Design Assumptions via Influent Sampling

Influent sampling at the plant during wet weather events will shed light on the wastewater characteristics of the wet weather flow, as well as the flow regime during events. More concrete numbers for influent TSS, BOD, and flow can be used to refine process design parameters, which may lead to a reduction in the size and cost of the treatment trains.

10.0 Comparison of Treatment Alternatives

10.1 Effluent Water Quality

While each flow scenario for each treatment train evaluated above is capable of producing blended effluent concentrations that meet permit limits, the resulting water quality differs widely between different scenarios. The TSS and BOD concentrations of the blended effluent for each treatment train and flow scenario is presented in Exhibit 10-1 and 10-2, respectively.

EXHIBIT 10-1
Blended Effluent TSS Concentrations

Treatment Train	**Wet Weather Treatment Train Effluent Conc. (mg/L)**	**Blended Effluent TSS Concentration (mg/L)**						
		Wet Weather Treatment Train Flow (mgd)						
		80	***200***	***380***	***470***	***540***	***900***	***1200***
#1) Vortex/Swirl Concentrators								
High Loading Rate:	154	59	81	99				
Low Loading Rate:	77	44	51				66	
#2) Conventional Clarifiers	99	48	60			75	82	
#3) CEPT w/ Conventional Clarifiers	44	38	39		41		42	
#4) CEPT w/ Plate Settlers	42	37	38				40	
#5) Ballasted Flocculation	21	33	30				25	24

Notes: Based on the 95th percentile wet weather TSS concentration of 36 mg/L and a maximum of 330 MGD through the existing plant. Allowable daily blended effluent TSS concentration on wet weather days is 99 mg/L, based on permit limits.

EXHIBIT 10-2
Blended Effluent BOD Concentrations

		Blended Effluent BOD Concentration (mg/L)						
		Wet Weather Treatment Train Flow (mgd)						
Treatment Train	**Wet Weather Treatment Train Effluent Conc. (mg/L)**	***80***	***200***	***380***	***470***	***540***	***900***	***1200***
#1) Vortex/Swirl Concentrators								
High Loading Rate:	100	38	52	64				
Low Loading Rate:	63	31	38				52	
#2) Conventional Clarifiers	74	38	52			71	79	
#3) CEPT w/ Conventional Clarifiers	47	28	32		37		41	
#4) CEPT w/ Plate Settlers	46	28	32				40	
#5) Ballasted Flocculation	36	26	28				33	33

Notes: Based on the 95th percentile wet weather BOD concentration of 23 mg/L and a maximum of 330 MGD through the existing plant. Allowable daily blended effluent BOD concentration on wet weather days is 106 mg/L, based on permit limits.

It should be noted that at wet weather flows higher than 200 mgd, the blended effluent BOD concentrations for Trains #1 and #2 exceed the NPDES permit Instantaneous (daily composite) Maximum Discharge Limitation of 60 mg/L (Exhibit 10-2). While this limit is stated in the permit, there are currently no reporting requirements for this specific data point.

In addition, with an estimated removal efficiency of 30 percent at high loading rates, the vortex/swirl treatment train does not meet removal efficiencies of primary clarification (55 percent).

As described in Section 3.1, the maximum flow through all the treatment trains, with the exception of the vortex swirl at high loading rates, is unlimited if the number of wet weather days is less than 7 days per month. To illustrate the risk of exceeding permit limits at these design flows, Exhibit 10-3 presents the maximum number of days that the wet weather treatment train can operate at its maximum capacity without exceeding monthly TSS permit limits.

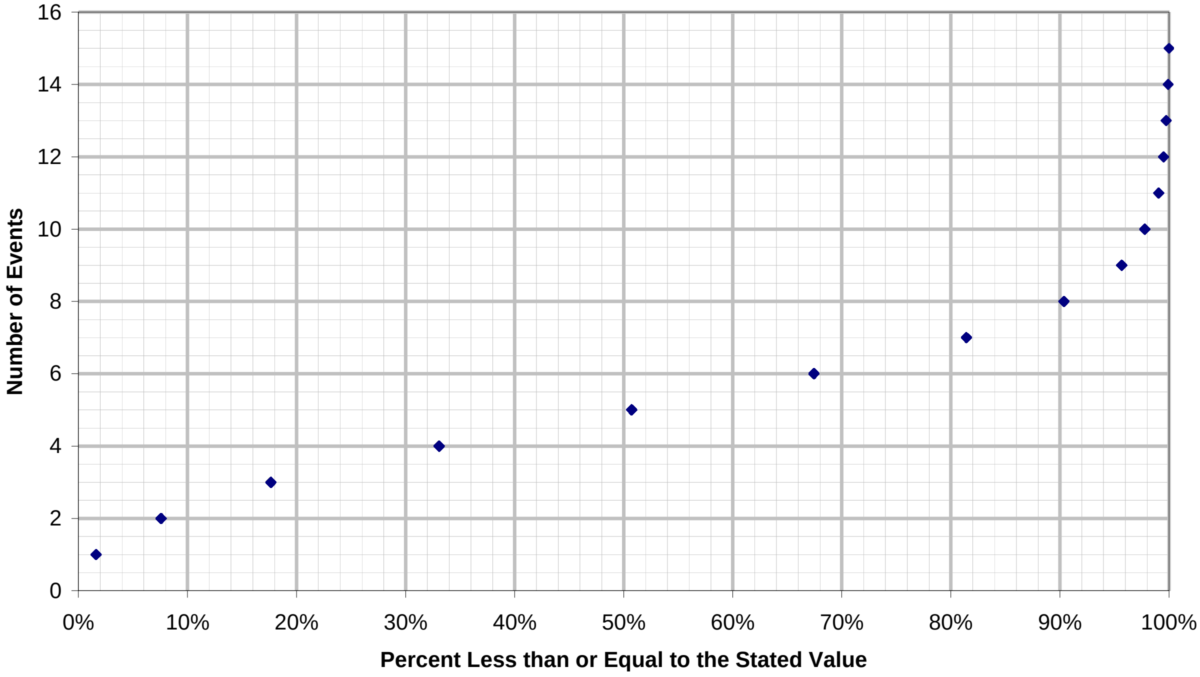
A frequency plot of the number of wet weather events per month and the duration of each event is shown in Exhibits 10-4 and 10-5 for comparison purposes. As shown, wet weather events have occurred at a historical maximum of 15 per month. This suggests that CEPT, CEPT with Plates, and Ballasted Flocculation have a very low probability of exceeding permit limits. Exhibit 10-5 also shows that approximately 95% of events do not last as long as 24 hours, which is the event duration assumed in this study. It should be noted that a continuous simulation-based approach would give a more accurate estimate of risk, and more detailed analyses should be performed during the facility planning and design phases.

EXHIBIT 10-3
Allowable Number of Operating Days of Wet Weather Treatment Train

	Maximum Allowable Number of Operating Days per Month[(1)]						
	Wet Weather Treatment Train Flow (mgd)						
Treatment Train	***80***	***200***	***380***	***470***	***540***	***900***	***1200***
#1) Vortex/Swirl Concentrators							
High Loading Rate:	13	9	7				
Low Loading Rate:	18	15				11	
#2) Conventional Clarifiers	17	13			10	9	
#3) CEPT w/ Conventional Clarifiers	23	21		20		20	
#4) CEPT w/ Plate Settlers	23	21				19	
#5) Ballasted Flocculation	UNLIMITED						

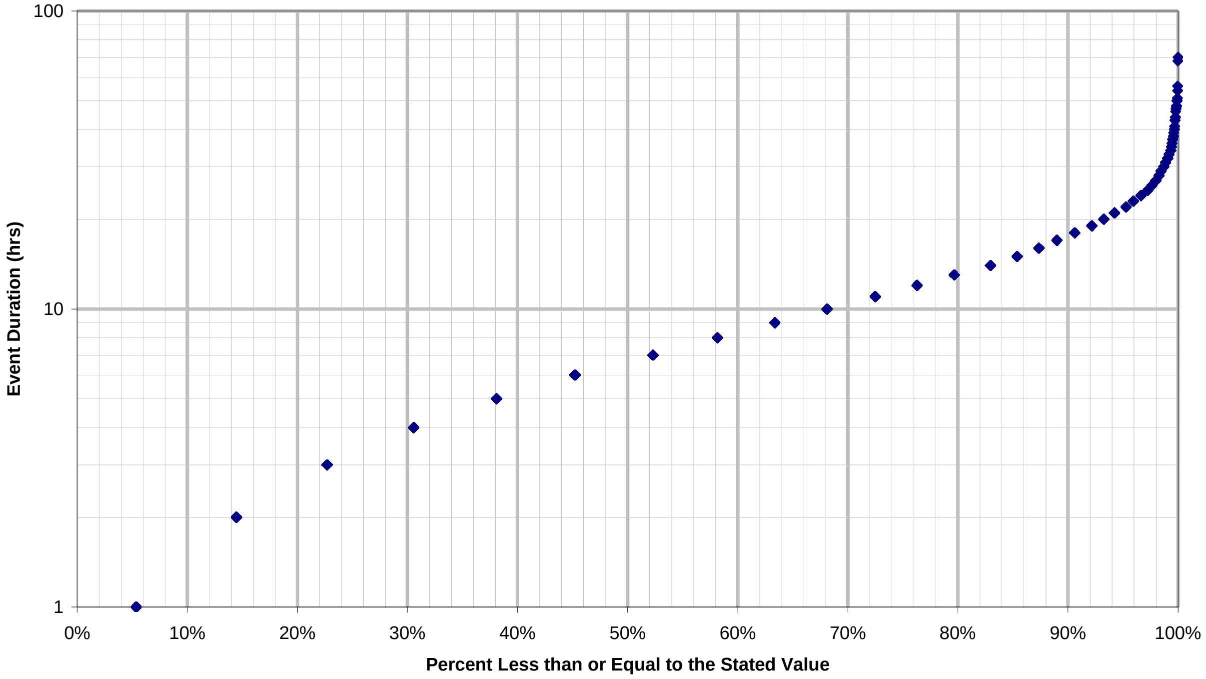
Notes:
(1) Allowable number of operating days without exceeding permit limits for monthly TSS concentrations. Assumes entire plant operates at maximum capacity during every wet weather event.

EXHIBIT 10-4
Cumulative Frequency Plot of the Number of Wet Weather Events per Month



Notes: Based on Philadelphia International Airport NOAA Rain Gauge Hourly Data from1902-2000. Minimum Interevent Time = 4 hrs, Minimum Storm = 0.1 Inches (provided by CDM)

EXHIBIT 10-5
Cumulative Frequency Plot of Wet Weather Event Duration



10.2 Capital, O&M and Life-Cycle Costs

The capital cost estimates for the five treatment trains are shown in Exhibit 10-6. Train #4, CEPT with Plates, is the most expensive, followed by Train #1, vortex/swirl at low loading rates. Trains #2, 3, and 5 appear to have similar costs throughout the entire flow range, with Train 5 being slightly less costly. Translated into a cost per volume treated, all trains appear to become more cost effective as flow capacity increases (Exhibit 10-7).

The comparison of O&M costs for each treatment train is shown in Exhibit 10-8. As expected, the O&M costs are lowest for vortex swirls at high loading and conventional clarifiers, which do not require chemical settling aids. Vortex swirls at low loading rates has the highest O&M costs for repair and maintenance of the large number of vortex units and gravity thickeners required.

Taking construction, non-construction, and O&M costs into consideration, Exhibit 10-9 shows the present value of the total cost of each wet weather treatment train. Train #4, CEPT with Plates, remains most costly since it requires the highest capital and O&M costs. Train #1, vortex/swirl concentrators, appears to be least costly from the life-cycle cost perspective, especially at lower flows. This is due to its low chemical usage and minimal operations and maintenance needs.

EXHIBIT 10-6
Comparison of Capital Costs for All Treatment Trains

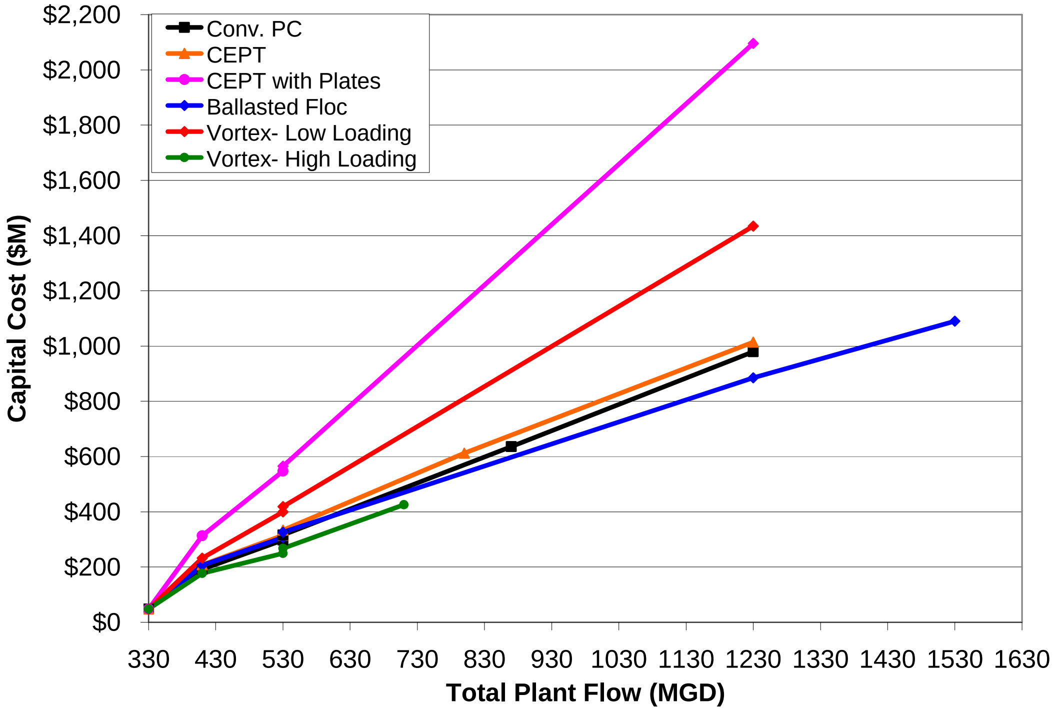


EXHIBIT 10-7
Comparison of Cost Effectiveness for all Treatment Trains

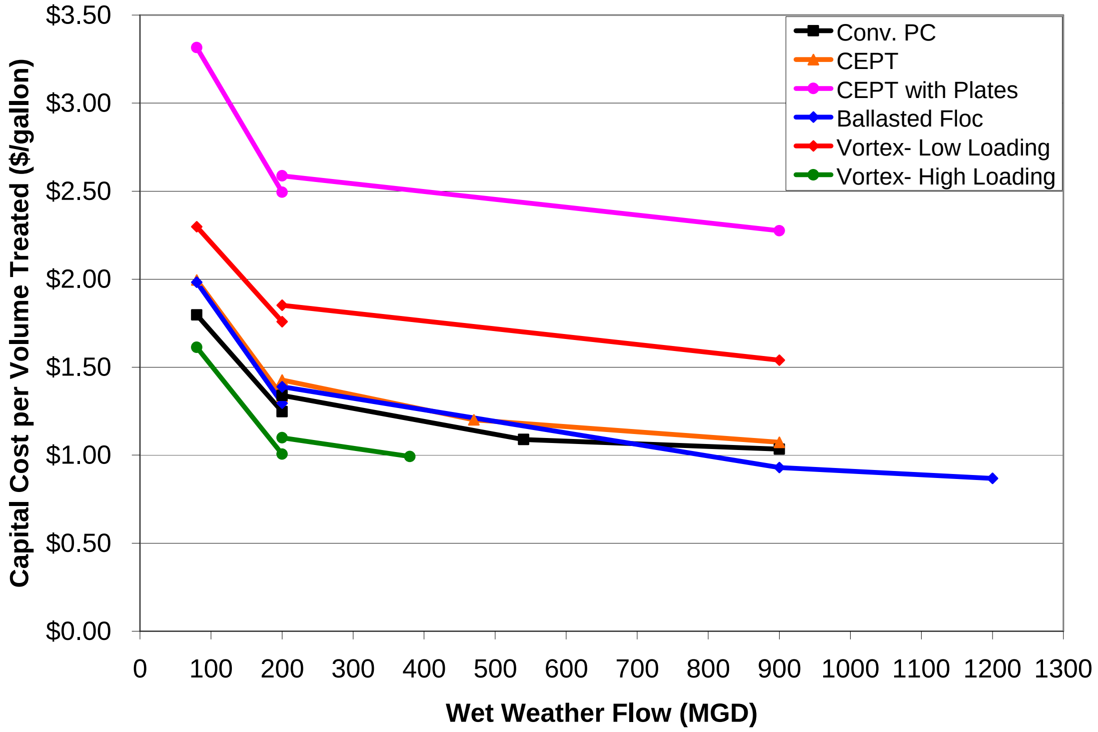


EXHIBIT 10-8
Comparison of Operations and Maintenance Costs for all Treatment Trains

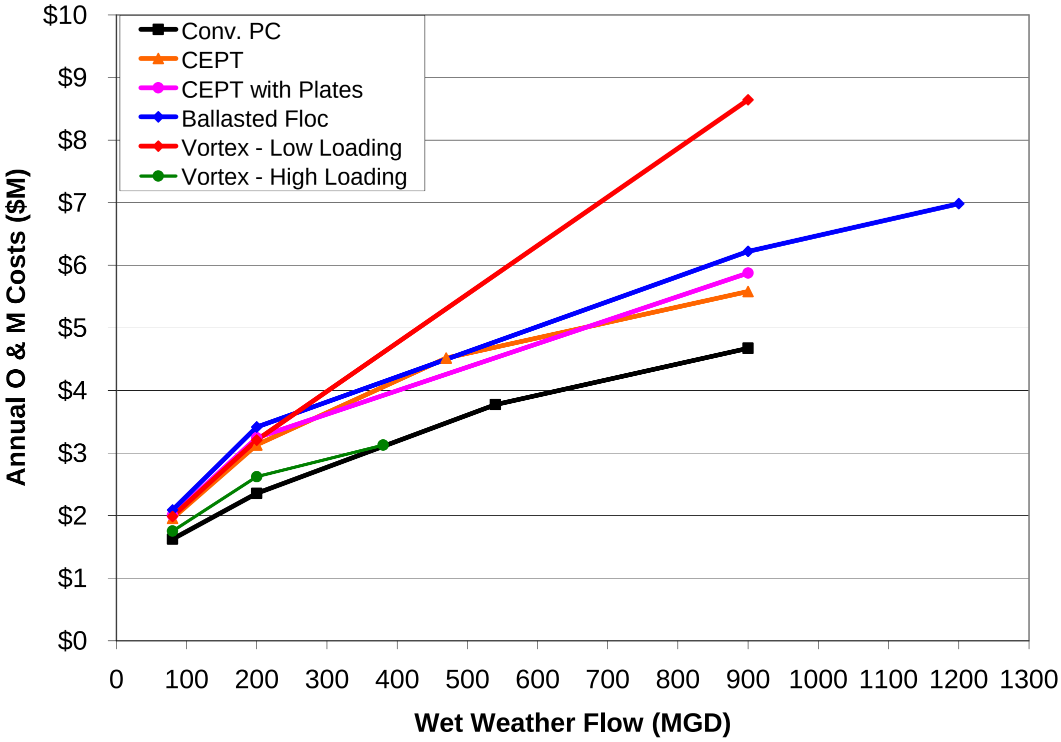
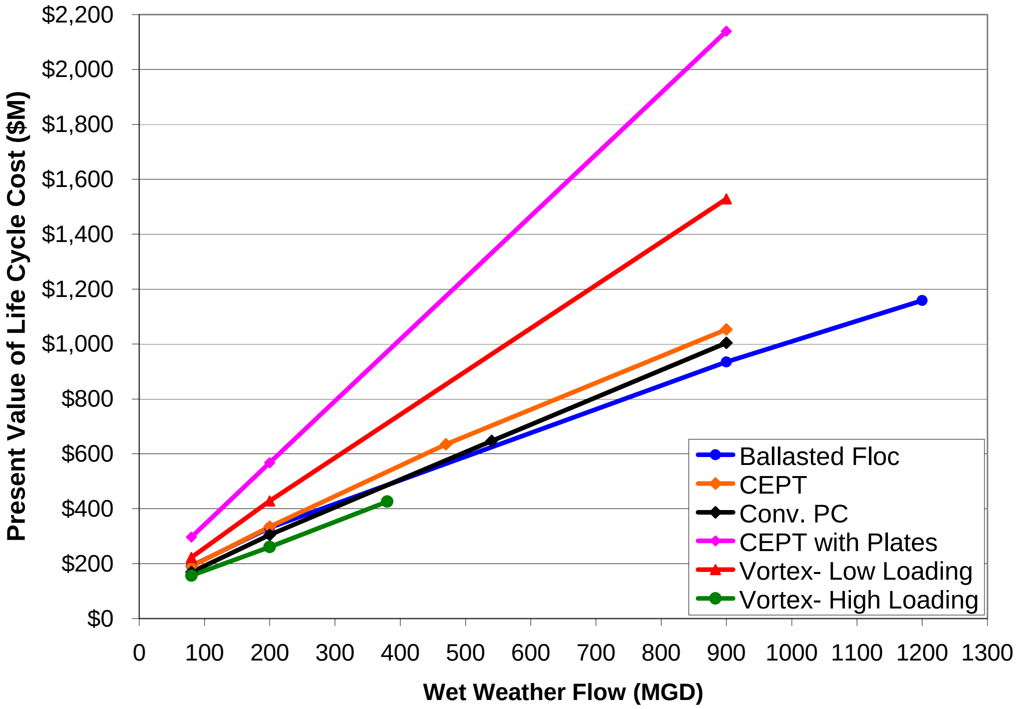


EXHIBIT 10-9
Comparison of Life-Cycle Costs for all Treatment Trains



10.3 Overall Comparison

Aside from capital, O&M, and lifecycle costs, there are numerous other criteria by which the treatment trains should be evaluated, including:

- Reliability of the system
- Community and environmental impacts or perception
- Ability to handle large variations in flow
- Land requirements
- Constructability
- Requirements for maintenance and operator attention
- Sustainability

These evaluation criteria were discussed in Workshop No. 2B, and are presented in TM-SE2 for various wet weather treatment technologies (CH2M HILL, 2008). Several key advantages and disadvantages of Treatment Trains #1 - #5, as evaluated in this report, are described in Exhibit 10-10.

EXHIBIT 10-10
Summary of Pros and Cons for Each Wet Weather Treatment Train

Treatment Train	Pros	Cons
Train #1: Vortex/Swirl Concentrators	• Simple operation • Low maintenance requirements – no moving parts	• Only cost competitive at high loading rates and low removal efficiencies. • Maximum design flow may decrease if the assumed number of operating days is greater than 7.
Train #2: Conventional Clarifiers	• Simple operation • Same technology as existing plant –operators familiar with equipment	• Space limited • May exceed instantaneous blended effluent BOD concentration at high flows • Maximum design flow may decrease if the assumed number of operating days is greater than 7.
Train #3: CEPT	• Lower chlorine dose possible due to high TSS removal efficiencies	• Operators unfamiliar with technology • Space limited • Uses chemicals • Can treat less flow on existing site than conventional clarifiers • Operators unfamiliar with technology

EXHIBIT 10-10
Summary of Pros and Cons for Each Wet Weather Treatment Train

Treatment Train	Pros	Cons
Train #4: CEPT with Plates	• Can treat 900 mgd with available land on site • Lower chlorine dose possible due to high TSS removal efficiencies • Unlimited number of operating days per month	• Highest capital and O&M costs • Operators unfamiliar with technology • Labor intensive to clean plants • Uses chemicals
Train #5: Ballasted Flocculation	• Can treat up to 1200 mgd with available land on site • Highest removal efficiencies • Unlimited number of operating days per month • Lower chlorine dose possible due to high TSS removal efficiencies	• Operators unfamiliar with technology • Second most labor intensive • Uses chemicals

The costs for wet weather treatment at the SE WPCP should be analyzed with the costs of other wet weather treatment alternatives, such as improvements in the collection system, to determine which treatment train alternatives and flow regimes should be evaluated further. Treatment trains that are selected for further evaluation should undergo more detailed design and costing methods, water quality sampling, and bench and pilot scale testing, so that removal efficiencies, land requirements, capital costs, and O&M costs can be further refined.

11.0 References

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Attachment SE-3.1

Breakdown of Capital and O&M Costs

SE WPCP Wet Weather Treatment Train Alternatives: Capital Cost Estimates

Train	Train #1: Vortex/Swirl (High Loading)			Train #1: Vortex/Swirl (Low Loading)			Train #2: Conventional Clarifiers				Train #3: CEPT				Train #4: CEPT with Plates			Train #5: Ballasted Flocculation			
Flow (mgd)	**80**	**200**	**380**	**80**	**200**	**900**	**80**	**200**	**540**	**900**	**80**	**200**	**470**	**900**	**80**	**200**	**900**	**80**	**200**	**900**	**1200**
Influent Pump Station	$2,122,627	$5,631,906	$9,388,002	$2,122,627	$5,631,906	$22,010,403	$2,122,627	$5,631,906	$13,045,081	$22,010,403	$2,122,627	$5,631,906	$12,756,816	$22,010,403	$2,122,627	$5,631,906	$22,010,403	$2,122,627	$5,631,906	$22,010,403	$29,225,910
Bar Screens, Grit Removal, and Fine Screens	$2,174,459	$3,571,408	$6,321,003	$2,174,459	$3,571,408	$16,274,338	$2,671,182	$4,393,646	$12,552,412	$18,730,269	$2,671,182	$4,393,646	$12,552,412	$18,730,269	$4,202,721	$6,921,999	$29,376,212	$4,146,536	$6,921,999	$29,376,212	$39,121,478
Vortex Swirl	$4,544,219	$8,559,632	$17,182,263	$18,992,110	$44,494,973	$162,023,952	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Flocculation Tanks	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$1,834,779	$2,948,232	$7,174,443	$13,080,486	$1,232,049	$2,292,811	$8,535,466	$0	$0	$0	$0
Primary Clarifiers	$0	$0	$0	$0	$0	$0	$5,260,886	$13,952,342	$33,916,953	$56,426,292	$4,998,354	$10,348,111	$23,829,752	$45,513,491	$31,218,084	$68,171,521	$310,824,165	$0	$0	$0	$0
Actiflo System	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$6,712,290	$13,938,850	$61,514,152	$81,881,502
Chemical Feed	$884,228	$1,341,043	$1,412,064	$884,228	$1,341,043	$1,697,079	$884,228	$1,341,043	$1,537,520	$1,697,079	$2,548,832	$4,454,101	$5,428,866	$6,503,527	$2,501,908	$4,394,173	$6,889,386	$2,586,797	$4,504,520	$7,366,049	$7,493,387
Chlorine Contact Chamber (1)	$5,785,202	$2,995,062	$5,350,790	$5,785,202	$2,995,062	$6,247,533	$5,785,202	$2,995,062	$6,247,533	$6,247,533	$5,785,202	$2,995,062	$5,871,000	$6,247,533	$5,785,202	$2,995,062	$6,247,533	$5,785,202	$2,995,062	$6,247,533	$6,247,533
Gravity Thickeners	$2,101,375	$5,188,585	$9,548,932	$2,101,375	$5,188,585	$23,626,401	$1,159,641	$2,336,314	$2,295,689	$2,413,240	$1,300,370	$3,688,352	$3,680,418	$4,537,578	$1,334,570	$3,652,905	$3,791,428	$2,197,719	$4,685,560	$4,607,787	$4,952,167
Yard Piping (large)	$87,258	$4,542,120	$10,949,456	$87,258	$4,542,120	$31,387,935	$351,671	$5,101,234	$15,891,273	$31,387,935	$305,074	$4,972,860	$13,333,799	$29,259,107	$345,950	$4,990,074	$25,038,634	$361,619	$5,185,832	$20,620,767	$26,705,083
Digesters at SW WPCP	$6,242,029	$6,224,117	$6,224,117	$6,200,750	$6,289,794	$6,307,706	$6,307,706	$6,271,882	$6,271,882	$6,283,824	$6,254,027	$6,367,471	$6,355,472	$6,379,355	$6,373,384	$6,349,501	$6,379,355	$6,248,000	$6,373,384	$6,403,238	$6,403,238
Subtotal Project Cost	$23,941,397	$38,053,873	$66,376,627	$38,348,009	$74,054,891	$269,575,347	$24,543,143	$42,023,429	$91,758,343	$145,196,575	$27,820,447	$45,799,741	$90,982,978	$152,261,749	$55,116,495	$105,399,952	$419,092,582	$30,160,790	$50,237,113	$158,146,141	$202,030,298
Additional Project Costs:																					
General Demolition	$239,414	$380,539	$663,766	$383,480	$740,549	$2,695,753	$245,431	$420,234	$917,583	$1,451,966	$278,204	$457,997	$909,830	$1,522,617	$551,165	$1,054,000	$4,190,926	$301,608	$502,371	$1,581,461	$2,020,303
Overall Sitework	$1,915,312	$3,044,310	$5,310,130	$3,067,841	$5,924,391	$21,566,028	$1,963,451	$3,361,874	$7,340,667	$11,615,726	$2,225,636	$3,663,979	$7,278,638	$12,180,940	$4,409,320	$8,431,996	$33,527,407	$2,412,863	$4,018,969	$12,651,691	$16,162,424
Plant Computer System	$2,035,019	$3,234,579	$5,642,013	$3,259,581	$6,294,666	$22,913,904	$2,086,167	$3,571,991	$7,799,459	$12,341,709	$2,364,738	$3,892,978	$7,733,553	$12,942,249	$4,684,902	$8,958,996	$35,622,869	$2,563,667	$4,270,155	$13,442,422	$17,172,575
Yard Electrical	$1,915,312	$3,044,310	$5,310,130	$3,067,841	$5,924,391	$21,566,028	$1,963,451	$3,361,874	$7,340,667	$11,615,726	$2,225,636	$3,663,979	$7,278,638	$12,180,940	$4,409,320	$8,431,996	$33,527,407	$2,412,863	$4,018,969	$12,651,691	$16,162,424
Yard Piping	$1,197,070	$1,902,694	$3,318,831	$1,917,400	$3,702,745	$13,478,767	$1,227,157	$2,101,171	$4,587,917	$7,259,829	$1,391,022	$2,289,987	$4,549,149	$7,613,087	$2,755,825	$5,269,998	$20,954,629	$1,508,040	$2,511,856	$7,907,307	$10,101,515
Subtotal with Additional Project Costs	$31,243,523	$49,660,304	$86,621,498	$50,044,152	$96,641,633	$351,795,828	$32,028,802	$54,840,575	$119,744,638	$189,481,530	$36,305,683	$59,768,662	$118,732,786	$198,701,582	$71,927,026	$137,546,937	$546,915,820	$39,359,831	$65,559,432	$206,380,714	$263,649,539
Subtotal with Contractor Markups (1)	$47,363,228	$75,281,917	$131,312,777	$75,863,806	$146,502,675	$533,300,488	$48,553,661	$83,134,884	$181,525,387	$287,242,157	$55,037,147	$90,605,556	$179,991,483	$301,219,180	$109,036,876	$208,512,560	$829,090,200	$59,667,044	$99,384,002	$312,860,264	$399,676,223
Subtotal with Escalation (2)	$56,741,147	$91,241,684	$159,938,963	$90,884,840	$177,561,242	$683,691,225	$58,167,286	$100,759,479	$224,909,954	$368,244,446	$65,934,502	$109,813,934	$223,009,448	$386,162,989	$130,626,177	$252,717,223	$1,062,893,637	$71,481,118	$120,453,411	$401,086,858	$512,384,918
Subtotal with Local Adjustment Factor (3)	$65,365,802	$105,110,420	$184,249,685	$104,699,336	$204,550,551	$787,612,292	$67,008,714	$116,074,920	$259,096,267	$424,217,602	$75,956,546	$126,505,652	$256,906,884	$444,859,763	$150,481,356	$291,130,241	$1,224,453,469	$82,346,248	$138,762,329	$462,052,060	$590,267,425
Dewatering	$478,828	$761,077	$1,327,533	$766,960	$1,481,098	$5,391,507	$490,863	$840,469	$1,835,167	$2,903,932	$556,409	$915,995	$1,819,660	$3,045,235	$1,102,330	$2,107,999	$8,381,852	$603,216	$1,004,742	$3,162,923	$4,040,606
Structural Piles	$15,304,402	$36,018,756	$61,498,606	$17,521,109	$41,718,838	$134,290,191	$23,497,058	$57,161,259	$127,318,237	$184,492,705	$25,059,764	$58,398,412	$113,675,451	$186,934,310	$20,643,141	$47,658,253	$131,502,609	$17,970,287	$40,803,944	$89,729,825	$102,658,755
Subtotal - Construction Cost, including Market Adjustment Factor (4)	**$93,321,386**	**$163,173,792**	**$284,137,197**	**$141,435,516**	**$284,913,060**	**$1,066,388,087**	**$104,646,130**	**$200,188,144**	**$446,487,122**	**$703,356,374**	**$116,808,627**	**$213,693,067**	**$428,262,293**	**$730,065,204**	**$198,060,851**	**$392,030,967**	**$1,568,988,620**	**$116,057,714**	**$207,656,668**	**$638,186,529**	**$801,511,805**
Total Construction Cost + Non-Construction Costs (5)	**$121,317,802**	**$212,125,929**	**$369,378,356**	**$183,866,171**	**$370,386,978**	**$1,386,304,514**	**$136,039,969**	**$260,244,588**	**$580,433,258**	**$914,363,286**	**$151,851,216**	**$277,800,987**	**$556,740,981**	**$949,084,766**	**$257,479,107**	**$509,640,257**	**$2,039,685,206**	**$150,875,028**	**$269,953,668**	**$829,642,488**	**$1,041,965,346**
Land Acquisition Cost	-	-	-	-	-	-	-	-	-	$9,227,680	-	-	-	$9,227,680	-	-	-	-	-	-	-
Additional Sludge Force Main and Pump to SW (with standard markups)	$7,741,926	$7,741,926	$7,741,926	$7,741,926	$7,741,926	$7,741,926	$7,741,926	$7,741,926	$7,741,926	$7,741,926	$7,741,926	$7,741,926	$7,741,926	$7,741,926	$7,741,926	$7,741,926	$7,741,926	$7,741,926	$7,741,926	$7,741,926	$7,741,926
Total Capital Cost (with non construction costs)	**$129,059,728**	**$219,867,855**	**$377,120,282**	**$191,608,097**	**$378,128,904**	**$1,394,046,440**	**$143,781,895**	**$267,986,514**	**$588,175,184**	**$931,332,892**	**$159,593,142**	**$285,542,913**	**$564,482,907**	**$966,054,372**	**$265,221,032**	**$517,382,183**	**$2,047,427,132**	**$158,616,954**	**$277,695,594**	**$837,384,414**	**$1,049,707,272**
Total Capital Cost ($M)	$129	$220	$377	$192	$378	$1,394	$144	$268	$588	$931	$160	$286	$564	$966	$265	$517	$2,047	$159	$278	$837	$1,050
.+50% Capital Cost ($M)	$194	$330	$566	$287	$567	$2,091	$216	$402	$882	$1,397	$239	$428	$847	$1,449	$398	$776	$3,071	$238	$417	$1,256	$1,575
.-30% Capital Cost ($M)	$90	$154	$264	$134	$265	$976	$101	$188	$412	$652	$112	$200	$395	$676	$186	$362	$1,433	$111	$194	$586	$735
Cost Efficiency ($/gallon)	**$1.52**	**$1.06**	**$0.97**	**$2.30**	**$1.85**	**$1.54**	**$1.70**	**$1.30**	**$1.07**	**$1.02**	**$1.90**	**$1.39**	**$1.18**	**$1.05**	**$3.22**	**$2.55**	**$2.27**	**$1.89**	**$1.35**	**$0.92**	**$0.87**
Total cost w/o new outfall (200 mgd only) (6)	-	*$201,269,552*	-	-	*$359,530,601*	-	-	*$249,388,211*	-	-	-	*$267,027,800*	-	-	-	*$498,812,242*	-	-	*$259,095,577*	-	-

Notes:
1. Contractor markups - use 1.516 multiplier (see TM-SE3 Section 3.3)
2. Escalation - multiplier depends on duration of construction (see Exhibit 3-7 in TM-SE3 Section 3.3)
3. Local Adjustment Factor - use 1.152 multiplier (see TM-SE3 Section 3.3)
4. Market Adjustment Factor - use 1.15 multiplier (see TM-SE3 Section 3.3)
5. Non-construction costs - use 1.3 multiplier (see TM-SE3 Section 3.3)
6. For 200 mgd flow scenarios, cost assumes construction of new outfall conduits. The total capital cost of the 200 mgd scenario assuming no new outfall conduits is provided in the last line item of this table.

SE WPCP Wet Weather Treatment Train Alternatives: Operations and Maintenance Cost Estimates (1)

	Flow (mgd)	Labor	Sludge Disposal	Equipment Power (2)	Building Electrical/ Heating	Chemicals	Repair & Maintenance	Grit and Screenings Disposal	Other (3)	Total	Horsepower requirements (HP)
Train #1: Vortex/Swirls (low loading)	80	$699,027	$160,864	$39,449	$3,373	$60,573	$936,611	$35,354	$50,819	$1,986,070	1,062
	200	$699,027	$402,160	$102,428	$4,659	$151,432	$1,707,719	$88,385	$50,819	$3,206,631	2,758
	900	$1,354,994	$1,578,767	$149,665	$8,908	$173,390	$5,176,807	$101,201	$101,639	$8,645,371	10,747
Train #1: Vortex/Swirls (high loading)	80	$699,027	$254,554	$40,563	$3,406	$60,573	$609,290	$35,354	$50,819	$1,753,587	1,092
	200	$699,027	$636,386	$97,229	$4,598	$151,432	$894,642	$88,385	$50,819	$2,622,518	2,618
	380	$699,027	$649,114	$143,541	$5,582	$154,461	$1,335,947	$90,153	$50,819	$3,128,643	4,352
Train #2: Conventional Clarifiers	80	$705,743	$137,424	$35,741	$3,496	$61,155	$594,635	$35,694	$51,308	$1,625,195	953
	200	$699,027	$340,290	$89,654	$4,648	$151,432	$930,707	$88,385	$50,819	$2,354,962	2,414
	540	$1,311,933	$347,095	$125,693	$6,852	$154,461	$1,636,960	$90,153	$101,639	$3,774,787	5,415
	900	$1,354,994	$389,632	$127,226	$8,900	$154,461	$2,436,369	$101,201	$101,639	$4,674,421	9,135
Train #3: CEPT	80	$699,027	$261,900	$37,484	$4,836	$241,031	$627,157	$35,354	$50,819	$1,957,609	1,009
	200	$699,027	$654,751	$93,636	$7,306	$602,577	$934,517	$88,385	$50,819	$3,131,019	2,521
	470	$1,311,933	$667,846	$132,579	$9,350	$614,629	$1,589,331	$90,153	$101,639	$4,517,459	5,613
	900	$1,354,994	$749,689	$132,579	$12,042	$689,951	$2,438,076	$101,201	$101,639	$5,580,170	9,520
Train #4: CEPT with Plates	80	$699,027	$261,900	$37,413	$5,044	$241,031	$667,025	$42,347	$50,819	$2,004,606	1,007
	200	$699,027	$654,751	$93,376	$7,429	$602,577	$1,029,275	$105,868	$50,819	$3,243,121	2,514
	900	$1,354,994	$749,689	$133,637	$14,753	$689,951	$2,710,235	$121,219	$101,639	$5,876,116	9,596
Train #5: Ballasted Flocculation	80	$699,027	$294,638	$50,690	$5,258	$241,868	$703,804	$42,347	$50,819	$2,088,452	1,365
	200	$699,027	$736,594	$122,797	$7,774	$604,670	$1,086,942	$105,868	$50,819	$3,414,492	3,307
	900	$1,354,994	$843,401	$182,122	$14,465	$692,347	$2,912,439	$121,219	$101,639	$6,222,625	13,077
	1200	$1,354,994	$843,401	$182,122	$15,759	$692,347	$3,674,634	$121,219	$101,639	$6,986,114	17,357

Notes:

1. All O&M costs are annualized costs based on escalation through a 30-year period. For flows of 470 mgd and higher, costs are based on an average flow of 337.5 mgd (see TM-SE3 Section 3.3)
2. Power costs are estimated based on the total horsepower requirements and the average-to-max flow ratio.
3. "Other" costs cover miscellaneous costs for vehicles, lab tests, office equipment, etc.

Percentage of Costs by Category

	Flow (mgd)	Labor	Sludge Disposal	Equipment Power	Building Electrical/ Heating	Chemicals	Repair & Maintenance	Grit and Screenings Disposal	Other
Train #1: Vortex/Swirls (low loading)	80	35.2%	8.1%	2.0%	0.2%	3.0%	47.2%	1.8%	2.6%
	200	21.8%	12.5%	3.2%	0.1%	4.7%	53.3%	2.8%	1.6%
	900	15.7%	18.3%	1.7%	0.1%	2.0%	59.9%	1.2%	1.2%
Train #1: Vortex/Swirls (high loading)	80	39.9%	14.5%	2.3%	0.2%	3.5%	34.7%	2.0%	2.9%
	200	26.7%	24.3%	3.7%	0.2%	5.8%	34.1%	3.4%	1.9%
	380	22.3%	20.7%	4.6%	0.2%	4.9%	42.7%	2.9%	1.6%
Train #2: Conventional Clarifiers	80	43.4%	8.5%	2.2%	0.2%	3.8%	36.6%	2.2%	3.2%
	200	29.7%	14.4%	3.8%	0.2%	6.4%	39.5%	3.8%	2.2%
	540	34.8%	9.2%	3.3%	0.2%	4.1%	43.4%	2.4%	2.7%
	900	29.0%	8.3%	2.7%	0.2%	3.3%	52.1%	2.2%	2.2%
Train #3: CEPT	80	35.7%	13.4%	1.9%	0.2%	12.3%	32.0%	1.8%	2.6%
	200	22.3%	20.9%	3.0%	0.2%	19.2%	29.8%	2.8%	1.6%
	470	29.0%	14.8%	2.9%	0.2%	13.6%	35.2%	2.0%	2.2%
	900	24.3%	13.4%	2.4%	0.2%	12.4%	43.7%	1.8%	1.8%
Train #4: CEPT with Plates	80	34.9%	13.1%	1.9%	0.3%	12.0%	33.3%	2.1%	2.5%
	200	21.6%	20.2%	2.9%	0.2%	18.6%	31.7%	3.3%	1.6%
	900	23.1%	12.8%	2.3%	0.3%	11.7%	46.1%	2.1%	1.7%
Train #5: Ballasted Flocculation	80	33.5%	14.1%	2.4%	0.3%	11.6%	33.7%	2.0%	2.4%
	200	20.5%	21.6%	3.6%	0.2%	17.7%	31.8%	3.1%	1.5%
	900	21.8%	13.6%	2.9%	0.2%	11.1%	46.8%	1.9%	1.6%
	1200	19.4%	12.1%	2.6%	0.2%	9.9%	52.6%	1.7%	1.5%

Supplemental Documentation
Volume 11

Analysis of Wet Weather Treatment Alternatives for Southwest WPCP

Updated: September 1, 2009

Final Tech Memo

Wet Weather Treatment Alternatives at Northeast, Southeast and Southwest WPCPs

SW2: Analysis of Wet Weather Treatment Alternatives for Southwest WPCP

Prepared for

Philadelphia Water Department

Philadelphia, PA

March 2009

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Suite 4400
Philadelphia, PA 1910

Executive Summary

Background and Project Summary

As part of the series of memoranda prepared for the Philadelphia Water Department's (PWD) Combined Sewer Overflow (CSO) Long Term Control Plan (LTCP) update, this report presents the conceptual design and cost analyses for four wet weather treatment alternatives for the Southwest Water Pollution Control Plant (SW WPCP). The wet weather treatment technologies for the SW WPCP evaluated in this report are as follows:

1. Vortex Swirl Concentrators
2. Conventional Clarifiers
3. Chemically Enhanced Primary Treatment (CEPT) with Conventional Clarifiers
4. Ballasted Flocculation (includes fine screening)

Conceptual treatment trains were developed for each treatment technology at various wet weather flows ranging from 220 million gallons per day (mgd) to 1740 mgd and cost curves for capital, operations and maintenance (O&M), and lifecycle costs were generated for each treatment train alternative.

Existing Plant and the New Wet Weather Treatment Facility

Currently, the SW WPCP has a flow capacity of 400 mgd. With several process and hydraulic modifications, as identified in the 2001 Stress Testing Report, the capacity of the existing plant can potentially reach 540 mgd (CH2M HILL, 2001). In sizing the wet weather treatment trains, it was assumed that these upgrades, costing $64.6 million, will have been completed, increasing the plant's capacity to a minimum of 540 mgd (Section 2). Any wet weather flow in excess of 540 mgd would be diverted to the new wet weather facility.

The new wet weather facility is sited in two tracts of land currently utilized by the Biosolids Recycling Center (BRC), the Upper and Lower BRC areas. Due to the likely infeasibility in routing a new outfall conduit from the BRC area through the Philadelphia International Airport to the Delaware River, a new outfall conduit to the Schuylkill River is proposed to be constructed for the new wet weather treatment facility. Unlike the Southeast and Northeast WPCPs, effluent from the wet weather facility will not commingle with the effluent from the conventional plant. This means that the regulating agencies may view the new facility as a separate wet weather treatment facility requiring a new discharge permit.

If blending of the two plant effluents is required or desired, the outfall for the existing plant could be relocated to the Schuylkill by constructing a new outfall conduit. The cost of this conduit, and thus comingling, is estimated at $155 million. Despite the difference in outfall locations, this report assumes that the SW WPCP and its new wet weather facility will operate as one system.

Flow Scenarios

Conceptual designs and cost estimates were developed for the design flows for each wet weather treatment train under evaluation (Exhibit ES-1). These flows were selected based on the ability to meet permit requirements (assuming commingling with existing plant), the capacity of the existing collection system, the land area available at the Upper and Lower BRC sites, and the maximum expected flow from the upgraded collection system, as described in Section 4.

EXHIBIT ES-1
Design Flows Evaluated for each Wet Weather Treatment Train

Treatment Train	Design Flows Evaluated (mgd)
#1) Vortex/Swirl Concentrators	220, 702
#2) Conventional Clarifiers	220, 600, 1200
#3) CEPT w/ Conventional Clarifiers	220, 550, 1000
#4) Ballasted Flocculation	220, 980, 1740

Comparison of Treatment Alternatives

Effluent Water Quality

Due to the varying removal efficiencies of each candidate treatment train, the resulting water quality differs widely between different trains. The TSS and cBOD concentrations of the effluent for each wet weather treatment train and flow scenario is presented under Section 10 in Exhibits 10-1 and 10-2, respectively. In general, ballasted flocculation provides the best treatment, achieving TSS and cBOD concentrations even lower than the existing plant.

Capital and O&M Costs

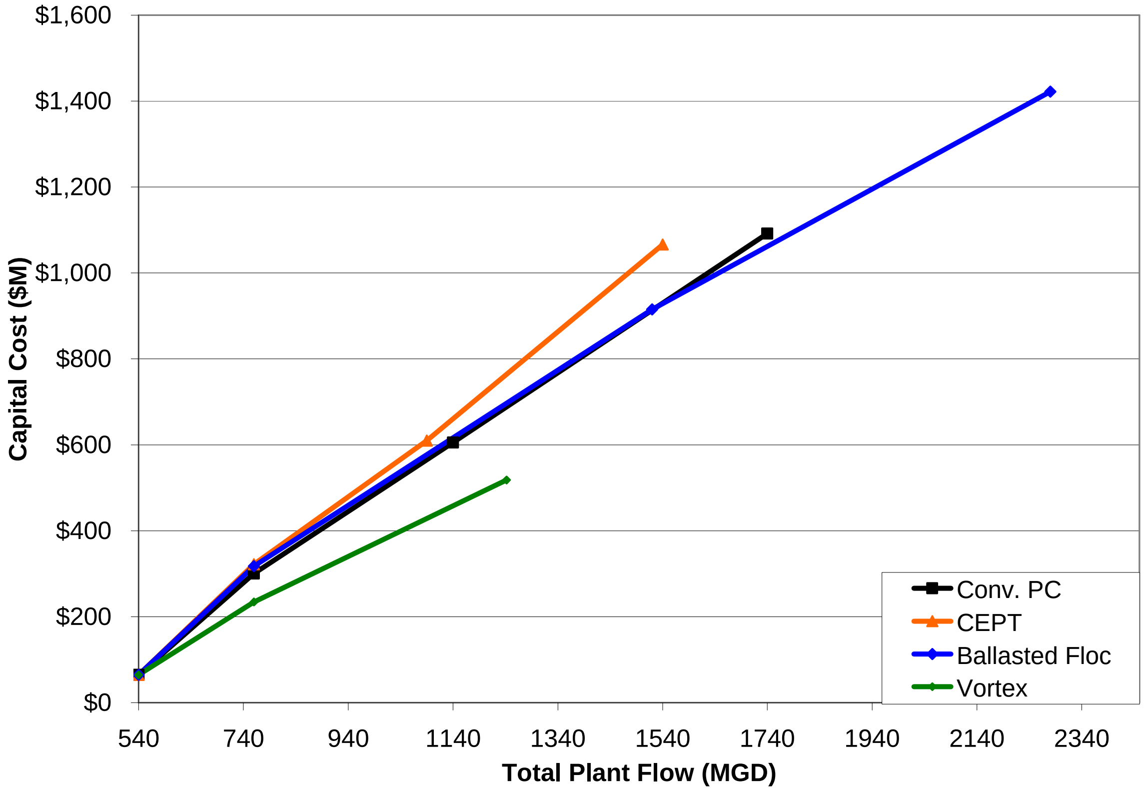
The capital cost estimates for the four treatment trains are shown in Exhibit ES-2. Train #3, CEPT, is the most expensive, followed by Trains #2 and #4, Conventional Clarification and Ballasted Flocculation, which appear similar in cost. The cost of Train #1, Vortex/Swirl, is significantly less expensive than the other three trains. Translated into capital cost per volume treated, all trains appear to become more cost effective as flow capacity increases (Exhibit ES-3).

The reason that CEPT is more expensive than Ballasted Flocculation for the SW WPCP wet weather facility is likely due to the limited length and increased number of its clarifiers, as described in Section 7.2, as well as the increased cost for piles.

The comparison of O&M costs for each treatment train is shown in Exhibit ES-5. As expected, the O&M costs for vortex swirls and conventional clarifiers, which do not require chemical settling aids, are the lowest. Ballasted Flocculation has the highest O&M costs due to its chemical usage and the complexity of its system.

Taking construction, non-construction, and O&M costs into consideration, Exhibit ES-6 shows the present value of the total cost of each wet weather treatment train. Again, CEPT and Ballasted Flocculation remain most costly due to their high capital and O&M costs. Train #1, vortex/swirl concentrators, is significantly less expensive compared with other technologies from the life-cycle cost perspective. This is due to its low chemical usage and minimal operations and maintenance needs.

EXHIBIT ES-2
Comparison of Capital Costs for All Treatment Trains



Note: Capital cost presented includes cost of improvements recommended in the Stress Testing Report ($64.6 million). Total plant flow includes flow from both the conventional plant and the wet weather treatment facility.

EXHIBIT ES-3
Comparison of Capital Cost Effectiveness for all Treatment Trains

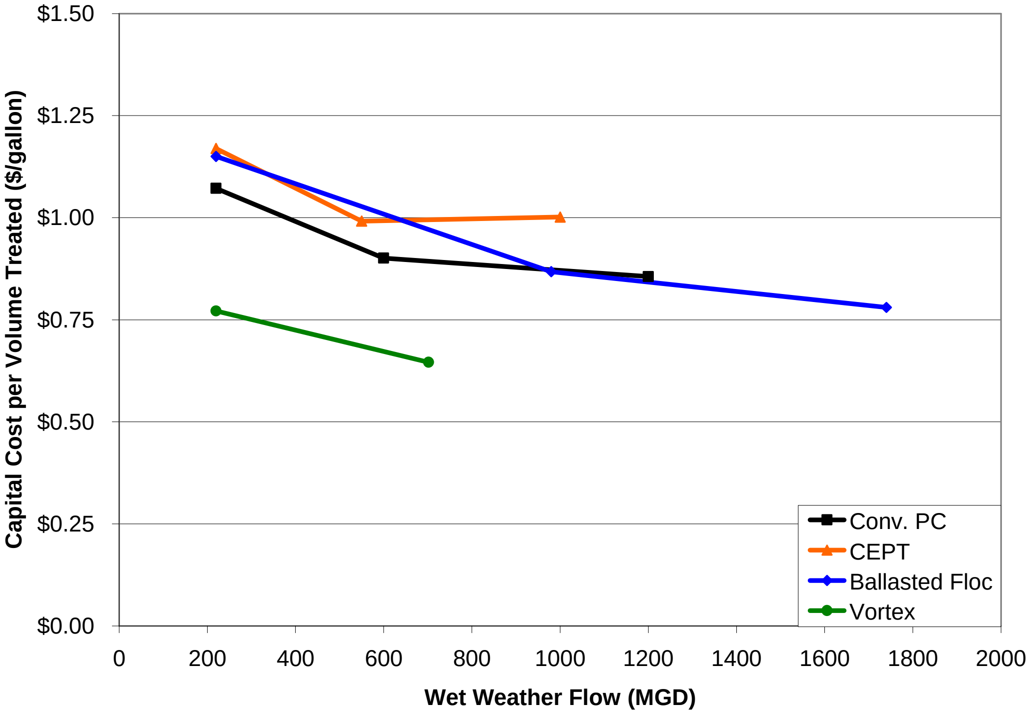


EXHIBIT ES-4
Comparison of Operations and Maintenance Costs for all Treatment Trains

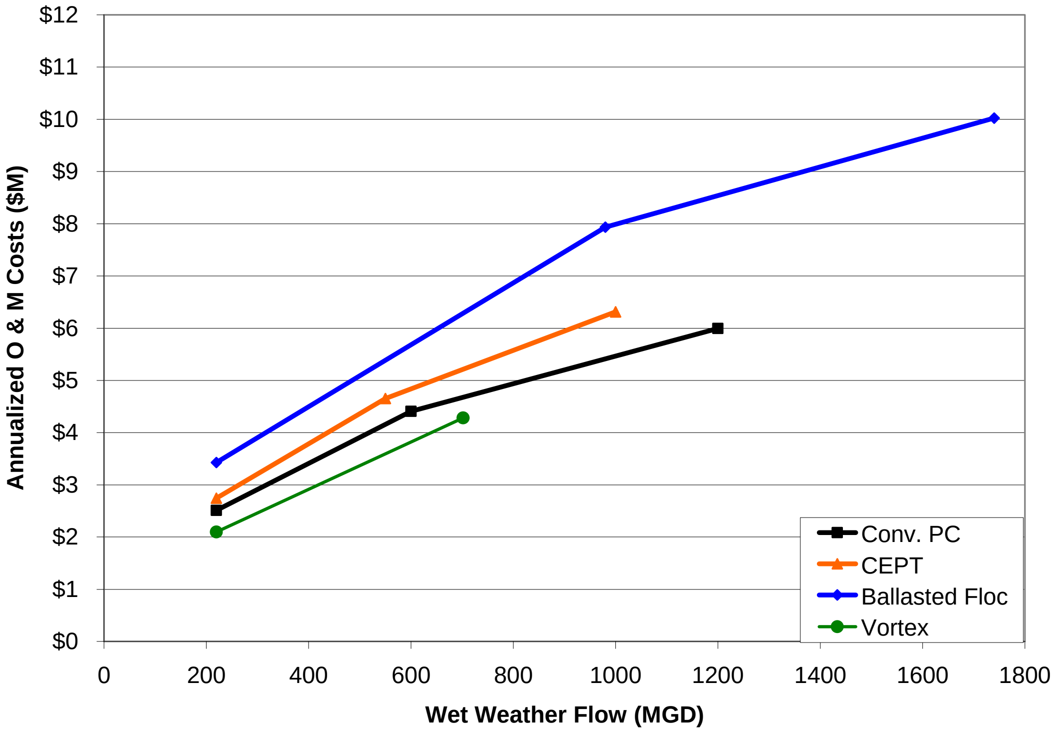
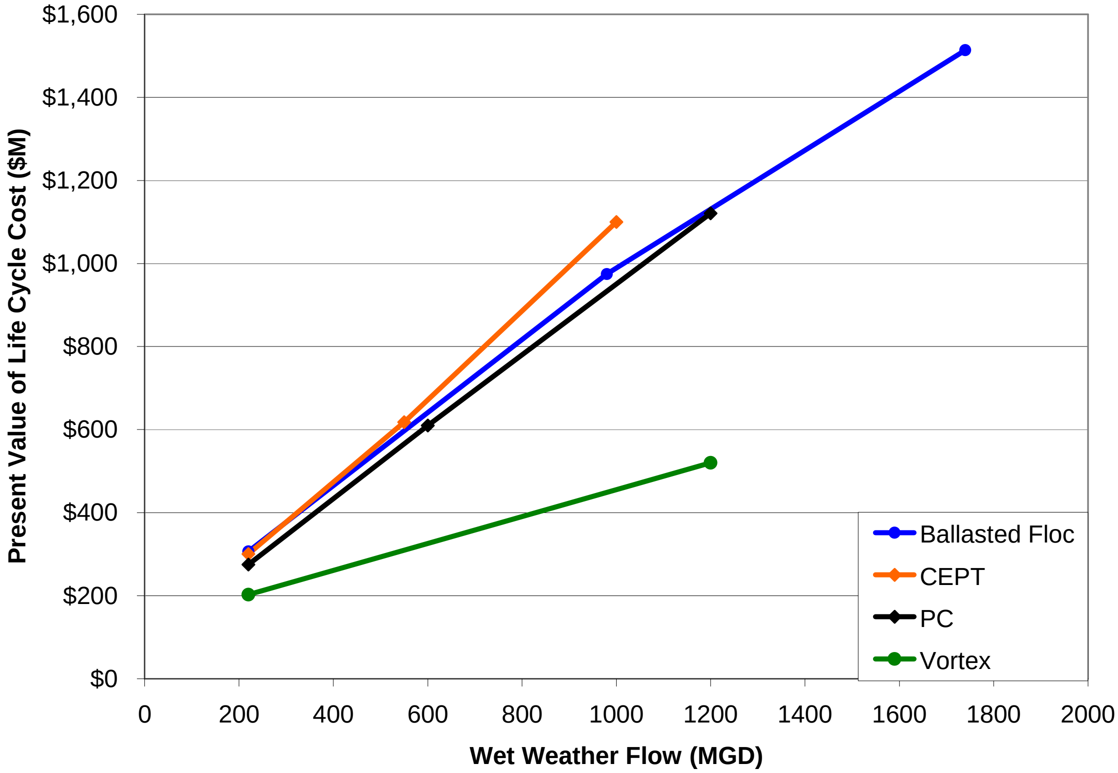


EXHIBIT ES-5
Comparison of Life-Cycle Costs for all Treatment Trains



Overall Comparison

Aside from capital, O&M, and lifecycle costs, there are numerous other criteria by which the treatment trains should be evaluated, including system reliability, community impacts, the ability to handle large variations in flow, land requirements, constructability, requirements for maintenance and operator attention, and sustainability. The main advantages and disadvantages for Treatment Trains #1 - #4, as evaluated in this report, are described in Exhibit ES-6.

EXHIBIT ES-6
Summary of Pros and Cons for Each Wet Weather Treatment Train

Treatment Train	Pros	Cons
Train #1: Vortex/Swirl Concentrators	• Simple operation • Low maintenance requirements – no moving parts	• Maximum design flow may decrease if the assumed number of operating days per month is greater than 7. • Unless operated at lower loading rates, removal efficiency may not be high enough to operate alone without blending effluent with main plant effluent.

EXHIBIT ES-6
Summary of Pros and Cons for Each Wet Weather Treatment Train

Treatment Train	Pros	Cons
Train #2: Conventional Clarifiers	• Simple operation • Same technology as existing plant –operators familiar with equipment	• Space limited • Maximum design flow may decrease if the assumed number of operating days is greater than 9 per month.
Train #3: CEPT	• Lower chlorine dose possible due to high TSS removal efficiencies • May be operated as Conventional Clarifiers if chemicals found to be unnecessary	• Operators unfamiliar with technology • Space limited • Can treat less flow on land available than conventional clarifiers • Uses two additional chemical systems for coagulation and flocculation
Train #4: Ballasted Flocculation	• Can treat up to 1740 mgd with available land on site • Highest removal efficiencies • Unlimited number of operating days per month • Lower chlorine dose possible due to high TSS removal efficiencies	• Operators unfamiliar with technology • Most labor intensive and complex system • Uses two additional chemical systems for coagulation and flocculation

The costs for wet weather treatment at the SW WPCP should be analyzed with the costs of other wet weather treatment alternatives, such as improvements in the collection system, to determine which treatment train alternatives and flow regimes should be evaluated further. Treatment trains that are selected for further evaluation should undergo more detailed design and costing methods, water quality sampling, and bench and pilot scale testing, so that removal efficiencies, land requirements, capital costs, and O&M costs can be further refined.

Contents

Exhibits

Attachment

1.0 Introduction

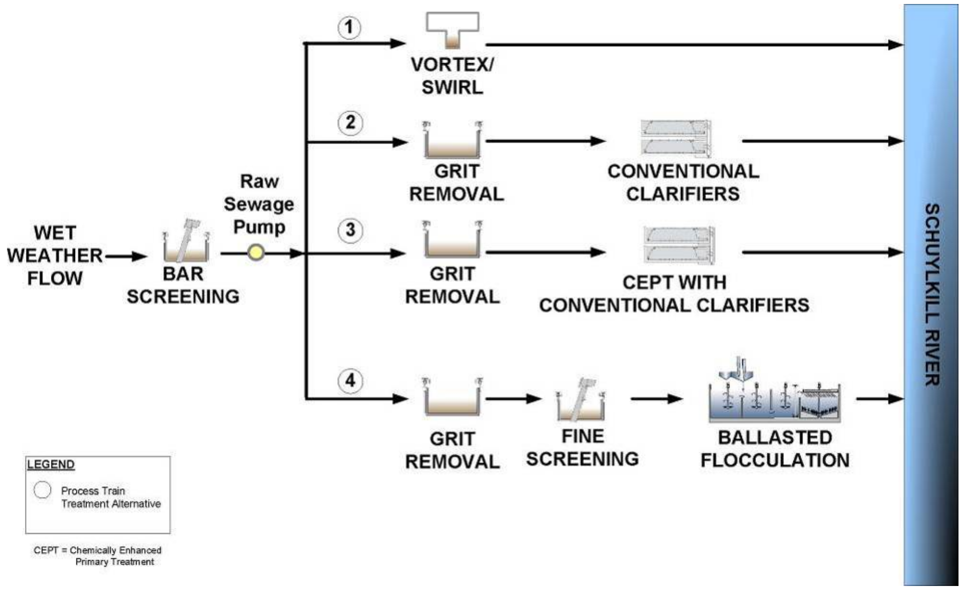
As part of the series of memoranda prepared for the Philadelphia Water Department's (PWD) Combined Sewer Overflow (CSO) Long Term Control Plan (LTCP) update, this report presents the conceptual design and cost analyses for four wet weather treatment alternatives for the Southeast Water Pollution Control Plant (SW WPCP). These treatment alternatives were short listed from previous evaluations by the LTCP team (PWD, CDM, and CH2M HILL) based on information from: water quality data analysis and review of available land for SW WPCP; survey of various potential wet weather treatment technologies; and site visits to three existing wet weather treatment facilities in Ohio (CH2M HILL, 2008b). A treatment train utilizing CEPT with Plate Settlers was evaluated for the Southeast WPCP, but was subsequently eliminated due to its extremely high cost (CH2M HILL, 2008c).

The wet weather treatment technologies for the SW WPCP evaluated in this report are as follows:

1. Vortex Swirl Concentrators
2. Conventional Clarifiers
3. Chemically Enhanced Primary Treatment (CEPT) with Conventional Clarifiers
4. Ballasted Flocculation (includes fine screening)

Conceptual treatment trains were developed for each treatment technology at various wet weather flows ranging from 220 million gallons per day (mgd) to 1740 mgd (Exhibit 1-1). Cost curves for both capital and operations and maintenance (O&M) costs were generated for each treatment train alternative. This report presents the conceptual design parameters, site layouts, cost estimates, and potential issues of each treatment train alternative.

EXHIBIT 1-1
Schematic View of Treatment Trains Evaluated



2.0 Improvements to Existing Plant

In order to increase the flow capacity of the SW WPCP for wet weather conditions, the potential of maximizing flow through the existing plant was evaluated. From 2004 to 2007, the SW WPCP treated an average daily flow of 193 mgd, a maximum daily flow of 432 mgd, and an instantaneous peak flow of 489 mgd. The maximum plant flow sustained over 12 hours was 466 mgd (CH2M HILL, 2008b).

According to stress testing results and recommendations, the SW WPCP's firm capacity can potentially reach 540 mgd with several process and hydraulic modifications (Exhibit 2-1). The necessary improvements to achieve this flow were identified in the 2001 Stress Testing Report and are based on results of stress tests on unit processes, long-term monitoring of the plant, hydraulic modeling, and input from SW WPCP plant staff (CH2M HILL, 2001).

In sizing the wet weather treatment trains, it was assumed that the upgrades proposed in the Stress Testing Report and identified in Table 2-1 will have been completed, increasing the plant's capacity to a minimum of 540 mgd. Thus, the baseline cost that is used in the wet weather treatment train cost estimates is $64.5 million (Exhibit 2-1). This is reflected in the cost curves for each treatment train, presented in latter sections of the report.

EXHIBIT 2-1
Cost Summary of Potential Improvements for Existing SW WPCP

	Improvement Description	Cost(1)
1	Replace caulking on secondary clarifier launders to improve flow distribution	Complete
2	Provide preliminary treatment for the BRC centrate that is recycled to the plant	$17,585,962
3	Modify existing RAS system in the secondary clarifiers	$8,717,624
4	Provide four gravity thickeners for thickening of primary sludge (tentative location west of the Final Sedimentation Tanks)	$25,165,565
5	Resolve hydraulic limitations between primary clarifiers and aeration basin	$11,121,009
6	Provide an additional effluent pump at the effluent pumping station	$1,981,532
	TOTAL	$64,571,692

(1) Assume escalation factor of 19.8% - based on 9/1/2009 start date and 2-year construction duration.

3.0 New Facility Location

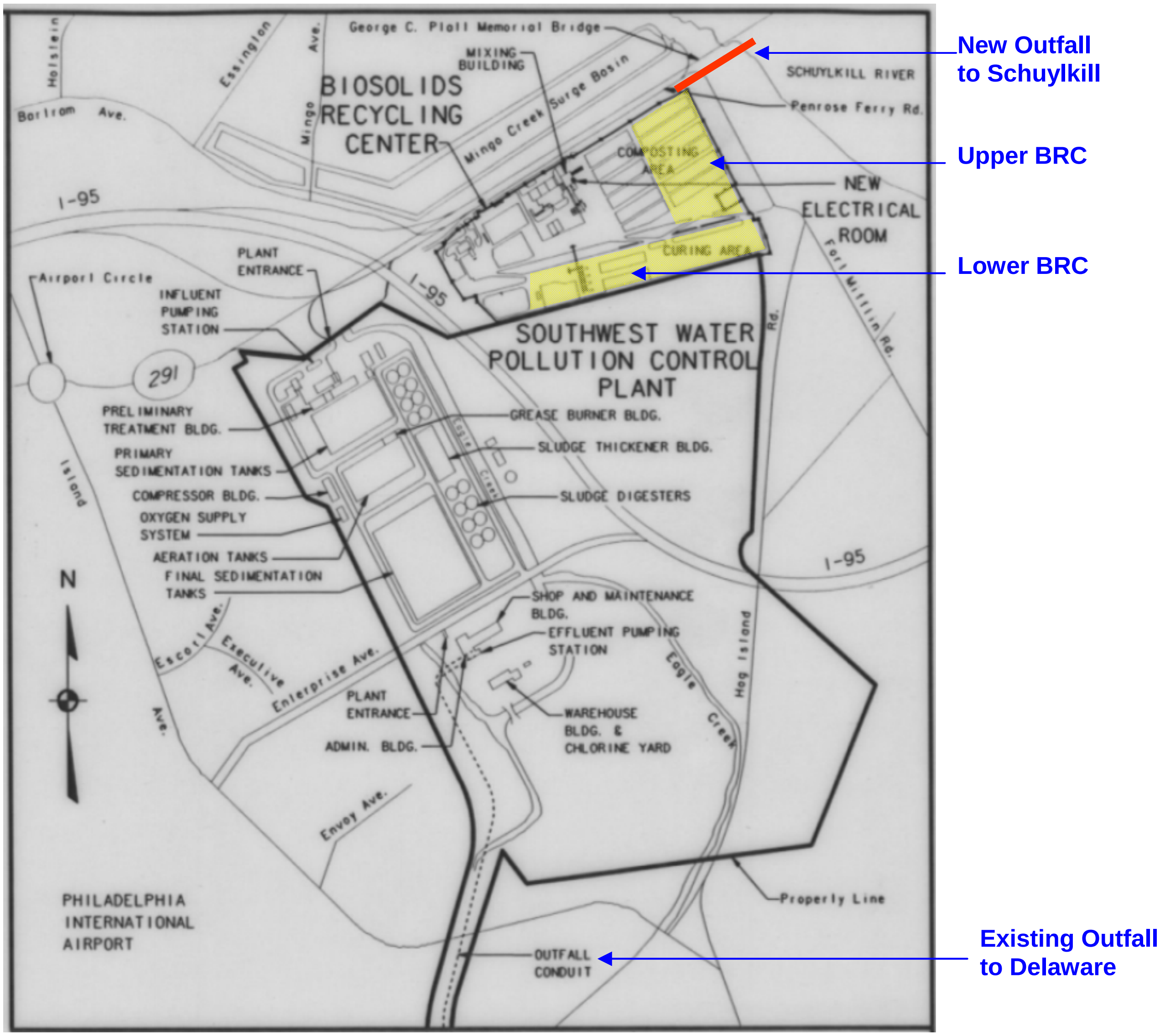
The existing SW WPCP is located east of the Philadelphia International Airport, near the confluence of the Schuylkill and Delaware Rivers. Due to proposed construction activities by both the Federal Aviation Authority (FAA) and the Army Corps of Engineers (ACOE) in the vicinity, the land area available for plant expansion is limited. While the impact of the proposed projects by the FAA and the ACOE is presently undetermined, it was decided that the wet weather treatment facility should be located in an area least likely to be affected by projects proposed by those entities. The area north of the lagoons, currently utilized by the Biosolids Recycling Center (BRC) for composting and curing, was chosen as a suitable location for the new wet weather treatment facility. This L-shaped area is comprised of two tracts of land referred to as the Upper BRC and the Lower BRC (Exhibit 3.1).

3.1 New Outfall to the Schuylkill

The outfall conduit for the existing SW WPCP passes underneath the airport as it runs southward from the plant to the Delaware River. Since it runs under an airport runway on FAA property, the expansion of this existing conduit is considered infeasible. Alternate routes to the Delaware also appear difficult for construction. Given the new wet weather facility's proximity to the Schuylkill River, the most logical alignment for the new outfall conduit is eastward along Penrose Avenue, terminating at the Schuylkill River near the George Platt Memorial Bridge (Figure 3.1).In order to construct a new outfall to the Schuylkill, a new discharge permit will need to be negotiated for the new wet weather treatment facility. Unlike the Southeast and Northeast WPCPs, effluent from the wet weather facility will not commingle with the effluent from the conventional plant. This means that the regulating agencies may view the new facility as a separate wet weather treatment facility, not as an expansion of a WPCP requiring secondary treatment.

If blending of the two plant effluents is required or desired, the outfall for the existing plant could be relocated to the Schuylkill by constructing a new outfall conduit. The cost of this conduit, and thus comingling, is estimated at $155 million. Since the value of comingling is questionable, the cost of this blending option is not included in the cost curves. In terms of plant operation, this report will treat the new wet weather facility as part of the SW WPCP, despite the difference in outfall locations.

EXHIBIT 3-1
New Wet Weather Facility Location for the SW WPCP



4.0 Wet Weather Treatment Alternatives: Evaluation Methodology

As described above, the new wet weather facility for the SW WPCP will be designed to treat all flows that cannot be treated by the conventional plant. As such, wet weather flows in excess of 540 mgd will be diverted to the new facility. The four wet weather treatment trains under evaluation for the new facility are:

1. Vortex Swirl Concentrators
2. Conventional Clarifiers
3. Chemically Enhanced Primary Treatment (CEPT) with Conventional Clarifiers
4. Ballasted Flocculation (includes fine screening)

Conceptual designs and cost estimates were performed for each treatment train at different design flows. This section describes the development of the various design flows and the key assumptions for design and cost estimating.

4.1 Design Flows

The design flows that were selected for evaluation for each treatment train are shown in Exhibit 4-1 and are described below in further detail.

EXHIBIT 4-1
Design Flows Evaluated for each Wet Weather Treatment Train

Treatment Train	Design Flows Evaluated (mgd)
#1) Vortex/Swirl Concentrators	220, 702
#2) Conventional Clarifiers	220, 600, 1200
#3) CEPT w/ Conventional Clarifiers	220, 550, 1000
#4) Ballasted Flocculation	220, 980, 1740

4.1.1 Minimum Design Flow: 220 MGD

The 220 mgd flow point reflects the capacity of the wet weather treatment train required to bring the treatment capacity of SW WPCP to the same level as the existing collection system capacity. In a technical memorandum provided by CDM, it was noted that the existing collection system can deliver 760 mgd to the SW WPCP assuming all process and hydraulic limitations in the plant are removed (Myers, 2007). With the assumption that 540 mgd can be treated by upgrading the existing plant, the new wet weather treatment train will need a minimum capacity of 220 mgd.

4.1.2 Design Flow by Permit Limits: 702 MGD

Unlike the Northeast and Southeast plants, no physical blending of the effluents from the conventional and wet weather plants at SW WPCP will actually occur (Section 2). For the purposes of this evaluation, we have considered the existing plant and its new wet weather facility as one system and have based the maximum allowable system flows on the water quality of the commingled flow. This allows for the determination of the maximum allowable flow through each wet weather treatment train for the system to continue meeting NPDES permit limits for weekly and monthly TSS and cBOD concentrations (Exhibit 4-2, CH2M HILL, 2008b).

With the exception of the Vortex/Swirl train, the flows through the candidate wet weather treatment trains were unlimited by permit requirements, assuming that the wet weather treatment facility operates for no more than seven days per month. The maximum allowable flow through the Vortex/Swirl train is 702 mgd. The maximum flows for the "unlimited" trains are bounded by other conditions as described in Sections 4.1.4 and 4.1.5.

It should be noted that if PWD were to negotiate a new discharge permit to the Schuylkill for the wet weather treatment facility, the maximum allowable flows through each wet weather treatment train would also need to be negotiated. Thus, the flow points analyzed in this report were used for the development of cost curves, but may not reflect what will be allowable under the regulatory framework.

EXHIBIT 4-2
Maximum Allowable Flow of Wet Weather Treatment Trains to Meet NPDES Permit Requirements

Treatment Train	TSS Removal Efficiency[1] (%)	Achievable Effluent TSS Concentration of Wet Weather Train[2] (mg/l)	Maximum Allowable Flow Through Wet Weather Train[3] (mgd)
#1) Vortex/Swirl Concentrators	30%	158	702
#2) Conventional Clarifiers	55%	102	Unlimited*
#3) CEPT w/ Conventional Clarifiers	80%	45	Unlimited*
#4) Fine Screening -> Ballasted Floc	91%	21	Unlimited*

*These flows are unlimited assuming the wet weather treatment train operates for no more than seven days per month, an estimate provided by CDM (CH2M HILL, 2008b).

(1) TSS removal efficiencies are based on industry standards. Specific references are provided in TM-SE2 (CH2M HILL, 2008a).

(2) Achievable effluent concentrations based on 95th percentile influent wet weather TSS concentration (226 mg/L)

(3) Maximum flow determined by NPDES Monthly TSS Limit assuming blending between conventional and wet weather plant. The allowable daily "blended" effluent TSS concentration during wet weather was calculated to be 99 mg/L (CH2M HILL, 2008b).

4.1.3 Design Flows by Available Land – Upper BRC: 550 MGD, 600, 980 MGD

While both the Upper and Lower BRC areas are available for the new wet weather facility, the two strips of land are separated by Penrose Ferry Road. To keep both the new wet weather facility and the BRC on the same side of the road, the use of the Upper BRC alone was assessed. It was found that a 550-mgd CEPT facility, a 600-mgd Conventional Clarification facility, or a 980-mgd Ballasted Flocculation could fit on the Upper BRC site alone. The 702-mgd vortex facility described above is also able to fit on this site.

4.1.4 Design Flows by Available Land – Upper and Lower BRC: 1000, 1200 MGD

Making full use of the land available in both the Upper and Lower BRC areas, it was found that either a 1000-mgd CEPT facility or a 1200-mgd Conventional Clarification facility could fit on the entire site.

4.1.5 Maximum Design Flow: 1740 MGD

According to CDM's assumptions on the capacity of the upgraded collection system, the collection system capacity for the SW WPCP could reach 2,280 mgd after transmission improvements, equivalent to three times the existing collection system capacity. Assuming the existing plant will be able to handle 540 mgd, the maximum flow to the new wet weather facility will be 1,740 mgd. The maximum design flow point used for the ballasted flocculation was thus 1,740 mgd. This facility will be able to fit on the Upper and Lower BRC areas.

4.2 Key Design Assumptions

4.2.1 Average Design Flow

In the previous section, the design flow capacities were identified for each treatment train based on permit limits, available land area, and collection system capacity. These flows are the peak flows that the wet weather facilities are designed to treat under each scenario.

The average flow that the wet weather facility will receive, however, depends on conditions in the collection system. Preliminary model simulations have been performed for the Southwest Drainage district (SWDD) under several deep tunnel and plant expansion scenarios (CDM, 2008). Simulation results suggest that the average flow delivered to the wet weather facility increases as the capacity of the facility increases, and is not highly sensitive to the volume of storage in the collection system (Exhibit 4-3).

Model runs for a 540-mgd and a 1,080-mgd wet weather facility generated an average flow of 362-mgd and 472-mgd, respectively, assuming the largest storage tunnel scenario. Based on these model results, the maximum average design flow assumed for the new wet weather treatment trains evaluated in this report is 472-mgd. For the Conventional Clarification 600-mgd and the CEPT 550-mgd scenarios, an average flow of 362-mgd was assumed. For trains with peak capacities less than 362 mgd, the average flow is assumed to be equivalent to the peak flow of the facility (Exhibit 4-4).

EXHIBIT 4-3
Average Annual Wet Weather Treatment Rates Under Various Deep Tunnel and Plant Expansion Scenarios

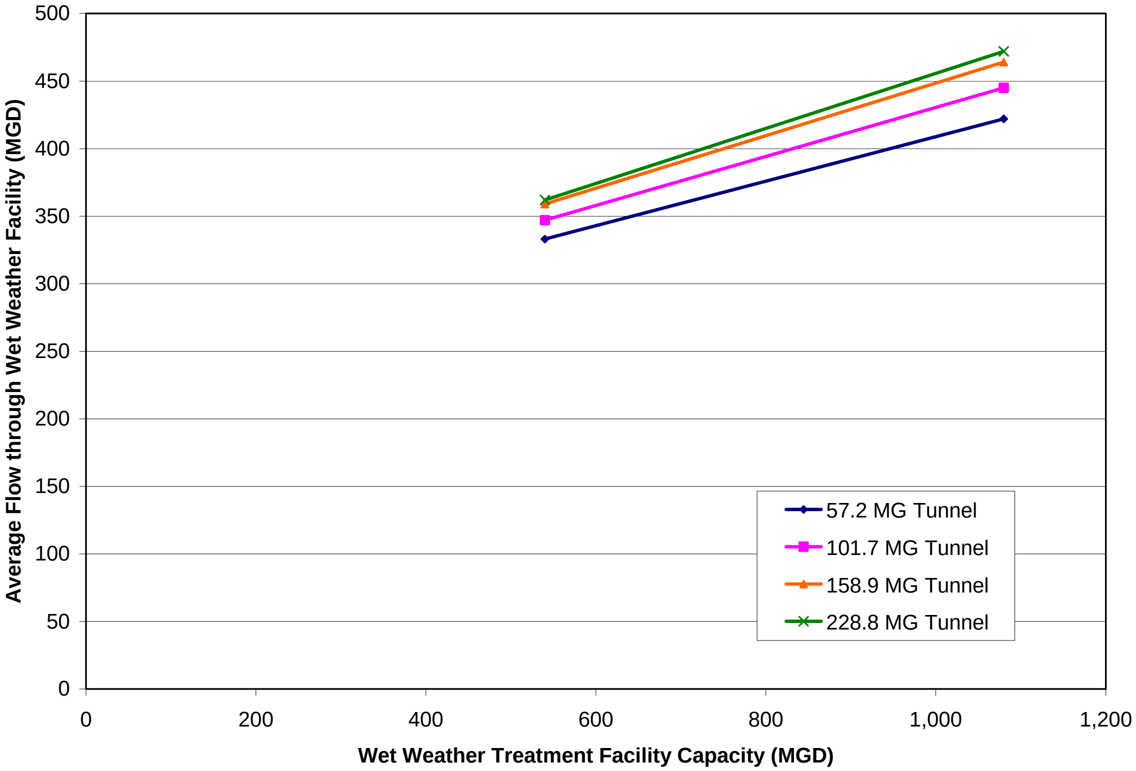


EXHIBIT 4-4
Average Design Flows

Maximum Design Flow (mgd)	Average Design Flow (mgd)
220	220
550, 600	362
980, 1000, 1200, 1740	472

4.2.2 Process

The process design described herein is based on conceptual design parameters and will require refinement as the planning and design efforts progress. For the purposes of developing capital costs, sizing of most facilities was based on maximum design flows. The average design flow, as described above, was used for sizing chemical storage facilities, storage for screenings and grit, and sludge handling facilities.

Preliminary Treatment

Each wet weather train evaluated in this report was sized to treat influent flow in excess of the plant's flow capacity of 540 mgd. A new influent conduit will divert excess wet weather flow to the new preliminary treatment building (PTB) of the wet weather treatment facility. The new PTB will contain an influent wet well at a similar elevation to the existing wet well, bar screens, influent pumps, and screenings and grit handling systems. The influent pumps were designed to increase the hydraulic grade line so that the wet weather flow can discharge to the river outfall by gravity from the wet weather treatment facilities. The screenings and grit handling systems include screenings washers and compactors, as well as grit concentrators and classifiers. This system will handle screenings from both the bar screens and the fine screens when required.

From the PTB, the wet weather flow will continue on to further treatment through processes dependent on each treatment train. These are described in further detail in Sections 5 through 8.

Disinfection

The final process of all treatment trains is chlorination and dechlorination. The wet weather flow will be dosed with sodium hypochlorite at the head of the new chlorine contact chamber. For all facilities with capacities of 600-mgd or less, the chlorine contact chamber is sized to provide a 20-minute detention time at peak flow. For facilities with higher capacities, the chamber is sized for a 10-minute detention time at peak flow, and it is assumed that the chlorine dosage will be increased correspondingly to provide adequate disinfection. Sodium bisulfite is then used for dechlorination at the end of the chlorine contact chamber. A new 700-ft long outfall conduit will convey the treated effluent to the Schuylkill River.

Chemical Feed

For CEPT and Ballasted Flocculation, which provide chemically-enhanced clarification, a coagulant and flocculant are added as settling aids. For CEPT, Train #3, these chemicals are added to a rapid mixer and flocculation basin upstream of the sedimentation tank. In the ballasted flocculation, Train #4, the settling aids are added to mixing zones that are part of the ballasted flocculation unit.

Ferric chloride was selected as the coagulant for all trains since it is currently used at PWD's water treatment plants. However, if there are concerns with the iron affecting the digestion process downstream, aluminum sulfate (alum) can be used as a substitute. Liquid polymer is used as the flocculant for all trains.

Ten-day storage at average flow was assumed for all chemicals.

Sludge Handling

Primary sludge from all treatment trains is pumped to gravity thickeners, where the solids concentration is expected to increase to a minimum of 3 percent. The thickeners are sized to handle the average wet weather flow (as presented in Exhibit 4-4) with a 95 percentile influent solids concentration (226 mg/L) for a continuous period of 24 hours.

The thickened sludge will be pumped to the plant's digesters for treatment. The sludge will be screened through StrainPress® sludge cleaners to remove inert solids before entering the digesters. Capital costs for each treatment train include the cost of extra digesters that may be required at the SW WPCP, assuming a maximum of seven wet weather days in one month. The digesters were sized to provide 20-day storage for solids, assuming average flow, a 95 percentile influent solids concentration (226 mg/L), an average wet weather event duration of five hours, and five events in 20 days. The new digesters will be located in the vacant area south of the existing digesters at the SW WPCP. The digesters needed for the SE WPCP wet weather facility will also be located in this area.

The design parameters that were assumed for all the treatment train processes are summarized in Exhibit 4-5. The process flows are described in further detail in each of the treatment train sections.

EXHIBIT 4-5
Key Process Design Assumptions for Wet Weather Treatment Trains(1)

Preliminary Treatment			
Bar Screens	Opening Size	15	mm (0.59 in)
	Screenings Production(2)	3.5	cf/mg
Influent Pumps	Type	Vertical End-Suction	
	Total Dynamic Head (TDH)	60	ft (match SW WPCP wet well elevations)
Fine Screens	Opening Size	6	mm (0.24 in)
	Screenings Production(2)	2.5	cf/mg
	Screenings Compaction Factor	2	
Grit Removal	Type	Vortex Grit Unit	
	Grit Production(2)	4	cf/mg
Screenings and Grit	Number of Days Storage	1	day
Primary Clarifiers	Type	Rectangular Basin	
	Sludge Collection Mechanism	Chain-and-flight	
Flocculation Tank	Detention Time (at max flow)	10	min
	Number of Stages	3	
Wet Weather Treatment Technology	**Surface Overflow Rate (gpd/sf)**		
Vortex/Swirl	36,000 (25 gpm/sf)		
Conventional Clarifiers	2,400 (3)		
CEPT	3,000		
Ballasted Flocculation	84,600 (60 gpm/sf)		
Chlorine Contact			

EXHIBIT 4-5
Key Process Design Assumptions for Wet Weather Treatment Trains(1)

Chlorine Contact Chamber	Detention Time (at avg flow)	20	min

Chemical Feed

Chemical	Purpose	Concentration	Storage (at avg flow)
Ferric Chloride	Coagulation	60 mg/L	10 days
Liquid Polymer	Flocculation	2 mg/L	10 days
Sodium Hypochlorite	Chlorination	5 mg/L	10 days
Sodium Bisulfite	De-chlorination	1.5 mg/L(4)	10 days

Primary Sludge Generation(5)

Train	% TSS Removal	% Solids in Sludge
#1: Vortex/Swirl	30%	0.07%(6)
#2: Conventional Clarifiers	55%	0.5%
#3: CEPT	80%	0.5%
#4: Ballasted Floc	90%	0.3%

Sludge Thickening

Gravity Thickeners	Max Hydraulic Loading Rate (limiting factor for Trains #1 and #5)	900	gal/sf/day
	Max Solids Loading Rate (limiting factor for Trains #2, #3, and #4))	30.7	lb/sf/day
	% Solids of Thickened Sludge	3	% minimum
StrainPress® Sludge Screens	Sludge Throughput	200 – 400	gpm

Digesters

Anaerobic Digesters	Detention Time	20	days
	Diameter	115	ft
	Side Water Depth	25	ft
	Volatile Solids Destruction	50	%

(1) Unless otherwise noted, all design parameters are based on standard textbook values.

(2) Estimated from 2004-2005 grit and screenings disposal records from the SE WPCP (CH2M HILL, 2008c).

(3) Based on stress testing results on existing primary clarifiers

(4) Assumes 1 mg/L residual chlorine concentration at the end of the chlorine contact chamber

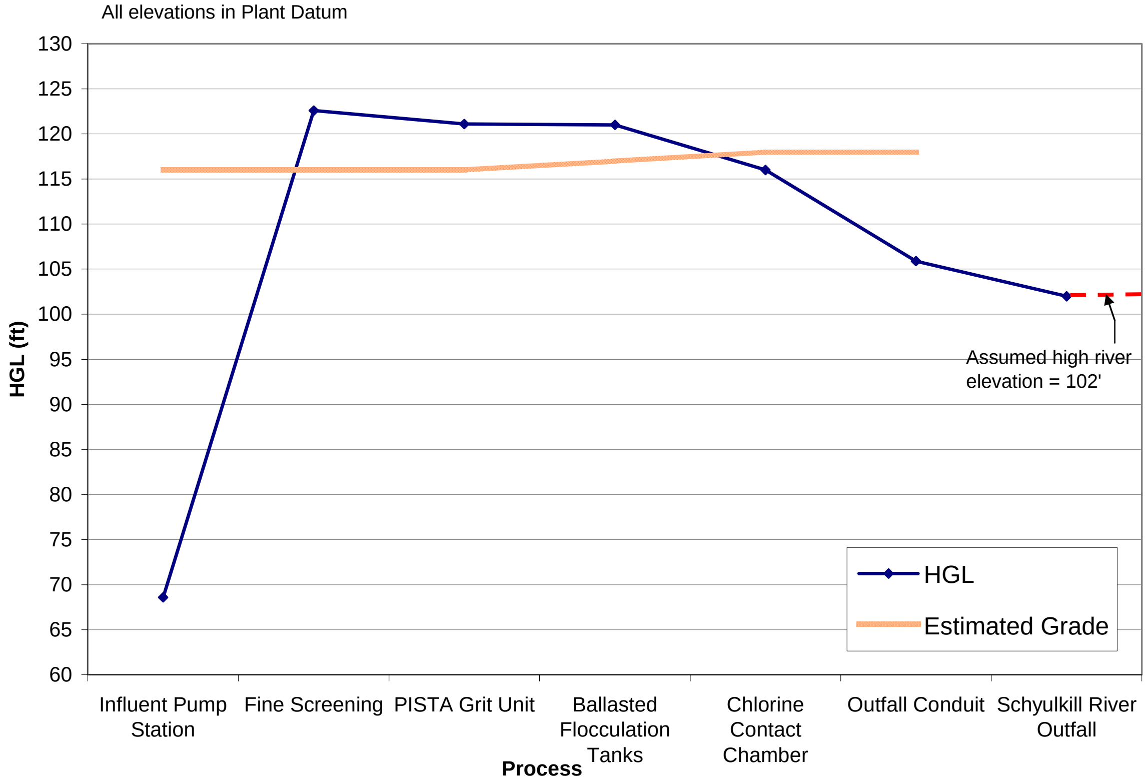
(5) Assumes 95 percentile influent TSS concentration of 226 mg/L, and volatile solids percentage of 70%

(6) Based on a 10% underflow from the vortex/swirl concentrator

4.2.3 Hydraulics

To eliminate the need for a new effluent pump station, the elevations of the new wet weather treatment trains were set to allow gravity flow to the new Schuylkill River outfall. A preliminary hydraulic profile for the ballasted flocculation train at 980 mgd is shown in Exhibit 4-6.

EXHIBIT 4-6
Preliminary Hydraulic Gradeline for the Ballasted Flocculation Treatment Train at 980 MGD



As an initial condition, the high river elevation was assumed to be 102 feet. This is similar to the assumption made for the Delaware River in the Southeast WPCP memo (CH2M HILL, 2008c). It is also based on the assumption that the Schuylkill River levels and the Delaware River levels are equal at their point of confluence.

The water surface level of the chlorine contact chamber was assumed to be 2 feet below grade (116 feet). Since the ground elevation at the Upper BRC site is much higher than the maximum river level, there is an approximate 10-ft drop between the chlorine contact chamber and the beginning of the outfall conduit. Headloss through the outfall conduit is estimated at 3.9 ft (using Manning's Equation).

The elevation of the chlorine contact chamber sets the elevations of the upstream unit processes. As shown in Exhibit 4-6, the tank walls may rise above grade by several feet. To be conservative, however, the capital cost estimates assume complete burial of all tanks.

4.2.4 Site Conditions

Two main assumptions were made on the site and soil conditions at the Upper and Lower BRC sites:

- Piles will be needed for foundations of all structures. A pile density and depth of 0.069 piles/sf and 30 feet were used for all water-bearing structures on site. A pile density and depth of 0.089 piles/sf and 50 feet were used for the outfall conduit going out to the Schuylkill River. These numbers were based on existing pile plans for the Northeast WPCP, since there are no similar structures at the existing BRC (CH2M HILL, 2008d). A pile density and depth of 0.0006 piles/sf and 30 feet were used for all other structures, based on drawings of the existing sludge dewatering facility at the BRC.
- Dewatering will be required for most buried structures. According to plant drawings, the groundwater elevation is approximately 10 to 15 feet below grade at the SW WPCP.

4.3 Cost Estimating Assumptions

CH2M HILL's costing model was used to develop conceptual level estimates of both capital and life-cycle costs for each of the treatment trains and flows. This tool was supplemented by budgetary quotes from vendors for all major pieces of equipment. These estimates are defined as Class 4 estimates by the Association for the Advancement of Cost Engineers (AACE) and have an expected level of accuracy of +50 to -30 percent.

4.3.1 Capital Costs

Construction Costs

Construction costs were developed using the costing model for each building or unit process of a treatment train, and were based on estimated materials, labor, equipment, and installation costs. Contractor markups applied to the construction subtotal costs are presented in Exhibit 4-7. The percentages used are industry standards and are in agreement with CDM's assumptions. The escalation factors applied are based on a construction start-date of September 1, 2009, and the estimated construction duration of each scenario (Exhibit 4-8). This start-date was chosen since PWD's LTCP Update must be submitted by this date. A location adjustment factor of 15.2 percent was applied to the escalated construction cost, which is in agreement with the ENR 20-city Construction Cost Index (CCI).

Lastly, a market adjustment factor of 15 percent was applied to account for: busy contractors; contractors selectively bidding jobs; contractors selectively choosing which Owners they want to do jobs for; premium wages to keep skilled workers and management staff; availability of crafts/trades; immigration impacts and uncertainty; abnormal fuel impacts and uncertainty; and abnormal material impacts of the last two years.

EXHIBIT 4-7
Contractor Markups Assumed in Capital Cost Estimates

Contractor Markups	%	Applied to:
Overhead (OH)	10%	Subtotal of Construction Cost
Profit (P)	5%	Subtotal of Construction Cost + OH
Mobilization, Bonds, and Insurance (MOB)	5%	Subtotal of Construction Cost + OH&P
Contingency	25%	Subtotal of Construction Cost + OH&P + MOB

EXHIBIT 4-8
Escalation Factors for Various Construction Scenarios

Flow Capacity of Wet Weather Treatment Train (mgd)	Estimated Construction Duration (months)(1)	Escalation Factor(2)
220	27	21.2%
550, 600, 702	36	23.9%
980, 1000, 1200, 1740	48	28.2%

(1) Escalation factors are based on mid-point of construction with a construction start-date of 9/1/2009.

(2) Construction durations were estimated based on facilities of similar size, and need to be refined through each stage of design.

Non-Construction Costs

A factor of 30 percent was applied to the total construction costs to estimate non-construction costs related to the project. The breakdown of these factors is shown in Exhibit 4-9.

EXHIBIT 4-9
Non-Construction Cost Factors

Non-Construction Expenditure	Factor*
Permitting	2%
Engineering	10%
Services During Construction	10%
Commissioning and Startup	3%
Legal/Administration	5%

*Each factor was applied to the total construction cost of the project, including all markups and escalation.

4.3.2 O&M and Life Cycle Cost Analysis

Life cycle and O&M costs of each treatment train at each flow were also estimated using CH2M HILL's costing model and were based on financial and operational assumptions as listed in Exhibit 4-9. The O&M costs cover labor, power for equipment and buildings, chemicals, and repair, maintenance and replacement of structures and equipment. The average flows that were assumed for the O&M costs are shown in Exhibit 4-4, as described in Section 4.2.1.

The additional labor required for each treatment train is dependent on the flow capacity of the train, as shown in Exhibit 4-11. It was assumed that new maintenance workers and operators would be hired for the new wet weather facility, working full time throughout the year. For some flow scenarios, it was assumed that a portion of the labor requirements during wet weather events could be met by increasing the number of shifts for existing operators, who would work overtime at a rate of 1.5 times their normal wage. It was assumed that the operators on overtime would work one 8-hour shift per wet weather event.

A detailed break down of the O&M costs and the energy requirements for each train are presented in Attachment SW-2.1. It should be noted that all O&M costs presented for the treatment trains are annualized O&M costs that include escalation over the 30-year period.

Life cycle costs were calculated using the total capital cost, including construction and non-construction costs, and O&M costs. The present value of the life cycle costs are presented in the cost summary section of each train.

EXHIBIT 4-10
Assumed Factors for Life Cycle Cost Estimates

Factor	Value	
Financial		
Annual Discount Rate	4.875	%
Life-Cycle Calculation Period	30	Years
Inflation Rate	4	%(1)
Operation		
Days of operation of wet weather treatment train	48	days(2)
Duration of wet weather event	5	Hours(2)
Labor		
Hourly wage for plant operator	$50.44	including fringe benefits
Hourly wage for plant operator on overtime	$75.65	including fringe benefits
Hourly wage for maintenance worker	$52.35	including fringe benefits
Fringe benefits and overhead multiplier	2.7	applied on top of raw hourly rate
Number of working hours for full time operators at wet weather facility	2,080	hours per year per operator
Number of working hours for operators on overtime at wet weather facility	408	hours per year per operator (16 hours per event)
Number of working hours for maintenance workers at wet weather facility	2,080	hours per year per worker

EXHIBIT 4-10
Assumed Factors for Life Cycle Cost Estimates

Factor	Value	
Power for Buildings		
Building Electrical Cost Assumed	$0.10	$/kwh
Building Electrical Requirements	2	watts/sf of building area
Building Heating Requirements	1.2	BTU/hr/surface area of building
Natural gas cost assumed	$14	per MBTU
Power for Equipment(3)	$0.10	$/kwh
Chemicals(4)		
Ferric Chloride	$310	$/dry ton
Liquid Polymer	$3983	$/dry ton
Sodium Hypochlorite	$1450	$/dry ton
Sodium Bisulfite	$1000	$/dry ton
Repair, Maintenance, and Replacement		
	Percentage assumed for annual O&M cost	
Finishes	2%	of finishes cost during construction
Equipment	1%	of capital cost of equipment
Instrumentation and Controls	5%	of capital cost of I&C
Mechanical	0.1%	of capital cost of mechanical work (incl. valves)
Electrical	1%	of capital cost of electrical equipment
Disposal		
Grit and Screenings Disposal and Hauling Costs	$100	per cubic yard
Final Sludge Disposal Costs(5)	$75	per wet ton
Other		
Other O&M Costs (including vehicles, lab tests, office equipment and other miscellaneous costs)	$10,000	per additional full-time operator and maintenance worker
Contingency		
Contingency applied to O&M costs	20	%

(1) Based on CCI Index

(2) Based on hydraulic model simulations for the SW WPCP (CDM, 2008).

(3) Equipment power costs estimated by PWD.

(4) Based on existing costs at the plant (McKeon, 2008)

(5) Final sludge mass assumes 30% dewatered cake.

EXHIBIT 4-11
Additional Labor Requirements for each Flow Scenario

Treatment Train Flow Capacity	Number of Additional Full-Time Operators(1)	Number of Existing Operators on Overtime(2)	Number of Additional Maintenance Workers(1)
220	1	1	2
550, 600, 702	2	0	4
980, 1000, 1200	2	1	4
1740	2	3	4

(1) Full-time operators and maintenance workers are new hires who work 2080 hours per year. Maintenance workers include different trades required for the facility (e.g. electricians, instrument technicians, mechanics, etc..)

(2) Existing operators on overtime work 8 hours per wet weather event, or 408 hours per year.

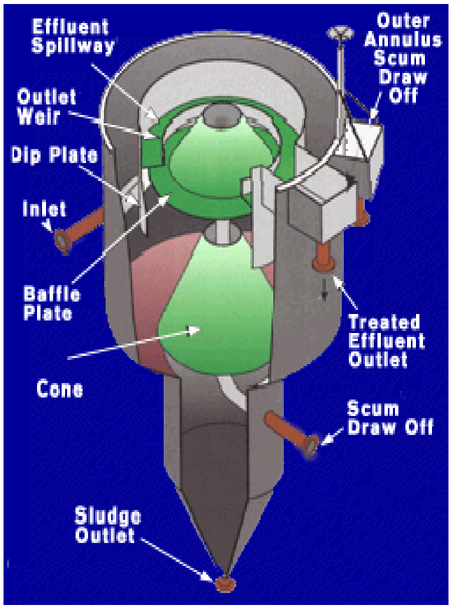
5.0 Treatment Train #1- Vortex/Swirl Concentrators

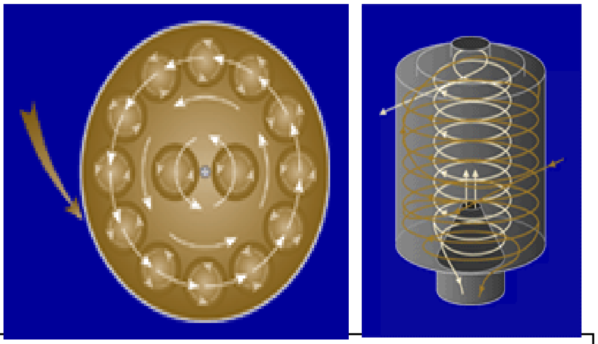
5.1 Process Flow Diagram

The first treatment train under evaluation utilizes the vortex separation technology as its main treatment process. After passing through bar screens and influent pumping at the PTB, the wet weather flow will enter the primary vortex/swirl concentrators. Vortex/swirl concentrators are flow-through structures with no moving parts. The wet weather flow enters the cylindrical structure tangentially, producing a swirling motion that concentrates the solids in the center (Exhibit 5-1). An underflow drain in the center of the unit continually draws the solid materials out of the flow.

The treated effluent flows out of the top of the vessel, continuing on to the chlorine contact chamber. The solids underflow, typically 10 percent of the influent, undergoes grit removal through a vortex grit unit before settling and thickening in gravity thickeners. The conceptual process flow diagram for this treatment train is shown in Exhibit 5-2.

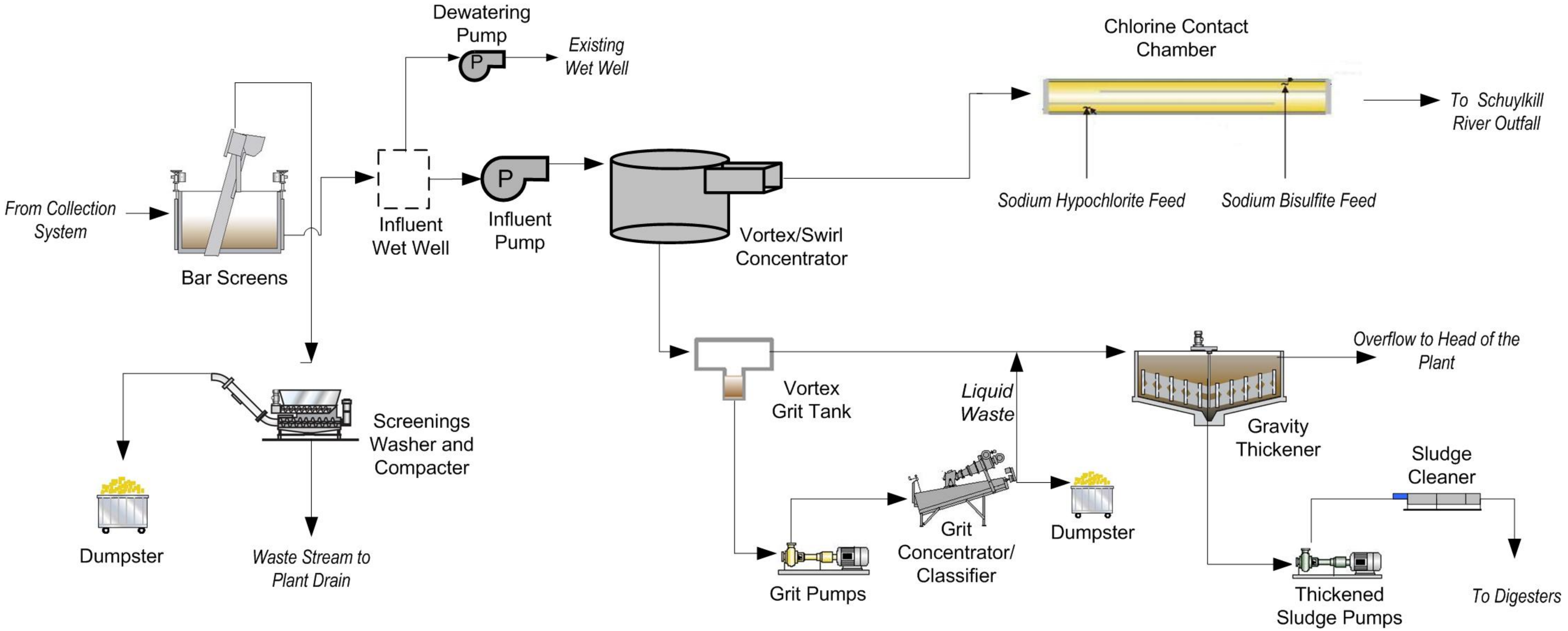
EXHIBIT 5-1
Diagrammatic Cutaway of Vortex/Swirl Device
(Storm King®, H.I.L. Technologies)





Flow Pattern Plan and Profile Views (H.I.L. Technologies)
The flow in vortex/swirl devices initially follows a path around the perimeter of the unit and is then directed into an inner swirl pattern with a lower velocity than the outer swirl. Solids separation is achieved by both centrifugal force and gravity because of the long flow path and inertial separation due to the circular flow pattern. The concentrated underflow passes through an outlet in the bottom of the vessel while the treated effluent flows out of the top of the vessel.

EXHIBIT 5-2
Process Flow Diagram and Key Process Design Parameters for Treatment Train #1: Vortex/Swirl Concentrators



	Bar Screens	Influent Pumps	Vortex/Swirl Concentrators		Vortex Grit Tank		Screenings Washer/ Compactor	Grit Pumps		Grit Concentrator	Grit Classifier	Screenings and Grit Prod.	Sodium hypochlorite			Sodium Bisulfite			Gravity Thickeners & Sludge Cleaners	Primary Sludge Pumps		Thickened Sludge Pumps		Sludge Prod.	Digesters
Flow (mgd)	# units	# units	# primary units	Loading rate on primary unit (gpm/sf)	# units	Dia (ft)	# units	# duty	# standby	# units	# units	Compacted volume (cf/day)	Total storage vol (gal)	# duty pumps	# standby pumps	Total storage vol (gal)	# duty pumps	# standby pumps	# Units	# Duty	# Standby	# Duty	# Stand by	lb/day	# Units
220	3	3	5	24.3	1	12	3	1	1	1	1	1,265	109,537	1	1	6,347	1	1	5	10	3	5	2	124,339	0
702	7	10	15	25.9	1	20	7	1	1	1	1	2,605	235,006	1	1	13,616	1	1	16	30	8	16	4	260,108	1

EXHIBIT 5-3
Conceptual Layouts and Footprints for Treatment Train #1: Vortex/Swirl Concentrators
702 MGD Layout

FLOW (mgd)	PTB	GRIT UNITS	VORTEX SWIRLS	CHEMICAL BUILDING	CCC	GRAVITY THICKENERS*	DIGESTERS	TOTAL FOOTPRINT (acres)
220	54' x 49' & 59' x 39'	12' DIA (1 unit)	40' DIA (5 units)	137' x 47'	109' x 212' (5 passes)	80' DIA (5 units)	-	1.5
702	145' x 56' & 112' x 39'	20' DIA (1 unit)	40' DIA (15 units)	213' x 47'	172' x 268' (8 passes)	80' DIA (16 units)	115' DIA (1 unit)	3.2

5.2 Conceptual Design and Site Layouts

The main design parameters for each flow scenario of this treatment train are shown in Exhibit 5-2. A conceptual site layout for the maximum flow scenario of 702 mgd is shown in Exhibit 5-3. The conceptual design in this report is based on a loading rate on the vortex/swirls of approximately 25 gpm/sf, providing an estimated removal efficiency of 30 percent.

As Exhibit 5-3 shows, a 702-mgd facility does not fully occupy the Upper BRC area, and does not utilize the Lower BRC area at all. This provides the option of designing vortex swirls with lower loading rates in order to achieve high removals. According to a study performed in Columbus, Georgia, the vortex swirl can achieve removal efficiencies of up to 70 percent at a 5 gpm/sf loading rate (WERF, 2003). This option may be considered if regulating agencies require removal efficiencies equivalent to that of primary treatment for the new wet weather facility.

5.3 Operational and Technology-Specific Issues

The effectiveness of vortex/swirl concentrators greatly depends on the hydraulic loading rate on the unit and the characteristics of the solids entering the unit. The optimal loading rate must be determined through pilot or operational testing. In order to operate the vortex/swirl at its optimal operating rate or “sweet spot”, the vortex/swirl units can be brought online one by one as the influent flow increases. Alternatively, an equalization basin can be constructed to maintain a specific flow-rate into the units. An equalization basin was not included in the cost estimates, but conservative hydraulic loading rates were assumed for facility sizing.

5.3.1 Startup and Shutdown

The pretreatment processes (bar screens, influent pumps, and grit removal) can be brought online quickly at the start of a wet weather event. Vortex/ swirl concentrators would be empty at the start of a wet weather event. At small flows, the wet weather flow will exit through the underflow. As flows increase, the vessel will fill due to the increased hydraulic load and begin discharging treated effluent to the outfall.

During shutdown, the vortex/swirl and grit units will be emptied by pumping from the underflow sections to SW WPCP’s existing influent wet well. The influent wet well in the new PTB would also be pumped down to the plant’s existing wet well using dewatering pumps (Exhibit 5-2).

For long term shutdown, the chlorine contact chamber could be pumped down, with the flow recycled to the head of the main plant.

5.3.2 Interaction with Main Plant

The waste streams generated by the screenings washer/compactor and the grit classifiers are sent to the gravity thickeners of the wet weather treatment train and will not affect the main plant.

The overflow from the gravity thickeners is conveyed to the head of the entire plant. The estimated overflow range from wet weather thickeners only ranges from 21 to 69 mgd, depending on the size of the plant. To minimize the effect of this volume, the overflow is recycled back to both the main plant and the wet weather facility so that it can be distributed across all units in operation.

5.3.3 Impact on plant operations

Since the vortex/swirl unit has no moving parts, it is expected to have little operations and maintenance requirements. However, operators' attention may be necessary to monitor the hydraulic loading rates into the vortex/swirls to ensure that the "sweet spot" is maintained. The treatment train also includes grit pumps, concentrators, and classifiers, as well as sludge pumps and other equipment, all of which require maintenance. In addition, the new chemical building will include storage of sodium hypochlorite and bisulfite, which are fed to the new chorine contact chamber. Storage of hypochlorite will need to be monitored, since it degrades over time. In addition, the hypochlorite feed-lines should be flushed or degassed periodically.

5.4 Cost Analyses

The estimated capital, O&M, and lifecycle costs for each flow scenario are presented in Exhibit 5-4. Total capital costs and the capital costs per volume treated for all scenarios are shown in Exhibits 5-5. The estimated O&M costs by category are also presented in Exhibits 5-6. A more detailed breakdown of these costs is presented in Attachment SW-2.1.

EXHIBIT 5-4
Cost Summary for Vortex/Swirl Treatment Train #1

	Wet Weather Flow (mgd)	
Cost	**220**	**702**
Capital Cost ($M)	$170	$453
Annual Operations and Maintenance Cost ($M)	$2.1	$4.3
Present Value of the Cost ($M)	$202	$520

EXHIBIT 5-5
Capital Costs for Treatment Train #1: Vortex/Swirl
Includes cost of upgrading existing plant capacity to 540 mgd

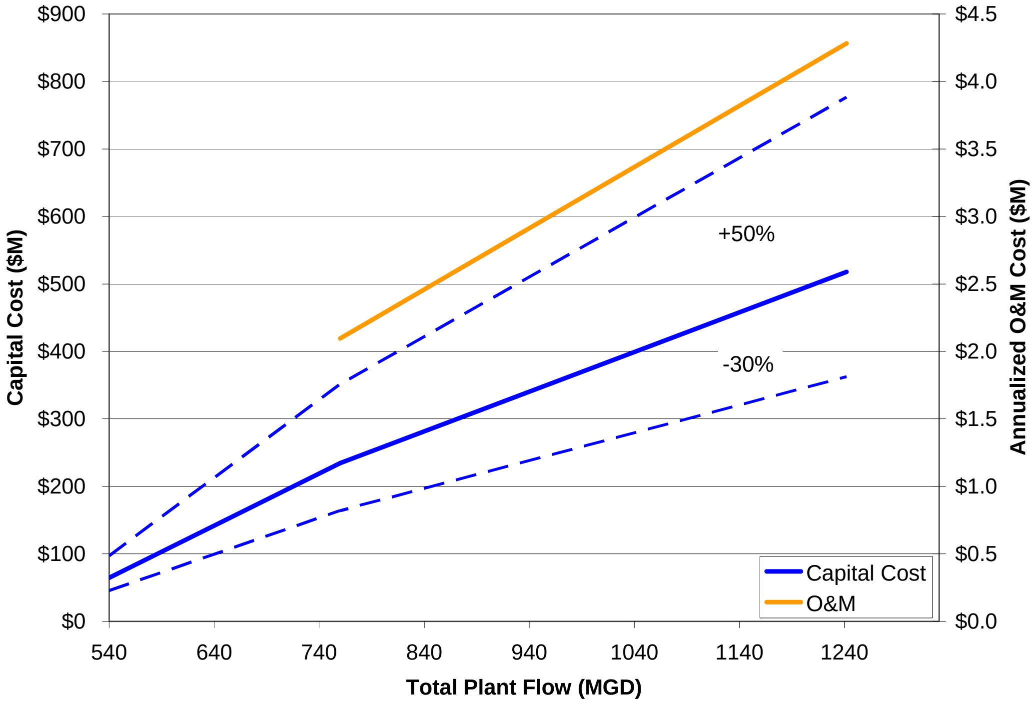


EXHIBIT 5-6
Capital Costs per Gallon Treated for Treatment Train #1: Vortex/Swirl

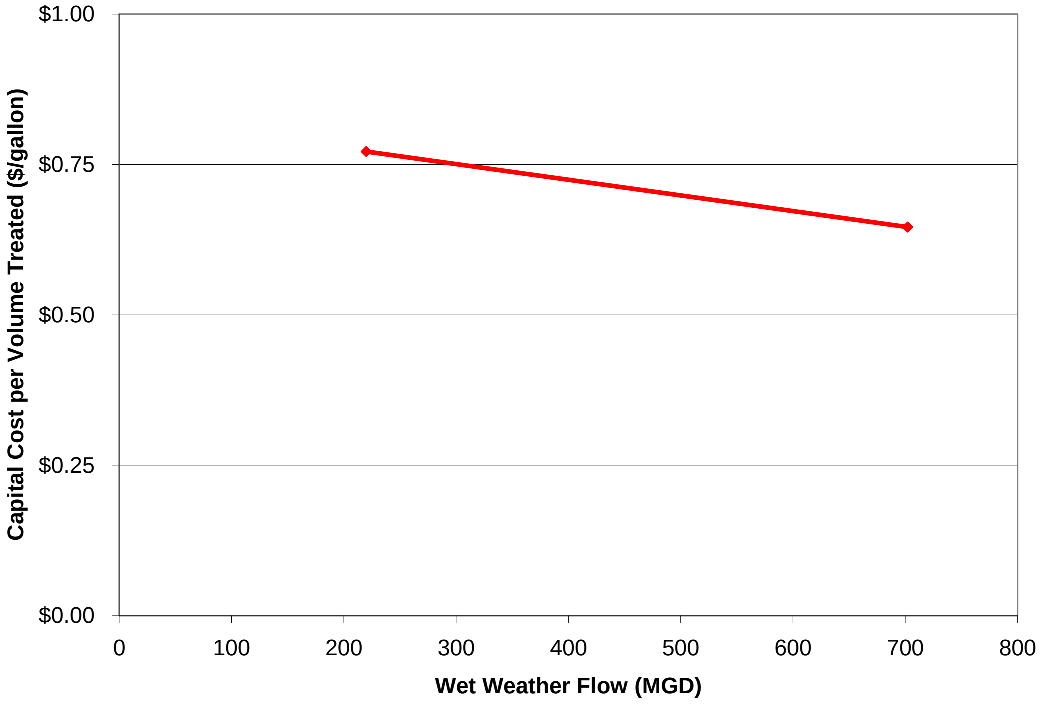
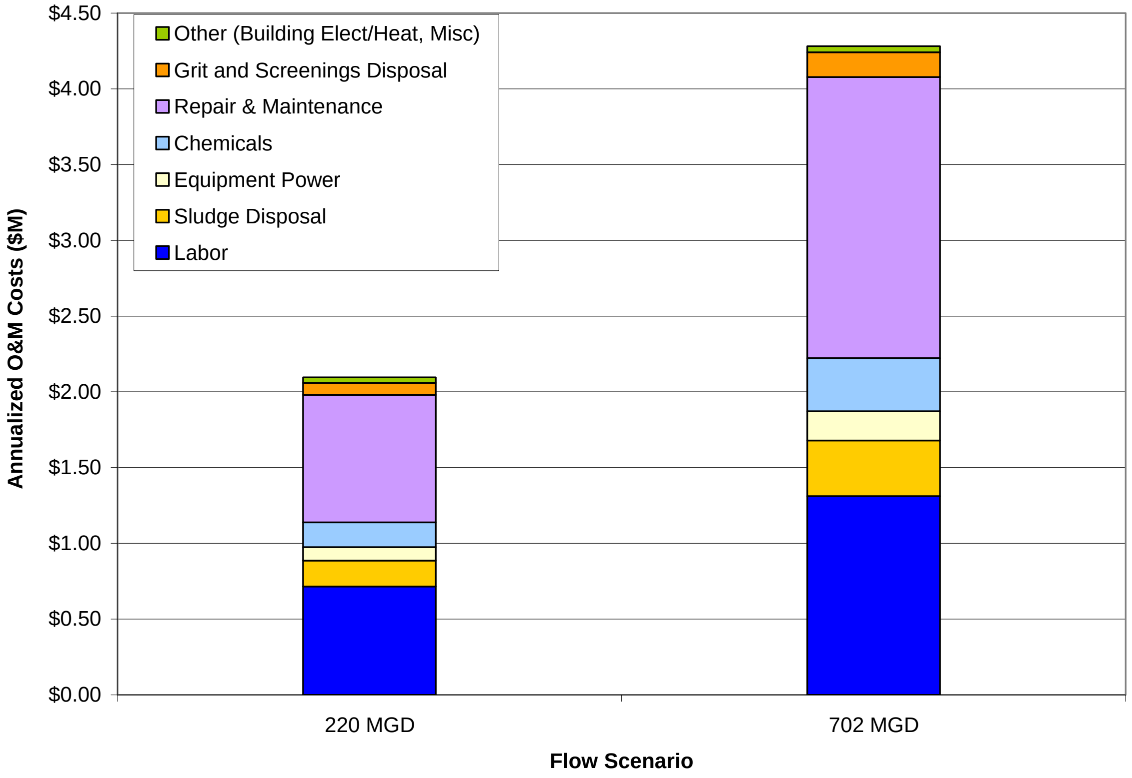


EXHIBIT 5-7
Operations and Maintenance by Category for Treatment Train #1: Vortex/Swirl



6.0 Treatment Train #2 - Conventional Clarifiers

6.1 Process Flow Diagram

Through treatment train #2, the wet weather flow undergoes essentially the same level of primary treatment as the flow through the existing SW WPCP. After preliminary treatment through the bar screens and grit removal, the wet weather flow passes through conventional primary clarifiers at a maximum loading rate of 2400 gpd/sf. This is the overflow rate achievable by the plant's existing primary clarifiers, as shown through stress testing (CH2M HILL, 2001). Primary sludge is collected by chain and flights in the clarifier tanks and is pumped to the gravity thickeners for thickening. The process flow diagram for this treatment train is shown in Exhibit 6-1.

6.2 Conceptual Design and Site Layouts

Conceptual designs were developed at three different flow scenarios for this train: 220, 600, and 1200 mgd. Key design parameters at these flows are shown in Exhibit 6-1. The conceptual layouts for the 600 and 1200 mgd scenarios are shown in Exhibit 6-2. The 600-mgd facility can fit on the Upper BRC area only, and the 1200-mgd facility utilizes the entire Upper and Lower BRC areas available.

6.3 Operational and Technology-Specific Issues

6.3.1 Startup and Shutdown

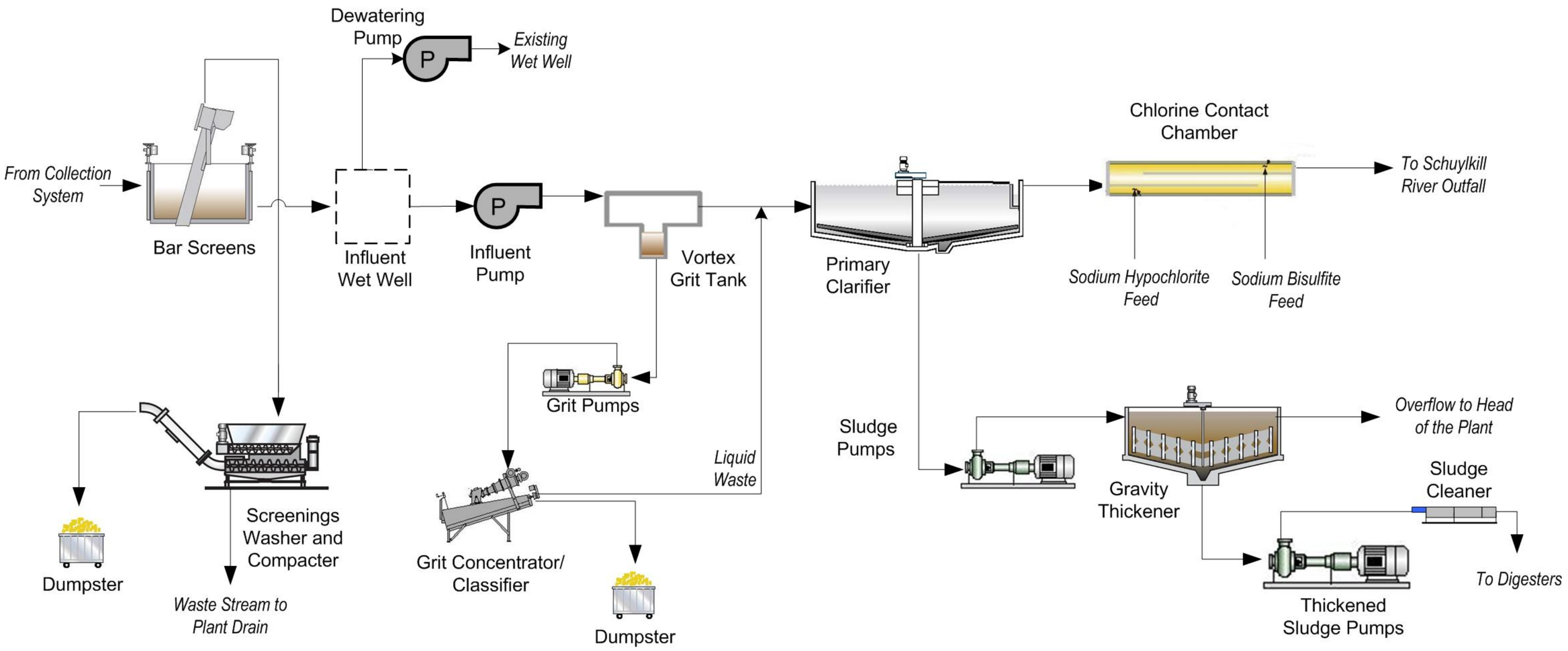
When the wet weather facility is initially put into service, it will take 2-3 hours before the conventional clarifiers begin to discharge treated wet weather flow. This is equivalent to the time needed to displace the existing wastewater in the tanks, or to fill the tanks if they are empty.

For shut down, the tanks may be filled with treated effluent, or drained down to the existing plant if freezing becomes an issue.

6.3.2 Interaction with Main Plant

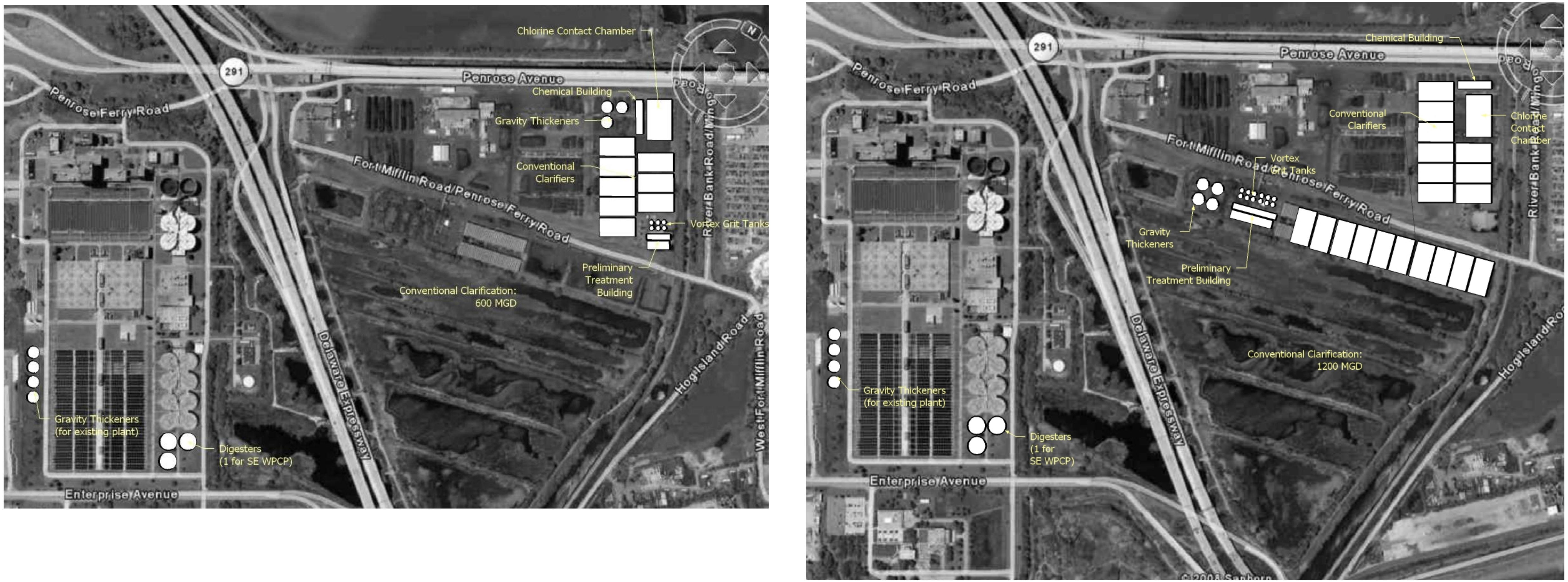
The waste streams generated by the screenings washer/compactor and the grit classifiers are sent to the primary clarifiers of the wet weather treatment train and will not affect the main plant. As with the other treatment trains, the overflow from the gravity thickeners will be conveyed to the head of the entire plant. The estimated overflow from wet weather thickeners only ranges from 4 to 25 mgd, depending on the size of the plant. To minimize the effect of this volume, the overflow is recycled back to the head of the entire plant so that it can be distributed across all units in operation.

EXHIBIT 6-1
Process Flow Diagram and Key Process Design Parameters for Treatment Train #2: Conventional Clarifiers



	Bar Screens	Influent Pumps	Vortex Grit Tank		Screenings Washer/ Compactor	Grit Pumps		Grit Concentrator	Grit Classifier	Screenings and Grit Prod.	Sodium Hypochlorite			Sodium Bisulfite			Clarification	Gravity Thickeners & Sludge Cleaners	Primary Sludge Pumps		Thickened Sludge Pumps		Sludge Prod.	Digesters
Flow (mgd)	# Units	# Units	# Units	DIA (ft)	# Units	# Duty	# Standby	# Units	# Units	Compacted Volume (cf/day)	Total Storage Vol (gal)	# Duty Pumps	# Standby Pumps	Total Storage Vol (gal)	# Duty Pumps	# Standby Pumps	# Trains	# Units	# Duty	# Standby	# Duty	# Standby	lb/day	# Units
220	3	3	3	32	3	3	1	3	1	1,265	109,537	1	1	6,347	1	1	3	2	3	1	2	1	228066	1
600	6	9	6	32	6	6	3	6	3	1,984	180,238	1	1	10,443	1	1	9	3	9	3	3	1	357648	1
1200	12	17	12	32	12	12	3	12	4	2,645	235,006	1	1	13,616	1	1	19	4	19	6	4	1	476865	1

EXHIBIT 6-2
Conceptual Layouts and Footprints for Treatment Train #2: Conventional Clarifiers
600 MGD Layout (left) 1200 MGD Layout (right)



Flow (mgd)	PTB	Grit Units	Clarifier Tanks	Chemical Building	CCC	Gravity Thickeners	Digesters	TOTAL FOOTPRINT (acres)
220	54' x 49' & 73' x 39'	32' DIA (3 units)	124' x 259' (3 units)	119' x 47'	109' x 211' (5 passes)	80' DIA (2 units)	115' DIA (1 unit)	3.4
600	132' x 53' x 133' x 39'	32' DIA (6 units)	124' x 236' (9 units)	213' x 47'	172' x 268' (8 passes)	80' DIA (3 units)	115' DIA (1 unit)	8.5
1200	236' x 58' & 227' x 39'	32' DIA (12 units)	124' x 224' (19 units)	213' x 47'	172' x 268' (8 passes)	80' DIA (4 units)	115' DIA (1 unit)	15.8

6.3.3 Impact on Plant Operations

The operations and maintenance requirements for this treatment train should be similar to those needed for corresponding processes at the existing plant.

6.4 Cost Analyses

The estimated capital, O&M, and lifecycle costs for each flow scenario are shown in Exhibit 6-3. Total capital costs and the capital costs per volume treated are also shown in Exhibits 6-4 and 6-5. Estimated O&M costs by category are presented in Exhibit 6-6. A more detailed breakdown of these costs is presented in Attachment SW-2.1.

EXHIBIT 6-3
Cost Summary for Conventional Clarifiers: Treatment Train #2

	Wet Weather Flow (mgd)		
Cost	**220**	**600**	**1200**
Capital Cost ($M)	$236	$541	$1,027
Annual Operations and Maintenance Cost ($M)	$2.5	$4.4	$6.0
Present Value of the Cost ($M)	$275	$610	$1,121

EXHIBIT 6-4
Capital Costs for Treatment Train #2: Conventional Clarifiers
Includes cost of upgrading plant capacity to 540 MGD

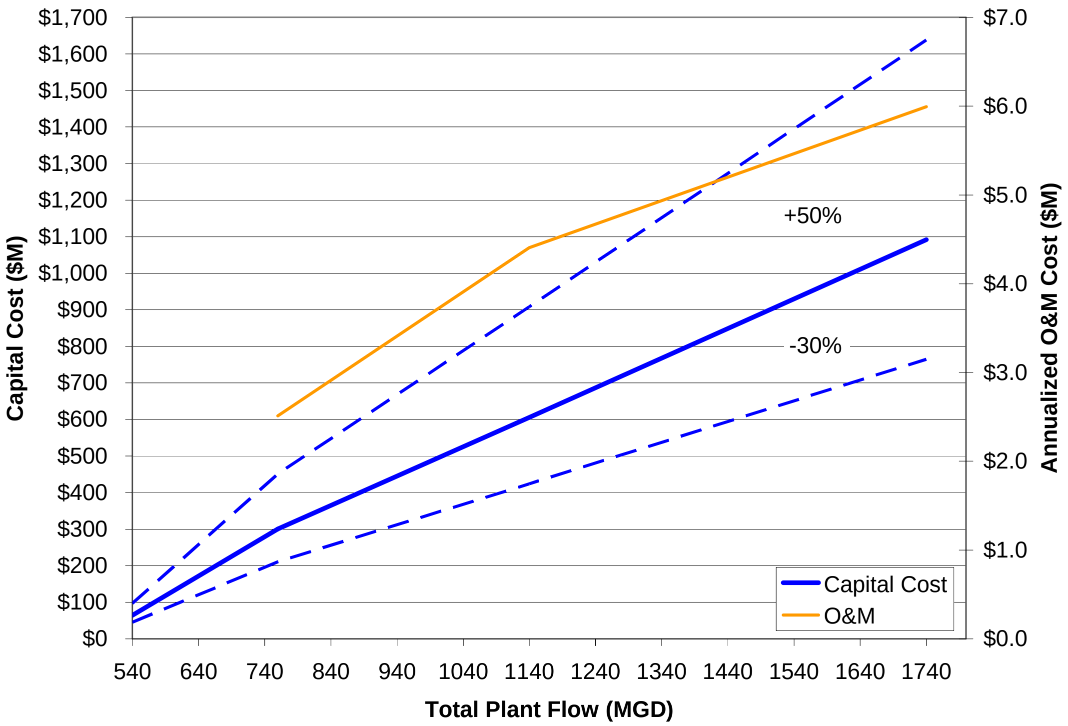


EXHIBIT 6-5
Capital Costs per Gallon Treated for Treatment Train #2: Conventional Clarifiers

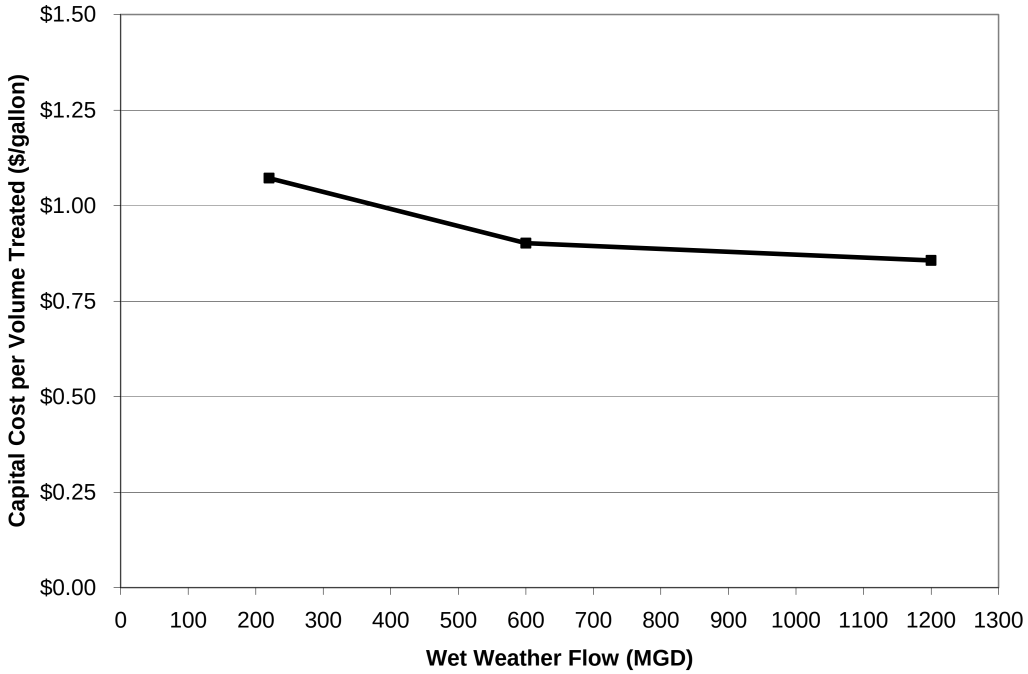
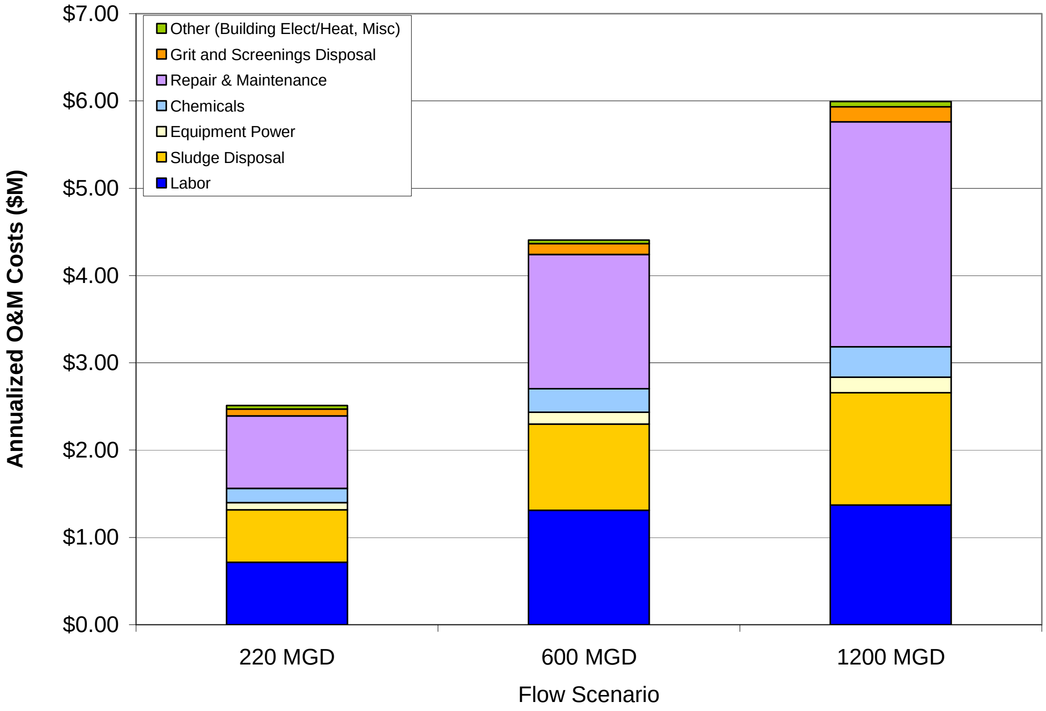


EXHIBIT 6-6
Operation and Maintenance Costs by Category for Treatment Train #2: Conventional Clarifiers



7.0 Treatment Train #3 - Chemically Enhanced Primary Treatment (CEPT)

7.1 Process Flow Diagram

Chemically enhanced primary treatment (CEPT) improves the removal efficiency of TSS and BOD through the addition of coagulants and flocculants to primary clarifiers. With chemical enhancement, the surface overflow rate of the primary clarifier is expected to increase from 2400 gpd/sf to 3000 gpd/sf, and the removal efficiency from 55 percent to 80 percent. As shown in the process flow diagram in Exhibit 7-1, the flow path is similar to Treatment Train #2. The only difference is the addition of rapid mixers and flocculation basins upstream of the primary clarifiers, along with their associated chemical feed and storage systems.

7.2 Conceptual Design and Site Layouts

Conceptual designs were developed at three different flow scenarios for this train: 220, 550, and 1000 mgd. Key design parameters at these flows are shown in Exhibit 7-1. The 550-mgd facility fits on the Upper BRC site alone, and the 1000-mgd facility utilizes both the Upper and Lower sites. As seen in Exhibit 7-2, the 1000-mgd requires more clarifiers per volume treated because the width of the Lower BRC tract limits the length of the clarifier tank to approximately 170-ft. Without this constraint, the length of the clarifiers in other flow scenarios can reach 250-ft.

The flow capacities in this train are lower than for Conventional Clarification due to the increased number of gravity thickeners required to treat the solids removed through CEPT.

7.3 Operational and Technology-Specific Issues

7.3.1 Startup and Shutdown

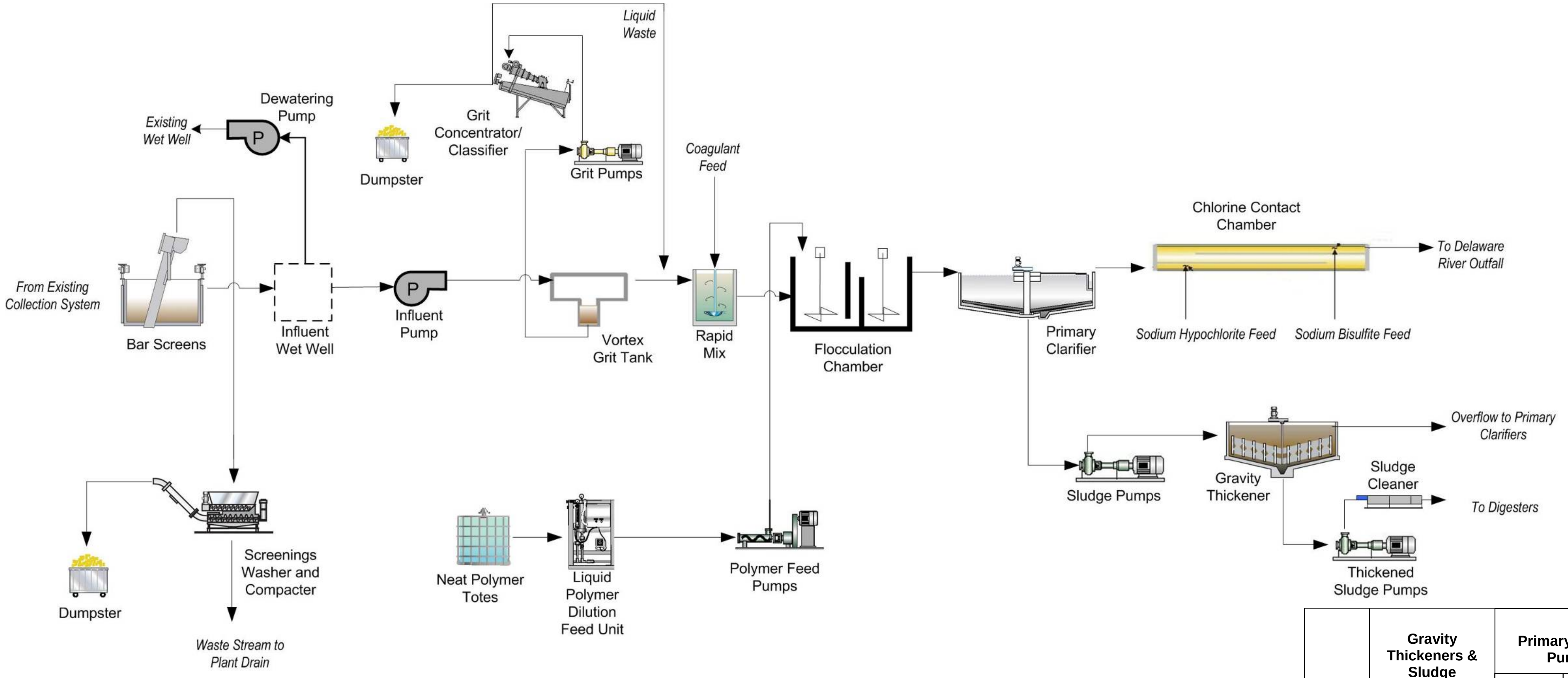
When the wet weather facility is initially put into service, it will take 2-3 hours before the clarifiers begin to discharge treated wet weather flow. This is equivalent to the time needed to displace the existing wastewater in the tanks, or to fill the tanks if they are empty.

For shut down, the tanks may be filled with treated effluent, or drained down to the existing plant if freezing becomes an issue.

The other processes in the system are physical or physical/chemical treatment systems that are easily and quickly brought online and will achieve normal levels of treatment efficiency quickly.

EXHIBIT 7-1

Process Flow Diagram and Key Process Design Parameters for Treatment Train #3: CEPT



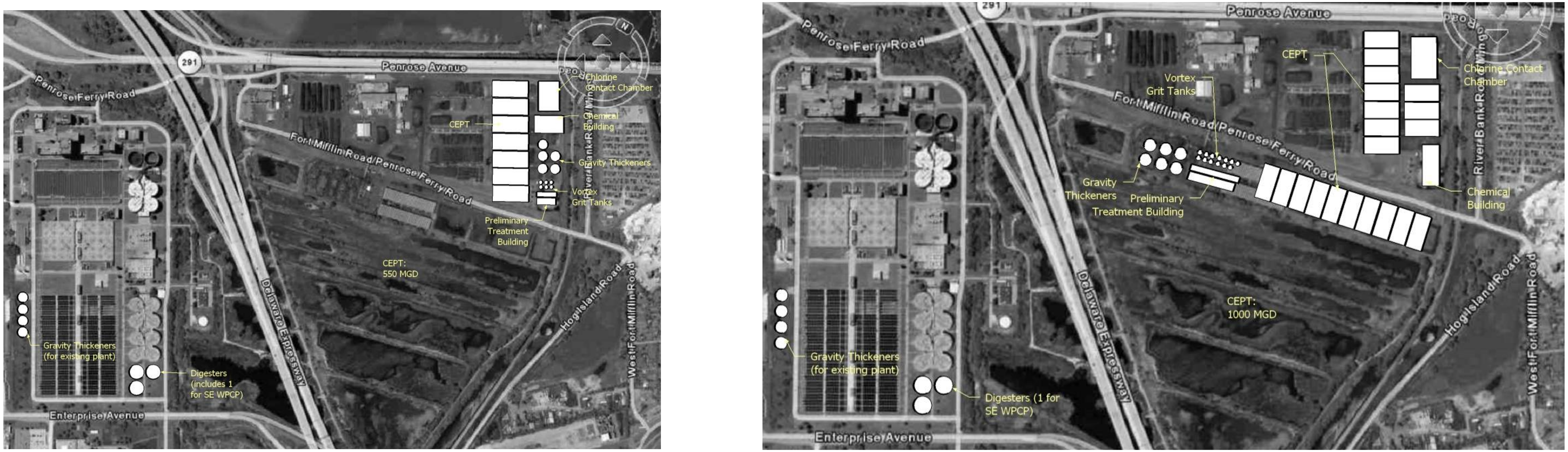
Flow (mgd)	Gravity Thickeners & Sludge Cleaners # Units	Primary Sludge Pumps		Thickened Sludge Pumps		Sludge Prod. (lb/day)	Digesters
		# Duty	# Standby	# Duty	# Standby		# units
220	3	3	1	3	1	399492	1
550	5	7	2	5	2	626475	1
1000	6	20	6	6	2	835300	2

Flow (mgd)	Bar Screens # Units	Influent Pumps # Units	Vortex Grit Tank		Screenings Washer/ Compactor # Units	Grit Pumps		Grit Concentrator # Units	Grit Classifier # Units	Screenings and Grit Prod. Compacted Volume (cf/day)	Ferric Chloride			Liquid Polymer			Sodium Hypochlorite			Sodium Bisulfite			Flocculation # Trains	Clarification # Trains
			# Units	DIA (ft)		# Duty	# Standby				Total Storage Vol (gal)	# Duty Pumps	# Standby Pumps	Total Storage Vol (gal)	# Duty Pumps	# Standby Pumps	Total Storage Vol (gal)	# Duty Pumps	# Standby Pumps	Total Storage Vol (gal)	# Duty Pumps	# Standby Pumps		
220	3	3	3	32	3	3	1	3	1	1,265	230,836	3	1	10,000	3	1	109,537	1	1	6,347	1	1	3	3
550	6	8	6	32	6	6	2	6	2	1,984	379,829	7	2	15,682	7	2	180,238	1	1	10,443	1	1	7	7
1000	10	14	10	32	10	10	3	10	5	2,645	495,247	20	5	20,909	20	5	235,006	1	1	13,616	1	1	20	20

EXHIBIT 7-2

Conceptual Layouts and Footprints for Treatment Train #3: CEPT

550 MGD Layout (left) 1000 MGD (right)



Flow (Mgd)	PTB	Grit Units	Flocculation Tanks	Clarifier Tanks	Chemical Building	CCC	Gravity Thickeners	DIGESTERS	TOTAL FOOTPRINT (acres)
220	54' x 49 & 73' x 39'	32' DIA (3 units)	127' x 55' (3 units)	127' x 208' (3 units)	119' x 100'	109' x 211' (5 passes)	80' DIA (3 unit)	115' DIA (1 unit)	3.6
550	119' x 54' & 133' x 39'	32' DIA (6 units)	127' x 56' (7 units)	127' x 223' (7 units)	209' x 100'	172' x 268' (8 passes)	80' DIA (5 units)	115' DIA (1 unit)	8.3
1000	197' x 58' & 195' x 39'	32' DIA(10 units)	107' x 51' (20 units)	107' x 171' (20 units)	229' x 100'	172' x 168' (8 passes)	80' DIA (6 units)	115' DIA (2 units)	14.6

7.3.2 Interaction with Main Plant

As described in the previous treatment trains, the overflow from the thickeners, ranging from 8 to 36 mgd depending on the flow scenario, is recycled back to the head of the plant for distribution across the main plant and the wet weather treatment train.

7.3.3 Impact on Plant Operations

CEPT requires the addition of chemicals, ferric chloride and polymer, that are not currently used at the SW WPCP. Storage of these new chemicals will need to be monitored to ensure that they are not degraded over time, especially during long periods of shutdown. The system effluent may need to be recycled to the head of the existing plant until the unit process is stabilized.

7.4 Cost Analyses

The estimated capital, O&M, and lifecycle costs for each flow scenario are shown in Exhibit 7-3. Total capital costs and the capital costs per volume treated are also shown in Exhibits 7-4 and 7-5. Estimated O&M costs by category are shown in Exhibit 7-6. A more detailed breakdown of these costs is presented in Attachment SW-2.1.

EXHIBIT 7-3
Cost Summary for CEPT Train #3

	Wet Weather Flow (mgd)		
Cost	**220**	**550**	**1000**
Capital Cost ($M)	$257	$545	$1,002
Annual Operations and Maintenance Cost ($M)	$2.7	$4.7	$6.3
Present Value of the Cost ($M)	$300	$618	$1,100

EXHIBIT 7-4

Capital Costs for Treatment Train #3: CEPT

Includes cost of upgrading plant capacity to 540 MGD

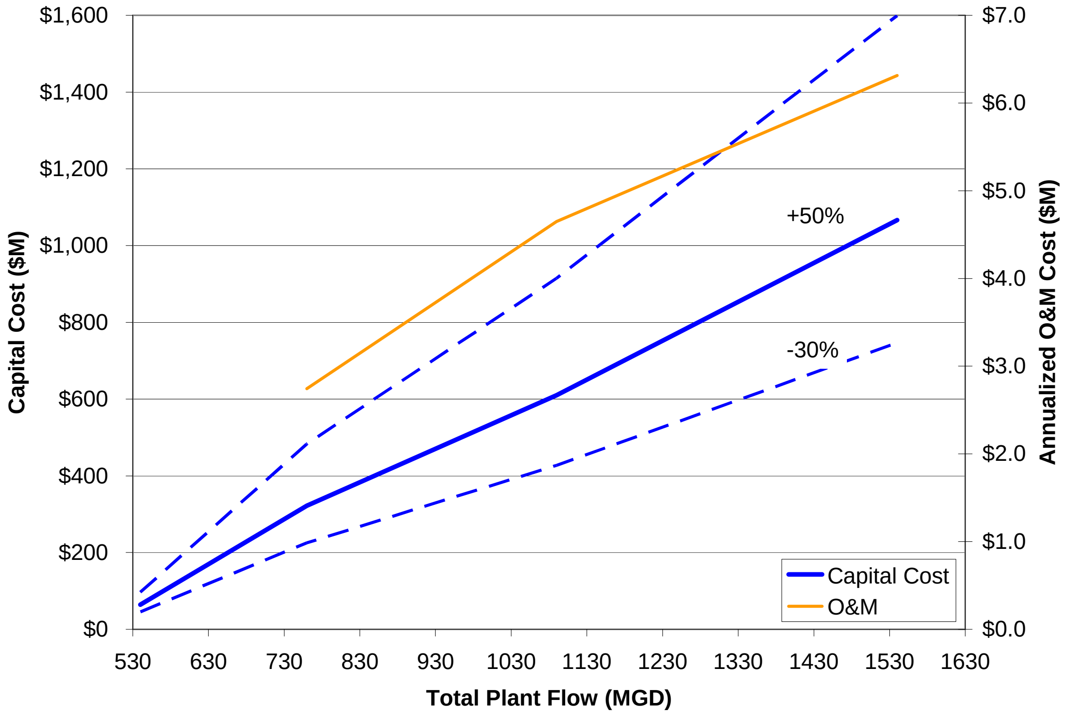


EXHIBIT 7-5

Capital Costs per Gallon Treated for Treatment Train #3: CEPT

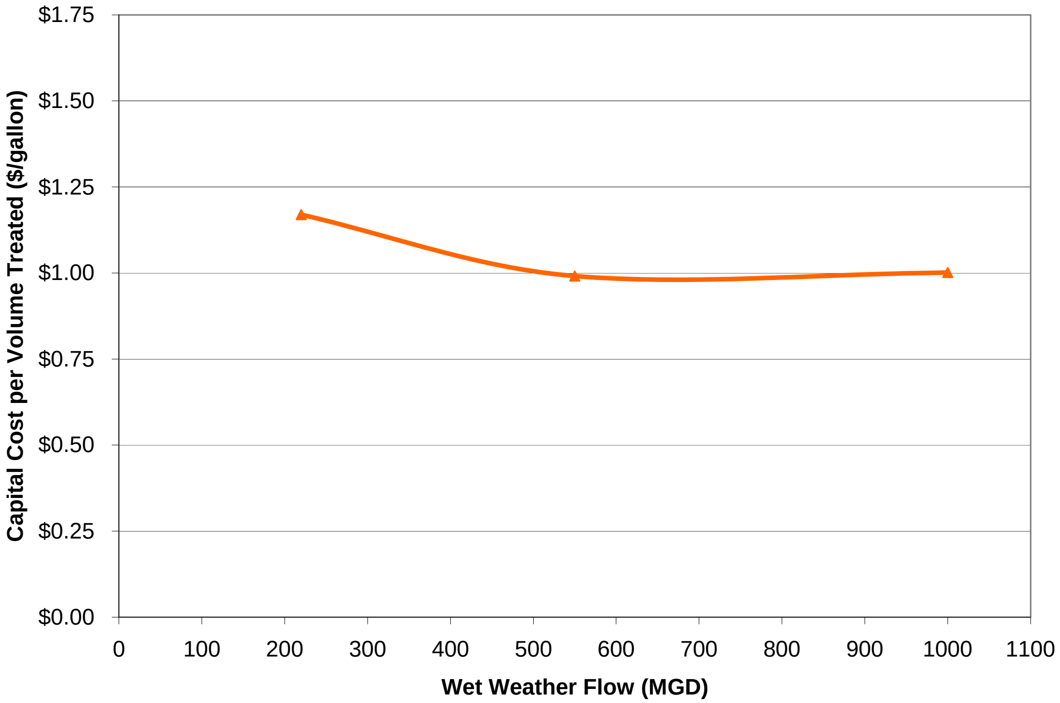
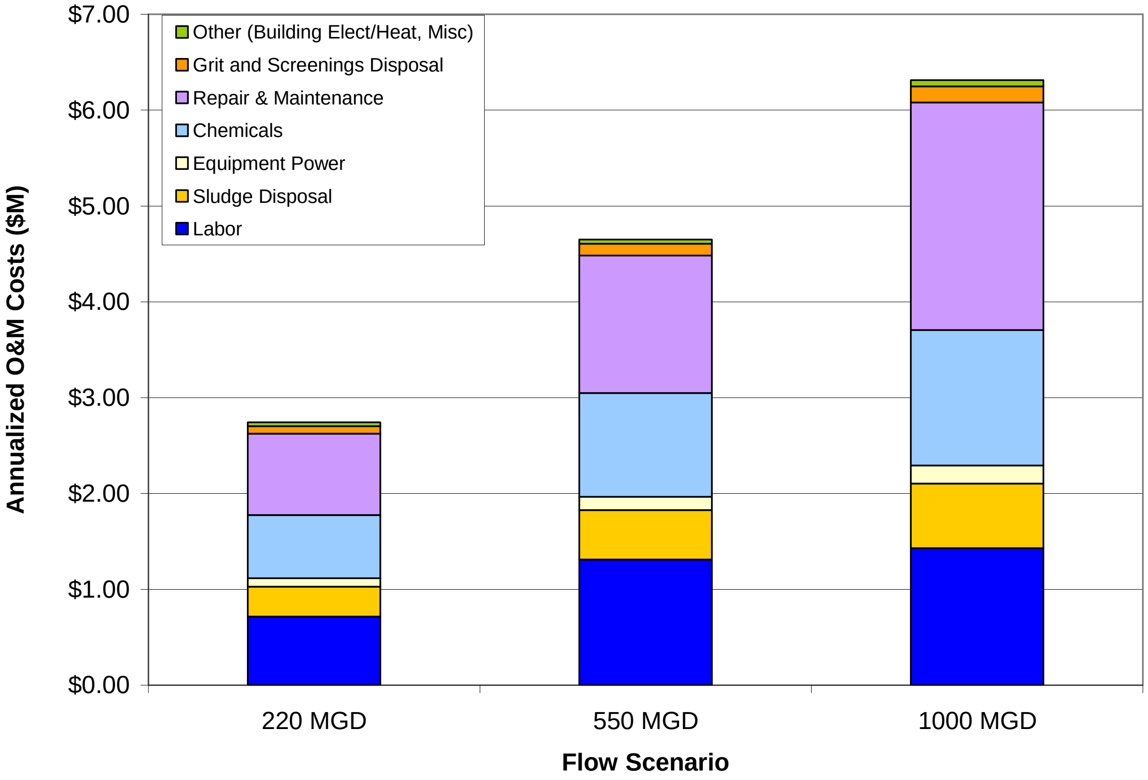


EXHIBIT 7-6

Operations and Maintenance Costs by Category for Treatment Train #3: CEPT



8.0 Treatment Train #4 - Ballasted Flocculation

The final treatment train uses ballasted flocculation to achieve removal efficiencies beyond that of CEPT. Ballasted flocculation, often referred to as "high rate treatment," creates extremely dense flocs with high settling velocities that can be removed efficiently even at very high surface overflow rates. Two proprietary systems that use ballasted flocculation are the DensaDeg and Actiflo systems. The DensaDeg system uses chemical sludge produced within it (recirculated from the clarifier underflow to the system influent) as a ballasting agent. The Actiflo system uses microsand as the ballasting agent. Both systems can achieve TSS removals in the range of 85 to 95 percent.

Actiflo requires separate gravity thickeners to process the sludge it generates, while Densadeg recirculates its sludge within its own process and therefore produces a thicker sludge not requiring thickening. The overall cost differential is not significant in most cases, however, since Densadeg has a lower overflow rate (40 gpm/sf compared with 60 gpm/sf) and larger footprint (CH2M HILL, 2007b).

Since the overall cost of the Actiflo and DensaDeg systems have been found to be similar, only one system was chosen for evaluation for this treatment train. The Actiflo system was selected in order to show the possibility of adding gravity thickeners to the plant layout. Pilot testing should be performed to determine the system best suited for the plant, while providing other benefits such as:

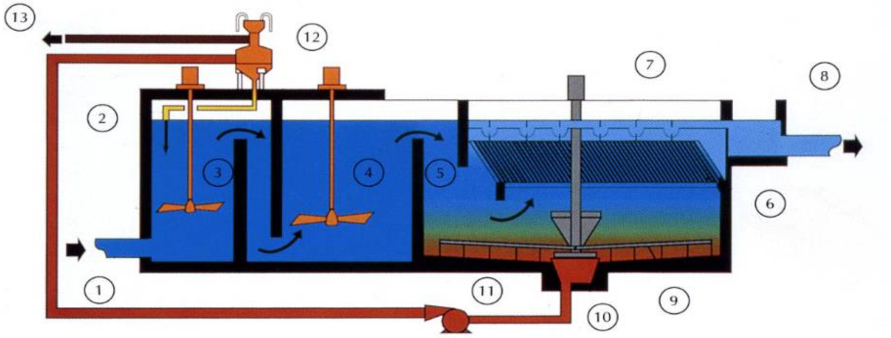
- Identification of influent wastewater constituents that may affect performance of either technology
- Determining suitable chemical dosages for the ballasted flocculation system
- Providing effluent quality information that can be used for design of downstream disinfection processes
- Assessing treatment performance at typical design overflow rates
- Providing better understanding of system operation through pilot testing.

8.1 Process Flow Diagram

In the ballasted flocculation treatment train, wet weather flow passes through bar screening, influent pumps, grit removal, and fine screening before entering the ballasted flocculation system (Exhibit 8-2). A schematic of the Actiflo system is shown in Exhibit 8-1.

Using the numbers in the Exhibit, the wastewater enters at point (1) along with the coagulant (ferric chloride) to the flash mixing zone (3) where microsand is also added (2). Addition of the coagulant enhances flocculation by destabilizing suspended solids in the wastewater. Compartment (4) is a gentle mixing zone where polymer is added to promote formation of strong flocs around the microsand. The flocculated solids flow to compartment (5), the clarification zone. Most of the solids settle at the bottom of this compartment, but this zone also has lamella settling modules (6) to enhance removal of suspended solids that may be present in the wastewater. The solids accumulated at the bottom of the clarification compartment (10) are recycled to a hydrocyclone (12), where the sludge is separated from the microsand. The microsand is recycled back to the flash mixing zone (3), and the sludge leaves the system by stream (13).

EXHIBIT 8-1
Schematic of the ACTIFLO High-Rate Primary Clarifier

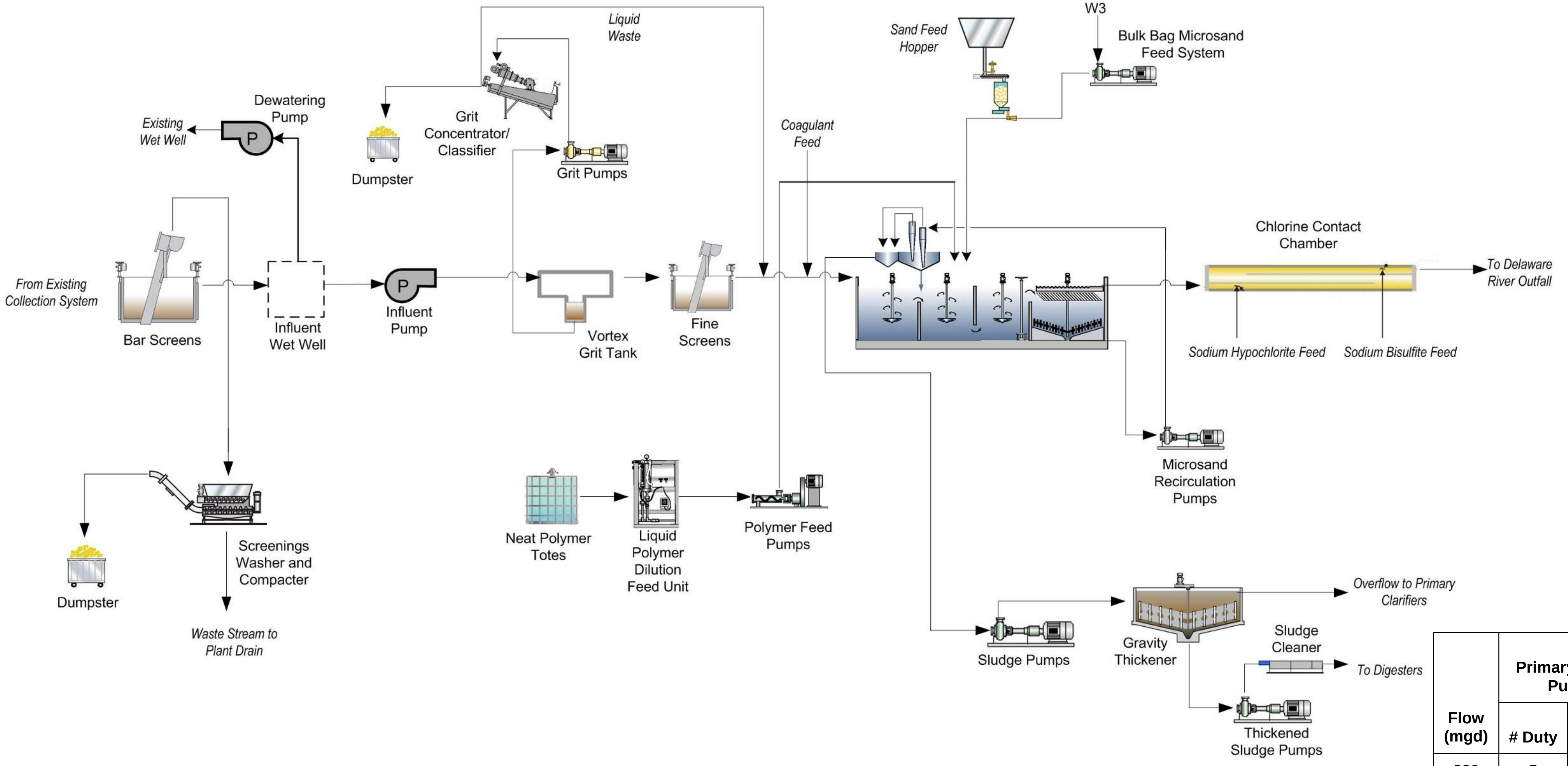


As shown in Exhibit 8-1, the sludge from the ballasted flocculation process is pumped to gravity thickeners to be thickened from 0.3 percent solids to 3-4 percent solids.

8.2 Conceptual Design and Site Layouts

Conceptual designs using the ballasted flocculation system were developed for flow capacities of 220, 980, and 1740 mgd. The key design parameters are presented in Exhibit 8-2. As seen in the conceptual layouts in Exhibit 8-3, the space requirements of this treatment train are minimal compared to the other alternatives. The 980-mgd facility fits on the Upper BRC site alone, utilizing the same area as a 550-mgd CEPT or 600-mgd Conventional Clarification plant. This is due to its extremely high surface overflow rate of 60 gpm/sf.

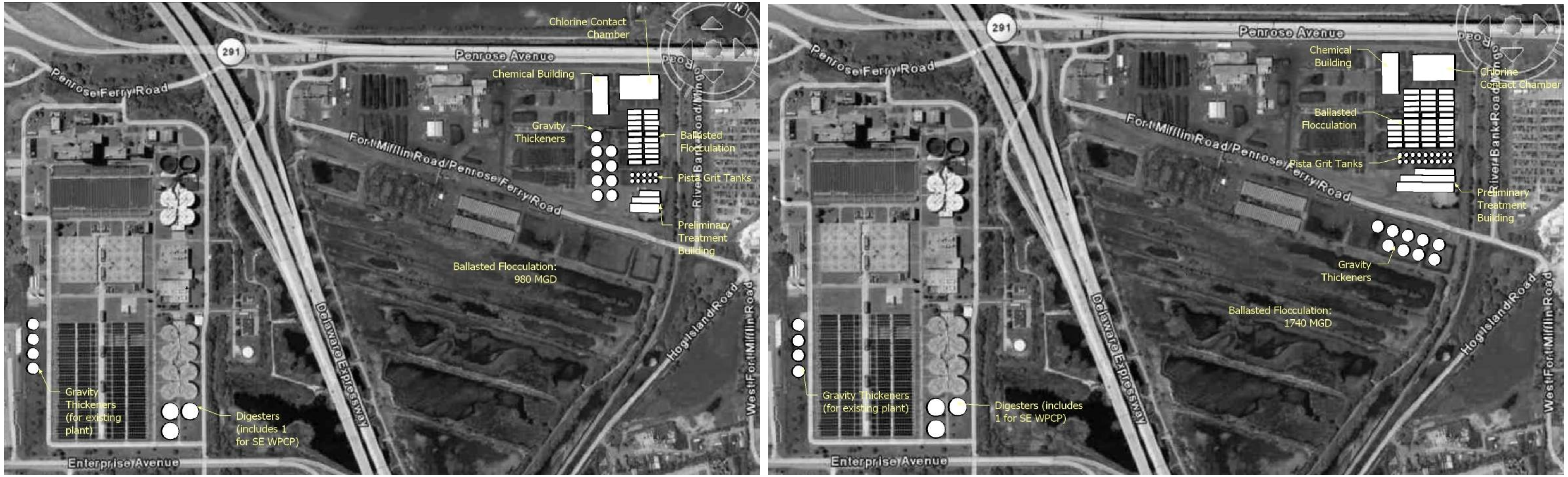
EXHIBIT 8-2
Process Flow Diagram and Key Process Design Parameters for Treatment Train #5: Ballasted Flocculation



Flow (mgd)	Primary Sludge Pumps		Thickened Sludge Pumps		Sludge Prod. lb/day	Digesters (SW WPCP)
	# Duty	# Standby	# Duty	# Standby		# units
220	5	2	4	1	449428	1
980	20	6	9	3	939713	2
1740	35	11	9	3	939713	2

Flow (mgd)	Bar Screens # Units	Influent Pumps # Units	Vortex Grit Tank		Fine Screening # Units	Screenings Washer/ Compactor # Units (for bar/fine screening)	Grit Pumps		Grit Concentrator # Units	Grit Classifier # Units	Screenings and Grit Prod. Compacted Volume (Cf/Day)	Ferric Chloride			Liquid Polymer			Sodium Hypochlorite			Sodium Bisulfite			Actiflo	Gravity Thickeners & Sludge Cleaners
			# Units	Dia (Ft)			# Duty	# Standby				Total Storage Vol (Gal)	# Duty Pumps	# Standby Pumps	Total Storag e Vol (Gal)	# Duty Pumps	# Standby Pumps	Total Storage Vol (Gal)	# Duty Pumps	# Standby Pumps	Total Storage Vol (Gal)	# Duty Pumps	# Standby Pumps	# Trains	# Units
220	3	3	3	32	3	6	3	1	3	1	1,515	230,836	5	2	10,000	5	2	109,537	1	1	6,226	1	1	5	4
980	10	14	10	32	10	20	10	3	10	3	3,168	495,247	20	5	21,455	20	5	235,006	1	1	13,616	1	1	20	9
1740	18	24	18	32	18	36	18	5	18	6	3,168	495,247	35	11	21,455	35	11	235,006	1	1	13,616	1	1	35	9

EXHIBIT 8-3
Conceptual Layouts and Footprints for Treatment Train #5: Ballasted Flocculation
980 MGD Layout (left), 1740 MGD (right)



Flow (Mgd)	PTB	Grit Units	Tanks	Chemical Building	CCC	Gravity Thickeners	Digesters	TOTAL FOOTPRINT (acres)
220	197' x 57' & 73' x 39'	32' (3 units)	25' x 85' (5 units)	119' x 100'	109' x 211' (5 passes)	80' DIA (4 units)	115' DIA (1 unit)	2.2
980	197' x 57' & 133' x 39'	32' (10 units)	20' x 86' (20 units)	231' x 100'	172' x 268' (8 passes)	80' DIA (9 units)	115' DIA (2 units)	4.7
1740	327' x 60' & 195' x 39'	32' (18 units)	35' x 86' (35 units)	231' x 100'	172' x 268' (8 passes)	80' DIA (9 units)	115' DIA (2 units)	7.4

8.3 Operational and Technology-Specific Issues

8.3.1 Startup and Shutdown

Ballasted flocculation systems stabilize quickly, with Actiflo taking less than 20 minutes and DensaDeg less than 45 minutes to start producing good quality effluent based on demonstration testing. Infilco Degremont indicated that the DensaDeg process will produce design effluent immediately if left filled with chlorinated plant effluent. However, based on piloting studies, a connection should be provided for discharging wet weather effluent to the head of the existing plant during startup until such time as the ballasted flocculation system performance stabilizes. To facilitate startup, the ballasted flocculation system should also be underloaded initially.

Shutdown can occur at the operator's convenience. Typically, equipment will simply need to be switched off. The hydrocyclones should be pumped down before being turned off. The tanks themselves can either be filled with treated effluent, or drained down. To prevent freezing during cold weather, any system that is not totally enclosed should have a constant flow of water, or be drained down. The cost estimate does not include a building for the ballasted flocculation units since they are able to be effectively operated in an outdoor environment, and the inclusion of a building would add unnecessary capital costs to this alternative.

The advantage of leaving the basins filled with water is that the startup time is substantially reduced and the basins reach their design effluent quality much more quickly. This reduces the volume of partially treated water that must be returned to the existing treatment plant. Running a small flow through the tanks also helps in maintaining equipment, such as the tank mixers. Actiflo's manufacturer recommends leaving the sand in the tanks only if the tanks are filled with effluent. With sand readily available in the tanks, treatment can begin sooner. If the system were fully drained, the sand within the Actiflo system would require removal and disposal to prevent freezing. Upon startup, sand would have to be reintroduced into the treatment flow using the bulk sand feed system. Infilco Degremont indicates that solids should be removed from the DensaDeg system within six hours to prevent septicity. The DensaDeg system can then be left filled with chlorinated plant effluent.

8.3.2 Interaction with Main Plant

During startup, effluent from the ballasted flocculation system will be discharged to the head of the main plant until system performance stabilizes.

Similar to the other treatment trains, recycle flows from the screenings washer/compactor and grit classifier will be conveyed to the ballasted flocculation system with the wet weather treatment train. The overflow stream from the gravity thickeners, however, must be sent to the head of the main plant for distribution across both the wet weather treatment train and the existing plant. Since this treatment train has the highest removal efficiency, it generates the highest sludge and overflow volumes. In addition, the solids content of the sludge is thinner compared to primary clarifier sludge as a result of the cyclones used to separate the ballast from the sludge. The estimated overflow volume is 16 to 128 mgd, depending on the flow capacity of the treatment train.

8.3.3 Impact on plant operations

To simplify routine operation, Actiflo and Densadeg typically have automated routine startup and shutdown sequences with PLC programming and adjustable timers (service interval, tank fill, equipment run, shutdown, and tank drain). However, operator attention will be necessary to monitor or optimize performance, and to confirm successful facility startup. The operators will have the following responsibilities:

- Start the process train
- Monitor coagulant and polymer dose and perform jar tests to optimize chemical dosing.
- Manage the loading of screenings and grit dumpsters.
- Observe equipment operation and contact maintenance if equipment malfunctions.

8.3.4 Other Issues

Foaming – Foaming may occur due to the addition of coagulants and polymer settling aids, and should be investigated in pilot studies. For example, during startup of the Actiflo unit at Lawrence WWTP in Lawrence, Kansas, the observed foaming resulted from the reaction of ferric chloride with biodegradable surfactants in the incoming wastewater. Foaming can be controlled using silica-based defoamers such as Tramfloc 110, Chemco DF, and Neo Solutions NS-8454 at low dosages.

Floc Carryover and Microsand Loss – Floc carryover is an issue for the DensaDeg system that should be investigated through pilot tests. As flows approach the design SOR, sludge densities may decrease, sending large flocs of sludge out in the effluent. These large flocs not only affect effluent quality in terms of TSS and BOD levels, but may also decrease effectiveness of the disinfection process downstream.

Regarding the Actiflo system, a certain degree of microsand loss is expected from normal operation of the system. The manufacturer indicates that about 8 pounds of microsand are lost for each million gallons of wastewater treated. The sand must be replaced for optimal operation of the system. According to information gathered during the team's site visit to the Cincinnati Metropolitan Sewer District, the SSO 700 Facility loses 350 lbs of sand per 15 mg wet weather event. In the conceptual design of this treatment train, adequate storage space was provided in the chemical buildings for 10 day storage of sand. Additionally, the microsand needs to be maintained in the system in case rapid startup is required, and the sand must be prevented from freezing during the winter so that the unit can start up quickly if needed during the cold season. The DensaDeg unit is totally drained when the system is shut down, and no chemical sludge is maintained in the system when it is not in use.

Sludge Concentration - One important difference between Actiflo and Densadeg is the sludge concentration that they produce. Sludge from the DensaDeg system can be four to five times more concentrated than sludge from the Actiflo system. Since the two systems are expected to produce the same mass of sludge, because they operate with similar coagulant dosages, it is expected that the volume of sludge produced in the ACTIFLO system will be four to five times greater than that in the DensaDeg unit. Gravity thickeners have been included in the conceptual design for the Actiflo treatment train to thicken the sludge to 3-4 percent solids. These thickeners may not be necessary if the Densadeg system is chosen.

8.4 Cost Analyses

The estimated capital, O&M, and lifecycle costs for each flow scenario are shown in Exhibit 8-4. Total capital costs and the capital costs per volume treated are also shown in Exhibits 8-5 and 8-6. Estimated O&M costs by category are presented in Exhibit 8-7. A more detailed breakdown of these costs is presented in Attachment SW-2.1.

EXHIBIT 8-4
Cost Summary for Ballasted Flocculation: Treatment Train #4

	Wet Weather Flow (mgd)		
Cost	**220**	**980**	**1740**
Capital Cost ($M)	$253	$851	$1,357
Annual Operations and Maintenance Cost ($M)	$3.4	$7.9	$10.0
Present Value of the Cost ($M)	$306	$974	$1,514

EXHIBIT 8-5
Capital Costs for Treatment Train #5: Ballasted Flocculation
Includes cost of upgrading plant capacity to 540 MGD

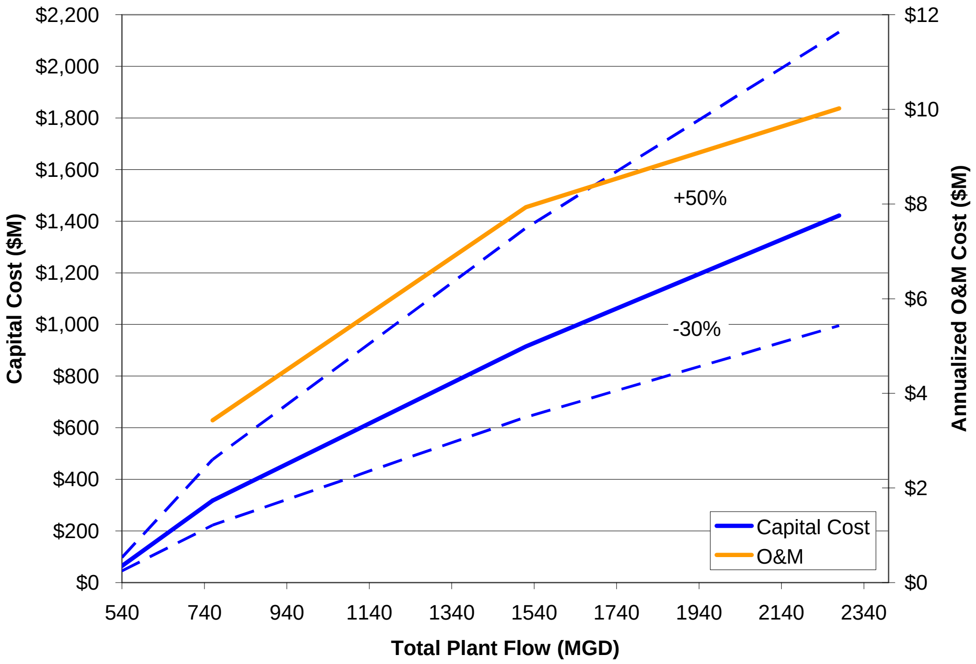


EXHIBIT 8-6
Capital Costs per Gallon Treated for Treatment Train #5: Ballasted Flocculation

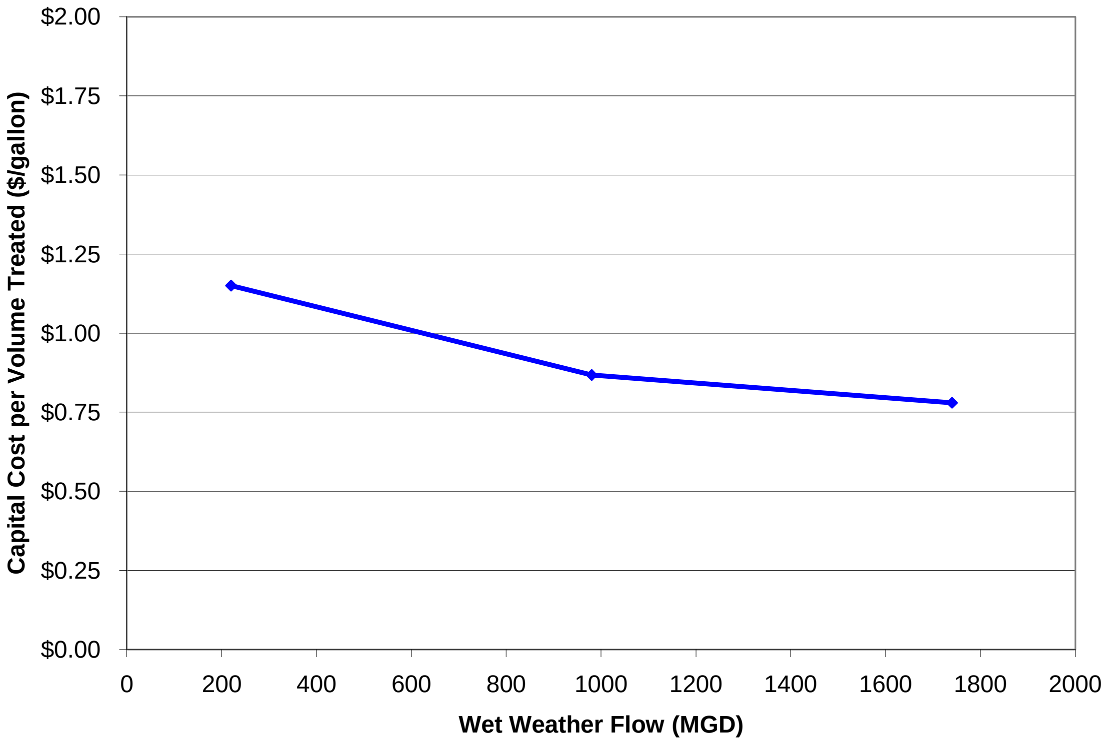
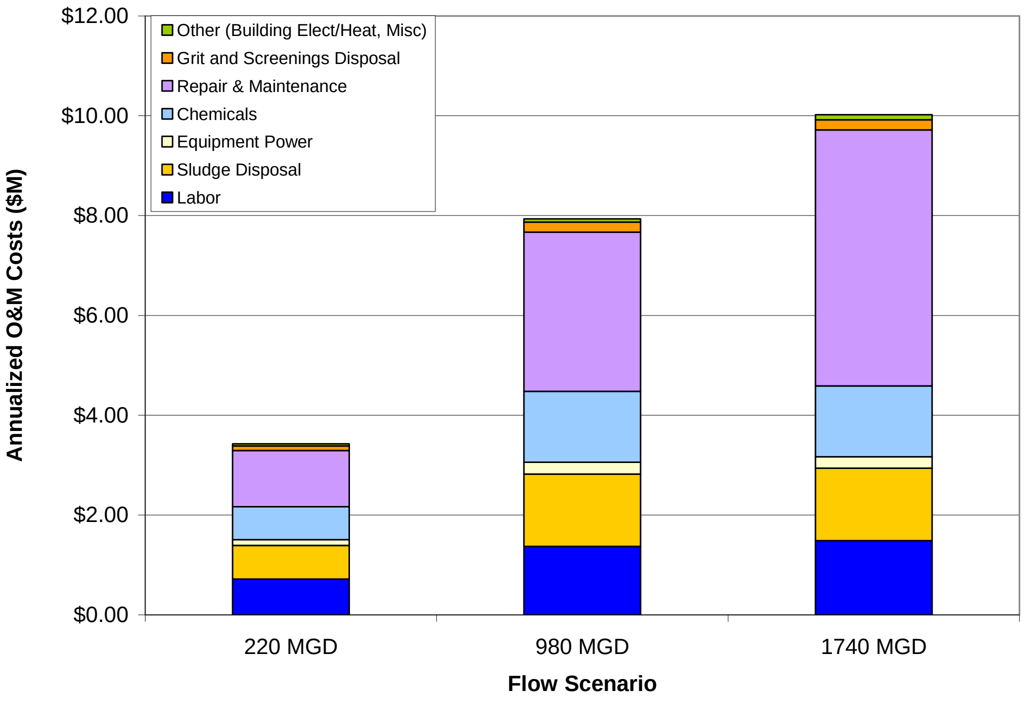


EXHIBIT 8-7
Operations and Maintenance Costs by Category for Treatment Train #5: Ballasted Flocculation



9.0 Alternatives for Optimizing Capital Costs

9.1 Ballasted Flocculation

As mentioned in Section 8, the costs presented for Treatment Train #5, Ballasted Flocculation, are based on the Actiflo system, which similar in cost to Densadeg, the other proprietary high rate treatment technology. If the ballasted flocculation treatment train is selected, a cost estimate for the Densadeg system should be developed to examine the cost differential. The main contributions to the cost differential will include:

- **Reduction in number of thickeners** - Densadeg maintains a 3-4 percent sludge thickness for its ballast, compared to the 0.3 percent sludge thickness in the Actiflo system.
- **Increase in footprint** – Densadeg has a 40 gpm/sf loading rate, compared to Actiflo’s 60 gpm/sf loading rate.
- **Elimination of fine screening** – Actiflo requires fine screening to protect the hydrocyclones in the system, which separate sand from sludge. Since Densadeg uses sludge only as its ballast, it does not require fine screening upstream.

Implications to operations and maintenance should also be examined between the two systems. For example, Actiflo requires sand as the ballasting agent, which requires storage and maintenance.

9.2 Refined Design Assumptions via Influent Sampling

Influent sampling at the plant during wet weather events will shed light on the wastewater characteristics of the wet weather flow, as well as the flow regime during events. More concrete numbers for influent TSS, BOD, and flow can be used to refine process design parameters, which may lead to a reduction in the size and cost of the treatment trains.

10.0 Comparison of Treatment Alternatives

10.1 Effluent Water Quality

As discussed in Section 3, effluent from the wet weather treatment facility will discharge to a new outfall at the Schuylkill River and will not commingle with the effluent from the main plant, which currently discharges into the Delaware River. It is likely that a new NPDES permit will need to be negotiated for this new discharge. If treated as a separate wet weather facility, it is clear that the effluent water quality in order from best to worst will come from: Ballasted Flocculation, CEPT, Conventional Clarification, and finally the Vortex/Swirl train (Exhibits 10-1 and 10-2).

10.1.1 Effluent Water Quality – Assuming Blending

An alternative way of analyzing water quality is to consider the new wet weather facility and the main SW WPCP as one system with a single discharge permit. In this system, the effluent from the two plants is “blended” before discharge into the water body, and this “blended” effluent must meet permit limits. This is similar to the water quality analyses performed for the Southeast and Northeast WPCPs.

The TSS and cBOD concentrations of the “blended” effluent for each treatment train and flow scenario is presented in Exhibit 10-1 and 10-2, respectively.

EXHIBIT 10-1

Blended Effluent TSS Concentrations

Treatment Train	**Wet Weather Treatment Train Effluent Conc. (mg/L)**	**Blended Effluent TSS Concentration (mg/L)**							
		Wet Weather Treatment Train Flow (mgd)							
		220	***550***	***600***	***702***	***980***	***1000***	***1200***	***1740***
#1) Vortex/Swirl Concentrators	158	61			99				
#2) Conventional Clarifiers	102	45		64				77	
#3) CEPT w/ Conventional Clarifiers	45	29	34				37		
#4) Ballasted Flocculation	21	22				21			21

Notes: Based on the 95th percentile wet weather TSS concentration of 22 mg/L and a maximum of 540 MGD through the existing plant. Allowable daily blended effluent TSS concentration on wet weather days is 112 mg/L, to meet monthly TSS permit limits.

EXHIBIT 10-2

Blended Effluent cBOD Concentrations

Treatment Train	Wet Weather Treatment Train Effluent Conc. (mg/L)	Blended Effluent cBOD Concentration (mg/L)							
		Wet Weather Treatment Train Flow (mgd)							
		220	***550***	***600***	***702***	***980***	***1000***	***1200***	***1740***
#1) Vortex/Swirl Concentrators	75	27			46				
#2) Conventional Clarifiers	64	24		37				47	
#3) CEPT w/ Conventional Clarifiers	54	21	31				38		
#4) Ballasted Flocculation	49	20				34			39

Notes: Based on the 95th percentile wet weather cBOD concentration of 8 mg/L and a maximum of 540 MGD through the existing plant.

As described in Section 4.1, the maximum flow through all the treatment trains, with the exception of the vortex swirl, is unlimited if the number of wet weather days is less than 7 days per month. To illustrate the risk of exceeding permit limits at these design flows, Exhibit 10-3 presents the maximum number of days that the wet weather treatment train can operate at its maximum capacity without the system exceeding monthly TSS permit limits. The ballasted flocculation train is unlimited in frequency of operation since its effluent quality (30 mg/L TSS) surpasses permit limits without blending.

EXHIBIT 10-3

Allowable Number of Operating Days of Wet Weather Treatment Train

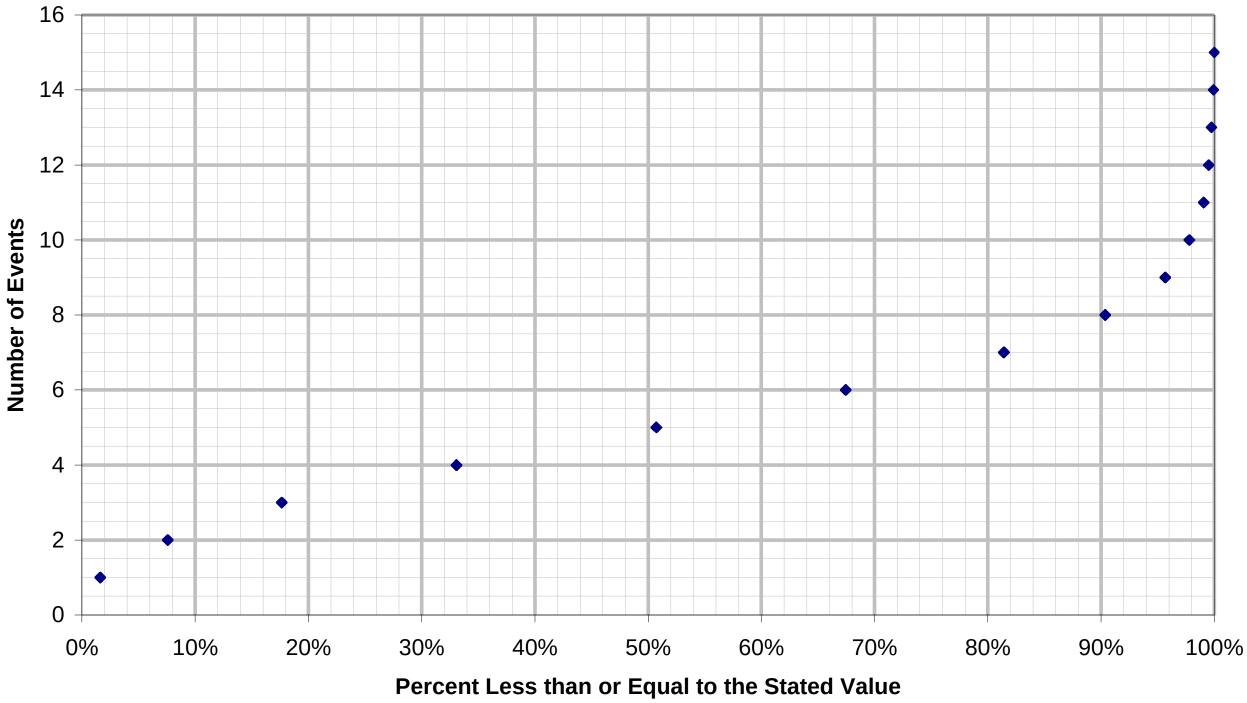
Treatment Train	Maximum Allowable Number of Operating Days per Month(1)							
	Wet Weather Treatment Train Flow (mgd)							
	220	***550***	***600***	***702***	***980***	***1000***	***1200***	***1740***
#1) Vortex/Swirl Concentrators	12			7				
#2) Conventional Clarifiers	17		11				9	
#3) CEPT w/ Conventional Clarifiers	UNLIMITED	25				22		
#4) Ballasted Flocculation	UNLIMITED							

Notes:
(1) Allowable number of operating days without exceeding permit limits for monthly TSS concentrations. Assumes entire plant operates at maximum capacity during every wet weather event.

A frequency plot of the number of wet weather events per month and the duration of each event is shown in Exhibits 10-4 and 10-5 for comparison purposes (Myers, 2008b). As shown, wet weather events have occurred at a historical maximum of 15 per month. This suggests that CEPT, and Ballasted Flocculation have a very low probability of exceeding permit limits. It should be noted that the wet weather event referred to in this plot occurs whenever rainfall exceeds 0.1 inch, and does not necessarily correspond to operation of the new wet weather treatment train. If the flow does not exceed the capacity of the conventional plant, the wet weather treatment train will not come online. Thus, the new wet weather treatment train is expected to operate less than 15 times per month.

It should be noted that a continuous simulation-based approach would give a more accurate estimate of risk, and more detailed analyses should be performed during the facility planning and design phases.

EXHIBIT 10-4
Cumulative Frequency Plot of the Number of Wet Weather Events per Month



Notes: Based on Philadelphia International Airport NOAA Rain Gauge Hourly Data from1902-2000. Minimum Interevent Time = 4 hrs, Minimum Storm = 0.1 Inches (provided by CDM)

10.1.2 Capital, O&M and Life-Cycle Costs

The capital cost estimates for the four treatment trains are shown in Exhibit 10-5. Train #3, CEPT, is the most expensive, followed by Trains #2 and #4, Conventional Clarification and Ballasted Flocculation, which appear similar in cost. The cost of Train #1, Vortex/Swirl, is significantly less expensive than the other three trains. Translated into a cost per volume treated, all trains appear to become more cost effective as flow capacity increases (Exhibit 10-6).

The reason that CEPT is more expensive than Ballasted Flocculation for the SW WPCP wet weather facility is likely due to the limited length and increased number of its clarifiers, as described in Section 7.2, as well as the increased cost for piles.

The comparison of O&M costs for each treatment train is shown in Exhibit 10-7. As expected, the O&M costs for vortex swirls and conventional clarifiers, which do not require chemical settling aids, are the lowest. Ballasted Flocculation has the highest O&M costs due to its chemical usage and the complexity of its system.

Taking construction, non-construction, and O&M costs into consideration, Exhibit 10-8 shows the present value of the total cost of each wet weather treatment train. Again, CEPT and Ballasted Flocculation remain most costly due to their high capital and O&M costs. Train #1, vortex/swirl concentrators, is significantly less expensive compared with other technologies from the life-cycle cost perspective. This is due to its low chemical usage and minimal operations and maintenance needs.

EXHIBIT 10-5
Comparison of Capital Costs for All Treatment Trains

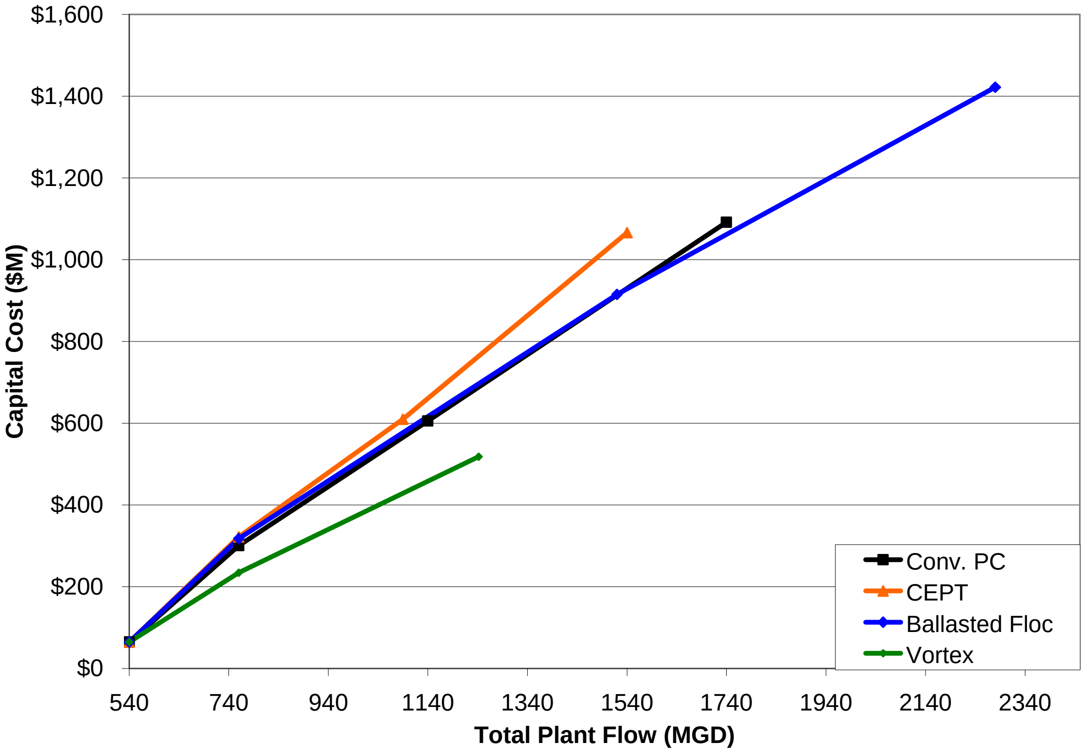


EXHIBIT 10-6

Comparison of Cost Effectiveness for all Treatment Trains

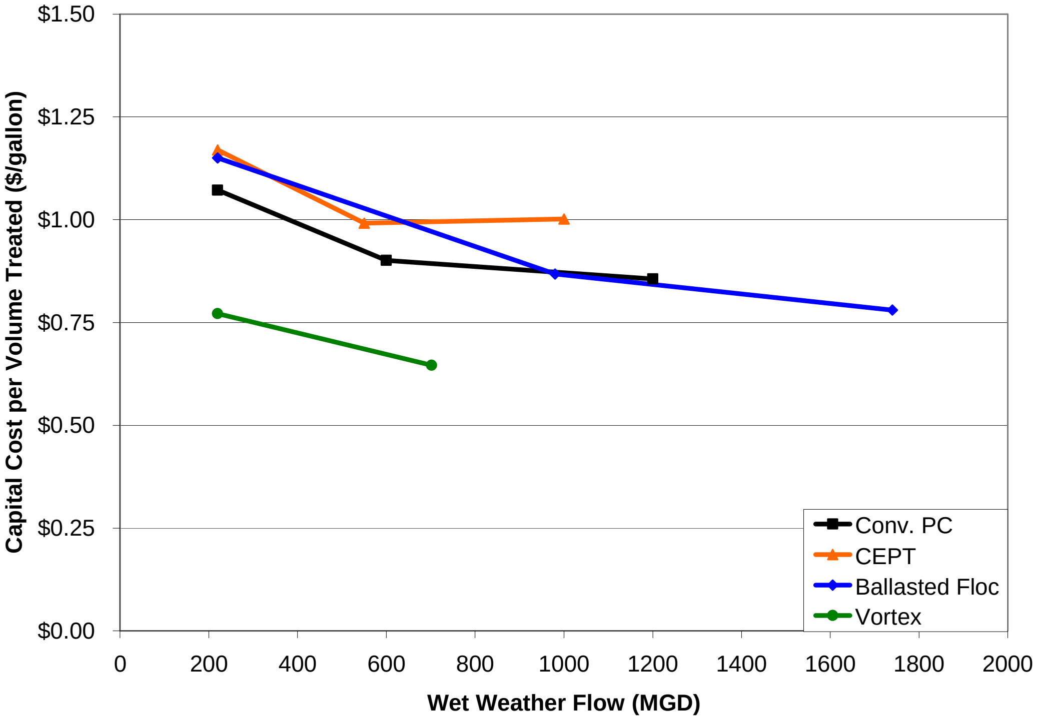


EXHIBIT 10-7

Comparison of Operations and Maintenance Costs for all Treatment Trains

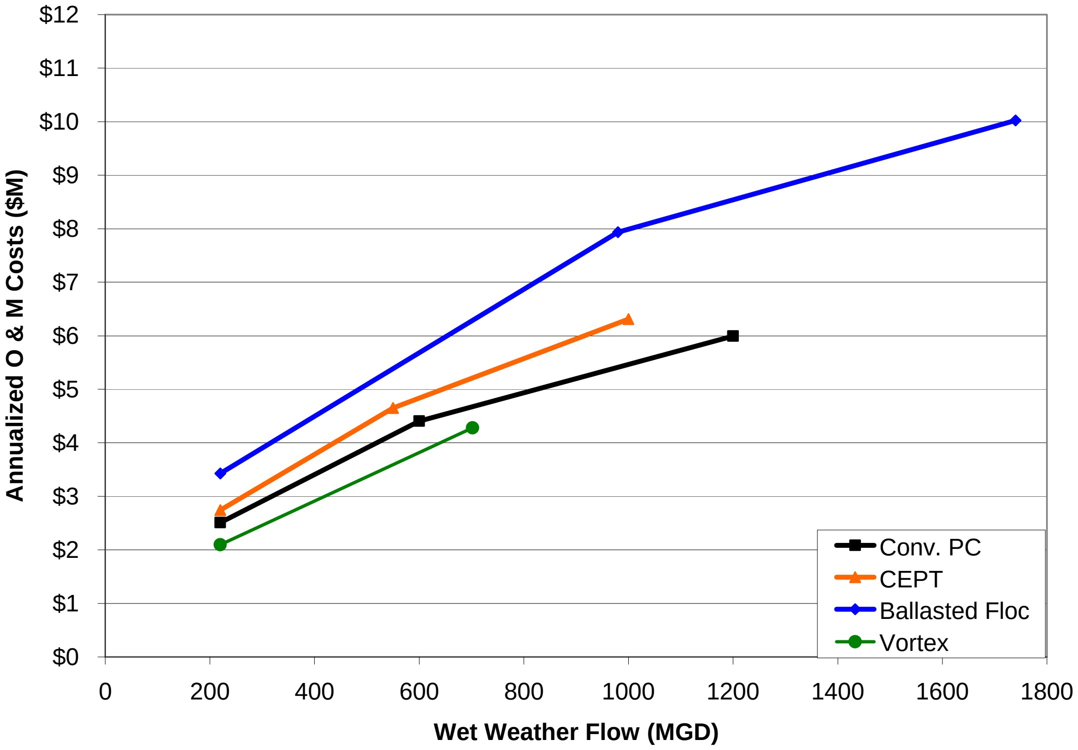
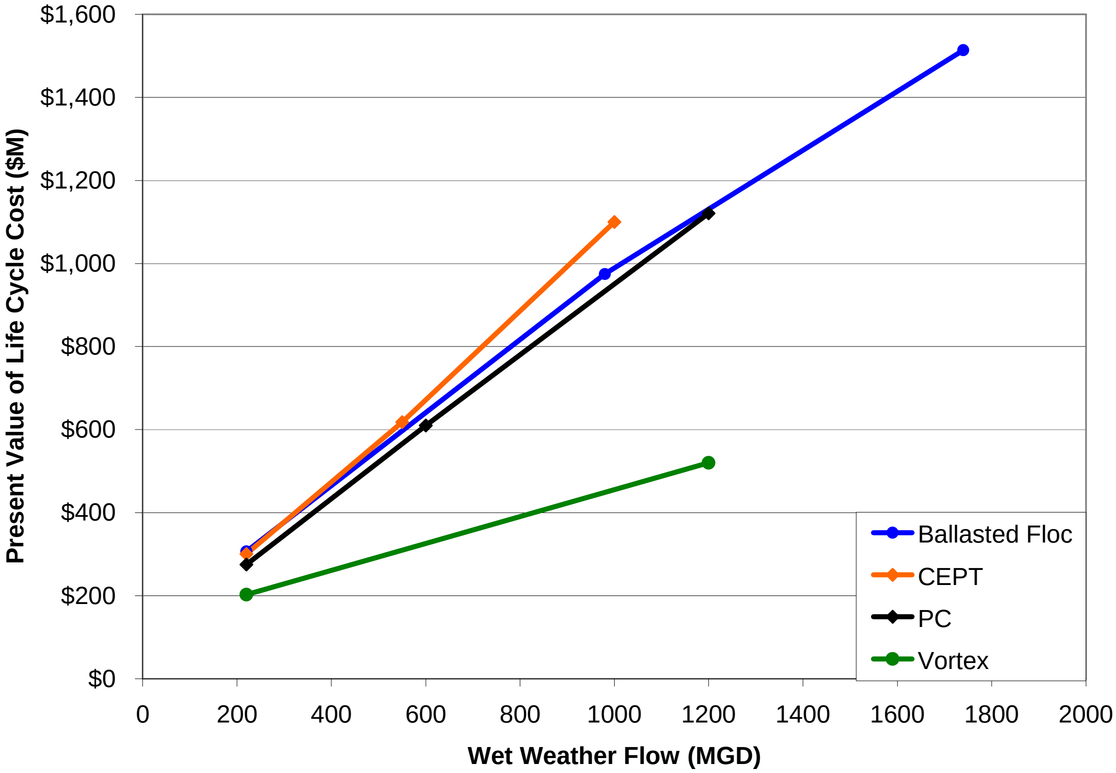


EXHIBIT 10-8
Comparison of Life-Cycle Costs for all Treatment Trains



10.2 Overall Comparison

Aside from capital, O&M, and lifecycle costs, there are numerous other criteria by which the treatment trains should be evaluated, including:

- Reliability of the system
- Community and environmental impacts or perception
- Ability to handle large variations in flow
- Land requirements
- Constructability
- Requirements for maintenance and operator attention
- Sustainability

These evaluation criteria were discussed in Workshop No. 2B, and are presented in TM-SE2 for various wet weather treatment technologies (CH2M HILL, 2008a). Several key advantages and disadvantages of Treatment Trains #1 - #4, as evaluated in this report, are described in Exhibit 10-9.

EXHIBIT 10-9
Summary of Pros and Cons for Each Wet Weather Treatment Train

Treatment Train	Pros	Cons
Train #1: Vortex/Swirl Concentrators	• Simple operation • Low maintenance requirements – no moving parts	• Maximum design flow may decrease if the assumed number of operating days per month is greater than 7. • Unless operated at lower loading rates, removal efficiency may not be high enough to operate alone without blending effluent with main plant effluent.
Train #2: Conventional Clarifiers	• Simple operation • Same technology as existing plant – operators familiar with equipment	• Space limited • Maximum design flow may decrease if the assumed number of operating days is greater than 9.
Train #3: CEPT	• Lower chlorine dose possible due to high TSS removal efficiencies • May be operated as Conventional Clarifiers if chemicals found to be unnecessary	• Operators unfamiliar with technology • Space limited • Can treat less flow on land available than conventional clarifiers
Train #4: Ballasted Flocculation	• Can treat up to 1740 mgd with available land on site • Highest removal efficiencies • Unlimited number of operating days per month • Lower chlorine dose possible due to high TSS removal efficiencies	• Operators unfamiliar with technology • Most labor intensive and complex system • Uses two additional chemical systems for coagulation and flocculation

The costs for wet weather treatment at the SW WPCP should be analyzed with the costs of other wet weather treatment alternatives, such as improvements in the collection system, to determine which treatment train alternatives and flow regimes should be evaluated further. Treatment trains that are selected for further evaluation should undergo more detailed design and costing methods, water quality sampling, and bench and pilot scale testing, so that removal efficiencies, land requirements, capital costs, and O&M costs can be further refined.

11.0 References

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Attachment SW-2.1

Breakdown of Capital and O&M Costs

SW WPCP Wet Weather Treatment Train Alternatives: Capital Cost Estimates

Train	**Train #1: Vortex/Swirl**		**Train #2: Conventional Clarifiers**			**Train #3: CEPT**			**Train #4: Ballasted Flocculation**		
Flow (mgd)	**220**	**702**	**220**	**600**	**1200**	**220**	**550**	**1000**	**220**	**980**	**1740**
Influent Pump Station	$6,211,840	$19,204,881	$6,211,840	$17,216,238	$32,224,067	$6,211,840	$15,440,402	$26,699,344	$6,211,840	$26,620,062	$45,396,179
Bar Screens, Grit Removal, and Fine Screens	$4,749,552	$9,819,610	$6,281,013	$12,522,818	$26,565,308	$6,281,013	$12,522,818	$20,881,889	$9,785,312	$32,776,926	$58,738,547
Vortex Swirl	$11,399,923	$32,130,118	$0	$0	$0	$0	$0	$0	$0	$0	$0
Flocculation Tanks	$0	$0	$0	$0	$0	$3,730,191	$8,596,429	$19,257,646	$0	$0	$0
Primary Clarifiers	$0	$0	$11,475,907	$31,479,253	$63,398,121	$9,347,391	$22,244,693	$44,722,607	$0	$0	$0
Actiflo System	$0	$0	$0	$0	$0	$0	$0	$0	$16,392,721	$68,027,829	$119,182,929
Chemical Feed	$1,658,414	$2,709,339	$1,509,522	$2,395,083	$2,711,950	$3,951,403	$6,745,873	$8,564,594	$4,170,695	$8,784,387	$10,114,942
Chlorine Contact Chamber (1)	$3,265,976	$6,247,533	$3,263,919	$6,247,533	$6,247,533	$3,263,919	$6,247,533	$6,247,533	$3,263,919	$6,247,533	$6,247,533
Gravity Thickeners	$4,094,524	$9,990,886	$2,109,922	$2,839,337	$3,900,703	$2,995,095	$4,870,987	$5,761,509	$3,907,373	$7,421,255	$8,141,207
Yard Piping (large)	$1,009,868	$2,981,295	$1,635,436	$5,811,516	$16,320,993	$1,399,466	$4,368,383	$12,451,821	$1,639,449	$9,442,449	$15,200,742
Digesters	$0	$6,259,941	$6,379,355	$6,295,765	$6,337,560	$6,325,676	$6,409,265	$14,728,460	$6,325,619	$11,678,693	$11,421,953
Subtotal Project Cost	$32,390,097	$89,343,603	$38,866,914	$84,807,543	$157,706,235	$43,505,994	$87,446,383	$159,315,403	$51,696,928	$170,999,134	$274,444,032
Additional Project Costs:											
General Demolition	$323,901	$893,436	$388,669	$848,075	$1,577,062	$435,060	$874,464	$1,593,154	$516,969	$1,709,991	$2,744,440
Overall Sitework	$2,591,208	$7,147,488	$3,109,353	$6,784,603	$12,616,499	$3,480,480	$6,995,711	$12,745,232	$4,135,754	$13,679,931	$21,955,523
Plant Computer System	$2,753,158	$7,594,206	$3,303,688	$7,208,641	$13,405,030	$3,698,009	$7,432,943	$13,541,809	$4,394,239	$14,534,926	$23,327,743
Yard Electrical	$2,591,208	$7,147,488	$3,109,353	$6,784,603	$12,616,499	$3,480,480	$6,995,711	$12,745,232	$4,135,754	$13,679,931	$21,955,523
Yard Piping	$1,943,406	$5,360,616	$2,332,015	$5,088,453	$9,462,374	$2,610,360	$5,246,783	$9,558,924	$3,101,816	$10,259,948	$16,466,642
Subtotal with Additional Project Costs	$42,592,978	$117,486,838	$51,109,992	$111,521,919	$207,383,699	$57,210,382	$114,991,994	$209,499,755	$67,981,460	$224,863,861	$360,893,902
Subtotal with Contractor Markups (1)	$64,568,292	$178,102,703	$77,479,553	$169,060,259	$314,380,726	$86,727,364	$174,320,675	$317,588,535	$103,055,645	$340,879,560	$547,092,600
Subtotal with Escalation (2)	$78,256,770	$220,669,250	$93,905,219	$209,465,661	$403,036,091	$105,113,565	$215,983,317	$407,148,502	$124,903,442	$437,007,595	$701,372,713
Subtotal with Local Adjustment Factor (3)	$90,151,799	$254,210,975	$108,178,812	$241,304,442	$464,297,577	$121,090,827	$248,812,781	$469,035,074	$143,888,765	$503,432,750	$807,981,365
Dewatering	$485,851	$1,340,154	$583,004	$1,272,113	$2,365,594	$652,590	$1,311,696	$2,389,731	$775,454	$2,564,987	$4,116,660
Structural Piles	$22,920,782	$47,676,536	$48,987,733	$119,161,825	$220,484,354	$50,393,334	$114,594,478	$198,490,902	$24,556,943	$63,013,829	$95,826,465
Subtotal - Construction Cost, including Market Adjustment Factor (4)	**$130,592,197**	**$348,711,815**	**$181,411,981**	**$415,999,137**	**$790,219,653**	**$197,957,263**	**$419,426,798**	**$770,403,063**	**$194,604,336**	**$654,363,301**	**$1,044,113,164**
Total Capital Cost (with non construction costs)	**$169,769,856**	**$453,325,359**	**$235,835,575**	**$540,798,878**	**$1,027,285,548**	**$257,344,441**	**$545,254,838**	**$1,001,523,981**	**$252,985,637**	**$850,672,291**	**$1,357,347,114**
Total Capital Cost ($M)	$170	$453	$236	$541	$1,027	$257	$545	$1,002	$253	$851	$1,357
.+50% Capital Cost ($M)	$255	$680	$354	$811	$1,541	$386	$818	$1,502	$379	$1,276	$2,036
.-30% Capital Cost ($M)	$119	$317	$165	$379	$719	$180	$382	$701	$177	$595	$950
Cost Efficiency ($/gallon)	**$0.77**	**$0.65**	**$1.07**	**$0.90**	**$0.86**	**$1.17**	**$0.99**	**$1.00**	**$1.15**	**$0.87**	**$0.78**

Notes:
1. Contractor markups - use 1.516 multiplier (see TM-SW2 Section 4.3)
2. Escalation - multiplier depends on duration of construction (see Exhibit 4-7 in TM-SW2 Section 4.3)
3. Local Adjustment Factor - use 1.152 multiplier (see TM-SW2 Section 4.3)
4. Market Adjustment Factor - use 1.15 multiplier (see TM-SW2 Section 4.3)
5. Non-construction costs - use 1.3 multiplier (see TM-SW2 Section 4.3)

SW WPCP Wet Weather Treatment Train Alternatives: Operations and Maintenance Cost Estimates (1)

	Flow (mgd)	Labor	Sludge Disposal	Building Electrical & Heating	Chemicals	Other (3)	Grit and Screenings Disposal	Equipment Power (2)	Repair & Maintenance	Total	Horsepower requirements (HP)
Train #1: Vortex/Swirls	220	$715,021	$171,218	$3,270	$163,176	$33,880	$79,366	$89,447	$840,477	$2,095,855	2,950
	702	$1,311,933	$367,341	$7,203	$350,086	$33,880	$163,438	$192,999	$1,855,270	$4,282,149	9,468
Train #2: Conventional Clarifiers	220	$715,021	$600,061	$4,200	$163,176	$33,880	$79,366	$84,411	$829,620	$2,509,734	2,784
	600	$1,311,933	$987,373	$6,682	$268,498	$33,880	$124,460	$135,428	$1,538,264	$4,406,518	7,769
	1200	$1,370,988	$1,287,403	$10,038	$350,086	$50,819	$170,276	$176,235	$2,577,338	$5,993,185	14,779
Train #3: CEPT	220	$715,021	$313,900	$5,865	$658,596	$33,880	$79,366	$86,403	$849,710	$2,742,741	2,850
	550	$1,311,933	$516,508	$10,147	$1,083,690	$33,880	$124,460	$136,717	$1,433,439	$4,650,775	7,189
	1000	$1,430,042	$673,458	$12,886	$1,412,989	$50,819	$170,276	$189,274	$2,373,861	$6,313,606	13,227
Train #5: Ballasted Flocculation	220	$715,021	$675,069	$9,773	$658,308	$33,880	$95,065	$116,004	$1,125,026	$3,428,146	3,826
	980	$1,370,988	$1,448,329	$14,605	$1,417,827	$50,819	$203,958	$239,699	$3,187,738	$7,933,962	16,416
	1740	$1,489,097	$1,448,329	$19,109	$1,417,827	$84,699	$203,958	$230,810	$5,127,044	$10,020,872	28,066

Notes:

1. All O&M costs are annualized costs based on escalation through a 30-year period. See TM-SW2 Section 4.2.1 for description of average flows
2. Power costs are estimated based on the total horsepower requirements and the average-to-max flow ratio.
3. "Other" costs cover miscellaneous costs for vehicles, lab tests, office equipment, etc.

Percentage of Costs by Category

	Flow (mgd)	Labor	Sludge Disposal	Building Electrical & Heating	Chemicals	Other	Grit and Screenings Disposal	Equipment Power	Repair & Maintenance
Train #1: Vortex/Swirls	220	34.1%	8.2%	0.2%	7.8%	1.6%	3.8%	4.3%	40.1%
	702	30.6%	8.6%	0.2%	8.2%	0.8%	3.8%	4.5%	43.3%
Train #2: Conventional Clarifiers	220	28.5%	23.9%	0.2%	6.5%	1.3%	3.2%	3.4%	33.1%
	600	29.8%	22.4%	0.2%	6.1%	0.8%	2.8%	3.1%	34.9%
	1200	22.9%	21.5%	0.2%	5.8%	0.8%	2.8%	2.9%	43.0%
Train #3: CEPT	220	26.1%	11.4%	0.2%	24.0%	1.2%	2.9%	3.2%	31.0%
	550	28.2%	11.1%	0.2%	23.3%	0.7%	2.7%	2.9%	30.8%
	1000	22.7%	10.7%	0.2%	22.4%	0.8%	2.7%	3.0%	37.6%
Train #5: Ballasted Flocculation	220	20.9%	19.7%	0.3%	19.2%	1.0%	2.8%	3.4%	32.8%
	980	17.3%	18.3%	0.2%	17.9%	0.6%	2.6%	3.0%	40.2%
	1740	14.9%	14.5%	0.2%	14.1%	0.8%	2.0%	2.3%	51.2%

Philadelphia Combined Sewer Overflow Long Term Control Plan Update

Supplemental Documentation
Volume 12

TTF Watershed Comprehensive Characterization Report

Updated: September 1, 2009

TOOKANY/TACONY-FRANKFORD WATERSHED COMPREHENSIVE CHARACTERIZATION REPORT

NOVEMBER 2005

PREPARED BY THE PHILADELPHIA WATER DEPARTMENT

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Appendix B

Section 1
Introduction

To meet the regulatory requirements and long-term goals of its CSO, stormwater, and drinking water source protection programs, The Philadelphia Water Department (PWD) has embraced a comprehensive watershed characterization, planning, and management program. Watershed management fosters the coordinated implementation of programs to control sources of pollution, reduce polluted runoff, and promote managed growth in the city and surrounding areas, while protecting the region's drinking water supplies, fishing and other recreational activities, and preserving sensitive natural resources such as parks and streams. PWD has helped form watershed partnerships with surrounding urban and suburban communities to explore regional cooperation based on an understanding of the impact of land use and human activities on water quality.

Coordination of these different programs has been greatly facilitated by PWD's creation of the Office of Watersheds (OOW), which is composed of staff from the PWD's planning and research, CSO, collector systems, laboratory services, and other key functional groups. One of OOW's responsibilities is to characterize existing conditions in local watersheds to provide a basis for long-term watershed planning and management.

OOW is developing a series of watershed management programs for each of the city's watersheds. Cobbs Creek was the first watershed for which an integrated watershed management plan was completed; the Tookany/Tacony-Frankford Watershed Partnership was second to complete a plan. This Comprehensive Characterization Report contains a series of technical documents that form the scientific basis for the Tookany/Tacony-Frankford Integrated Watershed Management Plan (TTFIWMP), released in 2005. The report characterizes the land use, geology, soils, topography, demographics, meteorology, hydrology, water quality, ecology, fluvial geomorphology, and pollutant loads found in the watershed. It presents and discusses data collected through the end of 2004. This report is intended as a single compilation of background and technical documents that can be periodically updated as additional field work or data analyses are completed. Sections of this report were completed at different times by different authors.

Section 2
Characterization of the Study Area

2.1 Watershed Description and Demographics

The Tookany/Tacony-Frankford Watershed is defined as the land area that drains to the mouth of Tacony Creek at the Delaware Estuary, encompassing approximately 36 square miles in southeastern Pennsylvania. This area includes portions of Montgomery and Philadelphia Counties. Figure 2-1 includes the watershed boundaries, hydrologic features, and political boundaries. Much of the information is based on the U.S. Census Bureau's TIGER (Topologically Integrated Geographic Encoding and Referencing) database.

The Tookany/Tacony-Frankford Watershed discharges to the Delaware River, and is made up of three linked stream segments: the Tookany Creek in the headwaters, which drains into the Tacony Creek, which becomes the Frankford Creek in the lower reaches. Named tributaries of the Tookany Creek include Mill Run, Rock Creek and Jenkintown Creek.

In a relatively undisturbed watershed, watershed boundaries follow topographic high points or contours. The U.S. Geological Survey (USGS) has subdivided the Tookany/Tacony-Frankford Watershed based on topography, as shown in Figure 2-2. These USGS subwatersheds are determined from the land area draining to a particular point of interest, such as a stream confluence or gauging site. These boundaries allow initial determinations of drainage areas and modeling elements. However, adjustments are made where necessary to include the effects of man-made alterations to the natural drainage patterns.

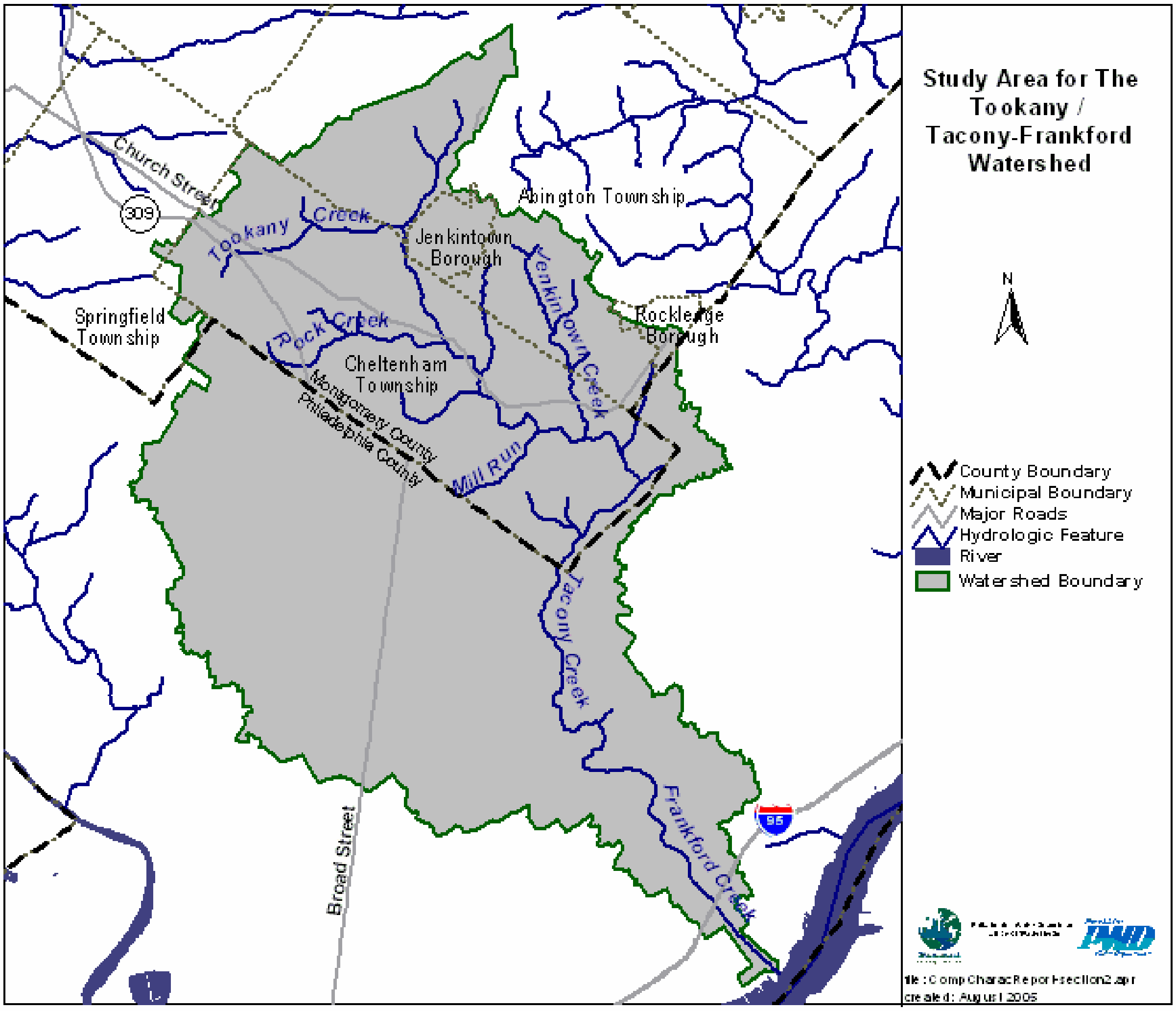


Figure 2-1 Tookany/Tacony-Frankford Study Area

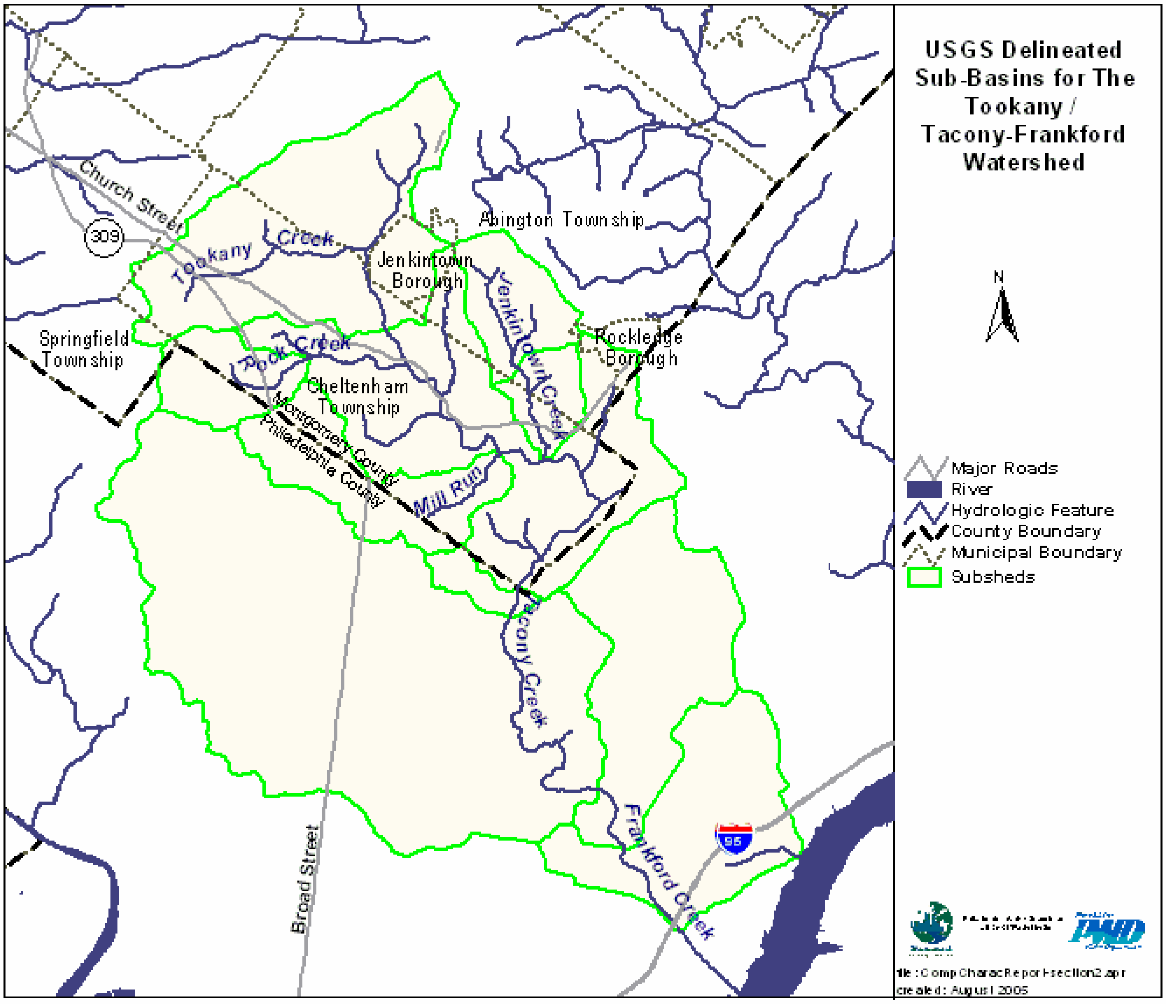


Figure 2-2 USGS Topographic Subwatersheds of the Tookany/Tacony-Frankford Watershed

2.2 Demographic Information

Population density and other demographic information in the watershed are available from the results of the 2000 census. Approximately 357,000 people live within the drainage area of the Tookany/Tacony-Frankford Watershed. Figure 2-3 shows the population density in the watershed at the census block level. Spatial trends in population correspond closely to land use, with multi-family row homes displaying the greatest population density of 20 people per acre or more, single-family homes displaying a lower density, and other land use types displaying the lowest density. In addition to population data, the U.S. Census Bureau provides a range of socioeconomic data that are often useful in watershed planning and general planning studies. Median household income and mean home value (Figures 2-4 and 2-5) are two of the many sample datasets provided.

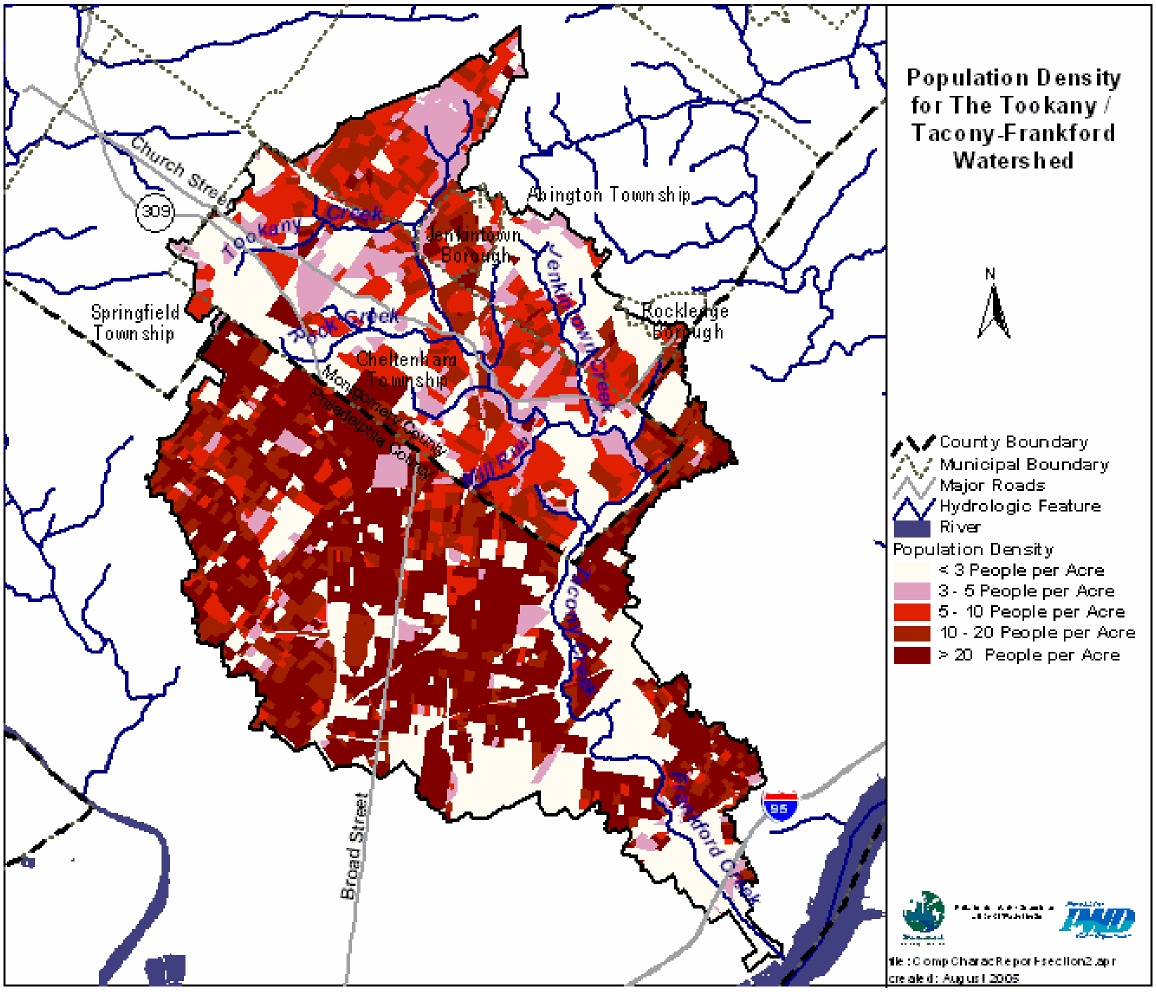


Figure 2-3 Population Density in Tookany/Tacony-Frankford Watershed by Census Block Group (Source: U.S. Census, 2000)

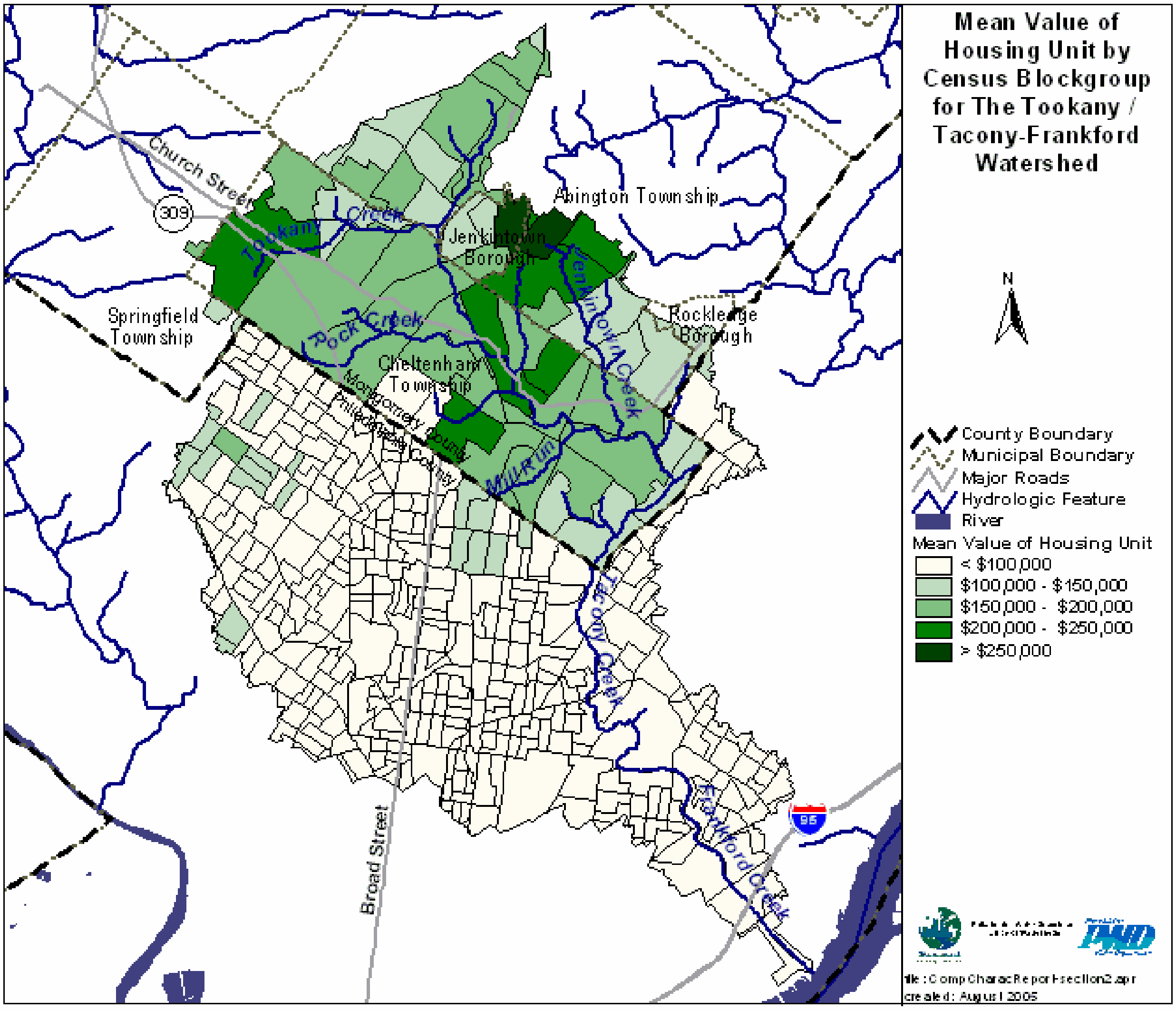


Figure 2-4 Mean Value of Housing Units in Tookany/Tacony-Frankford Watershed by Census Block Group (Source: U.S. Census, 2000)

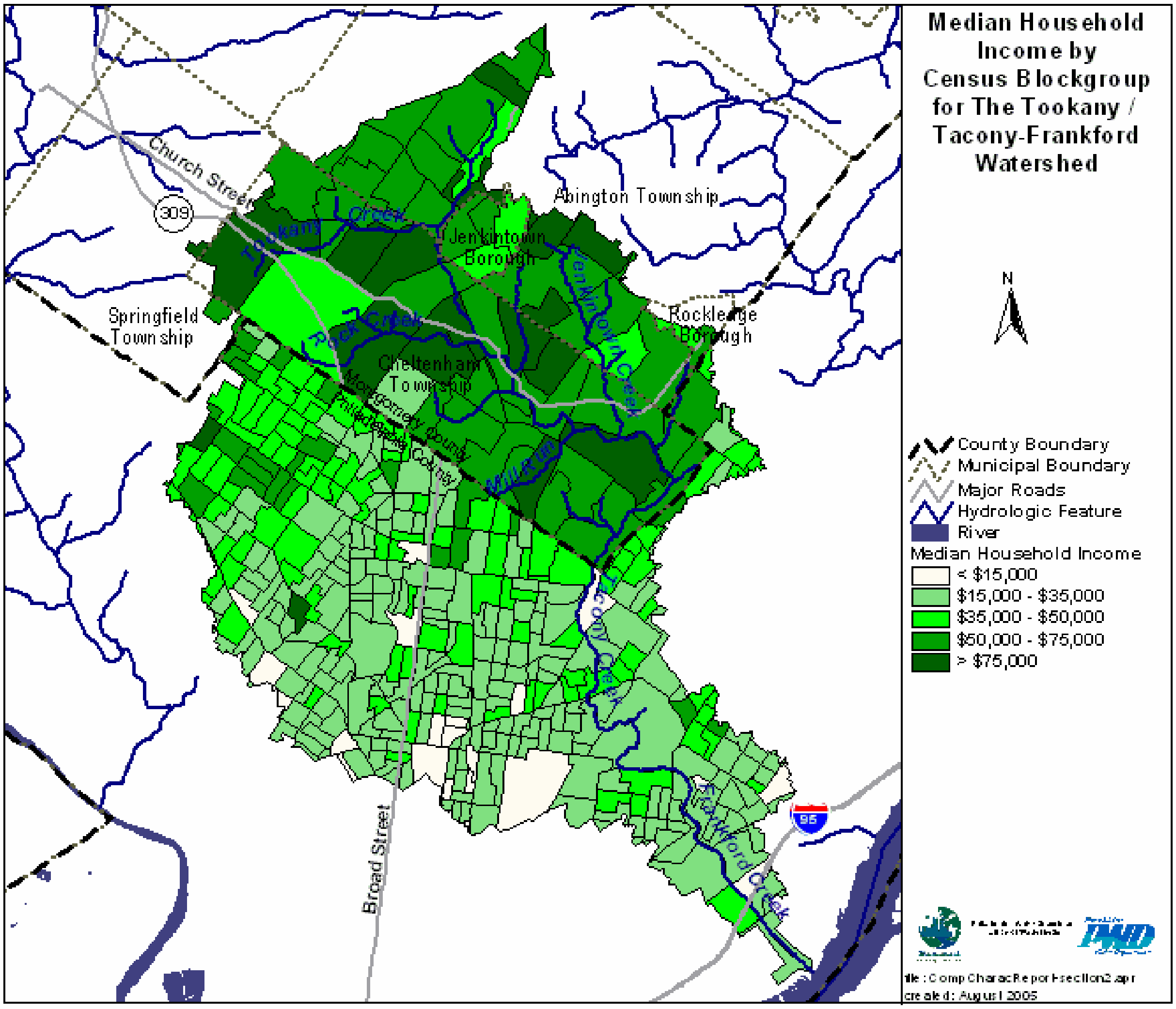


Figure 2-5 Median Household Income in Tookany/Tacony-Frankford Watershed by Census Block Group (Source: U.S. Census, 2000)

2.3 Land Use

Land use information for the Tookany/Tacony-Frankford Watershed was obtained from the Delaware Valley Regional Planning Commission (DVRPC). Figure 2-6 is the 1996 land use map for the study area. The upper reaches and headwaters of the Tookany/Tacony-Frankford Watershed are characterized primarily by a mix of multiple-family and detached single-family residential areas, golf courses and parkland. The lower portions of the Tookany/Tacony-Frankford Watershed are primarily high-density residential areas in the City of Philadelphia, with commercial areas along highway corridors. Riparian lands within the City consist mainly of relatively undisturbed parkland.

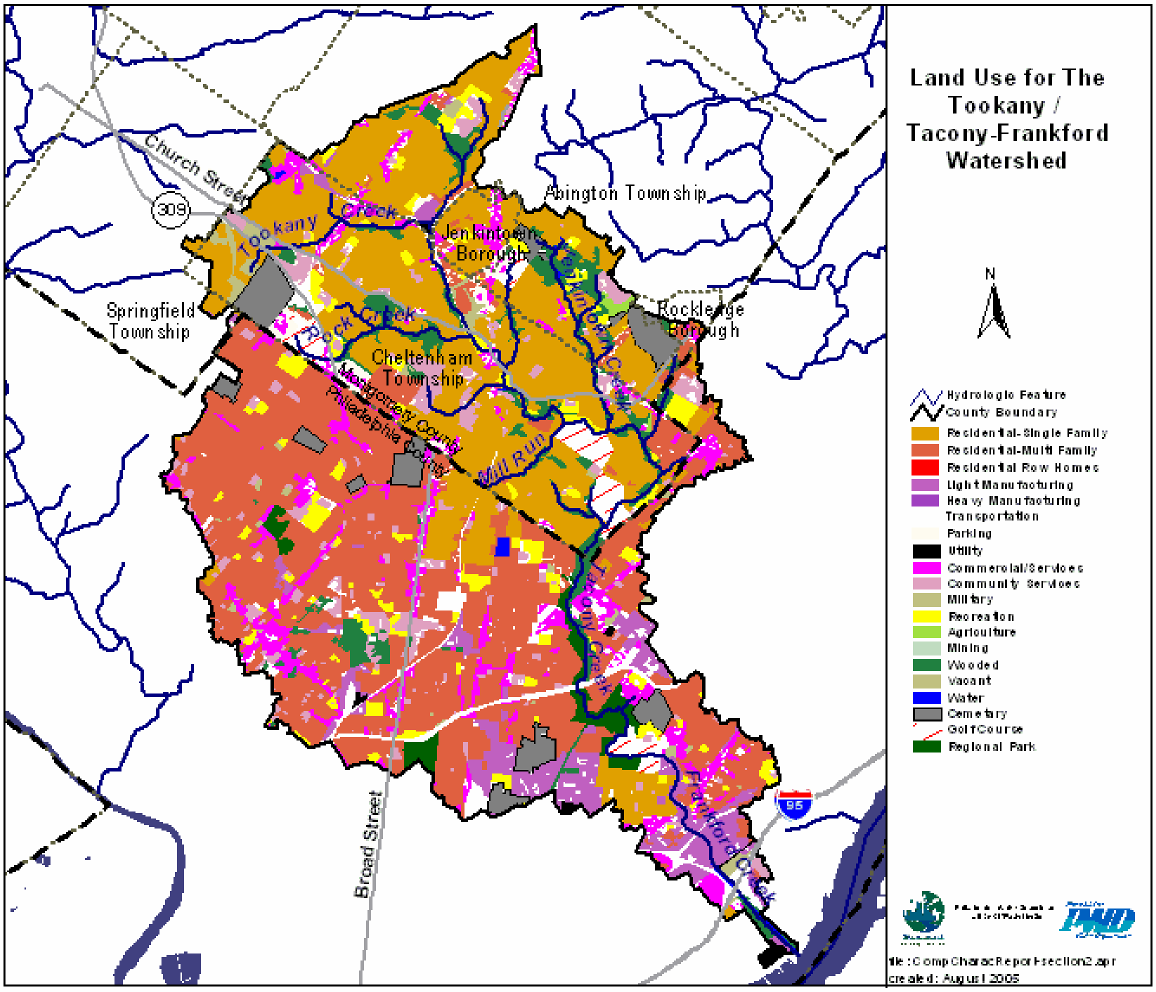


Figure 2-6 Land Use in the Tookany/Tacony-Frankford Watershed (Source: DVRPC 1995)

One of the primary indicators of watershed "health" is the percentage of impervious cover within the watershed. Based on numerous research efforts, studies and observations, a general categorization of watersheds has been widely applied to watershed management based on percent impervious cover (Schueler 1995). Percent impervious cover and other indicators of stream health are summarized in Table 2-1. Table 2-2 illustrates that the entire watershed has greater than 25% impervious cover, placing it in the "Non-Supporting" category of stream health.

Table 2-1 Impervious Cover as an Indicator of Stream Health (Schueler 1995)

Characteristic	Sensitive	Degrading	Non-Supporting
Percent Impervious Cover	0% to 10%	11% to 25%	26% to 100%
Channel Stability	Stable	Unstable	Highly Unstable
Water Quality	Good to Excellent	Fair to Good	Fair to Poor
Stream Biodiversity	Good to Excellent	Fair to Good	Poor
Pollutants of Concern	Sediment and temperature only	Also nutrients and metals	Also bacteria

Table 2-2 Estimated Total Impervious Cover

Watershed	County	Total Area (ac)	Acres Impervious	Percent Impervious
Tacony-Frankford	Philadelphia	10,844.5	5810.0	53.6
Tookany	Montgomery	10,226.7	2808.6	27.5

Table 2-3 summarizes several of the impacts of traditional development on streams and watersheds, most of which are created by the addition of impervious cover across the portions of the land surface. Figure 2-7 illustrates the changes to the volume and duration of runoff before and after development. Figure 2-7 also illustrates the benefits of using various BMPs and low impervious techniques to manage stormwater.

Table 2-3 Impacts of Traditional Development on Watershed Resources (from Schueler 1995)

Changes in Stream Hydrology ▪ Increased magnitude/frequency of severe floods ▪ Increased frequency of erosive bankfull and sub-bankfull floods ▪ Reduced ground water recharge ▪ Higher flow velocities during storm events	**Changes in Stream Morphology** ▪ Channel widening and downcutting ▪ Streambank erosion ▪ Channel scour ▪ Shifting bars of coarse sediments ▪ Imbedding of stream substrate ▪ Loss of pool/riffle structure ▪ Stream enclosure or channelization
Changes in Stream Water Quality ▪ Instream pulse of sediment during construction ▪ Nutrient loads promote stream and lake algae growth ▪ Bacteria contamination during dry and wet weather ▪ Higher loads of organic matter ▪ Higher concentrations of metals, hydrocarbons, and priority pollutants ▪ Stream warming ▪ Trash and debris jams	**Changes in Stream Ecology** ▪ Reduced or eliminated riparian buffer ▪ Shift in external production to internal production ▪ Reduced diversity of aquatic insects ▪ Reduced diversity of fish ▪ Creation of barriers to fish migration ▪ Degradation of wetlands, riparian zones and springs ▪ Decline in amphibian populations

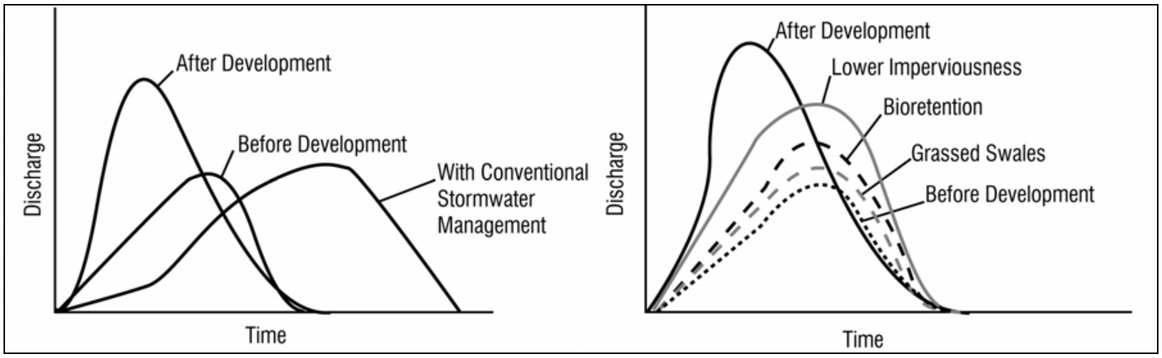


Figure 2-7 Comparison of Volume and Duration of Stormwater Runoff Before and After Land Development, and Reductions in Runoff from BMPs. (Prince George's County Department of Environmental Resources *et. al.*, undated)

2.4 Geology and Soils

Geology and soils play a role in the hydrology, water quality, and ecology of a watershed. The Tookany/Tacony-Frankford Watershed is located primarily within the Piedmont physiographic province. Geologic formations on the surface in the area include gneiss and schist in most of the watershed; sand is dominant in the lower reaches of the watershed (as shown in Figure 2-8). Soils in the upper portions of the Tacony Creek subwatershed include stony and silty loams, as shown in Figure 2-9. Soil in much of the rest of the watershed is classified as urban or made land and is not representative of the original undisturbed soil.

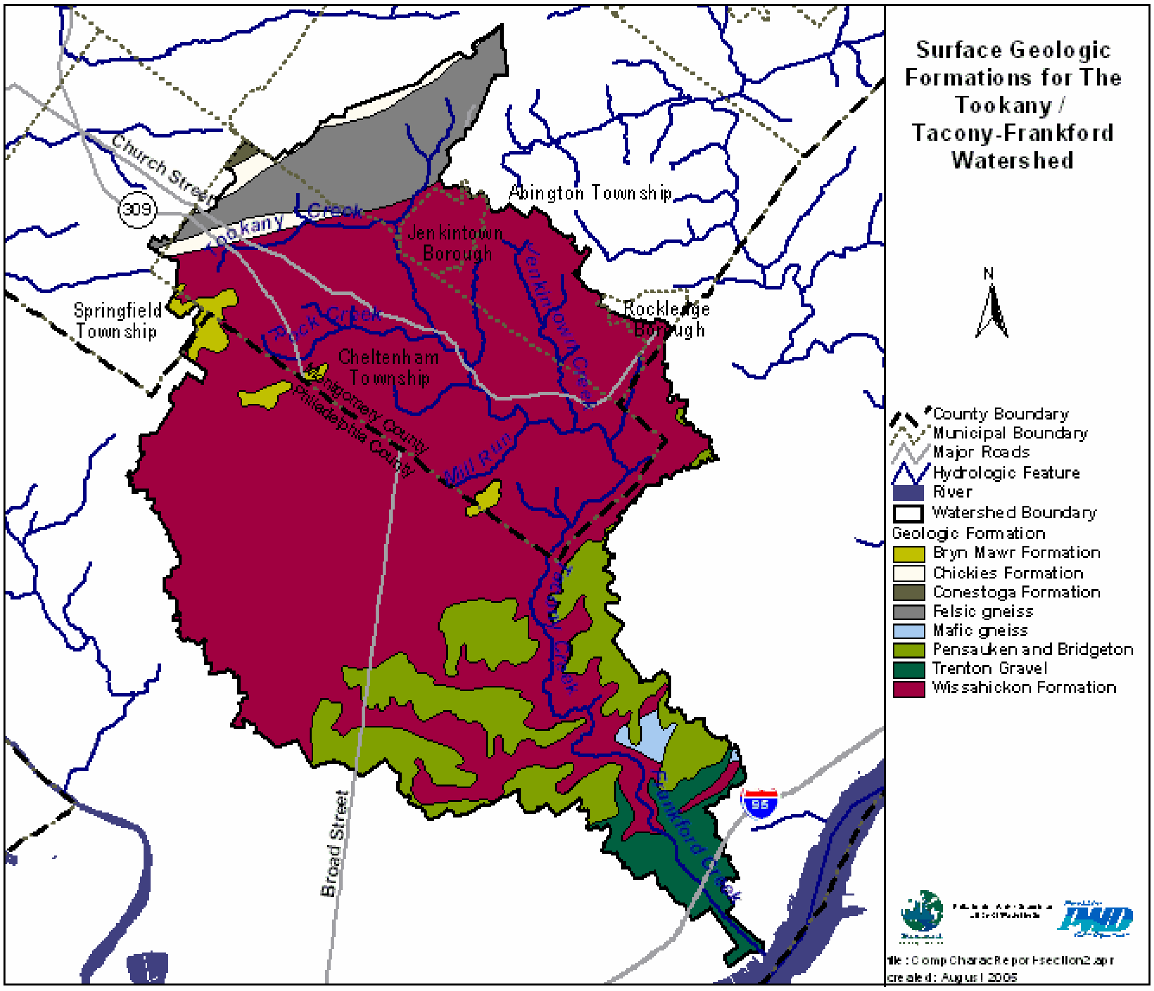


Figure 2-8 Surface Geologic Formations of the Tookany/Tacony-Frankford Watershed (Source: USGS)

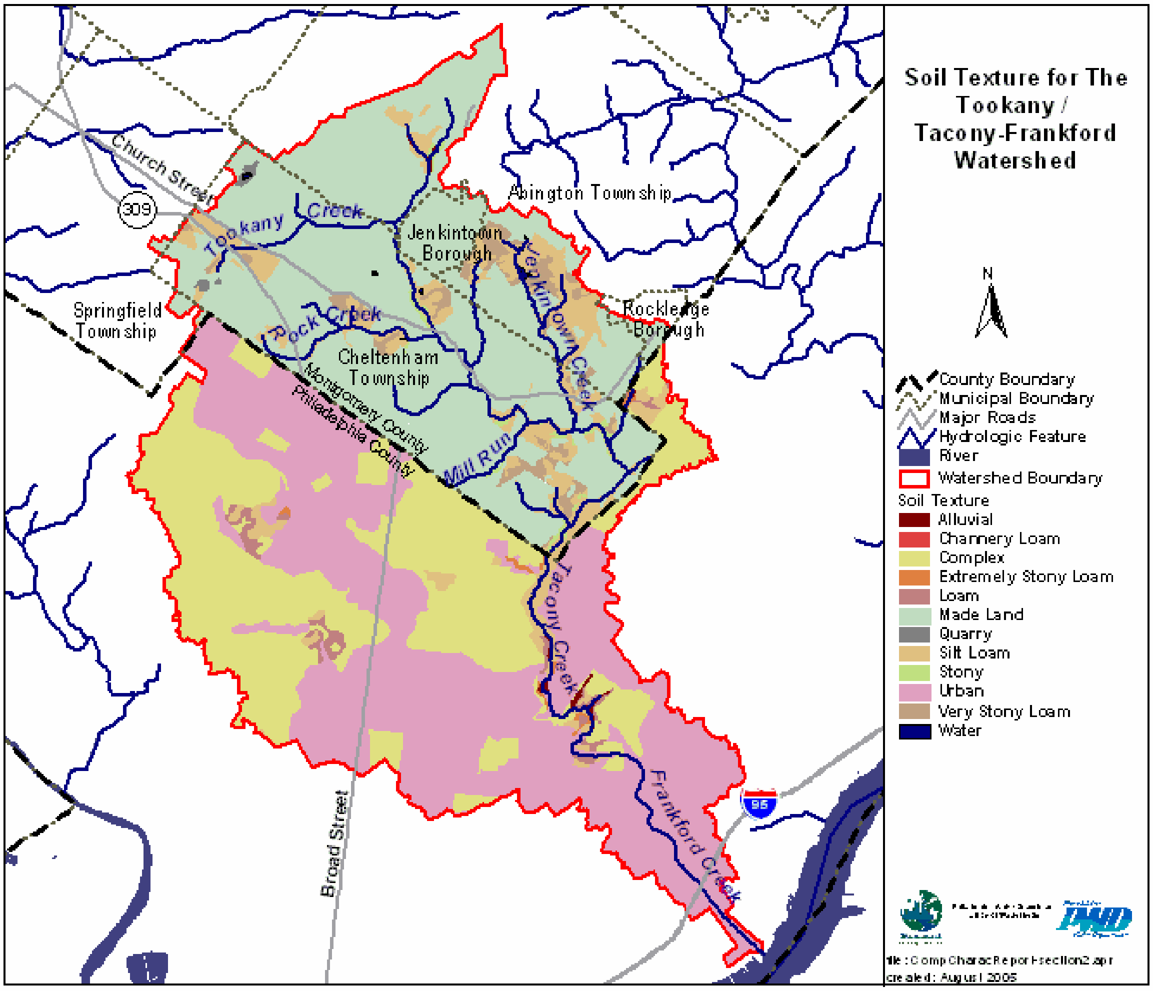


Figure 2-9 Soil Texture Types in the Tookany/Tacony-Frankford Watershed (Source: USDA, NRCS from the Soil Survey Geographic (SSURGO) database)

Section 3
Sampling and Monitoring Program Methods

3.1 Background

PWD's Office of Watersheds (OOW) has carried out an extensive sampling and monitoring program to characterize conditions in the Tookany/Tacony-Frankford Watershed. The program is designed to document the condition of aquatic resources and to provide information for the planning process needed to meet regulatory requirements imposed by EPA and PA DEP. The program includes hydrologic, water quality, biological, habitat, and fluvial geomorphological aspects. OOW is well suited to carry out the program because it merges the goals of the city's stormwater, combined sewer overflow, and source water protection programs into a single unit dedicated to watershed-wide characterization and planning.

Under the provisions of the Clean Water Act, the National Pollutant Discharge Elimination System (NPDES) requires permits for point sources that discharge to waters of the United States. In the Tookany/Tacony-Frankford Watershed, stormwater outfalls and wet weather sewer overflow points discharging to surface waters are classified as point sources and are regulated by NPDES.

EPA's Combined Sewer Overflow Control Policy, published in 1993, provides the national framework for regulation of CSOs under NPDES. The Policy guides municipalities and state and Federal permitting agencies in meeting the pollution control goals of the CWA in as flexible and cost-effective a manner as possible. As part of the program, communities serviced by combined sewer systems are required to develop long-term CSO control plans (LTCPs) that will result in full compliance with the CWA in the long term, including attainment of water quality standards. PWD completed its LTCP in 1997 and is currently implementing its provisions. The strong focus of the National CSO Policy on meeting water quality standards is a main driver behind PWD's water quality sampling and monitoring program.

Regulation of stormwater outfalls under the NPDES program requires operators of medium and large municipal stormwater systems or MS4s, such as the separate-sewered portions of the Tookany/Tacony-Frankford Creek watershed, to obtain a permit for discharges and to develop a stormwater management plan to minimize pollution loads in runoff over the long term. Partially in administration of this program, PA DEP assigns designated uses to water bodies in the state and performs ongoing assessments of the condition of the water bodies to determine whether the uses are met and to document any improvement or degradation. These assessments are performed primarily with biological indicators based on the EPA's Rapid Bioassessment Protocols (RBPs) for benthic invertebrates and physical habitat. The Tookany/Tacony-Frankford Creek is listed by the PA DEP as impaired for one or more designated uses, not requiring a TMDL.

The Tookany/Tacony-Frankford Creek and its tributaries are designated warm water fisheries. All of the Tookany portion of the watershed plus tributaries, and the upper, non-tidal portion of the Tacony Creek are classified as unattained by PA DEP. For this reason, the stormwater permit for the City of Philadelphia specifies that the state of the aquatic resource must be evaluated periodically. Because PA DEP has endorsed biomonitoring as a means of determining attainment of uses, PWD periodically performs RBPs in the Tookany/Tacony-Frankford Creek.

OOW is responsible for characterization and analysis of existing conditions in local watersheds to provide a basis for long-term watershed planning and management. The extensive sampling and monitoring program described in this section is designed to provide the data needed for the long-term planning process.

3.2 Summary of Physical and Chemical Monitoring

PWD's Office of Watersheds (OOW) and Bureau of Laboratory Services (BLS) have planned and carried out an extensive sampling and monitoring program to characterize conditions in the Tookany/Tacony-Frankford Creek watershed. The program includes hydrologic, water quality, biological, habitat, and fluvial geomorphological components. Again, because the OOW has merged the goals of the city's stormwater, combined sewer overflow, and source water protection programs into a single unit dedicated to watershed-wide characterization and planning, it is uniquely suited to administer this program.

Sampling and monitoring follow the Quality Assurance Project Plan (QAPP) and Standard Operating Protocols (SOPs) as prepared by BLS. These documents cover the elements of quality assurance, including field and laboratory procedures, chain of custody, holding times, collection of blanks and duplicates, and health and safety. They are intended to help the program achieve a level of quality assurance and control that is acceptable to regulatory agencies.

Tables 3-1 and 3-2 summarize the types, amounts, and dates of recent sampling and monitoring performed by PWD, PA DEP, and USGS. A river mile-based naming convention is followed for sampling and monitoring sites located along waterways in the watershed. The naming convention includes three letters and three or more numbers which denote the watershed, stream, and distance from the mouth of the stream. For example, site TFJ110 is named as follows:

- "TF" indicates the Tookany/Tacony-Frankford watershed.
- "J" indicates Jenkintown Creek, a tributary to Tookany Creek.
- "110" places the site 1.10 miles upstream of the confluence of Jenkintown Creek and Tookany Creek.

Table 3-1 Summary of Physical and Biological Sampling and Monitoring

		Physical			Biology			
	USGS		**USGS**	**USGS Annual**	**PWD**			**PA DEP**
Site Name	**Gauge**	**Stream Name**	**Daily Flow**	**Peak Flow**	**RBP III***	**RBP V****	**Habitat**	
	1467089	Frankford Creek	1965-1982	1966-1980				
TF280	1467087	Tacony Creek	1982-Present	1982-Present				
TF324		Tacony Creek			November 2000 March 2004	November 2000 June 2004	November 2000 March 2004	
TF396		Tacony Creek			Mar-04	Jun-04	Mar-04	
TF500		Tacony Creek			November 2000 March 2004	Jun-04	November 2000 March 2004	
TF620	1467086	Tacony Creek	1965-1982	1966-1985	November 2000 March 2004	November 2000 June 2004	November 2000 March 2004	1999
TF760		Tookany Creek			Nov-00		Nov-00	
TF827		Tookany Creek			Mar-04	Jun-04	Mar-04	
TF975		Tookany Creek			November 2000 March 2004	November 2000 June 2004	November 2000 March 2004	
TF1120	1467083	Tookany Creek	1973-1978	1974-1978	November 2000 March 2004	November 2000 June 2004	November 2000 March 2004	
TF1270		Tookany Creek			Mar-04		Mar-04	1999
TFU010		Unnamed Tributary			Mar-04		Mar-04	1999
TFJ013		Jenkintown Creek			Mar-04		Mar-04	1999
	1467085	Jenkintown Creek	1973-1978	1974-1978				
TFJ110		Jenkintown Creek			Nov-00		Nov-00	
TFM006		Mill Run			Mar-04		Mar-04	
TFR064		Rock Creek			Mar-04		Mar-04	1999

* EPA Rapid Bioassessment Protocol III Benthic Macroinvertebrates

** EPA Rapid Bioassessment Protocol V Ichthyofaunal (Fish)

3.3 Water Quality Sampling and Monitoring

A range of water quality samples were collected between 1999 and 2004 at 9 sites in the watershed. The sites are listed in Table 3-2 and are shown on Figure 3-1. Three different types of sampling were performed as discussed below. Parameters were chosen based on state water quality criteria or because they are known or suspected to be important in urban watersheds. The parameters sampled during each type of sampling are listed in Table 3-4. Water quality in each reach and section of the watershed is characterized in Section 5.

The sampling and analysis program meets AMSA (2002) *et al.* recommendations for the minimum criteria that should form the basis for impairment listings:

- Data collected during the previous five years may be considered to represent current conditions.
- At least ten temporally independent samples should be collected and analyzed for a given parameter.
- A two-year minimum data set is recommended to account for inter-year variation, and the sample set should be distributed over a minimum of two seasons to account for inter-seasonal variation.
- No more than two-thirds of the samples should be collected in any one year.
- Samples collected fewer than four days apart at the same river location should be considered one sample event.
- Samples collected within 200 meters [about 0.1 miles] of each other will be considered the same station or location. This convention was followed except where two sampling sites were chosen to represent conditions upstream and downstream of a modification such as a dam.

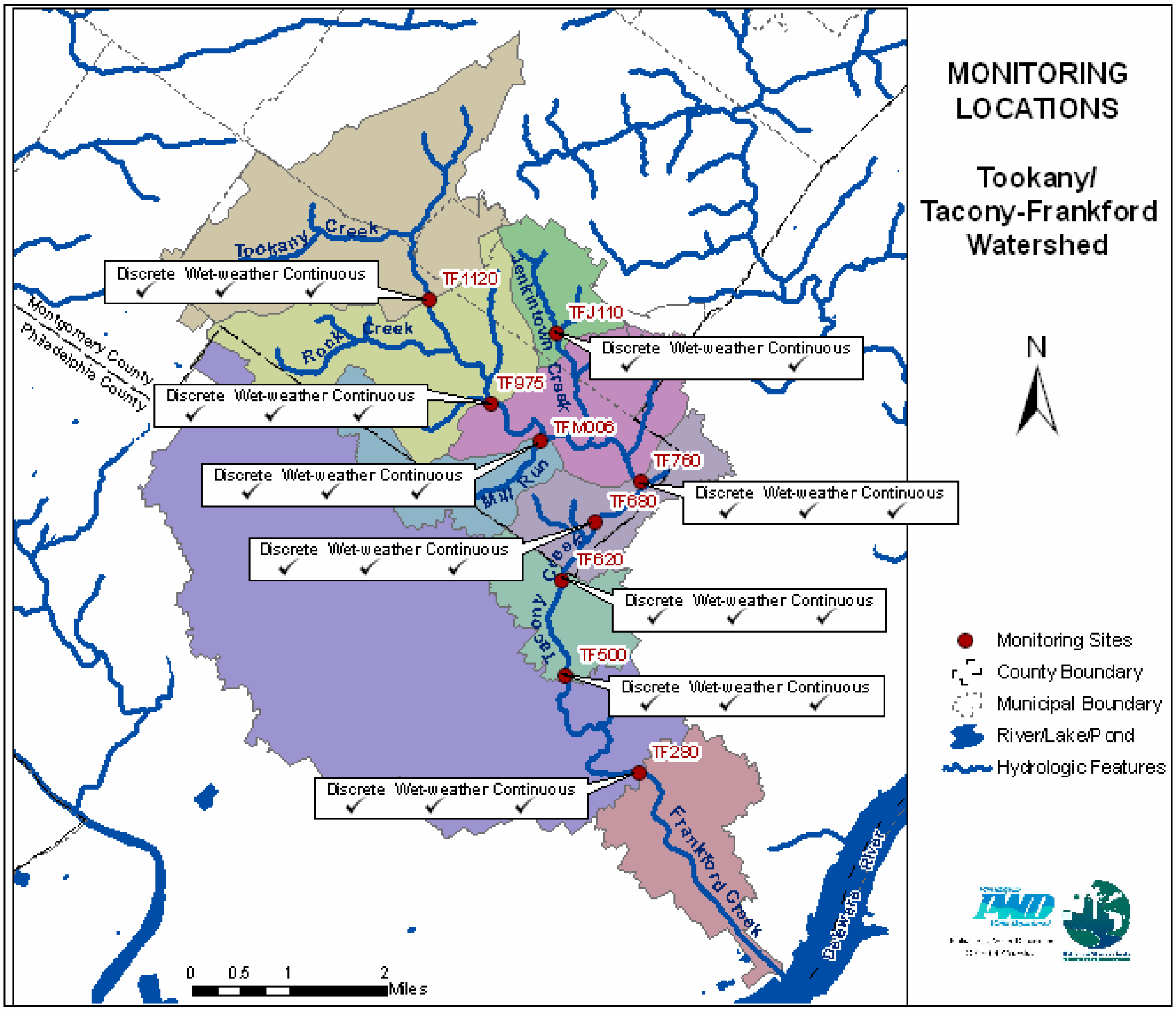


Figure 3-1 Water Quality Sampling Sites in the Tookany/Tacony-Frankford Watershed

Table 3-2 Summary of Water Quality Sampling and Monitoring

		Chemical		
	USGS	**PWD**		
Site	**Gauge**	**Discrete**	**Continuous (hrs)**	**Wet Weather**
TF280	1467087	32 samples 6/29/2000 - 9/2/2004	11109	12 periods 3/19/2001 - 9/1/2004
TF500		25 samples 6/29/2000 - 8/26/2004	3335.5	2 periods 5/21/2001 - 11/1/2002
TF620*	1467086	27 samples 6/29/2000 8/26/2004	9972.5	13 periods 10/15/2002 - 3/7/2003
TF680*		4 samples 7/27/2004 - 9/2/2004		9 periods 5/1/2003 - 9/1/2004
TF760		22 samples 6/29/2000 - 8/26/2004	1701.25	2 periods 5/21/2001 - 11/1/2002
TF975		27 samples 6/29/2000 - 9/2/2004	6298	12 periods 10/29/2002 - 9/1/2004
TF1120	1467083	24 samples 6/29/2000 - 9/2/2004	6462.75	10 periods 10/15/2002 - 9/1/2004
TFJ110	1467085	21 samples 6/29/2000 - 8/26/2004	2593.25	
TFM006		16 samples 11/29/2001 - 9/2/2004	2543.25	2 periods 7/7/2004 - 9/1/2004

*** Sites TF620 and TF680 were combined for analysis in many instances.**

Table 3-3 Water Quality Parameters Sampled

Parameter	Units	Discrete	WETW	Continuous
Physical Parameters				
Temperature	deg C	X	X	X
pH	pH units	X	X	X
Specific Conductance	µMHO/cm @ 25C	X	X	X
Alkalinity	mg/L	X	X	
Turbidity	NTU	X	X	X
TSS	mg/L	X	X	
TDS	mg/L	X	X	
Oxygen and Oxygen Demand				
DO	mg/L	X	X	X
BOD_5	mg/L	X	X	
BOD_{30}	mg/L	X	X	
$CBOD_5$	mg/L	X	X	
Nutrients				
Ammonia	mg/L as N	X	X	
TKN	mg/L	X	X	
Nitrite	mg/L	X	X	
Nitrate	mg/L	X	X	
Total Phosphorus	mg/L	X	X	
Phosphate	mg/L	X	X	
Metals				
Aluminum (Total)	mg/L	X	X	
Aluminum (Dissolved)	mg/L	X	X	
Calcium (Total)	mg/L	X	X	
Cadmium (Total)	mg/L	X	X	
Cadmium (Dissolved)	mg/L	X	X	
Chromium (Total)	mg/L	X	X	
Chromium (Dissolved)	mg/L	X	X	
Copper (Total)	mg/L	X	X	
Copper (Dissolved)	mg/L	X	X	
Fluoride (Total)	mg/L	X	X	
Fluoride (Dissolved	mg/L	X	X	
Iron (Total)	mg/L	X	X	
Iron (Dissolved)	mg/L	X	X	
Magnesium (Total)	mg/L	X	X	
Manganese (Total)	mg/L	X	X	
Manganese (Dissolved)	mg/L	X	X	
Lead (Total)	mg/L	X	X	
Lead (Dissolved)	mg/L	X	X	
Zinc (Total)	mg/L	X	X	
Zinc (Dissolved)	mg/L	X	X	
Biological				
Total Chlorophyll	µg/L	**X**	**X**	
Chlorophyll-*a*	µg/L	X	X	
Fecal Coliform	CFU/100mls	X	X	
E. coli	CFU/100mls	X	X	
Osmotic Pressure	mOsm	X		
Miscellaneous				
Phenolics	mg/L	X	X	

3.3.1 Discrete Interval Sampling

Discrete, or "grab" samples were collected at nine sites on a weekly basis for four weeks during three seasonal monitoring periods (Fall/winter, spring and summer). Samples were collected regardless of flow or precipitation. Each site along the stream was sampled once during the course of a few hours, to allow for travel time and sample processing/preservation. The purpose of discrete sampling was initial characterization of water quality under both dry and wet conditions and identification of parameters of possible concern. Discrete sampling followed the Standard Operating Protocol (SOP) "Field Procedures for Grab Sampling".

3.3.2 Continuous Monitoring

Continuous data were collected at eight sites for a total of over 44,000 hours. During continuous sampling, data for selected parameters were collected at 15-minute increments by a submerged instrument (YSI Sonde 6600) over approximately two weeks. The instrument measured parameters using voltage and diffusion-based probes rather than physically collecting samples. Parameters measured included stage, dissolved oxygen, temperature, pH, and turbidity. This method produces 96 measurements per parameter every 24 hours, but cost and quality control are more challenging compared to discrete sampling. The SOP for continuous sampling describes the extensive quality control and assurance procedures applied to the data.

3.3.3 Wet Weather Event Sampling

At eight sites, a series of samples was collected over the course of several wet weather events. During wet weather sampling, several discrete samples were collected just before and during the course of a wet weather event. The data allow characterization of water quality responses to stormwater runoff and wet weather sewer overflows.

3.3.4 PWD/USGS Cooperative Water Quality Monitoring Program (1970-1980)

In the early 1970s, the Philadelphia Water Department began a study in cooperation with the U.S. Geological Survey (USGS) titled, "Urbanization of the Philadelphia Area Streams." The purpose of this study was to quantify the pollutant loads in some of Philadelphia's streams and possibly relate the degradation in water quality to urbanization. PWD and the USGS established six stream gauging stations in Tookany/Tacony-Frankford Watershed and conducted monthly water quality sampling from 1971 to 1980 at 5 of these locations. Of six original gauges, only the gauge at Castor Avenue (01467087) remains operational today. Monthly "snapshot" water quality samples were collected at each site and analyzed for conductivity, BOD_5, total phosphate, ammonia, nitrite, nitrate, and fecal coliform. The program collected about ten years of monthly samples. Figure 3-2 and table 3-4 show the locations of the monitoring stations from the PWD/USGS Cooperative Program.

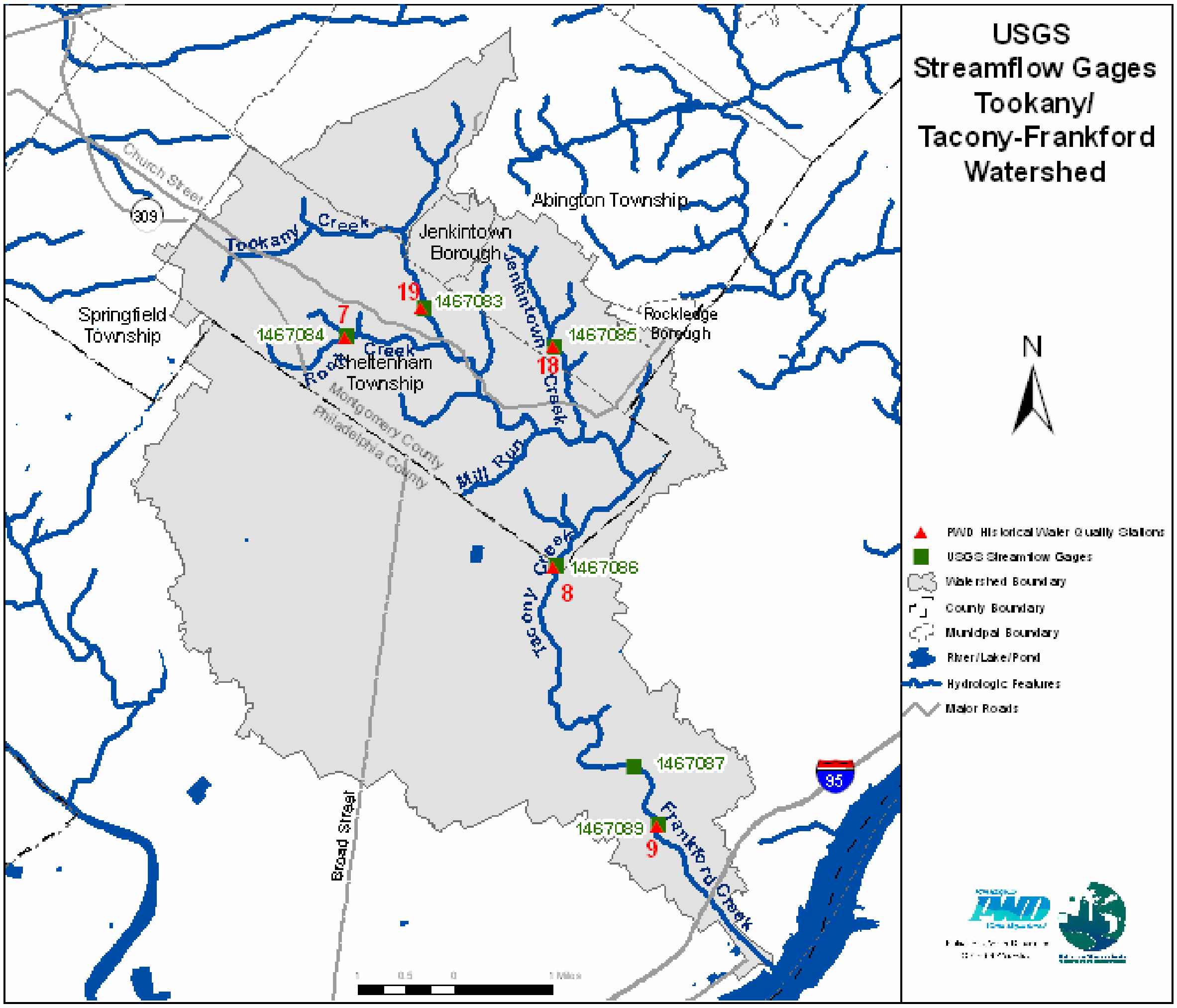


Figure 3-2 PWD/USGS Cooperative Program Water Quality Stations in the Tookany/Tacony-Frankford Watershed

Stream discharge was recorded at the time samples were collected, enabling comparisons to present day water quality. Historic samples were characterized as wet or dry based on a flow frequency analysis conducted in 2001. Spring and winter flows were typically higher than summer and fall flows, so samples were analyzed by season. For each season, a sample was determined to be wet if the instantaneous flow was greater than the estimated wet/dry weather flow break point. Some samples with discharge below the break point that had noticeably lower conductivity and greater TSS concentration were also characterized as "wet". Despite this check, it is assumed that many samples were collected within 48 hours of a rain event but classified as "dry".

3.4 Hydrologic and Outfall Monitoring

Hydrologic monitoring included a system of precipitation gauges and measurement of flows at stream gauges and at points within the sewer system (outfalls and CSO regulators). Characterization of hydrologic and hydraulic data is presented in Section 4.

3.4.1 Precipitation Data

Precipitation data are available from the National Oceanography and Atmospheric Administration (NOAA) and from local gauges operated by PWD and other organizations. NOAA's gauge at the Philadelphia International Airport, located in southeastern Philadelphia, has over 100 years of hourly precipitation data; the period of record runs from January 3, 1902 through the present. Additional precipitation data can be obtained from PWD's network of 24 rain gauges throughout the city; these data are available in 15-minute increments from the early 1990s to the present. Nine of the City gauges are located in or near the Tookany/Tacony-Frankford Creek watershed, as shown in Figure 3-3.

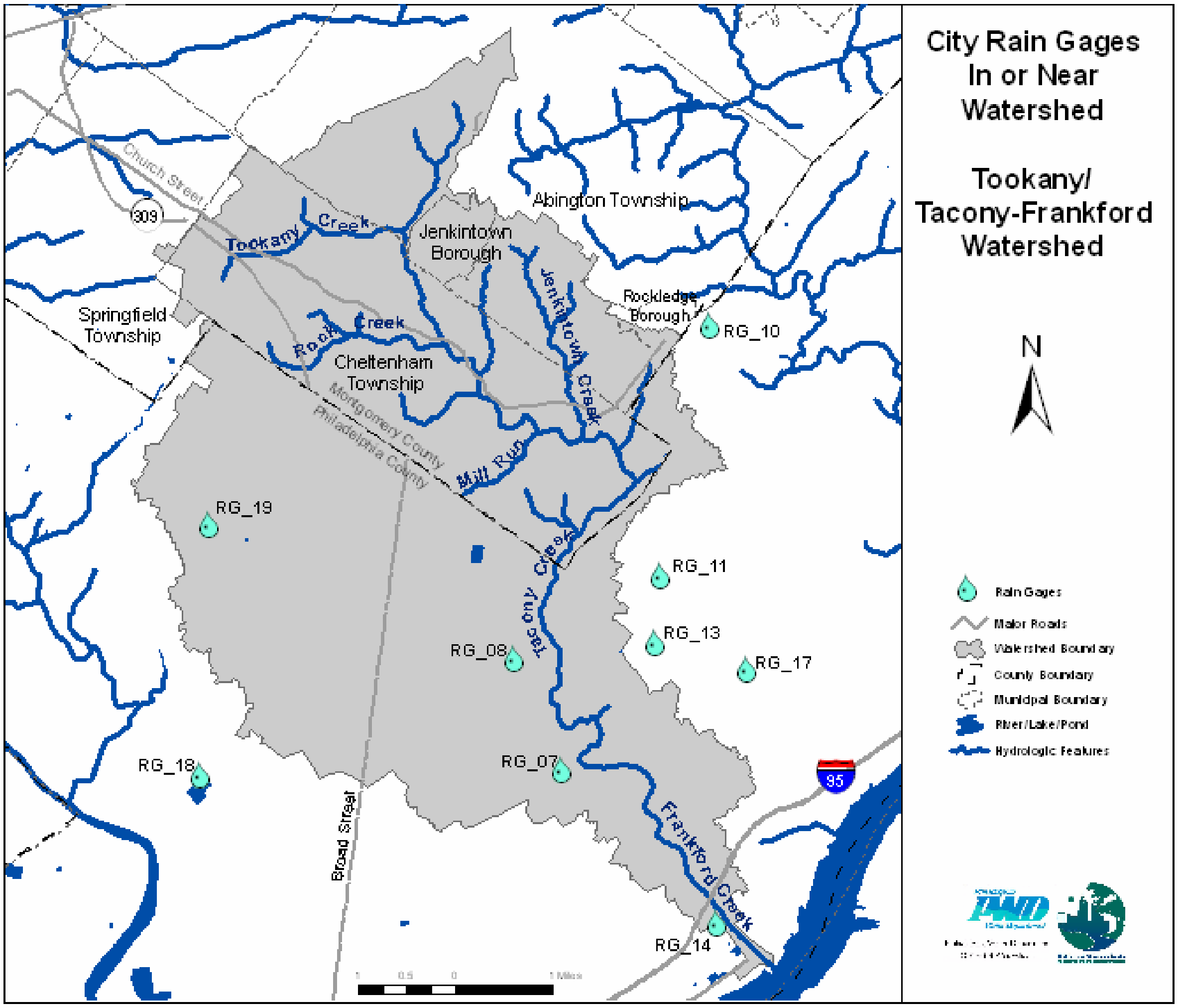


Figure 3-3 PWD Rain Gauges located in or near Tookany/Tacony-Frankford Watershed

3.4.2 Sewer Flow Instrumentation

PWD maintains real-time level monitors in the Tacony-Frankford Creek sewer system. At these points, monitors are typically present in the trunk sewer just above the regulator and in the outfall pipe itself. The magnitude of discharges from the city's CSO outfalls are estimated using a combination of this monitored data and calibrated computer models.

3.4.3 Streamflow Data

PWD and the USGS augmented the existing stream gauging network in the watershed as part of the Cooperative sampling program, establishing three new stream gauges from 1971 to 1973. A gauge was established at Castor Avenue in 1982, which is the only gauge still in operation. However, PWD and USGS are in the process of re-establishing the former gauge at the city line. Table 3-5 contains summary information for each of the six gauging stations for their respective periods of record. Historical stage-discharge rating curves are available for four of the stations and are shown in Figure 3-4.

Table 3-4 Periods of Record for Flow and Water Quality Data

Station ID	Location	Quality Data (Period)	Streamflow Data (Period)
01467089	Frankford Creek at Torresdale Ave.	10/9/67 - 3/7374	10/1/64 - 6/29/82, 5/14/82 – 6/29/82
01467087	Frankford Creek at Castor Ave.*	9/24/25 - 8/24/76	7/1/82 - 9/30/03
01467086	Tacony Creek at County Line	11/9/67 - 10/1/73	10/1/65 - 11/17/88
01467085	Jenkintown Creek At Elkins Park		10/01/73 - 9/30/78
01467084	Rock Creek above Curtis Arboretum near Philadelphia	10/4/71 - 10/1/73	5/1/71 – 9/30/78
01467083	Tookany Creek near Jenkintown		10/1/73 - 9/30/78

*Active Gauge

Table 3-5 Summary Statistics for Six Gauge Stations

Station ID	Average Daily Flow Statistics (cfs)		
	Minimum	**Mean**	**Maximum**
01467089	3.7	57.3	1980
01467087	0.39	40.5	3140
01467086	2.5	26.5	900
01467085	0.14	2.07	45
01467084	0.33	2.51	87
01467083	1.6	9.74	207

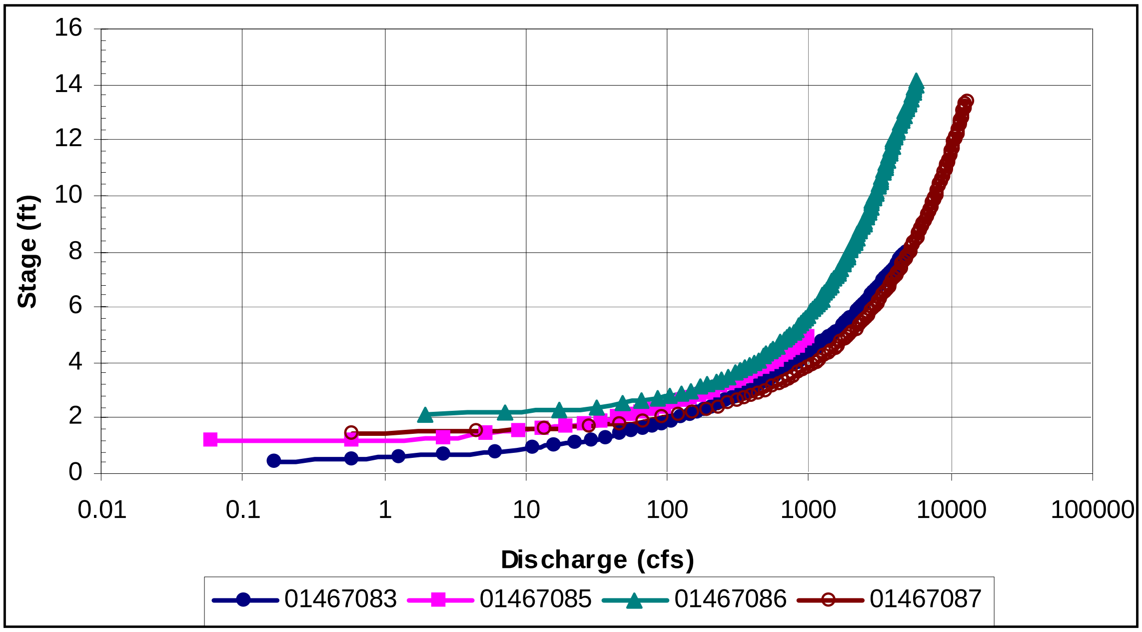


Figure 3-4 Historical stage-discharge rating curves available for four stations

3.4.5 STORET

The majority of the data available from STORET, USEPA's water quality database, for the Tookany/Tacony-Frankford Watershed were from the PWD/USGS Cooperative Program, "Urbanization of the Philadelphia Area Streams." The STORET inventory of water quality data within the Tookany/Tacony-Frankford Creek Watershed will be attached as an Appendix at a later date.

3.5 Benthic Macroinvertebrate Sampling

During 3/24/04 to 4/1/04, the Philadelphia Water Department conducted Rapid Bioassessment Protocols (RBP III) at twelve (n=12) locations within the Tookany/Tacony-Frankford Watershed (Figure 3-5). Using EPA guidelines, macroinvertebrates were collected by placing a standard ($1m^2$) kicknet at the downstream portion of a riffle. The substrate was then kicked and scraped manually one meter from the net aperture to remove benthic invertebrates. Four rocks of varying size were randomly chosen within the sampling sites and manually scraped to remove benthic invertebrates. This procedure was repeated at another riffle location with less flow. Specimens were then preserved in 70% ETOH (ethyl alcohol) and returned to the laboratory in polyethylene containers. In the laboratory, samples were placed in an 11" x 14" gridded (numbered) pan and random subsamples, or "plugs" were examined until 100 individuals were collected. Macroinvertebrates were identified to genus, with the exception of mollusks, aquatic worms, chironomids, crayfish, and leeches, which were identified to the family level.

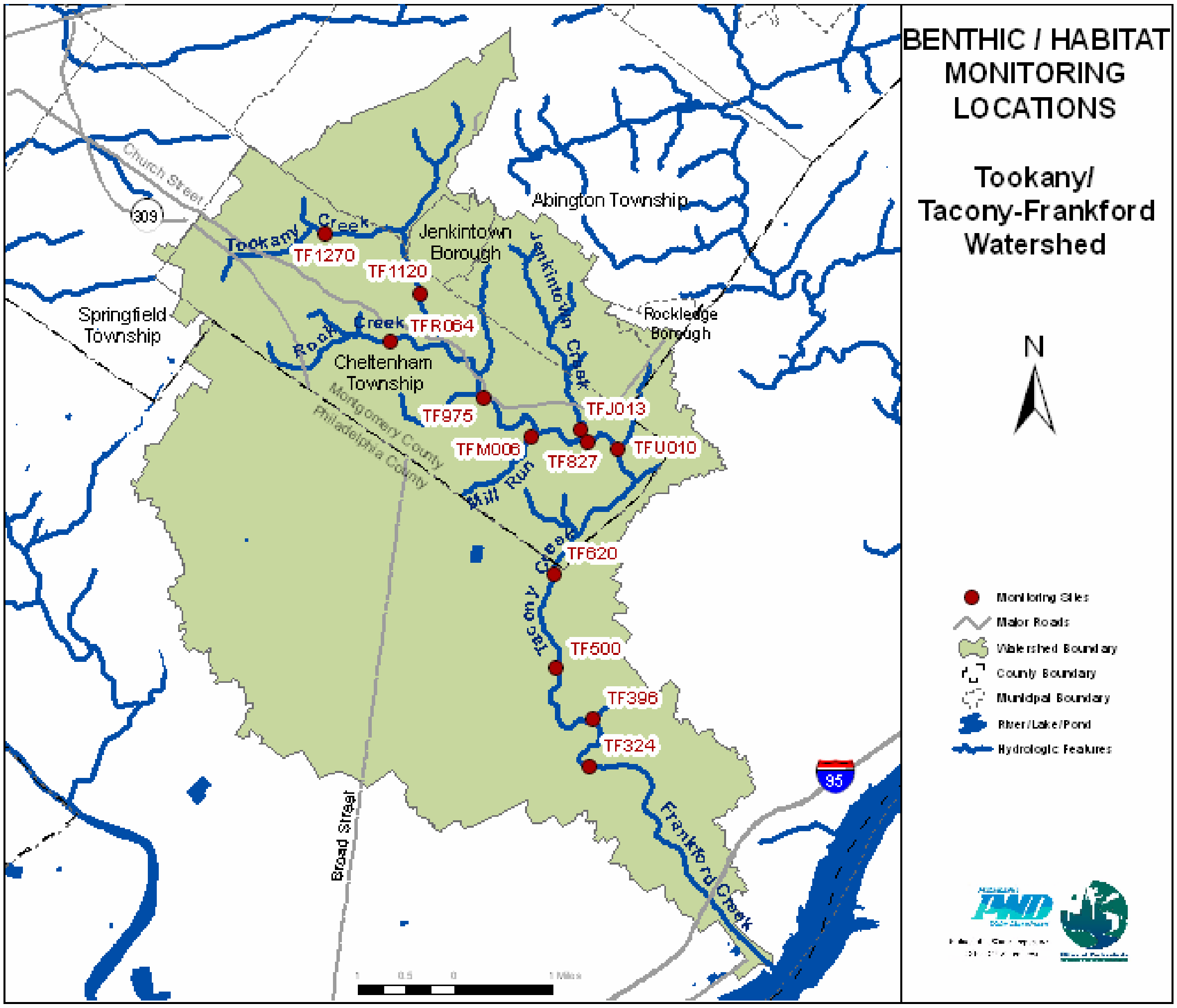


Figure 3-5 Benthic Macroinvertebrate Monitoring and EPA Habitat Assessment Sites in the Tookany/Tacony-Frankford Watershed, 2004

3.5.1 Metrics:

Biological integrity and benthic community composition of the 12 sites were assessed using the metrics in table 3-6. (EPA guidelines for RBP III and PA DEP Modified Rapid Biological Assessments)

Table 3-6 Biological Condition Scoring Criteria for RBP III

Metric	Biological Condition Scoring Criteria			
	6	4	2	0
Taxa Richness (a)	>80%	79-70%	69-60%	<60%
Hilsenhoff Biotic Index (Modified) (a)	<0.71	0.72-1.11	1.12-1.31	>1.31
Modified EPT Index (a)	>80%	79-60%	59-50%	<50%
Percent Contribution of Dominant Taxon (a)	<10	11-16	17-22	>22
Precent Modified Mayflies (a)	<12	13-20	21-40	>40
Ratio of Scrapers/Filter (b) Collectors	>50%	35-50%	20-35%	<20%
Community Loss Index (b)	<0.5%	0.5-1.5	1.5-4.0	>4.0
Ratio of Shredders/Total (b)	>50%	35-50%	20-35%	<20%

[a] Metrics used to quantify scoring criteria (PA DEP)
[b] Additional metrics used for qualitative descriptions of sampling locations (EPA)

Upon completion of the total biological scoring criteria, each site was compared to a reference site according to its drainage area and geomorphologic attributes. The reference sites chosen were French Creek, located at Coventryville, and Rock Run, a tributary of French Creek. Using the following chart, benthic quality of each site was established to identify spatial trends of impairment along the river continuum (Table 3-7).

Table 3-7 Biological Condition Categories for RBP III

% Comparison to Reference Score (a)	Biological Condition Category	Attributes
>83%	Nonimpaired	Comparable to the best situation within an ecoregion. Balanced trophic structure. Optimum community structure for stream size and habitat quality.
54-79%	Slightly impaired	Community structure less than expected. Species composition and dominance lower than expected due to loss of some intolerant forms. Percent contribution of tolerant forms increases.
21-50%	Moderately impaired	Fewer species due to loss of most intolerant forms. Reduction in EPT index.
<17%	Severely impaired	Few species present. If high densities of organisms, then dominated by one or two taxa.

(a) Percentage values obtained that are intermediate to the above ranges will require subjective judgment as to the correct placement. Use of the habitat assessment and chemical data may be necessary to aid in the decision process.

3.6 Ichthyofaunal (Fish) Sampling

3.6.1 Fish Collection in Non-Tidal Portions

Between 6/2/04 and 6/16/04, PWD biologists conducted fish assessments at seven (n=7) locations within the Tookany/Tacony-Frankford Watershed (Figure 3-5). Fish were collected by electrofishing as described in EPA's Rapid Bioassessment Protocol V (RBP V) (Barbour *et al*., 1999). Depending on stream conditions, Smith-Root backpack or tote barge electrofishers were used to stun fish. A 100m reach of the stream was blocked at the upstream and downstream limits with nets to prevent immigration or emigration from the study site. Each reach was uniformly sampled, and all fish captured were placed in buckets for identification and counting. An additional pass without replacement was completed along the reach to ensure maximum likelihood population and biomass estimates.

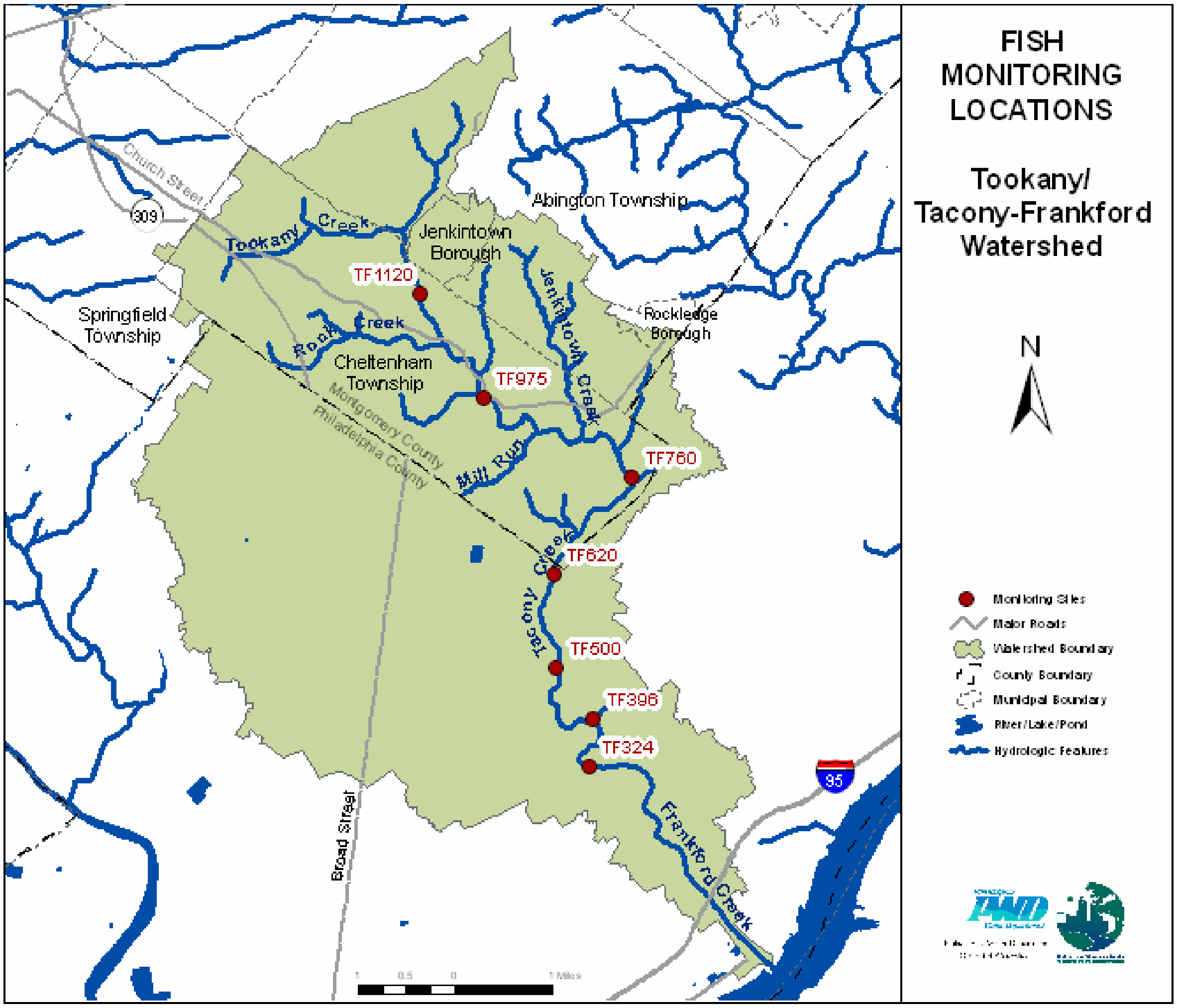


Figure 3-5 Non-Tidal Fish Monitoring Sites in the Tookany/Tacony-Frankford Watershed, 2004

3.6.2 Fish Collection in Tidal Portions

Between 8/1/04 and 8/8/04, staff biologists completed fish assessments at two (n=2) tidal locations in the Tookany/Tacony-Frankford Watershed (Figure 3-6). Fish inhabiting tidal portions of Frankford Creek were collected with Smith-Root electrofishing apparatus mounted aboard a small aluminum-hulled johnboat. Electrofishing was conducted for ten-minute intervals in a downstream direction, targeting areas with suitable fish habitat. It was not feasible to install block nets or otherwise prevent net movement of fish into or out of the sampling area.

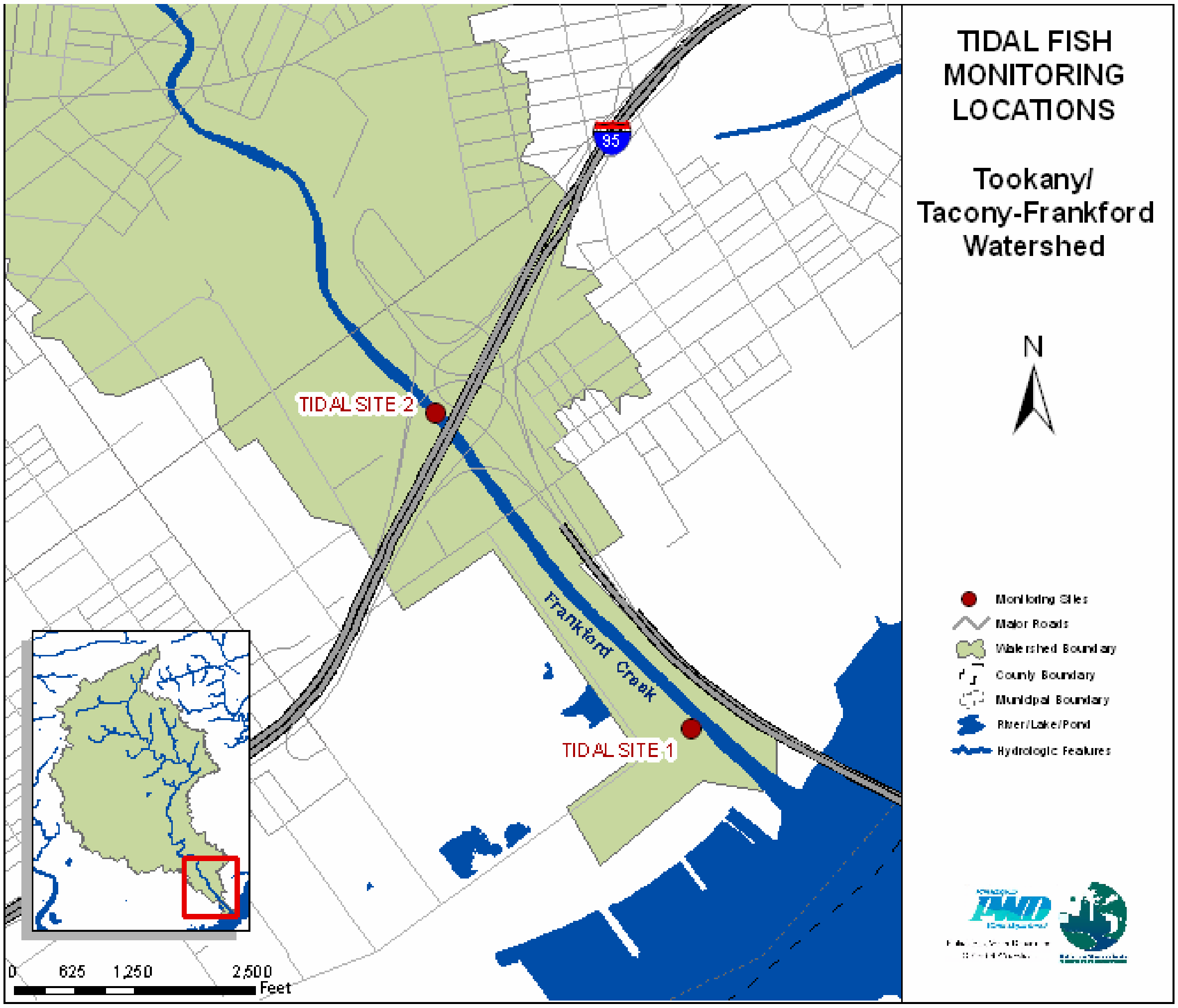


Figure 3.6 Tidal Fish Monitoring Sites in Frankford Creek, 2004

3.6.3 Sample Processing

Fish were identified to species, weighed (± 0.01 g) with a digital scale (Model Ohaus Scout II) and measured to the nearest 0.1 cm using a Wildco fish measuring board. Large fish that exceeded the digital scale's capacity were weighed using spring scales (Pesola). Any external deformations, lesions, tumors, cysts, or disease were noted during processing. Species that could not be identified in the field (*e.g.*, small or juvenile cyprinids) were preserved with 10% formalin solution and stored in polyethylene bottles for laboratory identification.

To facilitate the process of acquiring total fish biomass and to reduce field time, a simple linear regression was developed between weight (g) and length (cm). Approximately 20 individuals of each species were weighed, and total lengths were measured. Once 20 individuals of each species were measured (both weight and length), biomass (g) for each fish was calculated using the regression analysis. Similar procedures were conducted at the reference locations (*i.e.*, French Creek and Rock Run) to obtain a discrete measure of the condition of the fish assemblages at each assessment location.

3.6.4 Fish IBI Metrics:

The health of fish communities in Tookany/Tacony-Frankford Watershed was assessed based on the technical framework of the Index of Biological Integrity (IBI) developed by Karr (1981). The analysis entailed the definition of "ecoregional-specific" metrics pertinent to the fish assemblages located in the lower Schuylkill River Drainage. Standardized metrics (*i.e.*, indices) were then integrated to provide an overall indication of the condition of fish assemblages at each assessment location. Individual metrics within the fish IBI framework were also used to provide quantitative information regarding a specific attribute of the respective assessment location (*e.g.*, pollution tolerance values). In addition to IBI metrics, other metrics were incorporated into the design to evaluate the overall ecological health of fish assemblages and as a means of comparison of each assessment site. Tables 3-8 and 3-9 describe the various indices and scoring criteria used for the IBI metrics in the Tookany/Tacony-Frankford Watershed. Additional metrics used in the analysis are displayed in Table 3-10.

Table 3-8 Metrics Used to Evaluate the Index of Biological Integrity (IBI) at Representative Sites.*

Metric	Scoring Criteria		
	5	3	1
1. Number Of Native Species	>67%	33-67%	<33%
2. Number Of Benthic Insectivore Species	>67%	33-67%	<33%
3. Number Of Water Column Species	>67%	33-67%	<33%
4. Percent white sucker	<10%	10-25%	>25%
5. Number Of Sensitive Species	>67%	33-67%	<33%
6. Percent Generalists	<20%	20-45%	>45%
7. Percent Insectivores	>45%	20-45%	<20%
8. Percent Top Carnivores	>5%	1-5%	<1%
9. Proportion of diseased/anomalies	<1%	1-5%	>5%
10. Percent Dominant Species[a]	<40%	40-55%	>55%

* Metrics used are based on modifications as described in Barbour, *et al*., 1999.

[a] Metric based on USGS NAWQA study (2002).

Table 3-9 Index of Biological Integrity (IBI) Score Interpretation.*

IBI	Integrity Class	Characteristics
45-50	Excellent	Comparable to pristine conditions, exceptional assemblage of species
37-44	Good	Decreased species richness, intolerant species in particular
29-36	Fair	Intolerant and sensitive species absent; skewed trophic structure
10-28	Poor	Top carnivores absent or rare; omnivores and tolerant species dominant
<10	Very Poor	Few species and individuals present; tolerant species dominant; diseased fish frequent

* IBI score interpretation based on Halliwell, *et al*., 1999.

Table 3-10 Additional Metrics Used to Evaluate Fish Assemblage Condition

Metric	Assessment Type
Species Diversity	Shannon (H') Diversity Index
Trophic Composition	Percentage of Functional Feeding Groups
Tolerance Designations	Percentage of Pollution Tolerant, Moderate And Intolerant Species
Modified Index Of Well-Being	MIwb Index

3.6.5 Species Diversity:

Species diversity, a characteristic unique to the community level of biological organization, is an expression of community structure (Brower *et al.*, 1990). In general, high species diversity indicates a highly complex community. Thus, population interactions involving energy transfer (*e.g.*, food webs), predation, competition and niche distribution are more complex and varied in a community of high species diversity. In addition, many ecologists support species diversity as a measure of community stability (*i.e.*, the ability of community structure to be unaffected by, or recover quickly from perturbations). Using the Shannon (H') Diversity Index formula, species diversity was calculated at each sampling location:

$$H' = -\Sigma\, n_i/N * \ln (n_i/N): \qquad \text{(eq. 1)}$$

where n_i is the relative number of the *i*th taxon and N is the total number of all species.

3.6.6 Trophic Composition and Tolerance Designations:

Trophic composition metrics were used to assess the quality of the energy base and trophic dynamics of the fish assemblages (Plafkin *et al.*, 1989). The trophic composition metrics offer a means to evaluate the shift toward more generalized foraging that typically occurs with increased degradation of the physiochemical habitat (Barbour *et al.*, 1999). Pollution tolerance metrics were also used to distinguish low and moderate quality sites by assessing tolerance values of each species identified at the sampling locations. This metric identifies the abundance of tolerant, moderately tolerant and pollution intolerant individuals at the study site. Generally, intolerant species are first to disappear following a disturbance. Species designated as intolerant or sensitive should only represent 5-10% of the community; otherwise the metric becomes less discriminatory. Conversely, study sites with fewer pollution intolerant individuals may represent areas of degraded water quality or physical disturbance. For a more detailed description of metrics used to evaluate the trophic and pollution designations of fish assemblages, see Barbour *et al.*, (1999).

3.6.7 Modified Index of Well-Being (MIwb):

Modified Index of Well-Being (MIwb) is a metric that incorporates two abundance and two diversity measurements. Modifications from the Ohio EPA (1987), which eliminate pollution tolerant species, hybrids and exotic species, were incorporated into the study in order to increase the sensitivity of the index to a wider array of environmental disturbances. MIwb is calculated using the following formula (equation 2):

$$MIwb = 0.5*\ln N + 0.5*\ln B + H_N + H_B \quad \text{(eq. 2)}$$

where;

N = relative numbers of all species
B = relative weight of all species
H_N = Shannon index based on relative numbers
H_B = Shannon index based on relative weight

3.7 Algae Sampling

Between 8/17/2004 and 9/17/2004, replicate algae samples were collected from three (n=3) sites within the Tookany/Tacony-Frankford Watershed (Figure 3-7). Samples were collected on six occasions to determine the biomass of benthic algae in terms of chlorophyll-*a* (chl-*a*), spatial variation in biomass within and between sites, the scouring effects of high flows, and algal accrual rates following a high flow event.

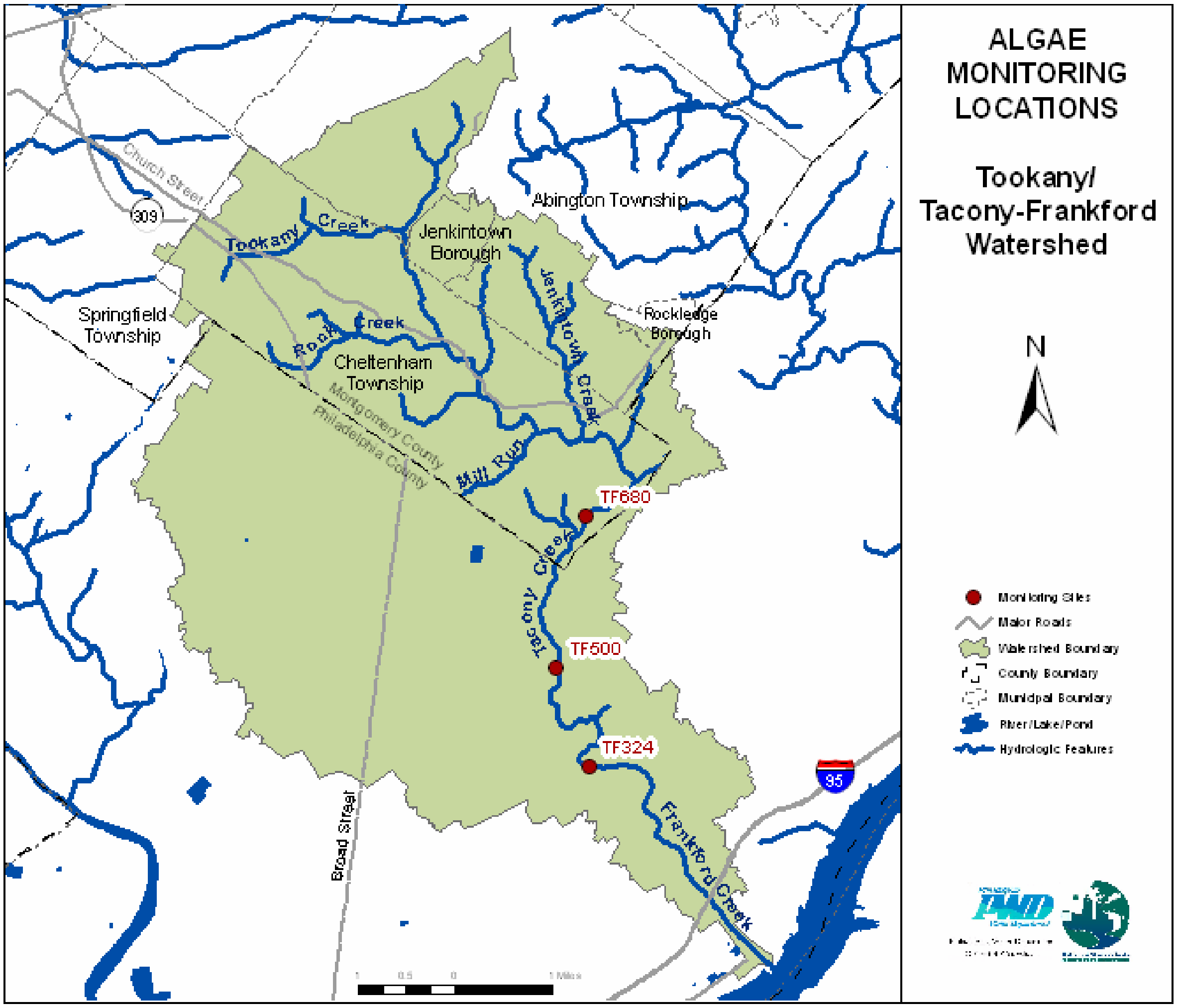


Figure 3-7 Algae Monitoring Locations in the Tookany/Tacony-Frankford Watershed, 2004

3.7.1 Periphyton Collection Procedure

Sampling was conducted on the main channel of the Tookany/Tacony-Frankford Creek at or near stations where continuous water quality parameters (*i.e.*, DO, temperature, pH, conductivity) were recorded. During the course of the study, TF280, TF500, and TF620 were the only stations that had continuously recording sondes. Because of heavy shading and different habitat conditions (*e.g.*, deeper water, slower flow) at TF500 than at TF280 and TF620, sampling focused on the latter two sites. Samples were collected near site TF280 at site TF324 and near site TF620 at site TF680. On one occasion, algal samples were also collected from TF500 (8/19/2004). The total number of samples collected with respect to site and date are shown in Table 3-11.

Table 3-11 Number of Periphyton Samples Collected with Respect to Site and Date from the Tookany/Tacony-Frankford Watershed, 2004

Date	Site	Sampling Program	# samples chl-*a*
8/19/04	TF324	Monitor	8
	TF500	Monitor	5
	TF680	Monitor	8
8/23/04	TF324	Monitor	5
	TF680	Monitor	5
8/26/04	TF324	Monitor	5
	TF680	Monitor	5
9/8/04	TF324	Monitor	0
	TF680	Monitor	4
	TF680	Scour	4
9/13/04	TF324	Monitor	4
	TF324	Scour	4
	TF680	Monitor	4
	TF680	Scour	4
9/17/04	TF324	Monitor	4
	TF324	Scour	4
	TF680	Monitor	4
	TF680	Scour	4

Because we were interested in determining how algal biomass was reduced following scouring by a high flow event, we attempted to collect initial algal samples near a predicted rain event, and additional algal samples following the rain event. However, during the sampling period, a rain event adequate to cause scouring did not occur. Because we were concerned that seasonal changes in biomass would occur before a sufficient scouring event did, we artificially simulated effects of a high flow event by removing algae from approximately 50 rocks at TF324 and TF680 and placing them back in the stream. Algal material was removed by scrubbing the rocks with plastic scouring pads. Algal material was sampled at TF680 on the same date for "pre-scour" data. "Pre-scour" samples could not be collected at TF324 because of elevated stream levels from a brief rain event. Subsequent "post-scour" samples were collected from both TF324 and TF680 on 9/13/2004 (Day 5) and 9/17/2004 (Day 9). Scoured substrates on day 0 were presumed to have chl-*a* concentrations less than 5 mg/m^2 and daily accrual rates for each site determined by dividing the net gain or loss of algae by time (days).

All samples were collected using the same methods. Composite algal samples (2-6 rocks) were collected from randomly selected rocks by brushing and scraping using toothbrushes and scalpels or other scraping tools. Material from each composite sample was placed in a separate container, labeled, and placed on ice in darkened containers until arrival at the laboratory. Composite algal samples were collected rather than individual rocks because when algal biomass is low or coverage is heterogeneous, sampling at the rock scale can artificially increase within-site variation and reduce the power of the data collected. To ensure adequate algal biomass and reduce within-site variation, all replicate algal samples were a composite of material from 2-6 rocks.

The area sampled was determined by wrapping the sampled area in aluminum foil. The 3-dimensional foil mold was carefully removed from the rock and cut with scissors so the foil lay as flat as possible. The area of the foil was then digitized using Scion Image (Beta 4.0.2), a windows version of NIH Image for the Macintosh, to calculate surface area.

In addition to algal biomass samples, samples were collected for quantitative taxonomic analysis. Composite samples were collected in the same manner as biomass samples and algal material removed by brushing and scraping. Algal material for each sample was placed in a separate container and preserved in 5-10% formalin for taxonomic identification of soft algae and diatoms. These samples will be analyzed by the Phycology Section at the Academy of Natural Sciences, but data will not be presented in this report.

3.7.2 Laboratory Procedures

Composite algal samples were processed by homogenizing the sample in a blender. The sample was measured in a graduated cylinder and the total volume brought to 1 L with deionized water. A 15 mL sub-sample for chl-*a* analyses was filtered through a 47 mm glass fiber filter (Whatman, 0.7-µm nominal pore size). For a subset of samples, an algal sub-sample was filtered through a weighed, pre-combusted glass fiber filter to determine percent solids and percent organic matter. Filters for both measures were stored frozen.

Algal samples were analyzed for chl-*a* according to Standard Methods for fluorometry (APAH 1992). Percent solids and percent organic matter were determined by drying the filters to a constant weight at 105ºC for 24 h (mass of solids) and burning the sample in a muffle oven at 550ºC for 1 h (APAH 1992). However, laboratory errors resulted in questionable AFDM data and these data are not reported.

3.7.3 Data Analyses

Spatial and temporal variation in algal biomass was examined using ANOVA (SYSTAT 10.2.01, 2002). Two-factor ANOVA was used to examine differences in chl-*a* with respect to site and sampling date for the general monitoring program. Because samples were only collected at TF500 on one occasion, these data were not included in the analyses. A three-factor ANOVA identified differences in chl-*a* between "scoured" and natural rocks with respect to site and date.

3.8 Habitat Assessment

3.8.1 EPA Habitat Assessment

Prior to benthic macroinvertebrate sampling procedures, habitat assessments at twelve (n=12) sites (Figure 3-5) were completed based on the Environmental Protection Agency's *Rapid Bioassessment Protocols for Use in Wadeable Streams and Rivers* (Barbour *et al*., 1999). Reference conditions were used to normalize the assessment to the "best attainable" situation. Habitat parameters are separated into three principal categories: (1) primary, (2) secondary, and (3) tertiary parameters. Primary parameters are those that characterize the stream "microscale" habitat and have greatest direct influence on the structure of indigenous communities. Secondary parameters measure "macroscale" habitat such as channel morphology characteristics. Tertiary parameters evaluate riparian and bank structure and comprise three categories: (1) bank vegetative protection, (2) grazing or other disruptive pressure, and (3) riparian vegetative zone width. Table 3-12 lists the various parameters addressed during habitat assessments.

Table 3-12 Habitat assessment criteria used at benthic monitoring stations.

Condition/Parameter	Condition			
	Optimal	**Suboptimal**	**Marginal**	**Poor**
Epifaunal Substrate/Available Cover	16-20	11-15	6-10	0-5
Pool Substrate Characterization	16-20	11-15	6-10	0-5
Pool Variability	16-20	11-15	6-10	0-5
Sediment Deposition	16-20	11-15	6-10	0-5
Embeddedness	16-20	11-15	6-10	0-5
Velocity/Depth Regime	16-20	11-15	6-10	0-5
Frequency of Riffles (or bends)	16-20	11-15	6-10	0-5
Channel Flow Status	16-20	11-15	6-10	0-5
Channel Alteration	16-20	11-15	6-10	0-5
Channel Sinuosity	16-20	11-15	6-10	0-5
Bank Stability*	9-10	6-8	3-5	0-2
Vegetative Protection*	9-10	6-8	3-5	0-2
Riparian Vegetative Zone Width*	9-10	6-8	3-5	0-2

*Both right and left banks are assessed separately.

3.8.2 Habitat Suitability Index (HSI) Model Methods

3.8.2.1 Model History and Assumptions

Prior to the development of Instream Flow Incremental Methodology (IFIM), a number of Habitat Suitability Index (HSI) models were developed by the U.S. Fish and Wildlife Service (USFWS). Based on empirical data and supported by years of research and comprehensive review of scientific literature, these models present numerical relationships between various habitat parameters and biological resources, particularly gamefish species and species of special environmental concern. Through evaluation of various input parameters, models arrive at a final index value between 0 and 1, a score of 1 corresponding to the ideal habitat condition, and zero indicating that some aspect of the habitat is unsuitable for supporting a naturally reproducing population of the species of interest.

Numerous assumptions are inherent with use and interpretation of the models. First and foremost is the assumption that habitat features alone are responsible for determining abundance or biomass of the species of interest at the study site. Clearly, no species exists in a vacuum; aside from habitat variables, other ecological and environmental interactions can strongly influence biological communities. HSI indices assume that users will use good professional judgment, consult with regional experts when necessary, and consider the possible effects of other factors (*e.g.*, competition, predation, toxic substances and other anthropogenic factors) when interpreting model output.

3.8.2.2 Model Data Requirements

Most types of data required by HSI models were available for all sites within Tookany/Tacony-Frankford Watershed. However, a number of habitat parameters were not directly measured in a fashion best suited for use with HSI models and required additional interpretation or normalization. Few water quality parameters were measured with equal sampling effort across all sites; some parameters were measured with continuous monitoring instruments at some sites and grab samples or hand-held meters at other sites. Some variables were not directly measured at some sites. To facilitate HSI analysis at these sites, (conservative) values were substituted based on sampling conducted at nearby sites and reference sites in neighboring watersheds. Turbidity data were excluded from the analyses entirely because all HSI were developed using Jackson Turbidity Units (JTU), which cannot be converted to/from modern Nephelometric Turbidity Unit (NTU) data. Any other significant modifications to the variables or the modeling approach are explained in Section 5.3.5 (Habitat Suitability Indices). A list of all HSI input variables for the seven HSI models applied to Tookany/Tacony-Frankford Watershed appears in Table 3-13.

Table 3-13 Habitat Suitability Index (HSI) variable matrix.

HSI Model Variable Matrix	Variable Type	Blacknose Dace	Common shiner	Creek Chub	Fallfish	Longnose Dace	Redbreast Sunfish	Smallmouth Bass
Total number of HSI variables		**16***	**9**	**20**	**6**	**6**	**10**	**13***
Average Temperature during growing season (May-Oct.)	**temperature**	X						X
Average Temperature in spawning season**		X	X		X		X	X
Maximum temperature sustained for 1 week			X			X	X	
Average Summer Temperature (Jul-Sep)				X	X			
Average temperature during spring (May-Jun)				X				
Average Turbidity (JTU)***	**water quality**	X	X	X	X		X	X
Average yearly pH value			X					X
Least suitable pH value (instantaneous)							X	
pH fluctuation classification				X				
Minimum dissolved oxygen concentration				X			X	X
Minimum dissolved oxygen conc. During spring				X				
Percent instream cover during average summer flow	**general stream characteristics**			X		X	X	X
Instream cover classification					X			
Percent shading of stream between 1000 and 1500 hrs.		X		X				
Percent vegetative cover							X	
Availability of thermal refugia (winter) (Y/N)				X				
Stream gradient (m/Km)		X		X				X
Average stream velocity during average summer flow				X		X		
Dominant substrate characterization					X		X	
Stream width		X		X			X	
Mode of stream depth during average summer flow					X			
Water level fluctuations								X
Stream margin substrate characterization (Y/N)		X						
Average velocity along stream margins		X		X				
Stream margin vegetation characterization				X				
Substrate food production potential				X				
Percent riffles	**riffles**					X		
Riffle substrate characterization		X	X	X		X		
Average velocity in riffles		X	X	X				
Average depth of riffles		X						
Average maximum depth of riffles						X		
Percent pools	**pools**	X	X	X			X	X
Pool substrate characterization		X						X
Pool classification			X	X				
Average depth of pools				X				X
Average velocity at 0.6 depth in pools		X	X					

* Some variables used more than once, applied to different life stages
**Spawning season varies by species. Common Shiner and Fallfish use a Y/N index.
*** Turbidity relationships developed using Jackson candle units; cannot be converted to NTU values

3.8.2.3 Suitability Index Expressions

HSI models use three major types of Suitability Index (SI) expressions or mathematical relationships to compute the suitability of a given habitat variable; they are (in increasing order of complexity): 1) categorized relationships, 2) linear equations (or more commonly, series of linear equations bounded by inflection points), and 3) suitability curves. Categorized relationships are used for a limited number of HSI variables in which the relationship between the habitat feature and suitability for the species of interest is fairly simple. Substrate size categorization is one example; many HSI models use dominant substrate type categories (*e.g.*, silt, sand, gravel, cobble, boulder, bedrock). Other SI variables that may be defined by simple categorization are temperature, dissolved oxygen, pH or, or in some cases, the variability of these measurements (Figure 3-8). Categorized data were processed directly within Microsoft Excel spreadsheet HSI models.

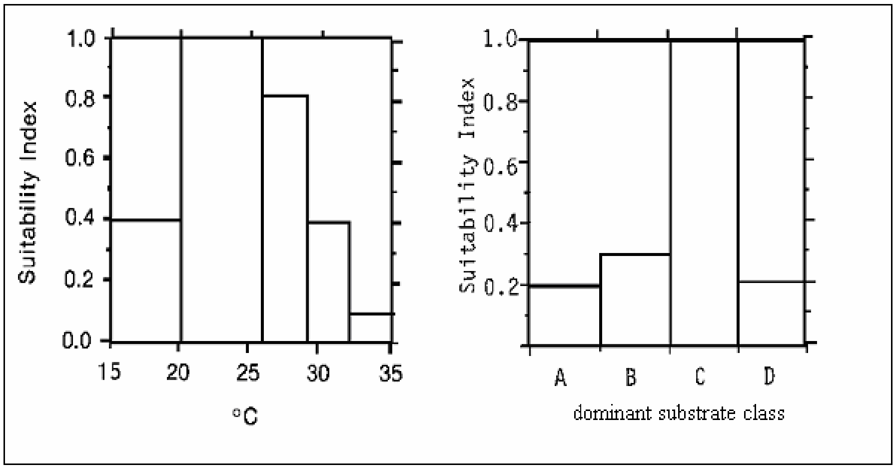


Figure 3-8 Categorized expressions in HSI models.

Many SI variables are defined by a series of linear relationships bounded by inflection points (*i.e.*, a collection of linear relationships that roughly approximate a curve). Many of these relationships include a range of unsuitable (SI=0) values, a range of ideal (SI =1.0) values, or both. Although all types of SI variables were, in some cases, defined by series of linear relationships (Figure 3-9), these expressions were less likely to be employed as models increased in complexity. As models become more complex, there is a corresponding increased focus on development of SI curves. SI variables defined by linear relationships were processed using linear equations and Boolean commands directly in Excel spreadsheet models.

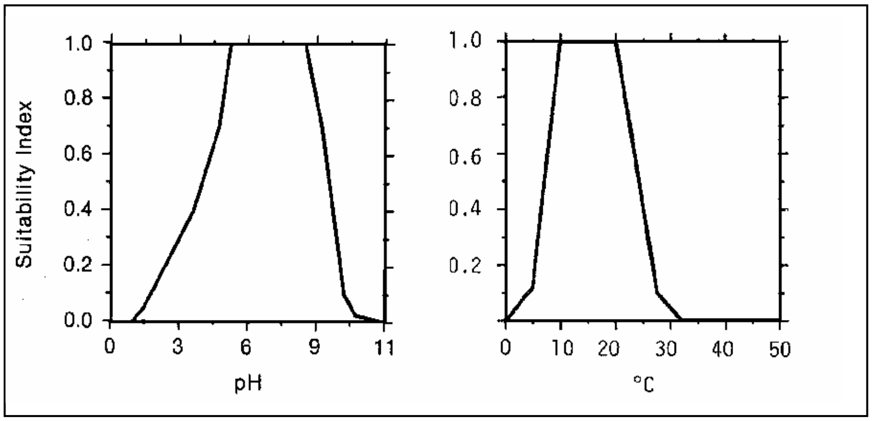


Figure 3-9 Linear expressions in HSI models.

SI curve relationships are considered the most precise and continuous of SI relationships, and therefore, appear more frequently in more complex HSI models. For example, curves allow models to accurately represent the non-linear, sub-asymptotic change in SI expected as a habitat variable approaches complete unsuitability or ideal suitability (SI score 0 or 1 respectively). Two general SI curve shapes were common, modified parabolae and "s-curves", though there was considerable variation in actual curve shape between different SI variables (Figure 3-10). As curve equations were not provided with HSI model documentation, lookup tables were generated by scanning curves with data extraction software (Data Thief). Subsequent data processing was handled in Excel.

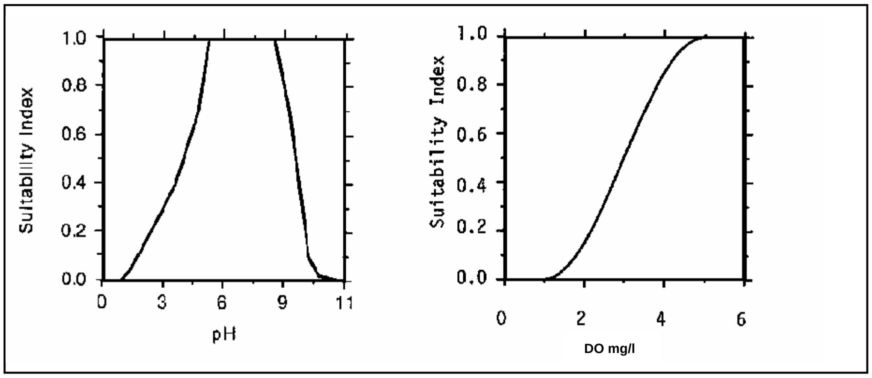


Figure 3-10 Curve relationships in HSI models.

3.8.2.4 Model Evaluation

HSI model output for each site was compared to EPA habitat data results. With the exception of longnose dace, smallmouth bass and fallfish HSI data, HSI model output was compared to observed fish abundance and biomass with correlation analyses. Several habitat models likely require modification in order to be useful in guiding or evaluating stream habitat improvement activities. While time constraints precluded the modification of models to better suit Tookany/Tacony-Frankford Watershed, it is hoped that such modifications will increase the usefulness of these models in the future.

3.9 Chemical Assessment

3.9.1 Fixed Interval Chemical Sampling

Bureau of Laboratory Services staff collected surface water grab samples at eight (n=8) locations within Tookany/Tacony-Frankford Watershed for chemical and microbial analysis (Figure 3-11). Samples from sites TF620 and TF680 were combined for analysis and considered TF620. Sampling events were planned to occur at each site at weekly intervals for one month during three separate seasons. Actual sampling dates were as follows: "winter" samples collected 1/15/04, 1/22/04, 1/29/04, and 2/5/04; “spring” samples collected 4/21/04, 4/29/04, 5/6/04, and 5/13/04; “summer” samples collected 8/5/04, 8/12/04, 8/19/04 and 8/26/04. A total of 96 discrete samples, comprising 3552 chemical and microbial analytes, were collected and recorded during the 2004 assessment of the Tookany/Tacony-Frankford Watershed. To add statistical power, additional discrete water quality samples from PWD's wet-weather chemical sampling program were included in analyses when appropriate. Sites TF280, TF500, TF620, TF760, TF975, TF1120 and TFJ110 were included in PWD's baseline chemical assessment of Tookany/Tacony-Frankford

Watershed in 2000. A single new site (TFM006), located on Mill Run and the Tacony Creek confluence was added for 2004.

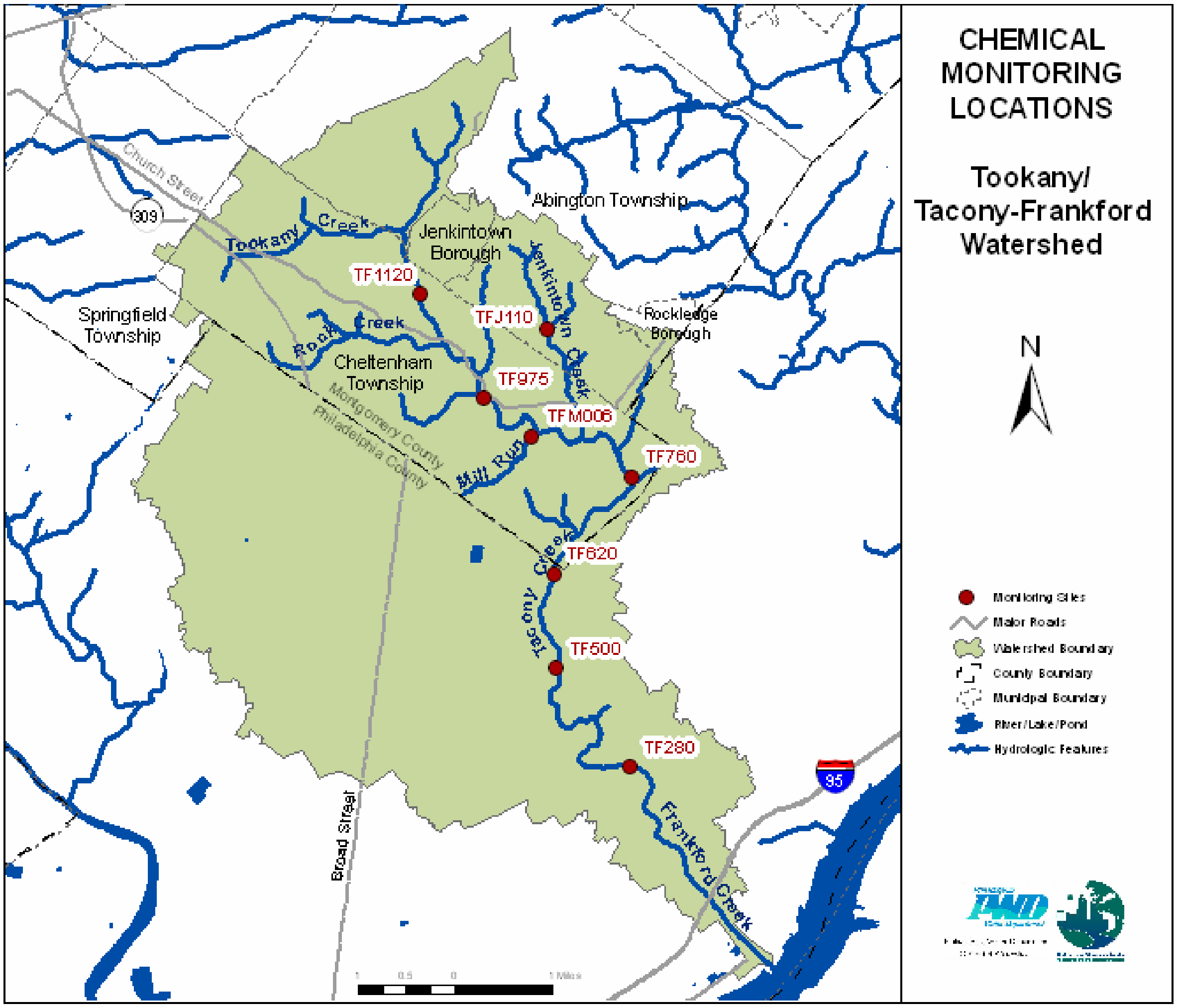


Figure 3-11 Fixed Interval Chemical Sampling Locations in the Tookany/Tacony-Frankford Watershed, 2004

Discrete sampling was conducted on a weekly basis and was not specifically designed to target wet or dry weather flow conditions. Depending on which definition of "dry weather" was used (*i.e.*, 48 hr interval or 72 hr interval), between 6-7 sampling events occurred during dry weather- this data is most pertinent to Target A of the Watershed Management Plan (Dry Weather Water Quality and Aesthetics). Specifically addressed are indicators 7 and 8 – chemical and microbial constituents that are influential in shaping communities of aquatic systems or that are indicative of anthropogenic degradation of water quality in the watershed.

3.9.2 Wet-Weather Targeted Sampling

Target C of the Watershed Management Plan addresses water quality in wet weather. Yet characterization of water quality at several widely spatially distributed sites simultaneously over the course of a storm event presents a unique challenge. Automated samplers (Isco, Inc.) were used to collect samples during nine runoff producing rain events in 2003 and 2004. Seven events took place in 2003 on 10/14/03, 5/2/03, 5/5/03, 5/7/03, 5/15/03, 7/10/03, and 9/23/03 and were monitored from four locations. Two events took place in 2004 on 7/7/04 and 8/30/04 and were monitored from six locations (Figure 3-12). Samples from sites TF620 and TF680 were combined for analysis and considered TF620.

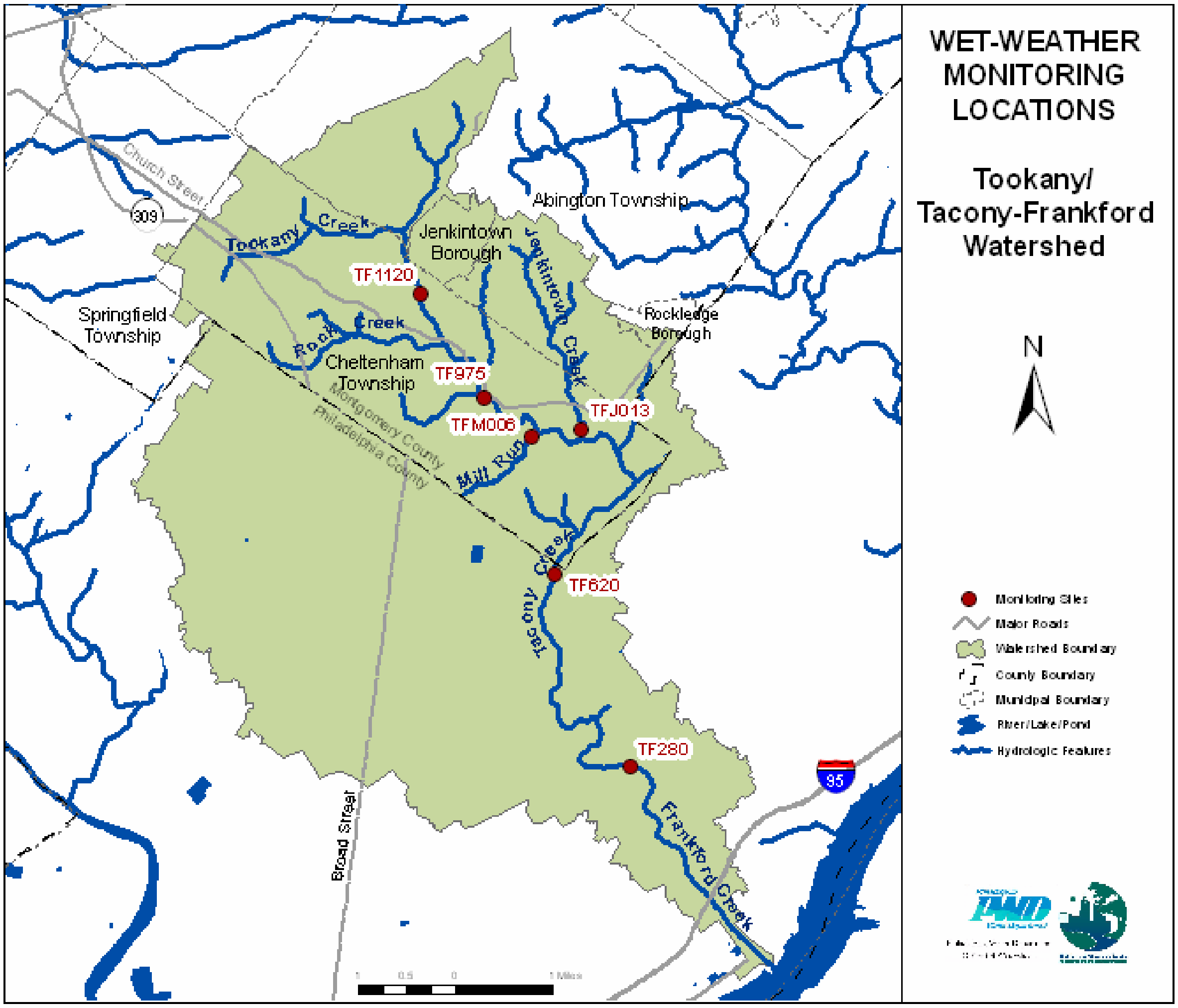


Figure 3-12 Wet Weather Sampling Sites in the Tookany/Tacony-Frankford Watershed, 2004

The automated sampler system obviated the need for BLS team members to manually collect samples, thereby greatly increasing sampling efficiency. Automated samplers were equipped with vented instream pressure transducers that allowed sampling to commence beginning with a small (0.1ft.) increase in stage. Once sampling was initiated, a computer-controlled peristaltic pump and distribution system collected the first 4 grab samples at 20 minute intervals and the remaining samples at 1.5 hr. intervals.

Use of automated samplers allows for a greater range of flexibility in sampling programs, including flow-weighted composite sampling based on a user defined rating curve, but stage discharge rating curves at these sites were poorly defined for larger flows. Though some difficulties were encountered due to a combination of mechanical failure, individual site characteristics, and/or vandalism, the 20 minute and 1.5 hour intervals were found to be generally satisfactory in collecting representative samples over the course of a storm event.

3.9.3 Continuous Water Quality Monitoring

Physicochemical properties of surface waters are known to change over a variety of temporal scales, with broad implications for aquatic life. Several important, state-regulated parameters (*e.g.*, dissolved oxygen, temperature, and pH) may change considerably over a short time interval, and therefore cannot be measured reliably or efficiently with grab samples. Self-contained data logging continuous water quality monitoring Sondes (YSI Inc. Models 6600, 600XLM) were deployed between 3/20/2001 and 10/5/2004 at seven (n=7) sites within Tookany/Tacony-Frankford Watershed in order to collect DO, pH, temperature, conductivity and depth data (Figure 3-13). Samples from sites TF620 and TF680 were combined for analysis and considered TF620. Sondes continuously monitored conditions and discretized the data in 15 min increments.

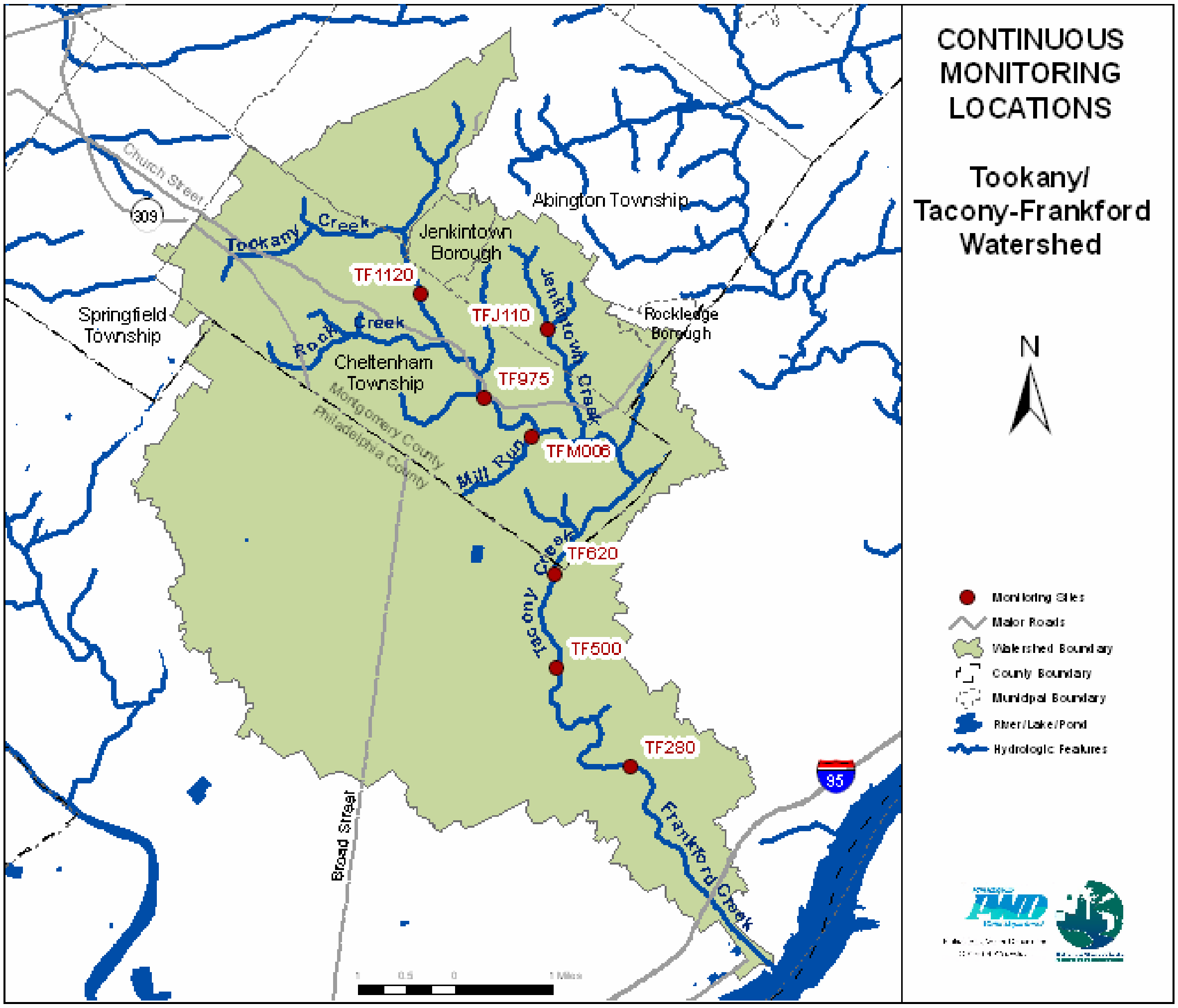


Figure 3-13 Continuous Water Quality Monitoring Sites in Tookany/Tacony-Frankford Watershed, 2004

Extended deployments of continuous water quality monitoring instruments in urban streams present challenges: drastic increases in stream flow and velocity, probe fouling due to accumulation of debris and algae, manpower required for field deployment and maintenance, and the need to guard against theft or vandalism. With refinements to Sonde enclosures and increased attention to cleaning and maintenance, PWD's Bureau of Laboratory Services has made wide-reaching improvements in the quality and recoverability of continuous water quality data, particularly dissolved oxygen (DO) data. Despite improvements, some DO data was rejected (Table 3-14) (See Appendix B). All pH and Temperature data was acceptable.

Table 3-14 Total Sonde hours and rejected DO data.

	2001			
Site	Total Hours Sonde Deployment	Rejected DO Data (hours)	Accepted DO Data (hours)	Percent DO Data Accepted
7th and Cheltenham	286.0	286.0		0.0
TF1120	978.3	560.0	418.3	42.8
TF280	432.5	347.5	85.0	19.7
TF500	307.5	230.3	77.3	25.1
TF620	307.3	229.8	77.5	25.2
TF760	979.3	897.0	82.3	8.4
TF975				
TFJ110				
TFM006				

	2002			
Site	Total Hours Sonde Deployment	Rejected DO Data (hours)	Accepted DO Data (hours)	Percent DO Data Accepted
7th and Cheltenham				
TF1120	808.0	398.0	410.0	50.7
TF280	404.3	228.3	176.0	43.5
TF500	750.8	252.0	498.8	66.4
TF620	1308.0	666.0	642.0	49.1
TF760	720.5	84.5	636.0	88.3
TF975	806.8	311.8	495.0	61.4
TFJ110				
TFM006				

	2003			
Site	Total Hours Sonde Deployment	Rejected DO Data (hours)	Accepted DO Data (hours)	Percent DO Data Accepted
7th and Cheltenham				
TF1120	3015.5	184.5	2831.0	93.9
TF280	4791.3	1620.3	3171.0	66.2
TF500				
TF620	3535.0	185.8	3349.3	94.7
TF760				
TF975	3284.3	384.3	2900.0	88.3
TFJ110				
TFM006				

	2004			
Site	**Total Hours Sonde Deployment**	**Rejected DO Data (hours)**	**Accepted DO Data (hours)**	**Percent DO Data Accepted**
7th and Cheltenham				
TF1120	1962.8	409.7	1553.0	79.1
TF280	5545.3	2344.0	3201.2	57.7
TF500	2278.0	759.5	1518.5	66.7
TF620	4815.5	408.5	4407.0	91.5
TF760				
TF975	2203.5	499.0	1704.5	77.4
TFJ110	2592.0	359.3	2232.8	86.1
TFM006	2541.8		2541.8	100.0

3.9.4 RADAR Rainfall Data and Analysis

Because storm events are inherently variable and do not evenly distribute rainfall spatially or temporally, PWD contracted with Vieux and Associates to obtain discretized measurements of rainfall intensity during storm events targeted by wet weather sampling. For each 15 minute interval, RADAR tower-mounted equipment measured high frequency radio wave reflection in the atmosphere above Tookany/Tacony-Frankford watershed. This information was provided to PWD as a series of relative reflectivity measurements for individual 1km^2 blocks. The resulting grid allowed for the summing of relative rainfall intensity within the sub-shed served by each sampling site over the course of each individual storm event (Figure 3-14). Individual intensity measurements were also graphed and arranged sequentially to produce animated time-series rainfall accumulation graphics. This analysis, combined with data from the PWD rain gauge network and stream stage measurements logged by the automated sampler, allowed for more thorough analysis of water quality data, particularly in determining whether some areas or sub-sheds may have contributed more runoff than others.

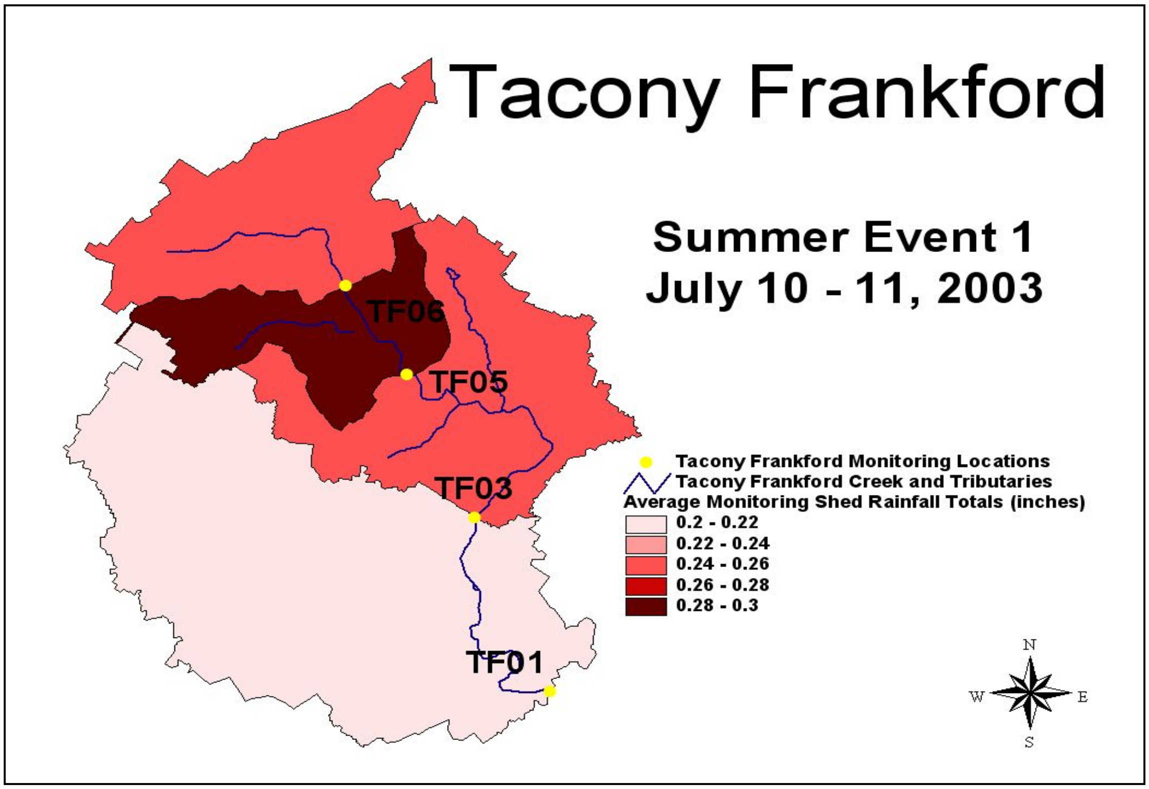


Figure 3-14 RADAR Rainfall Totals by Subshed (7/10/03-7/11/03)

3.10 Fluvial Geomorphological (FGM) Analysis

Between December 2003 and March 2004, Philadelphia Water Department staff conducted FGM analysis on the Tookany/Tacony-Frankford Creek and its tributaries. Analysis was conducted in order to characterize channel morphology, disturbance, stability, and habitat parameters as well as to provide a template for hydrologic and hydraulic modeling and serve as a baseline for assessing channel bank and bed changes.

3.10.1 Watershed Characterization

Philadelphia Water Department staff collected existing information from key stakeholders including existing maps, GIS layers, aerial photographs, studies, and documents. Topographic information, geological maps, soils maps, and aerial photographs were reviewed to identify key features along the stream corridor that may not be apparent in the field. Regional curve data developed for the Northeast was used to determine ranges of hydraulic geometry relationships based on the bankfull discharge. This information was used strictly for field calibration purposes and comparison to actual observations.

3.10.2 Stream Survey

Philadelphia Water Department staff cruised 30 miles of streams within the study area. Cruising consisted of a team of environmental engineers and biologists walking the entire length of Tookany/Tacony-Frankford Creek and its tributaries and characterizing channel morphology, disturbance, stability, and habitat parameters. Philadelphia Water Department staff also performed a qualitative habitat assessment using customized parameters from the *Rapid Steam Assessment Technique* (RSAT, Washington Metropolitan council of Governments) and the *Qualitative Habitat Evaluation Index* (Ohio). Data was recorded on a *Measured Reach Stream Morphology, Channel Stability, and Habitat Evaluation Field Form*. Digital photographs were taken at strategic points throughout the cruised reaches and coded for reference. Base maps were used to mark stream classification boundaries, channel stability zones, and habitat features.

A *Cruised Reach Field Form* and a *Watershed Data Summary Spreadsheet* was completed for each reach. Data from the field forms was entered into a *Watershed Data Summary Spreadsheet.* The spreadsheet was programmed to generate qualitative ratings on bank and bed erosion conditions, shear stresses, channel stability and habitat value.

3.10.3 Stream Cross Sections

Philadelphia Water Department staff surveyed cross sections of Tookany/Tacony-Frankford Creek to characterize the morphological features of the channel, provide a template for hydrologic and hydraulic modeling, and serve as a baseline for assessing channel bank and bed changes (erosion and sediment accretion). Approximately 4 cross sections were surveyed per mile (102 cross sections). Each cross section extended a minimum of 25′ beyond the top of bank on both sides of the stream. Features surveyed included breaks in slope, bankfull stage, water surface and thalweg. A permanent monument (5/8″ reinforcing bar with a color cap) was established on one side of the cross section to mark the location and relative elevation. The approximate location of each cross section was also coded and mapped. Three digital photographs of each cross section were taken (upstream, downstream, and across the stream) to photo-document existing conditions.

Using the elevations established, cross section data was entered into an excel spreadsheet to provide an illustration of the cross section along with defining certain morphological characteristics.

3.10.4 Bank Pins and Scour Chains

Bank pins and scour chains have not been installed in Tookany/Tacony Creek; however they may be installed in the future. Bank pins and scour chains will provide PWD the opportunity to measure stream bank erosion rates and observe streambed degradation/aggradation.

3.10.5 Guiding Principles for Fluvial Geomorphologic Restoration of Tacony Creek

3.10.5.1 Identification Ranking and Analysis of Stream Impacts

A Geographic Information System (GIS) map and associated relational database for the information collected in the field was created. This system was used to assess the geographic distribution of impacted and vulnerable areas. Stream impacts were ranked on a comparative subwatershed basis as to their impacts and relative magnitude of contribution to overall water quality deterioration in the entire watershed. Impacts were ranked by both type of problem and by subwatershed. Rankings are shown in Tables 3-15 and 3-16.

Table 3-15 Ranking for Stability Parameters

Outfall Area (ft^2)	Ranking Value
0	0
0.1 to 5.0	1
5.1 to 10.0	2
10.1 to 15.0	4
15.1 to 20.0	6
20.1 to 30.0	10
30.1 to 40.0	12
40.1 to 50.0	14
50.1 to 60.0	16
60.1 to 80.0	18
80.1 to 100.0	20
100.1 to 120.0	21
120.1 to 140.0	22
140.1 to 160.0	23
160.1 to 180.0	24
>180.1	25

Culverts (% Culverted)	Ranking Value
0	0
0.1 - 5.0	3
5.1 to 10.0	6
10.1 to 15.0	9
15.1 to 20.0	12
21.0 to 40.0	15
40.1 to 60.0	18
>60	20

Channels (% Channelized)	Ranking Value
0	0
0.1 - 5.0	2
5.1 to 10.0	4
10.1 to 15.0	6
15.1 to 20.0	8
21.0 to 40.0	10
40.1 to 60.0	12
>60	15

Infrastructure Pts	Ranking Value
0	0
1 to 5	1
6 to 10	2
11 to 15	3
16 to 20	4
>20	5

Shear Stress	Possible Size Range of Material Moved	Ranking Value
<0.01	0.1-2	1
<0.02	0.2-5	2
<0.2	1-10	3
<1	10-50	3
<2	20-500	7
<10	50-1000	10

Channel Type	Ranking Value
C	0
E	0
B	2
G	3
F	5
D	5

Reach Bed Stability	Ranking Value
Aggrading	4
Degrading	5
Indeterminate	3
Stable	0

Bank Erosion	Value	Ranking Value
Low	10-19.5	1
Moderate	20-29.5	3
High	30-39.5	5

Entrenchment Ratio	Value	Ranking Value
Entrenched	1-1.4	5
Moderately Entrenched	1.41-2.2	3
Slightly Entrenched	>2.2	1

Bed Materials	D50 (mm)	Stability Ranking Value
Silt and Clay	2<	5
Sand	<2 through 12	5
Gravel	12 through 96	3
Cobble	96 through 512	2
Boulder	512 through 4096	1
Bedrock	> 4096	0

Table 3-16 Ranking for Habitat Parameters

Riparian Width	Ranking Value DSL	Ranking Value DSR
<10	5	5
10-25'	3	3
25-100	1	1
>100	0	0

Riparian Composition	Ranking Value DSL	Ranking Value DSR
Paved/Bare Ground	5	5
Yards/Lawn/Pasture	4	4
Vines/Herbaceous/Shrubs	3	3
Modified/Mixed/Broken Forest	1	1
Natural Forest (Multi-Tiered)	0	0

Canopy Cover	Ranking Value DSL	Ranking Value DSR
0-20	5	5
21-40%	4	4
41-60%	3	3
61-80%	1	1
81-100%	0	0

Bed Materials	D50 (mm)	Ranking Value
Silt and Clay	<2	5
Sand	<2 through 12	4
Gravel	12 through 96	2
Cobble	96 through 512	0
Boulder	512 through 4096	1
Bedrock	> 4096	5

Sediment Supply	Ranking Value
Low	1
Moderate	3
High	5

Sinuosity	Ratio	Ranking Value
Low	1-1.2	5
Moderate	1.2-1.4	3
High	>1.4	0

Woody Debris	Ranking Value
Absent	5
Few	3
Moderate	1
Frequent	0

Attachment Sites	Ranking Value
<25% Exposed	0
25-75% Exposed	3
>75% Exposed	5

Section 4
Characterization of Watershed Hydrology

This section examines the components of the hydrologic cycle for the Tookany/Tacony-Frankford Watershed. The hydrologic cycle includes precipitation, evaporation, infiltration into soil, stormwater runoff over the land surface and in the sewer system, surface water flow in streams, and groundwater. The different types of sewer systems that serve the area are discussed in this section because they are an important part of the hydrologic cycle in the urban environment.

4.1 Components of the Urban Hydrologic Cycle

One way to develop an understanding of the hydrologic cycle is to develop a water balance. The balance is an attempt to characterize the flow of water into and out of the system by assigning estimated rates of flow for all of the components of the cycle. It is also important to understand that the natural water cycle components including precipitation, evapotranspiration (ET), infiltration, stream baseflow, and stormwater runoff must be supplemented by the many artificial interventions related to urban water, wastewater, and stormwater systems.

The first step in developing a water balance for the urban hydrologic cycle is to identify the system boundaries and the pathways that allow water to cross those boundaries. For the Tookany/Tacony-Frankford Watershed, the system includes: the land surface within the watershed boundaries, structures and vegetation on the surface, and the subsurface beneath the watershed. Inputs to the system are precipitation and outside sources of potable water. Outflows from the system include streamflow through the system outlet, evaporation and transpiration losses to the atmosphere, and flows of wastewater to the system outlet. In addition, it is possible for subsurface exchanges to occur across the boundary.

Precipitation that falls on the land surface may evaporate, be taken up by plants and be lost through transpiration, or flow directly to a water body over land or through a storm sewer system. Flow in streams consists of stormwater runoff, combined sewer overflow, delayed wet weather inputs through shallow groundwater, and a baseflow component due to the discharge of groundwater to the creek during dry weather and wet weather. A portion of potable water pumped in from outside the watershed enters the sanitary sewer system and is sent to outside treatment plants, and a portion is lost to consumptive uses.

The system inflows and outflows can be split into a number of components. These are shown below as a simple, "input equals output" water balance with the many natural and anthropogenic components of a typical urban water cycle.

Inflows: ***P + OPW + WW/IND Rech + EDR + WW Disch***

Outflows: ***RO + SWW + GWW + EDW + BF + OWD + ET***

where:

P is the average precipitation at the Philadelphia gage,

OPW is the outside potable water brought in,

WW/IND Rech is the wastewater and industrial discharge back to groundwater,

EDR is the estimated domestic recharge from private septic systems,

WW Disch is the discharge of water to creeks from larger wastewater plants or industrial facilities,

RO is the surface water runoff component of precipitation,

SWW is the withdrawal of water from the creek, primarily for public water supply and industrial use,

GWW is the groundwater withdrawal from public water supply or industrial wells,

EDW is the estimated domestic withdrawal of groundwater from private wells,

BF is the median baseflow of streams,

OWD is the discharge of wastewater to outside plant, and

ET is the evaporation and transpiration of water and is used to close the equation. It thus contains the sum of errors of the other terms as well as the estimated ET value.

4.1.1 Precipitation

P + OPW + WW/IND Rech + EDR + WW Disch = RO + SWW+ GWW + EDW + BF + OWD + ET

Precipitation is the primary, natural inflow to the hydrologic system. Precipitation data used to estimate this component are available from the National Oceanography and Atmospheric Administration (NOAA) and from local gauges operated by PWD and other organizations. NOAA's gauge at the Philadelphia International Airport, located in southeastern Philadelphia, has over 100 years of hourly precipitation data covering a period of record from January 3, 1902 through the present. The average annual rainfall in the Philadelphia area based upon the airport gauge is 41 inches. Most months have average precipitation totals of 3-4 inches. The driest season is late fall, and the wettest is late summer when thunderstorms are common (Table 4-1). Average temperatures during the winter months are above the freezing point during the day and below the freezing point at night. Snow and snowmelt events occur, but it is rare for a snow pack to accumulate and last through the season.

Additional precipitation data can be obtained from PWD's network of 24 rain gauges throughout the city; these data are available in 15-minute increments from the early 1990s to the present. Nine of the city gauges are located in or near the Tookany/Tacony-Frankford Watershed, as shown in Section 3, Figure 3-1. Data from these gauges provide precipitation at a higher level of spatial and temporal detail.

Table 4-1 Average Monthly Precipitation, Temperature, and Potential Evaporation

Month	Average Precipitation (in)	Average Temperature High (°F)	Average Temperature Low (°F)	Potential Evaporation (in/month)
January	3.3	39.2	24.4	2.1*
February	2.9	42.1	26.1	2.1*
March	3.6	50.9	33.1	2.1
April	3.4	63	42.6	4.5
May	3.5	73.2	52.9	5.4
June	3.6	81.9	61.7	6.3
July	4.1	86.4	67.5	6.6
August	4.3	84.6	66.2	5.7
September	3.4	77.4	58.6	4.2
October	2.8	66.6	46.9	2.7
November	3.0	55	37.6	2.1
December	3.3	43.5	28.6	2.1*

** estimated*

4.1.2 Outside Potable Water

P + OPW + WW/IND Rech + EDR + WW Disch = RO + SWW+ GWW + EDW + BF + OWD + ET

The watershed is generally supplied with drinking water from sources of water outside the watershed. For the Philadelphia portion of the watershed, water is imported into the watershed through the drinking water distribution system from raw water drawn from the Schuylkill and Delaware Rivers. For the outside communities, most of the water is supplied by Aqua America (formerly Philadelphia Suburban Water Company).

For the Tookany/Tacony-Frankford Watershed, most of this water never leaves the urban infrastructure used to transmit drinking water to and convey wastewater from homes to wastewater treatment plants outside the watershed. In this sense, this component of the watershed water balance is not critical to watershed planning activities.

4.1.3 Wastewater and Industrial Recharge to Groundwater

P + OPW + WW/IND Rech + EDR + WW Disch = RO + SWW+ GWW + EDW + BF + OWD + ET

This component represents water that has been used in homes or industry, has been treated, and is subsequently discharged back to the groundwater, thus making it an "inflow" component. Available data suggest that there are no such discharges within the watershed. For this reason, this component is not included in the table of estimated flows for components of the hydrologic cycle.

4.1.4 Estimated Domestic Recharge

P + OPW + WW/IND Rech + EDR + WW Disch = RO + SWW+ GWW + EDW + BF + OWD + ET

This component represents water that has been used in homes and is subsequently discharged to septic systems. In this way, it represents an inflow component to the groundwater portion of the hydrologic cycle. Although the number of septic tanks within the watershed is hard to accurately quantify; the 1990 census data indicated that about 1075 septic tanks were present in the watershed, 706 of which are within the city of Philadelphia. This number is believed to be a high estimate of the actual number.

Based on this information and an estimate of 50 gallons of sewage per person per day discharged to septic systems, this component represents potential 53,750 gallons per day in the Tookany/Tacony-Frankford Watershed. These flows may also be expressed as approximately 0.03 inches per year for the Tookany/Tacony-Frankford Watershed.

4.1.5 Wastewater Discharges to the Stream

P + OPW + WW/IND Rech + EDR + WW Disch = RO + SWW+ GWW + EDW + BF + OWD + ET

This component represents water that has been used in homes or industry, has been treated, and is subsequently discharged back into the stream, thus making it an "inflow" component. There are believed to be three active industrial point source dischargers and five sites with industrial stormwater permits in the Tookany/Tacony-Frankford Watershed (see Table 9-4). The permit for one facility, Biello Auto Parts Inc., that was once listed as active has expired. This component is assumed to be negligible in comparison to the main inflow components and is not included in the table of estimated flows for components of the hydrologic cycle.

4.1.6 Runoff

P + OPW + WW/IND Rech + EDR + WW Disch = RO + SWW+ GWW + EDW + BF + OWD + ET

Precipitation is the primary natural inflow component of the water cycle. This inflow component generally results in three natural outflow components: evapotranspiration (ET), runoff, and infiltration into the groundwater. Thus runoff is one of the major, natural outflow components to be estimated.

The amount of stormwater runoff depends on a variety of factors, including rainfall intensity, surface ponding of rain, ground slope, and, most importantly, the imperviousness of the ground surface. The amount of impervious cover follows patterns of land use and population density because manmade structures and pavement are the cause of impervious surface. Estimates of imperviousness can be further refined by examining the relative proportion of impervious surfaces on the USGS quadrangles and in aerial photos. Because of the urbanized nature of the watershed, runoff is almost always collected into a sewer system. Depending on the location within the watershed, it can either be discharged through storm sewers or through combined sewers. Therefore, this component is further discussed under the Runoff/Outside Wastewater Discharge component below.

4.1.7 Surface Water Withdrawals

P + OPW + WW/IND Rech + EDR + WW Disch = RO + SWW+ GWW + EDW + BF + OWD + ET

This outflow component represents intakes for water withdrawal for drinking water or industrial use. For the Tookany/Tacony-Frankford Watershed, no permitted withdrawals exist, and this component can be left out of the water balance table.

4.1.8 Groundwater Withdrawals

P + OPW + WW/IND Rech + EDR + WW Disch = RO + SWW+ GWW + EDW + BF + OWD + ET

This outflow component represents groundwater pumping for industrial use or public water supply. There are no public supply or industrial wells of significance in the watershed, and this component can be left out of the water balance table.

4.1.9 Estimated Domestic Withdrawals

P + OPW + WW/IND Rech + EDR + WW Disch = RO + SWW+ GWW + EDW + BF + OWD + ET

The entire watershed is served by a public water supply distribution system. There are no areas where domestic wells form a significant source of supply, and groundwater pumping can be ignored as a significant component of the water balance.

4.1.10 Baseflow

P + OPW + WW/IND Rech + EDR + WW Disch = RO + SWW+ GWW + EDW + BF + OWD + ET

Precipitation results in three natural outflow components: evapotranspiration (ET), runoff, and infiltration into the groundwater. In most shallow groundwater systems, the surface watershed generally corresponds to the recharge and discharge area of the groundwater system. This means that infiltration enters the groundwater aquifer, and flows underground to the stream for eventual discharge as stream baseflow. This allows us to equate infiltration with stream baseflow, making it possible to estimate infiltration through baseflow separation techniques at stream gauges.

In pervious areas, the amount of water that infiltrates the soil, and thus reappears as stream baseflow, depends on soil properties. At the beginning of a storm, when soil pores are usually not saturated, the moisture content of the soil determines the amount of infiltration that can occur. Capillary suction forces caused by surface tension in the pores also affect the infiltration rate. The size, shape, and distribution of soil pores determine the rate at which a soil can transmit flow in both the unsaturated and saturated states. The infiltration rate decreases as soil pores become filled with water during the course of the storm. When the pores become completely saturated, the water transmission rate reaches equilibrium. Sandy soils allow the highest infiltration rates, while soils with high clay content allow very slow infiltration; loams and mixtures of different soil types fall between the two extremes. Table 4-2 lists typical values for saturated hydraulic conductivity, capillary suction, and initial moisture deficit for a range of NRCS soil textures (Handbook of Hydrology, D.R. Maidment, Editor in Chief, McGraw-Hill, Inc., 1993, pp 5.1-5.39.) Soil textures found in the watershed were discussed in Section 1. It is important to remember that in urbanized areas, the original soils have often been disturbed, compacted, or replaced by fill material that may have different hydraulic characteristics from the undisturbed state.

Table 4-2 Typical Hydraulic Properties of Different NRCS Soil Textures

	Saturated Hydraulic Conductivity (in/hr)	Capillary Suction (in)	Initial Moisture Deficit (fraction)
Sand	9.3	2.0	0.35
Loamy Sand	2.4	2.4	0.31
Sandy Loam	0.86	4.3	0.25
Loam	0.52	3.5	0.19
Silt Loam	0.27	6.6	0.17
Sandy Clay Loam	0.12	8.6	0.14
Clay Loam	0.08	8.2	0.15
Silty Clay Loam	0.08	10.8	0.11
Sandy Clay	0.05	9.4	0.091
Silty Clay	0.04	11.5	0.092
Clay	0.02	12.5	0.079

The simplest way to compute infiltration, which is generally difficult to measure and/or model, is to perform baseflow separation on streamflow. In this way, if baseflow is assumed to equal infiltration, then the infiltration component can be directly balanced by the baseflow component. For the Tookany/Tacony Frankford Watershed, this approach results in an annual infiltration/baseflow component ranging from 7.1 to 14.0 inches per year, depending on the gage location within the watershed. Downstream locations on Frankford Creek (1467087 and 1467089) are the most urbanized, and have the lowest baseflow relative to drainage area. Smaller tributaries (Rock Creek, 1467084) are the least impaired and have higher baseflow relative to drainage area. Upstream areas of Tacony Creek (1467086) and Tookany Creek (1467083), as well as Jenkintown Creek (1467085) also have relatively high baseflow relative to drainage area.

4.1.11 Runoff and Outside Wastewater Discharges

P + OPW + WW/IND Rech + EDR + WW Disch = RO + SWW+ GWW + EDW + BF + OWD + ET

Almost the entire watershed is served by sewers. Depending on the area of the watershed, stormwater may enter surface water directly, enter a combined sewer, or enter a separate storm sewer system. Unsewered areas, where runoff flows overland to the stream system, make up approximately 9% of the Tookany/Tacony-Frankford Watershed. These areas are mainly natural areas located along the stream corridor, such as Tacony Creek Park, where storm sewers are not necessary.

Sewered areas within the watershed are served by two types of sewer systems. In areas served by combined sanitary and storm sewers, the sewer system conveys flows to an interceptor sewer and later to a wastewater treatment plant under dry weather conditions. During larger wet weather events, a combined flow regulator structure diverts a portion of the flow to a receiving stream. 47% of the Tookany/Tacony-Frankford Watershed is serviced by combined sewers, all of which is within Philadelphia County. The City of Philadelphia has 31 regulator structures within the watershed, as shown in Figure 4-1. 25 of these structures are instrumented with continuous flow monitors.

Except for park lands, the rest of the watershed area is serviced by separate sanitary and storm sewer systems. In these areas, the storm sewer system conveys most surface runoff directly to a receiving stream. A portion of stormwater, known as infiltration and inflow, enters the sanitary sewer system during wet weather. The occurrence of CSO and the categorization of sampling periods as wet or dry are discussed later in section 4.3.2.

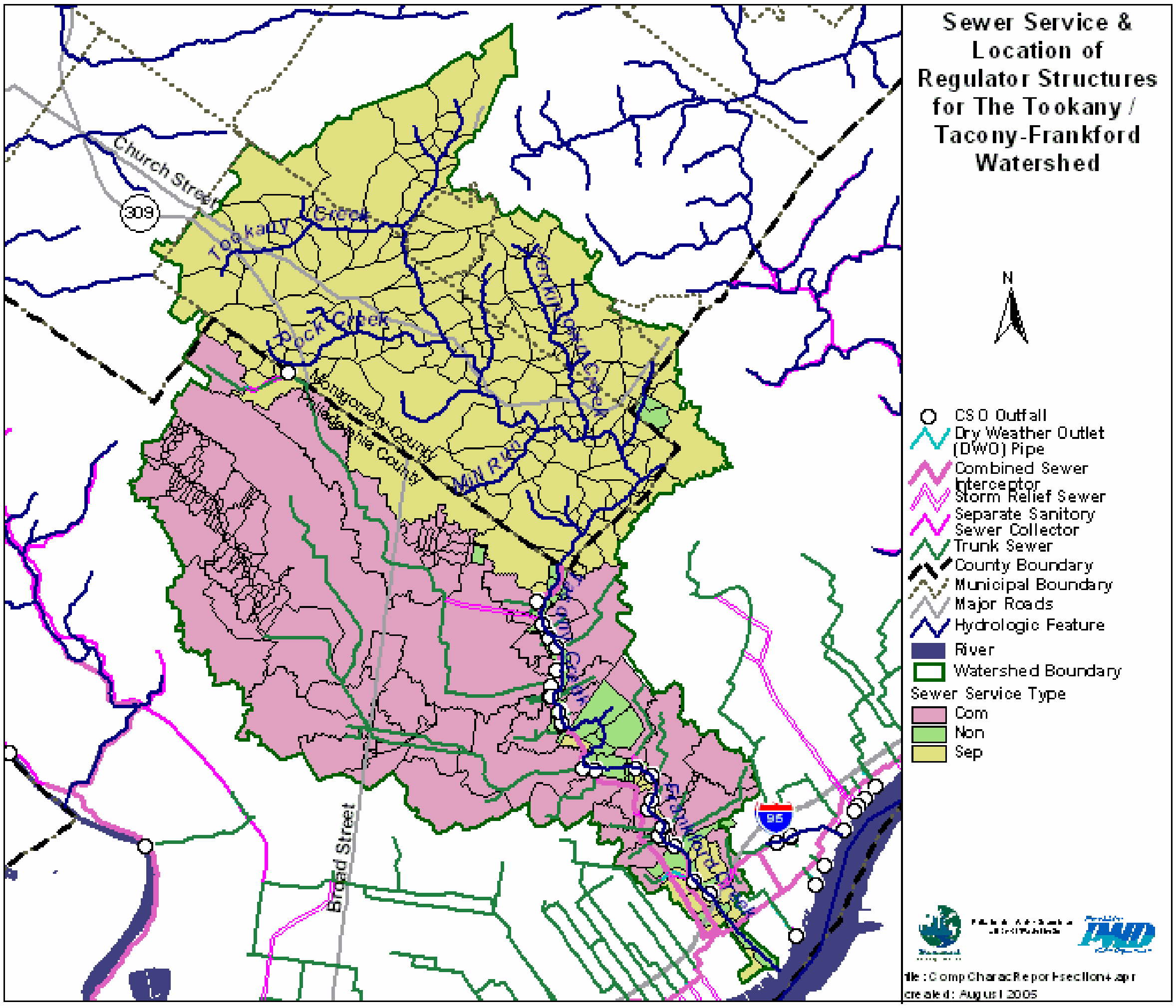


Figure 4-1 Types of Sewer Service and Locations of Regulator Structures

4.1.11 Hydrologic and Hydraulic Modeling

Estimates of the volume, frequency, and duration of combined sewer overflows are based on results from calibrated hydrologic and hydraulic models. Model calibration depends on data from PWD's extensive rainfall gauge network and sewer monitoring program.

The hydraulic and hydrologic model development process focused the greatest detail on the interceptor sewer system, using the USEPA Storm Water Management Model (SWMM)

Extended Transport (EXTRAN) module. The EXTRAN module of SWMM was chosen as the most appropriate tool for the interceptor model. This model is the most widely used and accepted model for interceptor and CSO modeling (Roesner *et al*., 1988). It accurately simulates complex hydraulic conditions that occur in combined sewer interceptors, including unsteady flow, surcharging, branched and looped pipe networks, pumps, orifices, and weirs.

Modeling took place in two tiers or levels of detail. To estimate the treatment rates of the combined sewer regulator structures, or the maximum flow that can pass through the regulator's connector pipe to the interceptor in wet weather, the Tier I sewershed hydrologic representation is in the form of ramp-function hydrographs loaded directly to EXTRAN. Later in the process, the combined sewersheds are modeled in the United States Army Corps of Engineers (USACOE) Storage, Treatment, Overflow, Runoff Model (STORM), providing a more detailed characterization of the hydrologic response of the system with an algorithm for the computation of rainfall excess. STORM thereby provides a wet weather characterization that is useful for assessment of impacts and for planning-level alternatives screening used to establish the direction for detailed facility planning and design.

At the Tier I level, STORM is run in continuous simulation mode using a long-term rainfall record. There is general agreement in the modeling community that single event or design storm simulations are not sufficient for the generation of long-term CSO statistics, including average annual frequency and volume (EPA, 1993). Continuous simulation more thoroughly accounts for antecedent conditions and inter-event conditions within the system. At the Tier II level, sewersheds, interceptors, and regulator structures all are represented in SWMM to support detailed facilities planning and design.

Discharge Monitoring Report and Annual Report Generation

The EXTRAN model is used for the hydraulic characterization of interceptors and regulators to a fine level of detail. The model supports estimates of sewer system overflow characteristics using STORM. This characterization of the combined sewersheds and trunk sewer system is at the correct level of detail for the hydrologic and hydraulic characterization requirements of NPDES permits for CSO and sanitary sewer facilities and for the alternatives analyses required for long term CSO control planning.

Quarterly discharge monitoring reports (DMR's) are required under the NPDES permit system. In addition, the results of the SWMM/NetSTORM model are used to prepare the CSO Annual Report required under Philadelphia's LTCP and Chapter 94 of the Pennsylvania Code. This report details progress on the three phases of the LTCP: implementation of the Nine Minimum Controls, construction of capital projects, and watershed-based planning. The report also summarizes CSO volume, frequency, and capture statistics for the year.

Annual CSO Frequency and Volume Stats

Table 4-3 lists estimated capture percentages for regulator structures in the Tookany/Tacony-Frankford Watershed, based on the modeling results listed in the CSO

Annual Reports. A capture percentage is defined as the percentage of combined sewage (mixed sanitary sewage and stormwater) that is "captured" and sent to a treatment plant during rainfall events over the course of a year. 85% capture is considered to be an ultimate goal for many communities as they implement CSO long term control plans. Based on Table 4-3, capture percentages are generally in the range 40-60% for the Tacony Creek High Level sewer system and 60-80% for the Upper Frankford Creek Low Level sewer system. It is important to note that percent capture for a given year is strongly dependent on the frequency and magnitude of rainfall events during that year. The five years of data listed in Table 4-3 are not sufficient to determine whether an increasing or decreasing trend has taken place. However, as the amount of data increases throughout implementation of the Long Term Control Plan, it will ultimately be possible to evaluate the effectiveness of the control measures.

Table 4-3 Estimated Annual Combined Sewage Capture Percentages

Year	Precipitation (in)	Capture (%) – Lowest and Highest Structure	
		Tacony	Upper Frankford Low Level
2003	46.72	43 - 45	64 - 65
2002	34.11	59 - 64	76 - 79
2001	30.62	51 - 53	70 - 72
2000	43.26	40 - 42	58 - 60
1999	48.6	39 - 40	57 - 59

4.1.12 EvapoTranspiration

P + OPW + WW/IND Rech + EDR + WW Disch = RO + SWW+ GWW + EDW + BF + OWD + ET

Once precipitation reaches the earth's surface, it may take a variety of paths. Typically, a portion enters soil pores through infiltration, a portion returns to the atmosphere through evaporation, and a portion runs off over the land surface (or often into a sewer in urbanized areas). A portion may also be stored temporarily in puddles, in plant parts, through freezing, or in manmade structures designed to detain stormwater; this portion then infiltrates, evaporates, or runs off at a later time.

One of the largest "outflows" of water from the system is evaporation and transpiration. Evapotranspiration includes evaporation, or loss of water to the atmosphere as water vapor, and transpiration, or loss of water to the atmosphere through plants. Evapotranspiration rates depend on temperature, wind speed, solar radiation, type of surface, type and abundance of plant species, and the growing season. Because of these factors, estimated evapotranspiration rates for the Philadelphia region vary seasonally. Neither the Philadelphia Airport nor the Wilmington Airport records evaporation data. One site in New Castle County, Delaware was located which has recorded daily evaporation data from 1956 through 1994. Average daily evaporation rates from this site were developed and are listed in Table 4-4 (City of Philadelphia Combined Sewer Overflow Program: System Hydraulic Characterization).

4.2 Tookany/Tacony-Frankford Watershed Water Cycle Component Tables

The relevant components of the urban water cycle have been estimated for the Tookany/Tacony-Frankford Watershed. Outside Potable Water is assumed to balance Outside Wastewater Discharges, with stormwater and CSOs considered as part of the Runoff component of the water cycle. Table 4-4 shows the results of the analysis, first in inches per year, then in million gallons per day. The inches per year figure simply takes all the flows over an average year, and divides by the area of the watershed. The million gallons per day table takes all the flows over an average year, and divides by 365 days to get an average daily value.

Table 4-4 Water Budget Components

		Inflow		Outflow		
	Period of Record*	P**	EDR	RO	BF	ET+Error
Component (in/yr)	1982 – 2002	42.1	0.085	11.4	7.06	23.7
Component (MGD)	1982 - 2002	66.1	0.134	17.9	11.1	37.3

***Period of Record applies to Runoff and Baseflow.**

****Precipitation uses 100 year rainfall record.**

4.3 Surface Water Characteristics

The above component tables contain values for runoff, ET, and baseflow. These values, however, are complicated by the fact that much of the water is collected in both separate and combined sewers. This section describes, in more detail, the surface water portion of the cycle.

Stormwater runoff ultimately reaches Tookany/Tacony-Frankford Creek and its tributaries through some limited direct surface runoff or through a combined or separate storm sewer. An understanding of the range and frequency of flows, the stage-velocity-discharge relationship, and trends over time is important for a more complete watershed characterization. This information is useful in water quality management, habitat restoration and management, and potable water and flood control applications.

During the USGS/PWD cooperative program in the 1970s, the USGS established streamflow gauging stations at six locations in the Tookany/Tacony-Frankford Watershed. These locations are presented in Section 3, Figure 3-2. Section 3, Table 3-4 contains summary information at each of the gauging stations for their respective periods of record. An historical rating curve is shown in Figure 4-2.

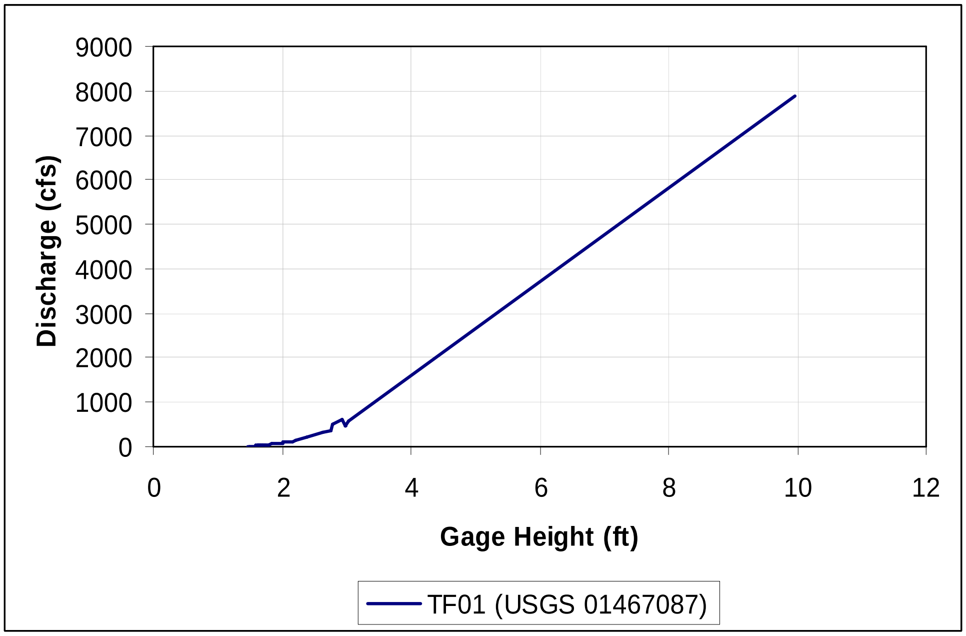


Figure 4-2 Historical Rating Curves for USGS Station 01467087

4.3.1 Evaluation of Total Flow for Trends

Magnitude and Frequency of Flow

Cumulative distribution plots for each of the six gauges listed in Section 3, Table 3-4 are presented in Figure 4-12. A cumulative distribution plot is a plot of discharge versus the percentage of time that a particular flow is not exceeded. These curves are not strictly probability curves because discharge is correlated to successive time intervals and is dependent upon season of the year. However, cumulative distribution plots provide a compact graphical summary of streamflow variability at the different gauging stations.

Trends in Total Flow

Modified Tukey box plots were used to identify seasonal and longer term discharge characteristics for the gauging station at Frankford Creek at Castor Ave. on the Tookany/Tacony-Frankford Creek. Tukey plots display statistical information including median, mean, minimum/maximum values, and selected percentile values as shown in Figure 4-3. Seasonal discharge characteristics are observed for an annual flow cycle using this approach. The discharge plots, discussed above, were used to delineate wet and dry flow regimes. A high flow season earlier in the year and a low flow season occurring later in the year are identified by the peak and trough locations on the plot. Discharges were plotted by weekly time segments, Figures 4-4, monthly in Figure 4-5, annual in, Figures 4-6 and by decade in Figure 4-7. Low flow years in 1985, 1992, and 1999 can be seen on the plots.

Figure 4-7 shows the decade modified Tukey box plots. This plot indicated that although daily flows in the 1980s and 1990s are somewhat lower than flows in the 1970s, the differences are statistically insignificant.

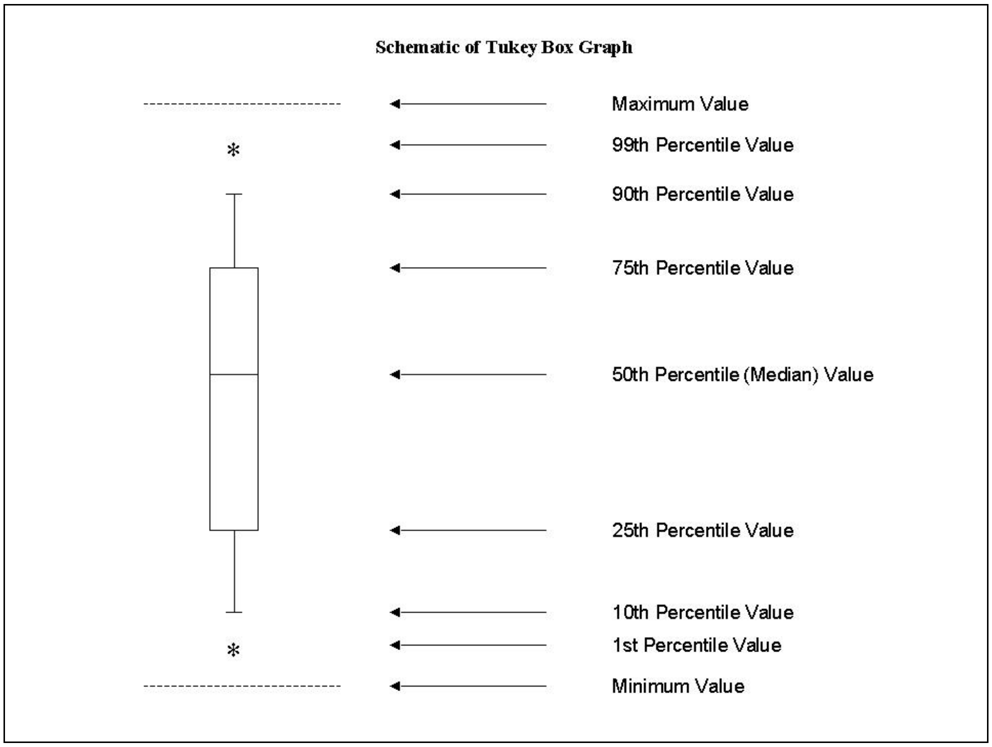


Figure 4-3 Explanation of Modified Tukey Box Plots

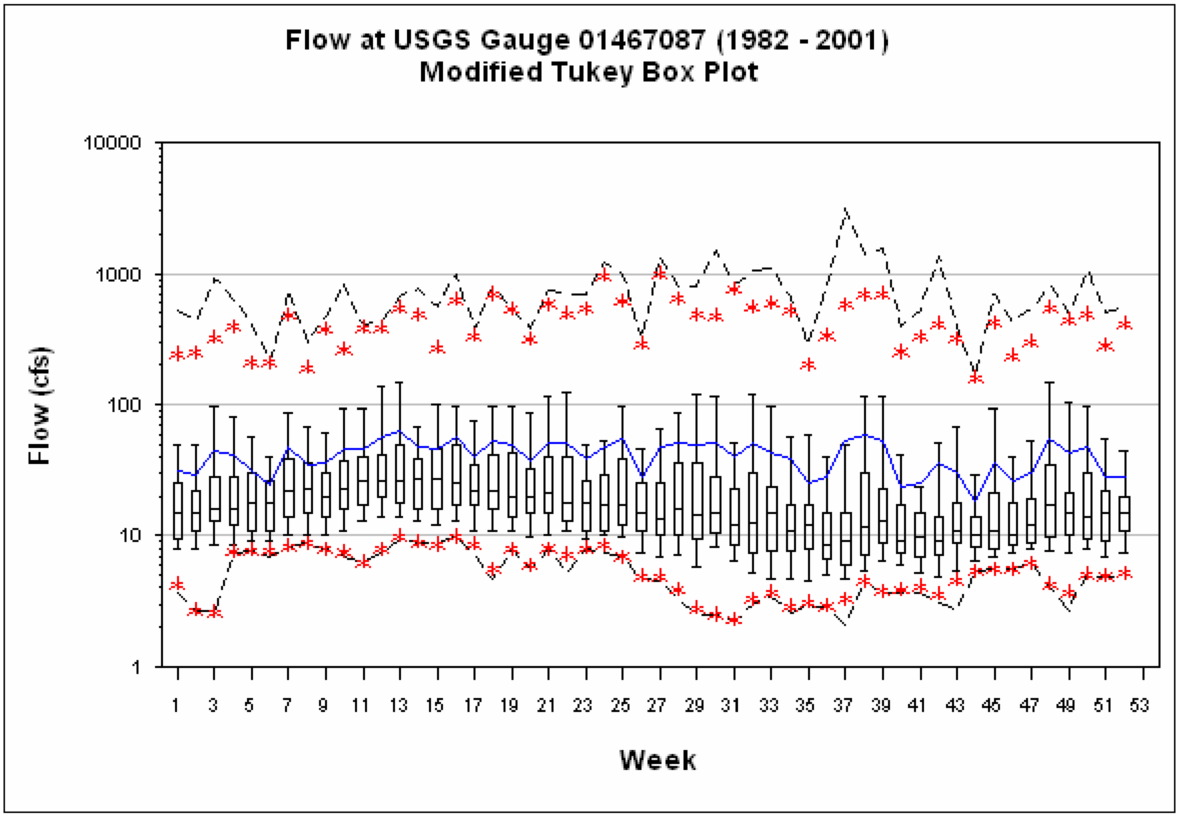


Figure 4-4 Temporal (weekly) trends in flow observed at USGS Gauge 01467087, 1982-2001.

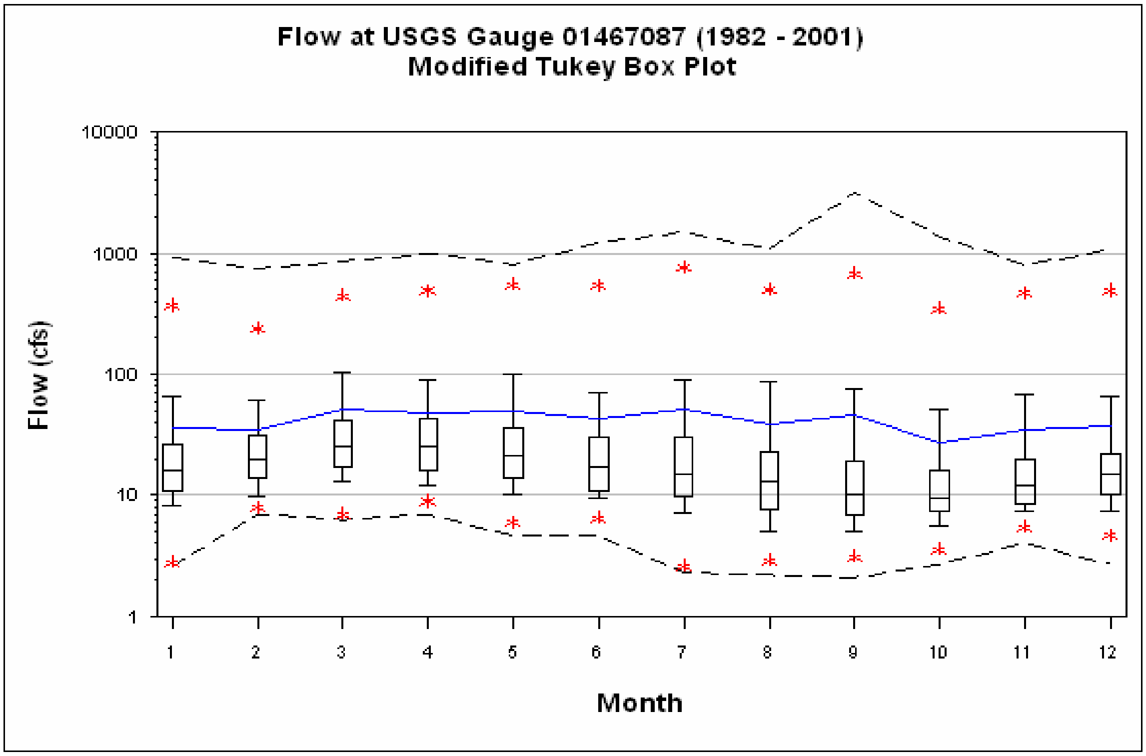


Figure 4-5 Temporal (monthly) trends in flow observed at USGS Gauge 01467087, 1982-2001.

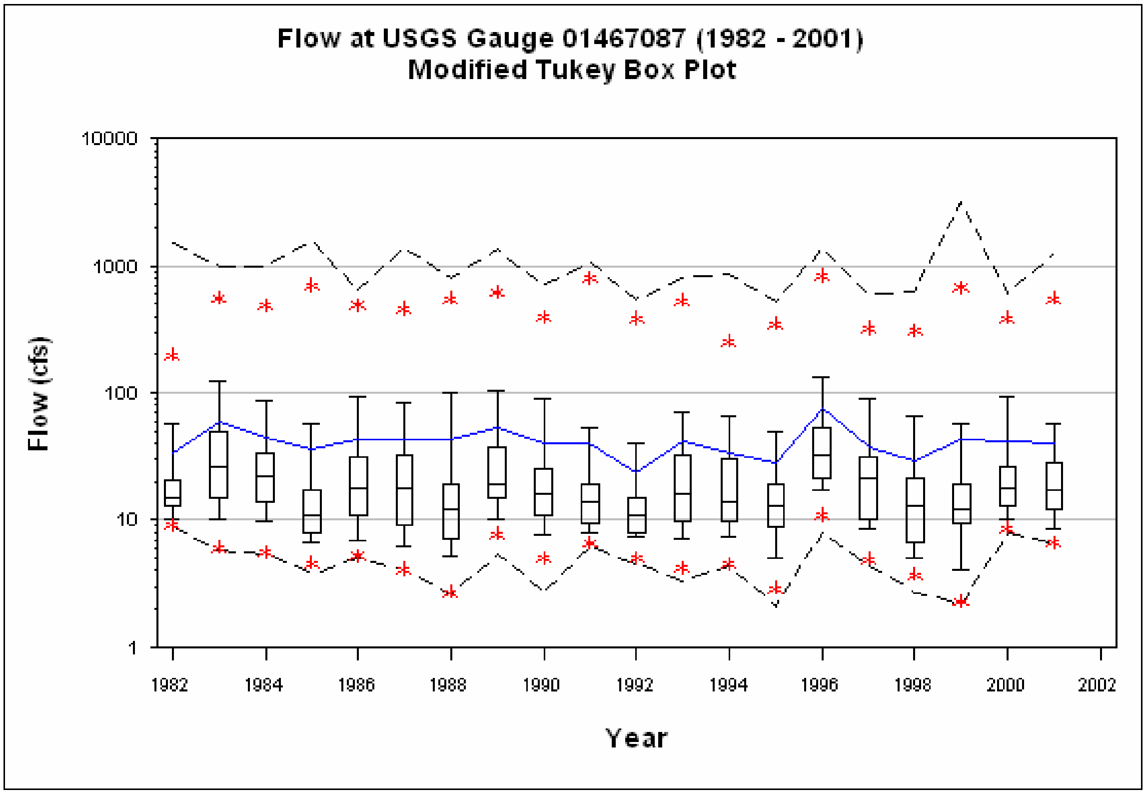


Figure 4-6 Temporal (yearly) trends in flow observed at USGS Gauge 01467087, 1982-2001.

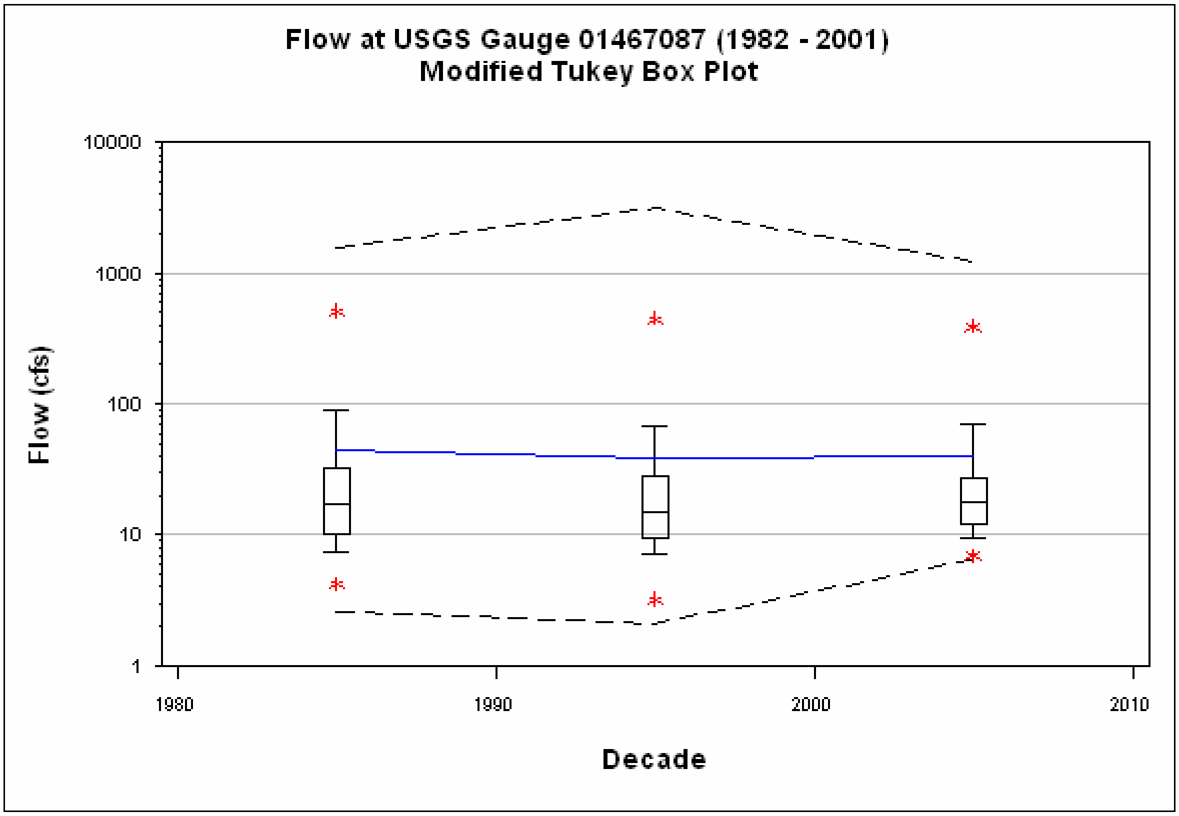


Figure 4-7 Temporal (decadal) trends in flow observed at USGS Gauge 01467087, 1982-2001.

4.3.2 Hydrograph Decomposition Analysis

Areas and Gauges Studied

The Tookany/Tacony-Frankford Watershed is highly urbanized and contains a large proportion of impervious cover. The hydrologic impact of urbanization can be observed through analysis of streamflow data taken from USGS gauges. Table 4-5 lists six gauges with available data, including their locations, periods of record, and drainage areas.

Table 4-5 Data Used for Baseflow Separation

Gauge	Name	Period of Record (yrs)	Drainage Area (sq. mi.)	N (days)	2N* (days)
01467083	Tacony Creek near Jenkintown	6	5.25	1.39	3
01467084	Rock Creek above Curtis Arboretum near Philadelphia	8	1.15	1.03	3
01467085	Jenkintown Creek At Elkins Park	6	1.17	1.03	3
01467086	Tacony Creek at County Line	24	16.6	1.75	3
01467087	Frankford Creek at Castor Ave.	21	30.4	1.98	3
01467089	Frankford Creek at Torresdale Ave.	18	33.8	2.02	5

The interval 2N* used for hydrograph separations is the odd integer between 3 and 11 nearest to 2N. N is calculated based on watershed area.

Baseflow Separation

Baseflow due to groundwater inflow is the main component of most streams in dry weather. Baseflow slowly increases and decreases with the elevation of the shallow aquifer water table. In wet weather, a stormwater runoff component is added to the baseflow. Estimation and comparison of these two components can provide insights into the relationship between land use and hydrology in urbanized and more natural systems.

Baseflow separation was carried out following procedures similar to those found in the USGS "HYSEP" program. The following text is taken from "HYSEP: A COMPUTER PROGRAM FOR STREAMFLOW HYDROGRAPH SEPARATION AND ANALYSIS U.S. GEOLOGICAL SURVEY Water-Resources Investigations Report 96-4040":

"Hydrograph analysis is a useful technique in a variety of water-resource investigations. Separation of streamflow hydrographs into base-flow and surface-runoff components is used to estimate the ground-water contribution to streamflow. Hydrograph-separation techniques also have been used to quantify the ground-water component of hydrologic budgets and to aid in the estimation of recharge rates. In addition, base-flow characteristics determined by hydrograph separation of hydrographs from streams draining different geologic terrains have been used to show the effect of geology on base flow (Sloto *et al*, 1991, p. 29-33).

"The HYSEP program uses three methods to separate the base-flow and surface-runoff components of a streamflow hydrograph—fixed interval, sliding interval, and local minimum. These methods can be described conceptually as three different algorithms to systematically draw connecting lines between the low points of the streamflow hydrograph. The sequence of these connecting lines defines the base-flow hydrograph. The techniques were developed by Pettyjohn and Henning (1979). Hydrograph separations were performed for the streamflow-measurement station French Creek near Phoenixville, Pa., using three methods. Each method is described below.

The duration of surface runoff is estimated using the empirically-defined relation:

$$N=A^{0.2}$$

where N is the number of days after which surface runoff ceases, and A is the drainage area in square miles (Linsley et al. 1982).

"The interval 2N* used for hydrograph separations is the odd integer between 3 and 11 nearest to 2N (Pettyjohn & Henning 1979). For example, the drainage area at the streamflow-measurement station French Creek near Phoenixville, Pa. (USGS station number 01472157), is 59.1 mi2. The interval 2N* is equal to 5, which is the nearest odd integer to 2N, where N is equal to 2.26. The N and 2N* values used for the six gauges in this analysis were listed in Table 4-5.

"The hydrograph separation begins one interval (2N* days) prior to the start of the date selected for the start of the separation and ends one interval (2N* days) after the end of the selected date to improve accuracy at the beginning and end of the separation. If the selected beginning and (or) ending date coincides with the start and (or) end of the period of record, then the start of the separation coincides with the start of the period of record, and (or) the end of the separation coincides with the end of the period of record.

"The sliding-interval method finds the lowest discharge in one half the interval minus 1 day [0.5(2N*-1) days] before and after the day being considered and assigns it to that day. The method can be visualized as moving a bar 2N* wide upward until it intersects the hydrograph. The discharge at that point is assigned to the median day in the interval. The bar then slides over to the next day, and the process is repeated."

Summary Statistics

The results of the hydrograph decomposition exercise support the relationships between land use and hydrology discussed above. For convenience, the flows in Table 4-6 are expressed as a mean volume divided by drainage area over a one-year time period. For reference, one inch per year is approximately equal to one cubic foot per second per acre. Table 4-6 shows streamflow statistics for French Creek as representative of a minimally impaired stream, compared to the six gauges of the Tookany/Tacony-Frankford Watershed. The degree of urban impact to baseflow and runoff can be seen in this table. The upstream portions of the watershed still show reasonable levels of baseflow, similar to those of French Creek (in the 12-13 inches per year range). In the downstream segments of Frankford Creek, baseflow is significantly reduced due to the high degree of impervious cover. Looking at baseflow as a percentage of total flow, the same pattern is evident, however, the effects of urbanization in the upstream areas is more evident using this way of measuring, because it accounts for the higher unit area total flow of the Tookany/Tacony-Frankford Watershed compared with French Creek. The table also indicates the elevated runoff due to urbanization (as a percentage of total rainfall). Again, runoff is generally higher in the downstream areas, and lower in the upstream areas.

Table 4-6 Annual Summary Statistics for Baseflow and Stormwater Runoff

	Baseflow (in/yr/unit area)				**Runoff (in/yr/unit area)**			
	Mean	**Max**	**Min**	**St.Dev.**	**Mean**	**Max**	**Min**	**St.Dev.**
French Creek 01475127	12.9	20.8	5.8	3.8	7.4	15.4	2.9	3.1
Frankford Creek 01467089	7.9	11.5	3.5	2.1	14.9	21.3	8.0	4.3
Frankford Creek 01467087	7.1	13.0	4.5	2.2	11.4	20.3	6.2	3.5
Tacony Creek 01467086	12.6	18.1	7.5	3.2	9.2	13.2	5.2	2.3
Jenkintown Creek 01467085	14.0	18.6	9.5	4.0	9.0	12.0	5.1	2.7
Rock Creek 01467084	12.6	17.0	9.4	3.0	14.9	20.5	10.2	3.6
Tacony Creek 01467083	13.5	18.0	10.8	2.9	10.3	13.6	6.7	2.6

	Baseflow (% of Annual Rainfall)				Runoff (% of Annual Rainfall)			
	Mean	**Max**	**Min**	**St.Dev.**	**Mean**	**Max**	**Min**	**St.Dev.**
French Creek 01475127	31%	44%	15%	7%	17%	30%	7%	5%
Frankford Creek 01467089	18%	24%	9%	4%	34%	46%	21%	7%
Frankford Creek 01467087	18%	25%	11%	4%	29%	39%	17%	6%
Tacony Creek 01467086	29%	40%	19%	6%	21%	27%	13%	3%
Jenkintown Creek 01467085	32%	38%	19%	8%	20%	23%	15%	3%
Rock Creek 01467084	28%	36%	19%	6%	33%	41%	21%	7%
Tacony Creek 01467083	31%	36%	22%	6%	24%	31%	20%	5%

	Baseflow (% of Annual Total Flow)				Runoff (% of Annual Total Flow)			
	Mean	**Max**	**Min**	**St.Dev.**	**Mean**	**Max**	**Min**	**St.Dev.**
French Creek 01475127	64%	75%	53%	5%	36%	47%	25%	5%
Frankford Creek 01467089	35%	48%	27%	5%	65%	73%	52%	5%
Frankford Creek 01467087	38%	49%	26%	6%	62%	74%	51%	6%
Tacony Creek 01467086	58%	67%	48%	5%	42%	52%	33%	5%
Jenkintown Creek 01467085	61%	68%	50%	7%	39%	50%	32%	7%
Rock Creek 01467084	46%	61%	36%	7%	54%	64%	39%	7%
Tacony Creek 01467083	57%	63%	51%	5%	43%	49%	37%	5%

As expected, the quantity of stormwater runoff on a unit-area basis follows patterns of impervious cover in the drainage area. The French Creek watershed, the least developed, has the smallest amount of stormwater runoff both as an annual mean quantity (7.4 in/yr/unit area) and as an annual mean percent of rainfall (17%). As expected, the more highly-developed downstream Frankford Creek has the most runoff both as an annual mean quantity (14.9 in/yr/unit area) and as an annual mean percent of rainfall (34%). Mean runoff from Frankford Creek is twice the mean runoff in the French Creek basin. The more upstream gauges in the Tacony and Tookany have intermediate quantities of stormwater runoff.

Expressing runoff as a percent of annual rainfall as in Table 4-6 provides an estimate of the upper bound of directly connected impervious area (DCIA), that portion of impervious surfaces that are hydraulically connected to the drainage system. In other words, percent DCIA may be less than this number but is no greater. Runoff from impervious surfaces that are not directly connected may ultimately infiltrate or evaporate rather than contributing to stormwater runoff. It is interesting to note that compared to the land use-derived estimates of total impervious cover presented in Section 4 (ranging from 32% to 47% impervious cover as calculated for each municipality), estimated DCIA is generally more than 90% of total impervious area in the watershed. These estimates are calculated as the long-term mean runoff, as a percentage of rainfall, divided by the impervious cover estimate listed in Section 4. For example, runoff in Frankford Creek is 46% of rainfall on an annual mean basis, and impervious cover for the Philadelphia is estimated at 47%. Therefore about 98% of impervious cover appears to be directly connected.

Example Time Series Graphs

Figures 4-8 through 4-10 provide some idea of trends in unit-area flow, baseflow, and runoff from year to year. Although there is considerable variability between years, flows at the six gauges generally follow the same patterns. For example, the Frankford Creek gauges at Castor Avenue and at Torresdale Avenue have the lowest unit-area baseflows and the highest stormwater runoff volumes almost every year of the period of record. This agreement between gauges suggests that the conclusions drawn from long-term mean flows in the previous section are valid for most individual years.

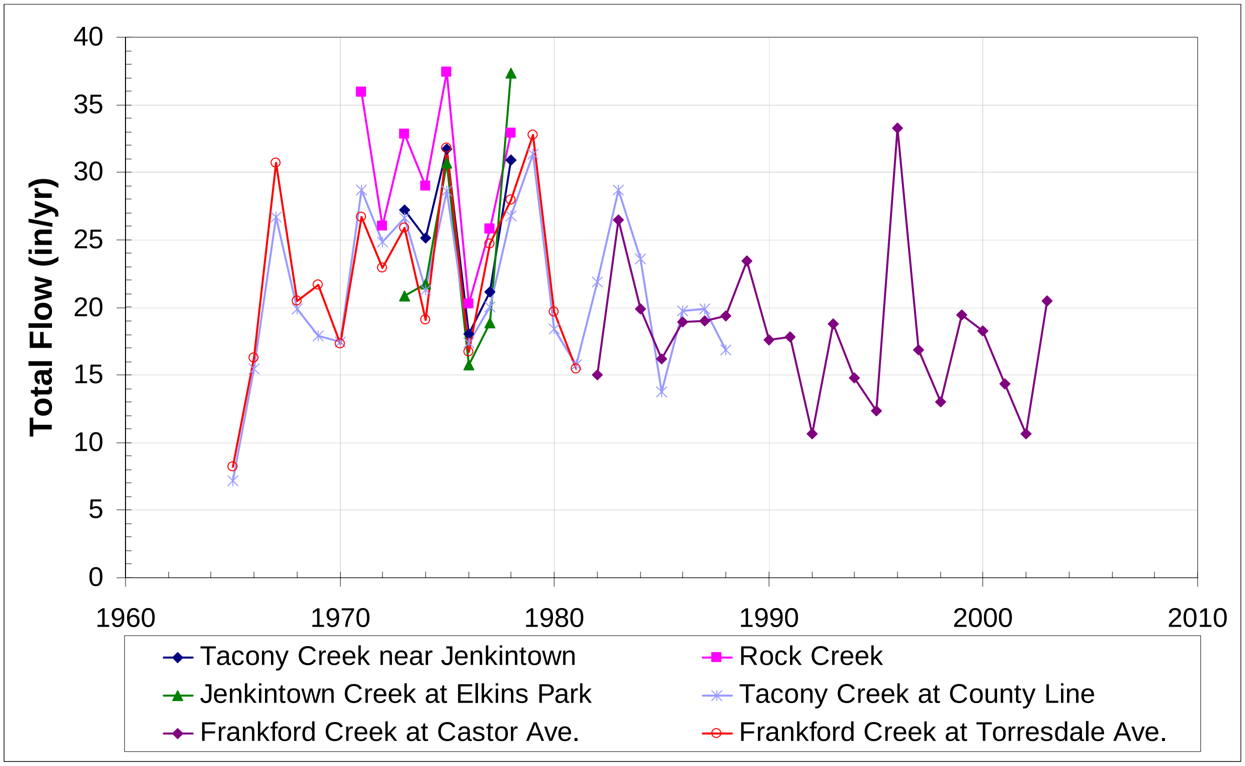


Figure 4-8 Total Flow (in/yr/unit area) Observed at six USGS Gauges in Tookany/Tacony-Frankford Watershed.

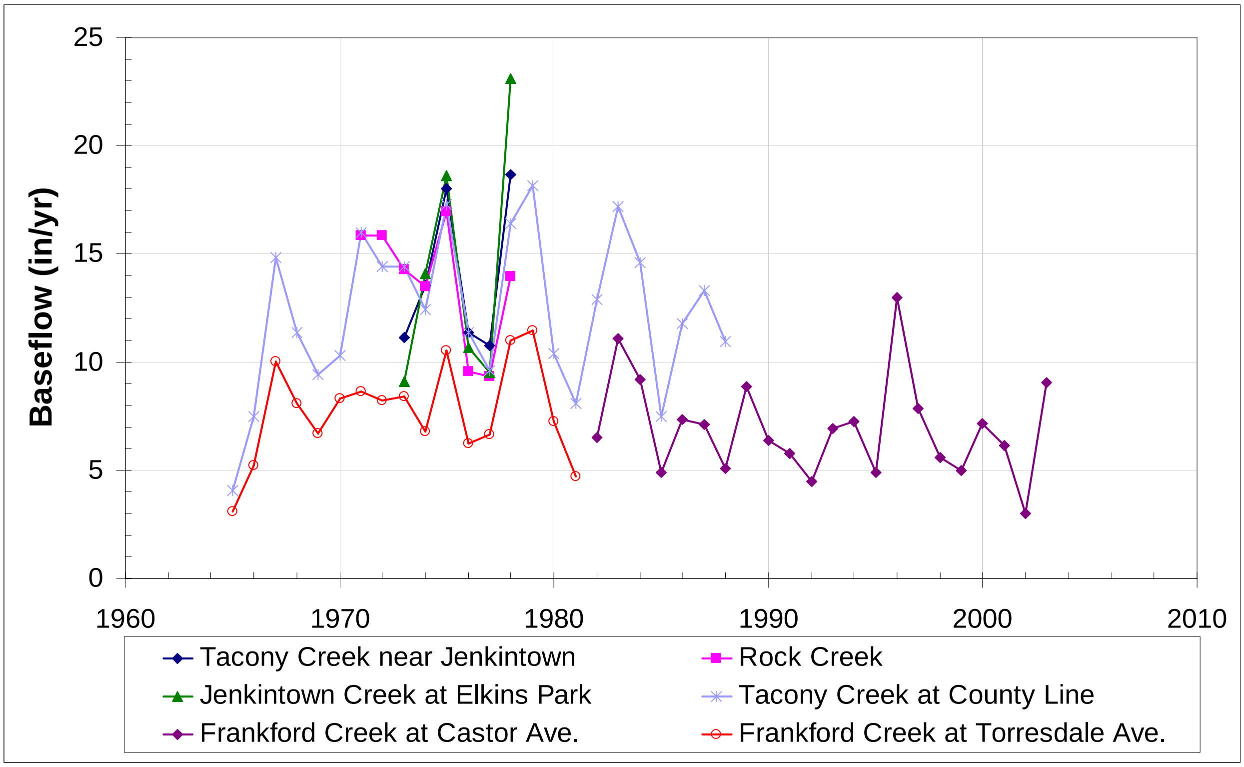


Figure 4-9 Calculated Total Baseflow (in/yr/unit area) at six USGS Gauges in Tookany/Tacony-Frankford Watershed.

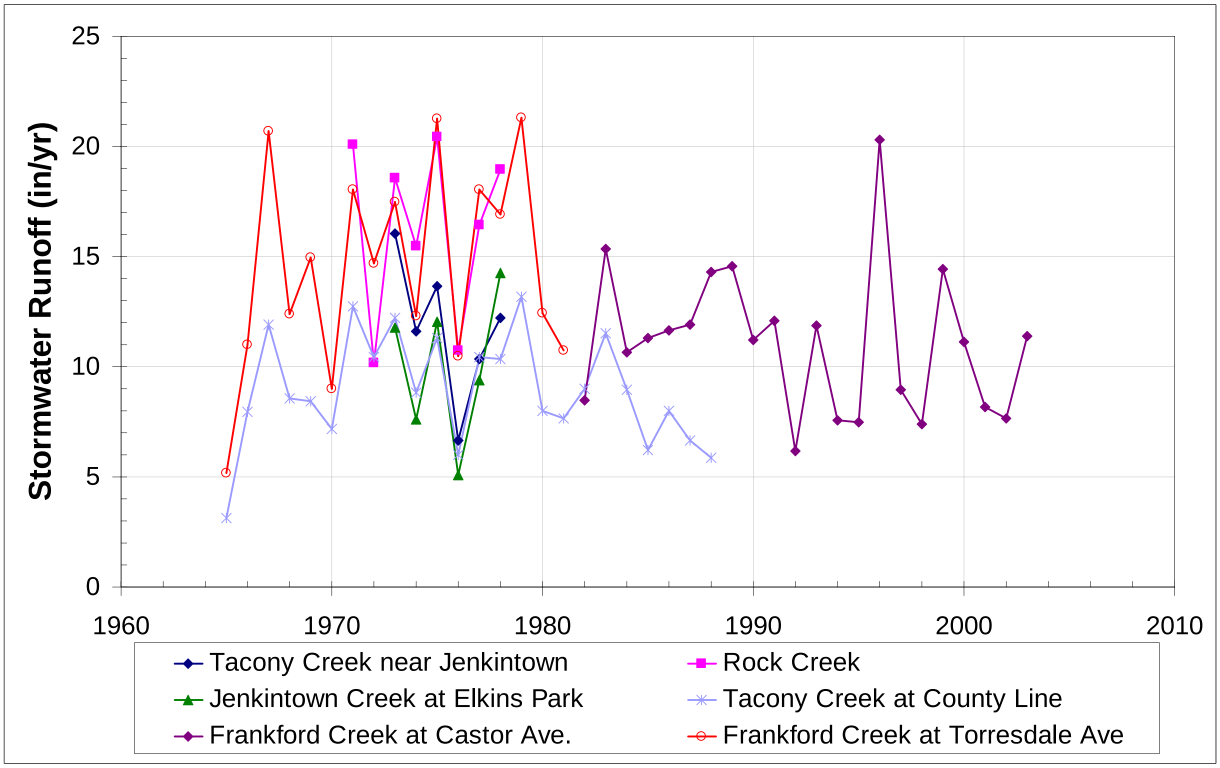


Figure 4-10 Calculated Total Stormwater Runoff (in/yr/unit area) at six USGS Gauges in Tookany/Tacony-Frankford Watershed.

Cumulative Distribution

The cumulative distribution of average daily flow at Tacony Creek near County Line (site TF620/680) and Frankford Creek at Castor Ave. (site TF280) provides more evidence that the Frankford Creek gauge experiences greater extremes of flow. The graph shows the percent of daily flow observations (horizontal axis) that are equal to or less than a given value (on the vertical axis). For example, Figure 4-11 indicates that average daily flow on a unit area basis at the Frankford Creek gauge was less than 0.1 inches on about 90% of days observed. Frankford Creek experiences greater extremes of flow than at the Tacony Creek gauge. On approximately 92% of days, flow at the Frankford Creek gauge is less than flow at the Tacony Creek gauge on a unit-area basis. On the wettest 8% of days, flow at the Tacony Creek gauge is greater than flow at the Frankford Creek gauge on a unit-area basis. These observations strengthen the evidence that downstream reaches of the creek (Frankford Creek) are more influenced by stormwater runoff than upstream reaches (Tacony Creek).

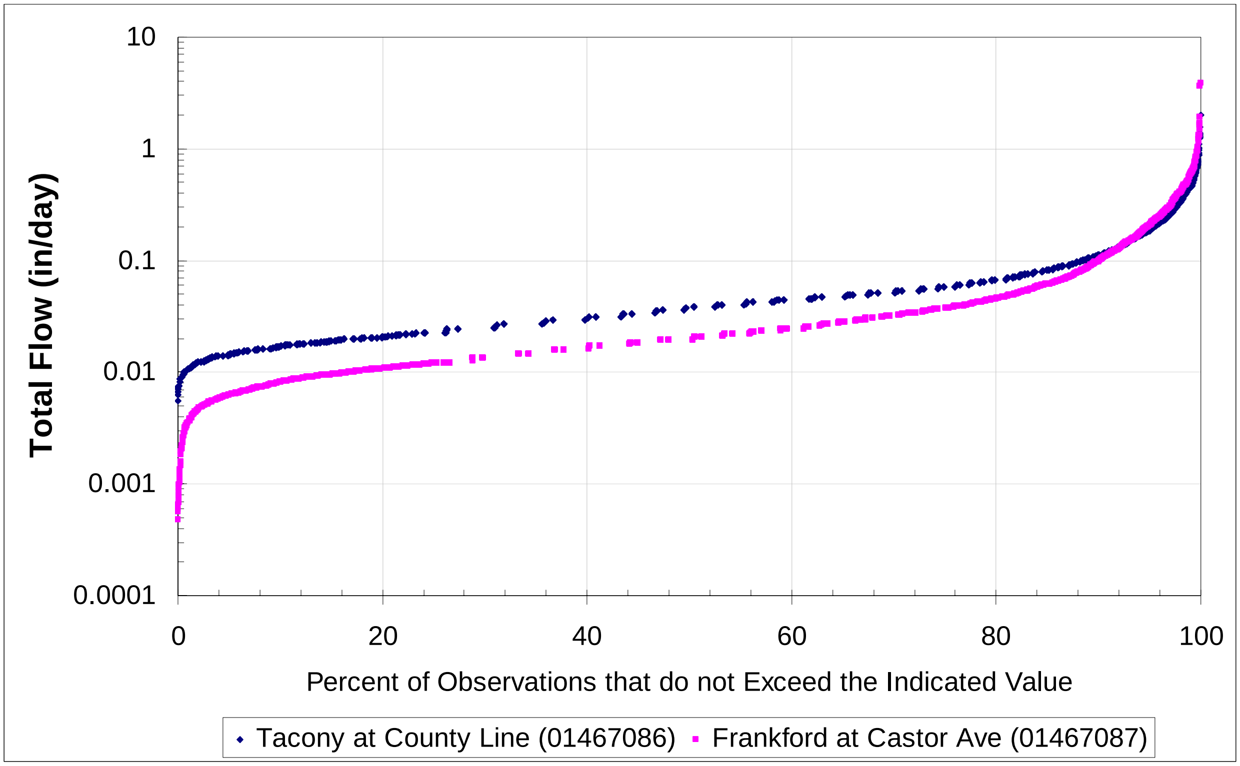


Figure 4-11 Cumulative Distribution Plot of Total Flow at two USGS Gauges in Tookany/Tacony-Frankford Watershed

Characterization of Wet and Dry Weather Sampling Periods

The evaluation of water quality data began with the segregation of water quality observations into wet and dry weather periods. This classification was based upon rainfall. To characterize samples as wet or dry, rainfall for the previous 48 hours was summed and if the total exceeded 0.05 inches the sample was flagged as wet. All samples not meeting this criterion were flagged as dry.

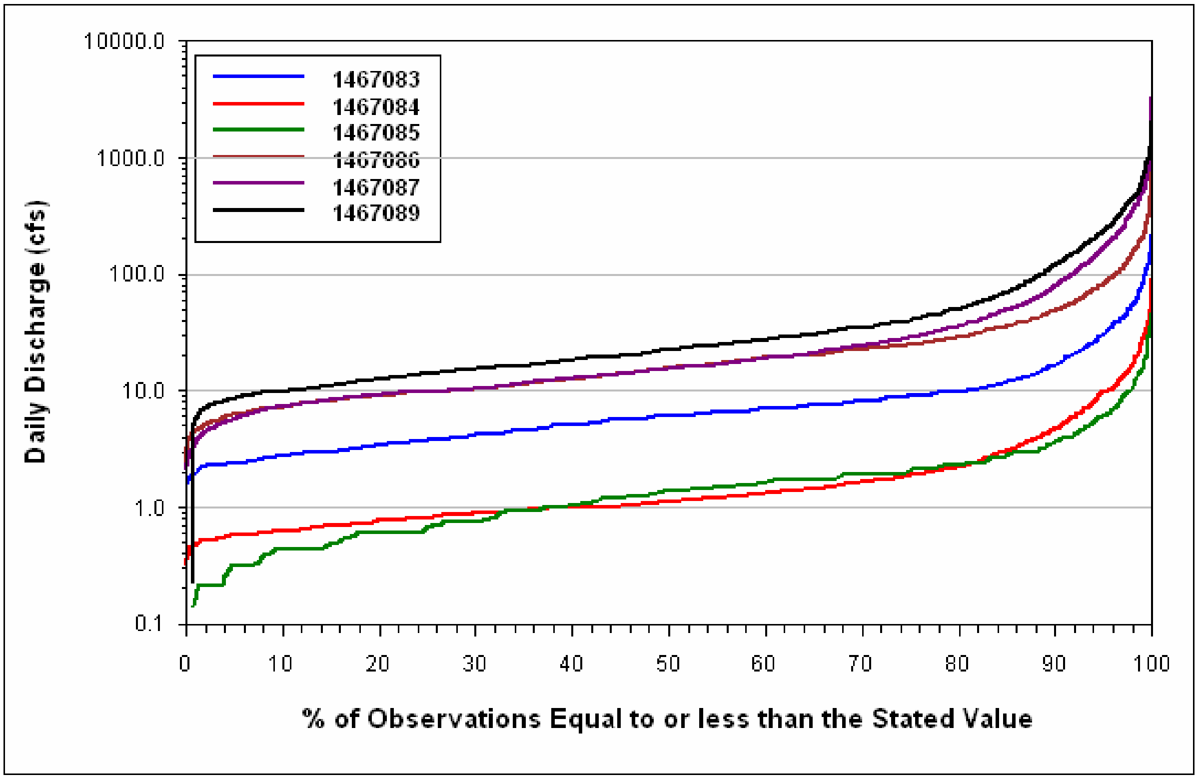


Figure 4-12 Cumulative Distribution Plot of Daily Discharge at six USGS Gauges in Tookany/Tacony-Frankford Watershed

Table 4-7 Wet Weather/Dry Weather Flow Estimates for Historical USGS Gauge Data

Gauge Name	Gauge Number	Season	Q3 (75%) (cfs)
Tacony Creek near Jenkintown	1467083	Annual	9
Tacony Creek near Jenkintown	1467083	Fall	6.7
Tacony Creek near Jenkintown	1467083	Spring	10
Tacony Creek near Jenkintown	1467083	Summer	8.2
Tacony Creek near Jenkintown	1467083	Winter	9.7
Rock Creek by Curtis Arboretum	1467084	Annual	1.9
Rock Creek by Curtis Arboretum	1467084	Fall	1.5
Rock Creek by Curtis Arboretum	1467084	Spring	2.3
Rock Creek by Curtis Arboretum	1467084	Summer	1.8
Rock Creek by Curtis Arboretum	1467084	Winter	1.8
Jenkintown Creek at Elkins Park	1467085	Annual	2.1
Jenkintown Creek at Elkins Park	1467085	Fall	1.5
Jenkintown Creek at Elkins Park	1467085	Spring	2.55
Jenkintown Creek at Elkins Park	1467085	Summer	2
Jenkintown Creek at Elkins Park	1467085	Winter	2.3
Tacony Creek at County Line	1467086	Annual	26
Tacony Creek at County Line	1467086	Fall	18
Tacony Creek at County Line	1467086	Spring	33
Tacony Creek at County Line	1467086	Summer	23
Tacony Creek at County Line	1467086	Winter	26
Frankford Creek at Castor Ave.	1467087	Annual	29
Frankford Creek at Castor Ave.	1467087	Fall	18
Frankford Creek at Castor Ave.	1467087	Spring	40
Frankford Creek at Castor Ave.	1467087	Summer	28
Frankford Creek at Castor Ave.	1467087	Winter	27
Frankford Creek at Torresdale Ave.	1467089	Annual	41
Frankford Creek at Torresdale Ave.	1467089	Fall	28.5
Frankford Creek at Torresdale Ave.	1467089	Spring	52
Frankford Creek at Torresdale Ave.	1467089	Summer	42
Frankford Creek at Torresdale Ave.	1467089	Winter	39

An example of trends in rainfall and corresponding CSOs can be observed in Figures 4-13 and 4-14. Figure 4-13 shows rainfall and CSO data for three CSO outfalls for the period April 12 to 16, 2004. A total of 4.09 inches of rain occurs during the period and CSOs are active. Because CSOs are observed at multiple points in the system, it can be inferred that sampling sites throughout the system are impacted by CSO and stormwater. The discrete sampling conducted during this period would be called wet days. Figure 4-16 shows rainfall and CSO data for the period June 7 to June 11, 2004. This period is classified as dry because neither rainfall nor CSO occurs. Table 4-8 shows the wet or dry categorization of sampling periods when discrete samples were collected. Table 4-9 lists the wet dates in the continuous monitoring or Sonde deployment periods.

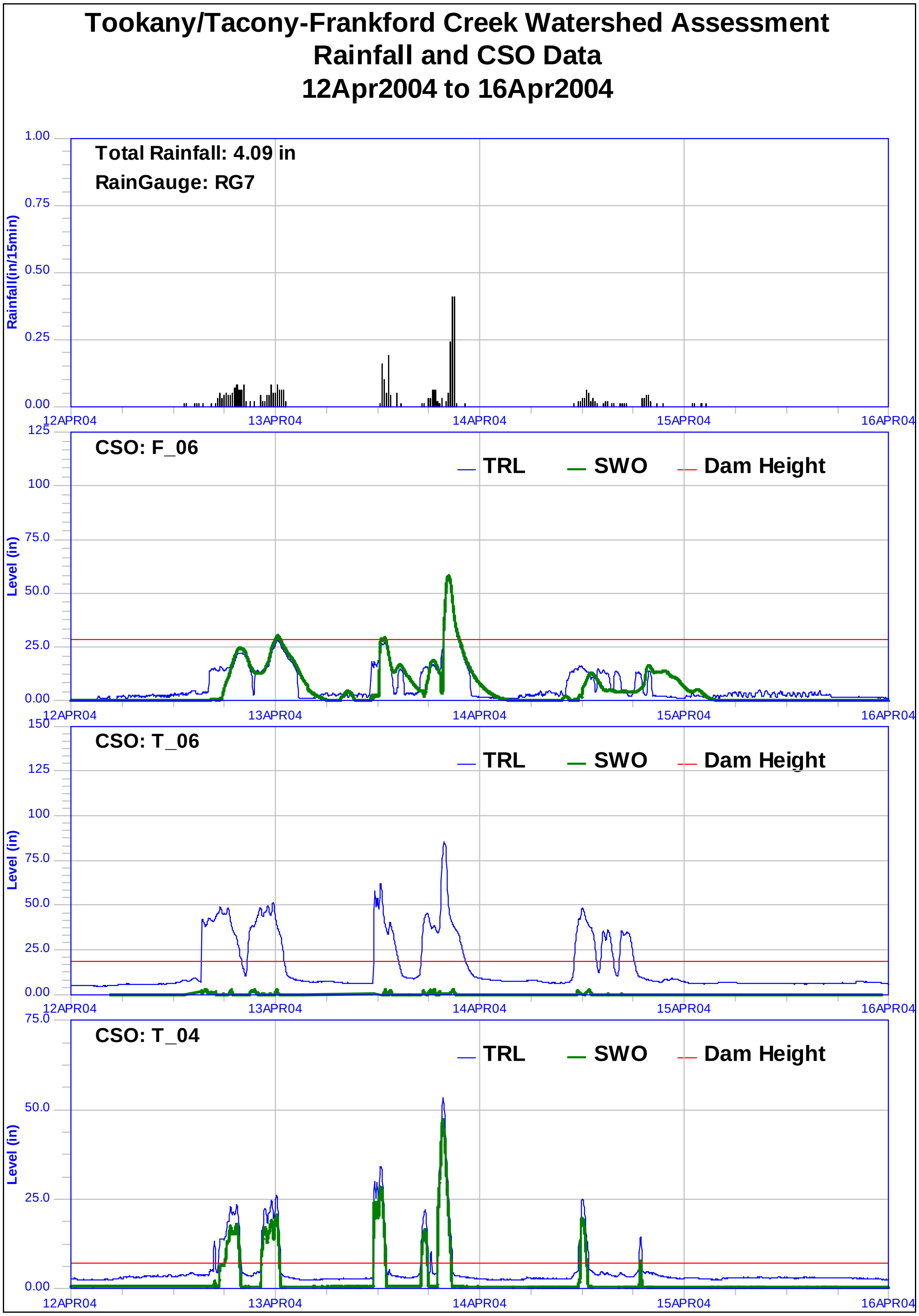


Figure 4-13 Rainfall and CSO plot for a wet period

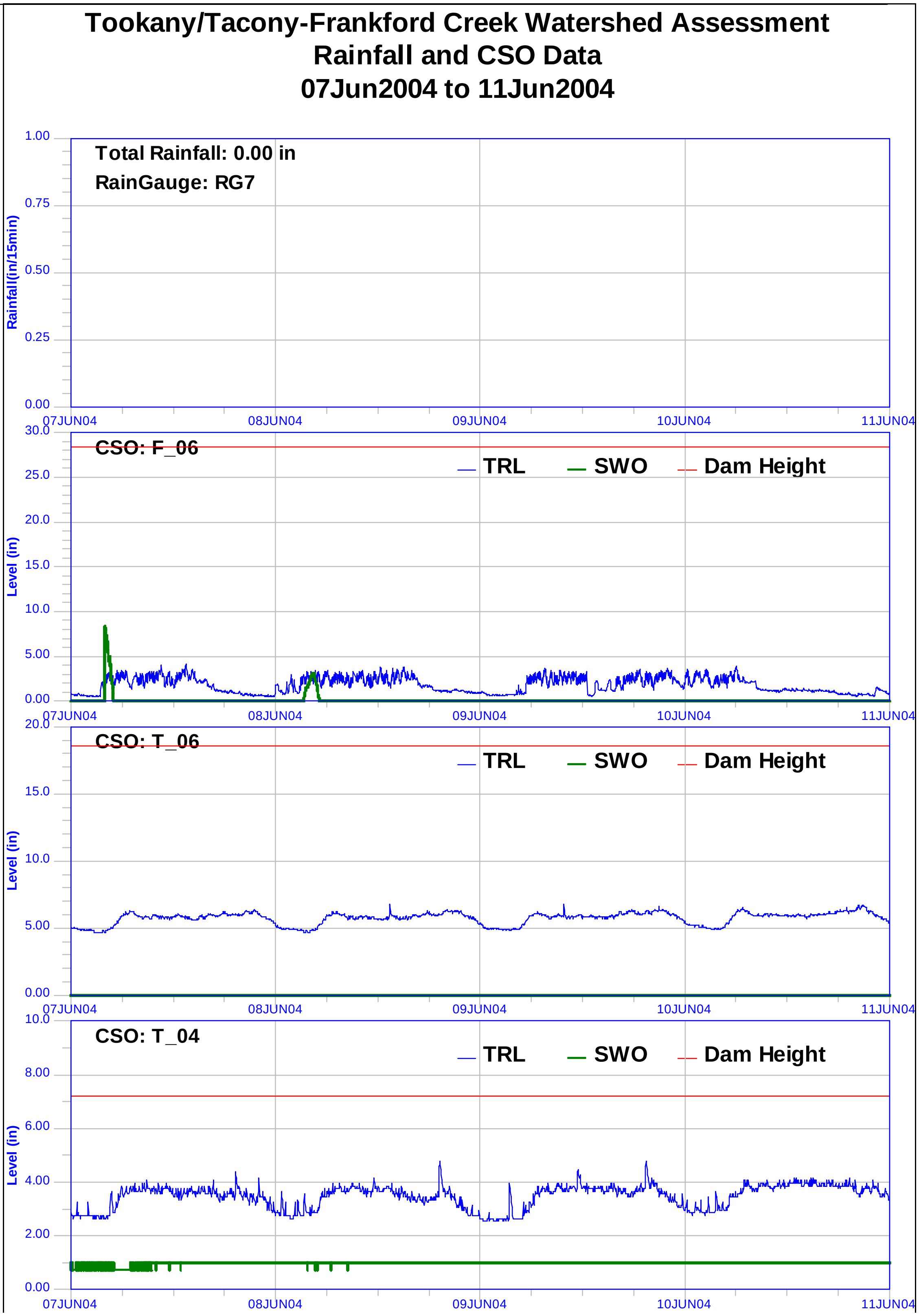


Figure 4-14 Rainfall and CSO plot for a dry period

Table 4-8 Wet and Dry Period Characterization

Date/Period	Weather Status	Sampling Type
6/29/2000	WET	Discrete
7/6/2000	DRY	Discrete
7/20/2000	WET	Discrete
8/10/2000	DRY	Discrete
8/31/2000	WET	Discrete
9/14/2000	WET	Discrete
9/27/2000	WET	Discrete
9/28/2000	WET	Discrete
10/12/2000	DRY	Discrete
10/26/2000	WET	Discrete
11/9/2000	DRY	Discrete
3/19/2001	WET	WETW
3/21-23/2001	WET	WETW
5/21-24/2001	WET	WETW
6/29/2001	DRY	Special
8/17/2001	DRY	Special
10/24/2001	DRY	Special
11/29/2001	DRY	Discrete
2/7/2002	DRY	Discrete
3/7/2002	DRY	Special
5/22/2002	WET	Special
8/1/2002	DRY	Special
8/15/2002	DRY	Special
10/15-18/2002	WET	WETW
10/18-29/2002	WET	WETW
10/24/2002	DRY	Discrete
11/12-14/2002	WET	WETW
1/15/2003	DRY	Discrete
2/12/2003	WET	Discrete
3/4-7/2003	WET	WETW
3/12/2003	DRY	Discrete
3/26-27/2003	WET	Special
4/21/2003	DRY	Discrete
5/1-4/2003	WET	WETW
5/5-7/2003	WET	WETW
5/7-9/2003	WET	WETW
5/15-17/2003	WET	WETW
6/10/2003	DRY	Discrete
6/24/2003	DRY	Discrete
7/9-11/2003	WET	WETW
7/18/2003	DRY	Discrete
9/22-24/2003	WET	WETW
10/3/2003	DRY	Special
10/14-16/2003	WET	WETW
1/15/2004	DRY	Discrete
1/22/2004	DRY	Discrete
1/29/2004	DRY	Discrete
2/5/2004	WET	Discrete
4/21/2004	DRY	Discrete
4/29/2004	WET	Discrete
5/6-13/2004	WET	Discrete
7/7-9/2004	WET	WETW
7/12/2004	WET	Discrete
7/27/2004	WET	Discrete
7/28/2004	WET	Special
7/29/2004	WET	Special
7/30/2004	WET	Special
8/5/2004	WET	Discrete
8/12/2004	WET	Discrete
8/19/2004	DRY	Discrete
8/23/2004	WET	Chlorophyll
8/26/2004	DRY	Discrete
8/30/2004	DRY	Discrete
8/30-9/1/2004	WET	WETW
9/2/2004	DRY	Discrete
9/8/2004	WET	Chlorophyll
9/13/2004	DRY	Chlorophyll
9/17/2004	WET	Chlorophyll
9/18/2004	WET	Special
9/28/2004	WET	Special

WETW = Series of samples taken during a wet weather hydrograph, but the first sample is taken in dry weather before the forecast storm.

Table 4-9 Wet Weather Days of Continuous Sampling Periods

Date/Period			Wet Weather Dates
03/20/01	To	03/26/01	3/21, 3/22, 3/23, 3/26
05/03/01	To	05/17/01	--
05/21/01	To	06/04/01	5/21, 5/22, 5/23, 5/24, 5/26, 5/27, 5/28, 5/29, 5/30, 5/31, 6/1, 6/2, 6/3, 6/4
05/22/01	To	06/05/01	5/22, 5/23, 5/24, 5/26, 5/27, 5/28, 5/29, 5/30, 5/31, 6/1, 6/2, 6/3, 6/4
08/17/01	To	08/29/01	8/19, 8/20, 8/21, 8/22, 8/23, 8/24, 8/25, 8/27, 8/28, 8/29
08/16/01	To	08/29/01	8/19, 8/20, 8/21, 8/22, 8/23, 8/24, 8/25, 8/27, 8/28, 8/29
06/26/01	To	07/03/01	7/1, 7/2, 7/3
07/13/01	To	07/18/01	7/18/2005
11/19/02	To	12/06/02	11/19, 11/21, 11/22, 11/23, 11/24, 11/27, 11/28, 11/29
09/25/02	To	10/09/02	9/25
10/23/02	To	11/05/02	10/25, 10/26, 10/27, 10/28, 10/29, 10/30, 10/31, 11/1
11/19/02	To	12/06/02	11/19, 11/21, 11/22, 11/23, 11/24, 11/27, 11/28, 11/29
09/10/02	To	09/25/02	9/14, 9/15, 9/16, 9/17, 9/24, 9/25
10/04/02	To	10/23/02	10/4, 10/5, 10/10, 10/11, 10/12, 10/13, 10/16, 10/17, 10/18
10/29/02	To	11/19/02	10/29, 10/30, 10/31, 11/1, 11/5, 11/6, 11/7, 11/8, 11/11, 11/12, 11/13, 11/14, 11/15, 11/16, 11/17, 11/18, 11/19
10/23/02	To	11/05/02	10/25, 10/26, 10/27, 10/28, 10/29, 10/30, 10/31, 11/1
11/19/02	To	12/06/02	11/19, 11/21, 11/22, 11/23, 11/24, 11/27, 11/28, 11/29
09/25/02	To	10/08/02	9/25, 9/26, 9/27, 9/28, 9/29, 9/30, 10/3, 10/4, 10/5
10/29/02	To	11/19/02	10/29, 10/30, 10/31, 11/1, 11/5, 11/6, 11/7, 11/8, 11/11, 11/12, 11/13, 11/14, 11/15, 11/16, 11/17, 11/18, 11/19
09/10/02	To	09/25/02	9/14, 9/15, 9/16, 9/17, 9/24, 9/25
10/04/02	To	10/23/02	10/4, 10/5, 10/10, 10/11, 10/12, 10/13, 10/16, 10/17, 10/18
03/04/03	To	03/12/03	3/4, 3/5, 3/6, 3/7, 3/8, 3/9
03/18/03	To	03/21/03	3/20, 3/21
04/01/03	To	04/15/03	4/1, 4/2, 4/3, 4/7, 4/8, 4/9, 4/10, 4/11, 4/12, 4/13, 4/14
04/15/03	To	04/29/03	4/25, 4/26, 4/27, 4/28
04/29/03	To	05/13/03	5/2, 5/3, 5/4, 5/5, 5/6, 5/7, 5/8, 5/9, 5/10, 5/11
05/13/03	To	05/20/03	5/16, 5/17, 5/18, 5/19
05/15/03	To	05/18/03	5/16, 5/17, 5/18
05/30/03	To	06/12/03	5/30, 5/31, 6/1, 6/2, 6/3, 6/4, 6/5, 6/6, 6/7, 6/8, 6/9
06/17/03	To	06/23/03	6/17, 6/18, 6/19, 6/20, 6/21, 6/22
07/08/03	To	07/14/03	7/8, 7/9, 7/10, 7/11, 7/12, 7/13, 7/14
03/25/03	To	03/27/03	3/26, 3/27
04/01/03	To	04/15/03	4/1, 4/2, 4/3, 4/7, 4/8, 4/9, 4/10, 4/11, 4/12, 4/13, 4/14
04/15/03	To	04/29/03	4/25, 4/26, 4/27, 4/28
04/29/03	To	05/08/03	5/2, 5/3, 5/4, 5/5, 5/6, 5/7, 5/8
05/13/03	To	05/20/03	5/16, 5/17, 5/18, 5/19
05/30/03	To	06/12/03	5/30, 5/31, 6/1, 6/2, 6/3, 6/4, 6/5, 6/6, 6/7, 6/8, 6/9
07/08/03	To	07/14/03	7/8, 7/9, 7/10, 7/11, 7/12, 7/13, 7/14
04/01/03	To	04/15/03	4/1, 4/2, 4/3, 4/7, 4/8, 4/9, 4/10, 4/11, 4/12, 4/13, 4/14
04/15/03	To	04/29/03	4/25, 4/26, 4/27, 4/28
04/29/03	To	05/13/03	5/2, 5/3, 5/4, 5/5, 5/6, 5/7, 5/8, 5/9, 5/10, 5/11
05/13/03	To	05/20/03	5/16, 5/17, 5/18, 5/19
05/30/03	To	06/12/03	5/30, 5/31, 6/1, 6/2, 6/3, 6/4, 6/5, 6/6, 6/7, 6/8, 6/9
07/08/03	To	07/14/03	7/8, 7/9, 7/10, 7/11, 7/12, 7/13, 7/14

Date/Period			**Wet Weather Dates**
04/01/03	To	04/15/03	4/1, 4/2, 4/3, 4/7, 4/8, 4/9, 4/10, 4/11, 4/12, 4/13, 4/14
04/15/03	To	04/18/03	--
04/29/03	To	05/13/03	5/2, 5/3, 5/4, 5/5, 5/6, 5/7, 5/8, 5/9, 5/10, 5/11
05/13/03	To	05/20/03	5/16, 5/17, 5/18, 5/19
07/08/03	To	07/14/03	7/8, 7/9, 7/10, 7/11, 7/12, 7/13, 7/14
03/18/03	To	03/21/03	3/20, 3/21
09/22/03	To	09/25/03	9/23, 9/24, 9/25
09/25/03	To	10/15/03	9/27, 9/28, 9/29, 9/30, 10/4, 10/5, 10/6, 10/14, 10/15
08/06/03	To	08/13/03	8/6, 8/7, 8/8, 8/9, 8/10, 8/11, 8/12
09/17/03	To	09/25/03	8/6, 8/7, 8/8, 8/9, 8/10, 8/11, 8/12
09/25/03	To	10/15/03	9/27, 9/28, 9/29, 9/30, 10/4, 10/5, 10/6, 10/14, 10/15
09/17/03	To	09/25/03	9/17, 9/18, 9/19, 9/20, 9/21, 9/23, 9/24, 9/25,
09/25/03	To	10/15/03	9/27, 9/28, 9/29, 9/30, 10/4, 10/5, 10/6, 10/14, 10/15
09/17/03	To	09/25/03	9/17, 9/18, 9/19, 9/20, 9/21, 9/23, 9/24, 9/25,
09/25/03	To	10/15/03	9/27, 9/28, 9/29, 9/30, 10/4, 10/5, 10/6, 10/14, 10/15
10/16/03	To	10/23/03	10/16, 10/17, 10/18, 10/19, 10/20, 10/22, 10/23
10/16/03	To	10/30/03	10/16, 10/17, 10/18, 10/19, 10/20, 10/22, 10/23, 10/24, 10/26, 10/27, 10/28, 10/29, 10/30
10/30/03	To	11/13/03	10/30, 10/31, 11/5, 11/6, 11/7, 11/8, 11/12, 11/13
11/13/03	To	11/26/03	11/13, 11/14, 11/19, 11/20, 11/21, 11/22, 11/24, 11/25, 11/26
03/26/04	To	04/04/04	3/27, 3/28, 3/29, 3/30, 3/31, 4/1, 4/2, 4/3, 4/4
04/06/04	To	04/20/04	4/6, 4/8, 4/9, 4/10, 4/11, 4/12, 4/13, 4/14, 4/15, 4/16
04/20/04	To	05/04/04	4/23, 4/24, 4/25, 4/26, 4/27, 4/28, 4/29, 5/3, 5/4
05/04/04	To	05/18/04	5/4, 5/5, 5/6, 5/7, 5/8, 5/9, 5/10, 5/11, 5/12, 5/15, 5/16, 5/17, 5/18
05/18/04	To	06/01/04	5/18, 5/19, 5/20, 5/21, 5/25, 5/26, 5/27, 5/31, 6/1
06/01/04	To	06/14/04	6/1, 6/2, 6/3, 6/4, 6/5, 6/6, 6/7, 6/8, 6/11, 6/12, 6/13
06/03/04	To	06/12/04	6/3, 6/4, 6/5, 6/6, 6/7, 6/8, 6/11, 6/12
06/14/04	To	06/29/04	6/14, 6/15, 6/16, 6/17, 6/18, 6/19, 6/22, 6/23, 6/24, 6/29
03/12/04	To	03/23/04	3/16, 3/17, 3/18, 3/19, 3/20, 3/21, 3/22, 3/23
03/26/04	To	04/03/04	3/27, 3/28, 3/29, 3/30, 3/31, 4/1, 4/2, 4/3
04/06/04	To	04/20/04	4/6, 4/8, 4/9, 4/10, 4/11, 4/12, 4/13, 4/14, 4/15, 4/16
04/20/04	To	05/04/04	4/23, 4/24, 4/25, 4/26, 4/27, 4/28, 4/29, 5/3, 5/4
05/04/04	To	05/18/04	5/4, 5/5, 5/6, 5/7, 5/8, 5/9, 5/10, 5/11, 5/12, 5/15, 5/16, 5/17, 5/18
05/18/04	To	06/01/04	5/18, 5/19, 5/20, 5/21, 5/25, 5/26, 5/27, 5/31, 6/1
06/01/04	To	06/14/04	6/1, 6/2, 6/3, 6/4, 6/5, 6/6, 6/7, 6/8, 6/11, 6/12, 6/13
06/14/04	To	06/29/04	6/14, 6/15, 6/16, 6/17, 6/18, 6/19, 6/22, 6/23, 6/24, 6/29
03/26/04	To	04/06/04	3/27, 3/28, 3/29, 3/30, 3/31, 4/1, 4/2, 4/3, 4/4, 4/5, 4/6
04/06/04	To	04/20/04	4/6, 4/8, 4/9, 4/10, 4/11, 4/12, 4/13, 4/14, 4/15, 4/16
04/20/04	To	05/04/04	4/23, 4/24, 4/25, 4/26, 4/27, 4/28, 4/29, 5/3, 5/4
05/04/04	To	05/18/04	5/4, 5/5, 5/6, 5/7, 5/8, 5/9, 5/10, 5/11, 5/12, 5/15, 5/16, 5/17, 5/18
05/18/04	To	06/01/04	5/18, 5/19, 5/20, 5/21, 5/25, 5/26, 5/27, 5/31, 6/1
06/01/04	To	06/11/04	6/1, 6/2, 6/3, 6/4, 6/5, 6/6, 6/7, 6/8, 6/11
06/14/04	To	06/29/04	6/14, 6/15, 6/16, 6/17, 6/18, 6/19, 6/22, 6/23, 6/24, 6/29
03/26/04	To	04/06/04	3/27, 3/28, 3/29, 3/30, 3/31, 4/1, 4/2, 4/3, 4/4, 4/5, 4/6
04/06/04	To	04/20/04	4/6, 4/8, 4/9, 4/10, 4/11, 4/12, 4/13, 4/14, 4/15, 4/16
04/20/04	To	05/04/04	4/23, 4/24, 4/25, 4/26, 4/27, 4/28, 4/29, 5/3, 5/4
05/04/04	To	05/18/04	5/4, 5/5, 5/6, 5/7, 5/8, 5/9, 5/10, 5/11, 5/12, 5/15, 5/16, 5/17, 5/18

Date/Period			Wet Weather Dates
05/18/04	To	06/01/04	5/18, 5/19, 5/20, 5/21, 5/25, 5/26, 5/27, 5/31, 6/1
05/19/04	To	06/01/04	5/19, 5/20, 5/21, 5/25, 5/26, 5/27, 5/31, 6/1
06/14/04	To	06/29/04	6/14, 6/15, 6/16, 6/17, 6/18, 6/19, 6/22, 6/23, 6/24, 6/29
03/26/04	To	04/07/04	3/27, 3/28, 3/29, 3/30, 3/31, 4/1, 4/2, 4/3, 4/4, 4/5, 4/6
04/07/04	To	04/21/04	4/8, 4/9, 4/10, 4/11, 4/12, 4/13, 4/14, 4/15, 4/16
04/21/04	To	05/06/04	4/23, 4/24, 4/25, 4/26, 4/27, 4/28, 4/29, 5/3, 5/4, 5/5, 5/6
05/06/04	To	05/19/04	5/6, 5/7, 5/8, 5/9, 5/10, 5/11, 5/12, 5/15, 5/16, 5/17, 5/18, 5/19
05/19/04	To	06/01/04	5/19, 5/20, 5/21, 5/25, 5/26, 5/27, 5/31, 6/1
06/01/04	To	06/14/04	6/1, 6/2, 6/3, 6/4, 6/5, 6/6, 6/7, 6/8, 6/11, 6/12, 6/13
06/14/04	To	06/29/04	6/14, 6/15, 6/16, 6/17, 6/18, 6/19, 6/22, 6/23, 6/24, 6/29
03/12/04	To	03/23/04	3/16, 3/17, 3/18, 3/19, 3/20, 3/21, 3/22, 3/23
03/26/04	To	04/06/04	3/27, 3/28, 3/29, 3/30, 3/31, 4/1, 4/2, 4/3, 4/4, 4/5, 4/6
04/06/04	To	04/20/04	4/6, 4/8, 4/9, 4/10, 4/11, 4/12, 4/13, 4/14, 4/15, 4/16
04/20/04	To	05/04/04	4/23, 4/24, 4/25, 4/26, 4/27, 4/28, 4/29, 5/3, 5/4
05/04/04	To	05/18/04	5/4, 5/5, 5/6, 5/7, 5/8, 5/9, 5/10, 5/11, 5/12, 5/15, 5/16, 5/17, 5/18
05/18/04	To	06/01/04	5/18, 5/19, 5/20, 5/21, 5/25, 5/26, 5/27, 5/31, 6/1
06/01/04	To	06/14/04	6/1, 6/2, 6/3, 6/4, 6/5, 6/6, 6/7, 6/8, 6/11, 6/12, 6/13
06/14/04	To	06/29/04	6/14, 6/15, 6/16, 6/17, 6/18, 6/19, 6/22, 6/23, 6/24, 6/29
06/29/04	To	07/15/04	6/29, 6/30, 7/1, 7/2, 7/3, 7/5, 7/6, 7/7, 7/8, 7/9, 7/12, 7/13, 7/14, 7/15
07/02/04	To	07/15/04	7/2, 7/3, 7/5, 7/6, 7/7, 7/8, 7/9, 7/12, 7/13, 7/14, 7/15, ,
06/29/04	To	07/15/04	6/29, 6/30, 7/1, 7/2, 7/3, 7/5, 7/6, 7/7, 7/8, 7/9, 7/12, 7/13, 7/14, 7/15,
07/15/04	To	07/30/04	7/15, 7/16, 7/18, 7/19, 7/20, 7/21, 7/22, 7/23, 7/24, 7/25, 7/26, 7/27, 7/28, 7/29, 7/30
07/30/04	To	08/12/04	7/30, 8/1, 8/2, 8/3, 8/4, 8/5, 8/6, 8/11, 8/12
08/12/04	To	08/20/04	8/12, 8/13, 8/14, 8/15, 8/16, 8/17, 8/18
08/20/04	To	09/08/04	8/21, 8/22, 8/23, 8/30, 8/31, 9/1, 9/2, 9/8
07/30/04	To	08/12/04	7/30, 8/1, 8/2, 8/3, 8/4, 8/5, 8/6, 8/11, 8/12
08/12/04	To	08/20/04	8/12, 8/13, 8/14, 8/15, 8/16, 8/17, 8/18
08/20/04	To	09/08/04	8/21, 8/22, 8/23, 8/30, 8/31, 9/1, 9/2, 9/8
07/30/04	To	08/12/04	7/30, 8/1, 8/2, 8/3, 8/4, 8/5, 8/6, 8/11, 8/12
08/12/04	To	08/20/04	8/12, 8/13, 8/14, 8/15, 8/16, 8/17, 8/18
08/20/04	To	09/08/04	8/21, 8/22, 8/23, 8/30, 8/31, 9/1, 9/2, 9/8
09/08/04	To	09/22/04	9/8, 9/9, 9/10, 9/11, 9/15, 9/16, 9/17, 9/18, 9/19, 9/20
09/22/04	To	10/05/04	9/28, 9/29, 9/30, 10/1, 10/2

4.4 Flooding

4.4.1 Introduction

A stormwater management plan has been initiated in this watershed by the Philadelphia Water Department in partnership with the watershed municipalities in Montgomery County under Pennsylvania's Act 167, the Storm Water Management Act of 1968. The Act 167 planning process and report will identify any "trouble spots" that may exist within the watershed area.

According to the Tookany Creek Watershed Management Plan, "there are several low-lying areas within the watershed that have experienced frequent flooding with damage to homes and businesses. It appears that dwellings were built over time in the floodplain without recognizing the value of the floodplain in attenuating floodwaters. Compounding the problem is the gradual addition of impervious surfaces over decades to the watershed's creeks, thus causing less on-site infiltration and more direct volume flowing quickly into the creeks."

The Tookany Creek Watershed Management Plan additionally discusses the role of floodplains and riparian areas in flood control: "The 100-year floodplain affects the health, safety and welfare of residents. While much of the time the floodplain may be dry, during storms the floodplain stores and conveys large quantities of water. Development within the floodplain reduces the carrying capacity and increases the height and destructive ability of floodwater. In addition to carrying flood waters, the floodplain and stream corridor serve other important functions. The condition of the stream corridor is important in minimizing erosion and water pollution, protecting water quality (temperature and velocity) and providing animal habitat and recreation opportunities."

Frequent damaging flooding does not appear to be a major concern within the study area. However, frequent smaller events of flooding occur in some locations, and damaging flooding has occurred during very large storms.

FEMA Floodplains and Flood Insurance Rate Maps

Information on floodplain extents, historical flooding events, and flood insurance rates is available from FEMA and provides an idea of flood hazards in the study area. The flood insurance rate map (Figure 4-15) provides a quick idea of the areas in the watershed that may experience flooding. As summarized in Table 4-10, Zones A and AE are areas where flooding is likely (1% or greater annual chance of occurrence) and zones X and X500 are areas where flooding is unlikely (less than an annual 1% chance due to elevation or flood protection structures).

Table 4-10 National Flood Insurance Program Zone Designations

Zone	Description
A	Zone A is the flood insurance rate zone that corresponds to the 100-year floodplains that are determined in the FIS by approximate methods. Because detailed hydraulic analyses are not performed for such areas, no base flood elevations or depths are shown within this zone. Flood insurance is generally mandatory in these zones.
AE	Zone AE is the flood insurance rate zone that corresponds to the 100-year floodplains that are determined in the FIS by detailed methods. In most instances, whole-foot base flood elevations derived from detailed hydraulic analyses are shown at selected intervals within this zone. Flood insurance is generally mandatory in these zones.
X and X500	Zone X is the flood insurance rate zone that corresponds to areas outside the 500-year floodplain, areas within the 500-year floodplain but not the 100-year floodplain (X500), and to areas of 100-year flooding where average depths are less than 1 foot, areas of 100-year flooding where the contributing drainage area is less than 1 square mile, and areas protected from the 100-year flood by levees. No base flood elevations or depths are shown within this zone. Flood insurance is generally not mandatory in these zones.

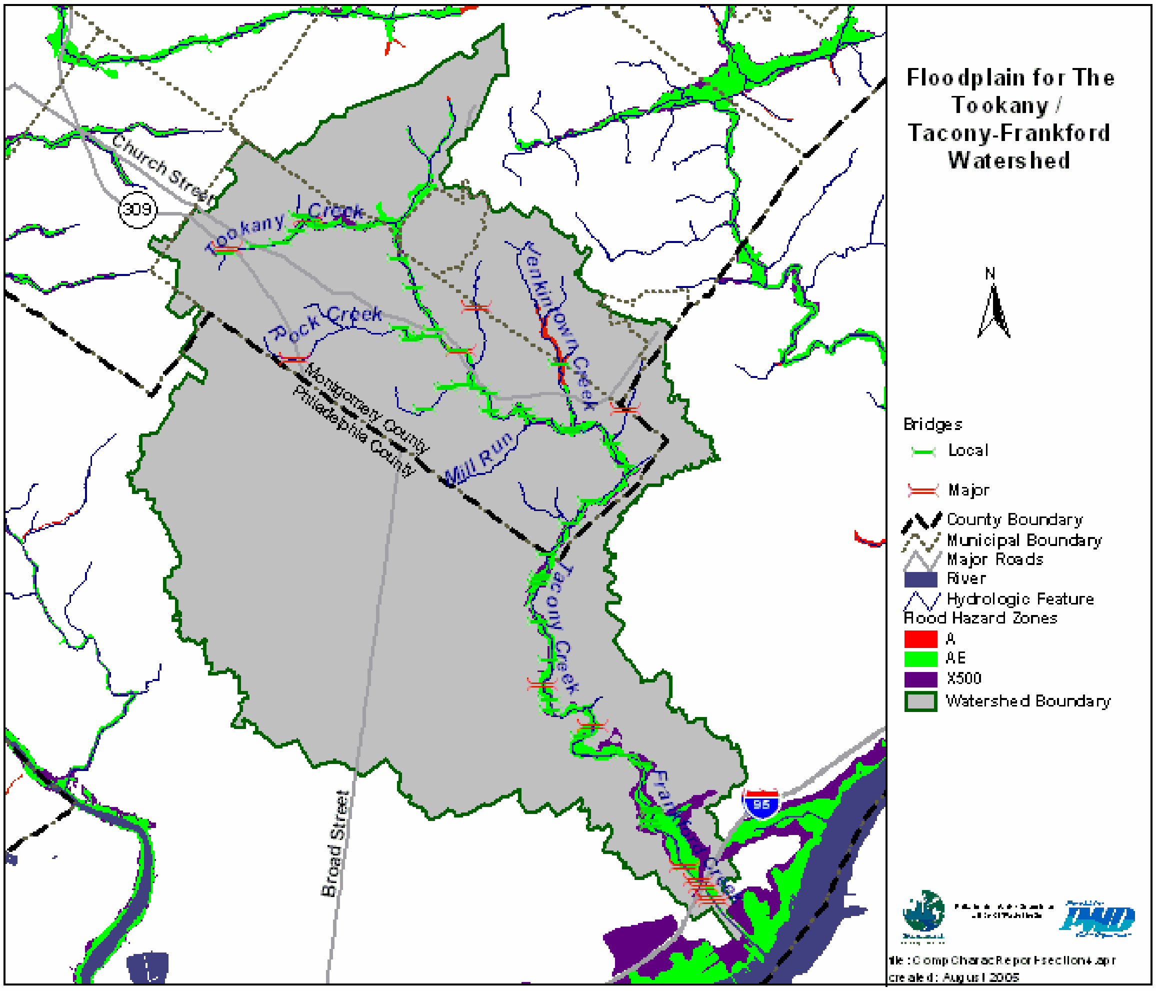


Figure 4-15 FEMA Flood Insurance Rates and Possible Flooding Areas

Table 4-11 Potential Flooding Locations Identified by County FEMA Studies

County	Sheet	Creek	River Mile (ft)	Road Crown/Bridge Deck Below 50-Yr Flood Elevation
Philadelphia	42P	Tacony-Frankford	1,300	Conrail (Partially in 10-yr)
Philadelphia	42P	Tacony-Frankford	1,900	Conrail (Partially in 10-yr)
Philadelphia	42P	Tacony-Frankford	6,400	Conrail
Philadelphia	42P	Tacony-Frankford	6,650	Aramingo Avenue
Philadelphia	43P	Tacony-Frankford	8,670	Conrail
Philadelphia	43P	Tacony-Frankford	9,820	Frankford Avenue
Philadelphia	43P	Tacony-Frankford	10,100	Torresdale Avenue
Philadelphia	43P	Tacony-Frankford	13,800	Wingohocking Street
Philadelphia	45P	Tacony-Frankford	19,980	"I" Street (Fully within 10-yr)
Philadelphia	46P	Tacony-Frankford	26,680	Tabor Road
Philadelphia	47P	Tacony-Frankford	31,220	Adams Avenue
Montgomery	280P	Tacony		Footbridge
Montgomery	280P	Tacony		Central Avenue
Montgomery	280P	Tacony		Footbridge
Montgomery	280P	Tacony		Footbridge
Montgomery	280P	Tacony		Jenkintown Road
Montgomery	281P	Tacony		Mill Road
Montgomery	281P	Tacony		High School Road
Montgomery	281P	Tacony		Church Road
Montgomery	282P	Tacony		Footbridge
Montgomery	282P	Tacony		Footbridge
Montgomery	282P	Tacony		Footbridge (within 10-year floodplain)
Montgomery	282P	Tacony		Conrail (within 10-year floodplain)
Montgomery		Jenkintown		Tookany Creek Parkway
Montgomery		Jenkintown		Footbridge

Floodplains and Flooding in the Tookany/Tacony-Frankford Watershed

FEMA's Flood Insurance Study for Philadelphia (FEMA, 1996) indicates that low-lying portions of the greater Philadelphia area have experienced damaging flooding in the past during major tropical events, including Hurricanes Connie and Dianne in August 1955 and Hurricane Agnes in June 1972. A major problem, as the data indicate, is that so much of the

Tookany/Tacony-Frankford Watershed has been developed before the emergence of any floodplain regulations, the most notable of which are the Federal Emergency Management Agency (FEMA) set of minimum floodplain standards, which were modified and made more rigorous in the mid-1990s.

The following text is taken from the Tacony-Frankford Watershed River Conservation Plan:

"Increases in residential development in the upper portion of the watershed, combined with the level topography of the coastal plain, assured that land adjacent to the watershed's streams would experience frequent and devastating floods. Public outcry demanded that the city government address flooding from the Tacony-Frankford Creek and to do something about the deplorable state of the water quality in the stream. Response to this threat to human health and safety resulted in the encapsulation of over half of the watershed into combined sewers that would carry raw sewage and increasing stormwater run-off from the watershed."

According to the Tookany Creek Watershed Management Plan, "In the early 1950s, the PA DEP built a levee along the Tookany Creek to contain the floodwaters to prevent damage to the surrounding homes. This has decreased the severe damage the area once experienced, but the surrounding area roads and some homes continued to flood. In 1978, a pump house was built on Rices Mill Road in Glenside, to curtail the more serious flood events. The Keswick area has experienced flooding as a result of inadequate storm sewer capacity. Many of the storm drains cannot capture and divert the flows in time to prevent flooding in the intersections. Many of the creeks also overflow their banks, causing localized flooding. Abington Township has recently completed a major flood attenuation project in the Baeder Creek sub-watershed due to ongoing and repeated damage."

Section 5
Characterization of Water Quality

5.1 PWD/USGS Cooperative Program (Water Quality and Flow Data)

The purpose of the PWD/USGS study conducted from 1971 to 1980 (described in section 3.4.4) was to quantify the pollutant loads in some of Philadelphia's streams and possibly relate the degradation in water quality to urbanization. Using six stations in the Tookany/Tacony-Frankford Watershed: 01467089 Frankford Creek at Torresdale Ave, 01467087 Frankford Creek at Castor Ave, 01467086 Tacony Creek at County Line, 01467085 Jenkintown Creek at Elkins Park, 01467084 Rock Creek above Curtis Arboretum near Philadelphia, and 01467083 Tacony Creek near Jenkintown (Figure 3-3), monthly "snapshots" of water quality samples were collected and analyzed for conductivity, BOD_5, total phosphate, ammonia, nitrite, nitrate, and fecal coliform.

5.1.1 Qualitative Discussion of PWD/USGS Data

Table 5-1 qualitatively summarizes water quality data collected by the PWD/USGS Cooperative Program. Tables 5-2 and 5-3 present a quantitative summary of this data.

The PWD/USGS Cooperative Program data indicate that total dissolved solids, pH, and nitrite did not appear to have been parameters of concern. Dissolved oxygen concentrations reported represent instantaneous daytime concentrations. This sampling method is not likely to have identified low DO conditions that would have typically occurred in the early morning. Fecal coliform bacteria concentrations often exceeded current standards with mean counts of 10^3 to 10^5 and maximum counts of 10^4 to 10^6. The highest coliform counts were found located furthest downstream at site 9, which correlates with site TF280.

Table 5-1 Qualitative Summary of Water Quality Data Collected 1970-1980

Parameter	Period of Observation	Comments
Discharge	1970-1980	Discharge at the upstream and downstream sites follow the same pattern, with discharge increasing downstream.
Temperature	1970-1980	Water temperature goes through a seasonal cycle and differs very little between cross-sections.
pH	1970-1973	All pH values fall between 6.5 and 8.5.
Specific Conductance	1970-1980	For most measurements, specific conductance was greatest along the mainstem both in and out of the City.
Dissolved Oxygen	1970-1980	Approximately one-quarter of all measurements fell below 6 mg/L in 1970, 1971, 1977, 1978, and 1979. Concentrations at the downstream site were generally lower for all years (the plot from 1980 is based on a small sample size), suggesting that urbanization had an observable affect on dissolved oxygen concentrations during the period. There may have been a slight downward trend in mean concentrations over time.
BOD	1970-1980	Most upstream BOD loads are less than 5 mg/L. Downstream BOD is higher and the mean is around 10 mg/L.
COD	1970-1973	COD concentrations range from about 5 to 37 mg/L at the downstream site and from about 7 to over 200 mg/L at the upstream site.
TOC	1970-1973	TOC concentrations range from about 1 to 11 mg/L at the upstream site and from about 3 to 54 mg/L at the downstream site.
Suspended Solids	1970-1973	Suspended solids are greatest in the downstream location, ranging as high as 800 mg/L. Upstream suspended solids are generally less than 10 mg/L.
Total Dissolved Solids	1970 – 1980	Mean TDS at all sampling sites with data were greater than 230 mg/L.
Organic Nitrogen	1972	The small number of data points available for organic nitrogen concentrations show relatively constant values at all sites with values ranging between 0 .07 and 0.88 mg/L.
Ammonia as Nitrogen	1970-1980	Most ammonia measurements are less than 2 mg/L though downstream peaks have reached as high as 10 mg/L, Downstream values are greater than upstream values for almost all measurements.
Nitrite as Nitrogen	1970-1980	Except for a few peaks, nitrite concentrations were less than 0.1 mg/L at the all locations. Concentrations at downstream locations were higher and reached a maximum of 1 mg/L.
Nitrate as Nitrogen	1970-1980	Nitrate concentrations were greatest at upstream locations with very few exceptions.
Total Phosphate	1970-1980	Concentrations at Site 9 (downstream) are considerably greater than those at Site 8 (upstream), suggesting a considerable input of phosphorus between the two stations. Concentrations at Site 8 appear to have been higher from 1970 to 1972 than later in the decade, with a maximum in 1971 of close to 30 mg/L.
Fecal Coliform	1970-1980	Coliform counts clearly increase from upstream to downstream for all years samples were taken. Upstream counts typically lie between 10^2 and 10^4 col/100 mL, while downstream counts lie between 10^3 and 10^6 col/100 mL. There may have been a slight downward trend over the course of the decade, but very few of the measurements would meet the current standard of 200 mg/L.

Parameter	**Period of Observation**	**Comments**
Aluminum	1970-1973	Few samples of aluminum taken at each location, shows a range of 0.1 to 0.34 mg/L.
Beryllium	1970-1973	All beryllium concentrations measured were less than 0.01 mg/L. (Only 1 sample was available per sampling location)
Cadmium	1970-1973	All cadmium concentrations at the upstream and downstream locations are less than 0.03 mg/L. The upstream samples were greater than the downstream peaks.
Calcium	1970-1973	The upstream and downstream concentrations follow the same pattern. The furthest downstream concentrations are greatest.
Chromium	1970-1973	Upstream and downstream concentrations range from 0.01 to 0.9 mg/L. In 1971, samples from the most downstream location have the highest values. In 1972 and 1973, the upstream location generally has the highest values.
Cobalt	1970-1973	All cobalt concentrations are less than 0.001 mg/L except for one value at the most downstream location of 0.05 mg/L.
Copper	1970-1973	Most of the copper concentrations are less than 0.05 mg/L. The downstream location reached about 0.5 mg/L for one sample.
Iron	1970-1973	All the measured iron concentrations at Sites 7 and 8 are less than 0.6 mg/L except in April 1973. The downstream concentrations are greater than upstream concentrations and reached over 2 mg/L.
Lead	1970-1973	All the measured lead concentrations at Sites 7 and 8 are less than 0.07 mg/L. The downstream concentrations are greater than upstream concentrations and reached 0.7 mg/L.
Magnesium	1970-1972	The concentrations vary between approximately 10 and 18 mg/L. The downstream and upstream concentrations have similar shapes.
Manganese	1972-1973	The upstream concentrations of manganese are generally greater than the downstream concentrations.
Nickel	1970-1973	Measured nickel concentrations are less than 0.01 mg/L (plotted as half the detection limit) during the study period.
Silver	1970-1973	Only 1 silver concentration was measured at each location, all were less than 0.001 mg/L. These values were not graphed.
Zinc	1970-1973	Other than a few peaks at Sites 7 and 8, downstream concentrations of zinc are greatest.

Table 5-2 Statistical Summary of Water Quality Parameters 11/9/70-1/7/80

Site	Statistic	Flow (cfs)	Temp. (°C)	DO (mg/L)	BOD (mg/L)	COD (mg/L)	TOC (mg/L)	Spec. Cond. (mhos)	TDS (mg/L)	TSS (mg/L)	pH	TP (mg/L)	ON (mg/L)	NH_3 (mg/L)	NO_2 (mg/L)	NO_3 (mg/L)	Fecal Col. (col/100 mL)
7	N	55	54	55	52	36	30	52	13	35	33	55	2	54	55	55	55
7	MIN	0.49	0	7	0.4	4.6	1	171	175	1	6.4	0.05	0.11	0.04	0.01	0.18	4.00E+01
7	MAX	17.4	23	16.8	17.7	36.6	11	1230	276	47	8.3	4.96	0.72	1.64	0.23	5.16	2.20E+05
7	MEAN	2.09	12.5	10.4	2.74	13.2	5.1	421	239	6.46	7.44	0.51	0.42	0.33	0.042	3.15	9.52E+03
7	STD	3.05	6.69	2.19	2.65	7.43	2.26	162	29.9	10.3	0.48	0.67	0.43	0.32	0.038	1.23	3.13E+04
8	N	106	106	109	97	35	30	106	13	35	33	107	2	104	108	108	106
8	MIN	0.95	0	2.5	0.2	4	1	131	150	0	6.4	0.06	0.08	0.01	0.006	0.73	1.00E+02
8	MAX	1150	26	17.2	9.8	26.8	10	924	299	166	8.8	2.77	0.6	5.71	1	6.03	5.30E+04
8	MEAN	34.6	12	10.8	2.77	11.7	5.3	408	243	11.8	7.62	0.34	0.34	0.31	0.037	2.75	5.57E+03
8	STD	114	7.56	2.4	1.88	6	2	134	51.8	31	0.59	0.36	0.37	0.76	0.097	0.95	1.02E+04
9	N	106	106	104	97	36	30	104	13	35	32	106	2	102	105	106	104
9	MIN	3	0	0	0.6	7.2	3	118	137	2	6.4	0.07	0.07	0.03	0.014	0.15	2.50E+01
9	MAX	1210	27.5	15.1	80.4	217	54	1160	461	807	8.3	27.2	0.88	9.8	0.29	5.94	2.58E+06
9	MEAN	50.7	12.9	8.91	10.2	49.8	13.5	439	286	52.7	7.51	2.04	0.48	1.19	0.073	2.02	1.46E+05
9	STD	132	7.89	2.93	11.6	52.8	12.1	163	89.1	162	0.47	3.48	0.57	1.71	0.055	1.05	4.04E+05
18	N	20	20	20	17	0	0	18	0	0	0	20	0	19	20	20	20
18	MIN	0.1	0	7.5	0.6	N/A	N/A	62	N/A	N/A	N/A	0.02	N/A	0.03	0.006	0.5	2.00E+01
18	MAX	91	23.5	13.9	7.3	N/A	N/A	313	N/A	N/A	N/A	0.69	N/A	0.4	0.031	7.04	7.10E+04
18	MEAN	11.3	11.2	10.8	2.65	N/A	N/A	231	N/A	N/A	N/A	0.18	N/A	0.12	0.016	3.08	7.00E+03
18	STD	25.7	6.96	2.16	1.89	N/A	N/A	57	N/A	N/A	N/A	0.18	N/A	0.11	0.006	1.28	1.82E+04
19	N	20	20	20	17	0	0	18	0	0	0	20	0	19	20	20	20
19	MIN	0.9	0	7.5	0.5	N/A	N/A	247	N/A	N/A	N/A	0.05	N/A	0.06	0	1.3	1.00E+02
19	MAX	53	23.5	15.7	14.8	N/A	N/A	619	N/A	N/A	N/A	0.74	N/A	1.03	0.066	8.34	2.80E+04
19	MEAN	9.51	10.9	10.9	3.41	N/A	N/A	435	N/A	N/A	N/A	0.2	N/A	0.2	0.028	3.33	2.94E+03
19	STD	11.8	7.15	2.4	3.37	N/A	N/A	117	N/A	N/A	N/A	0.16	N/A	0.23	0.016	1.53	6.25E+03

Notes

- N = number of samples; STD = standard deviation
- Spec. Cond. = specific conductance; TP = total phosphorus; ON = organic nitrogen
- N/A indicates that no samples were collected.

Table 5-3 Statistical Summary of Metals Concentrations 11/9/70-10/1/73

Site	Statistic	Zn (mg/L)	Ca (mg/L)	Mg (mg/L)	Fe (mg/L)	Ni (mg/L)	Cd (mg/L)	Cu (mg/L)	Cr (mg/L)	Co (mg/L)	Mn (mg/L)	Pb (mg/L)	Be (mg/L)	Al (mg/L)	Ag (mg/L)
7	N	34	7	7	19	6	26	33	35	7	18	28	1	4	1
7	MIN	0.01	14	11	0.05	0.005	0.0005	0.005	0.005	0.005	0.08	0.0005	0.005	0.1	0.0005
7	MAX	0.46	37	18	0.82	0.005	0.02	0.03	0.51	0.005	4.02	0.07	0.005	0.22	0.0005
7	MEAN	0.097	31.6	14.3	0.27	0.005	0.0022	0.0068	0.049	0.005	0.48	0.012	0.005	0.16	0.0005
7	STD	0.099	7.98	2.29	0.17	0	0.004	0.0046	0.1	0	0.9	0.014	N/A	0.049	N/A
8	N	32	8	8	19	5	25	32	35	7	18	27	1	4	1
8	MIN	0.02	19	10	0.07	0.005	0.0005	0.005	0.005	0.005	0.05	0.0005	0.005	0.12	0.0005
8	MAX	0.9	40	17	1.68	0.005	0.02	0.02	0.12	0.005	0.79	0.05	0.005	0.21	0.0005
8	MEAN	0.12	32.4	14.3	0.34	0.005	0.006	0.0072	0.019	0.005	0.21	0.013	0.005	0.15	0.0005
8	STD	0.16	7.67	2.19	0.37	0	0.0056	0.0046	0.028	0	0.19	0.013	N/A	0.042	N/A
9	N	34	7	7	19	6	26	34	36	7	18	28	1	4	1
9	MIN	0.02	27	11	0.37	0.005	0.0005	0.005	0.005	0.005	0.09	0.0005	0.005	0.14	0.0005
9	MAX	0.75	44	17	2.2	0.005	0.029	0.5	0.85	0.05	0.85	0.68	0.005	0.34	0.0005
9	MEAN	0.17	36.9	14.6	0.68	0.005	0.0074	0.029	0.053	0.011	0.3	0.094	0.005	0.23	0.0005
9	STD	0.16	5.52	2.23	0.47	0	0.0073	0.085	0.15	0.017	0.21	0.16	N/A	0.1	N/A

Notes

- Concentrations below the detection limit were most likely reported as equal to the detection limit, resulting in a standard deviation of zero for some parameters.
- N/A indicates that the sample size was too small to calculate a standard deviation.

5.1.2 PWD Water Quality Monitoring Program

To supplement historical data, PWD's Office of Watersheds (OOW) conducted an extensive sampling and monitoring program to characterize the current conditions of the Tookany/Tacony-Frankford Watershed. The program was designed to document the condition of aquatic resources, provide information for the planning process needed to meet regulatory requirements imposed by EPA and PA DEP, and monitor long term trends as implementation of the TTFIWMP proceeds.

Two types of water quality sampling were carried out by PWD in the Tookany/Tacony-Frankford Creek, including discrete sampling before and during wet weather events, and continuous sampling. Figure 5-1 presents the locations of each sampling site and the subshed area draining to that monitoring location. Discrete sampling was performed from June 2000 through December 2004. Wet weather sampling involved the collection of discrete samples before and during a wet weather event, allowing the characterization of water quality responses to stormwater runoff and sanitary and combined sewer overflows. From March 2001 through October 2003, PWD captured data for 12 wet weather events. The second type of sampling to be conducted was continuous water quality monitoring, carried out by introducing YSI 6600 and 600XLM Sondes, shallow depth continuous water quality monitors, and probes that record dissolved oxygen, pH, and turbidity readings. The equipment was deployed to three locations periodically for a number of days to collect continuous data samples and observe water quality fluctuations. The Sonde data for the Tookany/Tacony-Frankford Watershed included over 80 deployments.

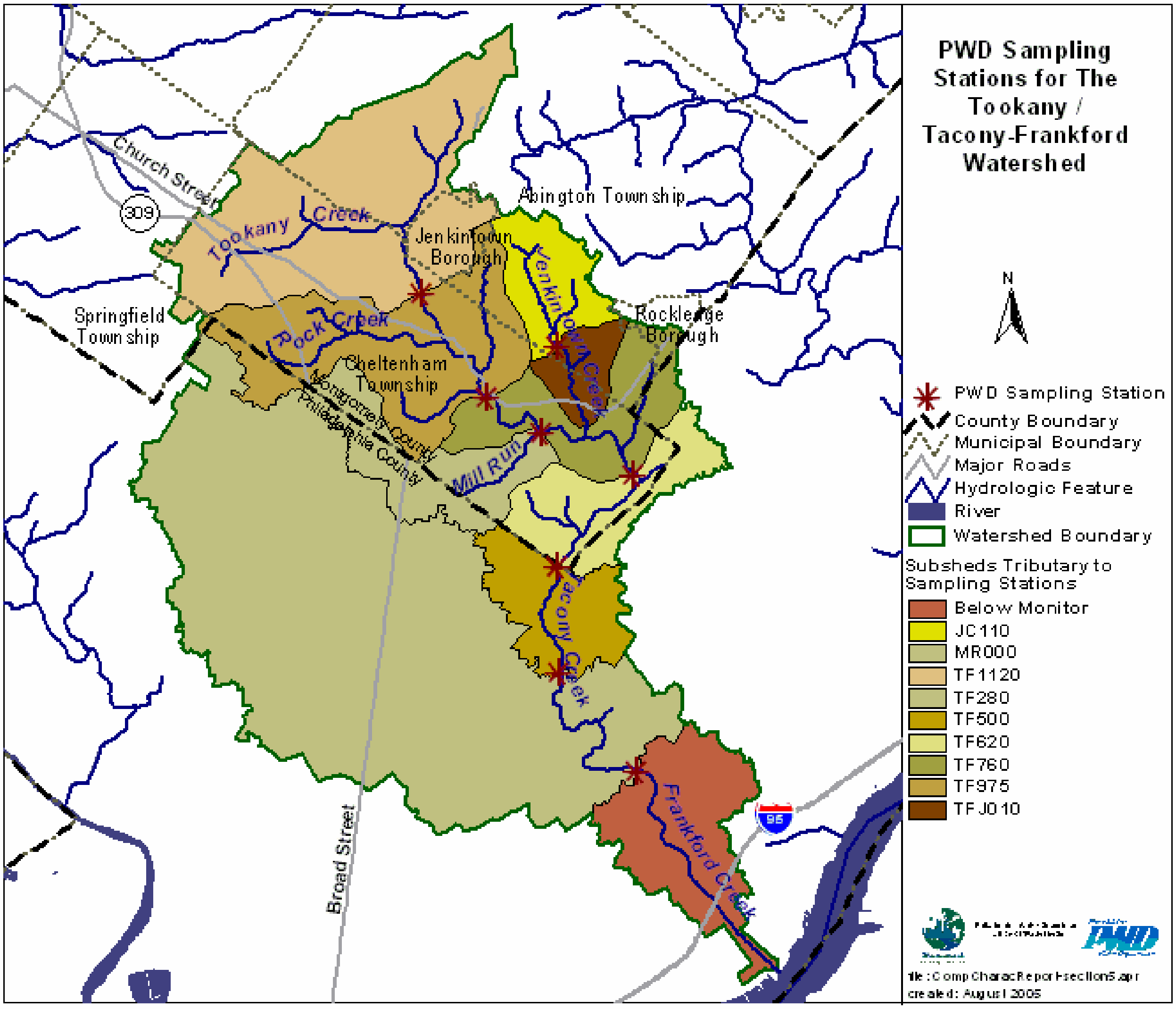


Figure 5-1 Eight Water Quality Monitoring Locations the Tookany/Tacony-Frankford Watershed (Area below monitor represents tidal unassessed portion of the creek)

5.2 Water Quality Analysis for Data Collected from 2000-2004

From 2000 through 2004, PWD has collected water quality data for sampling locations in the Tookany/Tacony-Frankford Watershed. Tables 5-4 thru 5-6 provide a basic, statistical profile of the data from this recent water quality monitoring program. Tables 5-4 and 5-5 provide data from the discrete monitoring program and table 5-6 provides data from the continuous monitoring program. Sample results were compared to relevant PA DEP general water quality criteria to provide an initial impression of which parameters might need further investigation. Applicable relevant standards include water uses to support a potable water supply, recreation and fish consumption, human health, and aquatic life to support warm water fishes.

In addition to the basic statistical profile, Tukey plots of water quality parameters from the 1970s USGS/PWD study and the more recent data are provided in Appendix A.

Table 5-4 Dry Weather Water Quality Summary - Parameters with Standards

Parameter	Standard	Target Value	Units	No. Obs.	Percentiles						No. Exceeding	% Exceeding
					0	25	50	75	90	100		
Al	Acute Maximum	0.75	mg/L	149	0	0.02	0.04	0.06	0.098	0.57	0	0
Al	Chronic Maximum	0.087	mg/L	149	0	0.02	0.04	0.06	0.098	0.57	15	10.1
Alk	Minimum	20	mg/L	130	21	65	72	77	81	89	0	0
BOD$_{30}$	No Standard	--	mg/L	98	2	3.41	4.15	5.24	8.1	100	0	0
BOD$_5$	No Standard	--	mg/L	130	0.3	2	2	2	2.185	20.4	0	0
Chl-*a* (water column)	Maximum	3	ug/L	30	0.63	1.12	3.04	6.65	38.576	127.92	15	50
Diss Cd	Acute Maximum	* 0.0043	mg/L	83	0	0	0	0	0.001	0	0	0
Diss Cd	Chronic Maximum	* 0.0022	mg/L	83	0	0	0	0	0.001	0	0	0
Diss Cd	Human Health Maximum	0.001	mg/L	83	0	0	0	0	0.001	0	0	0
DissCr	Acute Maximum	0.0015	mg/L	46	0	0	0	0	0.001	0	0	0
Diss Cr	Chronic Maximum	0.001	mg/L	46	0	0	0	0	0.001	0	0	0
Diss Cu	Acute Maximum	* 0.013	mg/L	74	0	0	0.01	0.01	0.006	0.02	0	0
Diss Cu	Chronic Maximum	* 0.0090	mg/L	74	0	0	0.01	0.01	0.006	0.02	1	1.4
Diss Cu	Human Health Maximum	1	mg/L	74	0	0	0.01	0.01	0.006	0.02	0	0
Diss Fe	Maximum	0.3	mg/L	110	0.02	0.05	0.05	0.08	0.133	0.59	3	2.7
Diss Pb	Acute Maximum	* 0.065	mg/L	65	0	0	0	0	0.001	0	0	0
Diss Pb	Chronic Maximum	* 0.025	mg/L	65	0	0	0	0	0.001	0	0	0
Diss Pb	Human Health Maximum	0.005	mg/L	65	0	0	0	0	0.001	0	0	0
Diss Zn	Acute Maximum	* 0.120	mg/L	73	0	0.01	0.01	0.02	0.022	0.24	2	2.7
Diss Zn	Chronic Maximum	* 0.120	mg/L	73	0	0.01	0.01	0.02	0.022	0.24	3	4.1
Diss Zn	Human Health Maximum	5	mg/L	73	0	0.01	0.01	0.02	0.022	0.24	0	0
DO **	Instantaneous Minimum	4	mg/L	133	2.45	8.78	10.08	13.01	14.46	16.21	2	1.5
DO **	Minimum Average	5	mg/L	133	2.45	8.78	10.08	13.01	14.46	16.21	3	2.3
E. coli	No Standard	--	/100mL	144	10	145	290	500	1800	36000	0	0
F	Maximum	2	mg/L	130	0.08	0.1	0.11	0.13	0.168	416	1	0.8
Fe	Maximum	1.5	mg/L	161	0.03	0.08	0.13	0.26	0.513	1.58	1	0.6
Hardness	No Standard	--	mg/L	86	32.4	164	178	191.66	200	214	0	0
Mn	Maximum	1	mg/L	161	0	0.02	0.04	0.06	0.084	0.17	0	0
NH$_3$T	Maximum	(pH dependent)	mg/L	103	0.1	0.1	0.1	0.1	0.2	1.13	0	0
NO$_2$	No Standard	--	mg/L	133	0.01	0.05	0.05	0.05	0.05	0.29	0	0

Parameter	Standard	Target Value	Units	No. Obs.	Percentiles 0	25	50	75	90	100	No. Exceeding	% Exceeding
NO23	Maximum	10	mg/L	204	0.4	2.06	2.45	2.8	3.239	3.54	0	0
NO_3	Human Health Maximum	10	mg/L	133	0.28	2.11	2.49	2.85	3.283	3.59	0	0
pH **	Maximum	9	dimensionless	132	6.85	7.35	7.52	7.64	7.76	8.03	0	0
pH **	Minimum	6	dimensionless	132	6.85	7.35	7.52	7.64	7.76	8.03	0	0
Phenolics	Maximum	0.005	mg/L	37	0.03	0.03	0.03	0.03	0.04	0.04	0	0
PO_4	No Standard	--	mg/L	133	0.04	0.1	0.1	0.1	0.1	0.21	0	0
Sp Cond **	No Standard	--	mg/L	142	227	411	507.5	605	697	1225	0	0
TChl	No Standard	--	mg/L	33	0.75	1.35	1.79	3.96	5.99	12.77	0	0
TDS	Maximum	750	mg/L	92	160	273	317.5	380.5	441	643	0	0
Temp C **	Maximum	(varies)	Deg C	129	0.1	5.5	16.1	20.2	21.8	27.6	9	7
TKN ***	Maximum	0.675	mg/L	124	0	0.3	0.35	0.5	0.616	1.83	11	8.9
TOC	No Standard	--	mg/L	8	1.23	1.3	1.58	1.84	1.99	1.99	0	0
Total Nitrogen ***	Maximum	4.91	mg/L	124	0.87	2.21	2.5	2.91	3.082	3.98	0	0
TP ***	Maximum	0.14	mg/L	138	0	0.05	0.05	0.09	0.163	0.69	14	10.1
TSS	Maximum	25	mg/L	104	1	1	1	2	3	24	0	0
Turbidity ***	Maximum	8.05	NTU	129	0.21	0.52	0.67	1.14	2.38	7.76	0	0

* *Water quality standard requires hardness correction; value listed is water quality standard calculated at 100* mg/L *CaCO3 hardness.*
** *These values are hand probe readings taken at the time of grab sampling.*
*** *Reference values from EPA 822-B-00-019*

Table 5-5 Wet Weather Water Quality Summary - Parameters with Standards

Parameter	Standard	Target Value	Units	No. Observations	Minimum	25th Percentile	Median	75th Percentile	90th Percentile	Maximum	No. Exceeding	% Exceeding
Al	Acute Maximum	0.75	mg/L	552	0.00167	0.071	0.17125	0.5855	2.158	19.346	120	21.74
Alk	Minimum	20	mg/L	562	14	43	56.5	70	77	91	7	1.25
BOD_{30}	No Standard	--	mg/L	150	1.96	4.57	6.29	10.9	21.34	125.4	0	0.00
BOD_5	No Standard	--	mg/L	567	1.95	2	3.45	6.62	14.4	147.3	0	0.00
Chl-*a* (Water Column)	Maximum	3	ug/L	62	0.55	1.44	2.645	4.5	16.04	75.62	27	43.55
Diss Cd	Acute Maximum	* 0.0043	mg/L	194	0.001	0.001	0.001	0.001	0.001	0.001	0	0.00
Diss Cd	Human Health Maximum	0.001	mg/L	194	0.001	0.001	0.001	0.001	0.001	0.001	0	0.00
Diss Cr	Acute Maximum	0.0015	mg/L	76	0.001	0.001	0.001	0.001	0.001	0.001	0	0.00
Diss Cu	Acute Maximum	* 0.013	mg/L	81	0.002	0.005	0.007	0.008	0.011	0.015	6	7.41
Diss Cu	Human Health Maximum	1	mg/L	81	0.002	0.005	0.007	0.008	0.011	0.015	0	0.00
Diss Fe	Maximum	0.3	mg/L	199	0.024	0.064	0.097	0.156	0.229	0.701	11	5.53
Diss Pb	Acute Maximum	* 0.065	mg/L	76	0.001	0.001	0.001	0.001	0.001	0.003	0	0.00
Diss Pb	Human Health Maximum	0.005	mg/L	76	0.001	0.001	0.001	0.001	0.001	0.003	0	0.00
Diss Zn	Acute Maximum	* 0.120	mg/L	56	0.003	0.0065	0.011	0.017	0.026	0.263	1	1.79
Diss Zn	Human Health Maximum	5	mg/L	56	0.003	0.0065	0.011	0.017	0.026	0.263	0	0.00
DO**	Minimum Average	4	mg/L	232	1.99	8.06	9.21	11.335	13.13	17.29	6	2.59
DO**	Instantaneous Minimum	5	mg/L	232	1.99	8.06	9.21	11.335	13.13	17.29	4	1.72
E. coli	No Standard	--	/100mL	628	0	1500	4700	20000	69000	1820000	0	0.00
F	Maximum	2	mg/L	564	0.0675	0.098	0.104	0.121	0.151	0.888	0	0.00
Fe	Maximum	1.5	mg/L	610	0.0403	0.224	0.419	1.269	4.195	50	139	22.79

Parameter	Standard	Target Value	Units	No. Observations	Minimum	25th Percentile	Median	75th Percentile	90th Percentile	Maximum	No. Exceeding	% Exceeding
Hardness	No Standard	--	mg/L	468	0.71	94.1	127	162	182.394	282	0	0.00
Mn	Maximum	1	mg/L	611	0.0076	0.037	0.071	0.139	0.283	3.054	13	2.13
NH_3T	Maximum	(pH dependent)	mg/L	196	0.1	0.1	0.113	0.205	0.398	2.98	0	0.00
NO_2	No Standard	--	mg/L	604	0.01	0.05	0.05	0.05	0.076	0.366	0	0.00
NO23	Maximum	10	mg/L	670	0.089	1.0045	1.6635	2.15	2.423	3.22	0	0.00
NO_3	Human Health Maximum	10	mg/L	604	0.249	1.023	2.1855	1.6545	2.47	3.27	0	0.00
pH**	Maximum	9	dimensionless	238	6.61	7.23	7.39	7.53	7.64	8.01	0	0.00
pH**	Minimum	6	dimensionless	238	6.61	7.23	7.39	7.53	7.64	8.01	0	0.00
Phenolics	Maximum	0.005	mg/L	117	0.03	0.03	0.04	0.04	0.042	0.187	14	11.97
PO_4	No Standard	--	mg/L	603	0.04	0.1	0.1	0.1	0.1	0.423	0	0.00
Sp Cond**	No Standard	--	mg/L	243	76	249	381	516	658	1897	0	0.00
TChl	No Standard	--	mg/L	76	0.66	1.435	2.37	4.925	17.06	83.25	0	0.00
TDS	Maximum	750	mg/L	184	56	158.5	230.5	307.5	398	1054	2	1.09
Temp C**	Maximum	varies	degC	238	0.5	8	13.9	19.8	21.7	24.7	6	2.52
TKN ***	Maximum	0.675	mg/L	524	0.154	0.5	0.752	1.21	2.97	15.9	295	56.30
TOC	No Standard	--	mg/L	5	1.35	1.51	1.54	1.82	1.832	1.832	0	0.00
Total Nitrogen ***	Maximum	4.91	mg/L	524	0.056	2.087	2.5705	3.0575	4.269	17.136	35	6.68
TP ***	Maximum	0.14	mg/L	601	0.001	0.067	0.1137	0.2549	0.557	3.45	242	40.27
TSS	Maximum	25	mg/L	188	1	1	2.6	10	54.5	408	30	15.96
Turbidity ***	Maximum	8.05	NTU	564	0.182	1.775	4.66	12.35	37.6	379	180	31.91

**Water quality standard requires hardness correction; value listed is water quality standard calculated at 100 mg/L CaCO3 hardness*
*** These values are hand probe readings taken at the time of grab sampling.*
**** Reference values from EPA 822-B-00-019*

Table 5-6: Sonde Data Meeting/Exceeding Standards

Parameter	Standard	Type	Period	No. Obs.	No. Exceed	% Exceeding	% Meeting
Sonde DO ave	Minimum Average		03/20/01 - 10/05/04	1540	29	1.88	98
Sonde DO min	Minimum		03/20/01 - 10/05/04	1540	104	6.75	93
Sonde Temp C	Maximum		03/20/01 - 10/05/04	177208	23350	13.18	87
Sonde pH mean	Maximum		03/20/01 - 10/05/04	2003	1	0.05	100
Sonde pH mean	Minimum		03/20/01 - 10/05/04	2003	1	0.05	100

5.3 Data Analysis and Water Chemistry

The PWD/USGS Cooperative program recorded a baseline of existing water quality that can now be compared with data collected by PWD from 2000-2004. Sample collection and laboratory techniques were comparable between the two data sets. This comparison allows for a more comprehensive analysis of water quality and the impacts of urbanization on the Tookany/Tacony-Frankford Watershed over the past 30 years.

5.3.1 Dissolved Oxygen

Along with temperature, dissolved oxygen (DO) concentration may be the most important factor shaping heterotrophic communities in streams and rivers. As sufficient DO concentration is critical for fish, amphibians, crustacea, insects, and other aquatic invertebrates, DO concentration is used as a general indicator of a stream's ability to support a balanced ecosystem (TTFIWMP Indicator 9). The Pennsylvania Department of Environmental Protection (PA DEP) has established criteria for both instantaneous minimum and minimum daily average DO concentration. Criteria are intended to be protective of the types of aquatic biota inhabiting a particular lake, stream, river, or segment thereof. Tookany/Tacony-Frankford Watershed is considered a Warm Water fishery (WWF) that cannot support salmonid fish year-round. Furthermore, the stream is not considered appropriate for a put-and-take fishery (*i.e.*, stocking trout to provide recreational opportunities). PA DEP water quality criteria require that minimum DO concentration in a WWF not fall below 4.0 mg/L and that daily averages remain at or above 5.0 mg/L.

Continuous water quality monitoring instruments (YSI Model 6600 and 600XLM Sondes) were deployed periodically at eight sites throughout Tookany/Tacony-Frankford Watershed from 2000 to 2004 to collect data in 15-minute intervals. A total of 1540 days, or the equivalent of over four years of DO data were collected from these monitoring locations. Installing, servicing, and repairing these instruments in an urban environment presented many challenges, as DO membranes were subject to fouling during and after storm events. A protocol for evaluating and rejecting data from intervals when probe failure occurred was developed (Appendix B). Intervals during which probe failure occurred are summarized in Appendix C. Quality of recovered data generally improved as procedures for cleaning and replacing sondes were developed and refined over the course of four years of study (Table 3-12).

When interpreting continuous DO data, one must keep in mind that *in situ* DO probes can only measure dissolved oxygen concentration of water in direct contact with the probe membrane. Furthermore, to obtain accurate measurements, DO probes should be exposed to flowing water or probes themselves must be in motion. Conditions found in urban areas (*e.g.*, severe flows, infrastructure effects, debris accumulation, vandalism, etc.) complicated installation and it was not always possible to situate instruments in ideal locations. Local microclimate conditions surrounding probes and biological growth on probes themselves probably contributed to errors in measurement. It was possible for Sondes situated in subtly different areas of the same stream site to exhibit marked differences in DO concentration due to flow, shading, and local microclimate differences.

DO concentration in Tookany/Tacony-Frankford Watershed was found to be highly variable, both seasonally and spatially, but in general, DO was controlled by temperature, natural community metabolism and inputs of combined sewage and untreated stormwater. As cold water has a much higher capacity for DO than warm water, DO violations were generally restricted to the warmer months. Most serious effects occurred at site TF280, but DO suppression was also observed at sites TF500 and TF620/680 (Table 5-7). Pronounced diurnal fluctuations in DO concentration were observed at sites TF280, TF1120, and TF620/680; most other sites showed only moderate fluctuation due to biological activity. Effects of stream metabolism on DO concentration are addressed in section 5.4-Stream Metabolism.

Site	Parameter	Standard	Reference	Dry Weather			Wet Weather			Comments
				No. Obs.	No. Exceed	% Exceed	No. Obs.	No. Exceed	% Exceed	
TF280	Sonde DO	5mg/L daily avg. 4mg/L min		15072	316	2.10	11439	530	4.63	Potential Problem
	Sonde Turb		8.05 NTU	5192	1045	20.13	7074	3563	50.37	Problem
TF500	Sonde DO	5mg/L daily avg. 4mg/L min		5126	0	0.00	3259	150	4.60	Potential Problem
	Sonde Turb		8.05 NTU	2579	10	0.39	1647	396	24.04	Problem
TF620	Sonde Turb		8.05 NTU	5298	244	4.61	7083	1727	24.38	Problem
	Sonde pH	6-9 inclusive		19380	598	3.09	20510	155	0.76	Potential Problem
TF760	Sonde Turb		8.05 NTU	3623	732	20.20	2710	1411	52.07	Problem
TF975	Sonde Turb		8.05 NTU	9328	360	3.86	9333	2972	31.84	Problem
TF1120	Sonde Turb		8.05 NTU	8972	561	6.25	8862	2722	30.72	Problem
TFJ110	Sonde Turb		8.05 NTU	550	0	0.00	894	251	28.08	Problem
TFM006	Sonde Turb		8.05 NTU	2412	40	1.66	3191	863	27.04	Problem
7th and Cheltenham	Sonde Turb		8.05 NTU	963	1	0.10	182	37	20.33	Problem

5.3.2 Biochemical Oxygen Demand (BOD)

Biochemical oxygen demand is an empirical test that measures depletion of oxygen within a water sample over a period of time due to respiration of microorganisms as well as oxidation of inorganic constituents (*e.g.*, sulfides, ferrous iron, nitrogen species) (Greenberg *et al*. 1992). Inhibitors may be used to prevent nitrification in a Carbonaceous Biochemical Oxygen Demand (CBOD) test, and the test may be carried out over the course of thirty or more days to yield ultimate BOD. The BOD_5 test, in which depletion of DO is measured over a five day period, was applied most consistently to water samples from sites in Tookany/Tacony-Frankford Watershed. BOD is one of the most important input parameters for computer simulation of oxygen demand in water quality models. As warm stream water has a limited capacity for DO, excess BOD may preclude warm water streams from meeting WQ criteria despite re-aeration due to diffusion and algal production of DO.

Tookany/Tacony-Frankford Watershed is not affected by municipal wastewater treatment plants or other permitted discharges that would introduce BOD to the stream. Elevated BOD_5 is thus a good indicator of the presence of organic material in stream water that may exert oxygen demand independently of natural stream metabolism. CSO and SSO discharges were believed to be the most important sources of wet weather BOD loading to Tookany/Tacony-Frankford Watershed. Elevated dry weather BOD_5 values were observed frequently at site TF280, and occasionally at sites TF975 and TFM006, suggesting the presence of sewage in dry weather. These results corroborate other sewage indicators observed at these sites (*e.g.*, fecal coliform bacteria, ammonia). Activities recommended to meet target A of the TTFIWMP will address these high priority sources.

Evaluation of BOD_5 results in a watershed where most sources exhibit spatial and temporal variability is difficult. The BOD_5 test provides little information when samples are dilute (MRL= 2mg/L), which is often the case in dry weather samples from streams lacking point source discharges or other sources of organic enrichment (87% of dry weather samples and 28% of wet weather samples had BOD_5 concentration below reporting limits). Analysts must also determine an appropriate series of dilution ratios without *a priori* knowledge of the sample's potential to deplete oxygen. For this reason, 4% of samples were reported as minimum values (*i.e.*, actual values were known to be greater than the value reported but the dilution sequence did not allow computation of an actual value); all samples in which BOD_5 concentration were reported as minimum values were collected in wet weather.

As BOD_5 concentration data were affected by a large number of imprecise values, nonparametric statistics were used in comparing between sites and evaluating wet weather effects. In the latter analysis, data from all sites were combined, non-detects were included as half the method reporting limit (MRL), and minimum values were included as if they were actual values. BOD_5 concentration was found to be significantly greater in wet weather than in dry weather (Mann-Whitney U test, $Z_{2,689} = -7.27$, $p<0.001$), and there was a significant effect of site in wet weather (Kruskal-Wallis ANOVA, $H_{8,565}= 73.32$, $p<0.001$, (Figure 5-2), which is likely due to frequent CSO discharge at site TF280 (mean wet weather BOD_5 11.79±18.22). Though sampling effort was not equal across sites, mean wet weather BOD_5 data suggest CSO discharge at site TF620/680 (5.98±6.55) and occasional SSO discharge or other sources of organic enrichment at sites TFM006 (7.21±7.84), TF975 (4.95±5.74) and TF1120 (4.13±3.89).

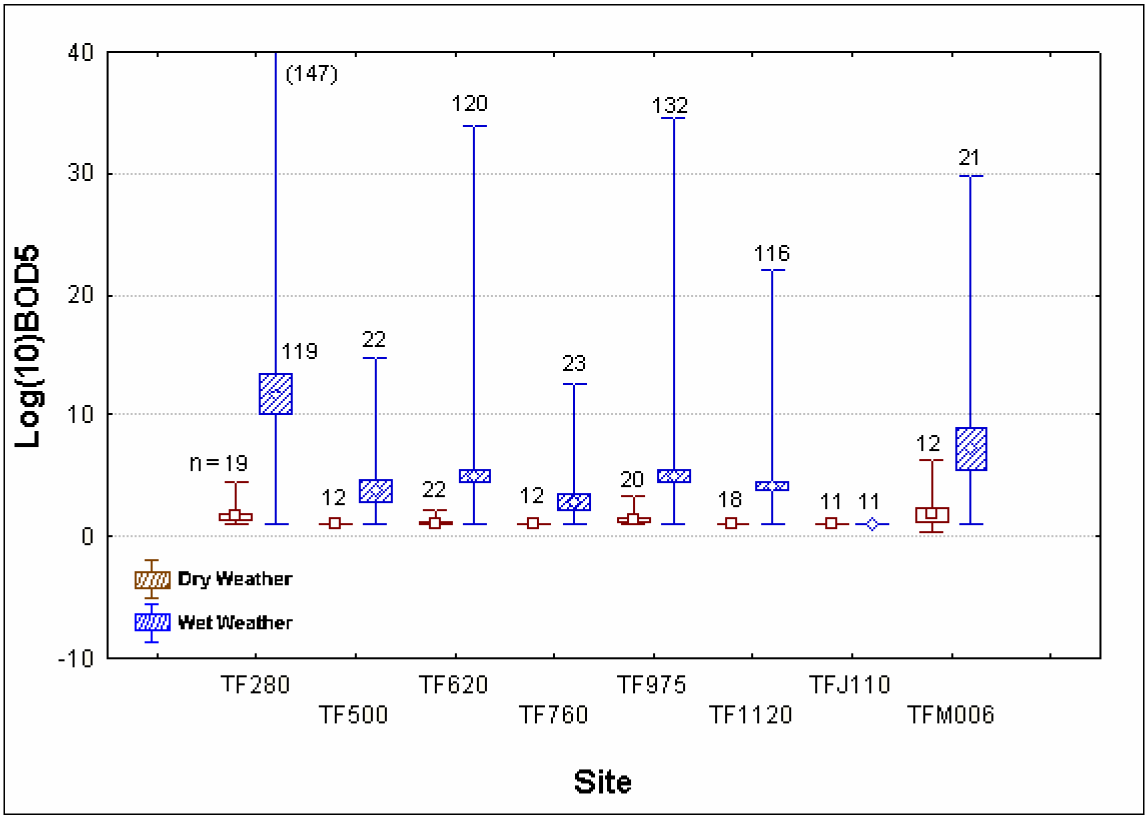


Figure 5-2 Five Day Biological Oxygen Demand of samples collected from 8 sites in Tookany/Tacony-Frankford Watershed in Dry and Wet Weather.

5.3.3 pH

Water quality criteria established by PA DEP regulate pH to a range of 6.0 to 9.0 in Pennsylvania's freshwater streams (Commonwealth of Pennsylvania, 2001). Direct effects of low pH on aquatic ecosystems have been demonstrated in streams affected by acid mine drainage (Butler *et al*. 1973) and by acid rain (Sutcliff and Carrick 1973). Aquatic biota may also be indirectly affected by pH due to its influences on other water quality parameters, such as ammonia. As pH increases, a greater fraction of ammonia N is present as un-ionized NH_3 (gas). For example, ammonia is approximately ten times as toxic at pH 8 as at pH 7. Extreme pH values may also affect solubility and bioavailability of metals (*e.g.*, Cu, Al), which have individually regulated criteria established by PA DEP.

Continuous pH data show that pH fluctuations most often occur at highly productive sites with abundant periphytic algae (Figure 5-3). Pronounced diurnal fluctuations in pH were observed at site TF620, and occasionally at site TF280. These sites occasionally violated water quality criteria by exceeding pH 9.0; minimum pH standards were rarely violated (Table 5-6). pH at shadier sites (*i.e.*, TF500 and sites upstream of site TF680) was probably less strongly influenced by metabolic activity and fluctuations in pH appeared noticeably damped as a result. Algal densities and stream metabolism effects on stream pH are discussed further in section 5.4 Stream Metabolism.

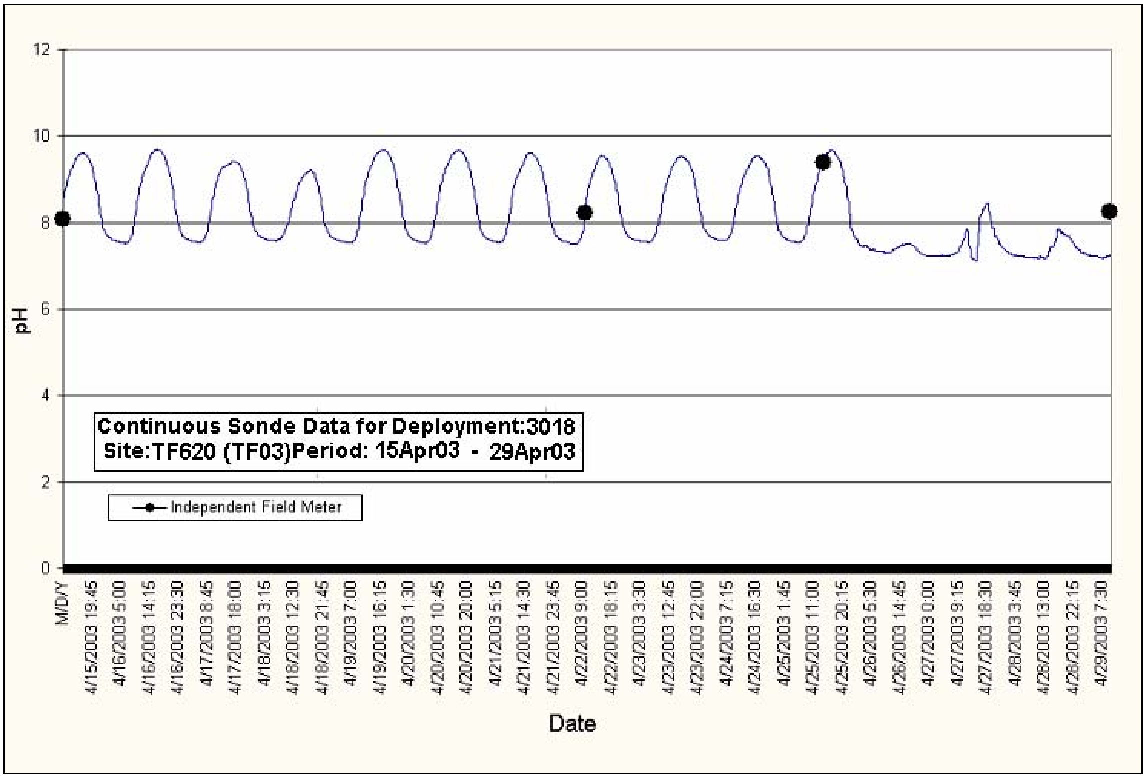


Figure 5-3 Example of pH fluctuations at site TF620, April 2003

Tookany/Tacony-Frankford Watershed is not known to be directly affected by anthropogenic inputs of acids or bases (*e.g.*, acid mine drainage, industrial discharge) that would tend to change stream pH independently of the natural bicarbonate buffer system. Accordingly, the TTFIWMP does not specifically address pH as a separate problem independent of stream eutrophication. Furthermore, as pH problems in Tookany/Tacony-Frankford Watershed are tied closely to DO problems, remediation efforts intended to decrease the frequency and geographic extent of low DO concentrations should generally decrease the severity of pH problems as well. One important caveat, however, is that pH problems may occur at any time of the year when algal production is high. It is possible to have severe fluctuations in DO that do not violate water quality standards due to the greater DO capacity of colder water. While there is a small compensatory effect of lower temperatures on pH toxicity, in general, pH effects may be present under high productivity conditions whenever they occur.

5.3.4 Fecal Coliform and *E. coli* Bacteria

Fecal coliform and *E. coli* bacteria concentrations are positively correlated with point and non-point contamination of water resources by human and animal waste and are used as indicators of poor water quality (Indicator 7, TTFIWMP). PA DEP has established a maximum limit of 200 colony forming units, or "CFU," per 100mL sample during the period 1May - 30Sept, the "swimming season" and a less stringent limit of

2000CFU/100mL for all other times. It should be noted that state criteria are based on the geometric mean of a minimum of five consecutive samples each sample collected on different days during a 30-day period (Commonwealth of Pennsylvania, 2001). As bacterial concentrations can be significantly affected by rain events and otherwise may exhibit high variability, individual samples are not as reliable as replicate or multiple samples taken over a short period.

Based on data from numerous sources (*e.g.*, EPA, USGS, USDA-NRCS, volunteer monitoring organizations, etc.), it appears likely that many, if not most, southeastern PA streams would be found in violation of water quality criteria for fecal coliform bacteria concentration during the swimming season given sufficient sampling effort. PWD has expended considerable resources toward documenting concentrations of fecal coliform bacteria and *E. coli* in Philadelphia's watersheds. The sheer amount of data collected allows for more comprehensive analysis and a more complete picture of the impairment than does the minimum sampling effort needed to verify compliance with water quality criteria. In keeping with the organizational structure of the watershed management plan, fecal coliform bacteria analysis has been separated into dry (Target A) and wet weather (Target C) components, defined by a period with at least 48 hours without rain as measured at the nearest gauge in PWD's rain gauge network.

5.3.4.1 Dry Weather Fecal Coliform Bacteria (Target A)

The geometric mean of 63 fecal coliform bacteria concentration samples collected from Tookany/Tacony-Frankford Watershed in dry weather during the non-swimming season from 2000-2004 did not exceed 2000CFU/100mL (Table 5-8). Only one sample, collected from site TF280, exceeded 2000CFU/100mL (estimated fecal coliform concentration 2100CFU/100mL). In contrast, dry weather geometric mean fecal coliform concentration exceeded water quality criteria of 200CFU/100mL during the swimming season at all sites except TFJ110 (Table 5-9). An improvement in mean fecal coliform concentration can be seen in both swimming and non-swimming season when data from 2000-2004 is compared to historical data from 1970-1980 (t-test $F_{2,140}$= 5.6, p <0.05; $F_{2,163}$ =3.76,p <0.05 respectively)

Table 5-8 Fecal Coliform Concentration (CFU/100mL) Dry Weather Non-swimming Season (1 Oct. - 30 Apr.)

	Valid N	Mean	Geometric Mean	Median	Minimum	Maximum	Std. Dev.
TF280	9	600	286	290	30	2100	777
TF500	8	468	226	330	10	1500	500
TF620	10	259	187	225	30	550	187
TF760	8	139	83	105	10	390	129
TF975	9	408	312	450	90	900	276
TF1120	9	229	186	200	40	410	131
TFJ110	6	55	42	65	10	90	34
TFM006	4	293	231	210	100	650	244

Table 5-9 Fecal Coliform Concentration (CFU/100mL) Dry Weather Swimming Season (1 May - 30 Sept.)

	Valid N	Mean	Geometric Mean	Median	Minimum	Maximum	Std. Dev.
TF280	12	1474	773	425	190	4800	1591
TF500	6	2655	2003	2300	800	6900	2261
TF620	15	833	700	700	340	2700	644
TF760	5	562	514	440	300	1000	275
TF975	13	1620	1130	860	450	6000	1652
TF1120	11	632	541	450	260	1500	409
TFJ110	4	175	173	185	130	200	31
TFM006	8	447	354	365	90	900	298

Collectively, mean fecal coliform bacteria concentration of sites in the City of Philadelphia were significantly higher during the swimming season than during the non-swimming season ($F_{2,68}$= 1.48, p=.000016). Sites in Montgomery County follow the same temporal pattern and have a significantly higher mean during the swimming season ($F_{2,64}$=1.83, p <0.05). This could be due to higher temperatures during the swimming season. Increased temperatures may allow bacteria to persist longer in the water column and in sediments. Additionally, bacteria load may increase in warmer weather as a result of wildlife and dog walking activity. Drought and decreased storm duration/intensity during summer months may also partially explain temporal variability in mean fecal coliform concentration. Greater amounts of rain and snow melt during the non-swimming season may dilute fecal coliform concentrations.

With the exception of intense sampling upstream and downstream of a point source, surface water grab samples do not usually allow one to determine source(s) of fecal contamination. Research has shown that fecal coliform bacteria may adsorb to sediment particles and persist for extended periods in sediments (VanDonsel *et al.* 1967, Gerba 1976). At sites where dry weather inputs of sewage are not indicated, presence of persistent background concentrations of bacterial indicators in dry weather may thus more strongly reflect past wet weather loadings than dry weather inputs (Dutka and Kwan, 1980). Clearly, there exist several possible sources of fecal coliform bacteria within the watershed, all or combinations of which may be acting within different spatial and temporal dimensions. PWD is piloting a Bacterial Source Tracking (BST) program that may eventually be useful in identifying the sources of fecal coliform bacteria collected in dry weather. Of particular interest is the relative proportion of the total bacterial load from human sources vs. domestic and wildlife animal sources.

5.3.4.2 Wet Weather Fecal Coliform Bacteria Concentration (Target C)

Wet weather fecal coliform concentration of 480 samples collected during the swimming season (*i.e.*, 5/1 - 9/30) and 140 samples collected during the non-swimming season were estimated. Geometric mean fecal coliform concentration of all samples collected in wet weather during the swimming season exceeded the 200 CFU/100mL water quality criterion (table 5-10, figure 5-4). All sites except TFJ110 had geometric mean fecal coliform concentration greater than $3\text{x}10^3$ CFU/100mL. Sites TF280 and TFM006 showed evidence of severe wet weather sewage impacts (estimated geometric mean fecal coliform concentration 23,773 and 13,787 CFU/100mL respectively).

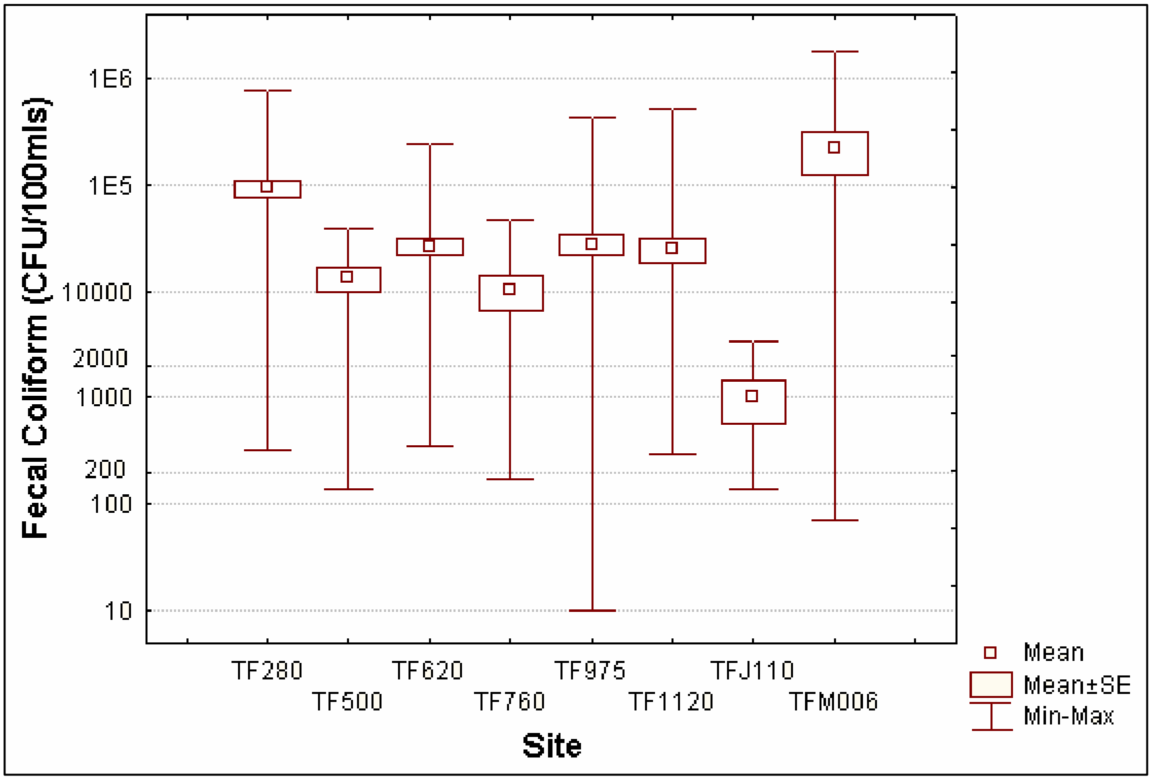


Figure 5-4 Fecal Coliform Bacteria Concentrations of Samples Collected from 8 sites in Tookany/Tacony Frankford Watershed in Wet Weather during the Swimming Season, 2000-2004.

The latter site is located on Mill Run, a historic stream with a drainage area of ca 1mi^2, 52% of which is estimated to be impervious surface. This stream is encapsulated in a storm sewer in Philadelphia, and presently surfaces at stormwater outfall T-88. From 1994 to 1995 PWD investigated 3500 homes within the Mill Run collection area for crossed connections and defective sanitary lateral pipes; although 130 problems were identified and corrected, sewage problems continued. In 2002, PWD sewer maintenance crews installed 6 slot regulators to allow contaminated baseflow in branch storm sewers to be routed to the sanitary sewer. Though subsequent outfall samples collected by PWD's Industrial Waste Unit showed reduced dry weather concentrations of fecal coliform bacteria, large sewage discharges are still reported periodically at the site.

Table 5-10 Fecal Coliform Concentration (CFU/100mL) Wet Weather, Swimming Season (1 May - 30 Sept.)

	Valid N	Mean	Geometric Mean	Median	Minimum	Maximum	Std. Dev.
TF280	104	95132	23774	32000	320	780000	163153
TF500	14	13766	6199	8500	140	40000	13323
TF620	98	27064	8808	8250	350	250000	44437
TF760	14	10446	3357	2950	170	48000	14147
TF975	107	28750	7275	6500	10	430000	61335
TF1120	110	25256	5503	4850	290	520000	66313
TFJ110	8	1004	580	455	140	3500	1219
TFM006	27	223534	15049	11200	70	1820000	497239

Surface water samples collected at site TFM006 in dry weather (n=6) do not indicate severe problems, however, results from a targeted wet weather sampling event 8/30/04-9/1/04 suggest that sewage impacts in wet weather are still a serious problem at this stormwater outfall (Figure 5-5). Source(s) of these sewage inputs remain unknown. PWD's Waterways Restoration Team (WRT) completed a streambank restoration project at this outfall in 2005, and removal of a large plunge pool was one component of the restoration design. It is hoped that reduction of stagnant water will reduce the influence of small wet weather sewage impacts on dry weather fecal coliform concentrations.

Mean wet weather fecal coliform concentration during the swimming season was significantly greater than that of the non-swimming season both within the City of Philadelphia ($F_{2,316}$= 1.11, p <0.05) and in Montgomery County ($F_{2,302}$= 1.35, p= 0.002). However geometric mean fecal coliform concentrations during the non-swimming season exceeded 2,000 CFU/100mL at sites TF280, TF500, TF620, TF975 and TF1120 (tables 5-10 and 5-11 and Figure 5-5). Although few samples were collected in wet weather during the non-swimming season, Sites TFM006 (geometric mean 137, n=2) and TFJ110 (geometric mean 51, n=3) did not exceed water quality standards. Improvements in mean fecal coliform concentration were observed in both the swimming (historical n=22, modern n=482) and non-swimming season when data from 2000-2004 was compared with historical data from 1970-1980 (t-test $F_{2,502}$=1.08, p=.004 and $F_{2,164}$=1.24, p=.002 respectively).

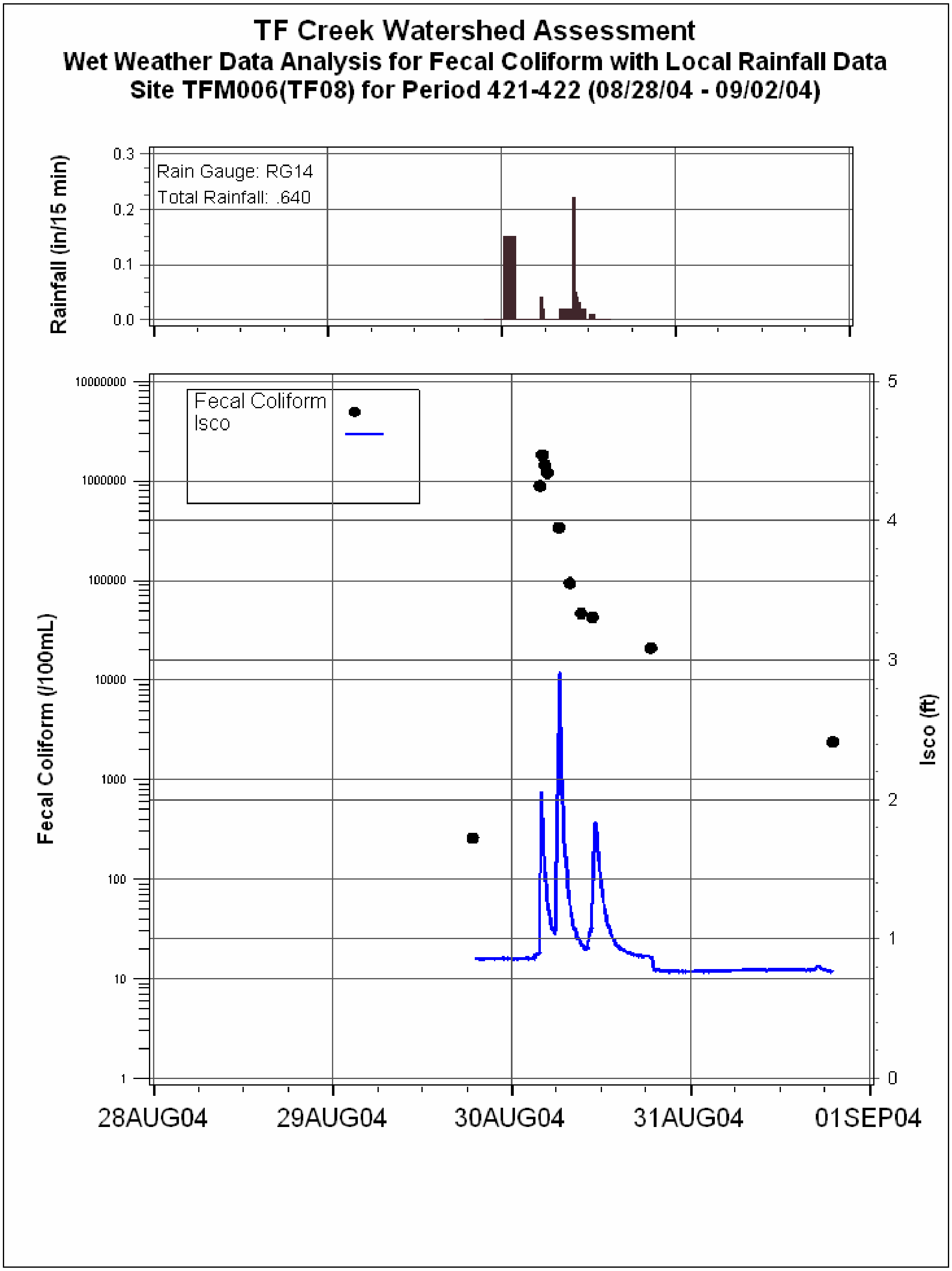


Figure 5-5 Fecal coliform analysis for wet weather event on August 30, 2004 at TFM006

Table 5-11 Fecal Coliform Concentration (CFU/100mL) Wet Weather, Non-swimming Season (1 Oct. - 30 Apr.)

	Valid N	Mean	Geometric Mean	Median	Minimum	Maximum	Std.Dev.
TF280	30	19959	4439	13150	20	70000	22417
TF500	9	14734	2439	3800	140	91000	29570
TF620	34	9038	3397	4000	110	35000	11028
TF760	9	4721	1311	3100	100	22000	6992
TF975	34	10361	3785	4750	100	49000	13111
TF1120	19	11272	3189	6200	50	47000	13559
TFJ110	3	60	51	40	30	110	44
TFM006	2	170	137	170	70	270	141

5.3.5 Temperature

Temperature has a very strong influence on the structure of aquatic communities, determining the saturation concentration of dissolved oxygen and the rate of many biological and physicochemical processes. Though aquatic organisms generally have enzymes capable of working over a range of temperatures, thermal preferenda and tolerance values determine, to a large degree, the range of many species' distributions. This effect is especially true of larger vertebrates, such as fish. Thermal WQ criteria for Tookany/Tacony-Frankford are based on the warm water fishery (WWF) designation, and reflect the fact that the watershed is not expected to have appropriate habitat for maintenance of self propagating populations of coldwater fish (*e.g.*, trout species).

Maximum temperature criteria for WWF vary temporally, but require stream temperatures below 87°F (30.5°C) for the warmest months of the year (*i.e.*, July through August). Heated wastes, such as industrial cooling waters, can neither cause stream temperature to exceed the maximum temperature criterion for a given time period, nor can they result in an increase of 2°F (~1.1°C) over one hour. Continuous water quality monitoring results suggest that temperatures in Tookany/Tacony-Frankford rarely exceed maximum WQ criteria, but increases of 2°F over a one hour period are common due to natural temperature fluctuations (Table 5-6). Flow modifications have probably reduced the influence of groundwater on baseflow water temperature. Dam construction and riparian buffer removal have also probably resulted in enhanced solar heating of stream water. Effects of temperature on fish populations are also discussed briefly in section 8.3 Fish Habitat Indices.

5.3.6 Other Physicochemical Parameters

5.3.6.1 Total Suspended Solids

Sediment transport in small streams is dynamic and difficult to quantify. Numerous factors can affect a stream's ability to transport sediment, but generally sediment transport is related to streamflow and sediment particle size. Stable streams are generally capable of maintaining equilibrium between sediment supply and transport, while unstable streams may be scoured of smaller substrate particles or accumulate fine sediments. The latter effect is particularly damaging to aquatic habitats. PA DEP has identified the cause of impairment in Tookany/Tacony-Frankford to be a combination of "Water/Flow

Variability", "Flow Alterations", and "Other Habitat Alterations". "Siltation" was not listed as a cause of impairment, but the effects of sediment deposition, where and when they occur, are probably addressed by "Other Habitat Alterations".

Water sampling techniques that are adequate to characterize most water quality parameters (*e.g.*, grab samples, automated sampling) are not generally appropriate for evaluating sediment transport in fluvial systems (Edwards and Glysson 1988); errors related to sampling technique should preclude computation of sediment transport during severe storm events that mobilize large streambed particles. TSS concentration (Log transformed) was significantly greater in wet weather than in dry weather ($F_{2,286}$= 8.72, p<0.001).

Maximum daily TSS concentration (log transformed) was found to be significantly positively correlated to average daily streamflow at site TF280 ($r_{(33)}$= 0.85, p<0.001, (Figure 5-6) and instantaneous TSS concentration (log transformed) was positively significantly correlated with instantaneous discharge at all gauged sites in the PWD Historical water quality database (unpublished data). These comparisons of TSS concentration to stream discharge supported the use of TSS concentration as a surrogate measure of the intensity of streamflow and the presence of eroded soil and streambed particles for the purpose of comparing concentrations of certain water quality parameters (*i.e.*, Phosphorus, Nitrate, toxic metals) with intensity of streamflow and soil erosion at stations where USGS gauges have been eliminated.

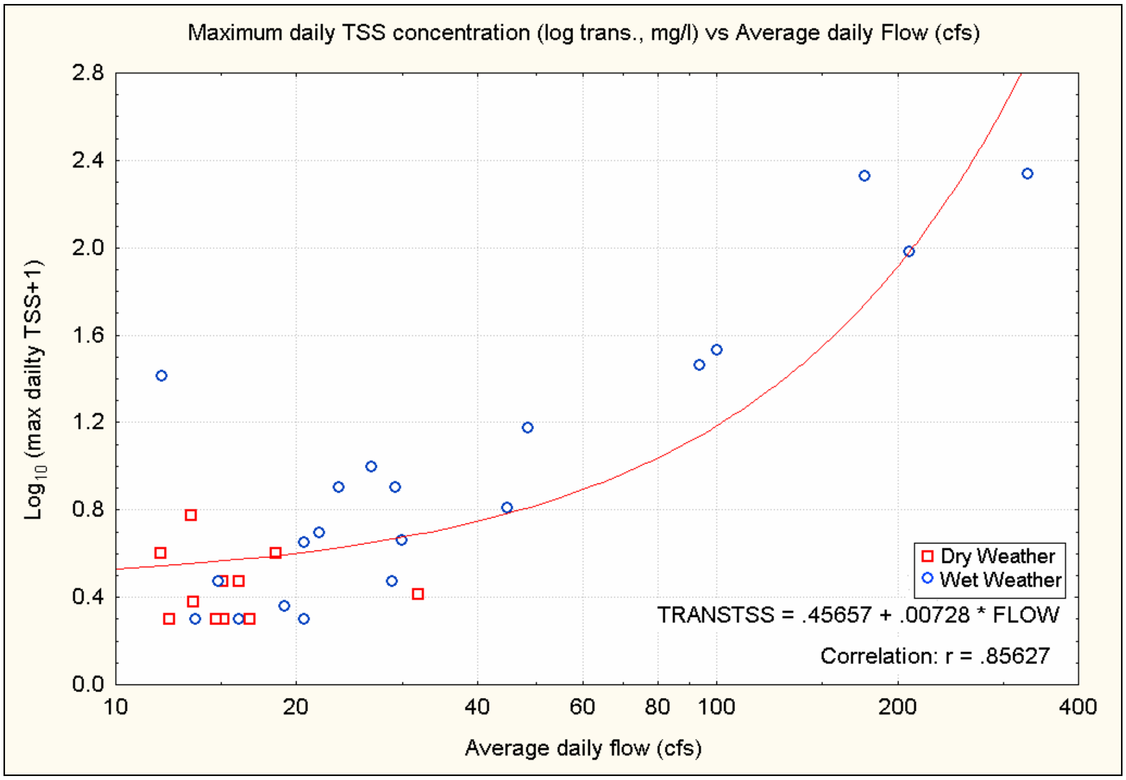


Figure 5-6 Maximum Daily Total Suspended Solids Concentration and Corresponding Average Daily Flow at site TF280.

5.3.6.2 Turbidity

Turbidity is a measure of the light scattering properties of particles suspended in water. In streams, turbidity can come from many sources, but the chief cause of increased turbidity is suspended sediment. While a correlation between turbidity and TSS certainly exists, the relationship between turbidity and TSS may differ between water bodies and even among different flow stages/seasons in the same water body due to sediment characteristics. Consistently turbid waters often show impairment in aquatic communities. Light penetration is reduced, which may result in decreased algal production; suspended particles can clog gills and feeding apparatus of fish, benthic invertebrates, and microorganisms. Feeding efficiency of visual predators may also be reduced.

PA DEP has not established numeric WQ criteria for turbidity, though General Water Quality Criteria (Title 25, Section 93.6) specifically prohibit substances attributable to any point or non-point source in concentrations inimical or harmful to aquatic life. Discharge of substances that produce turbidity are also specifically prohibited. As turbidity may vary considerably from stream to stream, the TTFIWMP uses a reference value of 8.05 NTU to define excess turbidity, based on an analysis of turbidity data from reference reaches in EPA Region IX, subregion 64. All sites in Tookany/Tacony-Frankford were determined to have excess turbidity in wet weather, and many sites were determined to potentially have problems with turbidity in dry weather as well (Table 5-7), though construction activities along SEPTA railroad tracks and within a restoration site in Cheltenham may have contributed excess turbidity in dry weather.

5.3.6.3 Conductivity and Total Dissolved Solids

Conductivity and Total Dissolved Solids (TDS) are measures of the concentration of ions and solids dissolved in water. TDS is an empirical laboratory procedure in which a water sample is filtered and dried to yield the mass of dissolved solids, while conductivity is a measure of the ability of water to conduct electricity over a given distance, expressed as microsiemens/cm (corrected to 25ºC, reported as Specific conductance) (Greenberg *et al.* 1993). With sufficient data, a good relationship between conductivity and TDS can be established. Waters containing large relative proportions of organic ions (*e.g.*, bog or wetland samples containing organic acids) generally have less conductivity for equivalent TDS concentration than waters containing primarily inorganic ions.

Dissolved ion content is perhaps most useful in determining the start of wet weather events at ungauged water quality monitoring stations. Conductivity probes are generally simple in design, robust, and very accurate. They are extremely sensitive to changes in flow, as stormwater (diluent) usually contains smaller concentrations of dissolved ions than stream baseflow. A notable exception to this rule concerns the application of ice melt chemicals to roads (primarily Sodium, Magnesium, and Potassium salts). When present in runoff or snowmelt, these substances can cause large increases in ionic strength of stream water. Though some formulations may increase levels of Chloride, PA DEP WQ criteria for Chloride (maximum 250mg/L) are intended to protect water supplies, and aquatic life effects have not been reliably demonstrated at moderate levels typically experienced in streams.

5.3.6.4 Hardness

Hardness is a calculated water quality parameter. Separate determinations of concentrations of Calcium (Ca) and Magnesium (Mg), which are the two primary cations in surface waters, are combined using the formula 2.497[Ca]+4.118[Mg], the result expressed as an equivalent concentration of $CaCO_3$ in mg/L. Waters of the Commonwealth of Pennsylvania must contain 20mg/L minimum $CaCO_3$ hardness concentration, except where natural conditions are less. No samples collected from Tookany/Tacony-Frankford had hardness concentration below this WQ criterion. Hardness is important in the calculation of WQ criteria for toxic metals (Commonwealth of Pennsylvania, 2001), as toxicity of most metals is inversely proportional to hardness concentration. Potential violations of water quality criteria for some toxic metals (*e.g.*, Cadmium) could not be determined, as hardness concentrations were small enough to decrease WQ criteria below reporting limits for the ICP-MS technique (*i.e.*, less than 1μg/L). These samples are discussed in greater detail in section 5.3.7.

5.3.6.5 Iron and Manganese

Iron (Fe) and Manganese (Mn) are generally not toxic in streams, but are regulated in waters of the Commonwealth of Pennsylvania for public water supply (PWS) protection (Commonwealth of Pennsylvania, 2001) because excess concentrations of these metals can cause color, taste, odor, and staining problems in drinking water and industrial applications. Both elements are essential nutrients for all life and relatively abundant in the soils and surface geology of the Tookany/Tacony-Frankford Watershed. Iron is particularly abundant (at approximately 5% of the Earth's crust it is second only to Aluminum in abundance among metals) and was detected in 746 of 761 samples collected from the Tookany/Tacony-Frankford Watershed. Manganese was less abundant but nevertheless detected in 745 of 762 samples. Presence of these metals in surface water samples may be natural- related to weathering of rock and soils- or due to stormwater runoff and ferrous materials in contact with the stream (*e.g.*, pipes and metal debris).

Violations of total recoverable Fe water quality criteria were frequent in wet weather and Mn criteria were exceeded in a small number (~2%) of samples (Table 5-5). However, neither Fe nor Mn is toxic to aquatic life at concentrations observed, and these constituents cannot be responsible for observed impairments in aquatic communities. Unlike toxic metals (*e.g.*, lead, cadmium and copper), Fe and Mn are not regulated by Pennsylvania Code Title 25, Chapter 16-Toxic Substances Criteria. Scientists from PWD's Bureau of Laboratory Services conducted a large scale case study of Fe and Mn concentrations in Tookany/Tacony-Frankford in 2000 and 2002, results of which are being prepared for publication.

5.3.7 Toxic Metals

Toxic metals have been recognized as having the potential to create serious environmental problems even in relatively small concentrations (Warnick and Bell 1969, LaPoint *et al*. 1984, Clements *et al*. 1988). As such, their presence in waters of the Commonwealth, treatment plant effluents, and other permitted discharges is specially regulated by Pennsylvania Code Title 25, Chapter 16-Toxic Substances Criteria. Considerable research over the past two decades has been directed at understanding the ecotoxicology of heavy metals (*e.g.*, biological pathways, physical and chemical mechanisms for aquatic toxicity, thresholds for safe exposure both acute and chronic, roles of other water quality constituents in bioavailability of toxic metals, etc.).

It is now widely accepted that dissolved metals best reflect the potential for toxicity to organisms in the water column, and many states, including PA, have adopted dissolved metals criteria (40 CFR 22227-22236). As many metals occur naturally in various rocks, minerals, and soils, storm events can expose and entrain soil and sediment particles that naturally contain metals. These inert particles are removed when samples are filtered for dissolved metals analysis (Greenberg *et al*. 1992). Total recoverable metals samples are digested and acidified to liberate organically-bound and complexed metals, but this process may also solubilize metals in inorganic and particulate states that are stable and inert under normal stream conditions, overestimating the potential for toxicity.

However, since it is not possible to filter samples collected with automatic sampling equipment immediately after collection, PWD has collected a greater number of total metals samples than dissolved metals samples. In order to ensure an adequate number of dissolved samples, particularly in wet weather, samples were collected from site TF280 during wet weather on two dates in summer 2004. Samples were collected manually by pumping through the automatic sampling tubing and apparatus and filtered immediately after collection. Site TF280 was sampled to conservatively direct sampling effort to the drainage that would be expected to contain the most potential sources of urban wet weather runoff pollution.

Analysis of paired dissolved/total metals concentration data suggests that most metals are generally found in considerably greater concentrations when total metals are measured, particularly in wet weather. Since dissolved metals concentrations are usually small or undetectable in both dry and wet weather, the potential for heavy metal toxicity in Tookany/Tacony-Frankford, at least for water column organisms, is believed to be low. Sediment and pore water conditions may result in greater concentrations or otherwise contribute to increased potential for toxicity to benthic organisms within stream sediment microhabitats, but these effects remain poorly defined and are difficult to measure. Total recoverable metals results and comparisons to discontinued total metals water quality criteria are included herein as a reference measure of the potential for sediment metal loading and metals loading to the Delaware estuary from Philadelphia's urban stormwater; though it is believed that, for at least some metals, samples more closely reflect natural soil and geologic features than water pollution.

With the exception of Aluminum and hexavalent Chromium, PA WQ criteria are based on hardness (as $CaCO_3$), to reflect inverse relationships between hardness and toxicity that exist for most metals (Figure 5-7). While these criteria are much improved over simple numeric criteria, they fail to describe the complex interactions between dissolved metals and other water constituents and physicochemical properties (*e.g.*, Dissolved Organic Carbon, pH, temperature, and ions other than Ca and Mg,). Hardness-based criteria may represent an intermediate step between simple numeric criteria and criteria based on more complex water quality models (*i.e.*, Biotic Ligand Model), drafts of which have been recently been presented by EPA.

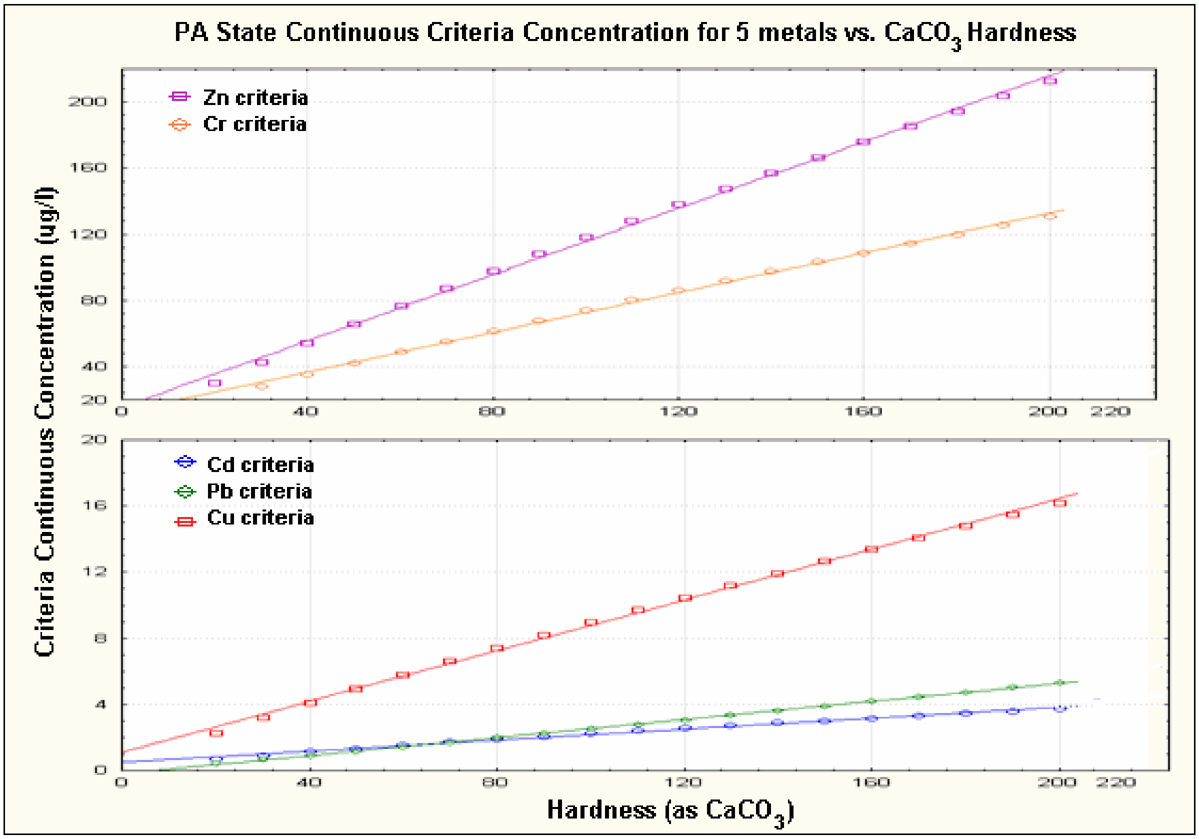


Figure 5-7 PA DEP Hardness-based Criteria Continuous Concentrations for 5 toxic metals.

5.3.7.1 Aluminum

Aluminum (Al) is the most abundant metal in the Earth's crust at approximately 8.1% by mass. As Al is a component of many rocks and minerals, particularly clays, weathering of rocks and soil erosion contribute Al to all natural waters. Water column Al concentrations were significantly higher in wet weather than in dry weather (Mann-Whitney test $Z_{2,699} = -13.28$, $p<.05$), which may be due to both natural and anthropogenic sources. Examination of paired dissolved and total recoverable Al concentrations from 45 samples collected from Tookany/Tacony-Frankford shows that while total recoverable Al concentrations may often exceed 100ug/L in wet weather, dissolved Al is rarely present in similar concentrations (Figure 5-8). This finding suggests that most Al is present in particulate form.

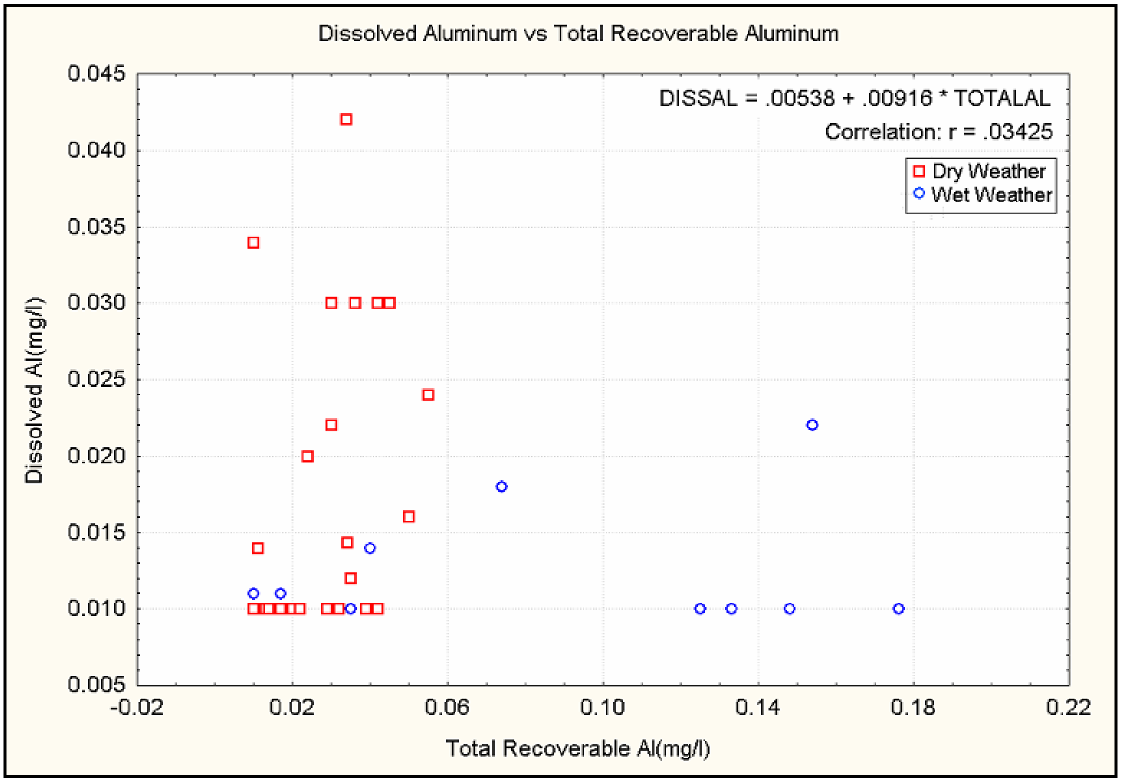


Figure 5-8 Scatterplot of Paired Dissolved Aluminum and Total Recoverable Aluminum Concentrations of Samples collected from 8 sites in Tookany/Tacony-Frankford Watershed, 2000-2004.

Al was detected in 643 of 701 samples from Tookany/Tacony-Frankford (Table 5-12). Though 120 of 135 samples found to be in violation of water quality criteria were collected in wet weather, violations occurred with similar relative frequency in dry and wet weather because wet weather samples were much more numerous overall and dry weather criteria are far more stringent than wet weather criteria (87µg/L and 750µg/L, respectively).

Table 5-12 Summary of Toxic Metals Samples Collected in Dry and Wet Weather and Corresponding Number of Samples Found to have Concentrations Below Reporting Limits

Parameter	Number of Dry Samples	Number of Dry Non-Detects	Number of Wet Samples	Number of wet Non-Detects
Total Aluminum	149	22	552	36
Dissolved Aluminum	55	26	12	7
Total Cadmium	129	129	605	560
Dissolved Cadmium	83	83	194	194
Total Chromium	102	82	548	267
Dissolved Chromium	46	45	76	76
Total Copper	154	0	609	0
Dissolved Copper	74	0	81	0
Total Lead	146	113	605	123
Dissolved Lead	65	65	76	59
Total Zinc	143	8	528	6
Dissolved Zinc	66	12	56	6

The strong correlation between Al and TSS (Figure 5-9) suggests that most of the Al present in wet weather water samples may be due to suspended particulate Al. However, wet weather suspended solids loads consist of a mixture of urban stormwater, eroded upland soils, and streambank particles. It is impossible to determine individual Al contributions of these sources. State water quality criteria for Al are based upon total recoverable fractions rather than dissolved, partially because under experimental conditions, Brook Trout (*Salvelinus fontinalis*) experienced greater mortality with increased total Al concentration despite constant levels of dissolved Al (the form of particulate Al present in this experiment was Aluminum hydroxide, and experimental pH was low). Furthermore, EPA has documented HQ waters that exceed WQ standards for Al (63FR 68353-68364). Al found in natural streams may be predominantly mica and clays, which are inert under normal stream conditions. As the Tookany/Tacony-Frankford Watershed is rich in both mica and clay soils, and rarely experiences pH < 6.0, other factors should probably be ruled out before attributing biological impairment to Al toxicity.

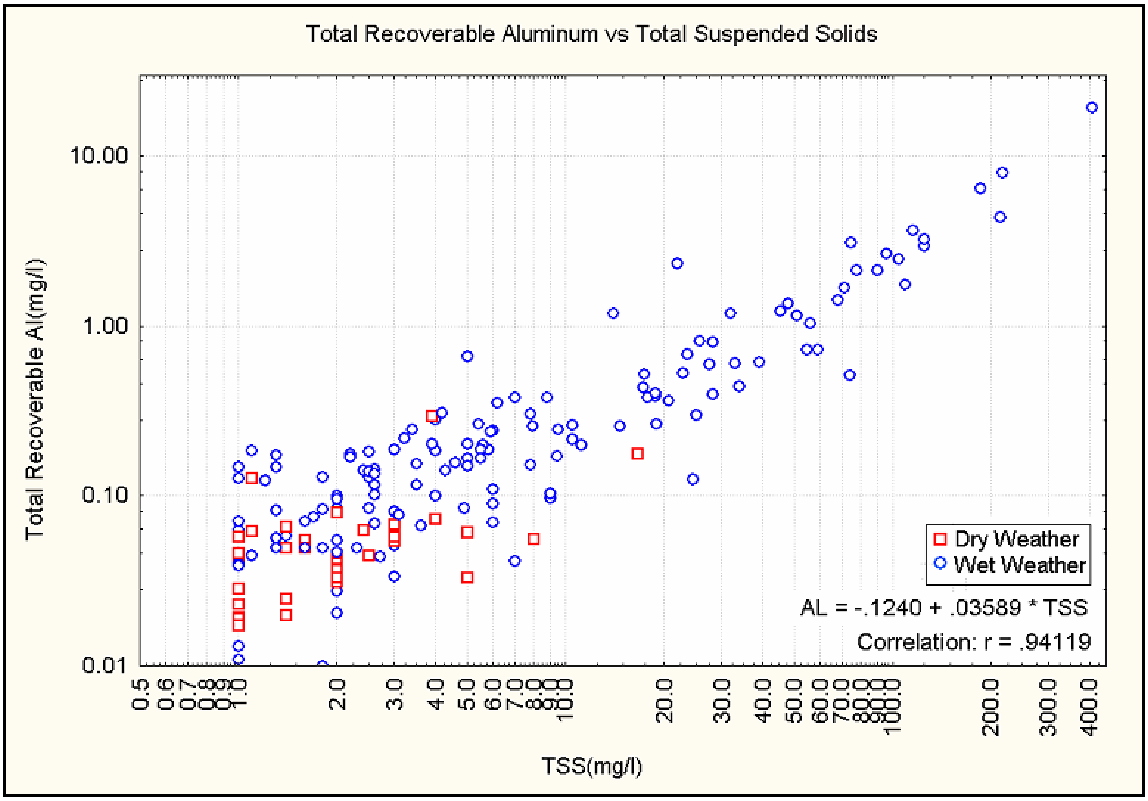


Figure 5-9 Scatterplot of Paired Total Recoverable Aluminum and Total Suspended Solids concentrations of samples collected from 8 sites in Tookany/Tacony-Frankford Watershed, 2000-2004.

5.3.7.2 Cadmium

Cadmium (Cd) is a heavy metal that is widely but sparsely distributed in the earth's crust. Cd is often associated with Zinc (Zn), but may also be found with other metals such as Copper (Cu) and Lead (Pb). For this reason, smelting and other industrial uses of nonferrous metals may be sources of Cd pollution. Other industrial sources include battery, pigment, and plastics manufacturing. Atmospheric deposition and some types of agricultural fertilizers may also contribute Cd to the environment. Cd has no known biological function, and may be toxic in very small concentrations. In aquatic environments, toxicity is assumed to be due to uptake of dissolved Cd, so PA DEP WQ criteria are based on dissolved concentrations.

Cd was rarely detected in water samples from Tookany/Tacony-Frankford Watershed. Though concentrations were nearly always below reporting limits, WQ criteria for Cd reflect the fact that this metal may be toxic in small concentrations. WQ criteria for Cd are calculated based on hardness and Cd concentrations less than 1ug/L may be a violation of water quality criteria in very soft water. Dissolved Cd was detected in only one of 277 samples (Table 5-12); there were no violations of state WQ criteria, but 4 of 276 samples in which Cd concentration was below reporting limits had sufficiently soft water (hardness < 34mg/L in dry weather or <26.5mg/L in wet weather) to lower the sample WQ criterion below the reporting limit.

Total recoverable Cd was only detected in 45 of 734 samples, and only in wet weather (Table 5-12). Of these samples, 15 would have exceeded the former total recoverable WQ criteria that were discontinued in 2001. An additional 14 samples would have had sufficiently soft water (hardness < 34mg/L in dry weather or <26.5mg/L in wet weather) to lower discontinued WQ criteria below the reporting limit. Although sediments and sediment pore water Cd concentrations may be a concern given observed increases in total recoverable Cd during wet weather, dissolved Cd concentrations were always small, and it is unlikely that Cd toxicity is responsible for observed biological impairment in Tookany/Tacony-Frankford.

5.3.7.3 Chromium

Chromium (Cr) is commonly used in alloys of stainless steel and, as Chromate salts, in other metallurgical and industrial applications. Of the two predominant naturally occurring forms, only hexavalent Chromium (Cr[VI]) is toxic, while trivalent Cr (Cr[III]) is an essential trace nutrient; Separate WQ standards exist for Cr[III] and Cr[VI]. Toxic Cr[VI] is much more soluble at normal stream pH than Cr[III] (Rai *et al*. 1989), so at the extremes, dry weather dissolved Cr samples probably more closely reflect actual water column concentrations of Cr[VI], while wet weather total recoverable Cr samples will contain a much greater proportion of insoluble, nontoxic Cr[III]. Despite the influence of other water quality constituents on the speciation and bioavailability of Cr, WQ criteria for Cr[VI] are absolute (CCC=10μg/L, CMC=16μg/L, dissolved fraction only).

Determinations of Cr described herein were obtained with ICP-MS equipment following acid digestion, a method that does not allow for speciation of Cr in either dissolved or total recoverable samples; concentrations were conservatively assumed to be Cr[VI], though the ratio of Cr[III] to Cr[VI] is very likely to be much greater in total recoverable samples as well as in wet weather samples. Dissolved Cr was detected in only one of 122 samples (Table 5-12), and there were no violations of WQ criteria (Table 5-5). Approximately 31 of 650 total recoverable Cr samples would have violated WQ criteria discontinued in 2001.

5.3.7.4 Copper

Copper (Cu) occurs naturally in numerous forms and is present to some degree in most soils and natural waters. Cu is also used industrially for electric wires and coils, as well as in building materials such as roofing and pressure-treated lumber. Cupric Ion (Cu^{2+}) is the bioavailable form of Cu in aquatic systems and its mode of toxicity involves ligand bonding with the gill surface of fish or similar structures of invertebrates. As such, WQ criteria are based on dissolved Cu concentration, which is a better predictor of Cu toxicity than total recoverable metal concentration. Dissolved concentrations are usually much smaller than total recoverable concentrations in natural waters, as Cu forms complexes and ligand bonds with other water column constituents (Morel & Hering, 1993). Cu can also be present in particulate form or be adsorbed to large particles that are trapped by filtering the sample.

Cu was always detectable in Tookany/Tacony-Frankford; all of the 763 samples collected had Cu concentration above reporting limits. Basic statistics for Total Cu and Dissolved Cu appear in (Table 5-12) and outliers excluded from subsequent analyses are tabulated in Appendix D (Contamination was suspected in two samples where the ratio of dissolved to total Cu exceeded 2:1, and also in a dry weather sample at site TF500 where Total Cu concentration was 102µg/L.). Some samples lacked hardness data, so conservative hardness values were substituted for the purpose of comparing observed dissolved Cu to WQ criteria. These substitute hardness values were mean hardness minus one standard deviation, calculated separately for dry and wet weather (hardness data aggregated for all sites and dates).

In 2004, PWD reinstated separate determinations of total and dissolved fractions on metals samples collected as part of the discrete interval sampling program. PWD also conducted two rounds of intensive metals sampling during wet weather at site TF280, which is believed to be the most chemically impaired non-tidal site in the watershed. As of May 2005, 152 paired dissolved and total copper results were available. The ratio of dissolved Cu to total recoverable Cu was significantly higher in dry weather samples than in wet weather samples (t-test, $F_{(2,148)}=2.809$, $p=.000039$). Furthermore, there was no strong relationship between dissolved and total recoverable Cu in wet weather samples (Figure 5-10). Despite total recoverable concentrations that ranged up to 200µg/L, maximum observed concentration of dissolved Cu was 22µg/L.

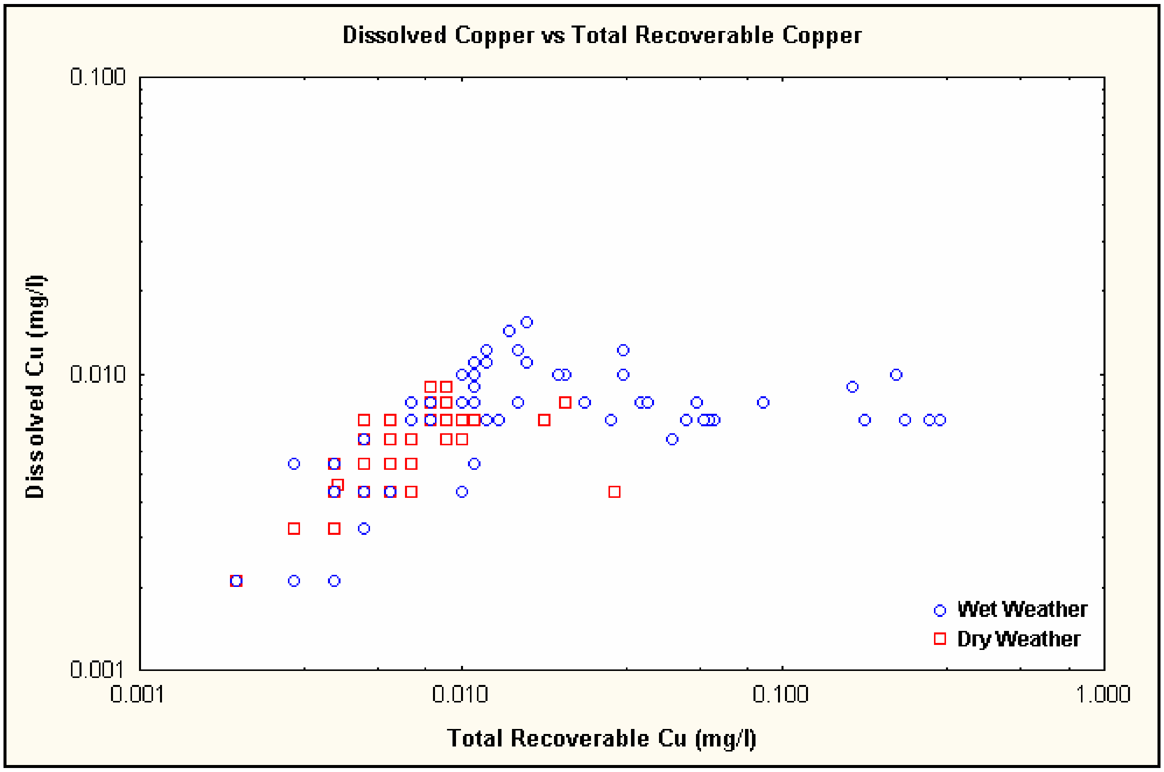


Figure 5-10 Paired Dissolved and Total Recoverable Copper Concentration of Samples Collected from 8 Sites in Tookany/Tacony-Frankford Watershed, 2000-2004.

As Cu strongly associates with sediment, pore water/sediment toxicity should not be ignored as a potential stressor to benthic invertebrates. The only sensitive taxa that were consistently collected throughout the watershed (though densities were low) were tipulid larvae; these relatively large larvae are shredders, and enshroud themselves in leaf packets. A diet and microhabitat rich in organic acids may confer resistance to heavy metal pollution. Mayflies, on the other hand, have been characterized as very sensitive to metals pollution (Clements *et al.* 1988, Clements *et al.* 1990) and the obvious disparity between Tookany/Tacony-Frankford sites and reference sites with respect to number and abundance of mayfly taxa may be attributable to heavy metal pollution. Sediment metals concentrations and reference site chemistry data are needed before any conclusions can be drawn.

Cu toxicity was also investigated using the Biotic Ligand Model (BLM) (DiToro *et al.* 2001). Data were lacking for some model input parameters, so conservative values were substituted. Many water chemistry parameters can affect Cu toxicity, particularly other ions and organic molecules that tend to compete with gill ligand bonding sites for available Cu. Figure 5-11 illustrates the effects of pH and temperature on Cu bioavailability and toxicity. BLM data were used only to determine whether Cu toxicity could affect the biology of Tookany/Tacony-Frankford Watershed, not to develop alternative water quality criteria. EPA is in the process of developing new WQ criteria for Cu incorporating the BLM with appropriate margins of safety for protecting aquatic life.

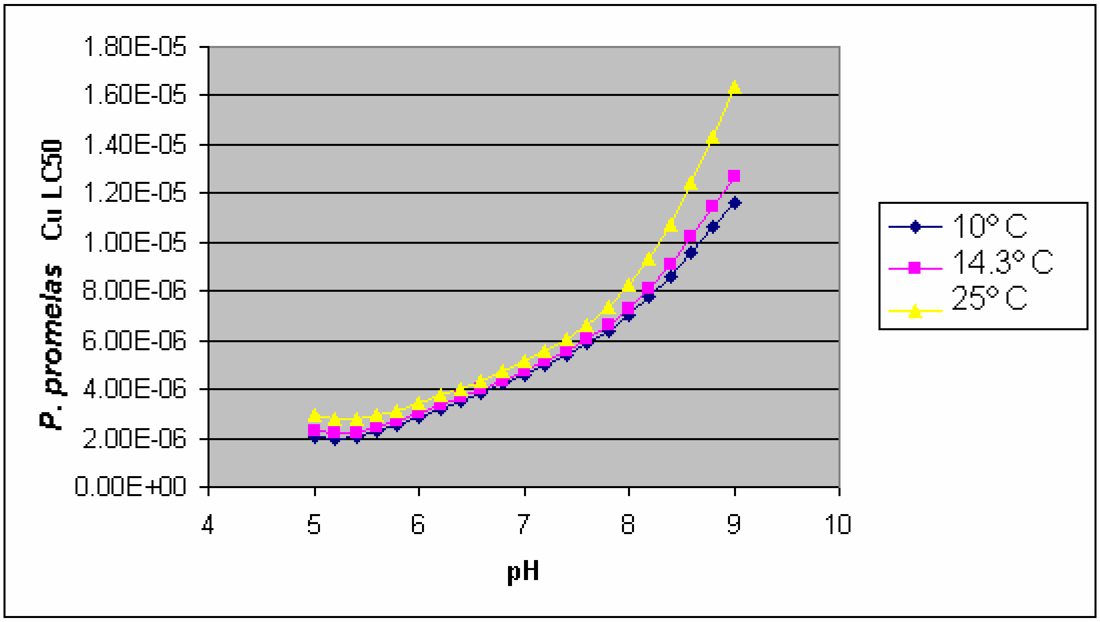


Figure 5-11 Effects of pH and Temperature on Copper Toxicity to Fathead Minnows.

The BLM was used to determine the LD50 of dissolved copper to Fathead Minnow (*Pimephales promelas*), and two cladoceran microcrustaceans (*Ceriodaphnia dubia*, and *Daphnia pulex*). For most parameters data entered into the model came from samples collected from Tookany/Tacony-Frankford Watershed. Data from each sample were entered into the model as a separate case and the LD50 of Cu was determined for each case. When data from Tookany/Tacony-Frankford Watershed were not available estimates from nearby streams were used. Parameters for which estimates were used included: DOC, Percent of DOC contributed by Humic Acids, Potassium, and Chloride. DOC competes for Cu with gill ligand sites and is positively correlated to the LD50 of Cu, therefore a conservative estimate of 2.9 mg/L from French Creek was used in place of 5.4 mg/L , an estimate given for PA streams (EPA document #822-B-98-005). Due to the lack of DOC characterization data, ten percent was used for the relative proportion of DOC made up by Humic acids as recommended by the model documentation (DiToro *et al.* 2001). Model input values for Potassium (K) were estimated by averaging potassium values from Pickering Creek, Trout Creek, and Wissahickon Creek, though K currently has no direct effect on metal toxicity in the BLM. Chloride model input values were calculated by averaging values from Pickering Creek and Trout Creek. When comparing dissolved Cu concentrations from Tookany/Tacony-Frankford Watershed to predicted LD50, the predicted LD50 concentration was reduced by an order of magnitude (margin of safety). Even with this margin of safety, no sample had dissolved Cu concentration above the LD50 for any of the target organisms

5.3.7.5 Lead

Lead (Pb) is a toxic heavy metal that was once commonly used in paints (as recently as 1978) and in automotive fuels (until being phased out in the 1980s). Pb is still used industrially in solder and batteries. Some areas have banned the use of lead in shotgun pellets and fishing weights, as chronic toxicity results when these items are ingested by waterfowl. Acute toxicity of Pb to aquatic life is considerably less than chronic toxicity, as evidenced by the large difference in CCC and CMC criteria (2.5 and 65µg/L, respectively, at 100mg/L $CaCO_3$ hardness). Dissolved Pb was only detected in 17 of 141 samples collected in Tookany/Tacony-Frankford; no violations of WQ criteria were found (Table 5-5). When compared to discontinued total recoverable metals criteria, 70 of 712 samples would have been violations.

5.3.7.6 Zinc

Zinc (Zn) is a common element present in many rocks and in small concentrations in soil. Zn is a micronutrient needed by plants and animals, but when present in greater concentrations in surface water, it is moderately toxic to fish and other aquatic life. Toxicity is most severe during certain sensitive (usually early) life stages. Zn is a component of common alloys such as brass and bronze and is used industrially for solders, galvanized coatings, and in roofing materials. Zn is usually present in surface waters of Tookany/Tacony-Frankford; only 14 of 671 individual total recoverable Zn samples and 18 of 122 dissolved Zn samples from Tookany/Tacony-Frankford had Zn below reporting limits (Table 5-5), though concentrations were relatively small.

Contamination was suspected in four sets of samples collected in 2004, where dissolved concentrations were consistently greater that total recoverable concentrations in 30 of 32 samples (Figure 5-12). Dates and sample information for these sample dates are summarized in Appendix D. Of 15 dissolved Zn samples exceeding WQ criteria, 14 are likely to have been affected by contamination. If these samples are ignored, dissolved Zn/total recoverable Zn ratios more closely mirror those of other metals (*i.e.*, higher in dry weather than in wet weather, Figure 5-12).

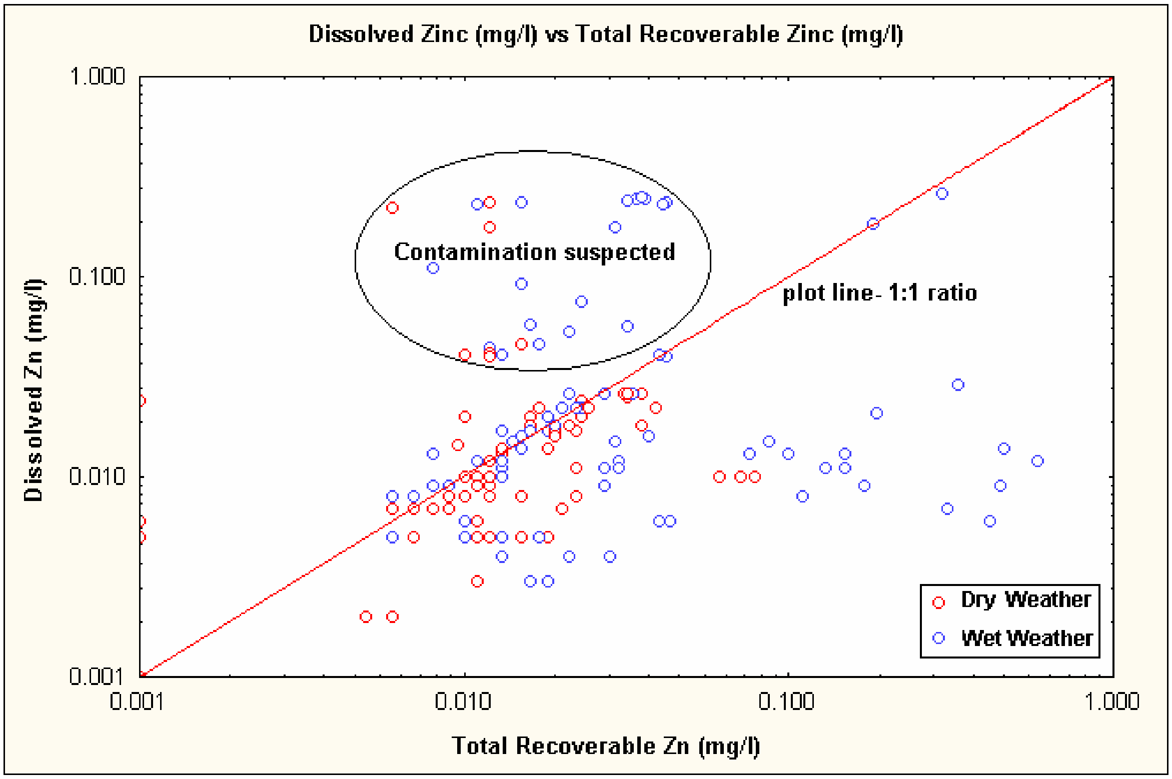


Figure5-12 Paired Total Recoverable and Dissolved Zinc Concentrations of Samples collected from 8 sites in Tookany/Tacony-Frankford Watershed, 2000-2004.

Discrepancies occurred with both dry and wet weather samples. Bench sheets did not indicate any problems with samples or the instrumentation, and all QC checks were passed. As samples were preserved and stored, the PWD Bureau of Laboratory Services (BLS) was able to re-analyze these samples, obtaining similar results. The analyst visually confirmed the presence of settled solids in sample containers used for total recoverable metal, while sample containers used for dissolved metals were visually clear. A series of subsequent filter blank trials showed filters used to prepare dissolved metals samples may have leached Zn, but the magnitude of the difference in total and dissolved concentrations was much too great to be explained by filter contamination. The source of contamination remains unknown.

The BLM was used to estimate the toxicity of dissolved Zn to fathead minnows (*Pimephales promelas*), rainbow trout (*Oncorhynchus mykiss*), and a cladoceran (*Daphnia magna)*. Input data were compiled or estimated in the same manner as dissolved copper model input data. An order of magnitude safety factor was applied to the LD_{50} concentrations generated by the model and the resulting concentration was compared with dissolved zinc data collected from the Tookany/Tacony-Frankford Watershed. Even with this safety margin, no observed dissolved zinc concentrations exceeded the calculated LD_{50} for the studied organisms.

5.3.8 Nutrients

5.3.8.1 Phosphorus

Phosphorus (P) concentrations are often correlated with algal density and are used as a primary indicator of cultural eutrophication of water bodies. N:P ratio analysis strongly suggests that P is the limiting macronutrient in the Tookany/Tacony-Frankford Watershed. Readily available dissolved orthophosphate (PO_4) was only detected in 5 of 129 total samples collected in dry weather, and in 55 of 584 wet weather samples, so nutrient analyses considered only total P concentrations (TP). TP includes some smaller fraction of P that is considered to be bioavailable, or readily usable by stream producers. Bioavailable P (BAP) includes soluble reactive P (SRP) and, depending on other factors, some portion of particulate inorganic P. Furthermore, some producer taxa can produce endogenous alkaline phosphatases and obtain P that is not normally available.

The Tookany/Tacony-Frankford Watershed has not been listed by PA DEP as impaired due to nutrients, and no WQ criteria exist for TP or OPO_4. For the TTFIWMP, TP concentrations were evaluated using a frequency distribution approach. Data were compiled for reference reaches in EPA Ecoregion IX, subregion 64 (median of 75th percentile value for each of four seasons=140µg/L) from EPA (822-B-00-019). This reference value is considerably greater than the mesotrophic/eutrophic boundary for TP suggested by Dodds *et al*. (1998) (*i.e.*, 75µg/L). Dry weather TP concentrations were usually below both reference values.

Total P concentration was below reporting limits in 58 of 135 samples collected in dry weather, but in only 87 of 555 wet weather samples. Elevated dry weather TP concentration was observed at sites TF280 and TFM006, probably due to dry weather sewage inputs. Log-transformed Mean TP concentration was significantly greater in wet weather than in dry weather ($F_{2,183}$=1.55, p=0.008), so stream producers in the Tookany/Tacony-Frankford Watershed are generally exposed to somewhat constant TP concentrations punctuated with episodic inputs of greater TP concentration due to runoff and erosion. Point sources of P include CSO and SSO discharges, contributing large amounts of phosphorus where and when they occur.

Phosphorus readily adsorbs to soil and sediment particles and is generally less mobile in soils than nitrogen compounds. Potential non-point sources of P are decomposing organic matter in or near the stream, runoff from industrial parks, golf courses, agriculture and residential areas, and inorganic P adsorbed to soil particles that are washed into the stream by erosive forces. In fact, soil erosion may be the greatest source of P in separate-sewered portions of Tookany/Tacony-Frankford. TP concentration was significantly positively correlated with TSS concentration, (Log transformed, $r_{(183)}$=0.60, p<0.001) (Figure 5-13). Wet weather phosphorus inputs, however, are coupled with physical disturbances (*e.g.*, hydraulic shear stress, other abrasive forces, reduced light availability). These stressors respond to changes in flow in a non-linear fashion. Some taxa have the ability to store intercellular reserves of inorganic nutrients ("luxury consumption") when concentrations exceed immediate demands. It is thus very difficult to estimate P concentrations available to stream producers and draw conclusions about stream trophic status. This topic is addressed in greater detail in Section 5.4.

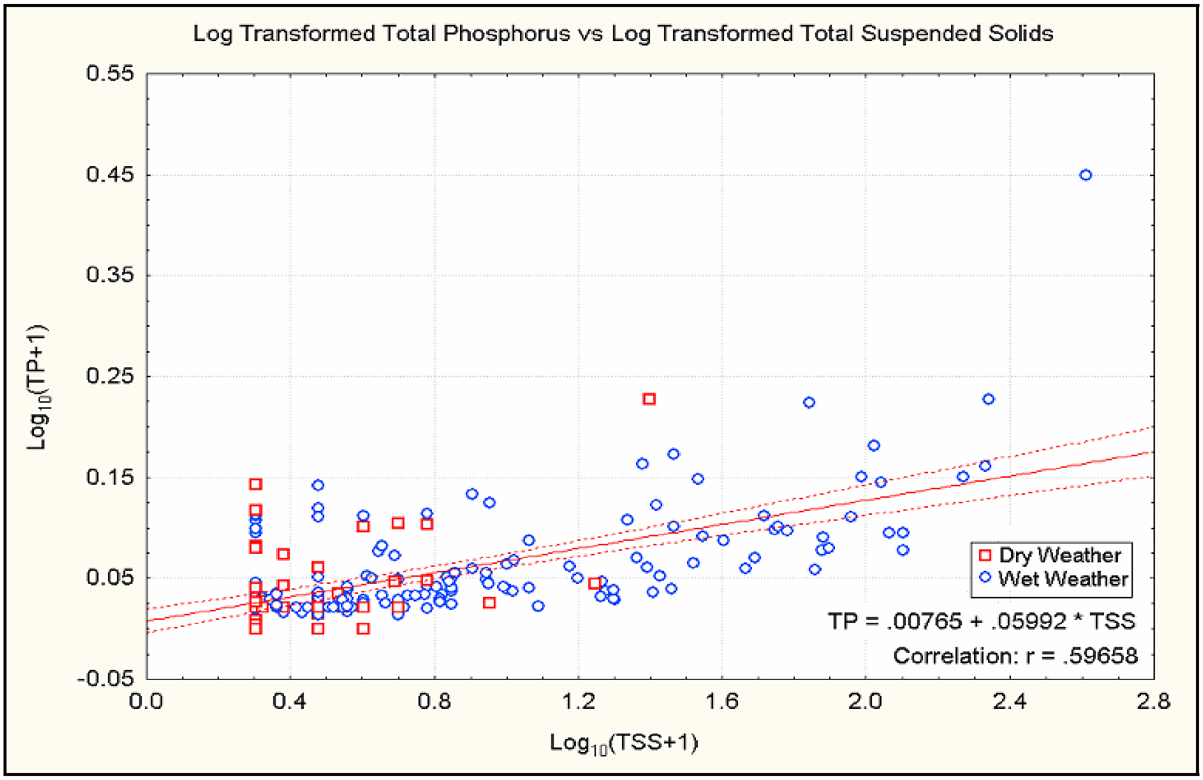


Figure 5-13 Scatterplot of Paired Total Phosphorus and Total Suspended Solids Concentrations of Samples Collected from 8 Sites in Tookany/Tacony-Frankford Watershed, 2000-2004.

5.3.8.2 Ammonia

Ammonia, present in surface waters as un-ionized ammonia gas (NH_3), or as ammonium ion (NH_4^+), is produced by deamination of organic nitrogen-containing compounds, such as proteins, and also by hydrolysis of urea. In the presence of oxygen, NH_3 is converted to nitrate (NO_3) by a pair of bacteria-mediated reactions, together known as the process of nitrification. Nitrification occurs quickly in oxygenated waters with sufficient densities of nitrifying bacteria, effectively reducing NH_3, although at the expense of increased NO_3 concentration. PA DEP WQ criteria for NH_3 reflect the relationship between stream pH, temperature, and ammonia speciation/dissociation. Ammonia toxicity is inversely related to hydrogen ion [H+] concentration; an increase in pH from 7 to 8 increases NH_3 toxicity by approximately an order of magnitude. At pH 9.5 and above, even background concentrations of NH_3 may be toxic.

Historic data comparisons show that, in the watershed overall, NH_3 concentrations have decreased significantly compared to samples collected from 1970 to 1980 ($F_{2,1001}=6.18$, $p<0.001$). Dry weather NH_3 concentrations, in particular, have improved dramatically. For example, in samples collected from 1970 to 1980, there was no significant difference in NH_3 concentrations between dry and wet weather samples at site TF280 ($F_{2,99}=1.19$, $p=0.77$), suggesting that sewage inputs or anoxic conditions were common at this site regardless of weather.

Though no dry weather samples collected from the Tookany/Tacony-Frankford Watershed from 2000-2004 contained NH_3 concentration in excess of 0.8mg/L and there were no violations of WQ criteria, 20 of 87 samples were above reporting limits, suggesting occasional inputs of untreated sewage, anoxic conditions, or the presence of other decomposing organic material. Site TF280 was responsible for most of these observations, and is believed to be the site most seriously affected by dry weather sewage inputs and anoxic conditions. Target A of the TTFIWMP is directed at further reducing dry weather sewage inputs through source track-down and infrastructure repair/improvements.

NH_3 concentration of sites within Tookany/Tacony-Frankford Watershed (log-transformed, all sites combined) was significantly higher in wet weather than in dry weather ($F_{2,710}=2.30$, $p=.0047$). NH_3 concentration was above detection limits in 211 of 436 total wet weather samples, though all samples with concentrations greater than 0.8mg/L were collected at site TF280.

There were no violations of WQ criteria due to the fact that pH remained near neutrality at the time samples were taken. Algal activity was observed to cause pH fluctuations, particularly at site TF620 in spring 2003. When severe, these fluctuations in pH caused NH_3 WQ criteria to decrease to within the range of values observed at other times. The NH_3 sampling regime was not ideal for identifying possible violations of WQ standards as discrete interval grab samples were collected in the morning, while daily pH maxima were typically reached in afternoon/early evening hours.

5.3.8.3 Nitrite

As an intermediate product in the oxidation of organic matter and ammonia to nitrate, nitrite (NO_2) is seldom found in unimpaired natural waters in great concentrations provided that oxygen and nitrifying bacteria are present. For this reason, NO_2 may indicate sewage leaks from illicit connections, defective laterals, or storm sewer overflows and/or anoxic conditions in natural waters. NO_2 was detected in only 14 dry weather samples collected from the Tookany/Tacony-Frankford Watershed; most of these observations were at site TF280 and most were collected prior to 2004. Comparison to data collected from 1970-1980 showed that the incidence of Nitrite detections in dry weather has been drastically reduced, suggesting fewer dry weather sources of sewage and/or reduced severity of anoxic conditions.

NO_2 concentrations were greater than reporting limits more frequently in wet weather (129 of 585 total samples) than in dry weather, but contribution of NO2 to total inorganic nitrogen was usually small and concentrations of many samples were estimated to be half the detection limit for the purpose of evaluating nutrient ratios. Large numbers of samples below detection limits prevented the use of parametric statistical methods to evaluate weather effects. Mann-Whitney U test analysis showed significantly greater NO2 concentration (log transformed, samples below MRL included as half the MRL) in wet weather than in dry weather ($Z_{2,717} = -2.75$, $p<0.005$).

5.3.8.4 Nitrate

Concentrations of nitrate (NO_3) are often greatest in watersheds impacted by (secondary) treated sewage and agricultural runoff, but elevated NO_3 concentrations in surface waters may also be attributed to runoff from residential and industrial land uses, atmospheric deposition and precipitation (*e.g.*, HNO_3 in acid rain) and decomposing organic material of natural or anthropogenic origin. Nitrate is a less toxic inorganic form of N than ammonia and serves as an essential nutrient for photosynthetic autotrophs. Availability of inorganic N can be a growth-limiting factor for producers, though usually only in oligotrophic (nutrient-poor) lakes and streams or acidic bogs.

PA DEP has established a limit of 10mg/L for oxidized inorganic nitrogen species (NO_3 + NO_2) (Commonwealth of Pennsylvania, 2001). This limit is based on public water supply use and intended to prevent methemoglobinemia, or "blue baby syndrome", not prevent eutrophication of natural water bodies. Waters of the Commonwealth that have been determined to be impaired due to excess nutrients have Waste Load Allocations (WLA) determined through the Total Maximum Daily Load (TMDL) process; Tookany/Tacony-Frankford Watershed has not been listed as impaired due to nutrient enrichment. For the TTFIWMP, NO_2 +NO_3 concentrations were evaluated using a frequency distribution approach. Data were compiled for reference reaches in EPA Ecoregion IX, subregion 64 (75th percentile of observed data=2.9mg/L). This reference value is considerably greater than the mesotrophic/eutrophic boundary for Total N suggested by Dodds *et al.* (1998) (*i.e.*, 1.5 mg/L TN).

Dry weather NO_3 concentrations in the Tookany/Tacony-Frankford Watershed are almost always found between the two aforementioned reference points (*i.e.*, between 1.5mg/L and 2.9mg/L). NO_3 concentrations typically decreased in wet weather. Mean NO_3 concentration (log transformed, all sites combined) was significantly lower in wet weather than in dry weather ($F_{2,180}$=1.70, p<0.001), and NO_3 was significantly negatively correlated with Log transformed TSS concentration (r(182)= -0.55, p<0.001, Figure 5-14). This relationship demonstrates dilution by stormwater and is the reverse of the phenomenon observed with P concentration. However, other forms of N (*i.e.*, TKN, NH_3, NO_2) tended to increase in concentration in wet weather. Nutrient dynamics and relationships to autotrophic community production are addressed in greater detail in section 5.4.

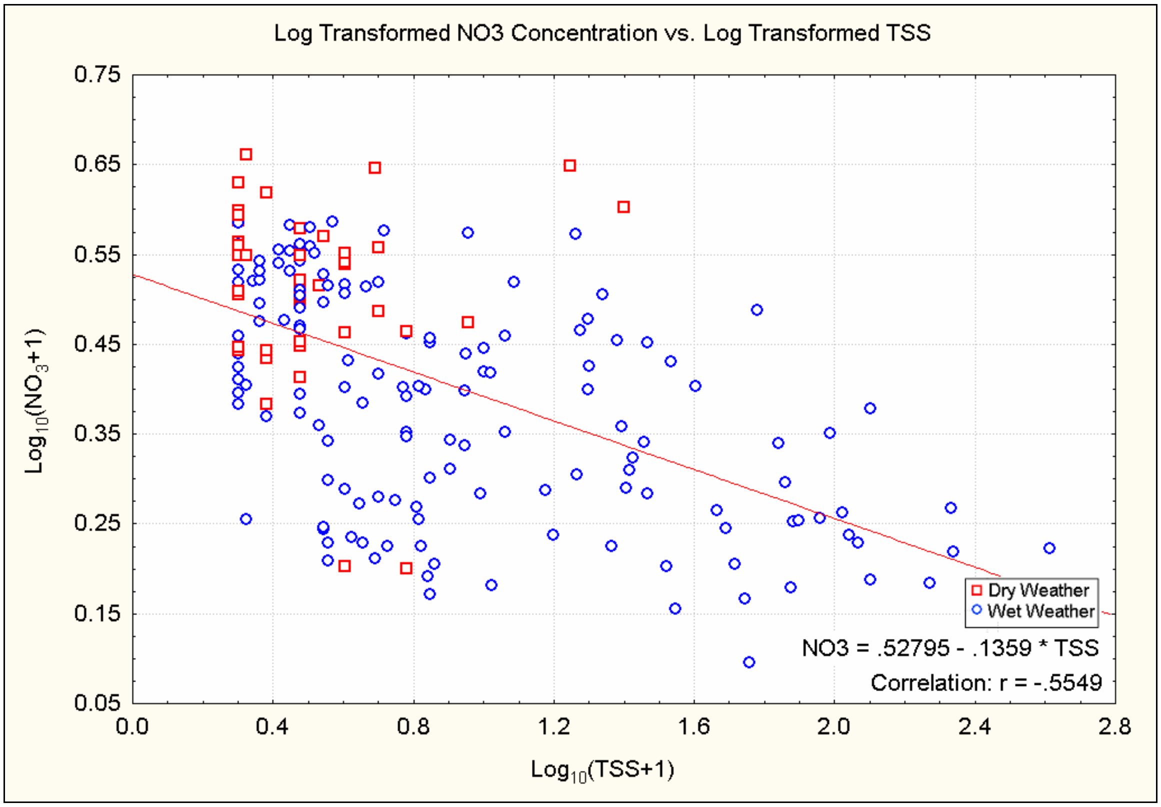


Figure 5-14 Scatterplot of Paired Nitrate and Total Suspended Solids Concentrations of Samples Collected from 8 sites in Tookany/Tacony-Frankford Watershed, 2000-2004.

Unusual dry weather samples were collected from site TF280 on July 7, 2004 and TFM006 on August 30, 2004 in which NO_3 concentration seemed diluted compared to most other dry weather baseflow samples. In the first case, accompanying data showed increases in TKN and NO_2, as would be expected with under anoxic conditions, but DO suppression could not be verified due to probe failure. In the second case, TKN was slightly elevated for a dry weather sample, but NO2 was below reporting limits and no DO data were available.

5.3.8.5 Total Kjeldahl Nitrogen

The Total Kjeldahl Nitrogen (TKN) test provides an estimate of the concentration of organically-bound N, but actually measures all N present in the trinegative oxidation state. Ammonia must be subtracted from TKN values to give the organically bound fraction. TKN analysis also does not account for several other N compounds (*e.g.*, azides, nitriles, hydrazone); these compounds are rarely present in significant concentrations in surface waters. Sampling results strongly suggest the most important source of organic N is sewage inputs from CSO and SSO discharge. Log-transformed Organic N concentration was significantly greater in wet weather than in dry weather ($F_{2,654}$=14.04, p<0.001). Organic N was also significantly positively correlated with fecal coliform bacteria concentration, r(647)=0.70, p<0.001 (Figure 5-15). As most organic N loadings to the watershed occur in wet weather, this N is probably transported out of the system and into the Delaware estuary before exerting nitrification DO demand or becoming available for uptake by algae.

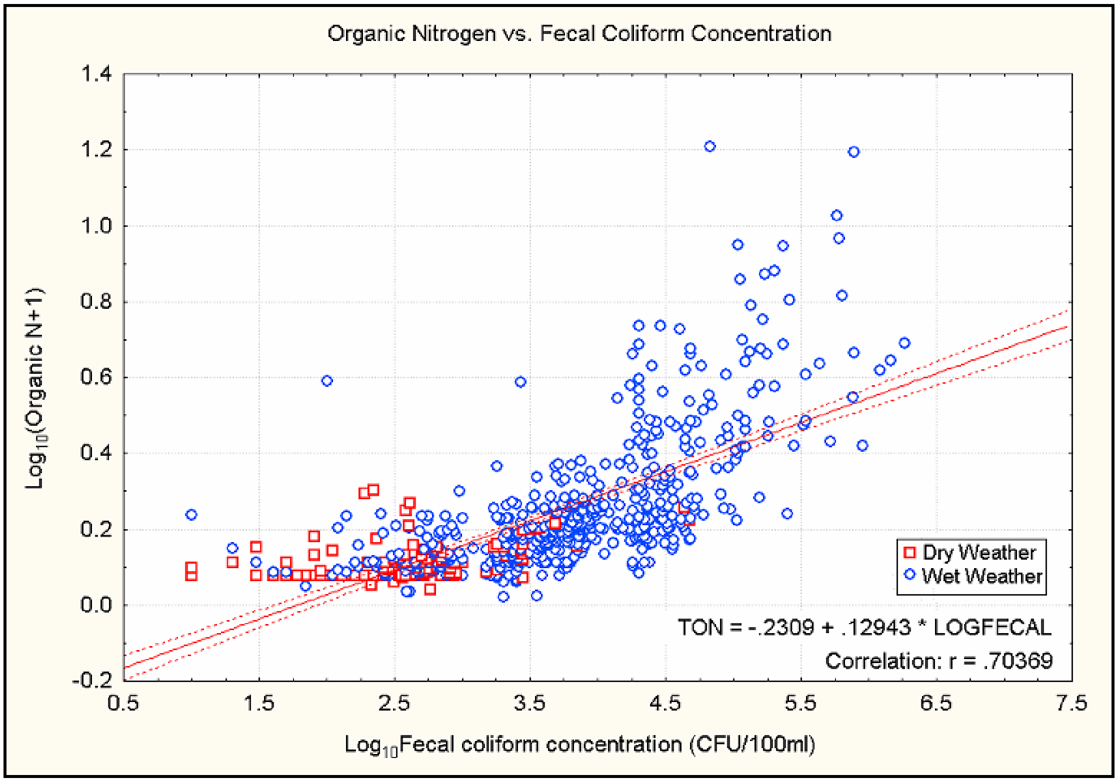


Figure 5-15 Scatterplot of Organic Nitrogen and Fecal Coliform Bacteria Concentrations of Samples Collected from 8 sites in Tookany/Tacony-Frankford Watershed, 2000-2004.

5.4 Stream Metabolism

Stream Metabolism is a measure of the basic ecosystem processes of primary productivity and community respiration. Primary productivity measures the total energy fixed by plants in a community by photosynthesis, and community respiration quantifies the use of reduced chemical energy by autotrophs as well as heterotrophs (Odum 1956). Benthic algae are important primary producers in aquatic systems and are often the greatest source of energy in mid-order streams with less than complete tree canopy. Where abundant, periphyton communities may strongly influence water column dissolved oxygen, pH and inorganic carbon speciation.

Continuous water quality data indicated that certain sites in Tookany/Tacony-Frankford experience pronounced diurnal fluctuations in DO and pH that can be reduced in magnitude following storm events (Figure 5-16). These fluctuations sometimes result in short-lived violations of state water quality standards, frequently so within 3 miles of the confluence with the Delaware River. As Tookany/Tacony-Frankford Watershed was not found to have large dry weather concentrations of chlorophyll in the water column that would be indicative of suspended phytoplankton, it was hypothesized that these pronounced fluctuations were due largely to periphytic algae.

Supporting this conclusion are observed reductions in the magnitude of fluctuations during and immediately after storm events (Figure 5-16) and increases in water column chlorophyll-a during storm events observed at some sites. The latter effect is difficult to characterize, as the degree to which chl-*a* increased in wet weather is believed to have been affected by algal density, predominant growth form, and stream velocity. To address these hypotheses, a study was carried out at sites TF280 and TF680 to determine the biomass of benthic algae in terms of chlorophyll-*a* (chl-*a*), spatial variation in biomass within and between sites, scouring effects of high flows, and algal accrual rates following a high flow event.

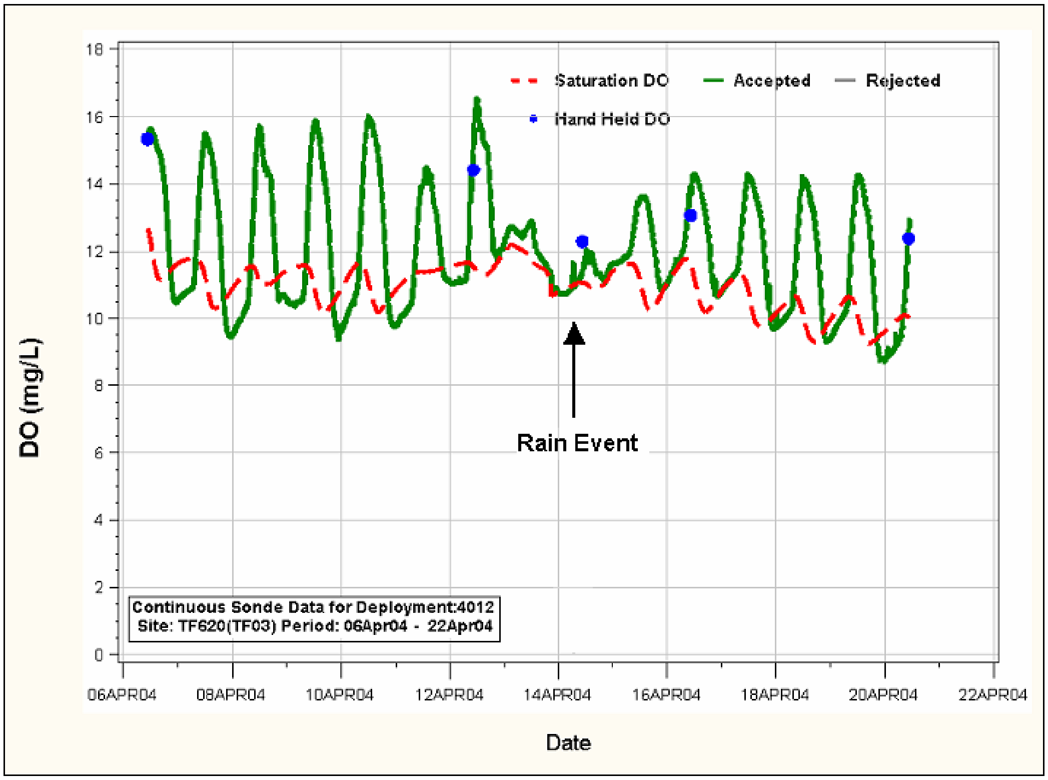


Figure 5-16 Continuous Plot of Water column Dissolved Oxygen Concentration at site TF620, April 2004.

Chlorophyll-*a* concentrations were consistently significantly greater at TF680 than at TF280 with mean concentrations ranging from 29.8 (±3.79) to 88.5 (±11.0) mg/m^2 at TF280, and from 108.5 (±14.8) to 127.9 (±12.8) mg/m^2 at TF680 (Figure 5-16). Mean chl-*a* at the TF680 site on 8 September 2004 was significantly lower (49.8 ± 6.5 mg/m^2) than on other sampling dates. This is possibly due to seasonal changeover in benthic algal community structure (summer die-off).

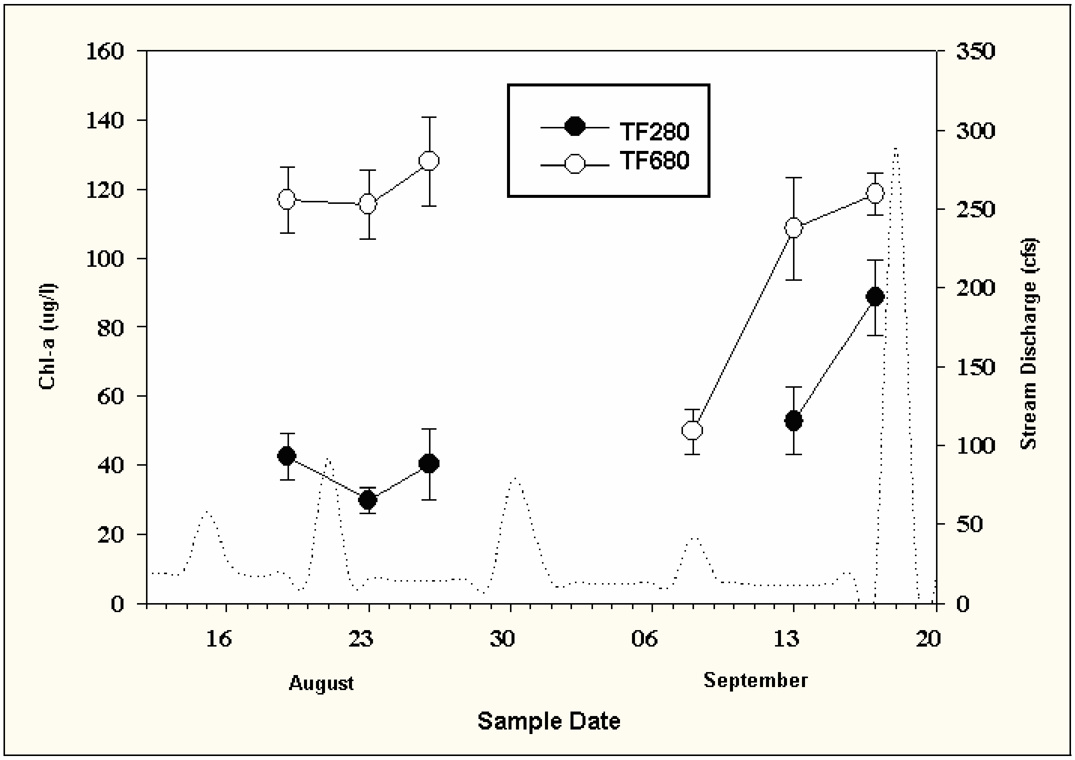


Figure 5-17 Chlorophyll-*a* Density on Natural and Artificially Scoured Substrates at sites TF 280 and TF620, September 2004

Algal accrual rates during the first 5 days following an artificial scouring experiment were similar to accrual rates on non-scoured rocks for each site (Figure 5-18). The average daily accrual rate for TF280 and TF620 was 8.36 ±1.30 mg/m^2 and 16.7 ± 4.34 mg/m^2, respectively. The accrual rate at TF03 of non-scoured rocks was 11.7 mg/m^2. During days 5-9 of the experiment, both sites lost biomass with an average daily loss rate of 1.73 (± 0.99) mg/m^2 at TF01 and 4.56 (± 1.31) mg/m^2 at TF620. The mean daily accrual rate of non-scoured rocks at TF01 during this time period was 8.96 mg/m^2 and 2.48 mg/m^2 at TF620.

Grazing, nutrients, current velocity, and scouring disturbances are likely the most important in driving algal communities in Tookany/Tacony-Frankford watershed. Differences in algal community structure between the two sites are likely the result of differential nutrient conditions, grazing pressures, and disturbance regimes. Light may also play a factor in explaining site differences (Triska *et al*. 1983, Hill and Knight 1988, Everett 1998).

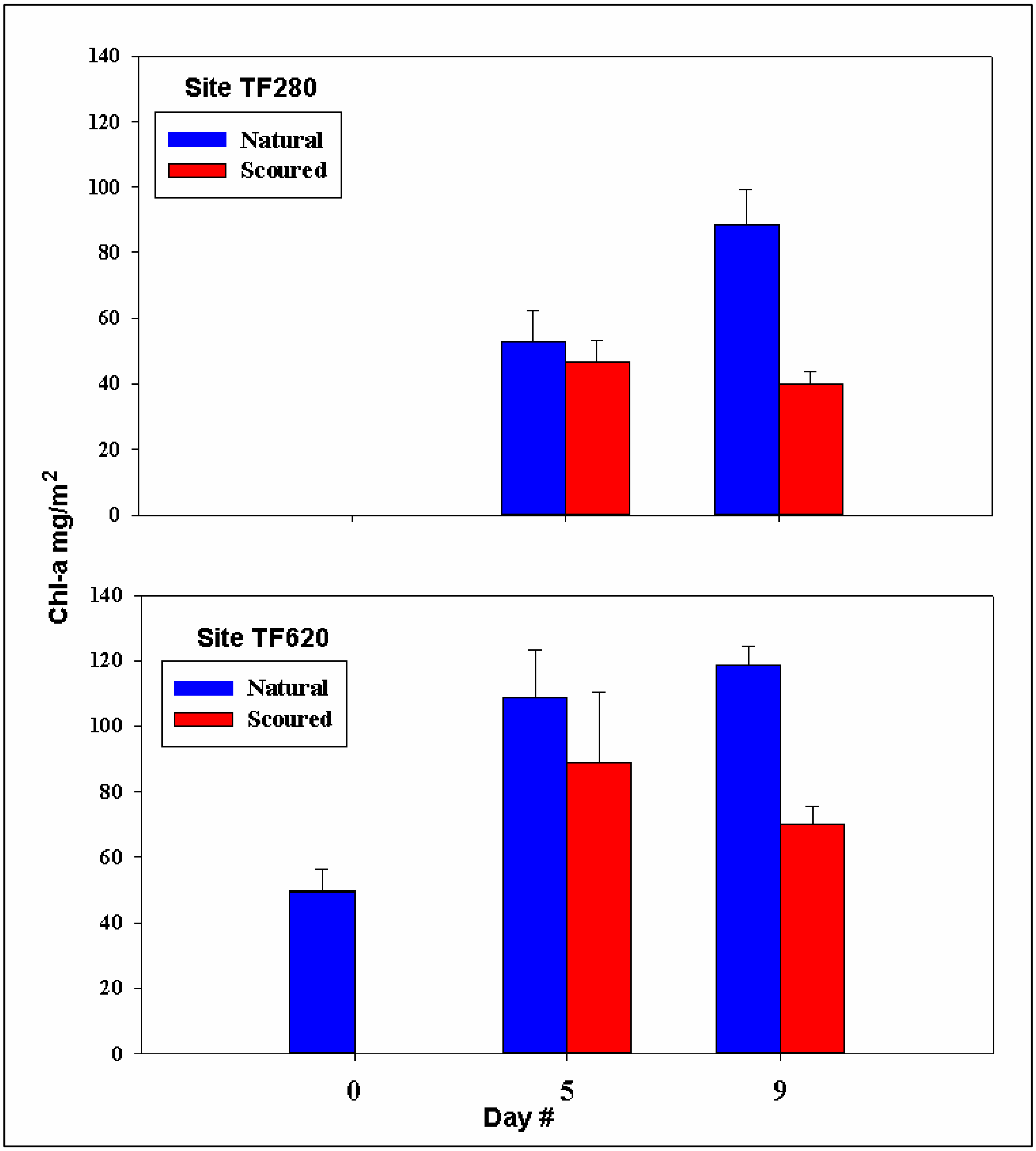


Figure 5-18 Chlorophyll-a Density on Natural and Artificially Scoured Substrates at sites TF280 and TF620, September 2004.

5.4.1 Relation of Algal Activity to Dissolved Oxygen Concentration

DO concentrations often strongly reflect autotrophic community metabolism and in turn, affect the heterotrophic community structure as a limiting factor for numerous organisms. Stream sites that support abundant algal growth often exhibit dramatic diurnal fluctuations in dissolved oxygen concentration. Algal photosynthesis infuses oxygen during the day (often to the point of supersaturation), while algae and heterotrophic organisms remove oxygen throughout the night. Diurnal fluctuations are more pronounced in the summer months than the autumn and winter months as colder water has a greater capacity for DO and biological metabolic activity is generally regulated by temperature.

Mainstem sites on Tookany/Tacony-Frankford Creek experience pronounced diurnal fluctuations in dissolved oxygen (DO) concentrations. When biological activity is high, DO concentrations may fall below the state-regulated limit of 4.0 mg/L. Violation of these standards is generally limited to the stretch of river within 6 miles of the confluence with the Delaware River and common within the lower three miles of the confluence (*i.e.*, downstream of site TF500). Dry weather dissolved oxygen suppression tends to occur at night and is likely caused by respiration of algae and microbial decomposition of algae and other organic constituents in the absence of additional photosynthetic oxygen production.

Following storm events, amplitude of daily DO fluctuations was reduced. DO concentrations may decrease sharply upon increase in stage, but it was difficult to determine how much of these instantaneous decreases were due to DO probe membrane fouling (Figure 5-19). It was hypothesized that anoxic effluent from storm sewers contributes to a sudden reduction in water column DO, but modeling of CSO discharge DO concentrations indicated that the discharge alone could not account for the observed DO reductions. BOD and SOD may have increased due to organic matter present in sewage. Mean BOD_5 was substantially higher at TF280 than at TF620 (Figure 5-2), although numerous samples were below reporting limits. Additionally, the scouring effect of high flows reduces algal biomass, and the oxygen produced through photosynthesis and consumed through respiration is reduced. As algal biomass accrues following scouring events, peak DO concentrations and range of diurnal fluctuations return to pre-flow conditions (Figure 5-20).

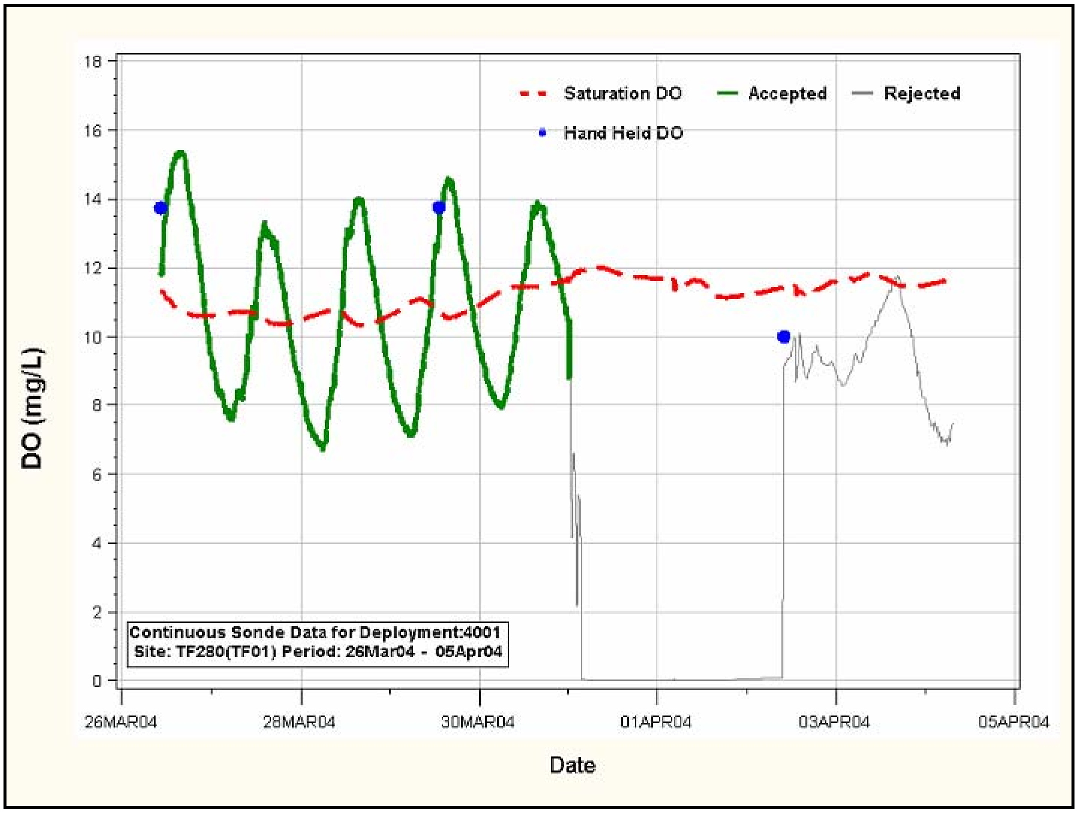


Figure 5-19 Continuous plot of Dissolved Oxygen Concentration at site TF280 Showing DO Probe Failure.

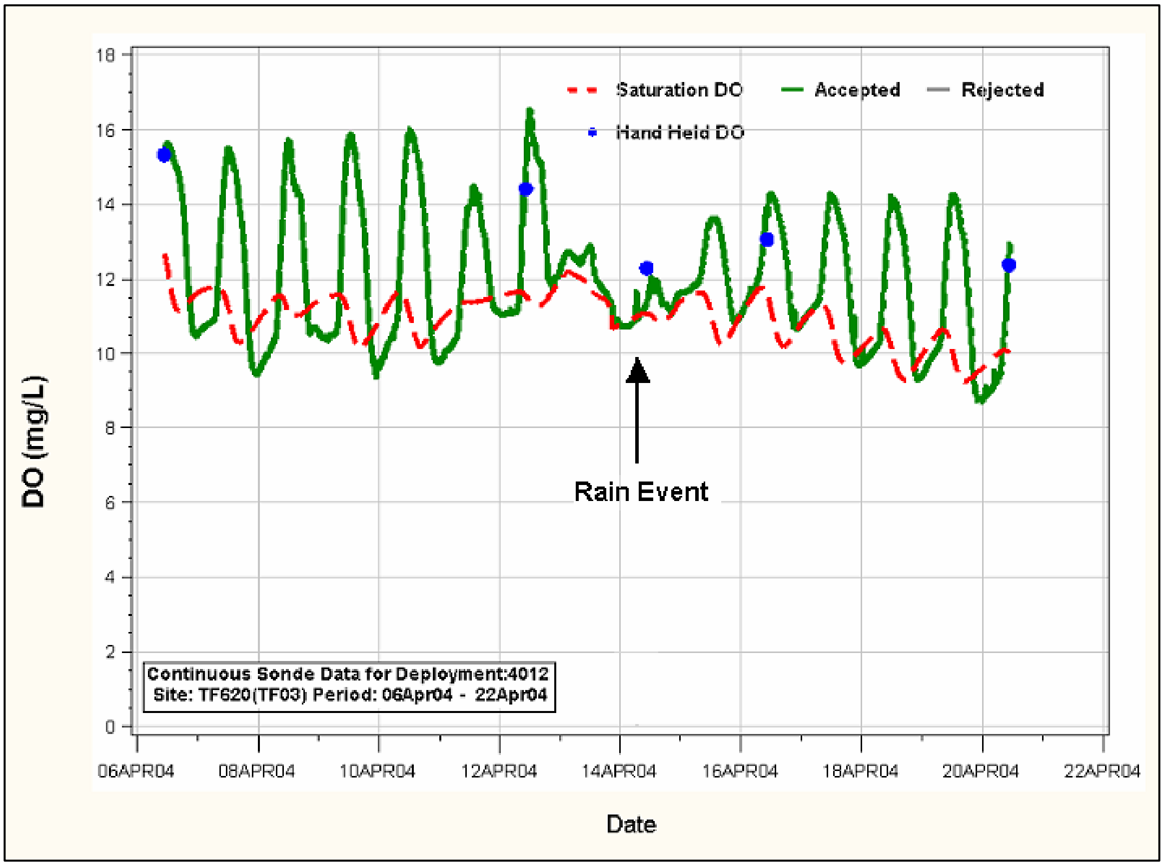


Figure 5-20 Continuous plot of Dissolved Oxygen Concentration at site TF280 returning to pre-flow conditions

Algal biomass at site TF280 was lower than at site TF620 further upstream. However, TF620 exhibits a higher mean DO and less pronounced diurnal fluctuations suggesting that the relationship between biomass and primary production is not straightforward. It is hypothesized that in dry weather the algae in combination with the residual effects of anoxic effluent, BOD and SOD accounts for the greater fluctuations in DO at site TF280. Further confounding the interpretation of this data is the fact that the sonde at site TF280 is located within a stagnant pool, the only location offering enough depth to allow the instrument to remain submerged at baseflow. Conversely, sonde locations at site TF620/680 are exposed to more streamflow, which replenishes the water surrounding the DO probe more frequently and helps keep the DO membrane itself from accumulating algae and debris. Microclimate conditions surrounding the DO probe membrane probably partially explain the difference in DO fluctuations observed between these two sites.

5.4.2 Relation of Algal Activity to stream pH

Fluctuations in pH can occur in freshwater systems as a result of natural and anthropogenic influences. Interplay between inorganic carbon species, known as the bicarbonate buffer system, generally maintains pH within a range suitable for aquatic life.

The bicarbonate buffer system describes the equilibrium relationship between carbon dioxide (CO_2) and carbonic acid (H_2CO_3), as well as bicarbonate (HCO_3^-) and carbonate (CO_3^{2-}) ions. In natural waters, the predominant source of hydrogen ions is carbonic acid. Biochemical metabolism of carbon throughout the day continually shifts the equilibrium equation, causing fluctuations in pH. As plants and algae consume carbon dioxide during photosynthesis, carbonic acid dissociates to replenish the CO_2 and maintain equilibrium. Decreasing carbonic acid concentrations cause elevated pH. As photosynthetic rates decline after peak sunlight hours, respiratory activities of aquatic biota replenish carbon dioxide to the system, decreasing pH. pH in Tookany/Tacony-Frankford Watershed is chiefly determined by this metabolic activity; the watershed is not heavily influenced by bedrock composition, groundwater sources or anthropogenic inputs, such as acid mine drainage.

Comparison of diurnal fluctuations of pH at sites TF280 and TF680 found that TF680 has greater variability between daytime and nighttime pH. This finding is attributed to the greater benthic algae biomass found at this site. pH affects aquatic biota directly, and also influences ionization of NH_3 and solubility/bioavailability of toxic metals. Severe fluctuations in pH driven by algal activity thus have the potential to exacerbate toxic conditions or even create toxic conditions where none previously existed.

5.4.2.1 Nutrient Limitation Effects on Primary Production

Nutrients are arguably the most important factor dictating algal standing crop, primary production, and community composition with examination of the nutrient-algae relationship requiring both an autecological and community-level approach (Borchardt 1996).

Nutrients can be a limiting factor to algal growth. In any given scenario, only one nutrient can limit algal growth for a given species at a time, although, at the community level, this rule does not apply where different species might be limited by different nutrients. Growth rates are not affected by nutrient concentrations alone. Light and temperature can affect nutrient uptake rates (*e.g.,*Falkner *et al*. 1980, Wynne and Rhee 1988), and more nutrients are often needed when light and temperature conditions are less than ideal (Goldman 1979, Rhee and Gotham 1981a,b, Wynne and Rhee 1986, van Donk and Kilham 1990). Additionally, nutrient uptake rates can vary depending on nutrient conditions. In steady-state growth conditions, the rate of nutrient uptake is equivalent to the rate at which nutrients are used in growth. However, cells may take up fewer or greater amounts of nutrients (for example, during nutrient pulses) and alter the nutrient ratios within the cell (Borchardt 1996).

The relationship between nutrients and algal biomass is complicated by numerous factors and findings are not consistent across ecoregions and water body types. Typically, nutrient enrichment stimulates periphyton growth in lotic systems and many studies have shown strong relationships between nutrient concentrations and algal biomass (*e.g.,* Jones *et al*. 1984, Welch *et al*. 1988, Kjeldsen 1994, Chetelat *et al*. 1999, Francouer 2001). However, other studies have shown no relationship between biomass and nutrient concentration (Biggs and Close 1989, Lohman *et al*. 1992). Periphyton standing crop can be highly variable (Morin and Cattaneo 1992) and other factors (described in subsequent sections) may override nutrient effects.

Of the necessary components for algal growth, nitrogen and phosphorus are likely to be growth-limiting in aquatic systems (Wetzel 2001) although carbon (Fairchild *et al.* 1989, Fairchild and Sherman 1993), trace metals (Winterbourn 1990), organic phosphorus (Pringle 1987) and silicates (Duncan and Blinn 1989) have also been implicated in limiting algal growth. Based on periphyton-nutrient studies, phosphorus is typically the limiting nutrient in the northern US (see Borchardt 1996 for review) while nitrogen has been shown to be limiting in the southwest (Grimm and Fisher 1986, Hill and Knight 1988a, Peterson and Grimm 1992) and Ozark (Lohman *et al.* 1991) regions.

In an effort to develop a practical system of stream classification based on nutrient concentrations similar to those used for lakes, Dodds *et al.* (1998) examined the relationship between chl-*a* (mean and maximum benthic chl-*a* and sestonic chl-*a*) and total nitrogen (TN) and total phosphorus (TP) in a large, global dataset. They defined the oligotrophic-mesotrohpic boundary by the lower third of the distribution of values with mean and maximum benthic chl-*a* concentrations of 20 mg/m^2 and 60 mg/m^2, respectively; and TN and TP concentrations of 700 µg/L and 25 µg/L, respectively. The mesotrophic-eutrophic boundary was represented by the upper third of the distribution of values with mean and maximum benthic chl-*a* concentrations of 70 mg/m^2 and 200 mg/m^2, respectively; and TN and TP concentrations of 1500 µg/L and 75 µg/L, respectively. Other recent studies examining specific chl-*a*-nutrient relationships include Dodds *et al.* (1997), Biggs (2000), Francouer (2001), Dodds *et al*. (2002a, b), Kemp and Dodds (2002).

N:P Ratio

Although nitrogen and phosphorus are the nutrients commonly limiting algal growth, the concentrations required to limit growth are less clear. Concentrations of phosphorus ranging 0.3-0.6 µg PO_4-P/L had been shown to maximize growth of benthic diatoms (Bothwell 1988) but higher concentrations have been needed in filamentous green algal communities (Rosemarin 1982), and even higher concentrations (25-50 µg PO_4-P/L) as algal mats develop (Horner *et al*. 1983, Bothwell 1989). Nitrogen has been shown to limit benthic algal growth at 55 µg NO_3-N/L (Grimm and Fisher 1986) and 100 µg NO_3-N/L (Lohman *et al.* 1991). In the past, the Redfield ratio (Redfield 1958) of cellular carbon, nitrogen, and phosphorus at 106:16:1 has been used to determine nutrient limitation. In benthic algae studies, ambient N:P ratios greater than 20:1 are considered phosphorus limited whereas those less than 10:1 are considered nitrogen limited. Nutrient limitation analysis was focused on steady state (*i.e.*, dry weather) conditions because these are the conditions under which limitation is most likely to affect periphyton communities.

Combining the above frameworks, most samples collected from sites in the Tookany/Tacony-Frankford Watershed in dry weather would be considered P-limited, mesotrophic with respect to TP, and eutrophic with respect to TN. A small number of samples would be considered not strongly limited by N or P and eutrophic with respect to both macronutrients. Sites TF500, TFJ110, and TF1120 were P-limited and never had TP concentrations exceeding the mesotrophic/eutrophic boundary of .075mg/L. TF620 was P-limited and not eutrophic for all but one sample which was considered co-limited and eutrophic. TF760 was always P-limited and did not have eutrophic concentrations of P in all but one sample. Two sites, TF280 and TFM006, were P-limited and had TP concentrations above the eutrophic boundary more often than not. The latter two sites also had other indicators of sewage (*e.g.*, fecal coliform bacteria) elevated in concentration in dry weather.

Sites TF280 and TF620 had similar mean TN values (2.59 ±0.49mg/L and 2.77± 0.45mg/L respectively), but mean dry weather TP concentration at site TF280 was significantly greater than at site TF620 ($F_{(47)}= 9.35$ $p=0.0002$). Given the greater TP concentration, one might expect greater algal biomass at site TF280. However, observed biomass was consistently smaller at site TF280 than at site TF620, which indicates that other parameters such as light, disturbance, grazing and scouring are controlling algal biomass.

5.4.2.2 Flow Effects on Stream Nutrient Concentrations

Stream nutrient concentrations in Tookany/Tacony-Frankford are dynamic. Macronutrients of greatest concern exhibited different responses to wet weather. NO_3 concentrations were relatively stable and adequate for abundant algal growth during dry weather and diluted in wet weather (mean NO_3 concentration 2.37mg/L ±0.65, and 1.49mg/L ±0.70, respectively). Conversely, other forms of N (*i.e.*, NH_3, NO_2, TKN) generally increased in concentration during wet weather, which is likely due to CSO and SSO discharge as well as presence of other organic constituents in stormwater runoff. Nitrate (NO_3) and ammonium ions NH_4^+ forms are generally bioavailable, but other forms are not available for algal growth. Total organic nitrogen concentration (TON; calculated as TKN minus NH_3) showed a significant positive correlation with fecal coliform concentration, suggesting that sewage is a primary source of organic loading to the watershed ($r_{(648)}=0.70$, $p<0.001$, Figure 5-15).

P concentration followed a pattern similar to NH_3 and TON, increasing in wet weather (Figure 5-13). This increase was likely due to CSO and SSO discharge, runoff, and soil erosion. Particle size mobilization and transport, traditionally related to flow by entrainment velocity curves (*i.e.* Shields curve), may determine the effective P loading for a given sediment load. Smaller particles, due to their greater relative surface area, can adsorb relatively more P than larger particles. Smaller particles are also generally more readily eroded and entrained in stormwater flow than larger particles.

Smaller storm events in Tookany/Tacony-Frankford thus probably contribute more to eutrophication than larger events. For example, if smaller sediment particles adsorb more P than larger particles as has been suggested, P loading becomes less efficient as larger particles are entrained in runoff. As shear stresses increase, streambank materials comprise a greater proportion of the sediment load. These particles are likely more similar to the soil parent material (*i.e.*, lower in P concentration) than more superficial soils layers that tend to incorporate more organic material. Furthermore, NH_3 showed a significant positive correlation with TSS ($r_{(380)}=0.46$, $p<0.001$), but the greatest concentrations of NH_3 were observed accompanying moderate TSS concentrations, suggesting that NH_3 concentration increases immediately due to sewage inputs but is diluted by stormwater in larger, more severe storm events (Figure 5-21).

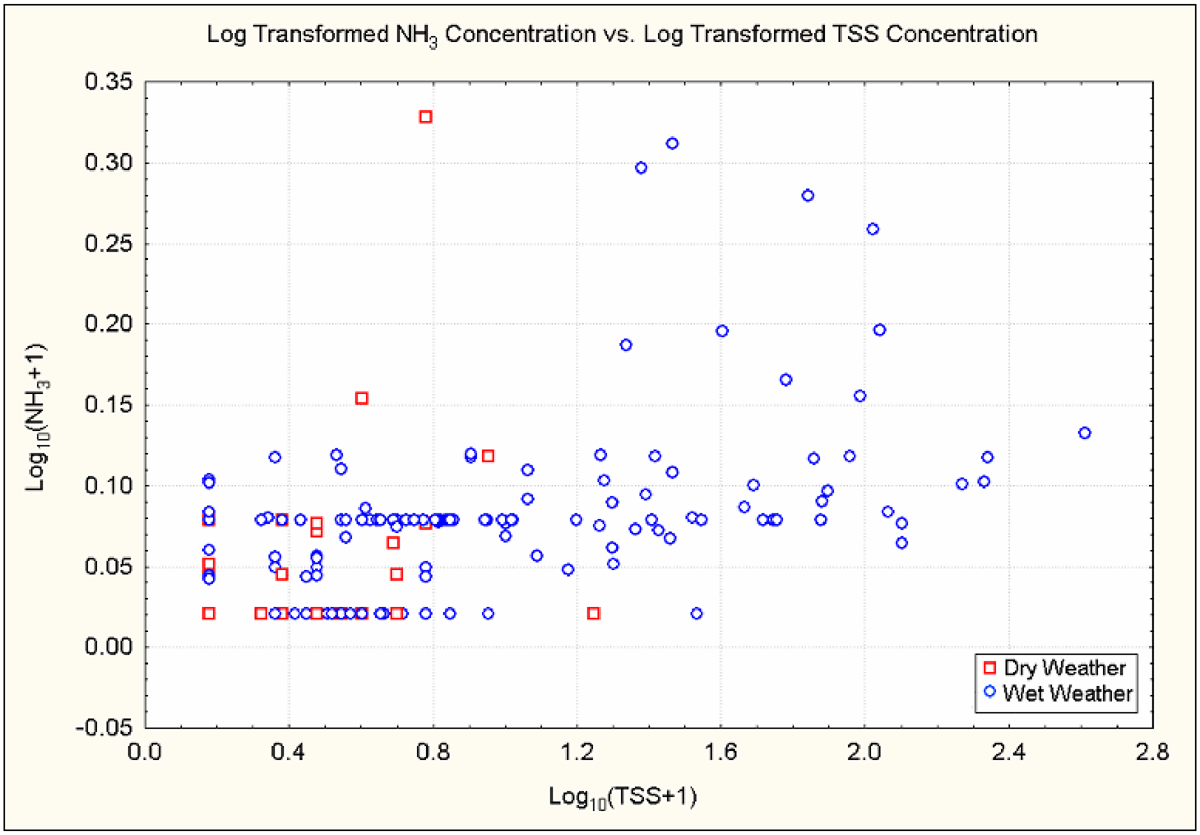


Figure 5-21 Scatterplot of log-transformed Ammonia and Total Suspended Solids Concentration of Samples Collected from 8 sites in Tookany/Tacony-Frankford Watershed, 2000-2004.

In addition to the decrease in relative bioavailability that accompanies high flows, physical stressors probably impose limits on the degree to which stream producers can take advantage of these increased concentrations. As flows increase, a greater proportion of the total nutrient load is transported out of the system, a greater proportion of the total load is inaccessible to producers, and much of the photosynthetic biomass (filamentous green algae and their associated epiphytes in particular) may be sloughed away and transported out of the system.

In areas served by combined sewers, the relative impact of small, intense storms is magnified. CSO discharge is minimally diluted by stormwater in the initial overflow phase, or "first flush". If nutrients present in these overflows can become deposited along with sediment or rapidly taken up by stream producers, discharges of short duration, particularly in which shear stresses do not result in major sloughing of algal communities, may have far-reaching consequences for stream nutrient dynamics and aquatic biota. A greater benefit may result from reducing frequency, number, and volume of small CSO discharges rather than attempting to capture releases from larger events.

Section 6
Biological Characterization

6.1 Historical and Existing Information

The Tookany/Tacony-Frankford Watershed was extensively developed as early as the 19th century. While under the control of the US Army Corps of Engineers from 1799 to 1940, the Tacony-Frankford creek channel was extensively modified, dammed, and channelized. Many businesses built mill races for hydropower and used the creek for waste disposal. With the exception of 302 acres acquired by Fairmount Park in 1915 and 1939, the remainder of the Philadelphia portion of the watershed was nearly built out in a construction boom that followed WWII. Major tributaries, including Little Tacony Creek, Wingohocking Creek, and Rock Run were buried in storm sewers both to protect people from what had essentially become open sewers, and to enable development consistent with the city's grid system. Likewise, suburban development consumed much of the Montgomery County portion of the watershed by the 1970s. Philadelphia Water Department Historian Adam Levine has amassed a collection of photographs, maps, and newspaper clippings documenting changes in Tookany/Tacony-Frankford Watershed brought about by urbanization. (More information is available on the internet at http://www.Phillyh2o.org/).

There is scant historical information about aquatic life in Tookany/Tacony-Frankford Watershed. In a 1998 report submitted to the Fairmount Park Commission (FPC), researchers from the Philadelphia Academy of Natural Sciences (ANS) reviewed existing information, citing macroinvertebrate surveys of Tookany and Baeder Creeks in Montgomery County by the Pennsylvania Department of Environmental Protection (PA DEP) in 1973, 1974, 1981, and 1998 (Fairmount Park Commission, 1999). According to ANS, most of these investigations were related to permits or spill responses, so results are probably not reflective of water quality throughout the basin.

A team of researchers from ANS conducted macroinvertebrate sampling at one site and collected fish at another site within Tacony Creek Park in 1998, documenting 8 benthic macroinvertebrate taxa and 9 species of fish. In 1999, PA DEP collected macroinvertebrates and surveyed habitats as part of the Unassessed Waters program, listing Tookany/Tacony-Frankford Watershed as impaired due to habitat alterations, flow variability and flow alterations (PA DEP, 2004 Integrated List of Waters). Philadelphia Water Department conducted a preliminary bioassessment of the watershed in 2000-2001, collecting macroinvertebrates and fish from 7 and 4 sites, respectively (Butler, *et al.* 2001). Sites sampled and collection methods were similar to the present study, allowing rough comparisons to be made.

Results of all historical studies have been consistent and unambiguous; impairment was evident in both macroinvertebrate and fish communities, whether measured as taxa richness, ecosystem function, or various numeric criteria used to evaluate aquatic communities (*e.g.*, Hilsenhoff Biotic Index, EPT index, Fish MIwb, etc.). The present study, however, is the first to integrate extensive physical habitat and chemical information.

When assessing an urban stream system that has been impaired for a long time, particularly one that lies at the center of a region of widespread impairment, it may be difficult to determine whether observed effects are the result of antecedent or ongoing impairments. There have been numerous improvements in water quality over the past 30 years, but the stream generally remains impaired.

6.2 Preliminary Documentation on the Biological Assessment of the Tookany/Tacony-Frankford Watershed

Though Tookany/Tacony-Frankford Watershed fish and benthic macroinvertebrate data suggest that many taxa have been extirpated or nearly extirpated in the past century, historical information to support these findings is generally lacking. There are simply no data to indicate what the biological communities of Tookany/Tacony-Frankford Watershed looked like prior to changes wrought by man. While some measures of community structure (*e.g.*, diversity indices) may provide meaningful information alone, conclusions of most analyses and metrics are enhanced by, or require, comparison to an unimpaired reference site. These unimpaired reference sites are often difficult to identify in southeast Pennsylvania due to extensive development and agricultural land uses. The most robust application of the reference site approach is a pair of sites located upstream and downstream of a suspected source of impairment. The downstream site in this scenario can be assumed to have a rather constant source of colonists, or "drift" from the upstream site, and all life stages of fish and macroinvertebrates are prone to displacement from the upstream site to the downstream site.

As applied to Tookany/Tacony-Frankford Watershed, reference site-based biological indexing methods assume that all similar habitats within a given ecoregion will have similar communities (absent major stressors) and that recovery of biological communities, particularly benthic macroinvertebrate communities, will occur quickly once stressors are removed. However, in regions where impairments occur watershed-wide and most first order streams have been eliminated, one cannot assume that study sites have a constant upstream source of colonists. Therefore, the most likely means of colonization of Tookany/Tacony-Frankford Watershed by rare or extirpated macroinvertebrate taxa is by winged adults, and the most likely means of re-colonization by rare or extirpated fish taxa is by passive dispersal (*i.e.*, purposeful or incidental inter-basin transfer by man).

Factors affecting re-colonization by macroinvertebrate taxa include:

1.) Geographic factors (*e.g.*, number and relative size of undisturbed first order tributaries within the watershed, distance to sources of colonists, predominant land cover and topological features separating target sites from sources of colonists, prevailing winds and climatic factors, natural and anthropogenic barriers to passive and active dispersal),
2.) Life history strategies (*e.g.*, propensity of the taxon to actively disperse, behaviors that increase the likelihood of passive dispersal, seasonal timing of oviposition and propensity to disperse prior to oviposition, duration of life cycle stages that are more prone to passive dispersal),

3.) Population factors (*e.g.*, stability of local populations representing potential colonists), and
4.) Miscellaneous factors, such as natural and anthropogenic mechanisms of passive dispersal.

Tookany/Tacony-Frankford Watershed is at the center of a region of widespread impairment due to urbanization (Figure 6-1). Some areas of the watershed may have water quality suitable for re-establishment of sensitive EPT taxa, but these taxa are generally much more abundant west of the Schuylkill River than in the Philadelphia region. PWD supports reintroduction of macroinvertebrates combined with stream restoration and stormwater BMPs for these areas.

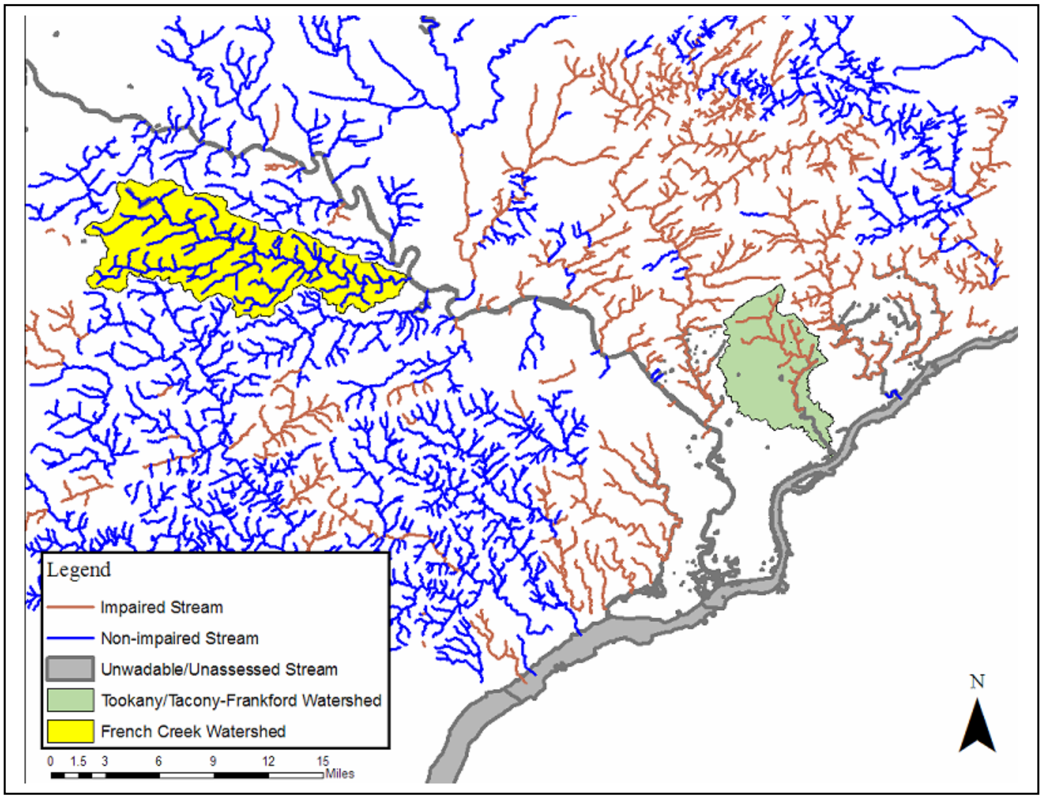


Figure 6-1 Southeastern PA stream segments in Tookany/Tacony-Frankford Watershed, French Creek watershed, and the surrounding region showing attainment status from PA DEP 2004 List of Waters (formerly 303d list).

The set of factors affecting recolonization by fish is simpler, as fish generally require water for all life stages and cannot disperse through the air. Poor water quality and physical impediments to upstream migration (*i.e.*, dams) probably prevent recolonization of non-tidal portions of Tookany/Tacony-Frankford Watershed via the Delaware River for most taxa, though American Eels are a noteworthy exception. The watershed is not actively stocked by the Pennsylvania Fish and Boat Commission (PAFBC), does not support game fish, and does not appear to be greatly affected by angling or similar activities that might result in releases of non-indigenous fish or aquatic life (*e.g.*, bait bucket release). Most of the common native fish species of southeast Pennsylvania are tolerant or moderately tolerant of water pollution.

Intolerant and non-game native fish species are unlikely to become established or re-established within the watershed other than by stocking, and PWD supports the efforts of ANS and FPC to reintroduce species such as tessellated darter and native minnows for which habitat in Tookany/Tacony-Frankford Watershed is appropriate. However, all restoration efforts should be well documented among watershed stakeholder communities so that progress can be tracked and results of subsequent ecological investigations are not jeopardized. Re-establishment of coastal plain wetlands and reintroduction of associated fish fauna (*e.g.*, Eastern mudminnow, sticklebacks, *Enneacanthus* spp.) is highly desirable, but probably not feasible in the watershed due to extensive development along the Delaware River.

Sites in Tookany/Tacony-Frankford Watershed were compared to reference sites on French Creek and Rock Run in Chester County, PA (Appendix F). Reference sites were chosen to represent a range of stream drainage areas, yet extensive impervious cover in portions of Tookany/Tacony-Frankford Watershed complicates these comparisons. Due to baseflow suppression, piping of tributaries, exaggerated storm flows and widespread erosion, sites in this urbanized watershed are difficult to categorize according to traditional frameworks (*e.g.*, stream order, link magnitude, drainage area, geomorphological attributes). These details are addressed in greater detail in Section 7.1 Habitat Assessment. Tookany/Tacony-Frankford Watershed is only linked to the tidal Delaware River and is considered a warmwater stream, while the reference sites have better connectivity and are classified as trout stocking fisheries or high quality trout stocking fisheries.

6.3 Fish

During the 2004 Tacony-Frankford Watershed fish assessment, PWD collected a total of 9774 individuals representing 17 species in 7 families (Table 6-1). Blacknose dace (*Rhinichthys atratulus)* and mummichog (*Fundulus heteroclitus),* two taxa extremely tolerant of poor stream conditions, were most abundant and comprised over half (56%) of all fish collected. Other common species included white sucker (*Catostomus commersoni*), satinfin shiner (*Cyprinella analostana*), banded killifish (*Fundulus diaphanus*), and swallowtail shiner (*Notropis procne*). Of 17 species collected in the watershed, four species comprised over 80% of the entire fish assemblage. Similarly, five species made up greater than 80% of the total fish biomass, with redbreast sunfish (*Lepomis auritus*) and American eel (*Anguilla rostrata*) contributing 42% of the biomass. American eel, blacknose dace, and satinfin shiner were found at all sites while bluegill sunfish (*Lepomis macrochirus*) and green sunfish (*L. cyanellus*) were each only found at one site and represented by a single individual. Two individual tessellated darters (*Etheostoma olmstedi*) were collected at two different sites (TF500, TF620) in the watershed; however, scientists from the Academy of Natural Sciences of Philadelphia likely stocked these fish as part of a reintroduction effort. The presence of only one tessellated darter at each site suggests that they have not become established and therefore were not included in the scoring criteria for the Index of Biotic Integrity. Overall, the non-tidal Tookany/Tacony-Frankford Watershed displayed the lowest fish diversity (*i.e.*, species richness) of all the watersheds in Philadelphia.

Table 6-1 Summary of Fish Species Collected at 7 Sites in Tookany/Tacony-Frankford Watershed, Summer 2004

Common Name	Scientific Name	TF396	TF280	TF500	TF620	TF760	TF975	TF1120
American eel	*Anguilla rostrata*	1	2	32	12	20	6	8
Banded killifish	*Fundulus diaphanus*	33	5	231	169	10	5	0
Blacknose dace	*Rhinichthys atratulus*	15	1	114	433	352	1662	847
Bluegill sunfish	*Lepomis macrochirus*	0	0	0	0	0	1	0
Brown bullhead	*Ameiurus nebulosus*	8	0	12	0	0	0	0
Common shiner	*Luxilus cornutus*	0	0	53	87	8	12	0
Creek chub	*Semotilus atromaculatus*	0	0	0	4	2	24	116
Green sunfish	*Lepomis cyanellus*	0	0	0	1	0	0	0
Hybrid sunfish	*Lepomis cyanellus x Lepomis gibbosus*	0	0	0	0	1	0	0
Mummichog	*Fundulus heteroclitus*	1101	800	179	0	0	0	0
Pumpkinseed sunfish	*Lepomis gibbosus*	0	0	1	1	0	12	0
Redbreast sunfish	*Lepomis auritus*	1	0	87	129	99	0	0
Satinfin shiner	*Cyprinella analostana*	52	4	667	763	257	27	1
Spotfin shiner	*Cyprinella spiloptera*	1	0	5	18	2	0	0
Spottail shiner	*Notropis hudsonius*	0	0	2	4	0	6	0
Swallowtail shiner	*Notropis procne*	3	0	366	345	0	0	0
Tessellated darter	*Etheostoma olmstedi*	0	0	1	1	0	0	0
White sucker	*Catostomus commersoni*	0	1	13	83	106	340	8
	TOTAL	**1215**	**813**	**1763**	**2050**	**858**	**2095**	**980**

Trophic composition evaluates quality of the energy base and foraging dynamics of a fish assemblage. This is a means to evaluate the shift towards more generalized foraging that typically occurs with increased degradation of the physicochemical habitat (Barbour, *et al.*, 1999). For example, the Tacony-Frankford fish assemblage was dominated by generalist feeders (69%) with insectivores composing 30% and top carnivores at less than 1% (Figure 6-2). Generalists become dominant and top carnivores become rare when certain components of the food base become less reliable (Halliwell *et al.*, 1999). Relative abundance of insectivores decreases with degradation in response to availability of the insect supply, which reflects alterations of water quality and instream habitat (Daniels, *et al.* 2002). The near absence of insectivores in the two upstream-most sites illustrates this point. Trophic composition was poor compared to reference sites. Though community composition varied between sites, the fish assemblage in Tookany/Tacony-Frankford Watershed was highly skewed towards a pollution tolerant, generalist feeding community.

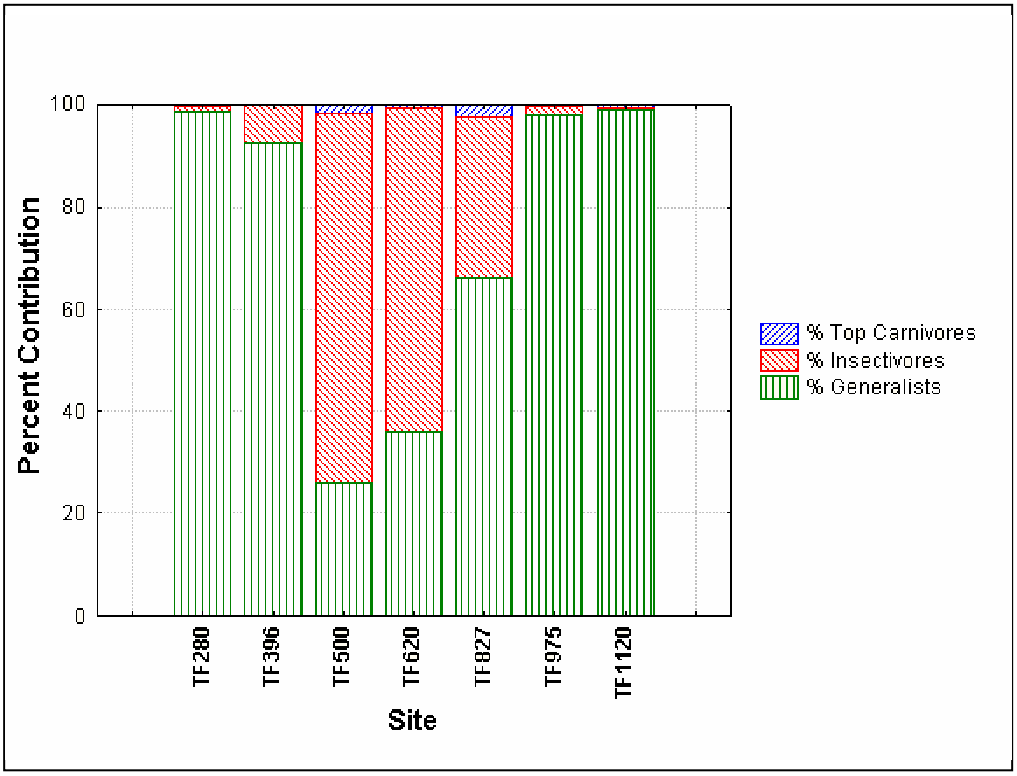


Figure 6-2 Fish Trophic Composition of the Tookany/Tacony-Frankford Watershed

Tolerance designations describe the susceptibility of a species to chemical and physical perturbations. Intolerant species are typically first to disappear following a disturbance (Barbour, *et al.*, 1999). For example, at least 70% of the fish collected at each monitoring station in Tookany/Tacony-Frankford Watershed were classified as "tolerant", and no "intolerant" species were collected (Figure 6-3). Moderately tolerant individuals were absent from the lowermost (TF280) and uppermost (TF1120) stations, and represented less than one percent (TF396) to 29% (TF500) of the assemblage at the remaining five sites. Furthermore, with approximately 91% of the fish assemblage composed of tolerant individuals, this watershed had the greatest percentage of fishes tolerant of poor stream conditions in all of Philadelphia's watersheds.

Figure 6-3 Fish Tolerance Composition of the Tookany/Tacony-Frankford Watershed

The Index of Biotic Integrity (IBI) is useful in determining long-term effects and coarse-scale habitat conditions because fish are relatively long-lived and mobile. A site with high integrity (*i.e.* high score) is associated with communities of native species that interact under natural ecosystem processes and functions (Karr, 1986). Since biological integrity is closely related to environmental quality, assessments of integrity can serve as a surrogate measurement of health (Daniels, *et al.* 2002). The mean IBI score for Tacony-Frankford Watershed was 21 (out of 50), placing it in the "poor" category for biotic integrity (Table 6-2). Low diversity, absence of benthic insectivorous species, absence of intolerant species, skewed trophic structure dominated by generalist feeders, high percentage of individuals with disease and anomalies, and high percentage of dominant species are characteristics of a fish community with "poor" biotic integrity. Spatial trends showed that only two sites received a "fair" IBI score, both centrally located within the watershed. Similar spatial trends were seen in Modified Index of Well-Being and Shannon Diversity Index values, which are measures of diversity and abundance. These indices were lowest in the lower and upper monitoring stations and highest in the middle of the watershed. This was to be expected because diversity is typically lower in upstream/smaller reaches of southeast Pennsylvania (Fairmount Park Commission 1999, W. Fairchild, personal communication). Overall, monitoring stations in the central portion of the watershed had higher biological integrity than downstream and upstream stations.

Table 6-2 Fish Community Attributes, Sampling Information, and Metric Scores for 7 Sites in Tookany/Tacony-Frankford Watershed and 3 reference sites in French Creek watershed

Metric	**FC472**	**FC1310**	**FCR025**	**TF324**	**TF396**	**TF500**	**TF620**	**TF827**	**TF975**	**TF1120**	**Avg(TF)**
Total Number of Fish Species*	22	18	18	6	9	13	12	9	10	5	9
Number of Benthic Insectivorous Species**	5	4	3	0	0	0	0	0	0	0	0
Number of Water Column Species	3	5	2	2	4	6	5	3	3	1	3
Number of Intolerant/Sensitive Species	3	4	3	0	0	0	0	0	0	0	0
Percent White Sucker	7.50	11.39	2.90	0.12	0.00	0.74	4.00	12.35	16.23	0.80	5
Percent Generalists	34.58	53.42	57.56	98.65	92.59	26.08	36.00	66.20	97.90	99.08	74
Percent Insectivores	37.56	35.02	38.77	1.11	7.33	72.11	63.41	31.47	1.81	0.10	25
Percent Top Carnivores	27.86	11.56	3.67	0.25	0.08	1.81	0.59	2.33	0.29	0.82	1
Percent Individuals with Disease and Anomalies	6.97	2.83	14.54	2.34	4.36	3.57	4.49	5.71	8.78	8.98	5
Percentage of Dominant Species	14.40	14.98	29.70	98.40	90.62	37.81	37.22	41.00	79.33	86.50	67
IBI Score	**Reference Streams**			16	20	34	30	22	14	14	21
Integrity Class				POOR	POOR	FAIR	FAIR	POOR	POOR	POOR	POOR
Area (m^2)	1420.14	1192.50	400.00	1972.71	1123.52	1046.19	1208.14	1327.33	1163.05	630.81	1210
Density (# Individuals/m^2)	0.28	0.98	1.70	0.41	1.08	1.69	1.70	0.65	1.80	1.55	1
Number Of Individuals	402.00	1168.00	681	813.00	1215.00	1763.00	2050.00	858.00	2095.00	980.00	1396
Total Biomass (g)	17612.56	9413.91	5040	4917.13	1219.66	13267.95	16001.37	9939.68	11270.18	7183.74	9114
Biomass per m^2	12.40	7.89	12.60	2.49	1.09	12.68	13.24	7.49	9.69	11.39	8
Modified Index Of Well-Being (MIwb)	12.21	12.21	11.37	0.00	2.71	10.22	10.58	9.37	6.75	0.00	6
Shannon-Weiner Diversity Index (H')	2.84	2.51	2.10	0.10	0.44	1.29	1.41	1.45	0.70	0.46	1
Number of Cyprinid Species	9	10	8	2	4	7	7	5	5	3	5
Percent Resident Species	92.54	100.00	99.12	100.00	100.00	100.00	99.95	99.88	99.95	100.00	100
Percent Introduced/Exotic Species	7.46	0.00	0.88	0.00	0.00	0.00	0.05	0.12	0.05	0.00	0
Percent Tolerant Fish	35.32	29.45	45.23	100.00	99.67	71.09	72.34	87.53	98.57	100.00	90
Percent Moderately Tolerant Fish	48.76	61.30	24.82	0.00	0.33	28.91	27.66	12.47	1.43	0.00	10
Percent Intolerant Fish	15.92	9.25	29.96	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0
Total Electrofishing Time (min)	62.28		77.23	77.43	61.68	61.44	67.87	50.62	61.76	42.32	60
Catch per Unit Effort (# Individuals/min)	6.45		8.82	10.50	19.70	28.71	30.21	16.95	33.92	23.16	23
Stream Order	4	3	2	3	3	3	3	3	3	3	

*"Total # of fish species" metric excluded non-resident fish and tessellated darter (recently introduced)

**"Number of benthic insectivorous species" metric excluded tessellated darter (recently introduced)
excluded from MIwb were brown bullhead, American eel, white sucker, satinfin shiner, spotfin shiner, green sunfish, bluegill sunfish, blacknose dace, banded killifish, mummichog, and common shiner.

Site TF324
A total of 813 individuals representing six species yielded a biomass of 5 kg during 77 minutes of electrofishing. This site had the lowest abundance (*i.e.* number of fish) and second lowest diversity in the watershed. Based on the site's estimated stream surface area of 1973 m^2, density and standing crop were estimated at 0.41 fish per m^2 and 2.5 grams per m^2 (g/m^2), respectively. This was the lowest density and second lowest standing crop in the watershed. Similarly, this site had the lowest catch per unit effort (CPUE) at 10.5 fish per minute of electrofishing (Table 6-2). Of the six species collected at site TF324, mummichog (*F. heteroclitus)*, a species extremely tolerant of high pollution levels and low dissolved oxygen, composed 98% of all fishes collected and 85% of the total biomass. There were neither intolerant or moderately tolerant taxa nor benthic insectivorous species collected at this location. Furthermore, the trophic structure of this assemblage was almost exclusively made up of generalist feeding taxa (98%).

Site TF324 received an Index of Biotic Integrity (IBI) score of 16 (out of 50), representing a "poor" quality fish assemblage and therefore, poor environmental health. To further support this characterization, the Modified Index of Well-Being (0.0) and Shannon Diversity Index (0.1) values, which are measures of diversity and abundance, were not only the worst in the watershed, but in all of Philadelphia's watersheds surveyed by PWD. These fish assemblage characteristics are symptomatic of a severely degraded stream system suffering from multiple chemical and physical stressors.

Site TF396
In 1123 m^2 of stream surface area, a total of 1215 individuals representing nine species were collected during 62 minutes of electrofishing. This site had the smallest total biomass (1.2 kg) and standing crop (1.1 g/m^2) in the watershed, with a density of 1.1 fish/m^2 and catch per unit effort of 19.7 fish/minute (Table 6-2). Intolerant taxa, benthic insectivorous species, and white suckers (*C. commersoni*) were not collected. As observed at the previous site, mummichog (*F. heteroclitus)*, a species extremely tolerant of high pollution levels and low dissolved oxygen, accounted for 91% of all fishes collected and 78% of total biomass. Three of the nine species collected at this site were represented by a single individual. Pollution tolerant taxa accounted for greater than 99% of the fish assemblage and generalist feeders (93%) dominated the trophic structure. This highly unbalanced community structure of generalist feeding, tolerant taxa, dominated by a single species, exemplifies a stream with inadequate environmental quality.

The IBI score of 20 (out of 50) was typical of a fish assemblage with "poor" biotic integrity. Disease, tumors, fin damage, and other anomalies were prevalent at site TF396 (4.4% of fish affected). The Modified Index of Well-Being (2.71) and Shannon Diversity Index (0.44) values were second lowest in the watershed and corroborate the IBI designation. These values represent 22% and 18% comparability, respectively, to reference stream conditions. Principal causes of impairment are probably low dissolved oxygen concentration and habitat modification (instability promoted by urbanized hydrology).

Site TF500
TF500 contained the most diverse fish assemblage in the watershed with 1763 individuals representing 13 species. The single tessellated darter (*Etheostoma olmstedi*) specimen

collected at this site was assumed to have been recently stocked as part of a reintroduction program, and was thus excluded from calculations and metrics. The presence of only one individual tessellated darter suggests that the species has not, and may not, become established at this site and thus was not considered members of the fish assemblage. This site had the greatest number of water column species (n=6), which is directly comparable to reference conditions, however, there were no benthic insectivores or intolerant species. Satinfin shiner (*C. analostana*), swallowtail shiner (*N. procne*), and banded killifish (*F. diaphanus*), three pollution tolerant species, composed approximately 72% of all fishes collected (Table 6-1). Despite this, TF500 had the lowest percentage of tolerant individuals and the greatest percentage of moderately tolerant individuals (Table 6-2). TF500 had the most relatively balanced trophic structure in the watershed with 72% insectivores, 26% generalists, and almost 2% top carnivores; representing the greatest percentage of the fish assemblage as insectivores and smallest percentage of generalists. This was one of only two sites in which the percentage of insectivores was greater than the percentage of generalist feeders. This shift toward specialized feeding typically occurs in response to a stabilizing insect supply, which reflects possible improvements of water quality and instream habitat. However, benthic macroinvertebrate survey results were poor.

In addition to positive scores for abundance, diversity, and trophic structure indices, TF500 had the second lowest percentage of individuals with disease, tumors, fin damage, or other anomalies. As a result, this site received the highest IBI score in the watershed (34 out of 50), characteristic of a fish assemblage with "fair" biotic integrity. This was one of only two sites that obtained a "fair" IBI score, with the rest of the watershed scoring poor for biotic integrity. Similarly, the Modified Index of Well-Being (10.22) and Shannon Diversity Index (1.29) values were the second and third highest values, respectively, in the watershed and further support the IBI classification.

Site TF620

A total of 2050 fishes representing 12 species were collected in 1208 m^2 of stream surface area in 68 minutes of electrofishing. This site had the greatest total biomass (16 kg) and standing crop (13.2 g/m^2), as well as the second greatest number of individuals (n=2050), density (1.7 fish/m^2), and catch per unit effort (30.2 fish/minute) in the watershed (Table 6-2). These relatively high abundance and diversity values, indicative of the quality of the fish assemblage, produced the best Modified Index of Well-Being (10.58) and second-best Shannon Diversity Index (1.41) values in the watershed. This was the only site in the watershed where a green sunfish (*Lepomis cyanellus*) was collected. Though diverse and abundant, the fish assemblage at TF620 lacked pollution sensitive taxa and benthic insectivorous species. Also, of the 12 species collected, three pollution-tolerant species composed 75% of all individuals collected and four species contributed 79% of the biomass. This unbalanced assemblage is symptomatic of degraded stream conditions.

Trophic composition also displayed unbalanced characteristics with less than 1% top carnivores, 36% generalist feeders, and 63% percent insectivores. Furthermore, approximately 4.5% of all fishes had some type of disease, tumors, fin damage, or other anomalies. Regardless of this unevenness and prevalence of anomalies, TF620 was one of only two sites with more insectivores than generalists and at least 25% moderately tolerant individuals, which helped elevate the IBI score. With positive scores for abundance, diversity, and trophic structure, this monitoring location received the second highest IBI score (30 out of 50) in the watershed and was considered to have a "fair" quality fish assemblage.

Site TF827

As the first monitoring station upstream of the Philadelphia county line, TF827 marks a transition in the trophic structure from an insectivore-dominated community, to generalist feeders (66%), with insectivore abundance decreasing relative to generalist feeders (Table 6-2). Likewise, pollution tolerant individuals increased in abundance (88%) while moderately tolerant (12%) individuals decreased. Of 9 species collected at this site, blacknose dace, satinfin shiner, and white sucker composed approximately 84% of the assemblage. This was the only location where a hybrid sunfish (*L. cyanellus* x *L. gibbosus*) was identified. Redbreast sunfish (*Lepomis auritus*), American eel (*Anguilla rostrata*), and white sucker made up over 75% of total fish biomass (~10 kg) (Table 6-1). This site had the second smallest abundance (n=858), density (0.65 fish/m^2), and catch per unit effort (17 fish per minute) in the watershed.

The Modified Index of Well-Being (9.37) was above average and the Shannon Diversity Index (1.45) was best in Tookany/Tacony-Frankford Watershed. Since 9 species were collected at a site with low abundance, the Shannon Diversity Index is high. However, with over 5% of the fish assemblage affected by disease, tumors, fin damage, or other anomalies; numerous white suckers; and absence of intolerant species and benthic insectivores, this site received a "poor" IBI score of 22 out of 50. Habitat modification, particularly effects of infrastructure, may be responsible for observed poor qualities of the fish assemblage at this site.

Site TF975

This site contained the greatest number of fish (n=2095), density (1.8 fish/m^2), and catch per unit effort (34 fish /minute) in Tookany/Tacony-Frankford Watershed (Table 6-2). However, greater than 95% of all fish collected were blacknose dace (79%) and white sucker (16%), species highly tolerant of poor water quality and degraded habitat. These two species also accounted for 79% of fish biomass (11 kg) collected at site TF975. Of 10 species collected, there were no intolerant species, no benthic insectivores, three water column species, and five cyprinid species. This was the only site where a bluegill sunfish (*L. macrochirus*) was collected. Trophic structure of the fish assemblage at this site was dominated by generalist feeders (98%), with very few insectivores and top carnivores. Likewise, pollution tolerant taxa made up 98% of the fish assemblage.

The large percentage of white sucker (16%) may be indicative of degradation as this species typically shows increased distribution or abundance despite historical disturbances and they shift from incidental to dominant in disturbed sites (Barbour, *et al.*, 1999). This site had the second highest percentage (8.8%) of fishes with disease, tumors, fin damage, or other anomalies, which is symptomatic of an impacted assemblage downstream of point source pollution or in areas where toxic chemicals are concentrated (Barbour, *et al.*, 1999). Taking into account the aforementioned problems, TF975 received an IBI score of 14 (out of 50), placing it into the "poor" classification for biotic integrity. The IBI score for this site was tied for worst in the watershed. Modified Index of Well-Being (6.75) and Shannon

Diversity Index (0.70) values were low and represented 55% and 28% comparability, respectively, to reference conditions.

Site TF1120
The fish assemblage at TF1120 contained only five species, least for this watershed and all of Philadelphia's watersheds surveyed by PWD using RBPV protocols. Blacknose dace constituted 86% of all fish collected at this location and one species (*C. analostana*) was represented by a single individual (Table 6-1). This site was devoid of intolerant taxa and benthic insectivorous species, and only contained one water column species. With 99% generalist feeders, this was the most highly skewed trophic structure in all of Philadelphia's watersheds surveyed by PWD. This site contained only pollution tolerant species and had the highest percentage (9%) of individuals with disease, tumors, fin damage, or other anomalies in this watershed. These are excellent measures of the subacute effects of chemical pollution and aesthetic value of nongame fishes (Barbour, *et al.*, 1999). The Modified Index of Well-Being (0.0) and poor IBI score (14 out of 50) were tied for worst in Tookany/Tacony-Frankford Watershed (with TF324) and in all of Philadelphia's watersheds monitored by PWD. Low species richness and trophic composition metrics combined with poor abundance and condition metrics reflect severely degraded stream quality.

6.4 Benthic Macroinvertebrates

A total of 2,137 individuals from 19 taxa were identified during the 2004 benthic macroinvertebrate survey of Tookany/Tacony-Frankford Watershed (Table 6-3). The average taxa richness of the watershed was 7 (Figure 6-4). Overall, moderately tolerant (91%) and generalist feeding taxa (96%) dominated the watershed. The average Hilsenhoff Biotic Index (HBI) of all assessment sites was 6.16. Pollution sensitive Ephemeroptera, Plecoptera, and Trichoptera (EPT) taxa were absent throughout the watershed (Table 6-4). One site had one modified EPT taxon present. Modified EPT taxa are EPT taxa with Hilsenhoff Biotic Index score less than or equal to four. Seven of 12 sites included in the present study were sampled by PWD in November 2000 using the same protocols, allowing some rough comparisons to be made. Most sites had reduced taxa richness and metric scores compared to year 2000 samples.

Table 6-3 Summary of Benthic Macroinvertebrates Collected at 12 sites in Tookany/Tacony-Frankford Watershed, Spring 2004

Taxon	**HBI score**	**TF324**	**TF396**	**TF500**	**TF620**	**TF827**	**TF975**	**TF1120**	**TF1270**	**TFU010**	**TFM006**	**TFR064**	**TFJ013**
Turbellaria (Flatworms)													
Cura	**7**	0	0	0	0	0	0	1	0	3	0	0	0
Oligochaeta (Worms)													
Lumbriculidae	**8**	0	1	0	1	0	1	0	0	2	1	1	0
Tubificidae	**10**	**114**	3	0	0	0	0	0	0	0	0	0	0
Hirudinea (Leeches)													
Erpobdellidae	**7**	4	1	0	0	0	0	2	1	0	0	0	0
Gastropoda (snails)													
Ancylidae	**7**	0	0	0	0	0	0	1	0	0	0	0	0
Physidae	**8**	0	0	0	0	0	0	0	0	0	0	1	0
Planorbidae	**6**	0	0	0	0	0	0	0	0	0	0	1	0
Bivalvia (Clams)													
Corbicula	**4**	0	3	0	0	0	0	0	0	0	0	0	0
Amphipoda (Scuds)													
Crangonyx	**6**	0	0	1	0	1	0	0	0	2	0	0	0
Isopoda (Sowbugs)													
Caecidotea	**6**	2	4	0	0	0	3	0	0	0	0	2	1
Ephemeroptera (Mayflies)													
Baetis	**6**	0	0	0	0	0	0	0	2	0	0	3	2
Trichoptera (Caddisflies)													
Cheumatopsyche	**6**	0	6	0	0	0	0	0	0	0	0	0	0
Chimarra	**4**	0	0	0	0	0	0	0	0	0	0	0	13
Hydropsyche	**5**	2	47	2	10	2	7	0	4	3	1	1	5
Coleoptera (Beetles)													
Stenelmis	**5**	0	1	0	0	7	0	0	0	0	0	0	48
Ectopria	**5**	0	0	0	0	0	0	0	0	0	0	0	1
Diptera (True flies)													
Hemerodromia	**6**	2	1	1	0	0	2	0	1	0	1	0	1
Simulium	**6**	0	0	0	0	0	3	0	0	1	0	0	0
Antocha	**3**	0	5	0	1	1	1	0	2	1	3	3	1
Tipula	**4**	0	1	0	1	1	1	1	1	1	0	1	3
Chironomidae	**6**	34	**126**	**129**	**321**	**239**	**147**	**108**	**123**	**176**	**130**	**108**	**129**
Total		**158**	**199**	**133**	**334**	**251**	**165**	**113**	**134**	**189**	**136**	**121**	**204**

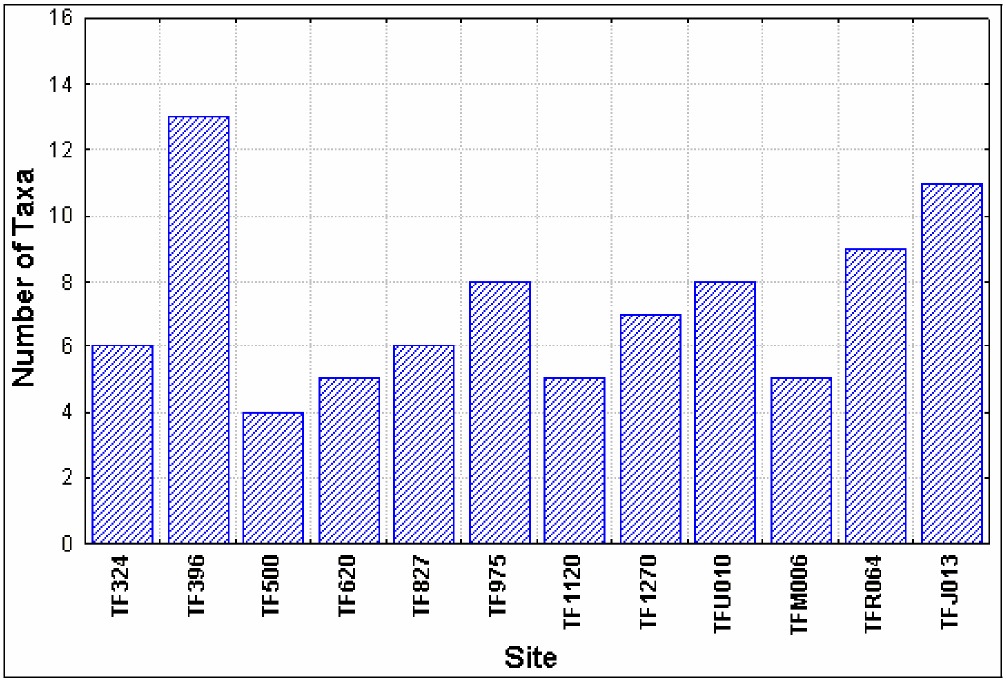


Figure 6-4 Benthic Macroinvertebrate Taxa Richness at 12 sites in Tookany/Tacony-Frankford Watershed, Spring 2004

Chironomidae (midges) dominated the benthic macroinvertebrate communities within the watershed (percent contribution ranged from 63% to 97%). Net-spinning caddisflies (Hydropsychidae), isopods, amphipods, tipulids, gastropods, and oligochaetes were also present throughout the watershed but in very low abundance (Table 6-3). Benthic macroinvertebrate communities of Tookany/Tacony-Frankford Watershed are thoroughly dominated by midges, suggesting stressors are affecting survival of more sensitive taxa.

Table 6-4 Summary of Benthic Macroinvertebrate Metric Scores from 12 sites in Tookany/Tacony-Frankford Watershed and Reference Sites in French Creek Watershed, Spring 2004

Site	Taxa Richness	Modified EPT Taxa	Hilsenhoff Biotic Index (modified)	Percent Dominant Taxon	Percent Modified Mayflies	Biological Quality (%)	Biological Assessment	Habitat Quality (%)	Habitat Assessment
TF324	6	0	8.92	72.15 (Tubificidae)	0.00	0.00	Severely Impaired	31.84	Non-Supporting
TF396	13	0	5.79	63.31 (Chironomidae)	0.00	0.00	Severely Impaired	74.53	Supporting
TF500	4	0	5.98	96.99 (Chironomidae)	0.00	0.00	Severely Impaired	62.03	Partially Supporting
TF620	5	0	5.96	96.11 (Chironomidae	0.00	0.00	Severely Impaired	72.41	Partially Supporting
TF827	6	0	5.94	95.22 (Chironomidae)	0.00	0.00	Severely Impaired	58.25	Non-Supporting
TF975	8	0	5.94	89.09 (Chironomidae)	0.00	0.00	Severely Impaired	54.95	Non-Supporting
TF1120	5	0	6.04	95.58 (Chironomidae)	0.00	0.00	Severely Impaired	58.02	Non-Supporting
TF1270	7	0	5.91	91.79 (Chironomidae)	0.00	0.00	Severely Impaired	48.03	Non-Supporting
TFU010	8	0	5.99	93.12 (Chironomidae)	0.00	0.00	Severely Impaired	48.46	Non-Supporting
TFM006	5	0	5.94	95.59 (Chironomidae)	0.00	0.00	Severely Impaired	38.60	Non-Supporting
TFR064	9	0	5.93	89.25 (Chironomidae)	0.00	0.00	Severely Impaired	64.69	Partially Supporting
TFJ013	11	1	5.57	63.24 (Chironomidae)	0.00	20.00	Moderately Impaired	60.53	Partially Supporting
FCR025	25	10	4.47	42.24 (Chironomidae)	27.44	Reference Sites			
FC1310	21	9	3.69	21.60 (*Hydropsyche*)	13.59				

Feeding measures describe functional feeding groups and provide information on the balance of feeding strategies in the benthic macroinvertebrate community (Barbour *et al.* 1999). The trophic composition of the watershed was skewed toward generalist feeding gatherer collectors (greater than 90%) (Figure 6-5). Particularly notable was the general lack of moderately tolerant filterer collector taxa (*e.g.*, Hydropsychidae, Simuliidae) which are often abundant in organically enriched streams. These taxa were generally present in moderate numbers at all sites studied in 2000, so their reduced abundance is disturbing. This may reflect severe water quality and habitat degradation or perhaps a lack of fine particulate organic matter (FPOM). Food source limitation may also impair survivability of other specialized feeders, such as cranefly larvae that rely on accumulated leaf material. Other shredders, and sensitive taxa in general, were not encountered. Specialized taxa are generally more sensitive to perturbation than generalist feeders.

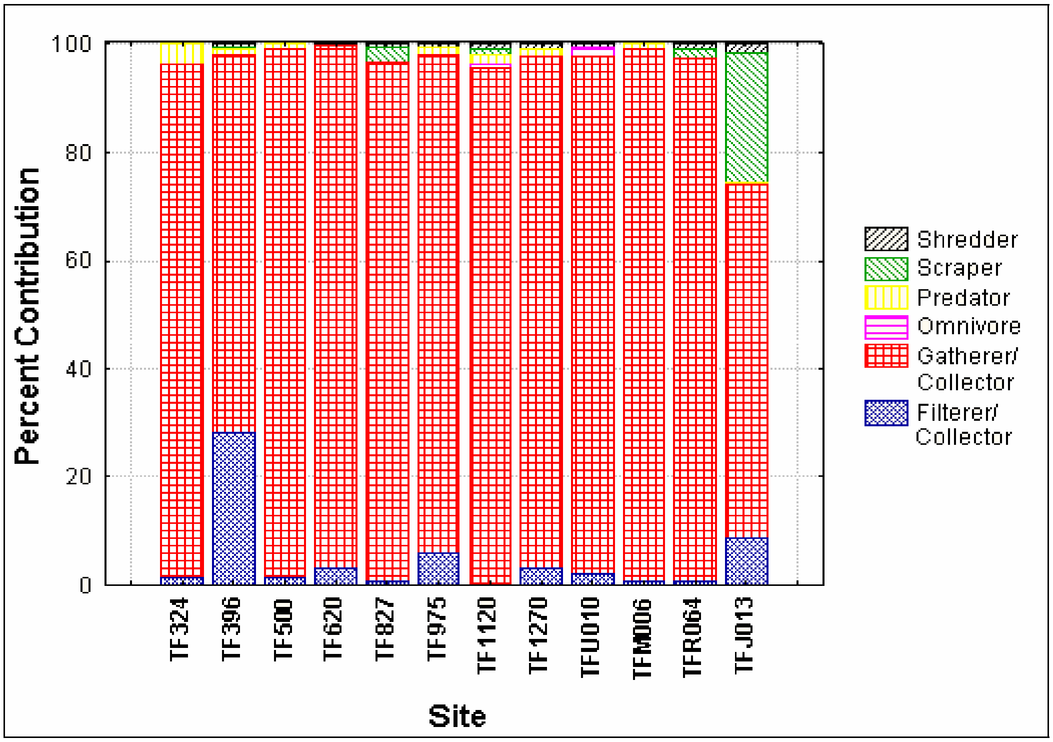


Figure 6-5 Benthic Macroinvertebrate Community Trophic Composition at 12 sites in Tookany/Tacony-Frankford Watershed, Spring 2004

Tolerance/intolerance measures are intended to be representative of relative sensitivity to perturbation and may include numbers of pollution tolerant and intolerant taxa or percent composition (Barbour *et al.* 1999). Moderately tolerant individuals (91%) dominated macroinvertebrates communities of Tookany/Tacony-Frankford Watershed. Sensitive taxa were poorly represented (2%), suggesting watershed-wide perturbation (Figure 6-6).

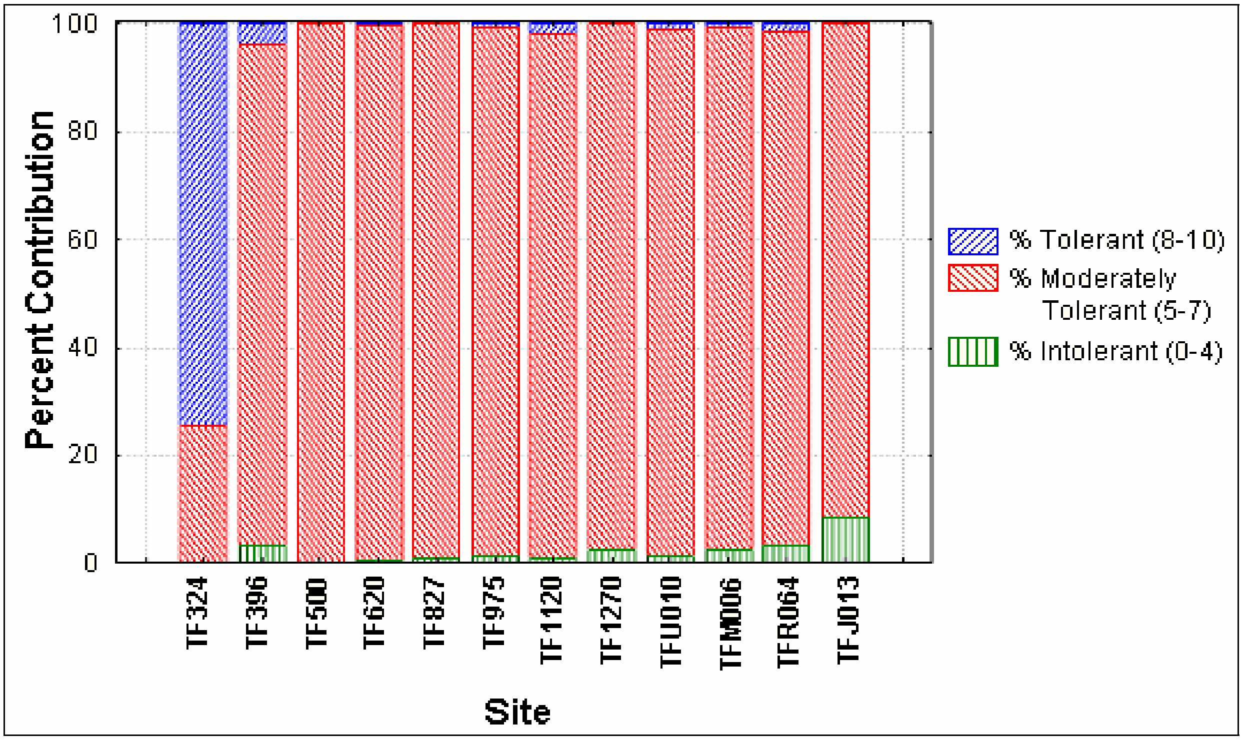


Figure 6-6 Tolerance Designations of Benthic Macroinvertebrate Communities at 12 sites in Tookany/Tacony-Frankford Watershed

The Hilsenhoff Biotic Index (HBI) is a metric used to determine the overall pollution tolerance of a site's benthic macroinvertebrate community. The HBI is oriented toward the detection of organic pollution. The HBI can range from zero (very sensitive) to ten (very tolerant). Differences in HBI score between reference and assessment sites greater than 0.71 indicate impairment. Mean HBI score of sites within Tookany/Tacony-Frankford Watershed was 6.16 (Figure 6-7). Dominance by moderately tolerant individuals and general lack of pollution-sensitive taxa contributed to the elevated HBI. In comparison, mean reference site HBI score was 4.08. When compared to reference conditions, Tookany/Tacony-Frankford Watershed mean HBI exceeded reference site mean HBI by 2.08, indicating severe impairment overall.

While HBI is very effective in determining whether a site is impaired relative to a reference site, HBI scores are not very useful in comparing impaired urban sites to one another, as these systems typically have one to three dominant taxa with similar HBI scores. For example, 90% of benthic macroinvertebrate samples collected by PWD in urban streams had HBI scores between 5 and 6. This lack of resolution is exacerbated when chironomids are not identified beyond the family level, as has been PWD practice.

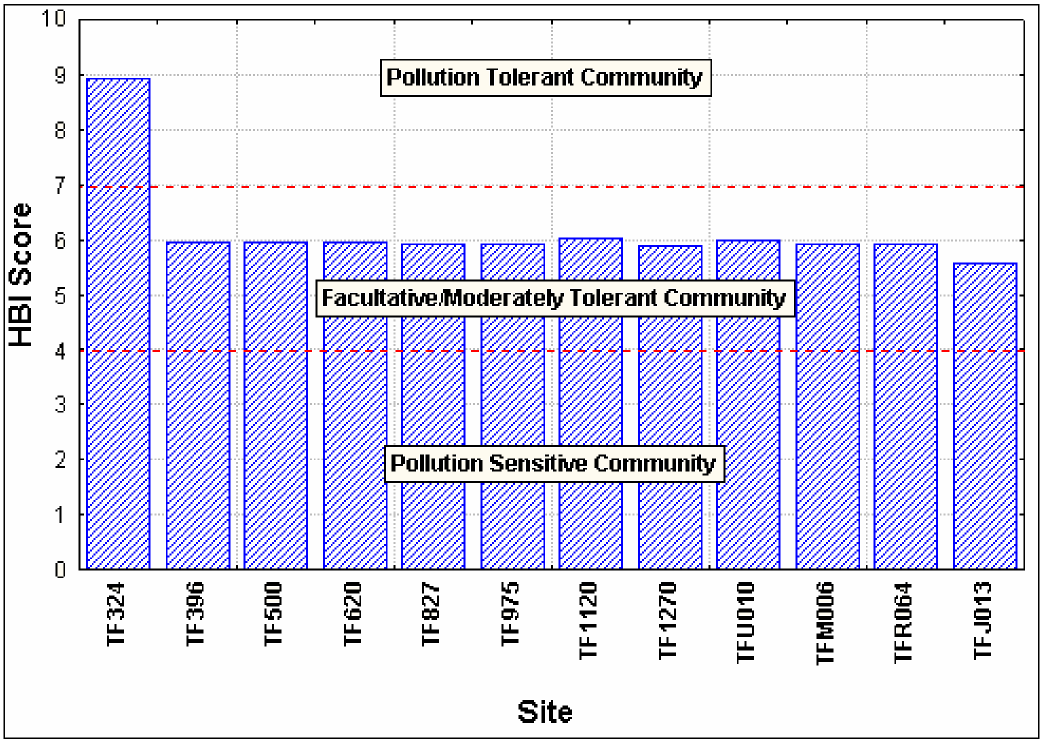


Figure 6-7 Hilsenhoff Biotic Index of Benthic Macroinvertebrate Communities at 12 sites in Tookany/Tacony-Frankford Watershed

Site TF324

Site TF324 received a total metric score of zero (0) out of a possible 30. The site was designated "severely impaired". Impairment is based primarily on low taxa richness (n=6) and the highest HBI score in the watershed (8.92) (Figures 6-4 and 6-7). This was the highest HBI score of any site assessed by PWD using RBPIII protocols. Despite a history of sampling sites below wastewater treatment plant discharge and in heavily urbanized stream systems, no other sites scored higher than 7. Tubificid worms dominated the benthic assemblage (72%) which accounts for the high HBI score. Tolerant individuals (75%) dominated the benthic assemblage at TF324 and there were no intolerant taxa collected. Generalist feeders (96%) also dominated the feeding structure of the site with predators being the only specialized feeders present (4%). The two specialized feeder taxa collected at TF324 were not pollution-sensitive.

Ten taxa were collected at this site during the 2000 survey, and tubificid worms were not collected. If the shift in benthic macroinvertebrate composition between these two subsamples reflects actual stream community changes, this site has become much more severely impaired over the past five years. Samples were collected in different seasons, and there were numerous natural disturbances (*e.g.*, floods and drought) over this period. It is assumed that water quality had been consistently poor at this site throughout the interval represented by these samples.

Site TF396

The assessment site at TF396 received a total metric score of zero (0) of 30 possible points. The site was designated "severely impaired". TF396 had the highest taxa richness (n=13) of all assessment sites and the lowest HBI (5.79) of mainstem assessment sites (Figures 6-4 and 6-7). Generalist feeders (98%) and moderately tolerant individuals (93%) dominated the site. TF396 scored substantially better in taxa richness, percent dominant taxon, and HBI than the other mainstem assessment sites. Site TF396 was the only mainstem site in which filterer collector taxa were well represented. A shift in community composition toward chironomid midges has been associated with water quality degradation, such as toxic metals contamination (Clements *et al.* 1988), but data from site TF396 are inconsistent with this explanation -- site TF396 had the best benthic macroinvertebrate community scores in mainstem Tacony-Frankford Creek despite frequent insults to water quality from CSO discharge and urban stormwater. Higher scores at this assessment location can probably be attributed to superior instream habitat and other site specific features that allow filterer collectors and other rare taxa to survive and/or recover from perturbations.

Site TF500
The total metric score at TF500 was zero (0) out of 30, which designated the site as "severely impaired". TF500 had the lowest taxa richness (n=4) of all assessment sites. TF500 also had an elevated HBI (5.98) and a very unbalanced trophic structure with 99% generalist feeders. Midge larvae (Chironomidae 97%) dominated the site. Like site TF324, 2004 metric scores and attributes of the benthic macroinvertebrate subsample were considerably worse than scores from 2000; relative abundance of filterer collector taxa decreased from 25% to <2%, and taxa richness decreased from 10 to 4. Researchers from ANS (Fairmount Park Commission, 1999) reported 63% chironomid relative abundance and 6% filterer-collector relative abundance in a quantitative benthic macroinvertebrate sample collected in winter 1998 near site TF500.

Site TF620
The total metric score at TF620 was zero (0) out of 30. The site was designated "severely impaired" when compared to the reference condition at FC1310. The site was dominated by Chironomidae (96%) and had a high HBI score (5.96). Generalist collector-gatherers (97%) dominated the feeding structure of the assemblage. When the 2000 subsample was compared to the 2004 subsample, relative abundance of filterer collector taxa decreased from 34% to 3%, and taxa richness decreased from 11 to 6. Again, if comparisons between single subsamples are representative of actual changes in benthic macroinvertebrate community structure, this site has become more severely impaired.

Site TF827
TF827 received a total metric score of zero (0) out of a possible 30. The site was designated as "severely impaired". The macroinvertebrate sample was dominated by chironomids (95%) and had low taxa richness (n=6) and an HBI score of 5.94. Generalist feeders (97%) and moderately tolerant individuals (99%) dominated the assemblage.

Site TF975
The assessment site at TF975 received a total metric score of zero (0) out of 30. The site was designated "severely impaired". Impairment was based primarily on low taxa richness (n=8) and an elevated HBI (5.94). Similar to other assessment sites, generalist feeders (98%) and moderately tolerant individuals (98%) dominated the assemblage. Chironomids composed 89% of the sub-sampled sorted for identification.

Site TF1120
The macroinvertebrate assemblage at TF1120 scored zero (0) out of 30. The site was deemed "severely impaired" when compared to the reference condition at FC1310. TF1120 had an elevated HBI score (6.04) and very low taxa richness (n=5). TF1120 was the only site surveyed where net-spinning caddisflies (Hydropsychidae) were not identified. Chironomids (96%) dominated the assemblage. When this site was sampled in 2000, filterer collectors were much more abundant, trophic and overall community composition was more even compared to results from the present study.

Site TF1270
The total biological score at TF1270 was zero (0), which designated the site as "severely impaired". TF1270 was the most upstream mainstem assessment site sampled during the 2004 survey. Similar to other assessment sites, there was an elevated HBI (5.93), low taxa richness (n=7) and abundance of chironomids (92%). Moderately tolerant individuals (98%) dominated the assemblage.

Site TFU010
TFU010 received a total metric score of zero (0) out of a possible 30. The site was designated as "severely impaired". TFU010 had an elevated HBI (5.99) and low taxa richness (n=8). The assemblage consisted mostly of chironomids (93%) and moderately tolerant individuals (98%). Although most feeding groups were represented, generalist feeders (98%) dominated the assemblage.

Site TFM006
The assessment site at TFM006 received a total metric score of zero (0) out of 30. The site was designated "severely impaired". The site had very low taxa richness (n=5) and a high HBI score (5.94). Similar to other assessment sites, generalist feeders (99%) and moderately tolerant individuals (97%) dominated the assemblage. Chironomidae (96%) dominated the benthic community and all metrics were scored as zero. Water quality in Mill Run was generally poor, with indicators of sewage present in dry and wet weather.

Site TFR064
The total metric score at TFR064 was (0) out of 30. The site was designated "severely impaired" when compared to the reference condition at FCR025. Resembling the rest of the watershed, TFR064 had an elevated HBI (5.93) and low taxa richness (n=9). Midge larvae composed 89% of the sub-sampled sorted for identification. Generalist feeders (97%) and moderately tolerant individuals (95%) dominated the assemblage.

Site TFJ013
The total biological score at TFJ013 was six (6) out of a possible 30. The site was designated as "moderately impaired". The metric score for TFJ013 was between two condition categories. The site was listed as "moderately impaired" because TFJ013 was the only site with a modified EPT taxon (*Chimarra*) present. The site was impaired primarily for low taxa richness (n=11) and an elevated HBI (5.57) score. Similar to other assessment sites, generalist feeders (74%) and moderately tolerant individuals (92%) dominated the assemblage. Compared to the rest of the watershed, the site had the smallest relative

proportion of the dominant taxon (Chironomidae, at 63%). PWD 2000 survey data suggest that sensitive *Chimarra* caddisflies may have been more abundant at this site than presently. Furthermore, two additional sensitive caddisfly taxa (*i.e.*, *Glossosoma*, *Dolophilodes*) were collected in 2000 but not in 2004.

6.5 Periphyton

Periphyton communities were sampled from a limited number of sites, chiefly to assess the role of periphyton regulating stream metabolism (Section 5.4). Several samples were preserved for taxonomic identification, but these analyses have not been completed. As most water chemistry parameters (*e.g.*, nutrients, BOD, etc.) have been fully characterized through extensive sampling, there is little need to use periphyton communities to infer an ecological condition. The ratio of water column chlorophyll-*a* to periphyton chlorophyll-*a* in dry weather and observed increases in concentrations of water column chlorophyll-*a* in wet weather suggest that attached algal communities are the dominant primary producers in Tookany/Tacony-Frankford Watershed and that storm events tend to scour and remove algal biomass.

Chlorophyll-*a* concentrations (± Standard Error (SE)) at sites TF324 and TF680 are shown in Section 5.4, (Figure 5-16). Although temporal patterns of chl-*a* were similar at both sites, chl-*a* concentrations were consistently significantly greater at site TF680 than at site TF324 ($F_{5,50}$= 14.27, p<0.05). Mean chl-*a* at site TF680 was significantly lower (49.8 ± 6.5 mg/m^2) on 9/08/2004 than on other sampling dates ($F_{4,50}$= 2.66, p= 0.043). Mean chl-*a* concentration at the TF02 site sampled 19 August 2004 (not shown in Figure) was 34.9 (± 6.9) mg/m^2.

An artificial scouring experiment was conducted to examine differences in accrual rates with respect to site and non-scoured substrates. As with the monitoring program, there were significant site differences in algal biomass with TF680 having greater chl-*a* concentrations than TF324 ($F_{2,32}$= 14.96, p <0.05). Algal accrual rates for each site were positive for the first 5 days of the study period with TF324 having an average daily accrual rate (8.36 ±1.30 mg/m^2) approximately half that of TF680 (16.7 ± 4.34 mg/m^2). During days 5-9 of the experiment, both sites lost biomass with an average daily loss rate of 1.73 (± 0.99) mg/m^2 at TF324 and 4.56 (± 1.31) mg/m^2 at TF680. The mean daily accrual rate of non-scoured rocks at TF324 during days 5-9 was 8.96 mg/m^2 (accrual rates could not be calculated for the first 5 days because of insufficient data). At TF680, the mean daily accrual rate of non-scoured rocks was 11.7 mg/m^2 and 1.98 mg/m^2 during days 0-5 and 5-9, respectively.

Algal samples for water column chl-*a* analyses were collected from sites on mainstem Tookany/Tacony-Frankford Creek during 2000-2002, and for benthic chl-*a* analyses during 2003. These data are presented in Appendix I to amalgamate all available chl-*a* data for the Tookany/Tacony-Frankford Watershed into a single document. Suspended water column samples were collected as grab samples at all Tookany/Tacony-Frankford Watershed sites on multiple occasions. In 2003, algal samples were collected from TF324, TF500, TF680, and TF760 on 16 October. Algal samples were processed and analyzed in the same manner as samples collected for the present study.

Water column (*i.e.*, suspended) chl-*a* concentrations are typically below 5 mg/L at all sites although concentrations at TF324 tend to be more variable (Table 5-7). The large spikes in chl-*a* concentrations are likely the result of scouring and suspension of benthic algae due to high flow events. Large river phytoplankton communities (potamoplankton) are typically prolific and can reach concentrations of 250 µg/L (Reynolds 1988), but Tookany/Tacony-Frankford Watershed is a relatively small, shallow stream. Given the baseflow concentrations observed, it is likely that the source of water column chl-*a* is suspended benthic algal material.

Benthic chl-*a* collected during 2003 showed a similar spatial pattern to that of this study. Chlorophyll-*a* concentrations at TF324, TF500, TF680, and TF760 were 114 mg/m^2, 222 mg/m^2, 167 mg/m^2, and 116 mg/m^2, respectively. As with the current study, it would be expected that chl-*a* concentrations would be greater at TF324 than at upstream sites because of the observed diurnal DO fluctuations. It appears that other factors such as disturbance, light, or grazing may be limiting accrual at TF324 and that the relationship between biomass and production is not as clear-cut as expected.

6.6 Summary of Biology by Reach

Site TF280/324

Site TF 324 is one of the most severely degraded aquatic habitats in the City of Philadelphia. Approximately one third of the watershed land area, roughly representing the drainage area of the former Wingohocking Creek, drains directly to the combined sewer outfall located just upstream of this site (Figure 7-1). This outfall is responsible for combined sewer overflows of 2 billion gallons per year on average. Due to stormwater collection system efficiency and the sheer size and imperviousness of its drainage area, it is assumed that even small storm events may cause discharge of combined sewage from this outfall. Sewage that is constantly present in the system is minimally diluted by stormwater in these small events, and the large scour pool downstream of this outfall is capable of storing many gallons of mixed discharge. One component of PWD's CSO long term control plan is construction of a Pelican gate within this outfall that will allow for storage and capture of combined sewer flows; this project is in the conceptual design stage. It is estimated that once completed, this gate will reduce the number of overflows from 69 to 51 per year on average at this site. It is hoped that this gate will capture small rain events and provide many benefits to dry weather water quality.

As evidenced by comparison to water quality data from the 1970s in which fecal coliform concentration was elevated in both wet and dry weather at this site (Appendix A), much improvement has been made with regard to controlling and managing this combined sewer, but tracking down and fixing sources of dry weather discharge is still a high priority. This site had the most severe wet weather loading of organic material (mean BOD_5 and TKN) in Tookany/Tacony-Frankford Watershed. Dissolved oxygen suppression due to the breakdown of organic matter is probably limiting the success of most taxa at this site. Saprobic conditions are further indicated by the dominance of tubificid worms and mummichogs, two taxa known to be tolerant of anoxia; the presence of black, reduced sediments and hydrogen sulfide odors which were commonly encountered here; and the fact that periphyton biomass was smaller at TF280 than upstream sites that do not typically experience frequent DO suppression.

Site TF396

Site TF396 is located only 0.7 mi upstream of site TF324, and was chosen to enable an assessment of effects from the large CSO outfall at site TF324. While nearly all attributes of this site were much improved over site TF324, this site is still considered severely impaired. Water quality and hydrologic impairment are assumed to be co-limiting factors. This site had excellent habitat relative to other sites in the watershed, and without the influence of combined sewer overflows and untreated stormwater it might be expected to have much better biological communities. While upstream of the former Wingohocking Creek, based on computer simulation this site is still subject to the effects of over 1 billion gallons per year of combined sewer overflows.

Dominance of the fish community by *H. heteroclitus* shows that these fish will ascend into non-tidal waters to exploit suitable habitats and further suggests that anoxic conditions at this site may limit the success of less tolerant fish taxa. Conversely, the macroinvertebrate community at site TF396 showed significant improvement over that of TF324, with the highest taxa richness and lowest HBI score on mainstem Tacony Creek. This finding suggests that long, extensive riffles with large, relatively stable, non-embedded substrate can partially offset effects of stormwater on a local scale. However, few of the macroinvertebrate taxa present at this site are considered sensitive to organic pollution, and sensitive taxa that were present (*i.e.*, tipulids) were found in small numbers.

Extensive riparian buffers on both banks fail to ameliorate the hydrologic effects of a 22mi^2 drainage area with 60% impervious surface, and stream segments just upstream and downstream of this site have severe habitat impairments as well. This site is exceptional and not representative of habitat south of Roosevelt Blvd. Surface geology and the sharp bend at the upstream limit of the sampling site allow for more stormwater flow energy dissipation and the left bank of this site (outside meander) has been protected by extensive large boulder rip rap revetments. A large stand of Japanese knotweed was the only vegetation present along this bank.

Site TF500

With drainage area of approximately 17 mi^2, site TF500 should be large and stable enough to support complex native fish and macroinvertebrate communities. Water quality, and to a more limited extent, habitat stability tend to generally improve from downstream to upstream within the City of Philadelphia. While fecal coliform counts were elevated at all city sites downstream of CSO outfalls, Site TF500 had smaller dry weather concentrations of NO_2, BOD_5, TKN and NH_3 than site TF280 (Appendix A). Continuous water chemistry results indicated that anoxic conditions were also less frequent than at site TF280 (Table 5.6); these findings correlate well with an increase in fish species richness, though not with macroinvertebrate taxa richness, which was lowest in the watershed.

North of site TF396, riparian zones of Tacony Creek Park are consistently wider and more densely forested than downstream portions that are narrower or have more mown lawn and golf course area. The mainstem of Tacony Creek North of Whitaker Avenue is a nearly continuous band of forested parkland (Figure 6-8). However, riparian buffers do not protect the stream from stormwater erosion effects, as only a small portion of stormwater flow reaches the stream as surface runoff. Effects of erosion and destabilization were very apparent – Site TF500 and other stream segments in its vicinity have been severely overwidened and straightened by exaggerated storm flows (Appendix F in preparation). The fish assessment site was bisected at its upstream limit by a large channel bar, and the downstream left bank had extensive deposits of fine sediment that were black in color and odorous.

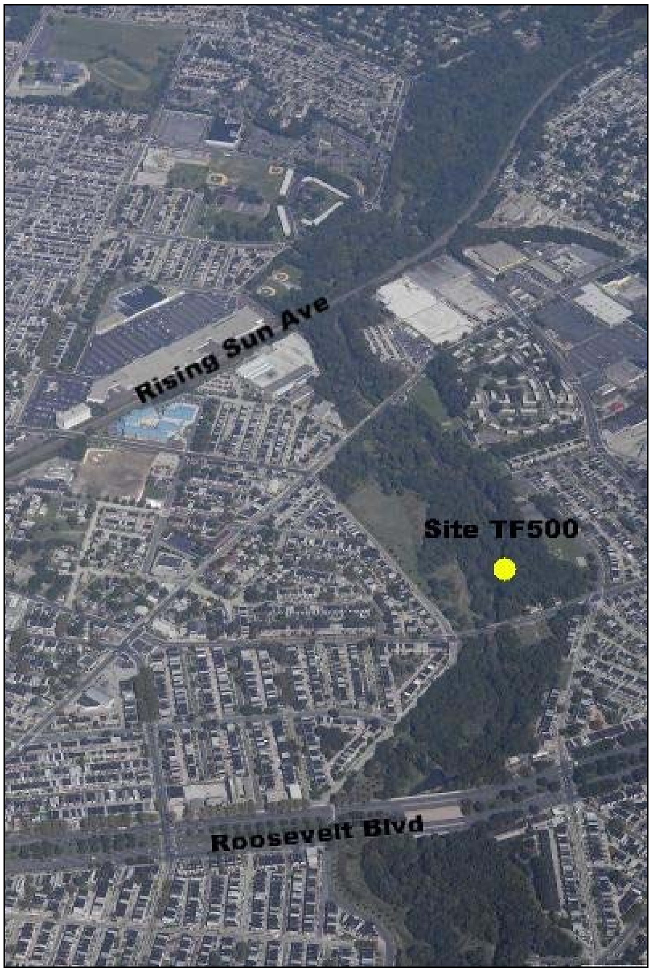


Figure 6-8 Oblique Aerial Photograph of site TF500 and Vicinity

Though mainstem Tacony Creek in Tacony Creek Park is disconnected from its floodplain, abandoned floodplains are generally wide and undeveloped, offering many opportunities for stormwater wetland creation. In a 1998 report to the Fairmount Park Commission, scientists from the Philadelphia Academy of Natural Sciences (ANS) recommended the creation of a wetland just downstream from site TF500 in a ballfield that has been largely abandoned due to frequent inundation. This site was also identified as having wetland creation potential in a wetland inventory performed by PWD in 2001. Another important task is maintenance of the steep slopes that drain directly to the stream at this point.

Erosion in gullies and along trails may introduce sediment to the stream. ATV use has been reduced since metal gates were installed in 2003.

Despite obvious habitat impairments, fish community metrics at site TF500 were substantially improved over site TF396, especially species richness and evenness. These improvements can be largely attributed to an increase in the number and relative abundance of insectivorous minnow taxa that feed in the water column (*i.e.*, *Cyprinella* and *Notropis* spp.). As these fish feed opportunistically on drifting food items, including terrestrial insects, increased abundance may be partially due to an increase in the availability of terrestrial insects which might be expected to accompany increased canopy cover and riparian zone vegetation. Substrates at site TF500 were typically much smaller than at sites TF396 and TF324, perhaps an important factor for species that spawn over sand and gravel substrates. Many species classified as pollution tolerant were present at site TF500 but not downstream, which corroborates the findings of water quality data (*i.e.*, poorer water quality downstream).

Site TF500 was located approximately 0.5mi downstream of the site where ANS collected fish in a 1998 survey of fish in Philadelphia Parks (Fairmount Park Commission, 1999 Volume III). While the fish community in the 1998 sample was generally similar to the 2004 sample, certain changes were noted. For example, ANS scientists collected 118 Spotfin shiners (*C. spiloptera*), but did not collect Satinfin shiners (*C. analostana*). The investigators concluded that *C. analostana* was not present in the basin, possibly due to interspecific competition, and recommended against its introduction. However, PWD did not record *C. spiloptera* from the basin in a 2000 assessment. In 2004, *C. analostana* was found at each assessment site, greatly outnumbering its congener. Though these results come from a small number of sites only, it appears that either a major shift in relative abundance has occurred since 1998, or the 1998 record is in error. The relative abundance of *Notropis* spp. was also interesting, with ANS collecting 183 *N. procne* and 117 *N. hudsonius*. In 2004, *N. procne* still appeared to be abundant in the basin, but *N. hudsonius* was rarely caught (12 individuals). In this case, however, intermediate (2000) sample data seem to support the hypothesis that a change in relative abundance has taken place (91*N. procne* and 57 *N. hudsonius* individuals collected in 2000). No specific explanation is offered for the observed change in relative abundance, but water quality and habitat modification, along with biotic interactions (*e.g.*, predation, competition) are possible factors.

Site TF620/680

Much like site TF500, site TF620 lies in a continuous belt of riparian forested parkland in Tacony Creek Park where canopy cover and width of riparian vegetated zone were considered good. Like all sites in Philadelphia served by combined sewer systems, this site shows elevated dry weather fecal coliform concentration (Tables 5-4 and 5-5), but most other dry weather water quality constituents were similar to site TF500 or improved slightly at site TF620 compared to downstream sites. Dissolved oxygen concentration, in particular, seems to be much improved over downstream locations, as site TF620 marks the upstream-most limit of the area in which DO concentration is considered to be a problem (Table 5-6). Sites for water chemistry monitoring and biological monitoring were not identical, and the water chemistry monitoring site was moved 0.5mi upstream in 2003 due to recurrent vandalism at the site 200m upstream of Adams Avenue.

Two dams separate site TF620 from site TF500. The first dam, located upstream of Rising Sun Avenue, is only about 3ft high, and creates a total water surface drop of approximately 1ft. The dam at Adams Avenue, however, is much larger and creates an impoundment of slower, deeper water where sediment deposition is high. Furthermore, site TF620 had the smallest percentage of boulder substrate in Tookany/Tacony-Frankford Watershed. Like most other sites, TF620 is in a region where most stream segments are extensively destabilized due to stormwater and urbanized hydrology. Because PWD protocols result in direct sampling of the richest habitat in an area, fish and macroinvertebrate sites probably score much higher for habitat metrics than would more typical stream segments upstream and downstream. The 100m segment chosen for fish sampling at TF620 was the only segment in this area where adequate pool and riffle habitats could be found.

The dam at Adams Avenue probably has other effects on aquatic biota other than increased sediment deposition and habitat homogeneity upstream. Over five feet in height, this dam is assumed to be an impediment to upstream migration of most fishes other than eels (*A. rostrata*), though eel abundance and biomass decreased from site TF500 to site TF620. Though stream size and drainage area no doubt are influential, and species richness is expected to be greatest in medium-sized streams, dams may be partially responsible for the absence or decreased abundance of certain species from downstream to upstream (*e.g.*, *A. nebulosus*). Furthermore, habitat between the sampling reach and the dam at Adams Avenue is a homogeneous run with sand and gravel substrates due to deposition caused by the dam. Sand and gravel are needed by many native species for spawning, a factor that may partially explain the increased number of native minnow species at sites TF620 and TF500 relative to sites with coarser substrates. The natural forested floodplain also probably provides more roots, coarse woody debris and snags of the type used by crevice spawners (*e.g.*, *Cyprinella* spp.).

Site TF760/827

Site TF 760 is the first assessment site within Montgomery County and this area marks numerous changes that have implications for water quality and biological communities. Most importantly, stormwater is collected in a separate sewer system which discharges directly to the stream, unlike downstream reaches which are served by combined sewers that discharge to the stream only when the receiving capacity is exceeded. Along mainstem Tookany Creek in Montgomery County, riparian buffer zone width becomes more variable and riparian zones are increasingly maintained as lawn. Predominant land use drastically changes from multi-family residential to single-family residential housing (Figure 2-7). The frequency and amount of stream area impacted by bridges, culverts, and channelized sections increases compared to the non-tidal portions of Tookany/Tacony-Frankford Watershed (especially within Tacony Creek Park upstream of Whitaker Avenue). Much of the land abutting streams is privately owned and maintained as lawn. Erosion control structures are often built by private landowners, and these structures vary widely in design, effectiveness and impacts to stream stability.

Site TF760 is another example of a site where the biological assessment points were shifted upstream from the location where water chemistry samples were taken. This change was necessary to find adequate habitat, as the chemical sampling point was located within a channelized section. The confluence of an unnamed tributary with a drainage area of 0.6 mi^2 was located between the biological assessment sites and the chemical monitoring site. Nearly 3000 ft of streambank restoration have been completed in Tookany Creek along Tookany Creek Parkway in Cheltenham Township as of May 2005. Restoration techniques used at this site followed a semi- naturalized revetment approach, incorporating live willow stakes and branch bundles. Telephone poles were trenched and pinned to the streambank and the toe of slope was reinforced with boulders. Construction activities at this restoration site and along railroad tracks in the vicinity of site TF1120 may have impacted the results of chemical samples and biological assessments. For example, continuous water quality monitoring probes recorded turbidity >8NTU during 20% of all dry weather observations (373 days of combined dry weather monitoring from 2000-2004, (Table 5-7).

Substrate at this site was much coarser than at site TF620, and the site was lacking pools, factors that contribute to decreased HSI scores for some species. Lack of pool habitat may partially explain the low abundance of Swallowtail Shiners and absence of Creek Chubs at this site. These fish are regarded as pool species and were found to be more numerous in sites with greater pool volume downstream and upstream of site TF760, respectively. This site also had many Redbreast sunfish, a species that was not found again in any upstream Tookany Creek sites. Decreased species richness at this site relative to site TF620 may be partially due to construction disturbances within the stream restoration area upstream of the assessment site. There are also 2 dams between site TF620 and TF760 which may impair upstream migration of fish.

Many fish require sand and gravel substrates for spawning, and fish assessments were conducted during the spawning season for many native species. The paucity of appropriate spawning substrates at sites TF760 and TF975 relative to site TF620 may help explain the decreased abundance of these species. Urbanized stormwater flows are exacerbated by extensive channelization and scour the streambed of sand and gravel substrates. A decrease in the proportion of sand and gravel substrates might be expected to correlate with an increase in overall health of the benthic macroinvertebrate community, as cobbles and larger substrates are more stable, but this site had one of the worst assemblages in Tookany/Tacony-Frankford Watershed. Again, construction disturbances may be partially to blame. While crayfish were not collected or enumerated, biologists observed them to be very abundant at this site while electrofishing. Increased crayfish abundance is probably also related to the increased substrate size.

Site TFJ013

Though impaired compared to reference sites on French Creek, site TFJ013 exemplifies some of the best conditions within Tookany/Tacony-Frankford Watershed. This sub-watershed was among the lowest in impervious cover (28%), and fewer Jenkintown Creek stream segments were channelized and culverted compared to many other tributaries in Montgomery County (Appendix F in preparation). Decreased impervious surface, combined with fewer infrastructure impacts, probably helps ameliorate the effects of urbanized hydrology. Jenkintown Creek has the best Baseflow characteristics in the watershed, as evidenced by USGS gauge data analysis (Table 4-6), so drought effects may be lessened compared to tributaries with smaller drainage area. Jenkintown Creek may serve as an example of changes one would hope to find once more severely degraded reaches in the watershed are restored.

Substrates in Jenkintown creek were generally coarser than in mainstem sites (Appendix F to be added at a later date), and most habitat attributes related to substrate and riffle stability for macroinvertebrates were rated suboptimal. Site TFJ013 had the best benthic macroinvertebrate community of all Tookany/Tacony-Frankford Watershed sites. Certain sensitive EPT taxa appear to have become less numerous or extirpated completely, based on comparison to 2000 PWD survey data, but there appears to be a population of *Chimarra* remaining. Repeated sampling or sampling at additional locations would enable us to draw stronger conclusions about whether this site has become more severely impaired since 2000. Water quality data do not indicate serious physicochemical stressors, so hydrologic modification is the most likely explanation for increased degradation, if the site is indeed continuing to degrade.

Jenkintown Creek is shallow and was not selected for fish sampling, but it is likely that Jenkintown Creek has many of the same species of fish as site TF1120 (*i.e.*, Blacknose Dace and Creek Chubs). A northern water snake was observed eating a small sunfish in Jenkintown Creek. A small instream pond located north of Indian Creek Road may support greater diversity of fish life.

Site TF975

Biological communities at site TF 975 showed signs of severe impairment, as benthic macroinvertebrate and fish species known to be tolerant of poor water quality were nearly completely dominant. This site had the greatest proportion of white suckers within the watershed and the second greatest proportion of blacknose dace and fish with deformities, lesions and tumors in the watershed. This site experienced water quality criteria exceedances frequently in both dry and wet weather. Indicators of dry weather sewage inputs (*e.g.*, fecal coliform bacteria concentration, *E.coli*) were highest among sites upstream of combined sewer outfalls (Appendix A). However, site TF975 is located within a small park in Cheltenham Township, so dog feces must be considered a potential source of indicator bacteria.

Numerous infrastructure impacts are present in the vicinity of this site. Bridge culverts and a dam located at High School Road promote instability and the semi-natural revetments installed along the right bank to curb erosion are beginning to deteriorate. Dams located downstream of the site (n=3) may partially explain the decreased fish species evenness relative to downstream sites. Upstream of High School Road, the stream has been extensively channelized, particularly along the left bank (20% of the left bank of Tookany Creek is channelized between site TF1120 and TF975). Stormwater outfalls (n=20) with combined cross sectional area 180ft^2 discharge to the stream between site TF1120 and site TF975, the greatest relative impact of stormwater outfall density outside the City of Philadelphia's Combined sewer system (Appendix F, in preparation). Like site TF827, habitat attributes associated with streambanks and riparian zone management scored poorly, despite the fact that these sites are located within parkland (Table 7-2).

Site TF1120

Site TF1120 is located just downstream of a straightened and recently channelized portion of Tookany Creek that runs parallel to SEPTA Railroad tracks. Gabion baskets were installed in 2004 to reinforce the railroad bed. Cheltenham Township also replaced many water mains in the vicinity of this site. Though sediment bags were used in combination with coffer dams and trash pumps, construction disturbance often caused the Creek to appear turbid throughout the course of work. Signs of hydrologic instability were very evident at this site, especially within the fish assessment site located immediately downstream of Washington Lane Bridge. Bedrock outcrops have been scoured of smaller substrates and the inside meander bar was observed to increase in size dramatically since 2000. Near the lower end of the fish assessment site, the stream is channelized along the right bank where the creek adjoins Chelten Hills Drive. The portion of Tookany Creek between site TF1270 and TF1120 has 24 stormwater outfalls with combined cross sectional area greater than 185ft^2.

Tree canopy was nearly complete throughout most of the site and algae were not observed to grow to nuisance densities. Continuous water quality data do not indicate DO stress at this site (Table 5-7) and there were few violations of WQ criteria at this site overall (Tables 5-4 and 5-5). It is believed that hydrologic modification and construction disturbances are responsible for the poor benthic macroinvertebrate and fish communities observed at this site. In addition to channelization and peak flow modification, four dams separate site 1120 from site TF975, probably limiting upstream migration of fish species, other than minnows that are known to have an affinity for smaller streams (*i.e.*, blacknose dace, creek chubs)

Section 7
Physical Habitat Characterization

7.1 Habitat Assessment

Tookany/Tacony-Frankford is an urban stream system that has been adversely affected by development and land use practices over the past century. Impervious cover is estimated at 40.9% of the watershed in total and 53.6% within the city of Philadelphia. More than 55% of the watershed, particularly the portion representing the former Wingohocking Creek, has been encapsulated and does not flow to natural surface waters, but to a combined sewer system. (Figure 7-1) Impervious cover, especially directly connected impervious cover, decreases groundwater recharge and the percent of annual streamflow represented by baseflow. Tookany/Tacony-Frankford streams are extremely "flashy"- increases in streamflow and erosive forces occur almost immediately following the onset of storm events. Both maximum discharge and total runoff volume are increased compared to an undeveloped watershed (Figure 7-2).

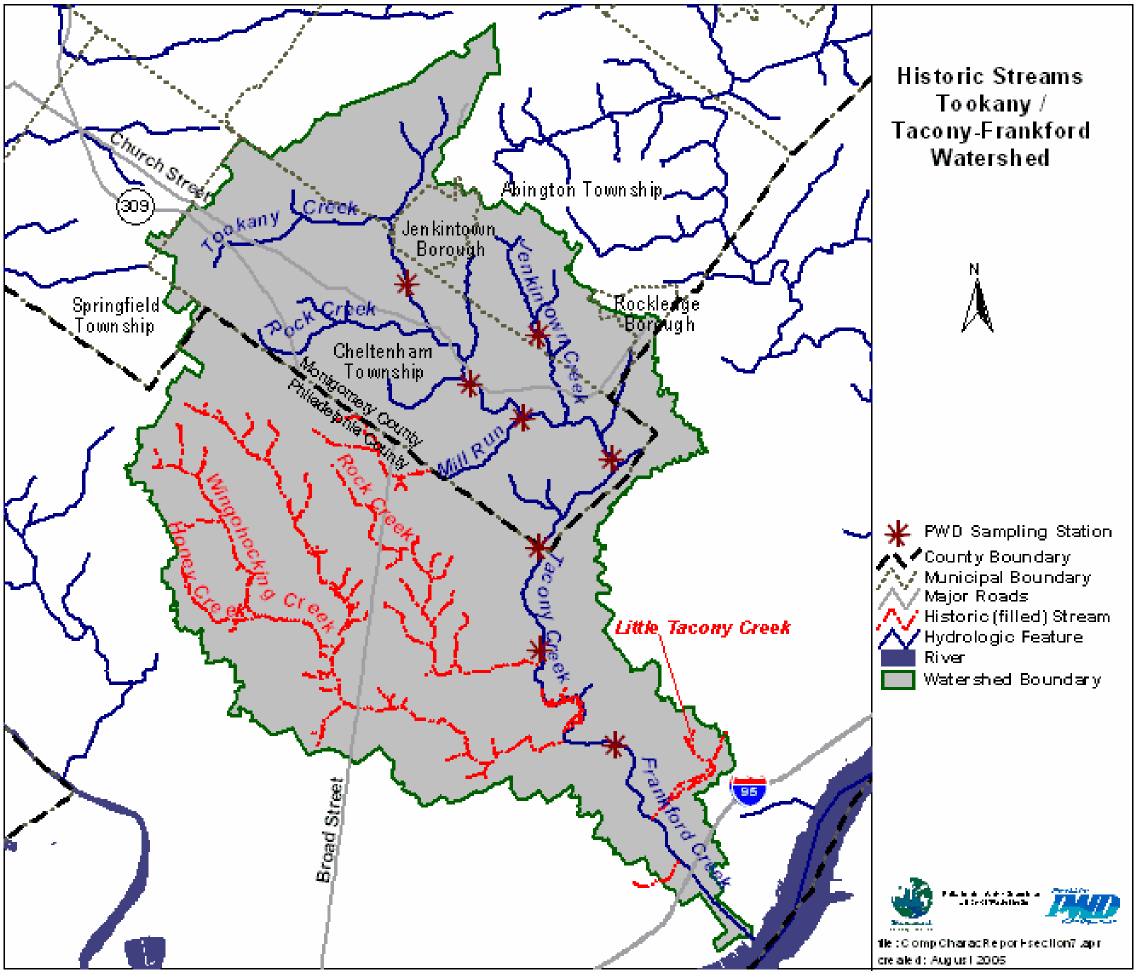


Figure 7-1 Historic and present day streams of the Tookany/Tacony-Frankford Watershed

Changes in hydrology have resulted in de-stabilization of much of the watershed. Urbanization promotes a cumulative, self-reinforcing pattern of streambank erosion. As stream channels become physically larger and further disconnected from their historic floodplains, more stormwater forces are restricted to the stream channel, where compromised, heavily eroded banks are least suited to dissipate them. These overwidened stream segments deficient in baseflow make very poor habitats for all but the most tolerant generalist species. Signs of habitat impairment were present in the watershed's biological communities; Tookany/Tacony-Frankford Watershed is nearly devoid of sensitive macroinvertebrates and fish taxa, while unstable stream banks have been extensively colonized by invasive species, especially Japanese knotweed (*Polygonum cuspidatum*).

Other habitat effects include widespread sedimentation in runs and pools as well as along channel and lateral bars. With few exceptions, historic first order tributaries and wetlands within the watershed have been filled in and/or piped into storm sewers. Erosion has exposed, threatened, and in some cases, destroyed valuable infrastructure and private property. Unfortunately, traditional solutions for addressing erosion and flooding problems may increase instability overall, exacerbating problems they are intended to solve. The Tookany/Tacony-Frankford Watershed Management Plan (TTFIWMP) outlines several options for detaining, infiltrating, and treating stormwater to reduce stream channel impacts. Healthy ecosystems require healthy habitats, and healthy habitats cannot be restored without addressing stormwater impacts.

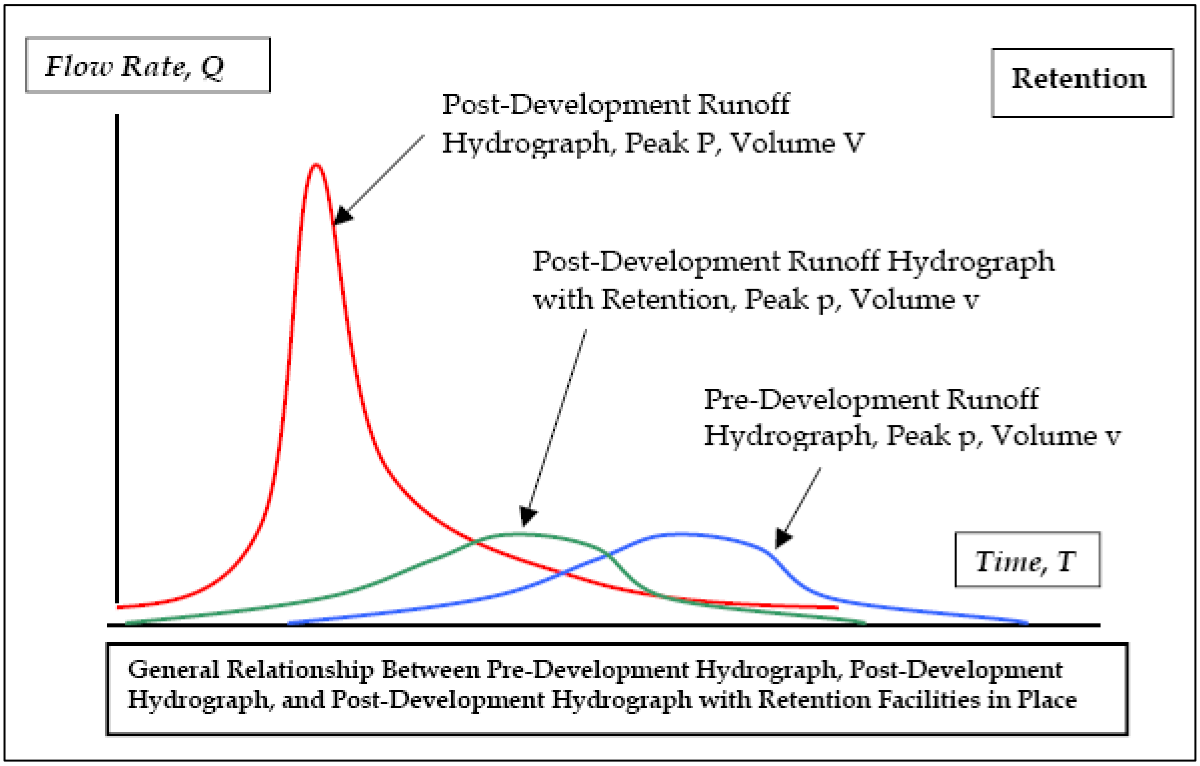


Figure 7-2 Typical Hydrographs for Developed and Natural Streams. (Source: Portland Bureau of Environmental Services, Stormwater Management Manual, 2004)

7.2 EPA Habitat Assessment Results

Comparison to Reference Sites

Habitat features at twelve Tookany/Tacony-Frankford Watershed sites were compared to those of the reference sites located in nearby Chester County. Mainstem and third order tributary sites were compared to French Creek reference sites, located in Coventry Township, Chester County, PA. Tributary sites, second order or less, were compared to Rock Run, a tributary to French Creek located in Coventry Township, Chester County, PA (Appendix F). In general, habitat was determined to be very poor, with seven of twelve sites designated "non-supporting" of the watershed's designated uses (Figure 7-3). Five sites, including three in Tacony Creek Park in the City of Philadelphia, had slightly better scores and were designated "partially supporting". Habitat degradation was considered to be the most important impairment in Tookany/Tacony-Frankford Watershed, corroborating the results of biotic indexing. Table 7-1 summarizes the results of habitat assessment using EPA habitat assessment protocols.

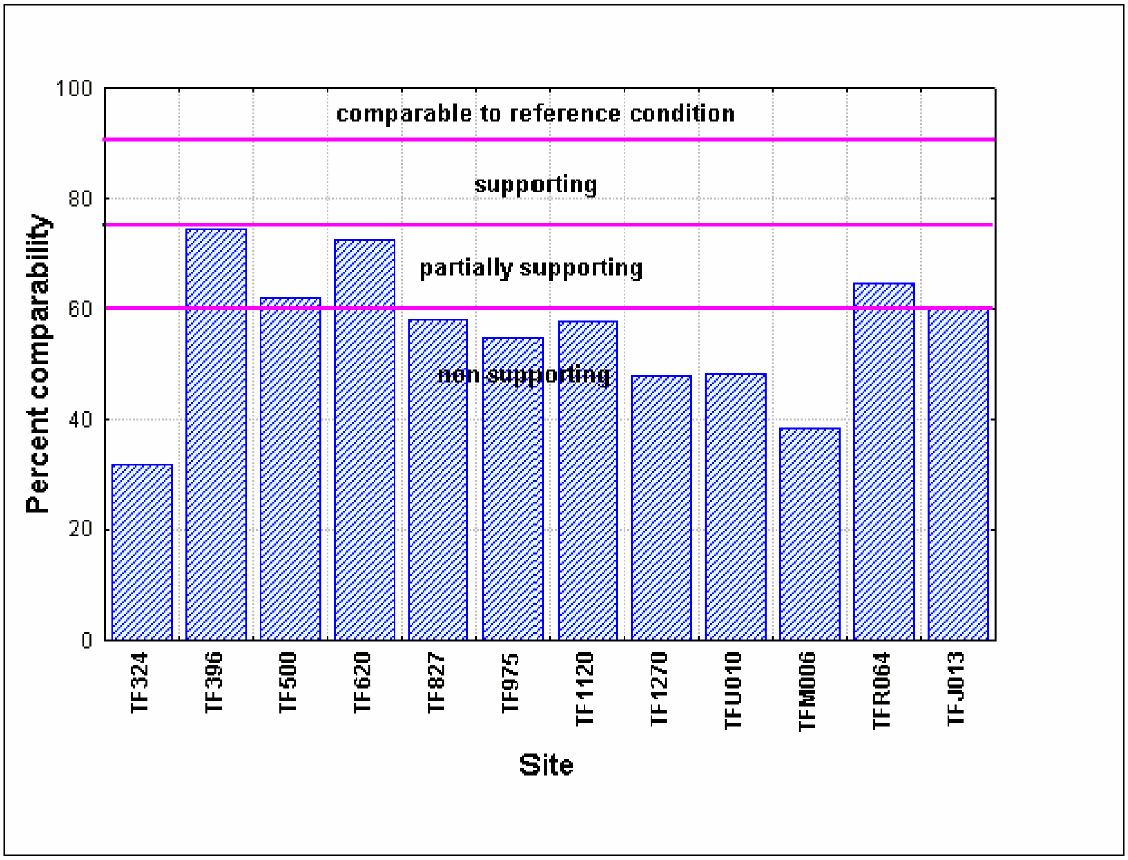


Figure 7-3 USEPA Habitat Assessment Percent Comparability to Reference Sites.

Table 7-1 EPA Physical Habitat Assessment Results for 12 sites in Tookany/Tacony-Frankford Watershed, Spring 2004

	Scores by Site											
Attribute	**TF324**	**TF396**	**TF500**	**TF620**	**TF827**	**TF975**	**TF1120**	**TF1270**	**TFJ013**	**TFM006**	**TFR064**	**TFU010**
Epifaunal Substrate/Available Cover	3	12.5	9.5	11	8.5	8	10	6.5	10.5	5	7.5	6
Pool Substrate	3	11	9.5	10.5	9	8.5	7	6.5	9	6	6	6
Pool Variability	4.5	11.5	9	9.5	8.5	6.5	10	5	12	2.5	4.5	2
Sediment Deposition	12	9	7	8	10	10	7.5	6.5	11	5.5	13.5	9
Channel Flow Status	8.5	11	7.5	12	9	9.5	7	8.5	11	7.5	8	7.5
Channel Alterations	1.5	16.5	12.5	16	10	9.5	8	11.5	6.5	6.5	14.5	12.5
Sinuosity	1	13	9	10.5	9.5	10.5	12	8.5	13.5	7.5	10	6.5
Bank Stability (Left Bank)	4	6	6.5	6	6	6.5	6	7.5	5	6	7.5	6.5
Bank Stability (Left Bank)	1.5	5	6	5.5	1	3.5	6	6	4	6.5	5	3.5
Vegetative Protection (Left Bank)	3.5	4.5	4.5	6	5	6	5	5	5.5	2	7.5	6.5
Vegetative Protection (Right Bank)	3	7	4	5.5	2	4	5	5	4	2	7.5	3.5
Riparian Zone Width (Left Bank)	1.5	5	5	7.5	3	3	4.5	4	4	2	8	5
Riparian Zone Width (Right Bank)	3.5	9	5	7.5	6	3.5	2	4.5	4	2	4.5	3.5
Embeddedness	3.5	11.5	9	14	9	10	8.5	8	12	8	15	9.5
Velocity/Depth Regime	8.5	13	16	14	14	8	13	8.5	13.5	8	12	8
Frequency of Riffles/Bends	5	12.5	11.5	10	13	9.5	11.5	8	12.5	11	16.5	15
Total	**67.5**	**158**	**131.5**	**153.5**	**123.5**	**116.5**	**123**	**109.5**	**138**	**88**	**147.5**	**110.5**

TF324

The mean habitat score at TF324 was 67.5, and the habitat was designated as "non-supporting" (31.84% comparison). All condition categories were scored as "marginal" or "poor" except sediment deposition (Table 7-1). Sediment deposition was scored as "suboptimal" because of a large CSO outfall upstream of the assessment site that routinely scours the area. The channel of the creek is relatively straight and there is extensive alteration of both banks. Pools were almost absent and epifaunal substrate was very inadequate. The riparian zone on both banks was reduced and both banks were unstable with poor vegetative protection. Both stream banks were highly eroded.

TF396

TF396 received a mean habitat score of 158.0. The site had a 74.53% comparison to the reference condition and was designated as "supporting" (Table 7-1). TF396 is located in an undisturbed area behind Friends Hospital, and the site had the highest mean habitat score of all assessment sites. The site had an even distribution of morphology types and substrate components. Most condition categories were scored as "suboptimal" or high "marginal". Highest scores were for channel alteration and riparian vegetative zone width on the right bank. The assessment site is one of the few areas within the watershed that has not had the surrounding land impacted by urbanization.

TF500

Site TF500 received a mean habitat score of 131.5 and was deemed "partially supporting" (62.03% comparison, Table 7-1). The site had an even distribution of morphology types and substrate components. Most habitat attributes were scored as "marginal". Most notable at the site was a large mid-channel bar at the upstream limit of the assessment site. The riparian zone on both banks was reduced and both banks were moderately stable with poor vegetative protection. Field observations included heavy erosion on both banks.

TF620

The mean habitat score at TF620 was 153.5 and the habitat was designated as "partially supporting" (72.41% comparison) (Table 7-1). The substrate of the assessment site was dominated by sand (40%) and run dominated the stream morphology (45%). Riffles composed 20% of the stream reach. The channel had a normal pattern and alteration was absent. TF620 is located in Tacony Park and the riparian zone at the assessment location was well preserved. Although sand was the dominant substrate, embeddedness was scored as suboptimal. The higher scores for embeddedness were most likely due to periodic surges of storm water that scour and redeposit sediment through out the assessment site.

TF827

TF827 had a mean habitat score of 123.5, which was 58.25% comparison to the reference site ("non-supporting" designation) (Table 7-1). Overall the habitat scored mostly as "marginal" and "poor". In particular, the right bank was very unstable with long stretches that were highly eroded. The right bank also had very poor vegetative protection. The instream morphology and substrate was evenly distributed, but the stream was channelized both upstream and downstream of the assessment site.

TF975

Site TF975 received a mean habitat score of 116.5 and was deemed "non-supporting" (54.95% comparison) (Table 7-1). The substrate of the stream reach was well distributed, but the morphology type of the stream was dominated by run (50%). Most condition categories were scored as "marginal". A dam is present upstream of the assessment site, and the stream is channelized downstream of the assessment location. The riparian zone at the site is highly reduced. The surrounding land use is residential with maintained lawns dominating the riparian vegetation.

TF1120

The mean habitat score at TF1120 was 123.0, which was a 58.02% comparison to the reference condition at FC1310 ("non-supporting" designation) (Table 7-1). Most habitat attributes were scored as "marginal". The substrate of the site was well distributed with a large portion of bedrock (15%) and a sizeable portion of sand (30%). A large bedrock outcropping comprised a substantial portion of the left bank of the assessment site. The riparian vegetative zone width of the right bank scored low because of an electrical/railroad access road and vehicle roadway.

TF1270

TF1270 had a mean habitat score of 109.5, which was 48.03% comparison to the reference site ("non-supporting" designation) (Table 7-1). The inorganic substrate of the site was dominated by sand (40%), and the morphology of the assessment reach was predominantly run (60%). A majority of the condition categories were scored as "marginal". Pool variability was scored low with pools comprising 10% of the stream morphology. The riparian zone on both banks was reduced and both banks had decreased vegetative protection.

TFU010

Site TFU010 received a mean habitat score of 110.5 and was deemed "non-supporting" (48.46% comparison) (Table 7-1). Most habitat attributes were scored as "marginal". The site had a disproportionate percentage of riffles (75%) and sand and gravel (35% each) dominated the substrate. Pools were almost absent and epifaunal substrate was less than desirable. TFU010 is located in a residential neighborhood with moderate erosion. The right bank was moderately unstable with a reduced riparian zone.

TFM006

The mean habitat score at TFM006 was 88.0, which was a 38.60% comparison to the reference condition at FCR025 ("non-supporting" designation) (Table 7-1). Most habitat attributes were scored as "marginal" or "poor". The site is located within a golf course and the riparian zone and vegetative protection were both poor. The channel is extensively armored or channeled and is relatively straight. Sand and gravel (35% each) dominated the substrate and pools were almost absent (5%). There were also large, thick mats of filamentous algae at the time of macroinvertebrate sampling/habitat assessment.

TFR064
TFR064 had a mean habitat score of 147.5, which was 64.69% comparison to the reference site ("partially-supporting" designation) (Table 7-1). The inorganic substrate of the site was predominately boulder and cobble (35% each). Riffle (40%) and run (50%) dominated the morphology of the stream reach. Pools were either shallow or absent throughout the site. Most condition categories were scored as "suboptimal" or "marginal". The higher gradient and number of riffles at the site increased scores for sediment deposition, embeddedness, and frequency of riffles.

TFJ013
Site TFJ013 received a mean habitat score of 138.0, and was designated as "partially-supporting" (60.53% comparison) (Table 7-1). The site had an even distribution of morphology types and substrate components. All habitat attributes were scored as either "suboptimal" or "marginal". The surrounding land use at TFJ013 is residential and there is heavy erosion throughout the assessment reach. Both banks were moderately unstable and the riparian zone on both banks was reduced. Rip-rap has been used on both banks in an attempt to reduce erosion.

7.3 Fish Habitat Suitability Indices (HSI)

7.3.1 HSI Model Selection

HSI models for seven species were selected for Tookany/Tacony-Frankford Watershed. Models were chosen to reflect the range of habitat types and attributes needed to support healthy, naturally-reproducing native fish communities and provide recreational angling opportunities in non-tidal portions of the watershed (Table 7-2). Two centrarchid fish, redbreast sunfish (*Lepomis auritus*), and smallmouth bass (*Micropterus dolomieu*), were included in the analysis. These species are tolerant of warmer water temperatures and require extensive slow, relatively deep water (*i.e.*, pool) habitats with appropriate cover or structure to achieve maximum biomass.

While black basses (*M. dolomieu* and its congener *M. salmoides*) are not native to Southeast Pennsylvania, they occupy the top carnivore niche and are among the most sought-after freshwater game fish in water bodies where they occur. Moreover, the only other large bodied piscivores known to occur in non-tidal portions of Tookany/Tacony-Frankford Watershed are American eels, native catadromous fish for which no HSI have been developed. Salmonid HSI models were available but inappropriate because coldwater fish generally cannot establish and maintain reproducing populations in warmwater streams, and PFBC does not stock salmonids in Tookany/Tacony-Frankford Watershed.

Five native minnow species were selected for HSI analysis: blacknose dace (*Rhinichthys atratulus*), common shiner (*Luxilis cornutus*), creek chub (*Semotilus atromaculatus*), fallfish (*Semotilus corporalis*), and longnose dace (*Rhinichthys cataractae*). Of these, *R. cataractae* and *S. corporalis* are not known to occur in Tookany/Tacony-Frankford Watershed. However, the former species' known affinity for stable, high quality riffle habitats and the substrate requirements of the latter species are reflected in HSI models, prompting inclusion in the analysis as indicators of riffle habitats and stream stability. The longnose dace HSI may be considered a surrogate indicator of habitat suitability for other native riffle species (*e.g.*, margined madtom) for which no HSI are available.

Table 7-2 HSI Data Summary

HSI Model Variable Matrix	Variable Type	Blacknose Dace	Common shiner	Creek Chub	Fallfish	Longnose Dace	Redbreast Sunfish	Smallmouth Bass
Total number of HSI variables		16*	9	20	6	6	10	13*
Avg. Temperature during growing season (May-Oct.)	temperature	X						X
Average Temperature in spawning season**		X	X		X		X	X
Maximum temperature sustained for 1 week			X			X	X	
Average Summer Temperature (Jul-Sep)				X	X			
Average temperature during spring (May-Jun)				X				
Average Turbidity (JTU)***	water quality	X	X	X	X		X	X
Average yearly pH value			X					X
Least suitable pH value (instantaneous)							X	
pH fluctuation classification				X				
Minimum dissolved oxygen concentration				X			X	X
Minimum dissolved oxygen conc. during spring				X				
Percent instream cover during average summer flow	general stream characteristics			X		X	X	X
Instream cover classification					X			
Percent shading of stream between 1000 and 1500 hrs.		X		X				
Percent vegetative cover							X	
Availability of thermal refugia (winter) (Y/N)				X				
Stream gradient (m/km)		X		X				X
Average stream velocity during average summer flow				X		X		
Dominant substrate characterization					X		X	
Stream width		X		X			X	
Mode of stream depth during average summer flow					X			
Water level fluctuations								X
Stream margin substrate characterization (Y/N)		X						
Average velocity along stream margins		X		X				
Stream margin vegetation characterization				X				
Substrate food production potential				X				
Percent riffles	riffles					X		
Riffle substrate characterization		X	X	X		X		
Average velocity in riffles		X	X	X				
Average depth of riffles		X						
Average maximum depth of riffles						X		
Percent pools	pools	X	X	X			X	X
Pool substrate characterization		X						X
Pool classification			X	X				
Average depth of pools				X				X
Average velocity at 0.6 depth in pools		X	X					

* Some variables used more than once, applied to different life stages
**Spawning season varies by species. Common Shiner and Fallfish use a Y/N index.
*** Turbidity relationships developed using Jackson candle units; cannot be converted to NTU values

7.3.2 Smallmouth Bass HSI Model

Smallmouth bass were not collected from Tookany/Tacony-Frankford Watershed in 2004, and there is insufficient data to determine whether black basses (*Micropterus* spp.) ever established reproducing populations in non-tidal portions of the watershed. The smallmouth bass HSI model identified several habitat attributes that would be detrimental to bass. Like most centrarchids, smallmouth and largemouth basses are able to acclimate to brief periods of suboptimal dissolved oxygen concentration. However, continuous water chemistry analysis indicated DO concentrations at sites TF324, TF396, and TF620 may drop below 3mg/l for extended periods, yielding HSI scores of zero (Table 7-3). DO suppression at these sites is likely due to sewage inputs.

Site TF1120 had HSI score 0.90, and may have good habitat for smallmouth bass, but one might not expect bass to occur in large numbers at a site so near the headwaters (Drainage area ca. 5sq mi), especially considering the baseflow reduction that often accompanies increased impervious cover. It may be more feasible to establish/restore populations of other native centrarchids (e.g. redbreast sunfish and rock bass) in upper watershed sites. All other sites appear to be limited by the size and frequency of pools with appropriate cover, especially site TF760, which lacked pool habitats and received an HSI score of zero (Table 7-3).

Stream restoration activities that increase the amount of instream and overhanging cover, or activities that create, expand or improve pool habitats probably will result in increased habitat suitability for smallmouth bass. Re-meandering of the stream channel, installation of flow diverters such as rock vanes and J-hooks, as well as the creation of bank habitat through log sill cribbing and cantilevered banks should also enhance habitat for smallmouth bass, and other centrarchids, and forage fish. Infrastructure assessments, inspections, and dry weather pollution source trackdown activities will likely reduce the severity and frequency of water quality (*i.e.*, DO and pH related) impacts at some sites, particularly downstream of TF620. It is unlikely that habitat impairment due to frequent water level fluctuations and effects of erosion and sedimentation will be ameliorated in the near future without significant investments in streambank restoration and basin-wide implementation of stormwater BMPs.

Table 7-3 Smallmouth Bass HSI Data Table

HSI Variable	TF324	SI	TF396	SI	TF500	SI	TF620	SI	TF760	SI	TF975	SI	TF1120	SI
Substrate type category	C	1.00	C	1.00	A	0.20	C	1.00	C	0.00	B	0.30	C	1.00
Percent pools	19.30	0.32	24.18	0.43	25.75	0.46	22.48	0.39	0.00	0.00	16.23	0.25	55.21	1.00
Avg. pool depth	0.48	0.40	0.56	0.46	0.36	0.30	0.37	0.31	0.00	0.00	0.27	0.22	0.48	0.40
Percent cover	70.00	0.84	45.00	1.00	15.00	0.60	5.00	0.20	60.00	0.92	20.00	0.80	50.00	1.00
Average pH	7.30	0.96	7.30	0.96	7.39	0.98	7.59	0.99	7.32	0.96	7.43	0.98	7.18	0.94
Dissolved Oxygen	0.24	0.00	0.24	0.00	0.10	0.00	6.21	0.98	5.19	0.70	6.61	0.98	6.22	0.98
Turbidity	25.00	1.00	25.00	1.00	25.00	1.00	25.00	1.00	25.00	1.00	25.00	1.00	25.00	1.00
Temperature (adult)	19.81	0.84	19.81	0.84	20.47	0.87	18.56	0.78	16.80	0.67	16.20	0.64	16.35	0.65
Temperature (embryo)	19.16	1.00	19.16	1.00	22.50	1.00	17.87	1.00	16.34	1.00	15.97	1.00	15.89	1.00
Temperature (fry)	19.81	0.82	19.81	0.82	20.47	0.86	18.56	0.74	16.80	0.63	16.20	0.58	16.35	0.59
Temperature (juvenile)	19.81	0.86	19.81	0.86	20.47	0.88	18.56	0.78	16.80	0.70	16.20	0.64	16.35	0.67
Water fluctuations	A	0.30	A	0.30	A	0.30	A	0.30	A	0.30	A	0.30	A	0.30
Stream Gradient	3.81	1.00	5.27	0.91	1.37	1.00	1.29	1.00	4.22	1.00	7.01	0.60	4.67	1.00
Food component		0.64		0.75		0.38		0.43		0.00		0.39		1.00
Cover component		0.64		0.72		0.39		0.47		0.23		0.39		0.85
Water Quality component		0.73		0.73		0.74		0.90		0.80		0.84		0.84
Reproduction component		0.00		0.00		0.00		0.67		0.00		0.68		0.84
Other component		1.00		0.91		1.00		1.00		1.00		0.60		1.00
H S I score		**0.00**		**0.00**		**0.00**		0.66		**0.00**		0.56		0.90
Abundance		**0.00**		**0.00**		**0.00**		**0.00**		**0.00**		**0.00**		**0.00**
Biomass		**0.00**		**0.00**		**0.00**		**0.00**		**0.00**		**0.00**		**0.00**

7.3.3 Redbreast Sunfish HSI Model

As a generalist species, redbreast sunfish (*Lepomis auritus*) are adaptable to a range of habitat attributes and may feed opportunistically upon a variety of prey types. Most suitability index (SI) variable expressions in this species' HSI include a large range of highly suitable values (or large area "under the curve"). HSI scores (Table 7-4) did not correlate well with observed *L. auritus* abundance or biomass (the correlation was, in fact, negative). Limiting factors included vegetative cover, temperature, and substrate-related variables, but the discriminatory power of the HSI was probably limited by lack of variability and marginal habitat available at all sites. pH limitation was difficult to identify due to differences in data collection methods between sites. Though pH fluctuations due to algal activity occasionally result in pH >9.0, the Redbreast sunfish HSI model was not designed to be used with the least suitable value picked from a continuous database. Because fish can avoid areas of unsuitable pH when they occur infrequently, model input was modified to exclude the worst 5% of pH values.

Table 7-4 Redbreast HSI Data

HSI Variable	TF324	SI	TF396	SI	TF500	SI	TF620	SI	TF760	SI	TF975	SI	TF1120	SI
Percent cover	70.00	1.00	45.00	1.00	15.00	0.76	5.00	0.52	60.00	1.00	20.00	0.88	50.00	1.00
Vegetated cover	5.00	0.50	5.00	0.50	5.00	0.50	5.00	0.50	5.00	0.50	5.00	0.50	10.00	0.60
Spawning temperature (summer)	20.33	1.00	20.33	1.00	22.18	1.00	19.78	0.40	18.23	0.40	16.85	0.40	16.82	0.40
Percent slow pools	19.30	0.43	24.18	0.49	25.75	0.72	22.48	0.47	0.00	0.20	16.23	0.39	55.21	0.91
Percent sand/gravel	16.00	0.39	36.00	0.94	65.00	1.00	52.00	1.00	14.00	0.37	25.00	0.50	29.00	0.66
Least suitable pH observed	8.52	0.99	8.52	0.99	8.37	1.00	9.03	0.81	8.01	1.00	8.48	1.00	8.36	1.00
Minimum DO (category)	A	1.00	A	1.00	A	1.00	A	1.00	A	1.00	A	1.00	A	1.00
Turbidity	25.00	1.00	25.00	1.00	25.00	1.00	25.00	1.00	25.00	1.00	25.00	1.00	25.00	1.00
Max temp growing season	27.28	1.00	27.28	1.00	26.55	1.00	26.09	1.00	24.54	0.80	22.43	0.80	24.59	0.80
Stream width	19.73	1.00	11.24	1.00	10.46	1.00	12.08	1.00	13.27	1.00	11.63	1.00	6.31	1.00
H S I score		**0.39**		**0.49**		**0.50**		**0.40**		**0.20**		**0.39**		**0.40**
Abundance		**0.00**		**1.00**		**87.00**		**129.00**		**99.00**		**0.00**		**0.00**
Biomass		**0.00**		**2.70**		**2214.05**		**3808.70**		**2525.69**		**0.00**		**0.00**

correlations	r^2 value
HSI: biomass/unit vol	**-0.21562**
HSI :abundance/unit vol	**-0.23605**

Likewise, summer temperature during spawning may poorly reflect habitat suitability for this species. The HSI was designed to be used throughout the species' range; temperature parameters should not be expected to be "optimal" in the temperate northeast. Fish may spawn at warmer downstream locations or in sunnier, sandy backwaters that are not accounted for in HSI model input. Observations made during electrofishing surveys suggested that Redbreast sunfish (and congeneric sunfishes) are most frequently found associated with cover, which can be difficult to measure quantitatively.

For example, site TF760 scored well for percent cover, due to the presence of many large boulders that were not exposed (Figure 7-4). Though this site was limited by a lack of pools and received a final HSI score of 0.2, it had the second greatest Redbreast sunfish abundance in Tookany/Tacony-Frankford Watershed. Fish collected were generally small (mean TL= 10.3 ±2.4; only four of 99 total individuals were >15cm). These findings reflect the fact that habitat requirements for a given species change over an individual's lifetime (as fish age they may require larger habitats for foraging) or even seasonally (such as specific substrate types and/or flow scenarios required during spawning). With more large, deep pool habitats, site TF 760 might support larger fish.

Figure 7-4 Instream Habitat at Cheltenham Restoration Site.

7.3.4 Longnose Dace

The longnose dace HSI model was applied to Tookany/Tacony-Frankford Watershed despite the fact that this species was not collected from the watershed in the 2004 fish survey. Longnose dace are, however, present in the nearby Pennypack and Wissahickon watersheds. This species is considered a riffle specialist, feeding and spawning in fast water in higher gradient, clear and cool streams. This species has good indicator potential, as hydrologic effects of urbanization tend to cause over-widening of stream channels, reduce baseflow and baseflow velocities, increase stream temperature, and generally make habitat unsuitable for this species.

High longnose dace HSI scores indicate favorable riffle conditions, not only for this species, but for a variety of other riffle dwellers such as margined madtoms and sensitive macroinvertebrate bioindicator taxa. High longnose dace scores might suggest that a site is appropriate for re-introduction, but scores in Tookany/Tacony-Frankford Watershed were marginal, reflecting general habitat unsuitability and stream instability caused by urbanized hydrology (Table 7-5). Stream restoration projects that are based in fluvial geomorphological (FGM) principles should help correct the problem of riffle substrate exposure due to overwidening (a universal problem in urbanized watersheds), while stormwater BMPs and infiltration projects could eventually begin to restore historic baseflow levels and mitigate the effects of scouring and sedimentation exhibited by streams with extensive impervious cover.

Table 7-5 Longnose Dace HSI Data

HSI Variable	TF324	SI	TF396	SI	TF500	SI	TF620	SI	TF760	SI	TF975	SI	TF1120	SI
Average stream velocity	25.00	0.56	31.00	0.76	30.00	0.72	22.00	0.47	21.00	0.43	20.00	0.39	13.00	0.18
Maximum depth in riffles	0.29	1.00	0.31	1.00	0.25	0.95	0.23	0.92	0.27	1.00	0.15	0.69	0.15	0.69
Percent riffles	52.38	1.00	28.57	1.00	42.86	1.00	19.05	0.76	14.29	0.57	28.57	1.00	23.81	0.95
Percent of substrate >5cm	28.00	0.56	30.00	0.60	20.00	0.40	32.00	0.64	31.00	0.62	44.00	0.88	27.00	0.54
Spring/Summer maximum temp.	21.28	0.58	21.28	0.58	20.34	0.87	20.73	0.83	20.37	0.86	18.35	1.00	18.63	1.00
Percent Cover	70.00	1.00	45.00	1.00	15.00	0.60	5.00	0.20	60.00	1.00	20.00	0.80	50.00	1.00
H S I Score		**0.56**		**0.58**		**0.40**		**0.20**		**0.43**		**0.39**		**0.18**
Abundance		**0.00**		**0.00**		**0.00**		**0.00**		**0.00**		**0.00**		**0.00**
Biomass		**0.00**		**0.00**		**0.00**		**0.00**		**0.00**		**0.00**		**0.00**

7.3.5 Fallfish

Fallfish was the third species for which an HSI model was applied despite an apparent absence of the species within the watershed. Fallfish have many attributes that make them suitable as indicator species. They are long-lived, and the largest native minnow that occurs in Southeast PA, capable of attaining lengths over 30 cm (1ft.). Fallfish also build large gravel mounds over which to spawn, and bury their eggs within for protection. Changes in several factors that typically accompany increased urbanization may be implicated in fallfish habitat loss or decreased suitability (*e.g.*, range of substrate materials available for use in constructing spawning mounds, stability and sufficiency of baseflow depth, sediment oxygen state, and frequency of hydrologic disturbance).

The fallfish HSI model was too simplistic, incorporating only four variables as modified for Tookany/Tacony-Frankford Watershed, and final scores did not reflect decreased habitat suitability caused by urbanization (Table 7-6). For example, nearly all mainstem stream reaches are overwidened, riffles substrates are coarsened, and dry weather (*i.e.*, baseflow) flow characteristics (particularly depth) are poor. Pools and runs generally are affected by sedimentation and may not have stable substrate of appropriate size for fallfish nest building in combination with the appropriate flow regime. Sediments may be poorly oxygenated or even anoxic, especially in lower reaches of the watershed. This is an unsuitable condition for not only fallfish, but other egg-burying cyprinid species (*e.g.*, cutlips minnow, creek chub) and benthic macroinvertebrates. Frequent severe scouring flows may also scour away or bury and stifle eggs and various aquatic macroinvertebrate life stages. To be useful in an urban setting, the fallfish HSI model would have to be modified to account for some of these effects.

Table 7-6 Fallfish HSI Data

HSI Variable	TF324	SI	TF396	SI	TF500	SI	TF620	SI	TF760	SI	TF975	SI	TF1120	SI
Temperature	22.24	0.73	22.24	0.73	21.50	0.82	20.92	0.89	22.38	0.71	18.72	1.00	19.26	1.00
Turbidity	25.00	1.00	25.00	1.00	25.00	1.00	25.00	1.00	25.00	1.00	25.00	1.00	25.00	1.00
Mode of stream depth	0.32	0.96	0.20	0.86	0.11	0.79	0.15	0.82	0.26	0.91	0.15	0.82	0.18	0.84
Favorable spawning temperature Y/N	Y	1.00	Y	1.00	Y	1.00	Y	1.00	Y	1.00	Y	1.00	Y	1.00
Substrate category	E	0.10	D	0.40	C	1.00	C	1.00	E	0.10	D	0.40	D	0.40
Cover category	C	0.40	C	0.40	C	0.40	C	0.40	C	0.40	C	0.40	B	0.70
Water quality component		0.86		0.86		0.91		0.94		0.85		1.00		1.00
Reproduction component		0.34		0.52		0.68		0.69		0.33		0.51		0.62
H S I score		**0.60**		**0.69**		**0.79**		**0.82**		**0.59**		**0.75**		**0.81**
Abundance		**0.00**		**0.00**		**0.00**		**0.00**		**0.00**		**0.00**		**0.00**
Biomass		**0.00**		**0.00**		**0.00**		**0.00**		**0.00**		**0.00**		**0.00**

7.3.6 Blacknose Dace HSI Model

The blacknose dace HSI model was modified to suppress the influence of two limiting variables (gradient and stream margin substrate) because limitation by these factors is not evident in fish collections from Philadelphia area streams. Geography and topographic features undoubtedly influenced blacknose dace distribution, but the relationship between stream gradient SI scores and blacknose dace abundance was weak. Similarly, there was no strong relationship between stream margin substrate SI scores and blacknose dace abundance. While most sites generally had coarser margin substrates than would be desirable, shallow low velocity habitats that could be used as "nursery habitat" by immature fish were present at all sites but TF324.

Once modified, the HSI model was a fair predictor of blacknose dace abundance and biomass (Table 7-7). SLR analysis of HSI score with observed abundance and biomass yielded r^2 values of 0.62 and 0.67, respectively. The blacknose dace is classified as a "tolerant" fish. In fact, along with *C. commersoni*, *A. rostrata*, and *Fundulus* spp., blacknose dace is one of the most common fish in degraded streams in southeast PA. Blacknose dace appears to be an "upstream" species, abundance and biomass increased in an upstream direction. The stream gradient factor in the HSI model probably addresses this aspect of the species' ecology. Life history strategies and morphological features that allow blacknose dace to exploit upstream reaches of natural streams may partially explain its dominance of streams that are hydrologically impaired due to urbanization.

Blacknose dace is a stocky fish, moderate in body form and somewhat rounded (dorsoventrally flattened) in comparison to vertically compressed minnows. Hydrodynamics may contribute adaptability to a variety of flow conditions and, in part, explain its abundance at degraded sites that are periodically exposed to intense scouring flows. Over-widening of channels and coarsening of stream substrate are typical of streams that are exposed to extremes in hydrology. Blacknose dace appear resilient to these factors. Other minnow species may not be as well adapted for these effects.

Table 7-7 Blacknose Dace HSI Data

HSI Variable	TF324	SI	TF396	SI	TF500	SI	TF620	SI	TF760	SI	TF975	SI	TF1120	SI
Percent shaded	15.00	0.61	50.00	1.00	50.00	1.00	70.00	1.00	20.00	0.77	90.00	0.83	95.00	0.67
Percent Pools	19.30	0.74	24.18	0.80	25.75	0.82	22.48	0.78	0.00	0.50	16.23	0.70	55.21	1.00
Stream gradient*	6.15	1.00	2.46	1.00	4.20	1.00	2.74	1.00	3.27	1.00	7.47	1.00	4.13	1.00
Stream Width	19.73	0.15	11.24	0.55	10.46	0.64	12.08	0.46	13.27	0.34	11.63	0.51	6.31	1.00
Temperature (growing season)	26.00	0.43	26.00	0.43	25.60	0.49	24.95	0.58	24.41	0.66	22.09	0.99	22.73	0.90
Turbidity (growing season)	25.00	1.00	25.00	1.00	25.00	1.00	25.00	1.00	25.00	1.00	25.00	1.00	25.00	1.00
Riffle substrate category	E	0.40	D	0.60	D	0.60	C	1.00	E	0.40	D	0.60	D	0.60
Riffle depth	19.60	1.00	23.53	1.00	15.24	1.00	14.48	1.00	18.12	1.00	10.67	1.00	10.16	1.00
Velocity in riffles	33.60	1.00	55.46	0.48	46.18	0.94	23.11	1.00	33.70	1.00	38.10	1.00	30.48	1.00
Temperature (spawning seas.)	19.86	1.00	19.86	1.00	22.50	1.00	18.90	1.00	16.33	1.00	16.85	1.00	16.35	1.00
Pool substrate category (adult habitat)	E	0.20	E	0.20	A	0.80	C	1.00	E	0.20	D	1.00	A	0.80
Velocity in pools (adult)	11.94	1.00	15.49	1.00	27.77	1.00	16.26	1.00	0.00	1.00	12.00	1.00	8.26	1.00
Riffle substrate category (juvenile Habitat)	E	0.30	D	0.50	D	0.50	C	1.00	E	0.30	D	0.50	D	0.50
Velocity in riffles (Juvenile)	33.60	1.00	55.46	0.38	46.18	0.60	23.11	1.00	33.70	1.00	38.10	0.90	30.48	1.00
Stream margins substrate (fry habitat)*	Y	1.00	Y	1.00	Y	1.00	Y	1.00	Y	1.00	Y	1.00	Y	1.00
Velocity in stream margins (fry)	3.05	1.00	7.62	1.00	10.67	1.00	6.10	1.00	6.10	1.00	6.10	1.00	6.10	1.00
Food/Cover component		0.15		0.84		0.86		0.81		0.34		0.76		0.92
Water quality component		0.57		0.57		0.62		0.69		0.75		0.99		0.93
Reproduction component		0.40		0.80		0.93		1.00		0.40		0.94		0.94
Adult component		0.20		0.20		0.89		1.00		0.20		1.00		0.89
Juvenile component		0.30		0.38		0.55		1.00		0.30		0.67		0.71
Fry component		1.00		1.00		1.00		1.00		1.00		1.00		1.00
H S I Score		**0.15**		**0.20**		**0.62**		**0.83**		**0.20**		**0.78**		**0.80**
Abundance	1.00		15.00		114.00		433.00		352.00		1662.00		847.00	
Biomass	0.08		36.79		332.81		1111.24		970.62		3768.12		3016.21	

Correlations	r^2 **value**
HSI: biomass/unit vol	0.67476
HSI: abundance/unit vol	0.62861

7.3.7 Creek Chub HSI Model

The creek chub HSI model produced good results overall. HSI score was correlated with creek chub abundance and biomass (SLR, r^2= 0.78 and 0.72, respectively). Furthermore, sites where no fish were collected had the lowest HSI scores in the watershed and the site with the highest HSI score had the greatest abundance and biomass in the watershed (Table 7-8). The HSI model scale of resolution was greatly compacted. Only two creek chubs were collected from four sites that were deemed unsuitable (HSI=0). The limiting factor in these cases was identified as low dissolved oxygen, which corroborates results of continuous water quality monitoring (Table 5-6). However, USFW scientists did not have access to continuous water quality data when building the model so it may be inappropriate to choose the lowest value from a continuous database.

Though creek chubs and blacknose dace share some habitat associations and both tended to be more numerous in upstream reaches, creek chubs generally showed a stronger affinity for narrower streams with abundant pools and overhead cover. For example, creek chub biomass increased almost tenfold from site TF975 to TF1120, while blacknose dace biomass decreased between these sites which differ greatly in width, percent pools, and surface to volume ratio. Blacknose dace biomass seemed more closely tied to stream surface area, while creek chub biomass seemed more attuned to volume, which may reflect the latter species' stronger association with pool habitats (Jenkins and Burkhead, 1993).

A similar effect was noted at site TF760, which was wide and lacked pool habitats. While blacknose dace biomass was reduced at site TF760 relative to the two upstream sites, creek chubs were nearly absent. Unlike creek chubs, blacknose dace did not show a strong association with pools. This site also had the most violations of daily minimum DO of all Montgomery County sites, which reinforces the view that blacknose dace are more tolerant of low DO than creek chubs.

With 20 habitat and water quality variables and 5 life requisite components, the creek chub HSI model was most complex of the models used (Table 7-2). As many water quality variables returned optimum suitability values (*i.e.*, SI= 1.0, Table 7-8), and most had limited discriminatory power, the model could be made simpler without sacrificing predictability. It is likely that if a smaller number of critical habitat variables were focused on, the model could have better resolution over a larger scale of final HSI scores.

Table 7.8 Creek Chub HSI Data

HSI Variable	TF324	SI	TF396	SI	TF500	SI	TF620	SI	TF760	SI	TF975	SI	TF1120	SI
Percent pools	19.30	0.58	24.18	0.72	25.75	0.77	22.48	0.67	0.00	0.20	16.23	0.48	55.21	1.00
Pool class (category)	B	0.60	A	1.00	C	0.30	C	0.30	C	0.30	C	0.30	B	0.60
Percent cover	70.00	1.00	45.00	1.00	15.00	0.22	5.00	1.00	60.00	1.00	20.00	0.59	50.00	1.00
Winter thermal cover	Y	0.90	Y	1.00	Y	0.57	Y	0.79	Y	0.59	Y	0.64	Y	100
Stream gradient	6.15	0.96	2.46	0.37	4.20	0.71	2.74	0.43	3.27	0.53	7.47	1.00	4.13	0.70
Stream width	19.73	0.21	11.24	0.46	10.46	0.53	12.08	0.42	13.27	0.37	11.63	0.44	6.31	1.00
Turbidity	25.00	1.00	25.00	1.00	25.00	1.00	25.00	1.00	25.00	1.00	25.00	1.00	25.00	1.00
pH (category)	B	0.80	B	0.80	B	0.80	C	0.40	A	1.00	B	0.80	B	0.80
Vegetation index	112.50	1.00	160.00	1.00	120.00	1.00	155.00	1.00	110.00	1.00	172.00	1.00	95.00	1.00
Substrate food index	C	0.50	B	0.70	C	0.50	C	0.50	B	0.70	B	0.70	B	0.70
Average summer water temp.	22.24	1.00	22.24	1.00	21.50	1.00	20.92	1.00	22.38	1.00	18.72	1.00	19.26	1.00
Minimum summer DO conc.	0.19	0.00	0.19	0.00	0.06	0.00	6.20	1.00	0.47	0.00	7.20	1.00	6.85	1.00
Average velocity (0.6 depth)	25.00	1.00	31.00	1.00	30.00	1.00	22.00	1.00	21.00	1.00	20.00	1.00	13.00	1.00
Average spring water temp	16.55	1.00	16.55	1.00	15.08	1.00	16.51	1.00	16.33	1.00	14.60	1.00	14.53	1.00
Minimum spring DO conc.	1.20	0.01	1.20	0.01	5.87	0.92	6.93	1.00	5.80	0.91	6.46	0.98	5.90	0.92
Average spring riffle velocity	33.60	1.00	55.46	1.00	46.18	1.00	23.11	1.00	33.70	1.00	38.10	1.00	30.48	1.00
Riffle substrate index	102.00	1.00	125.00	1.00	115.00	1.00	123.00	1.00	114.00	1.00	114.00	1.00	92.00	1.00
Average stream margin velocity	3.05	1.00	7.62	1.00	10.67	0.81	6.10	1.00	6.10	1.00	6.10	1.00	6.10	1.00
Percent summer shade	15.00	0.28	50.00	0.80	50.00	0.80	70.00	1.00	20.00	0.33	90.00	1.00	95.00	1.00
Average maximum depth	0.37	0.91	0.42	0.97	0.33	0.85	0.31	0.83	0.30	0.81	0.21	0.61	0.39	0.94
Food component		0.75		0.85		0.75		0.75		0.85		0.85		0.85
Cover component		0.82		0.95		0.53		0.74		0.57		0.62		0.92
Water quality component		0.00		0.00		0.00		0.40		0.00		0.95		0.95
Reproduction component		0.01		0.01		0.98		1.00		0.98		1.00		0.98
Other component		0.69		0.60		0.70		0.56		0.57		0.68		0.88
H S I score		**0.00**		**0.00**		**0.00**		**0.40**		**0.00**		**0.80**		**0.91**
Abundance	0.00		0.00		0.00		4.00		2.00		24.00		116.00	
Biomass	0.00		0.00		0.00		23.10		9.40		116.53		1105.20	

Correlations	**r^2 value**
HSI :biomass/unit vol	0.728771
HSI: abundance/unit vol	0.787745

7.3.8 Common Shiner HSI Model

Common shiner HSI model results were fair. The model performed well in identifying unsuitable conditions in the lower watershed, but did not help explain the absence of common shiners from site TF1120, which had the highest HSI score in the watershed (Table 7-9). Due almost entirely to this site, SLR coefficients between HSI score and common shiner abundance and biomass were lowered: r^2= 0.45 and 0.48, respectively (However, if site TF1120 were ignored, r^2 values increased to 0.92 and 0.93, respectively). The HSI score at site TF760 was zero, due to a lack of pools, and though the species was collected at site TF760, abundance and biomass were reduced compared to mid-watershed sites with more pool habitat available.

Common shiners were most abundant in Tacony Creek in the City of Philadelphia at sites TF500 and TF620. These sites had the best diversity, fish index of biological integrity (IBI), and modified index of well-being (MIWB) scores in the watershed Table 7-9. Much like the redbreast sunfish model, SI variables used are general in nature, and contain a large range of suitable values (redbreast sunfish and common shiners are both considered generalist species). Interspecific competition, low productivity, water quality and hydrologic perturbations are among the possible explanations for low common shiner abundance in upstream segments of Tookany/Tacony-Frankford Watershed.

Table 7-9 Common Shiner HSI Data

HSI Variable	TF324	SI	TF396	SI	TF500	SI	TF620	SI	TF760	SI	TF975	SI	TF1120	SI
Max. summer temperature	26.00	0.29	26.00	0.29	25.60	0.33	24.95	0.43	24.41	0.50	22.09	0.96	22.73	0.82
Least suitable pH throughout year	8.52	0.99	8.52	0.99	8.37	1.00	9.03	0.88	8.01	1.00	8.48	1.00	8.36	1.00
Turbidity	25.00	1.00	25.00	1.00	25.00	1.00	25.00	1.00	25.00	1.00	25.00	1.00	25.00	1.00
Riffle substrate category	E	0.20	D	0.80	D	0.80	C	1.00	E	0.20	D	0.80	D	0.80
Percent pools	19.30	0.35	24.18	0.53	25.75	0.56	22.48	0.46	0.00	0.00	16.23	0.23	55.21	0.99
Velocity in pools	3.66	0.85	4.57	0.90	8.53	0.99	4.88	0.91	0.00	0.00	12.50	1.00	2.44	0.80
Pool class	B	1.00	B	1.00	C	0.60	C	0.60	C	0.60	C	0.60	B	1.00
Adequate spring temp (spawning)	Y	1.00	Y	1.00	Y	1.00	Y	1.00	Y	1.00	Y	1.00	Y	1.00
Riffle velocity	33.60	0.37	55.46	0.00	23.09	0.87	23.11	0.87	33.70	0.37	38.10	0.22	30.48	0.52
Food/Cover component		0.20		0.81		0.74		0.74		0.00		0.23		0.90
Water quality component		0.29		0.29		0.33		0.72		0.80		0.99		0.94
Reproduction component		0.20		0.00		0.86		0.97		0.20		0.22		0.76
H S I Score		**0.20**		**0.00**		**0.33**		**0.80**		**0.00**		**0.22**		**0.86**
Abundance	0.00		0.00		53.00		87.00		8.00		12.00		0.00	
Biomass	0.00		0.00		305.58		625.91		93.11		80.58		0.00	

Correlations	**r^2 value**
HSI: biomass/unit vol	0.485461
HSI: abundance/unit vol	0.479658

7.4 Sensitivity Analysis

A pseudo-Monte Carlo approach was used with all HSI models to determine which habitat attributes were most sensitive, and thus influential in the final HSI score. Data for all variables was compiled and basic statistics (*i.e.*, mean, standard deviation, range) were computed. Most physicochemical variables were found to most closely fit a normal (Gaussian) distribution, while other parameters (*e.g.*, stream width, percent shade) best fit an even distribution, so two separate random number generators (Microsoft Excel and Statistica) were used to obtain an array of values for model input. Each case in the array was a combination of random values within the range of values that might have come from a stream in Tookany/Tacony-Frankford Watershed. In combining the randomly generated results, variables were considered completely independent, so some combinations of random input values were less realistic than others (*e.g.*, very low average yearly temperature and very high growing season temperature; very wide stream with 100% shade; severe DO fluctuations and stable pH). To be sure, Interdependencies exist between some variables, but these relationships were difficult to quantify and build into the Monte Carlo procedure. It was assumed that the influence of these unlikely combinations would be suppressed by using a large number of iterations.

The habitat attribute input array for each HSI model was used with the model to compute the final HSI score for each case in ten trials of 1000 iterations each, for a total of 100,000 iterations in total for each model. Values for the input array were re-computed between trials, and the correlation of each variable with final HSI score was computed after each trial. After ten trials were completed, habitat attributes were ranked according to the mean of their correlation scores. In interpreting sensitivity analysis results, it should be noted that many variables were almost always completely suitable (*i.e.*, SI=1) and not found to be important in determining the HSI score for a given species. Those variables that have a limiting effect are thus more likely to influence the score than variables that tend to maintain the total score at or near complete suitability (*i.e.*, HSI=1). If the situation was reversed and many habitat variables were influential and less suitable, a variable or variables that tended to increase scores would be more influential.

Blacknose Dace

Sensitivity analysis showed that stream width was the most important attribute in determining habitat suitability for blacknose dace (Table 7-10). This corroborates results of the 2004 fish assessment, and other records in the PWD bioassessment database which have shown the species to be more abundant in upstream reaches. Stream gradient would likely have ranked high in HSI influence, had the model been adequately calibrated to the range of stream gradient values present in Tookany/Tacony-Frankford Watershed, as mainstem sites were generally found to have milder slopes than upstream and tributary sites. During the infrastructure assessment procedure in which PWD biologists walked entire segments of the stream, blacknose dace were observed in very small tributaries that originate in stormwater pipes, in some cases even in small disconnected pools left by intermittent streams. Blacknose dace is assumed to be a fast colonizer of these small tributaries, feeding primarily on dipteran larvae (*e.g.*, chironomids, mosquitoes).

Table 7-10 Blacknose Dace HSI Model Sensitivity Analysis

HSI Variable	*r* value	*r*²	rank
Stream Width	0.60	0.36	1
Pool Substrate Category (adult habitat)	0.29	0.09	2
Riffle Substrate Category (juvenile habitat)	0.23	0.05	3
Riffle Substrate Category	0.15	0.02	4
Velocity in Riffles (juvenile)	0.04	0.00	
Temperature (growing season)	0.03	0.00	
Percent pools	0.02	0.00	
Percent shaded	0.01	0.00	
Velocity in Riffles	0.01	0.00	

Common Shiner

Common shiner is described as primarily a pool shiner (Jenkins and Burkhead 1993, Trial and Nelson 1983), and "percent pools" was found to be the second most influential variable in final HSI score (Table 7-11). It was unusual, however, that riffle attributes were found to be so influential in final HSI score. Exceptional sites such as TF396 that were steep in gradient and not overwidened tended to have greater velocity in riffles. Habitat at sites such as TF396, while highly desirable overall and good for a majority of indicator species, is actually not as suitable for common shiners as more degraded sites. So, in this case, riffle velocity and substrate had an important influence on total HSI score. Common shiners do not appear to exploit small streams and upstream reaches, as do blacknose dace and creek chubs; rather they show a preference for larger, mid-watershed stream segments with a mix of pool habitats, especially if large, slow pools are present.

Table 7-11 Common Shiner HSI Model Sensitivity Analysis

HSI Variable	r value	r²	rank
Riffle Velocity	0.58	0.34	1
Percent pools	0.37	0.14	2
Riffle Substrate Category	0.19	0.04	3
Pool Class	0.08	0.01	
Max. Summer Temperature	0.07	0.01	
Velocity in Pools	0.02	0.00	

Creek Chub

As mentioned previously, the creek chub HSI model includes a large number of habitat attribute input variables (n=20), many of which nearly always scored perfect suitability (SI=1). A small number of variables were very powerful in the analysis, and seemed to perform well in estimating habitat suitability (Table 7.8). In the original HSI analysis of Tookany/Tacony-Frankford Watershed data, minimum oxygen concentration in spring and summer limited suitability at all sites in Philadelphia and site TF760.

When the sensitivity analysis was initially run using a simple random number generator that limited the output values to a range with even distribution, DO variables were very important, accounting for a majority of the variance in HSI total score (Table 7.12). However, when the sensitivity analysis was performed using randomly generated, normally distributed minimum oxygen values, the influence of spring DO concentration was reduced and summer DO concentration was almost negligible (Table 7.12). The pH habitat suitability factor was an ordinal variable (only three categories were valid input values as applied to the Tookany/Tacony-Frankford Watershed) and thus very influential on the total HSI score once DO input variables were converted to an array of values fitting the normal distribution. As pH and oxygen fluctuations are inter-related, it may be sufficient to say that downstream sites that exhibit problems with either variable will be generally unsuitable for creek chubs.

Table 7-12 Creek Chub HSI Model Sensitivity Analysis

HSI Variable	**r value**	**r^2**	**rank**
Minimum spring DO conc.	0.614072	0.377201	1
Minimum summer DO conc.	0.503348	0.253712	2
pH (category)	0.165738	0.02763	3
Percent summer shade	0.031921	0.001353	
Average maximum depth	0.030484	0.001102	
Pool class (category)	0.030215	0.001136	
Average stream margin velocity	0.026425	0.001058	
Substrate food index	0.024913	0.000768	
Stream width	0.024608	0.000931	
Stream gradient	0.02374	0.000919	
Percent pools	0.021388	0.000684	
Winter thermal cover	0.019738	0.000553	
Percent cover	0.012689	0.000379	

Table 7-13 Creek Chub HSI Model Modified Sensitivity Analysis

HSI Variable	**r value**	**r^2**	**rank**
pH (category)	0.867203	0.752314	1
Minimum spring DO conc.*	0.199296	0.040377	2
Winter thermal cover	0.08947	0.009113	3
Percent pools	0.07437	0.006729	
Stream width	0.066559	0.004954	
Percent summer shade	0.05645	0.003858	
Substrate food index	0.047608	0.002867	
Pool class (category)	0.039874	0.003218	
Stream gradient	0.034031	0.002056	
Percent cover	0.03317	0.001707	
Minimum summer DO conc.	0.013052	0.001139	
Average maximum depth	0.005239	0.001379	
Average stream margin velocity	0.002902	0.000752	
*Dissolved oxygen values randomly generated to fit normal distribution			

Fallfish

Sensitivity analysis performed with the fallfish HSI model suggested that substrate and temperature variables had the most influence on total HSI score (Table 7-14). The model was very simple, and since the species was not collected from Tookany/Tacony-Frankford Watershed, there was no opportunity to compare model output with observed fish data.

Table 7-14 Fallfish HSI Model Sensitivity Analysis

HSI Variable	r value	r^2	rank
Substrate Category	0.537861	0.318505	1
Favorable Spawning Temperature Y/N	0.484223	0.25853	2
Temperature	0.279436	0.086915	3
Mode of Stream Depth	0.027016	0.001389	
Cover category	2.85E-15	1.06E-12	

Longnose Dace

The longnose dace HSI model was similar to the fallfish model in that it did not appear to have a sufficient number of input variables to estimate habitat suitability for the species. Results of sensitivity analysis suggested that the longnose dace model was very sensitive to stream velocity (Table 7-15). Many sites in Tookany/Tacony-Frankford Watershed probably do not have the swift flowing riffles with moderate depth during baseflow that this species needs in order to thrive. Unfortunately, the one site that appeared to have adequate physical habitat, TF396, probably could not support a population of longnose dace due to water quality problems.

Table 7-15 Longnose Dace HSI Model Sensitivity Analysis

HSI Variable	r value	r^2	rank
Average Stream Velocity	0.870711	0.758267	1
Percent Cover	0.164372	0.027557	2
Percent of Substrate >5cm	0.150228	0.022929	3
Maximum Depth in Riffles	0.012016	0.001503	
Percent Riffles	0.011341	0.000912	

Redbreast Sunfish

The redbreast sunfish HSI model used an ordinal (*i.e.*, categorical) variable for minimum dissolved oxygen concentration, and suggested that habitat suitability for this species is not adversely affected at 5.0 mg/l and is still moderately suitable (SI=0.70) at 3.0mg/l (Aho, *et al*. 1986). Results were very similar to the creek chub model. In the absence of influence from DO concentration, pH was very influential, overshadowing the other variables (Table 7-16). As mentioned previously, pH and DO fluctuations are interrelated, and sites that exhibit severe fluctuations in either DO or pH will be less suitable habitat for redbreast sunfish and fish in general.

Table 7-16 Redbreast Sunfish HSI Model Sensitivity Analysis

HSI Variable	r value	r^2	rank
Least suitable pH observed	0.830002	0.68896	1
Spawning temperature (summer)	0.107977	0.000726	2
Percent slow pools	0.098623	0.001564	3
Percent sand/gravel	0.020353	0.000987	
Vegetated cover	0.009163	0.001039	
Percent cover	0.00622	0.000543	
Max temp growing season	0.00385	0.000558	

Smallmouth Bass

The smallmouth bass HSI model was considered to be the most comprehensive and refined of all HSI models used. One explanation for this is the fact that Smallmouth bass are large predators and economically important. All factors appear to have been considered and included in the model, yet there are few extraneous factors. The only shortcoming was the number of variables defined by ordinal data.

When minimum DO concentration values were generated for sensitivity analysis input as a range of values with an even distribution, low DO values appeared frequently in the input array and the influence of DO concentration on final HSI score was the most important factor (Table 7-17). When minimum DO input values were fitted to a normal distribution, the incidence of low DO concentrations was much less and the overall influence of DO on the final HSI score decreased and physical habitat features became much more influential. Unfortunately, no smallmouth bass were collected from Tookany/Tacony-Frankford Watershed, so further interpretation of the model output was not possible. Factors the model suggested were influencing habitat suitability (*i.e.*, substrate type, percent pools and DO) were considered to be limiting for other indicator species as well.

Table 7-17 Smallmouth Bass HSI Model Sensitivity Analysis

HSI Variable	*r* value	r^2	rank
Dissolved O_2	0.55121	0.304095036	1
Percent pools	0.342683	0.117847336	2
Substrate type category	0.14563	0.021791216	3
Percent cover	0.063263	0.004417092	4
Gradient	0.031777	0.002482453	5
Avg. pool depth	0.01208	0.00074076	
Temperature (juvenile)	0.005166	0.001810854	
Temperature (adult)	0.001128	0.001648207	
Average pH	0.001279	0.000938872	
Temperature (fry)	0.007792	0.00155506	

Table 7-18 Smallmouth Bass HSI Model Modified Sensitivity Analysis

HSI Variable	*r* value	r^2	rank
Percent pools	0.658775	0.434124162	1
Substrate type category	0.252076	0.06438798	2
Percent cover	0.127203	0.016691022	3
Gradient	0.089035	0.00852654	4
Dissolved O_2*	0.066097	0.004928978	5
Temperature (adult)	0.022228	0.001333032	
Temperature (juvenile)	0.020963	0.001260527	
Temperature (fry)	0.018387	0.002537125	
Avg. pool depth	0.010251	0.000591149	
Average pH	0.004575	0.000323035	
***Dissolved oxygen values randomly generated to fit normal distribution**			

Section 8
Indicator Status Update

Overview

An important component of the Comprehensive Characterization Report is a concise update on the biological, chemical and physical conditions within the Tookany/Tacony-Frankford Watershed. Indicator status updates derived within this report will be used as a tool for identifying spatial and temporal trends of a particular stream reach or for the entire watershed. Moreover, indicators defined in the Tookany/Tacony-Frankford Integrated Watershed Management Plan (TTFIWMP) will serve as benchmarks for future restoration projects. The indicators addressed in this section are:

- Indicator 3: Stream Channels and Aquatic Habitat
- Indicator 5: Fish
- Indicator 6: Benthos
- Indicator 7: Effects on Public Health (Bacteria)
- Indicator 8: Effects on Public Health (Metals and Fish Consumption)
- Indicator 9: Effects on Aquatic Life (Dissolved Oxygen)

8.1 Indicator 3: Stream Channels and Aquatic Habitat

Indicator 3 of the TTFIWMP stresses the importance of physical habitat features that will support healthy fish and benthic communities. As described in Section 3.8.1, thirteen habitat variables, ranging from instream parameters to riparian zone width and quality were compared against reference conditions to obtain an overall habitat integrity score.

In 2004, PWD staff biologists surveyed habitat at 12 sites throughout the Tookany/Tacony-Frankford Watershed. Monitoring locations along the mainstem of Tookany Creek (Montgomery County) received uniform scores of “Non-Supporting”, indicating a region of severe habitat degradation (Figure 8-1). In general, upstream reaches in Tookany Creek lacked habitat heterogeneity, possessed poor riparian zones, and experienced high levels of channelization. Moreover, poor bank stability and exaggerated levels of sediment deposition also contributed to the poor aquatic habitat in the upper portions of the watershed.

Habitat values in the middle portion of Tacony Creek varied among sites, ranging from “Non-Supporting” to “Supporting” (*i.e.*, good). With the exception of site TF 396, a site with exceptional habitat for an urbanized stream, assessment sites in Tacony Creek possessed the same attributes as the upstream reaches (erosion, poor bank stability, reduced riparian zones and heavy sediment deposition).

Rock Creek and Jenkintown Creek sites, the two surveyed upstream tributaries, both were rated as partially supporting, indicating slightly better habitat conditions relative to the mainstem.

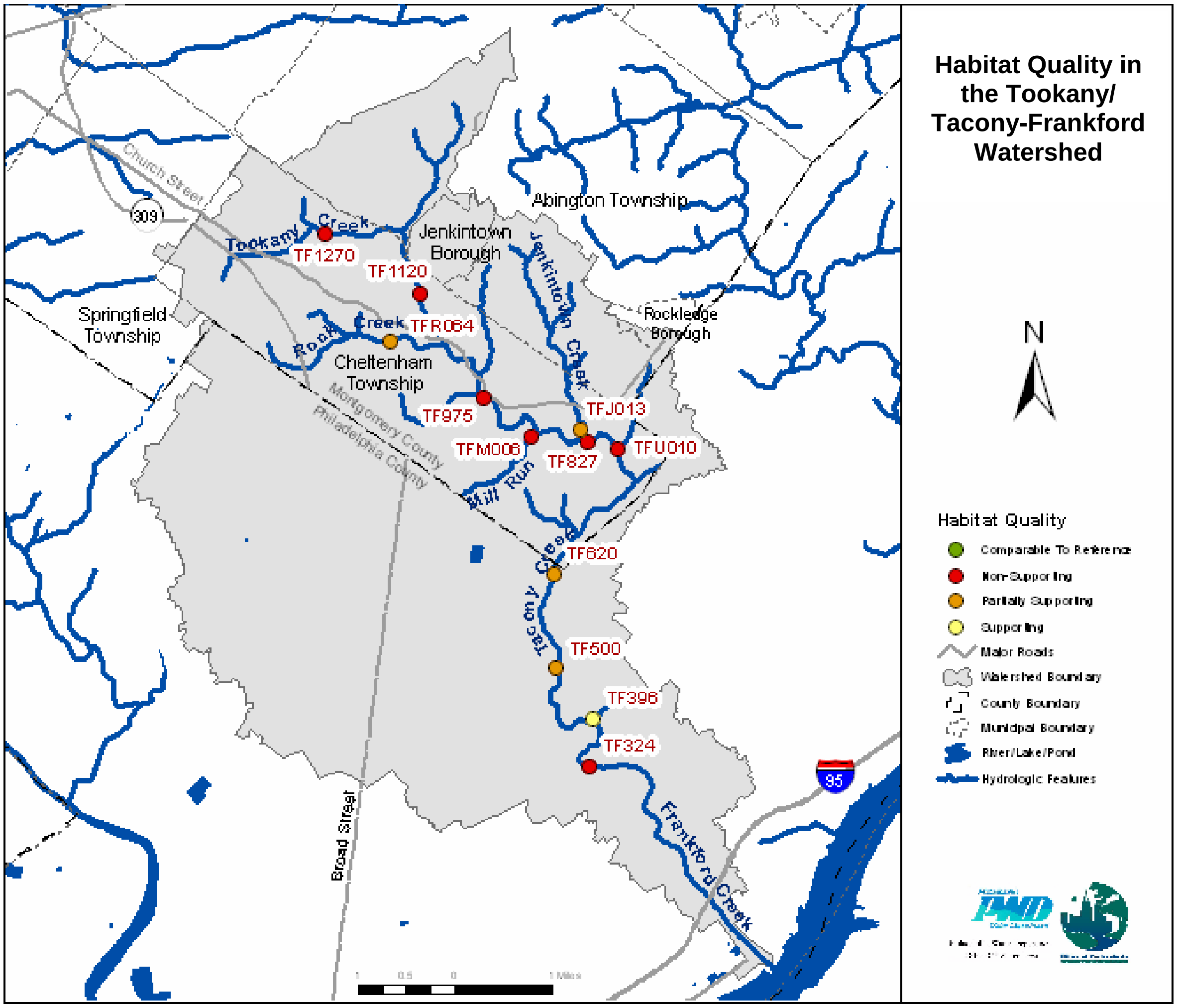


Figure 8-1 Tookany/Tacony-Frankford Watershed Habitat Quality Indicator Status Update.

8.2 Indicator 5: Fish

During 2000, three surrogate indicators were used to define the integrity of fish communities in the Tookany/Tacony-Frankford Basin. Relative abundance (*i.e.*, density), pollution tolerance, and number of native species provided a semi-quantitative measurement of fish assemblage health. With the development of ecoregion-specific metrics, PWD replaced these early indicators in 2004 with the Index of Biological Integrity (IBI), a multi-metric approach that characterizes fish community health at a particular stream reach or at the watershed scale (Section 3.6).

Fisheries data revealed a mean IBI score of 21 (out of 50), placing the Tookany/Tacony-Frankford Watershed in the “poor” category for fish community health (Figure 8-2). Low diversity, absence of benthic insectivorous species, absence of intolerant species, skewed trophic structure dominated by generalist feeders, high percentage of individuals with disease and anomalies, and high percentage of dominant species are characteristics of a fish community with "poor" biotic integrity. Spatial trends showed that only two sites received a "fair" IBI score, both located in Tacony Creek Park in the City of Philadelphia. Similar spatial trends revealed that Modified Index of Well-Being (MIWB) and Shannon Diversity Index values, which are measures of diversity and abundance, were lowest in the lower and upper monitoring stations and highest in the middle of the watershed, mirroring the habitat indicator results. Overall, monitoring stations in the central portion of the watershed had higher biological integrity and thus environmental quality, than either downstream or upstream stations.

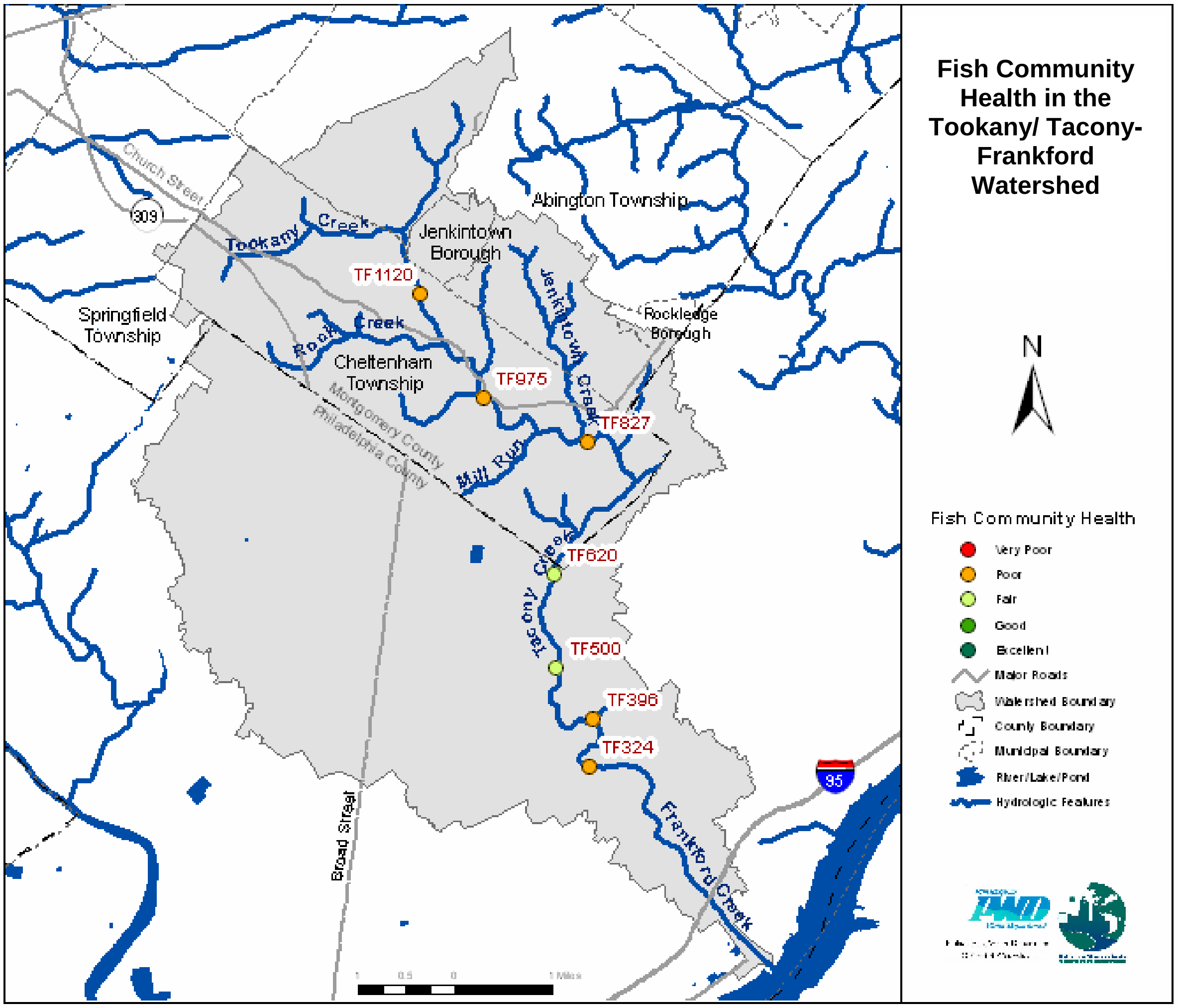


Figure 8-2 Tookany/Tacony-Frankford Watershed Fish Indicator Status Update

8.3 Indicator 6: Benthos

Benthic macroinvertebrate monitoring occurred at 12 sites in Tookany/Tacony-Frankford Watershed during 2004. Similar to the 2000 sampling effort, Rapid Bioassessment Protocol III (RBP III) was chosen as the approved method for assessing the condition of the macroinvertebrate community in Tookany/Tacony-Frankford Watershed.

The assessment conducted in 2004 reconfirmed earlier findings of the Pennsylvania Department of Environmental Protection (PA DEP) and Philadelphia Water Department (PWD). Benthic impairment in Tookany/Tacony-Frankford Watershed was omnipresent;

with the exception of Jenkintown Creek, all stream segments were designated "severely impaired" (Figure 8-3).

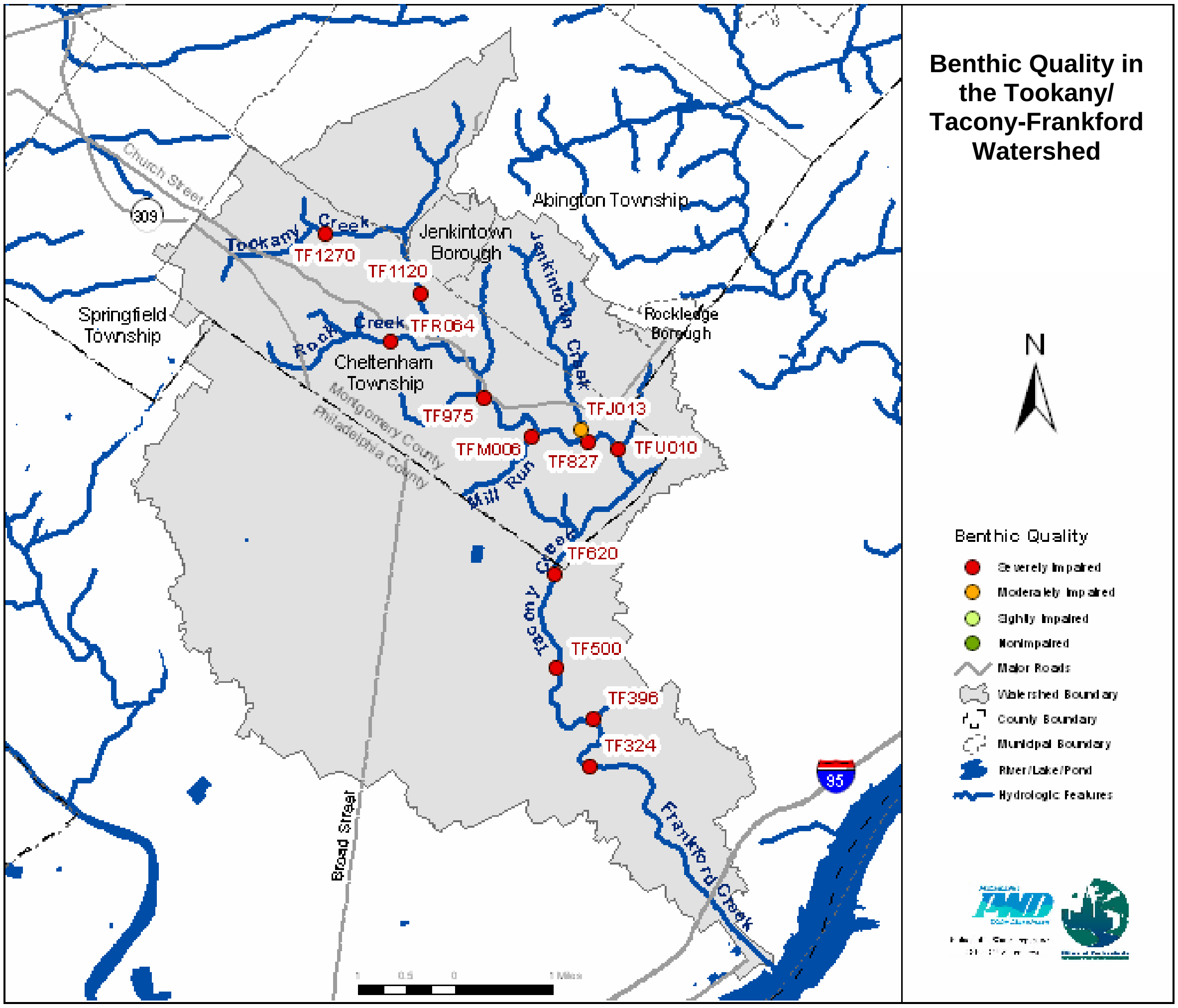


Figure 8-3 Tookany/Tacony-Frankford Watershed Benthic Indicator Status Update.

The severity of impairment throughout Tookany/Tacony-Frankford Watershed suggests that attaining healthy benthic communities in mainstem localities and associated tributaries is not a feasible option at this time. Habitat restoration, flow attenuation and possibly, active re-introduction (*i.e.*, "invertebrate seeding") may be the only solutions to ensure a viable benthic community within this watershed.

8.4 Indicator 7: Public Health Effects (Bacteria)

Based on Pennsylvania's water quality criteria, the maximum fecal coliform concentration during the swimming season (*i.e.*, May 1 through September 30) shall not exceed a geometric mean of 200 colony forming units (CFU) per 100 ml for five non-consecutive samples. During the remainder of the year, the maximum fecal coliform concentration should be equal to or less than a geometric mean of 2000 CFU per 100 ml based on five samples collected on different days.

Discrete chemical samples taken at ten sites (n=10) in Tookany/Tacony-Frankford Watershed between 2000 and 2004 were used to calculate the percentage of samples meeting the appropriate standard (*i.e.*, swimming vs. non-swimming seasons) during wet and dry periods.

During dry weather, fecal coliform concentrations from May 1st through September 30th were placed in the “red” category (met standards less than ninety percent of the time) at all sites in Tookany/Tacony-Frankford Watershed (Figure 8-4). Between 91.1% - 100% of samples at all sites along Tookany-Tacony/Frankford mainstem did not meet the water quality standard of 200 CFU/100 ml during dry weather. Conversely, all sites with the exception of TF 280 met the non-swimming standard (2000 CFU/100 ml) greater than ninety-eight percent of the time during dry periods (Figure 8-4).

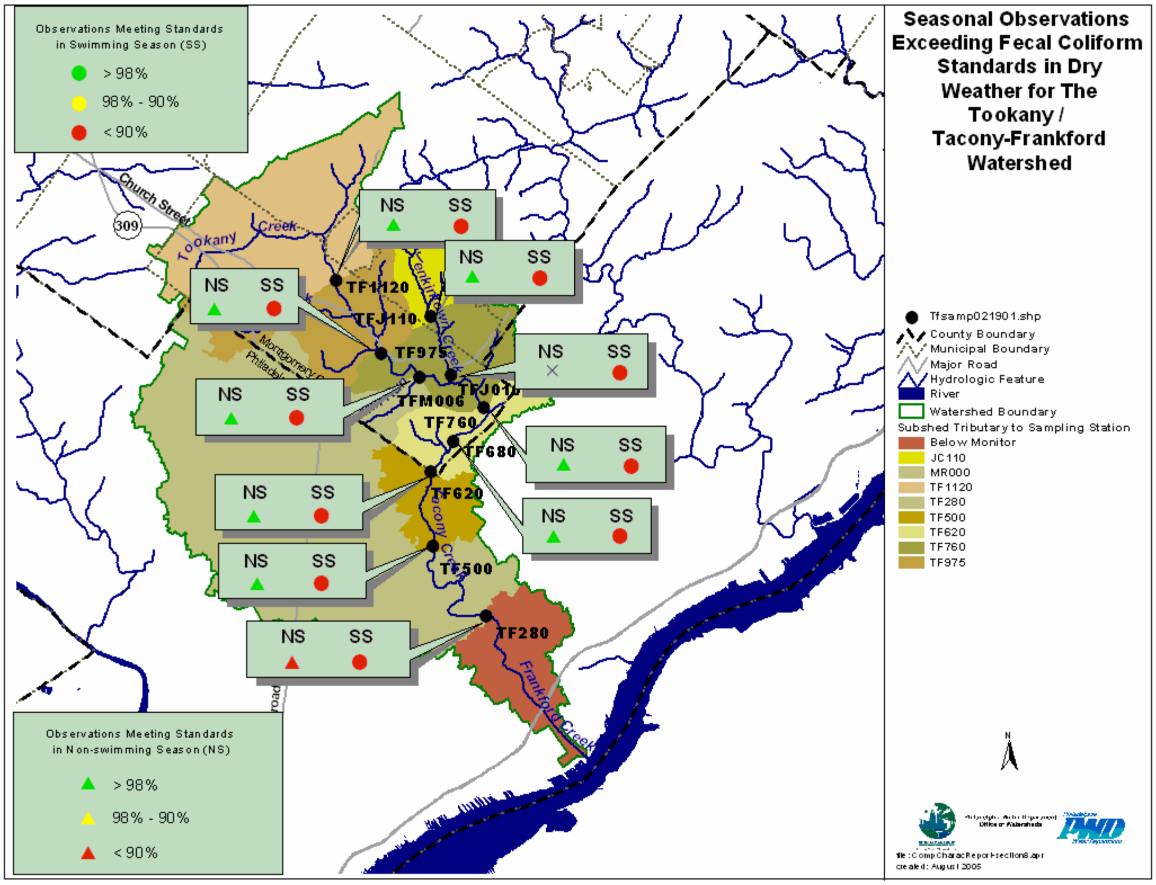


Figure 8-4 Fecal Coliform Samples Meeting Standards in Dry Weather during the Swimming and Non-Swimming Seasons.

Wet weather sampling results showed concentrations of fecal coliform exceeding water quality standards at all mainstem sites in Tookany/Tacony-Frankford Watershed during swimming and non-swimming seasons (Figure 8-5). Approximately 87.5% to 100 % of samples taken during the swimming season at the mainstem sites exceeded standards. Samples taken during the non-swimming period showed similar results with exception of the two major tributaries, Mill Run and Jenkintown Creek. Samples taken at these localities met the water quality standards greater than 98% of the time (Figure 8-5).

Figure 8-6 depicts the relationship (*i.e.*, magnitude of departure) between the geometric mean of fecal coliform concentrations and the appropriate standard at each site during dry and wet weather conditions. During the swimming season, concentrations of fecal coliform exceeded the standard at all locations along mainstem Tookany and Tacony Creeks in dry and wet weather. Most pronounced were sites TF500 and TF975, with fecal coliform levels exceeding the standard by a factor of 5 (*i.e.*, >1000 CFU/100 ml) during dry periods. Other sites along the continuum ranged between 1 to 4 times the standard during dry weather. All sites, with the exception of TFJ110, showed concentrations greater than five times the standard during wet weather.

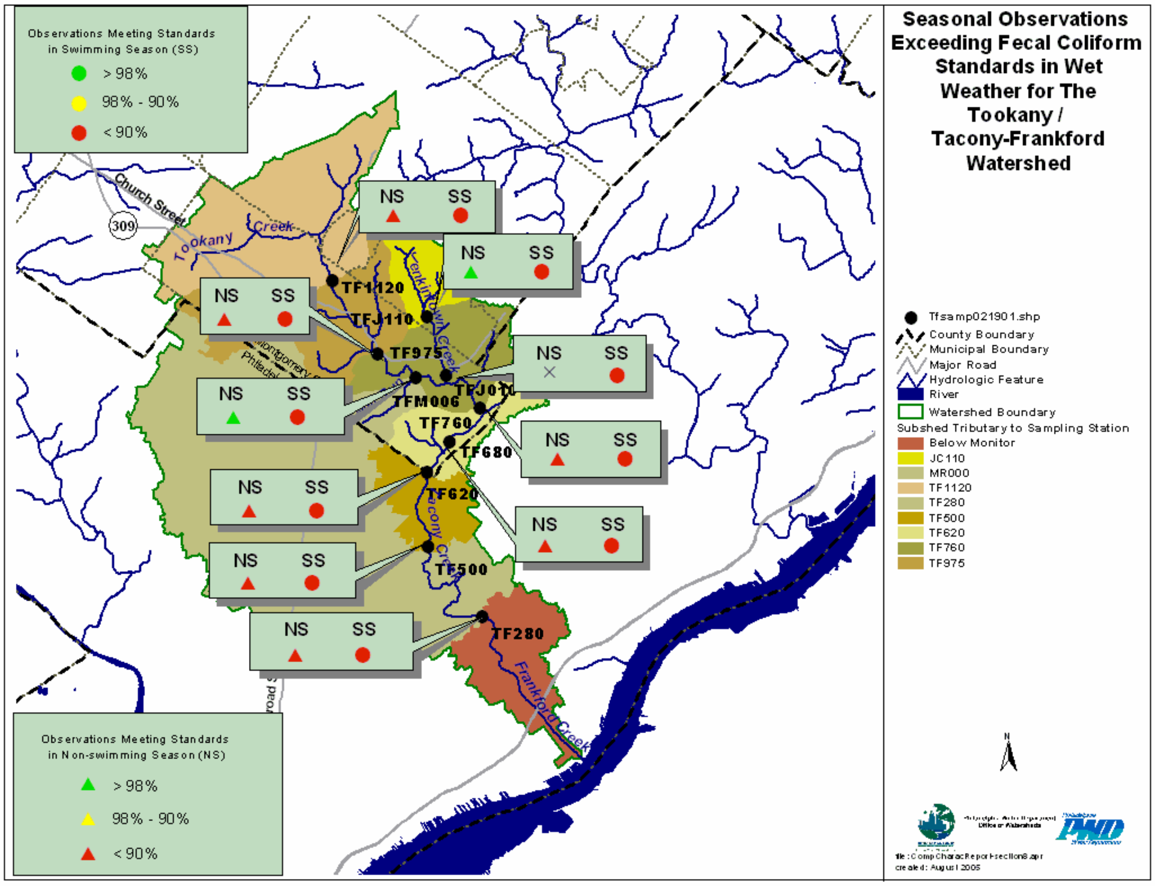


Figure 8-5 Fecal Coliform Samples Meeting Standards in Wet Weather during the Swimming and Non-Swimming Seasons.

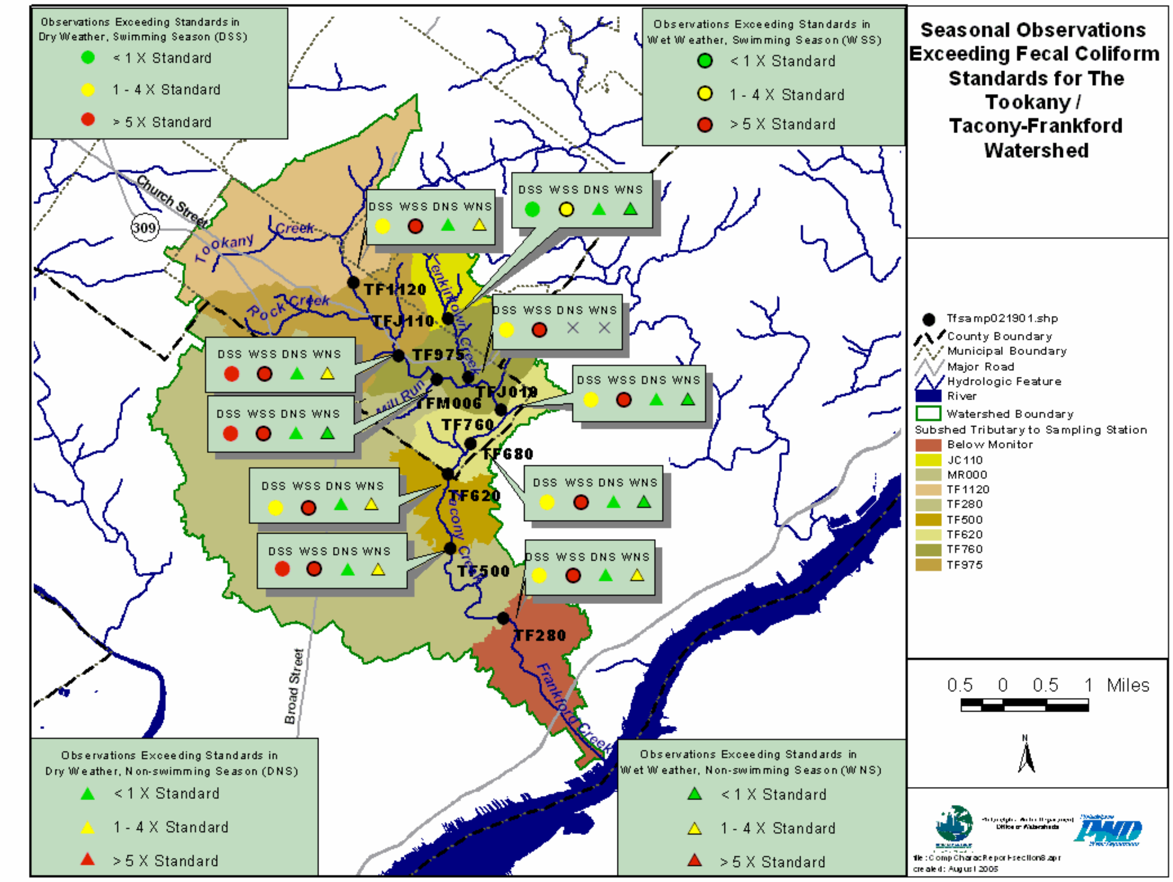


Figure 8-6 Seasonal Observations Exceeding Fecal Coliform Standards during Dry and Wet Weather

8.5. Indicator 8: Public Health Effects (Metals and Fish Consumption)

Relatively small amounts of certain toxic compounds can kill aquatic life through acute poisoning, while chronic levels may be harmful to developmental stages of fish and macroinvertebrates. For example, bioaccumulation of toxins in fish may have a profound effect on fecundity and may also pose a threat to humans who regularly consume fish. The established indicator measures the percent of aluminum, cadmium, chromium, copper, lead and zinc samples meeting state standards at various sites in Tookany/Tacony-Frankford Watershed.

Results suggest acute standards intended to protect aquatic life were met at all locations during dry-weather, while concentrations for aluminum exceeded chronic standards at most localities (Figures 8-7 and 8-8, respectively). Similarly, concentrations of aluminum exceeded acute standards regularly during wet conditions (Figure 8-7). In addition, copper generally exceeded acute standards during wet weather more than 10 % of the time at sites TFM006, TF620 and TF280.

Figure 8-9 represents observations of samples exceeding human health standards for toxic metals. As shown, all sites met standards greater than 98% of the time during dry and wet conditions.

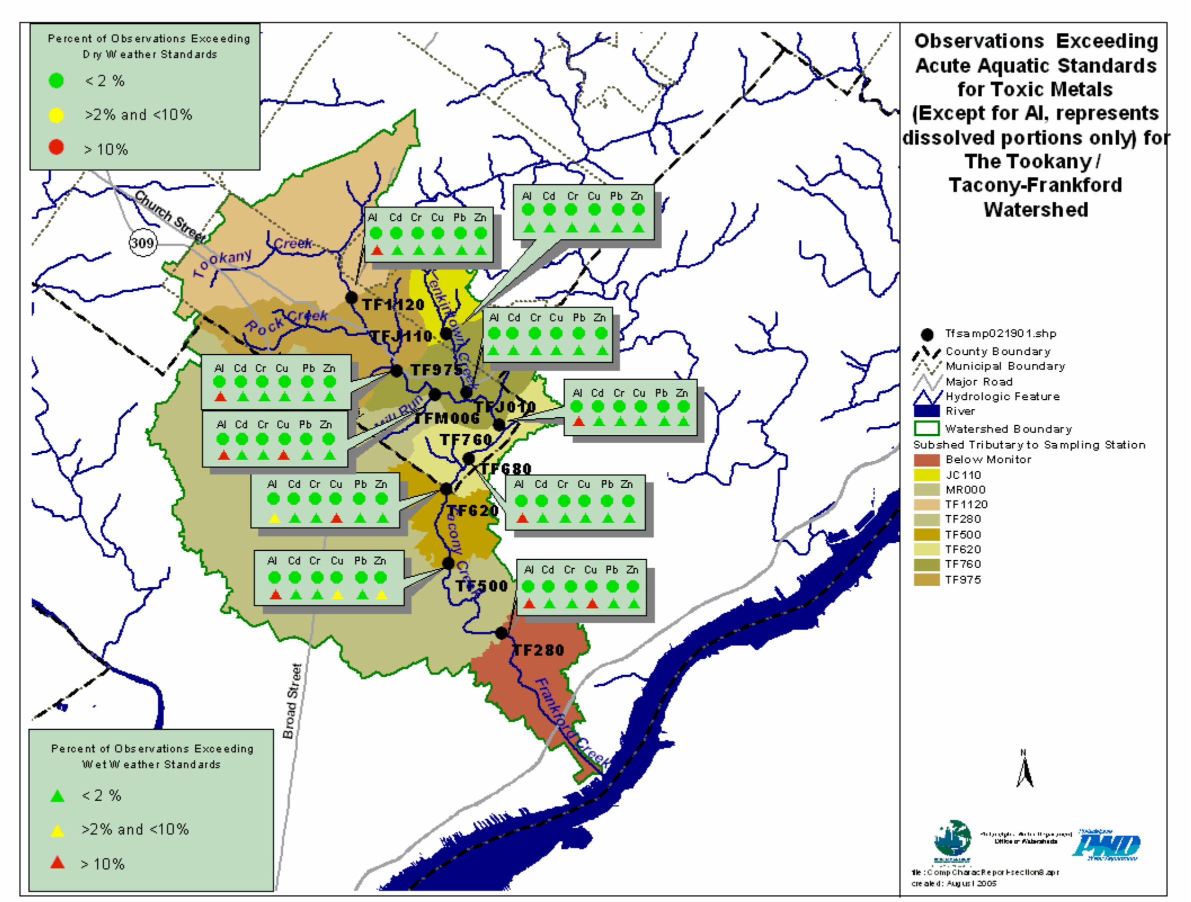


Figure 8-7 Acute Aquatic Standards for Toxic Metals during Wet and Dry Conditions.

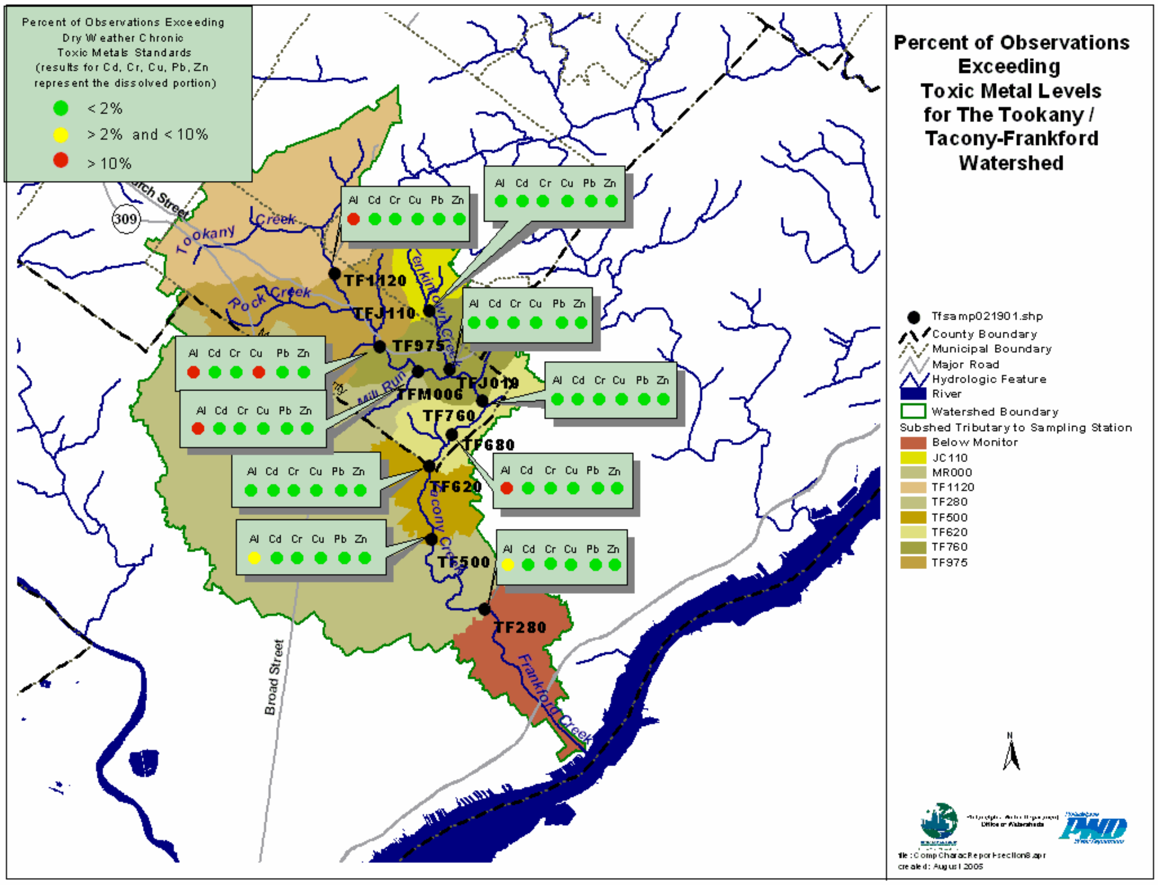


Figure 8-8 Percent Exceedance of Dry Weather Chronic Toxic Metals Standards.

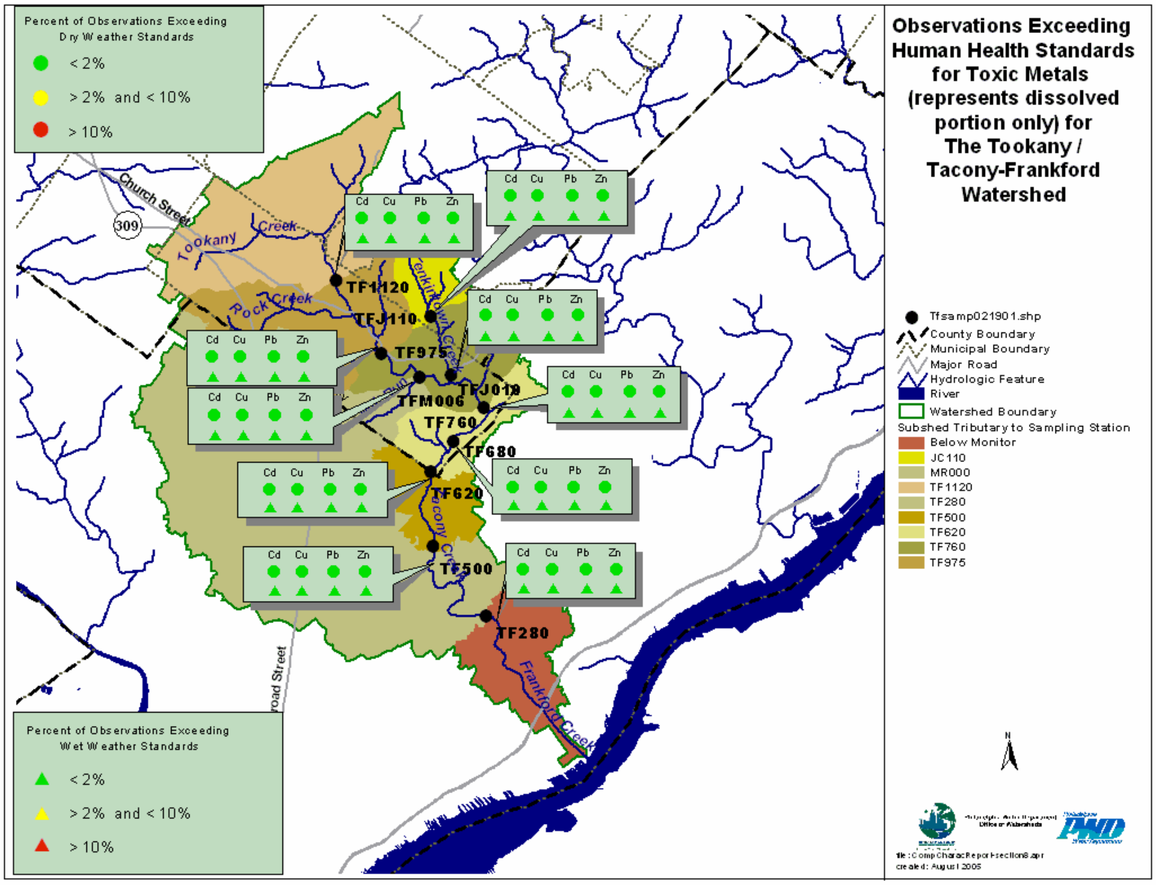


Figure 8-9 Observations Exceeding Human Health Standards for Toxic Metals in Wet and Dry Weather.

8.6. Indicator 9: Aquatic Life Effects (Dissolved Oxygen)

Automated water quality monitors (*i.e.*, Sondes) were deployed in Tookany/Tacony-Frankford Watershed at seven locations along the mainstem and three locations in major tributaries between 2000 and 2004. Sondes were deployed for approximately two-week periods, recording dissolved oxygen concentrations (mg/L) every 15 minutes. Upon completion of a cycle, Sondes were retrieved from the stream and exchanged for a reconditioned unit.

Continuous data from the mainstem sites indicated that daily average DO concentrations met minimum standards (daily average >5 mg/L of O_2,) greater than 90% of the time (Figure 8-10), with some locations meeting standards greater than 98% of the sampling period. Similar results were observed in Mill Run and Jenkintown Creek. Daily minimum standards for dissolved oxygen (instantaneous minimum 4 mg/L of O_2), however, indicate a potential problem in the downstream portion of the watershed. Site TF280 met minimum daily standards less than 90% of the sampling period while all other locations met the daily minimum standard between 90% and 100 % of the time.

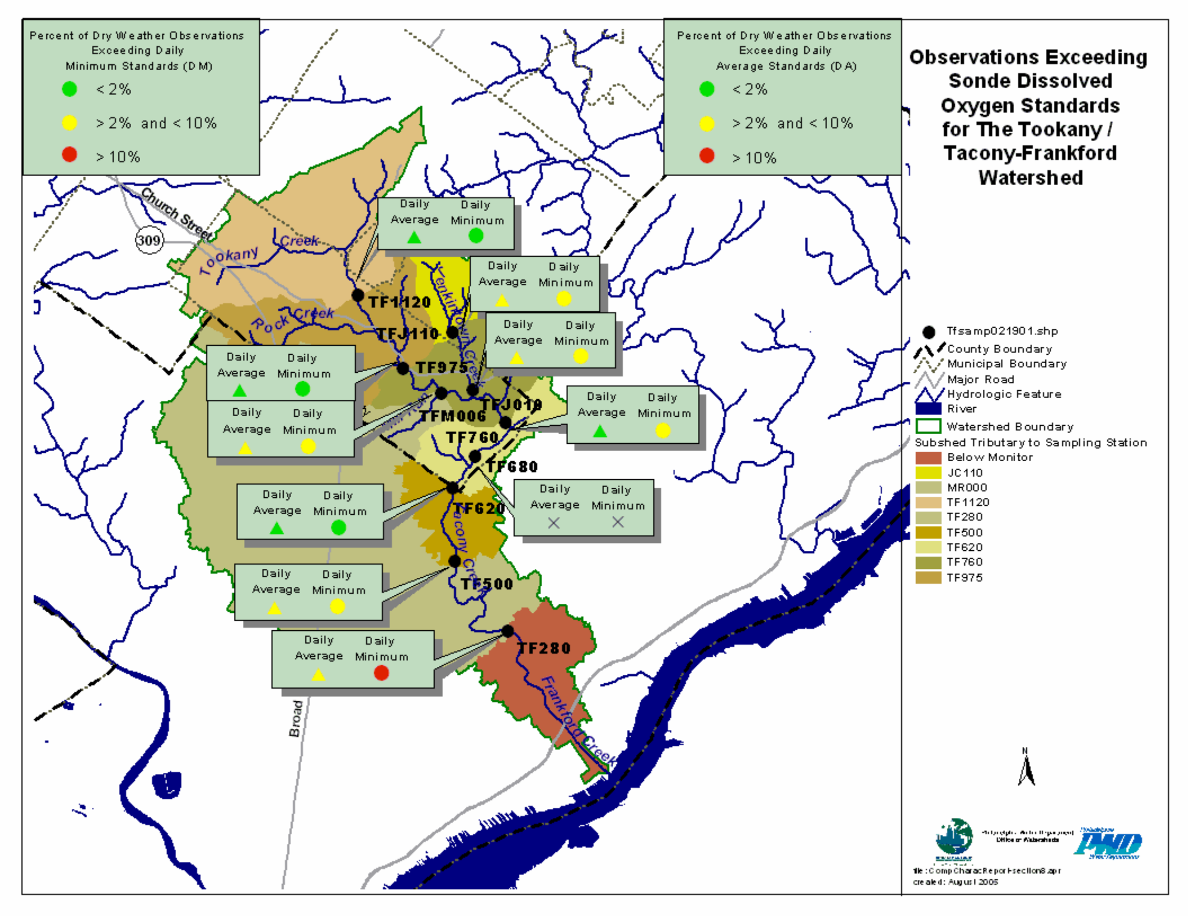


Figure 8-10 Observations Exceeding Dissolved Oxygen Standards.

Section 9
Active and Potential Sources of Water Quality Constituents

9.1 Model Description and Data Sources

9.1.1 Introduction

This subsection summarizes the results of a preliminary estimate of loading rates of various pollutants to Tookany/Tacony-Frankford Creek and tributaries. The waters in the drainage area receive point source discharges including CSO and other urban and suburban stormwater, sanitary sewer overflows, and limited industrial storm, process, and cooling waters. Combined sewers service approximately 47% of the watershed. Nonpoint sources in the basin include atmospheric deposition, limited direct overland runoff from urban and suburban areas, and limited individual on-lot domestic sewage systems discharging through shallow groundwater. Results for the Tookany/Tacony-Frankford Watershed were obtained using the detailed Storm Water Management Model (SWMM).

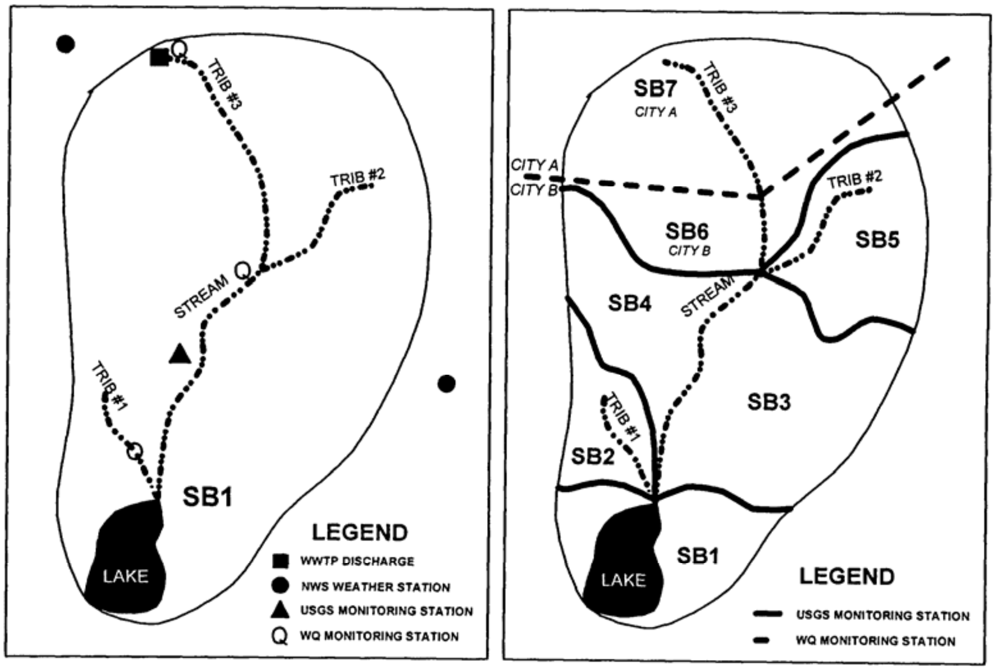
9.1.2 The Storm Water Management Model (SWMM)

The U.S. EPA's Storm Water Management Model (SWMM) was used to develop the watershed-scale model for the Tookany/Tacony-Frankford Watershed. The major components of the SWMM model used in the development of the Tookany/Tacony-Frankford Watershed model were the RUNOFF and EXTRAN modules.

The RUNOFF module was developed to simulate both the quantity and quality of runoff in a drainage basin and the routing of flows and contaminants to sewers or receiving body. The program can accept an arbitrary precipitation (rainfall or snowfall) hyetograph and performs a step by step accounting of snowmelt, evapo-transpiration losses, infiltration losses in pervious areas, surface detention, overland flow, channel flow, and water quality constituents leading to the calculation of one or more hydrographs and/or pollutographs at a certain geographic point such as a sewer inlet. The driving force of the RUNOFF module is precipitation, which may be a continuous record, single measured event, or artificial design event.

The EXTRAN module was developed to simulate hydraulic flow routing for open channel and/or closed conduit systems. The EXTRAN module receives hydrograph inputs at specific nodal locations by interface file transfer from an upstream module (*e.g.* the RUNOFF module) and/or by direct user input. The module performs dynamic routing of stormwater flows through storm drainage systems and receiving streams.

9.1.3 Planning Areas/Units (Subsheds)



A. Map of Watershed and Location of Potential Data Sources B. Delineation of Subbasins by Drainage and Jurisdiction

Figure 9-1 Conceptual Framework for Delineation of Model Units

Model subsheds were delineated differently in areas with separate storm sewers and areas with combined sewers. In areas with separate storm sewers, a digital elevation model was used to delineate topographic drainage areas to points along the stream. Figure 9-1 illustrates this delineation conceptually. The points chosen were locations where a fluvial geomorphological analysis of the stream was conducted as part of a related study. In areas with combined sewers, model subsheds coincided with sewersheds, or topographic areas draining to individual regulator structures. Model subsheds were further refined in two ways. First, subsheds extending across the county boundary were separated into two areas to allow pollutant loads to be summed individually. Second, subsheds were delineated at a finer scale in some areas with known flooding problems, such as the Wingohocking area in the northwest portion of the drainage area within Philadelphia. The model was not optimized for the loading analysis; rather, a model was created to adequately serve multiple purposes such as pollutant loading analyses, combined sewer infrastructure studies, flood management studies, and water quality studies.

The planning areas or jurisdictional sub-watersheds range in size from less than 1 acre to greater than 1400 acres. The mean size of the planning areas is about 430 acres with a median size of about 71 acres. The largest planning area is located in the City, and drains to CSO regulator T14. The smallest basin also is located in the City and contributes to CSO regulator T14. Eighty percent of the planning areas are between 5 and 1000 acres.

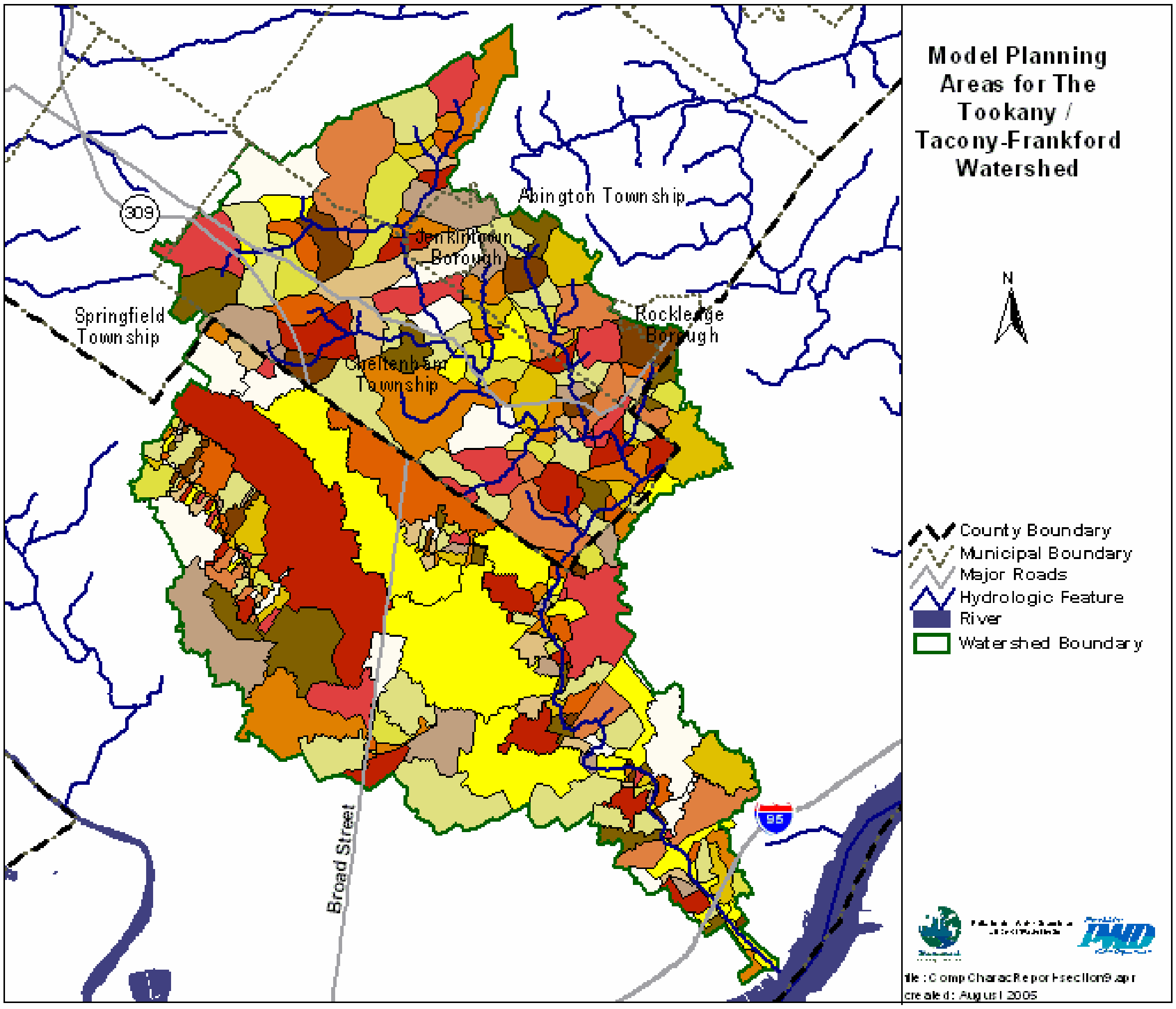


Figure 9-2 Planning Areas or Model Units in the Tookany/Tacony-Frankford Watershed

9.1.4 Land Use

Data used to define the land uses by planning area were compiled by the Delaware Valley Regional Planning Commission (DVRPC) and are shown in Figure 2-6.

9.1.5 Event Mean Concentrations (EMCs)

Event Mean Concentrations (EMCs) are defined as the total mass load of a chemical parameter yielded from a site during a storm divided by the total runoff water volume discharged from the site during the storm. The EMC is widely used as the primary statistic for evaluations of stormwater quality data and as the stormwater pollutant loading factor in analyses of pollutant loads to receiving waters.

Use of EMCs in Loading Analyses: Nonpoint source pollution loading analyses typically consist of applying land use- specific stormwater pollution loading factors to land use scenarios in the watershed under study. Loading rates of urban stormwater pollution (nutrients, metals, BOD, fecal coliform) are determined by the quantity of runoff from the land surface. Thus, they are closely related to the imperviousness of the land use type.

Runoff volumes are computed for each land use category based on percent imperviousness of the land use and annual rainfall. These runoff volumes are multiplied by the land use specific EMC load factor (mg/L) to obtain nonpoint source pollutant loads by land use category. This analysis can be performed on a subarea or watershed-wide basis, and the results can be used to perform load allocation studies, to evaluate pollution control alternatives, or as input into a riverine water quality model.

The model calculates pollutant loads based upon nonpoint source pollution loading factors (expressed as lb/acre/year) that vary by land use and the percent imperviousness associated with each land use. The pollution loading factor M_L is computed for each land use L by the following equation:

$$M_L = EMC_L * R_L * K$$

where:

M_L = loading factor for land use L (lb/acre/year)
EMC_L = event mean concentration of runoff from land use L (mg/L); EMCs may vary by land use and pollutant
R_L = total average annual surface runoff from land use L (in/yr); and
K = 0.2266, a unit conversion constant.

By multiplying the pollutant loading factor by the acreage per land use and summing for all land uses, the total annual pollution load from a sub-basin can be computed. The EMC coverage is typically not changed for various land use scenarios within a given study watershed.

In areas drained by separate storm sewers, applying EMCs to calculated runoff volumes provides reasonable estimates of stormwater pollutant loadings to surface water. In areas drained by combined sewers, this approach estimates the pollutant load entering the sewer system; additional analysis is required to estimate the pollutant load to the receiving water.

History and Sources of EMCs: Once point source discharges from treatment plants and industrial facilities were addressed in the 1970s and 1980s, more attention was focused on stormwater runoff from urban areas as a source of water quality degradation. As pollution from stormwater and urban drainage began to be investigated, studies focused on the types of pollution and methods to reduce the loads. However, these investigations did not consider the achievable level of improvement of receiving water bodies with the mitigation of stormwater pollution. In addition, many research studies concluded that additional and more comprehensive information was needed to make such assessments. This need led to the development of the Nationwide Urban Runoff Program, also known as NURP.

The goals of NURP were to develop and provide information to local decision makers, the States, EPA, and other parties for use in assessing the impacts of stormwater and urban runoff on water quality. The information collected also was intended to aid in the development of water quality management plans and provide a foundation for local, State and Federal policy decision making about water quality issues.

The NURP studies investigated 10 standard water quality constituents to characterize urban runoff. As a result of data collected through the NURP program, EMCs for these and other pollutants were developed from over 2,300 station-storms at more than 81 urban sites located in 28 different metropolitan areas. These studies greatly increased the knowledge of the characteristics of urban runoff, its effects upon the designated uses of receiving water bodies, and the performance efficiencies of various control measures. Pertinent conclusions from the NURP Program include:

- The variance of the EMCs, when data from sites are grouped by land use type or geographic region, is so great that differences in measures of central tendency among groups are not statistically significant.

- Statistically, the entire sample of EMCs and the medians of all EMCs among sites are log-normally distributed.

EMCs often are used in screening-level models. The pollutant loads (L_i) are estimated as the product of the area of urban land (A_U), the rainfall-runoff depth as estimated by a modified rational formula approach (d_r), and a constant pollutant concentration (C_i), usually estimated from the EMCs reported by NURP (i.e., $L_i = C_i A_u d_r$).

Since the conclusion of the NURP Program in the 1980's, additional urban runoff quality monitoring data has been collected. One large effort conducted by the United States Geological Survey resulted in the collection of urban runoff data for over 1,100 station-storms at 97 urban sites in 21 metropolitan areas. Additionally, EPA required many major cities to collect urban runoff quality data as part of the application requirements for stormwater discharge permits under the National Pollutant Discharge Elimination System (NPDES). Data from 800 station-storms from 30 cities was gathered and incorporated into a database by CDM. CDM analyzed the data collected from NURP, USGS, and NPDES to assess if additional EMC observations (more degrees of freedom) would uncover statistically significant differences in EMCs among various land uses. While the resulting EMCs from the combined data sets did not indicate statistical differences in water quality among land uses, the pooled EMCs were significantly different than the NURP EMCs for several parameters (*e.g.*, TSS, Cu, and Pb) and would produce different loading rates for urban areas. Table 9-1 illustrates the EMCs used in the Tookany/Tacony-Frankford Watershed Study and the source of each EMC value.

Table 9-1 Event Mean Concentrations

Land Use	**Mean EMCs, mg/L**											**Source (Equivalent Category)**
	BOD	**COD**	**TSS**	**TP**	**DP**	**TKN**	**NO2+ NO3**	**Pb**	**Cu**	**Zn**	**Fecal**	
Agriculture/Pasture	14.1	40.0	70.0	0.121	0.026	0.965	0.543	0.0300	0.0135	0.195	30000	EPA 1982 Chesapeake Bay Program
Commercial	14.1	52.8	78.4	0.315	0.129	1.73	0.658	0.0675	0.0135	0.162	30000	Smullen, J. T., *et al*. 1999
Community Services	14.1	52.8	78.4	0.315	0.129	1.73	0.658	0.0675	0.0135	0.162	30000	Smullen, J. T., *et al*. 1999
Industrial/ Light Manufacturing	14.1	52.8	78.4	0.315	0.129	1.73	0.658	0.0675	0.0135	0.162	30000	Smullen, J. T., *et al*. 1999
Military	14.1	52.8	78.4	0.315	0.129	1.73	0.658	0.0675	0.0135	0.162	30000	Smullen, J. T., *et al*. 1999
Utility	14.1	52.8	78.4	0.315	0.129	1.73	0.658	0.0675	0.0135	0.162	30000	Smullen, J. T., *et al*. 1999
Transportation	24.0	103	141	0.430	0.129	1.82	0.830	0.5270	0.052	0.367	30000	FHA, 1990.
Parking	24.0	103	141	0.430	0.129	1.82	0.830	0.5270	0.052	0.367	30000	FHA, 1990.
Water/Wetlands (Atmospheric Input)	1	1	1	0.064	0.02	1.022	0.571	0.00266	0.0022	0.0652	1	EPA 1982 Chesapeake Bay Program
Residential Single-Family	14.1	52.8	78.4	0.315	0.129	1.73	0.658	0.0675	0.0135	0.162	30000	Smullen, J. T., *et al*. 1999
Residential Multi-Family	14.1	52.8	78.4	0.315	0.129	1.73	0.658	0.0675	0.0135	0.162	30000	Smullen, J. T., *et al*. 1999
Wooded	14.1	52.8	40.5	0.145	0.129	0.505	0.245	0.0675	0.0135	0.162	30000	EPA 1982 Chesapeake Bay Program
Parks	14.1	52.8	78.4	0.145	0.129	3.19	1.0100	0.0675	0.0135	0.162	30000	EPA 1982 Chesapeake Bay Program
Cemetery	14.1	52.8	407	0.75	0.100	3.19	1.0100	0.0675	0.0135	0.162	30000	EPA 1982 Chesapeake Bay Program
Urban Recreation	2.00	52.8	60	0.188	0.100	3.19	1.0100	0.0675	0.0135	0.162	30000	EPA 1982 Chesapeake Bay Program
Vacant	2.00	52.8	60	0.188	0.100	3.19	1.0100	0.0675	0.0135	0.162	30000	EPA 1982 Chesapeake Bay Program
Golf Courses	14.1	52.8	407	0.75	0.100	3.19	1.0100	0.0675	0.0135	0.162	30000	EPA 1982 Chesapeake Bay Program

Note: All metals data are from Smullen (1999), except Highway. Atmospheric contributions are included in these values. The EMC for fecal coliform is based on NURP data as reported in NOAA (1987).

9.1.6 Baseflows

Most streams exhibit dry weather flow due to groundwater infiltration. As discussed in Section 4, baseflows for the individual planning areas were determined using USGS streamflow gauging data.

Baseflow due to groundwater inflow is the main component of most streams in dry weather. Baseflow slowly increases and decreases with the elevation of the shallow aquifer water table. In wet weather, a stormwater runoff component is added to the baseflow. Estimation and comparison of these two components can provide insights into the relationship between land use and hydrology in urbanized and more natural systems. For a more detailed explanation of the baseflow separation techniques used, see Section 4.3.

9.1.7 Constituent Source Types

For a watershed or TMDL study, an inventory of pollutant sources to the receiving water bodies must be compiled. The various types of sources usually considered are listed below. Note that urban stormwater runoff has some attributes of both point and nonpoint sources.

- Point (industrial and municipal dischargers, CSOs, SSOs);
- Nonpoint (stormwater, urban drainage, leaking septic systems);
- Background (instream, baseflow); and
- Atmospheric.

Stormwater and Urban Drainage: Stormwater from areas with separate storm sewers contributes to water body impairment in highly urbanized, impervious catchments. Pollutants most frequently associated with stormwater include sediment, nutrients, bacteria, oxygen demanding substances, oil and grease, heavy metals, other toxic chemicals, and floatables. The primary sources of these pollutants include automobiles, roadways (pavement, bridges), housekeeping and landscaping practices, industrial activities, construction, non-storm connections to drainage systems, accidental spills and illegal dumping. Calculations used to estimate pollutant loads in stormwater are described in Section 9.1.5.

Combined Sewer Overflows (CSOs): In many cities throughout the United States, stormwater runoff and sanitary wastewater are collected in the same sewer (a combined sewer). In dry-weather conditions, all flows are conveyed to and treated at a local or regional wastewater treatment plant. In wet-weather conditions, the capacity of the combined sewer system can be exceeded and discharges of mixed sanitary and stormwater then occur to receiving waters. The fraction of sanitary sewage in discharges varies from storm to storm, but is typically on the order of 10% over the long term, while the remaining 90% is untreated stormwater. For constituents where sanitary sewage and untreated stormwater concentrations are the same order of magnitude (*e.g.*, TSS, nutrients), concentrations in CSO are similar or slightly higher than when compared to stormwater. For constituents where sanitary concentrations are typically lower (*e.g.*, metals such as Pb, Cu, Zn), concentrations in CSO are slightly lower than in untreated stormwater. For bacteria and other pathogens, concentrations in CSO are one or more orders of magnitude higher than those found in stormwater.

Estimating loads to surface waters from an area served by a combined sewer requires three steps.

1. Stormwater flow and load entering the sewer system are estimated by the methods described in Section 9.1.5.

2. A hydraulic simulation of the sewer system predicts the portion of flow that is captured and sent to a wastewater treatment plant, the portion of flow that overflows to the receiving water (CSO), and the fractions of CSO made up of sanitary sewage and stormwater.

3. Using known volumes and pollutant concentrations of sanitary sewage and stormwater reaching the receiving water (step 2), the total pollutant load reaching the receiving water is estimated.

Municipal and Industrial Process Water Discharges: A search of federal and state NPDES permit databases was performed to identify permitted dischargers within the Tookany/Tacony-Frankford Watershed. Table 9-2 presents the list of dischargers and the information found for each point source.

Sanitary Sewer Overflows (SSOs): SSOs result in discharges of untreated wastewater that can affect stream quality and occasionally back up into basements and city streets. The USEPA has found that SSOs represent a significant threat to health and the environment in areas where they occur frequently. Frequent SSOs may indicate that the capacity of the collection system is insufficient to convey the flows introduced or that the system is in need of maintenance or repair. Potential causes of excess flow include infiltration and inflow, illegal connections, population growth, and under-design. Problems requiring maintenance or repair may include broken or cracked pipes, tree roots, poor connections, and settling. Proper maintenance can help prevent problems or identify them before they become extremely costly to repair (USEPA, 2000).

Sanitary Sewer Overflows (SSOs) are a known source of bacterial and other pollution to the Tookany/Tacony-Frankford Watershed. Currently, no inventory of SSOs exists for the area within the two counties that contain the Tookany/Tacony-Frankford Watershed. Since the data collection effort required to obtain SSO load information was beyond the scope of this screening-level study, SSO loads were not considered part of this study. An SSO assessment methodology will be implemented as part of the Phase II efforts.

Septic Tanks: Although there are septic systems in the watershed, most of the population is served by sanitary sewers. The number of septic tanks within the watershed is difficult to accurately quantify; according to 1990 census data there are estimated to be about 1,075 septic tanks present in the watershed, 706 of which are located within the city of Philadelphia. This number is believed to be a high estimate of the actual number.

Compilations of septic tank and on-lot sewer systems have not been completed to date. Detailed assessment of individual municipalities for septic tank and on-lot sewage disposal inventories and/or permits was beyond the scope of the current phase of this study.

Atmospheric Sources: Pollutants from atmospheric deposition on land surfaces are considered to be included in the calculations of stormwater runoff. Direct deposition on water surfaces also is included in these calculations by the use of a water surface land use type. Specifically, precipitation falling on the water surface land use was assigned EMCs of nutrients and metals derived from rainfall data. For this study, the water surface EMCs were taken from the Chesapeake Bay Program literature (EPA, 1982).

Table 9-2 Active Point Sources Permitted Under NPDES

PA NPDES ID.	Site Name	Available Information
PA0010961	SPS Technologies Aerospace Products Division	NPDES Pmt Industrial Wastewater Discharge Minor
PA0024252	Sun Refining & Marketing Co.	NPDES Pmt Industrial Wastewater Discharge Minor
PAR600026	Allegheny Iron Radiation	PAG-03 Discharge of Stormwater Assoc w Industrial Activities
PA0040991	Bayway Refining Company (Inc.)	NPDES Pmt Industrial Wastewater Discharge Minor
PAR800085	Roadway Express	PAG-03 Discharge of Stormwater Assoc w Industrial Activities
PAR800064	BFI Waste Systems of North America	PAG-03 Discharge of Stormwater Assoc w Industrial Activities
PAR600024	S D Richman Sons Incorporated	PAG-03 Discharge of Stormwater Assoc w Industrial Activities
PAR230045	Sunoco Incorporated Frankford Plant	PAG-03 Discharge of Stormwater Assoc w Industrial Activities

9.2 Results: Estimated Annual Constituent Loads

Figures 9-3 through 9-11 show estimated loading rates for stormwater runoff and CSO. Table 9-3 breaks load estimates into two geographic regions, the upper and lower Tookany/Tacony-Frankford. The loads are estimates of the total input to the stream system. For example, the surface runoff listed for lower Tookany/Tacony-Frankford (an area serviced by combined sewers) is relatively low because it does not include the volume that is captured, treated, and discharged outside the system. With some exceptions, higher pollutant loading rates are found in the lower Tookany/Tacony-Frankford Watershed, in and near the densely populated areas of Philadelphia. Loads from areas with combined sewers are higher for some constituents because a portion of the discharge is made up of sanitary sewage. In these areas, the pollutant load is a function both of pollutants washed from the land surface and pollutants added to the sewer system directly by residences and businesses. Thus, areas of higher loading shown in the figures do not necessarily indicate that stormwater from those areas is more polluted.

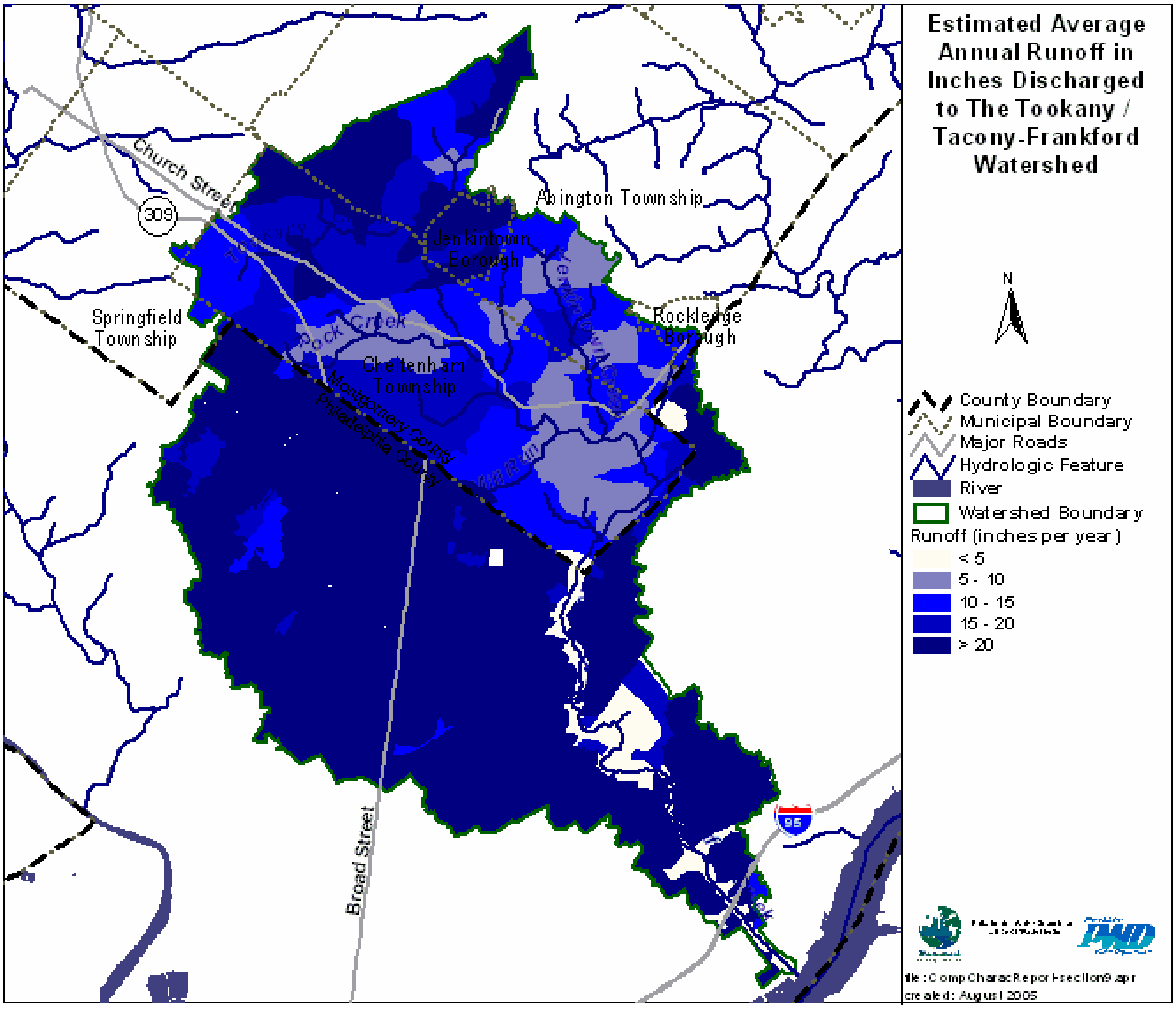


Figure 9-3 Estimated Annual Runoff for Tookany/Tacony-Frankford Watershed

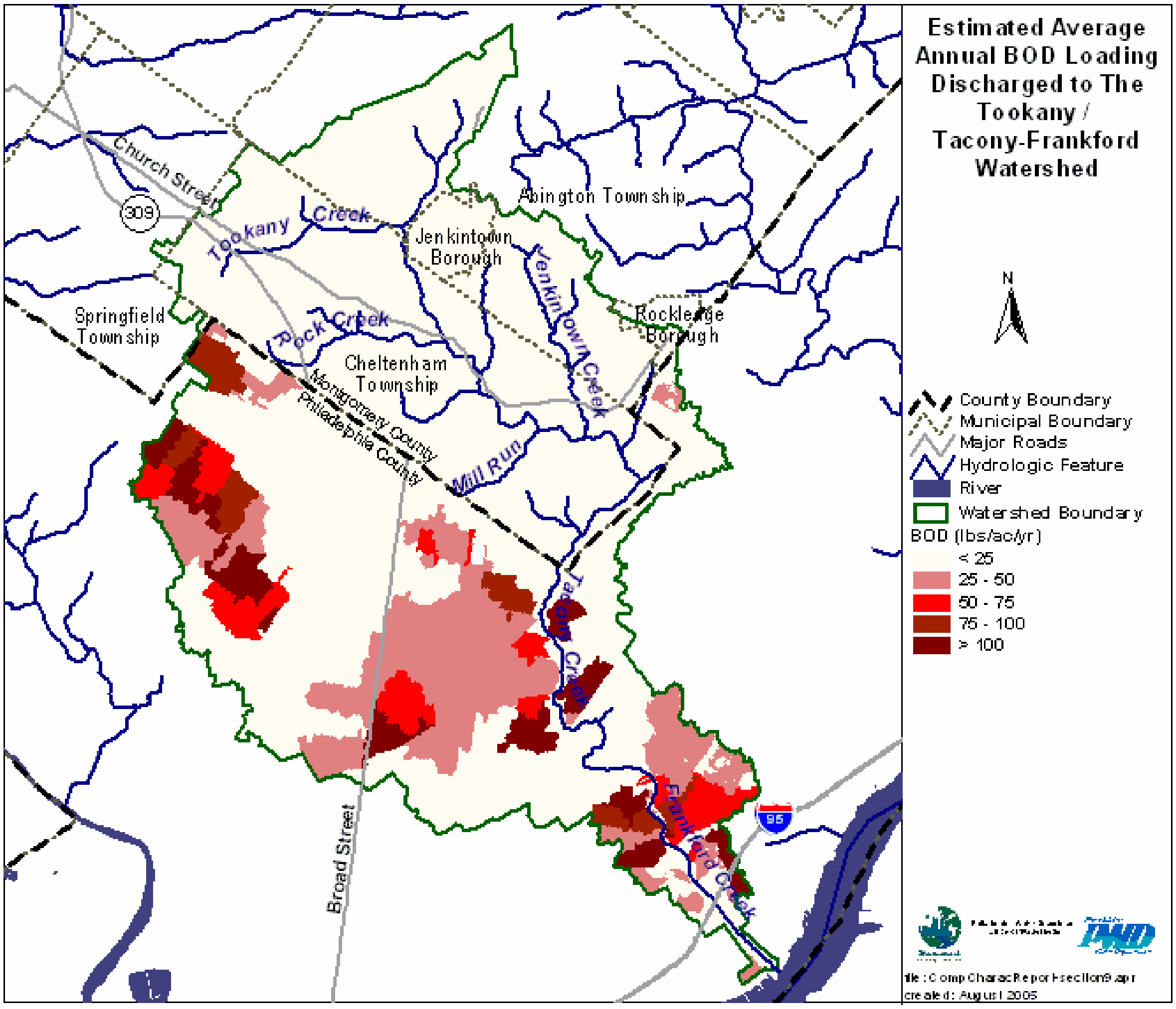


Figure 9-4 Estimated Annual Loading Rate for BOD for Tookany/Tacony-Frankford Watershed

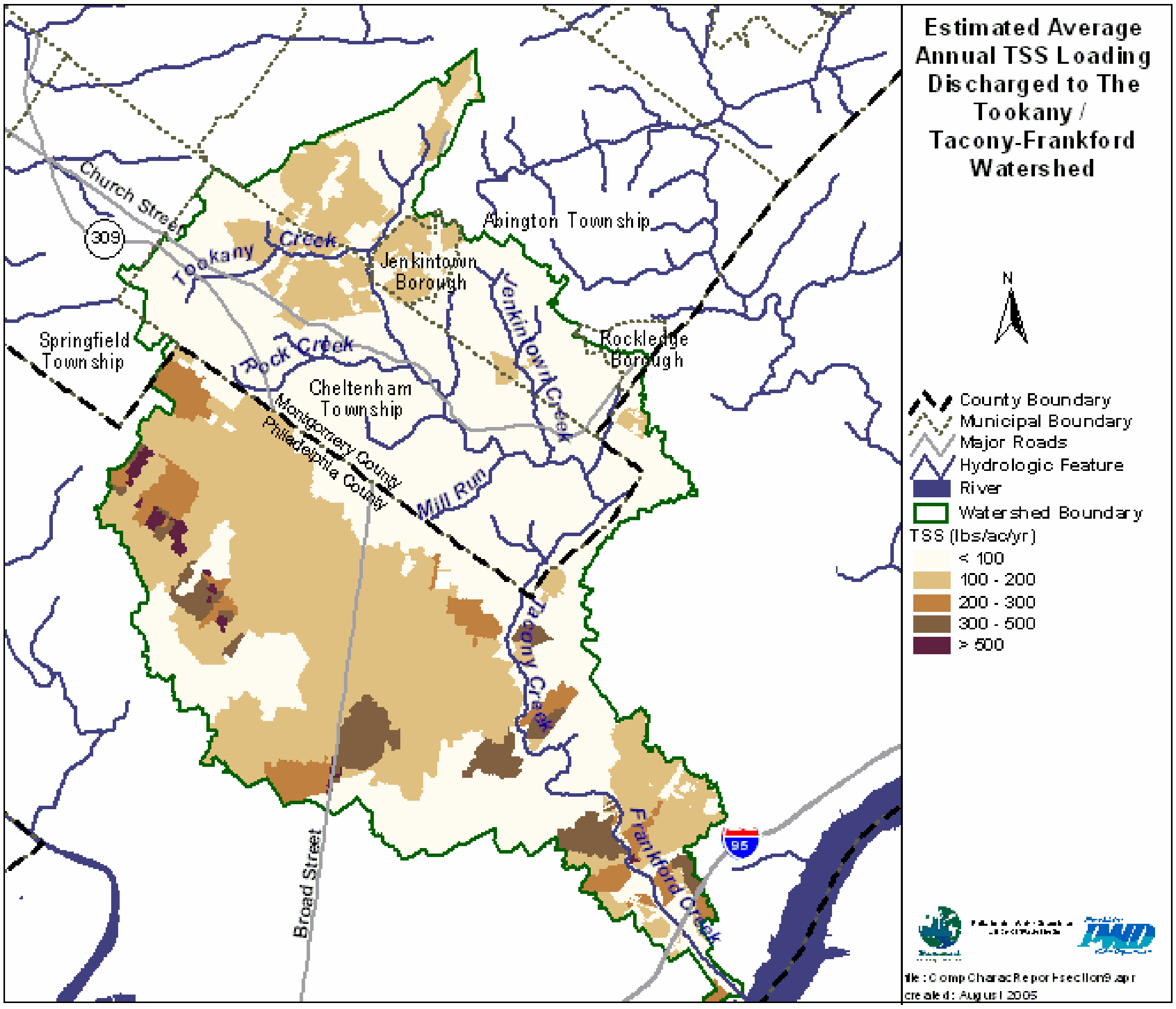


Figure 9-5 Estimated Annual Loading Rate for TSS for Tookany/Tacony-Frankford Watershed

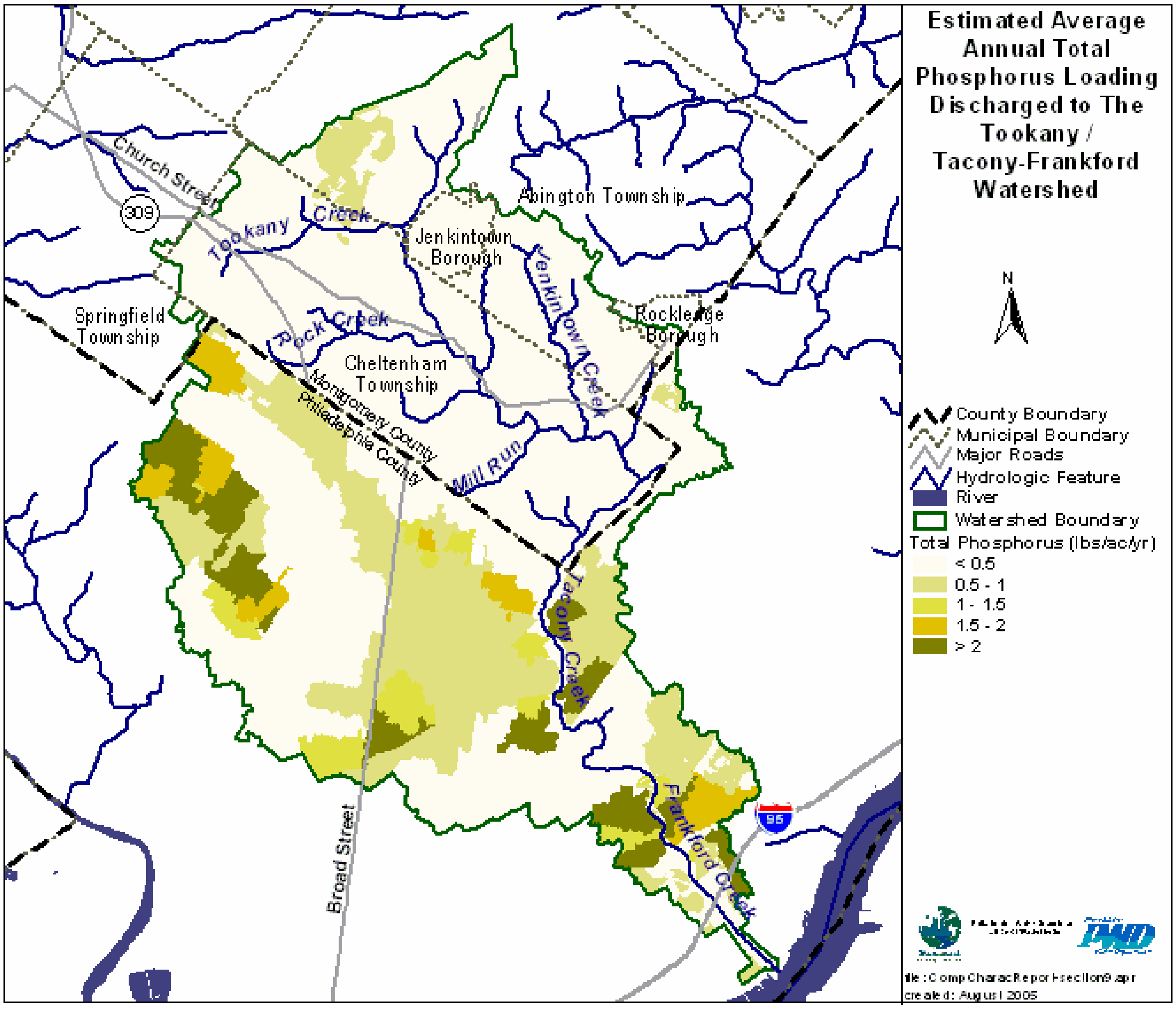


Figure 9-6 Estimated Annual Loading Rate for Total Phosphorus for Tookany/Tacony-Frankford Watershed

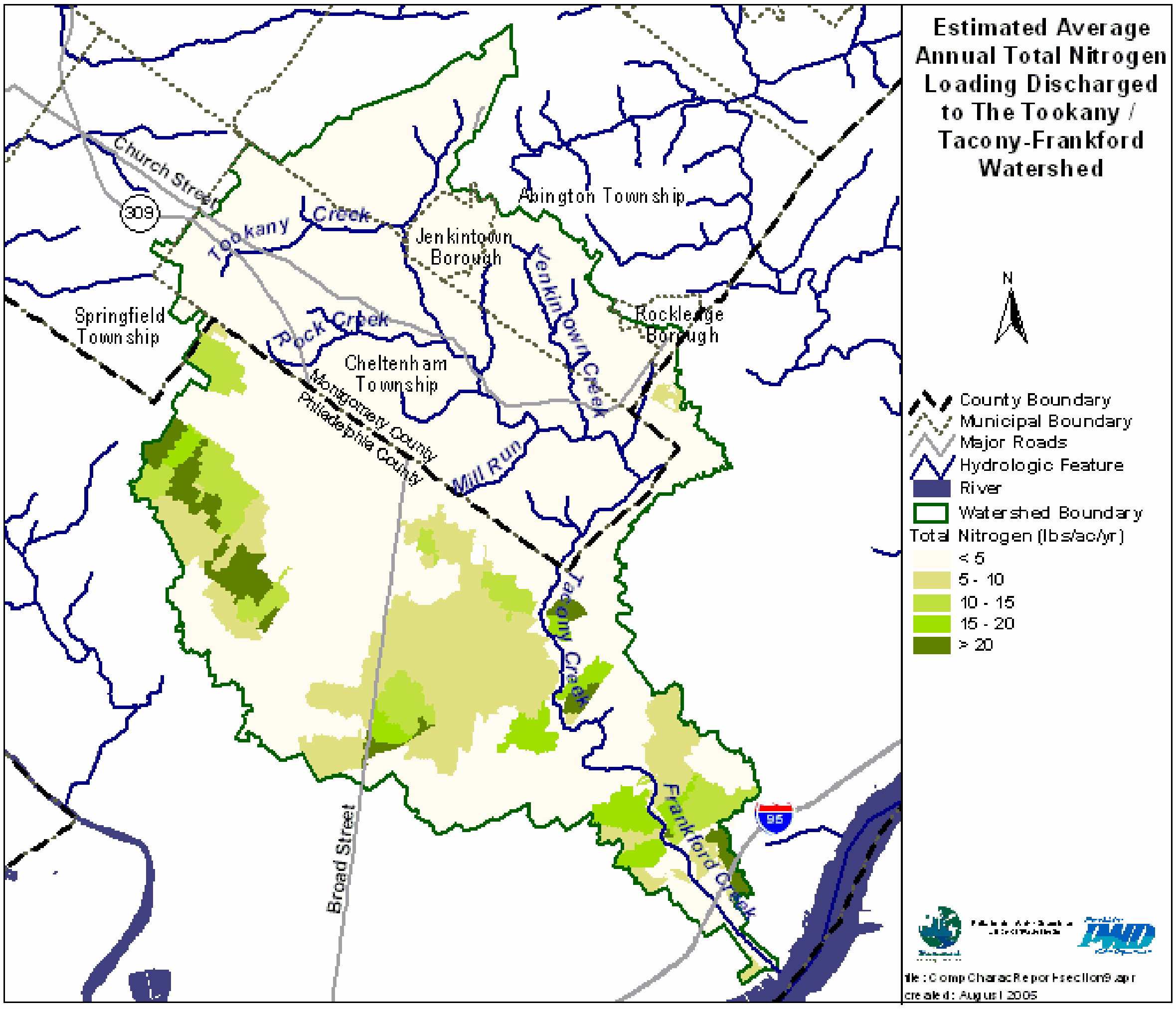


Figure 9-7 Estimated Annual Loading Rate for Total Nitrogen for Tookany/Tacony-Frankford Watershed

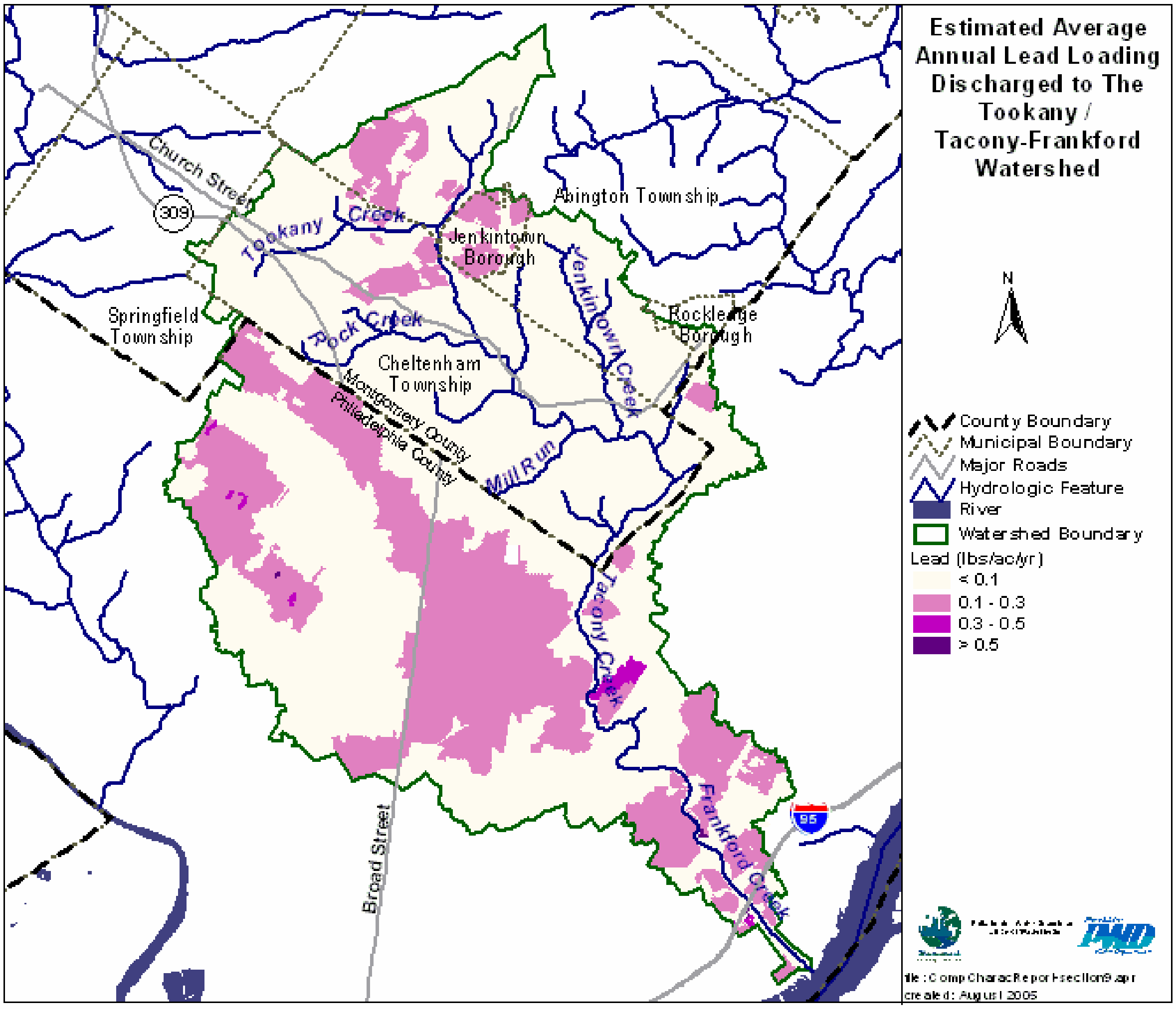


Figure 9-8 Estimated Annual Loading Rate for Lead for Tookany/Tacony-Frankford Watershed

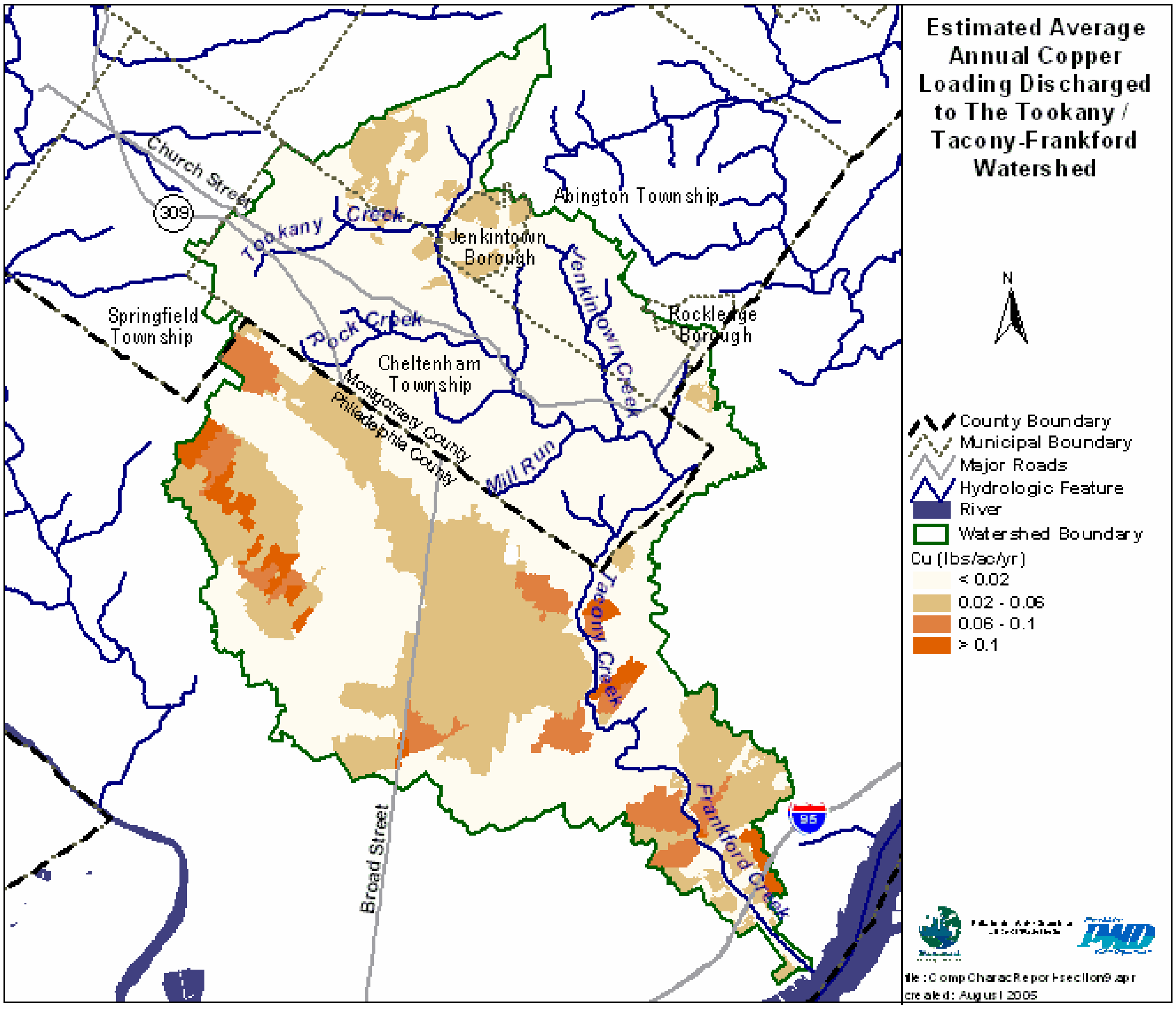


Figure 9-9 Estimated Annual Loading Rate for Copper for Tookany/Tacony-Frankford Watershed

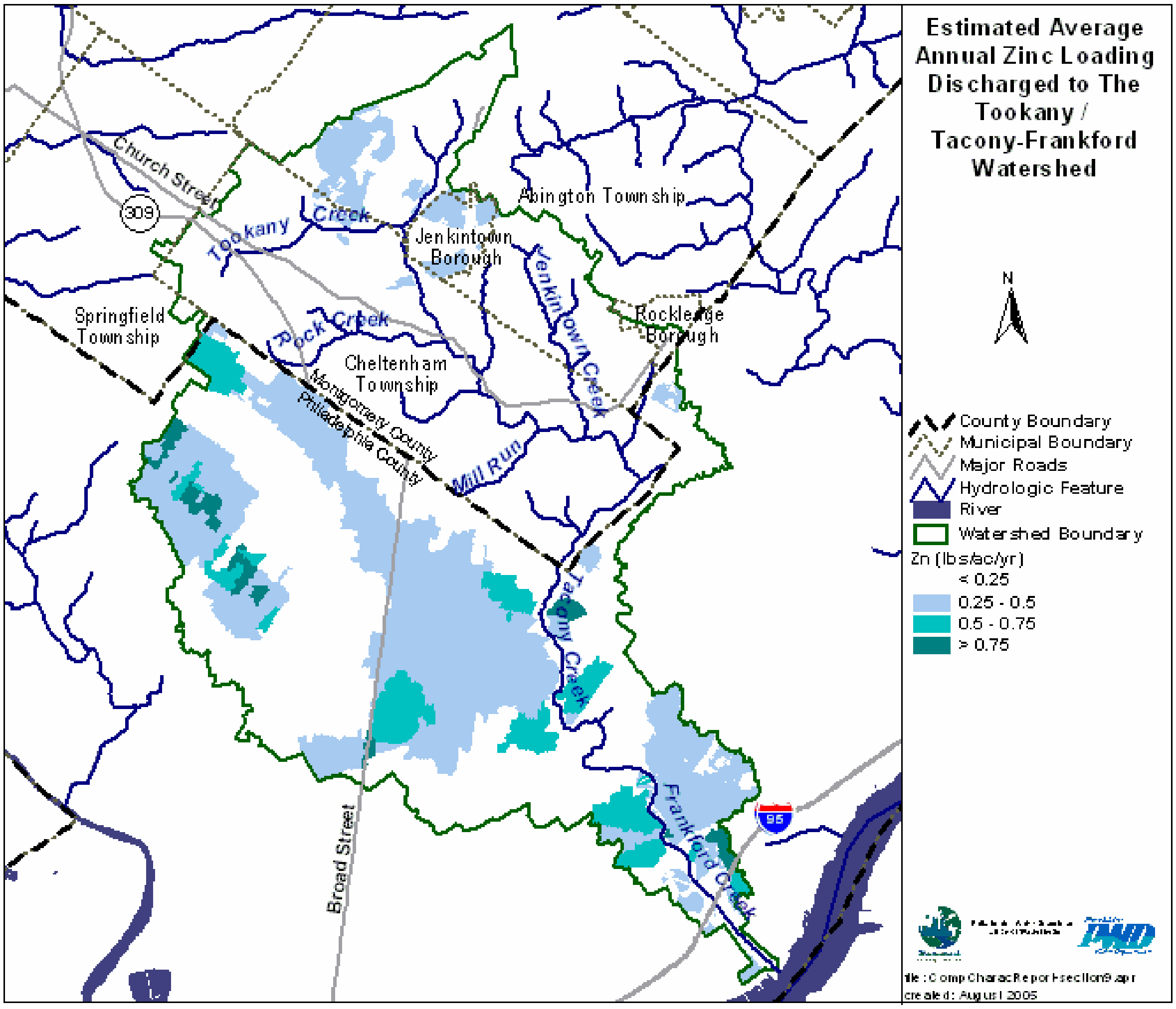


Figure 9-10 Estimated Annual Loading Rate for Zinc for Tookany/Tacony-Frankford Watershed

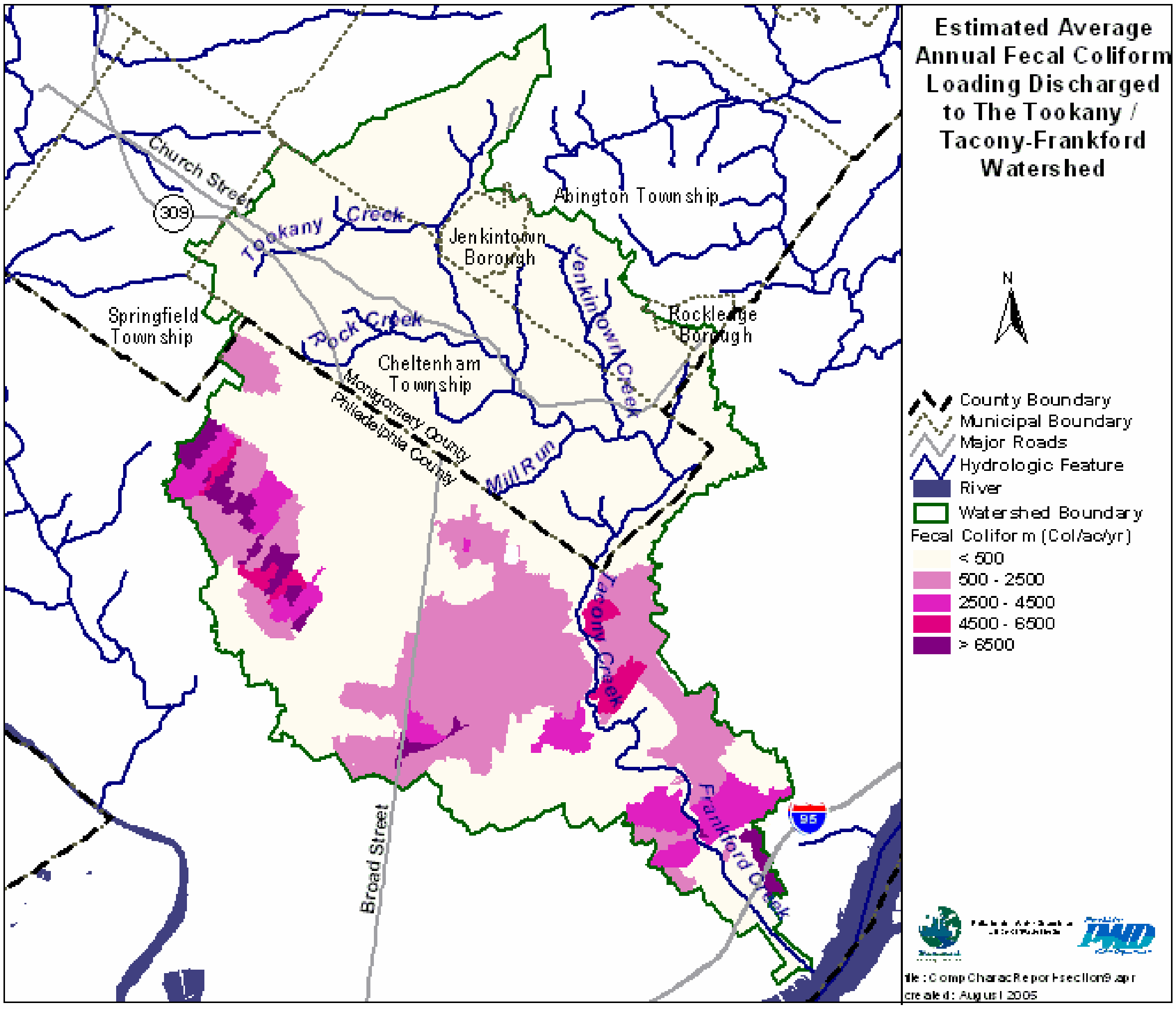


Figure 9-11 Annual Loading Rate for Fecal Coliform for Tookany/Tacony-Frankford Watershed

Table 9-3 Mean SWMM-Estimated Loads by Basins

Watershed	**Area (ac)**	**Surface Runoff (in/yr)**	**Surface Runoff (MG)**	**BOD (ton/yr)**	**TSS (ton/yr)**	**Fecal (col/yr)**	**TN (ton/yr)**	**TP (ton/yr)**	**Cu (ton/yr)**	**Pb (ton/yr)**	**Zn (ton/yr)**
Tookany Creek (outside City)	8,855	6.8	1630	33.0	187	6.5E+14	5.8	0.7	0.03	0.17	0.39
Tacony-Frankford Creek (in City)	12,200	10.4	3460	123	692	2.4E+15	21.1	2.8	0.12	0.62	1.44

9.2.1 Relative Contribution of Source Types

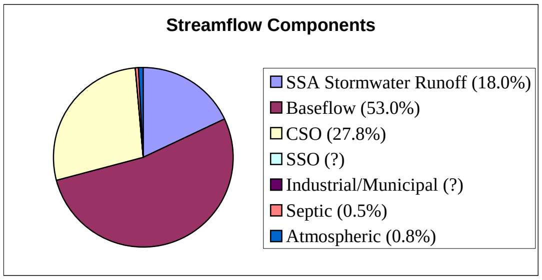
Figure 9-12 presents the approximate relative contribution each source (stormwater runoff from separate sanitary areas, baseflow, CSOs, industrial and municipal point sources, septic tanks, and atmospheric sources) contributes to the total potential load to the Delaware River from the Tookany/Tacony-Frankford Watershed area. As expected in highly urbanized settings, runoff from separate sanitary areas is a significant (over 10%) source of water pollution for most pollutant types except fecal coliform. Baseflow contributes a significant amount of total nitrogen. Separate sanitary overflows (SSOs) may be a significant source of pollutants, but information concerning these sources was insufficient to include in the current analysis. The results indicate that CSOs are a dominant source of the total load for all parameters. The model indicates that almost 90% of the fecal coliform introduced to the system is the result of CSOs; however, this portion may change when future work accounts for the contribution of SSOs. Industrial and municipal point sources are a relatively small source of pollutants. Septic tank loads are significant only for phosphorus and nitrogen. However, the reliability of the data available on septic tanks in the watershed is questionable. Atmospheric inputs, based on wetfall or concentrations within rainfall, are included in the EMCs for all land use types except for wetlands and open water. Atmospheric loads to wetlands and water were small (1% or less) but measurable.

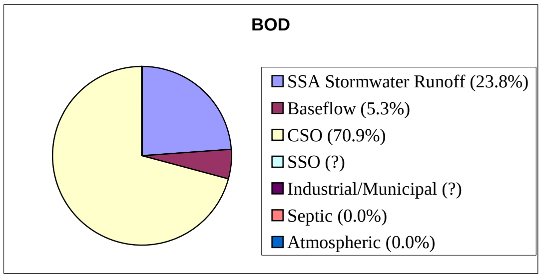
Table 9-4 presents the average areal loads contributed by runoff from separate and combined sewer areas. Areal loads show the intensity of loading rather than total loads. The areal loadings for most parameters are similar for the two sources, but the fecal coliform loads introduced by combined sewer areas are approximately 100 times greater per acre than those introduced by runoff from separate sewer areas. For comparison, the table includes loads for the other sources.

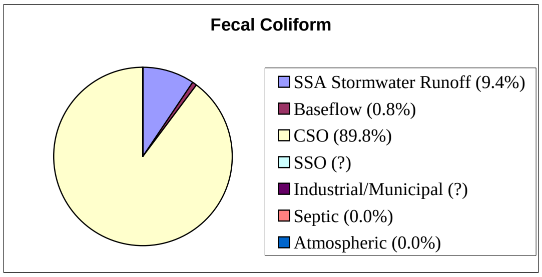
Table 9-4 Estimated Annual Area Loads by Source (lb/ac except as noted)

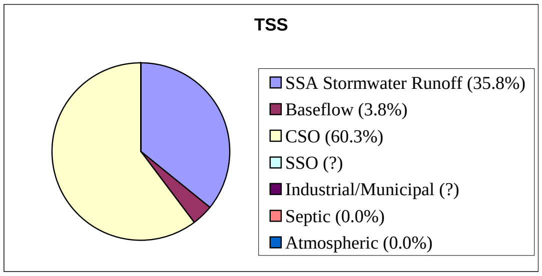
Parameter	SSA Stormwater Runoff (lb/ac)	Baseflow	CSO	Industrial/ Municipal	Septic	Atmospheric
BOD	22.4	2.5	73	0	0	0
TSS	127	6.8	235	0	0	0
Fecal Coliform (col/ac)	2.2E+11	9.8E+9	2.3E+12	0	0	0
Total Nitrogen	3.90	5.9	12.3	0	0.072	0.062
Total Phosphorus	0.50	0.34	1.74	0	0.027	0.002
Copper	0.02	0.015	0.06	0	0	8.5E-05
Lead	0.12	0.002	0.19	0	0	1.0E-04
Zinc	0.27	0.041	0.50	0	0	2.5E-03

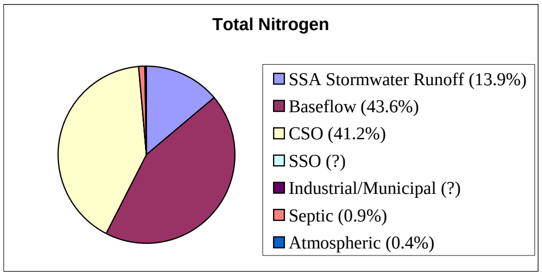
Figure 9-12 –Estimated Annual Relative Contribution of Constituent Sources

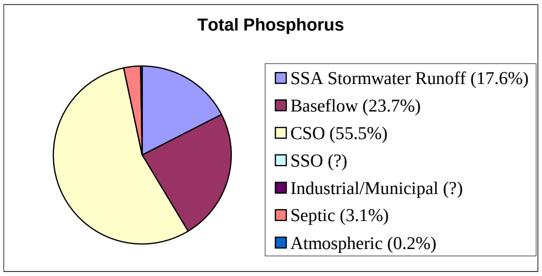


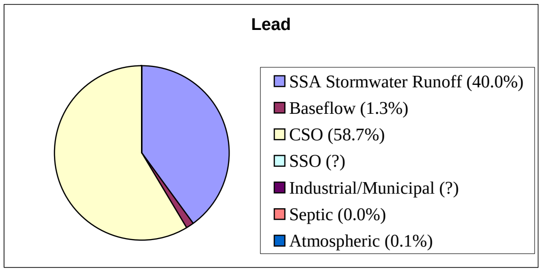


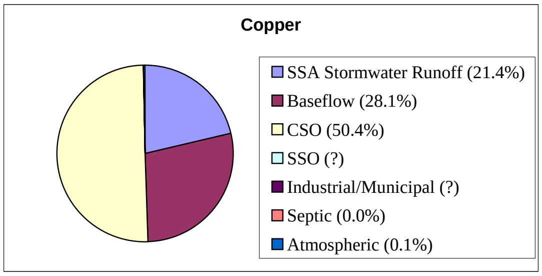


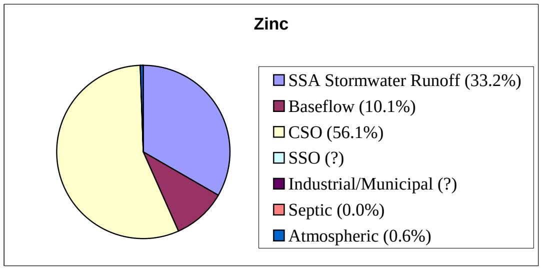












Notes:

- SSA = separate sanitary area runoff
- CSO = combined sewer overflow
- Sanitary sewer overflows (SSOs) were not explicitly included in this analysis.
- The model indicates that direct atmospheric loads to surface water were found to contribute less than 0.4% of the load for any parameter studied. This result is due mainly to the fact that very little area is classified as water or wetlands.

9.2.2 Sources of Uncertainty

Baseflow water quality information is based upon water quality sampling data obtained between 1999 and 2000. The data represents background conditions; if significant dry weather pollutant inputs are present, these will be reflected in the baseflow concentrations.

EMCs are based on literature values. The EMCs used for this study for urban land uses are from Smullen, Shallcross, and Cave (1999). These values represent a compilation of stormwater monitoring data from NURP, the USGS, and NPDES Phase I Municipal Stormwater Monitoring Requirements.

Sanitary sewer overflows (SSOs) are believed to be a significant potential source of bacterial and other pollution in the watershed. For the watershed study, estimates of SSO flows and pollutant loads were not calculated due to lack of readily available information on municipal sewer systems. Future studies may include a more thorough investigation of these sources.

Failures of septic tanks can contribute nutrient and bacterial loads to receiving waters. For this screening level study, the 1990 census data for on-lot septic systems was used to determine the number of septic systems in each drainage area. Although of limited accuracy, the census data indicated that over 1075 septic systems were located within the watershed. Since extensive research into on-lot systems and Act 537 plans for Montgomery Counties will be required, the 1990 census counts of septic systems were used for all portions of the Tookany/Tacony-Frankford Watershed study except Philadelphia.

9.3 Comparison of Load Estimates

Table 9-5 compares several loading rate estimates for Tookany/Tacony-Frankford Creek. These estimates are based on historical water quality monitoring, 2000-2004 water quality monitoring, and SWMM model estimates. The loads from the monitoring data were calculated by applying wet weather and dry weather pollutant concentrations to USGS historical flow data. The resultant loads were averaged over the period of record to determine the average daily load.

Table 9-5 compares the loads of some conventional water quality parameters calculated from the results of the first 50 months of sampling of the PWD/USGS Cooperative Program. Ammonia and nitrate loads were not calculated for the estimate. The loading rates estimated by SWMM are much larger than the instream mass load estimated from the current monitoring data. This difference is not a mistake but a result of the modeling philosophy:

- SWMM loads represent the total potential load to be delivered downstream and do not specifically account for the instream processes that reduce the total load.
- For the screening level study, the loads were used to estimate an overall delivery ratio for each pollutant, rather than estimate delivery ratios for various land uses by pollutant.

- The instream mass loads were based on limited, discrete, wet and dry weather monitoring data in addition to streamflow data from the 1970s.

- Loading is based on national EMCs which are measures of central tendency with significant variance. Local conditions may not be reflected by the national EMCs.

9.4 Delivery Ratios

The delivery ratio represents the fraction of the original pollutant load remaining after a particular pollutant travels downstream and is affected by instream processes. Data available in the literature indicate that the delivery ratio varies with drainage-area size. Some representative values calculated by the USDA for sediment are:

Drainage Area (sq. miles)	Delivery Ratio
0.5	0.33
10	0.18
100	0.10

However, the delivery ratios may vary substantially for any given size of drainage area. Other important factors affecting pollutant delivery include soil texture, relief (slope), types of erosion, sediment transport system, and deposition areas. For instance, a watershed with fine soil texture, high channel density, and high stream gradients would generally have a higher than average delivery ratio for watersheds of similar drainage area. Also, edge-of-field delivery ratios can approach 1.0 while delivery ratios for larger study areas can be less than 0.05. Instream processes also affect the delivery ratio. Such processes include deposition, sediment and water column diagenesis, remineralization, and volatilization. These processes are discussed in the next section.

The delivery ratios were calculated by dividing the runoff loads by the 2000-2004 sampling means, if available. Table 9-5 presents the calculated delivery ratios for two sites along Tookany/Tacony-Frankford Creek (TF620 and TF680). Although delivery ratios might be expected to decrease with distance downstream, the data do not display such behavior. The delivery ratio for most pollutants increases from the upstream to the downstream cross-sections; the delivery ratios for total suspended solids stay about the same. This trend may be largely explained by greater urbanization in the downstream reaches of Tacony-Frankford Creek; much of the loading occurs downstream where less time and distance are available for degradation processes to take place.

Table 9-5 Comparisons of Load Estimates for Tookany/Tacony-Frankford Creek

	Historic Data		2000-2004 Monitoring Data		2000-2004 vs. Historical		SWMM Estimate		Calculated Delivery Ratio	
	Upstr.	Downstr	Upstr.	Downstr	Upstr.	Downstr	Upstr.	Downstr	Upstr.	Downstr
Drainage Area (sq. mi)	16.60	33.80*	16.60	30.40*						
Discharge (cfs)	34.6	50.7	26.5	40.5	-23.4%	-20.1%				
BOD_5 (lb/day)	517	2790	405	2668	-21.7%	-4.37%	599	1470	0.68	1.8
TSS (lb/day)	2202	14,413	1455	5255	-33.9%	-63.5%	3403	8318	0.43	0.63
Total N (lb/day)							105	255		
NH_3 (lb/day)	57.9	325	21.9	109	-62.2%	-66.5%				
NO_2 (lb/day)	6.91	20.0	6.15	14.4	-11.0%	-28.0%				
NO_3 (lb/day)	513	552	258	290	-49.7%	-47.5%				
Total P (lb/day)	63.5	558	13.9	95.9	-78.1%	-82.8%	13.5	33.1	1.0	2.9
Fecal Coliform (col/day)	4.7E+12	1.8E+14	4.4E+12	6.7E+13	-6.38%	-62.8%	5.9E+12	1.5E+13	0.75	4.5
Cu (lb/day)	1.34	7.93	1.14	8.30	-14.9%	4.67%	0.60	1.47	1.9	5.6
Cd (lb/day)	1.12	2.02	0.14	0.44	-87.5%	-78.2%				
Cr (lb/day)	3.55	14.5	0.29	1.09	-91.8%	-92.5%				
Fe (lb/day)	63.5	186	50.5	458	-20.5%	146%				
Pb (lb/day)	2.43	25.7	0.43	5.68	-82.3%	-77.9%	3.07	7.55	0.14	0.75
Zn (lb/day)	22.4	46.5	3.29	17.9	-85.3%	-61.5%	7.12	17.4	0.46	1.0

Note: “Upstream” corresponds to station 8 for the historical and Radzuil data, station TF620 for the 2000-04 monitoring data and USGS station 01467086 (Tacony Creek at County Line). “Downstream” corresponds to station 9 for the Historical, station TF280 for the 2000-04 monitoring data, and USGS station 01467089 (Frankford Creek at Torresdale Ave).

* The difference in drainage area at the downstream end is because the recorded drainage area for the USGS station includes the Old Frankford Creek.

Appendix A: Temporal Changes in Water Quality

Tukey plots were used to characterize water quality parameters by comparing load changes as Tookany/Tacony-Frankford Creek passes through Montgomery County and the City. Using the wet/dry flow designations, box plots compared current water quality data with historical (PWD/USGS Cooperative Program 1970-1980) water quality data. Ammonia, total phosphate, and fecal coliform are shown in this section of the report. Figure A-1 shows the schematic of the modified Tukey plots.

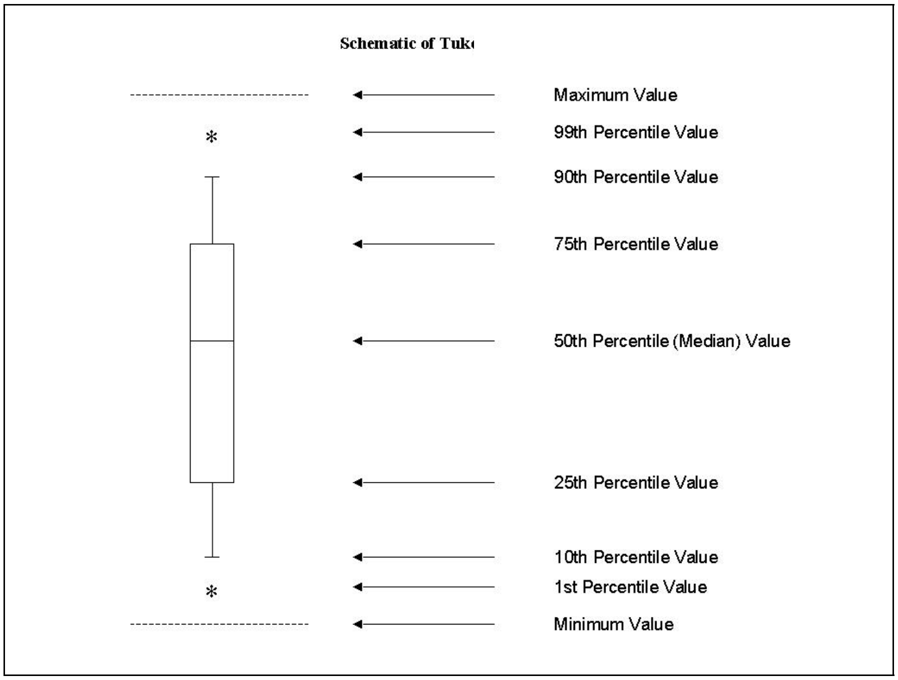


Figure A-1 Schematic Diagram of the Modified Tukey Box Plot

The ammonia, total phosphate, and fecal coliform plots, Figures A-2 through A-23, display an increased concentration from the upstream location at the County Line (TF620, or Site 8) to the downstream location at Castor Avenue (TF280, or Site 9). Malfunctioning regulators and higher loading rates during storm events are the most likely cause. However, other sources of fecal coliform bacteria not previously considered include urban runoff, broken or leaking sewers, failing septic systems, and unanticipated pump station discharges from non-gravity separate sewer systems. For these three constituents, the concentrations have decreased since the historical data collection.

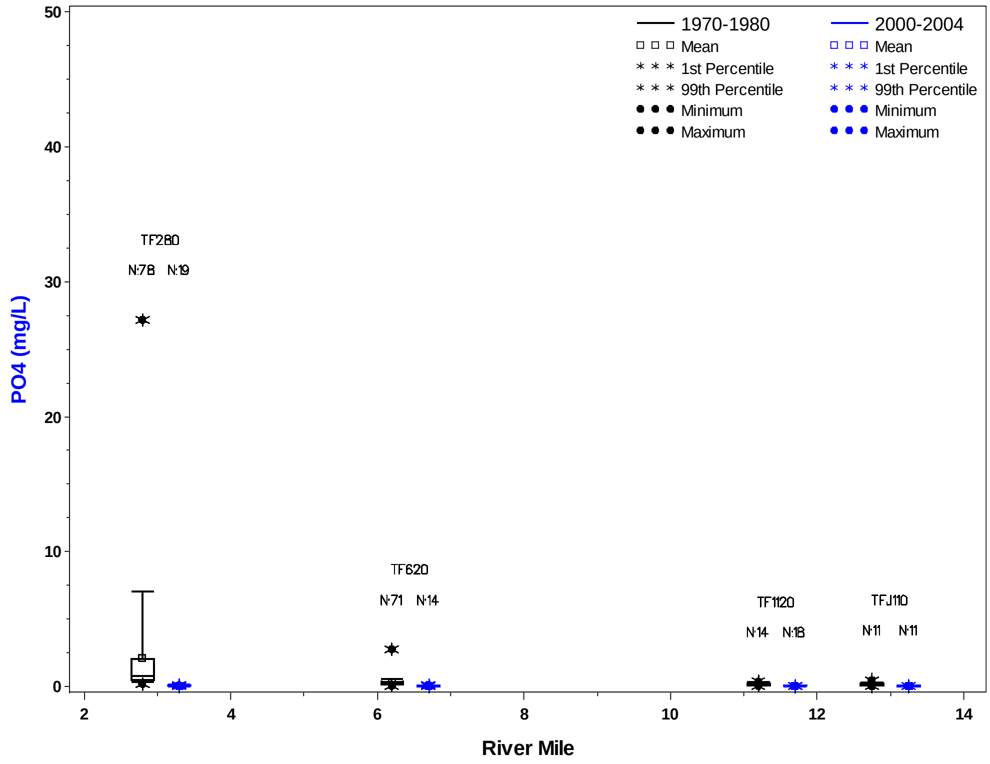


Figure A-2 Paired Modified Tukey Diagrams for Phosphate Dry Weather

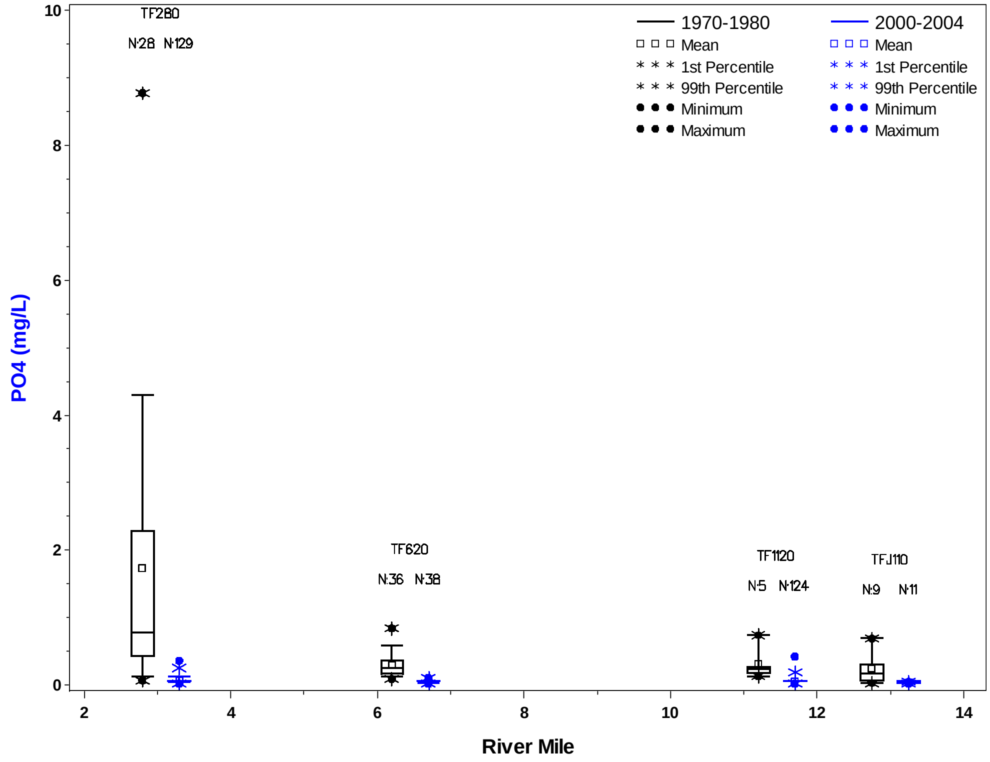


Figure A-3 Paired Modified Tukey Diagrams for Phosphate Wet Weather

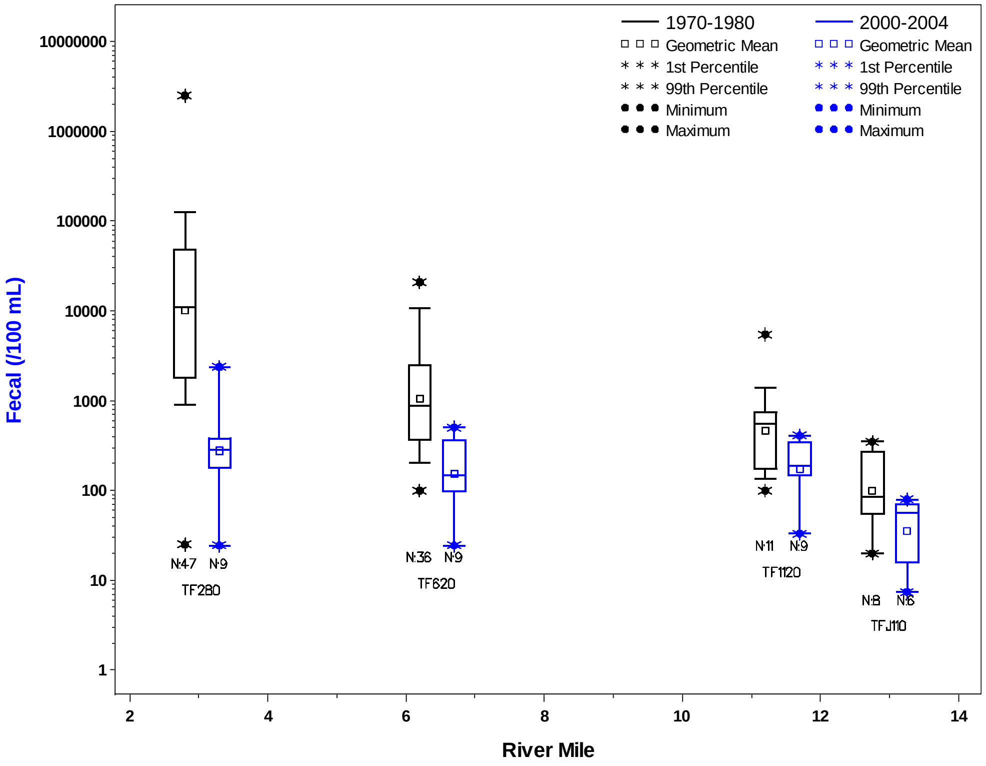


Figure A-4 Paired Modified Tukey Diagrams for Fecal Coliform Non-Swimming Dry Weather

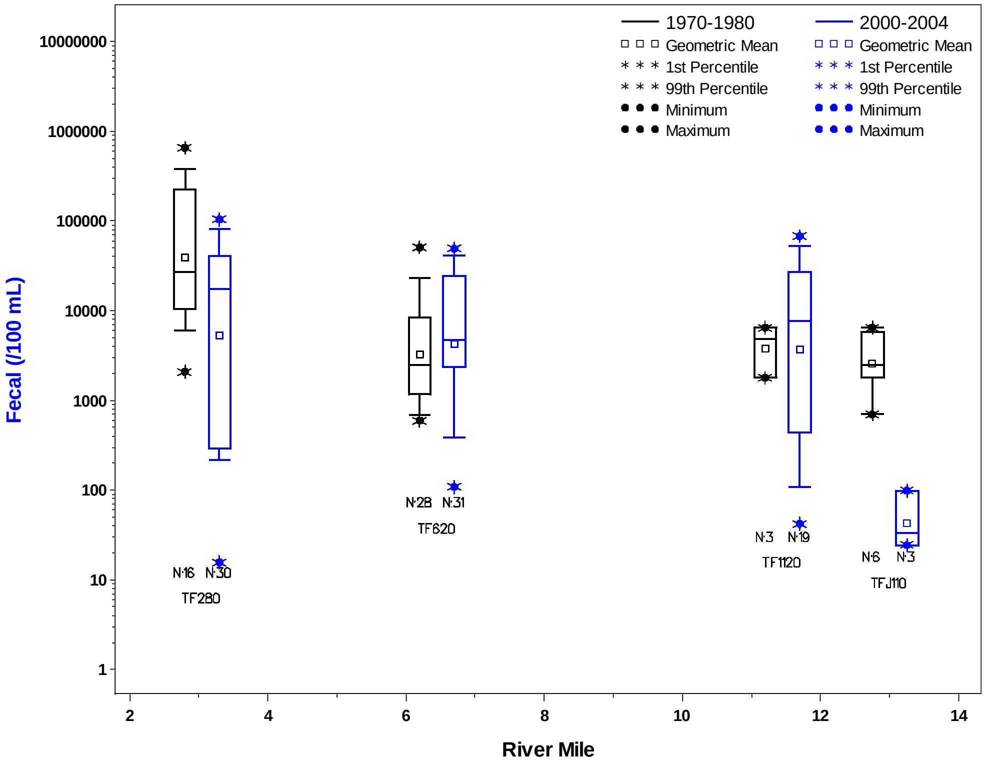


Figure A-5 Paired Modified Tukey Diagrams for Fecal Coliform Non-Swimming Wet Weather

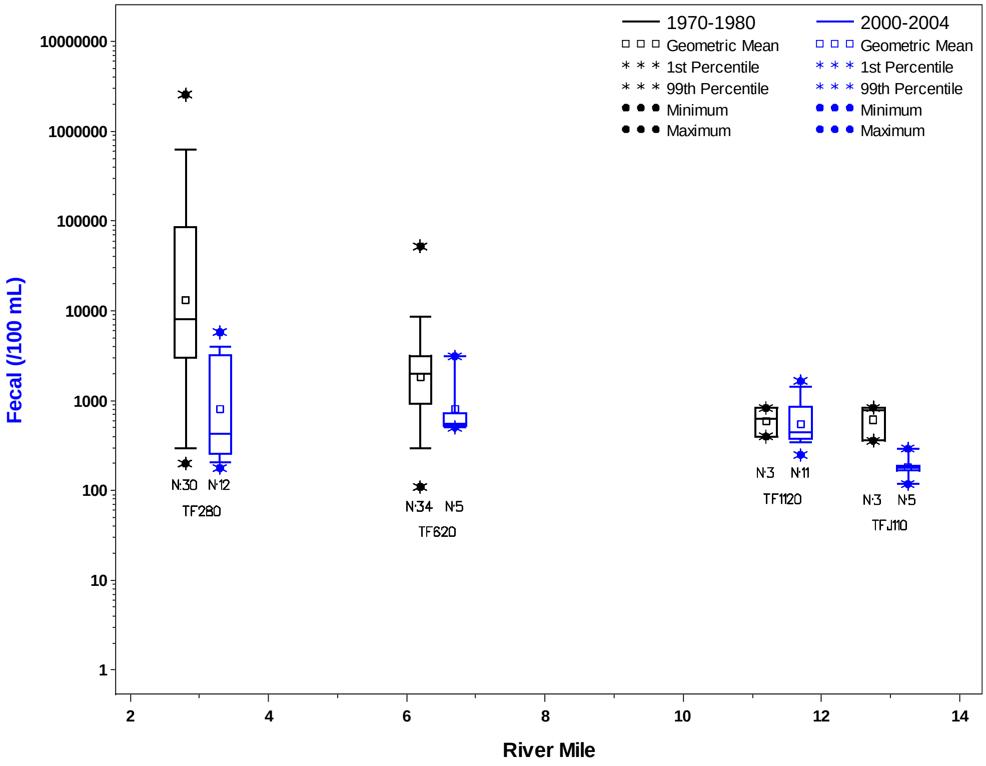


Figure A-6 Paired Modified Tukey Diagrams for Fecal Coliform Swimming Dry Weather

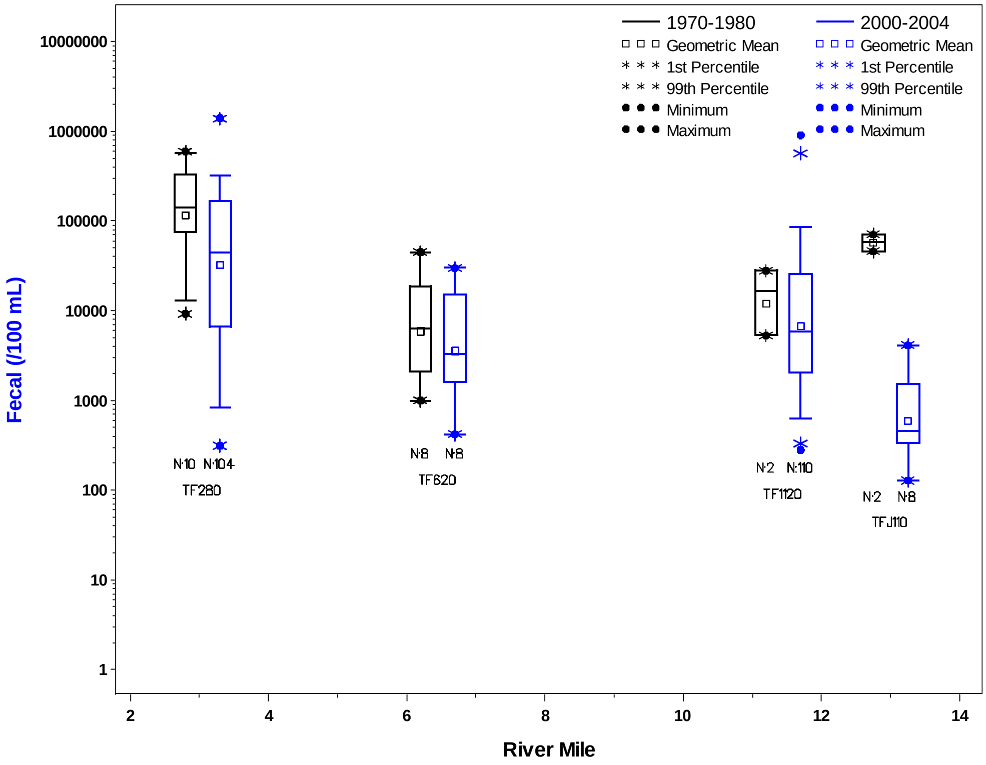


Figure A-7 Paired Modified Tukey Diagrams for Fecal Coliform Swimming Wet Weather

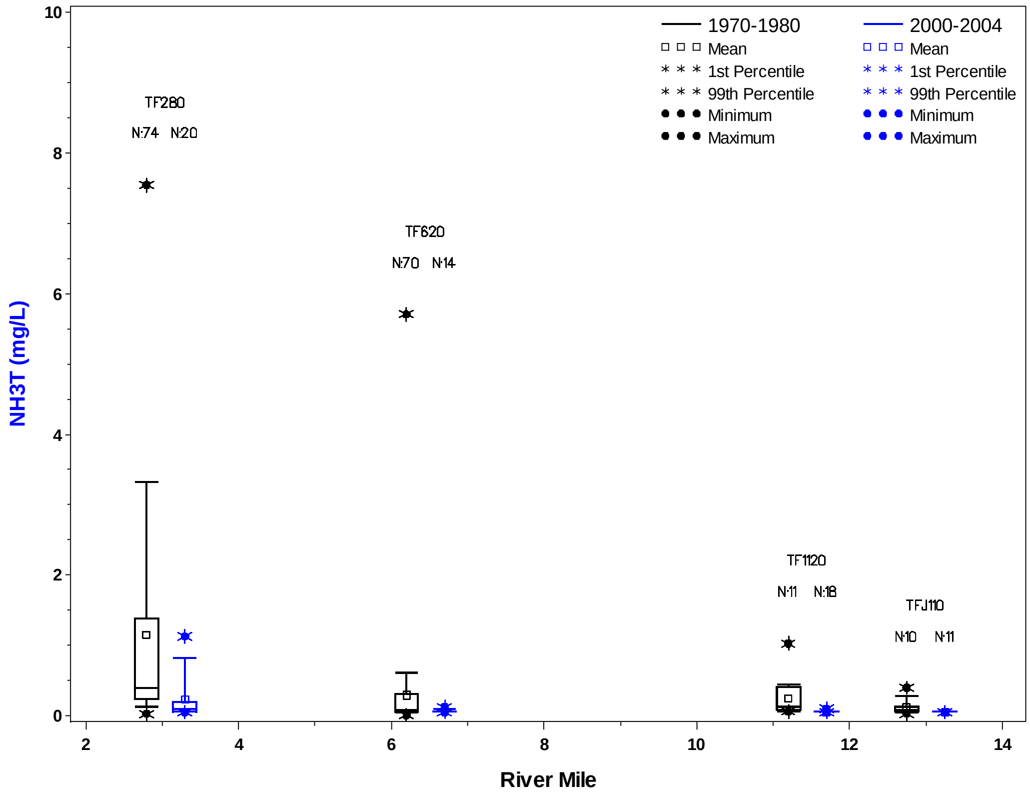


Figure A-8 Paired Modified Tukey Diagrams for Ammonia Dry Weather

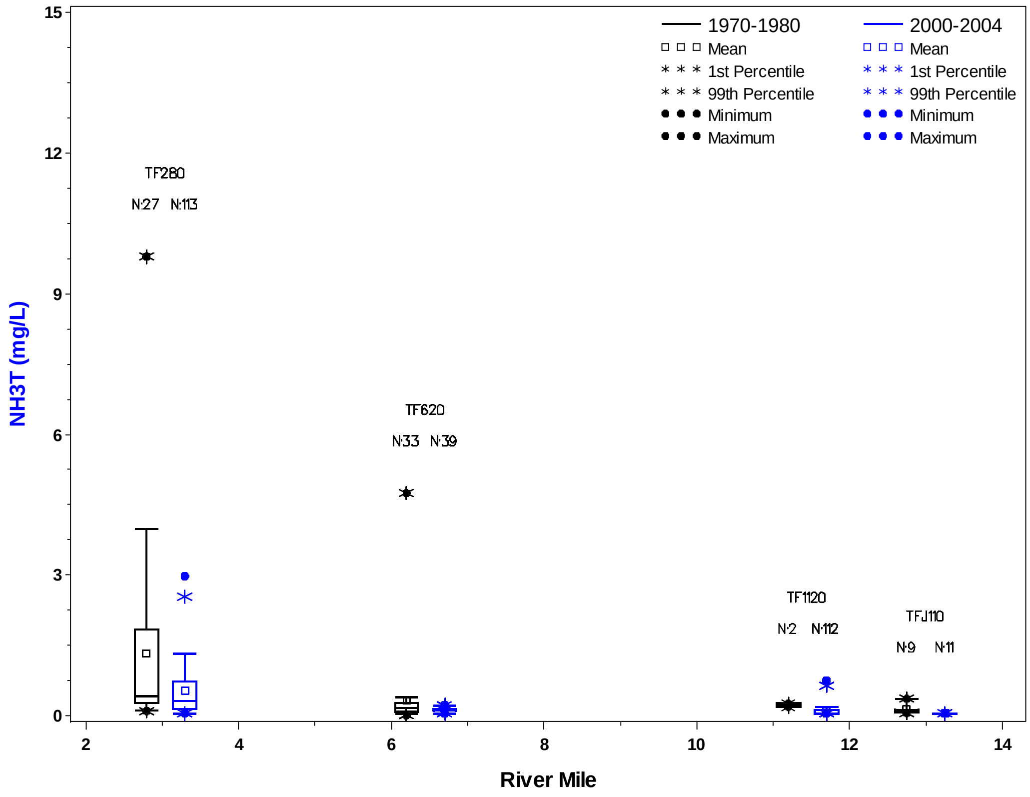


Figure A-9 Paired Modified Tukey Diagrams for Ammonia Wet Weather

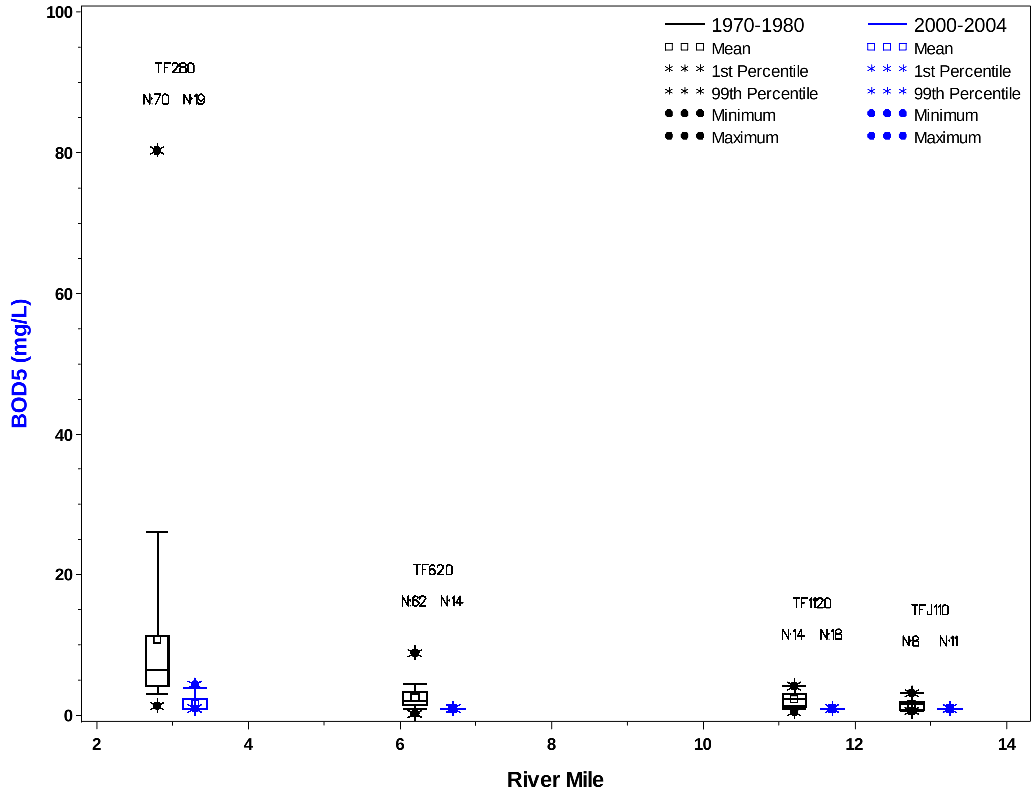


Figure A-10 Paired Modified Tukey Diagrams for BOD5 Dry Weather

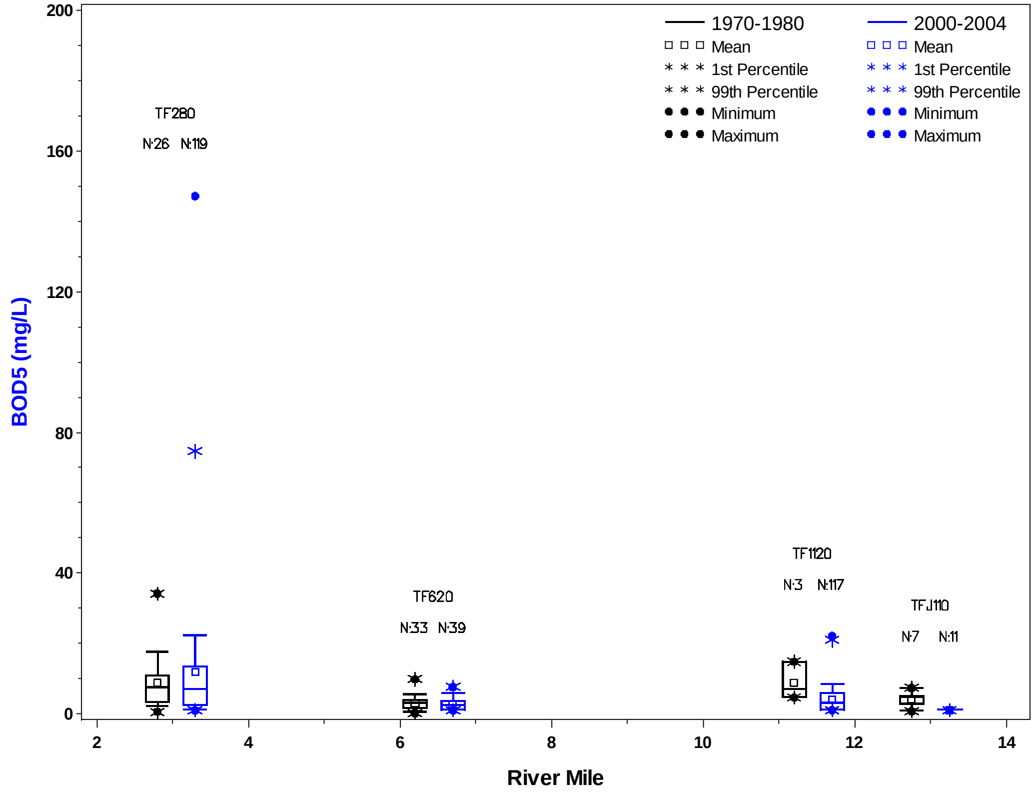


Figure A-11 Paired Modified Tukey Diagrams for BOD5 Wet Weather

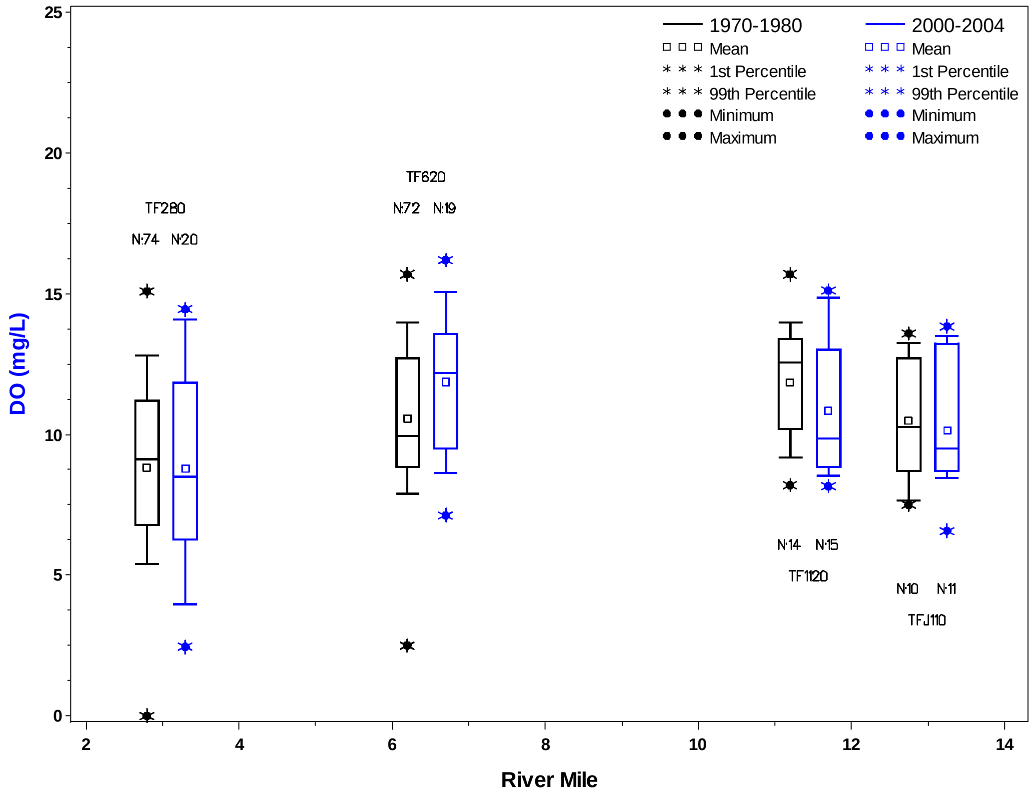


Figure A-12 Paired Modified Tukey Diagrams for Dissolved Oxygen Dry Weather

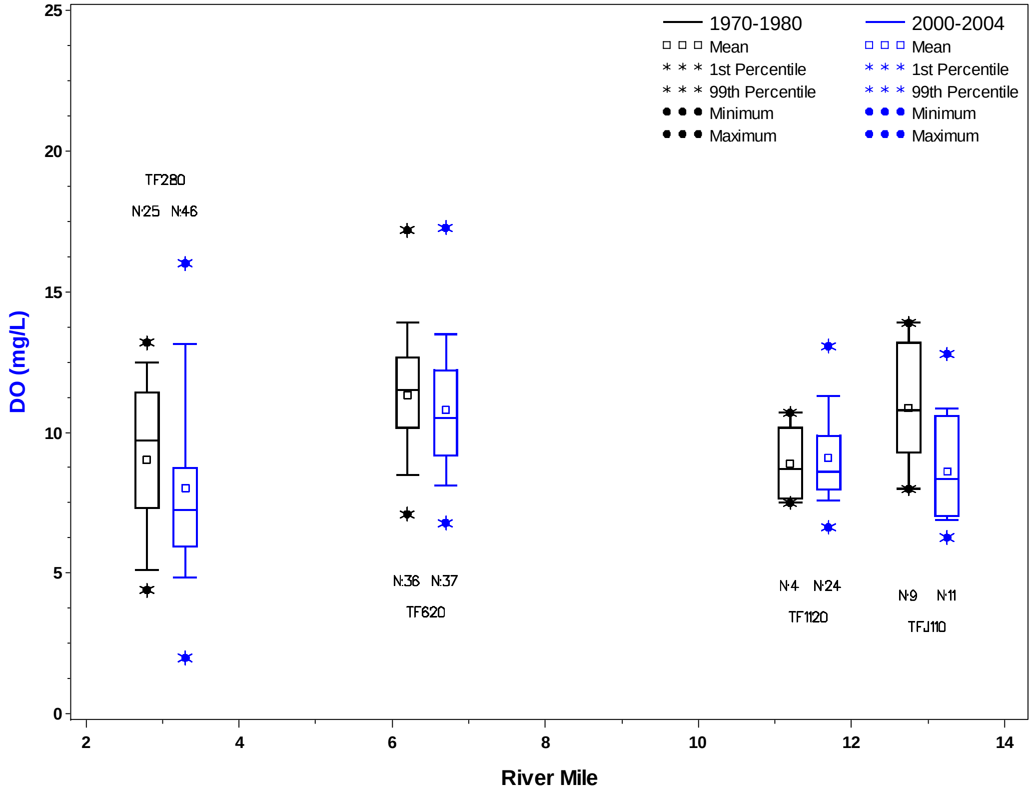


Figure A-13 Paired Modified Tukey Diagrams for dissolved oxygen Wet weather

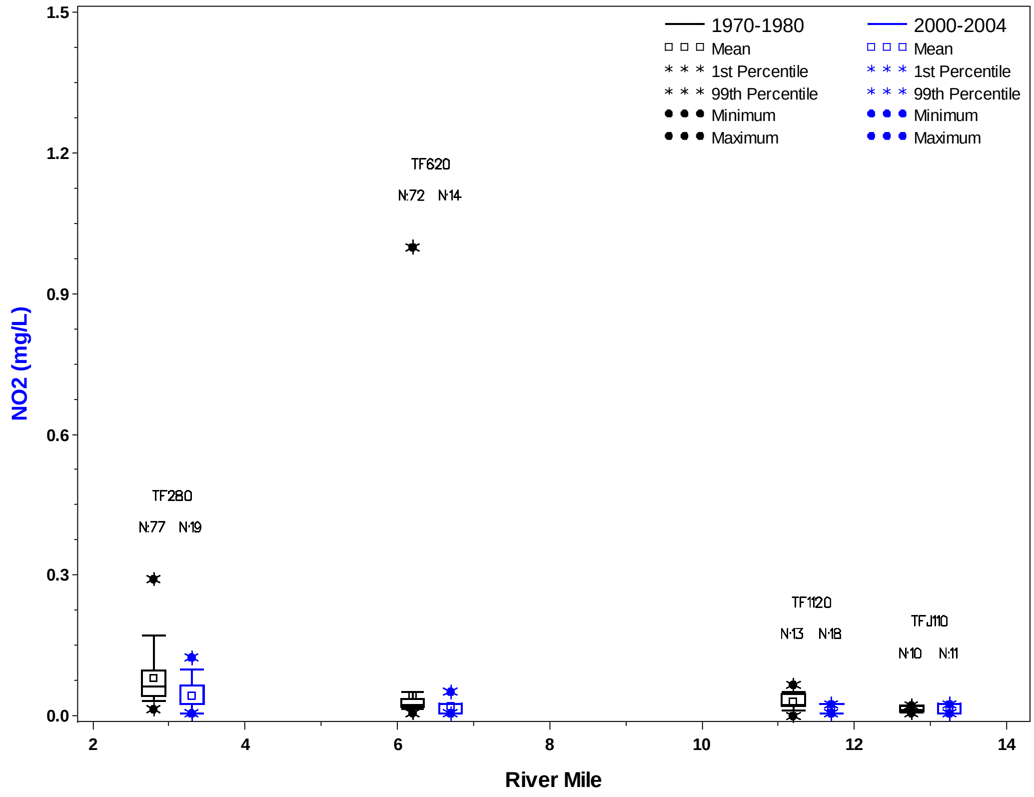


Figure A-14 Paired Modified Tukey Diagrams for Nitrite Dry Weather

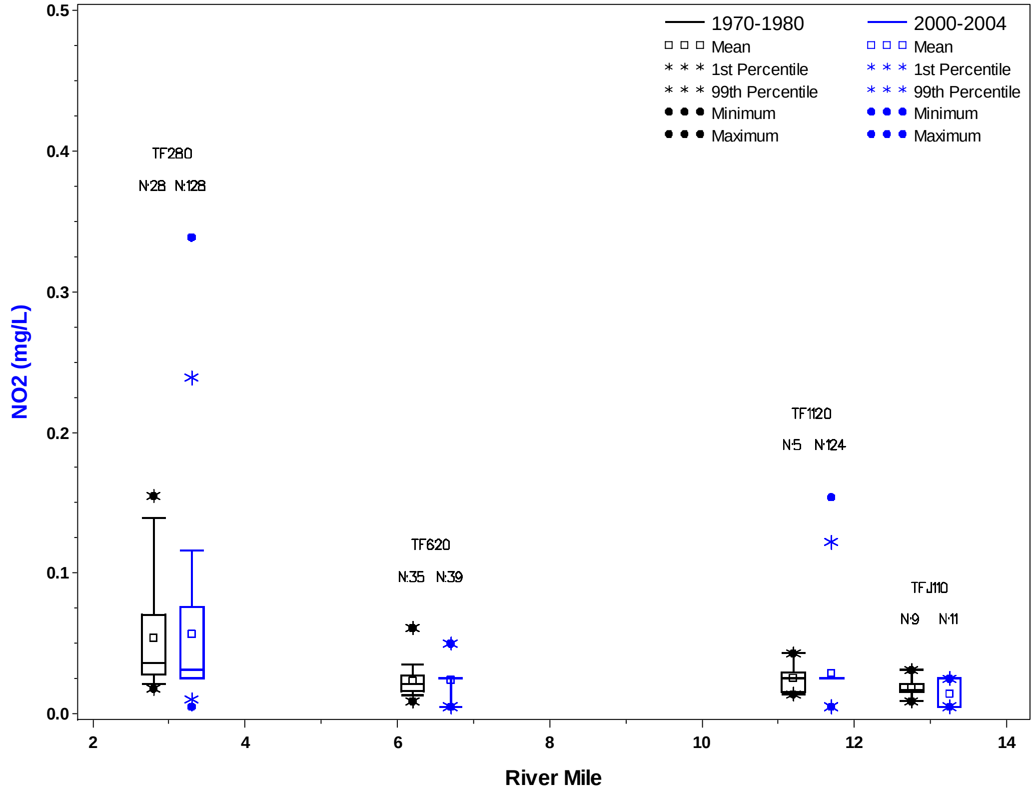


Figure A-15 Paired Modified Tukey Diagrams for Nitrite Wet Weather

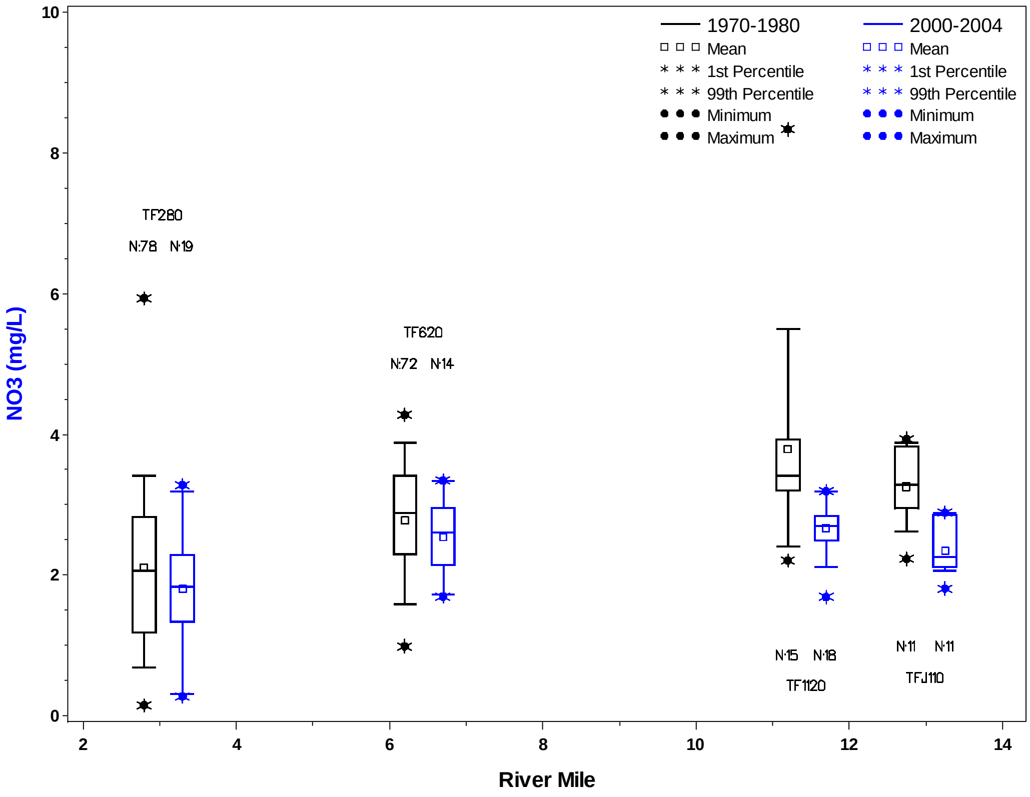


Figure A-16 Paired Modified Tukey Diagrams for Nitrate Dry Weather

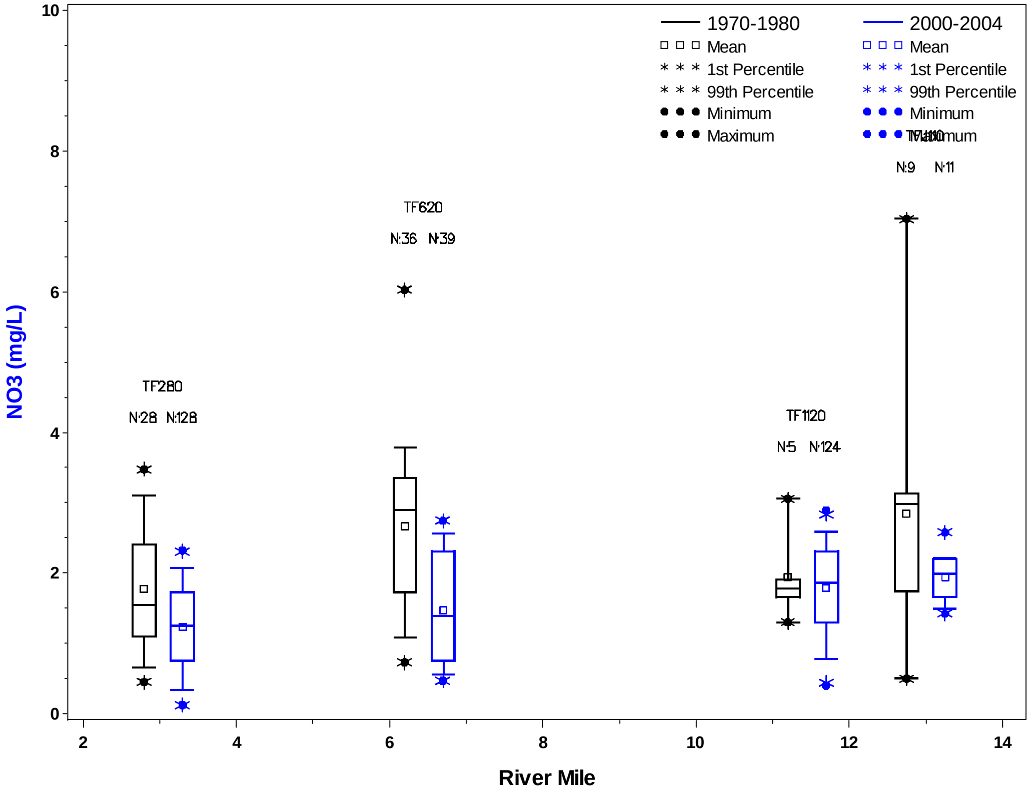


Figure A-17 Paired Modified Tukey Diagrams for Nitrate Wet Weather

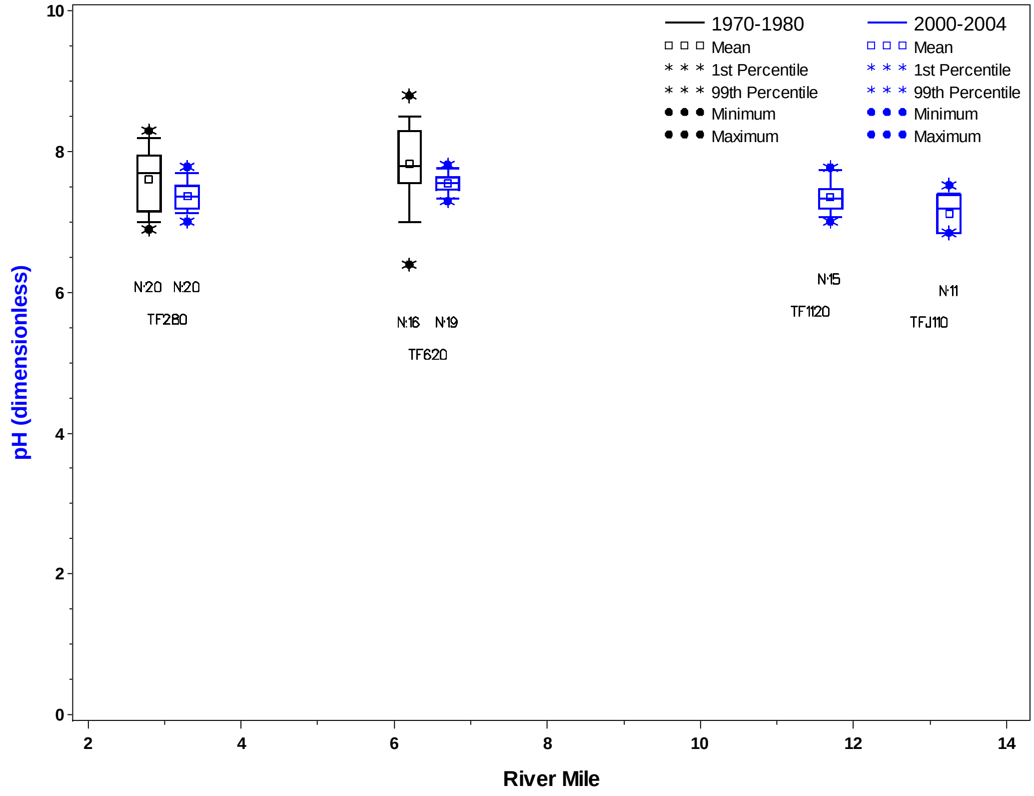


Figure A-18 Paired Modified Tukey Diagrams for pH Dry Weather

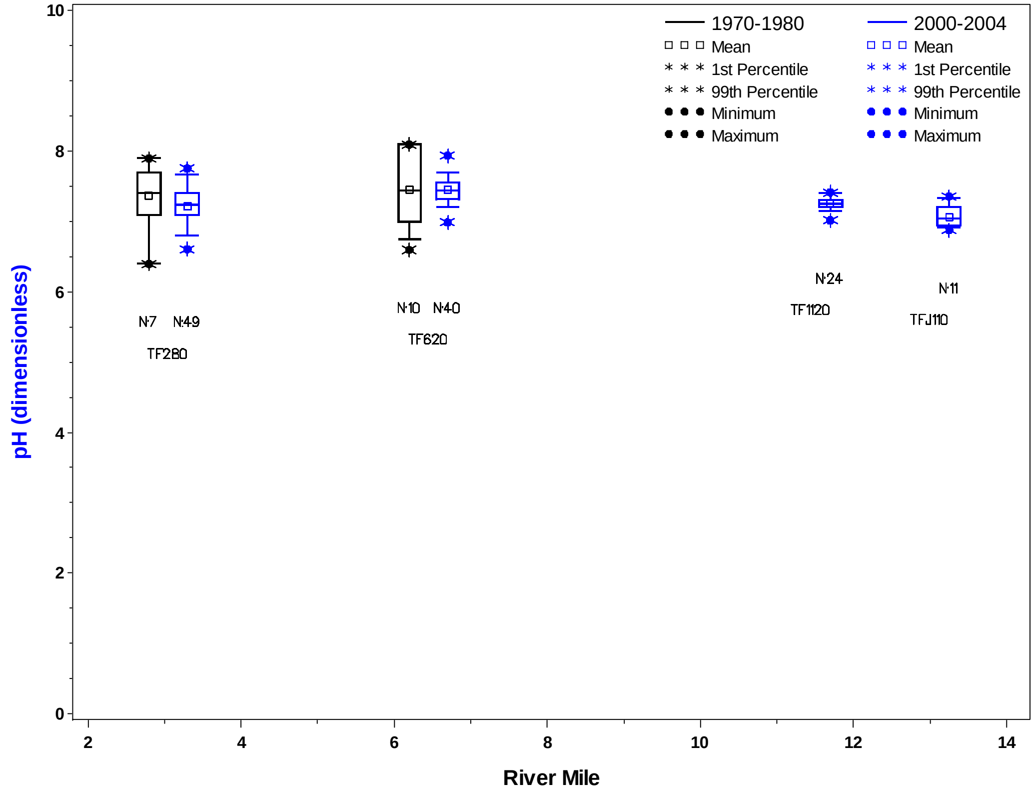


Figure A-19 Paired Modified Tukey Diagrams for pH Wet Weather

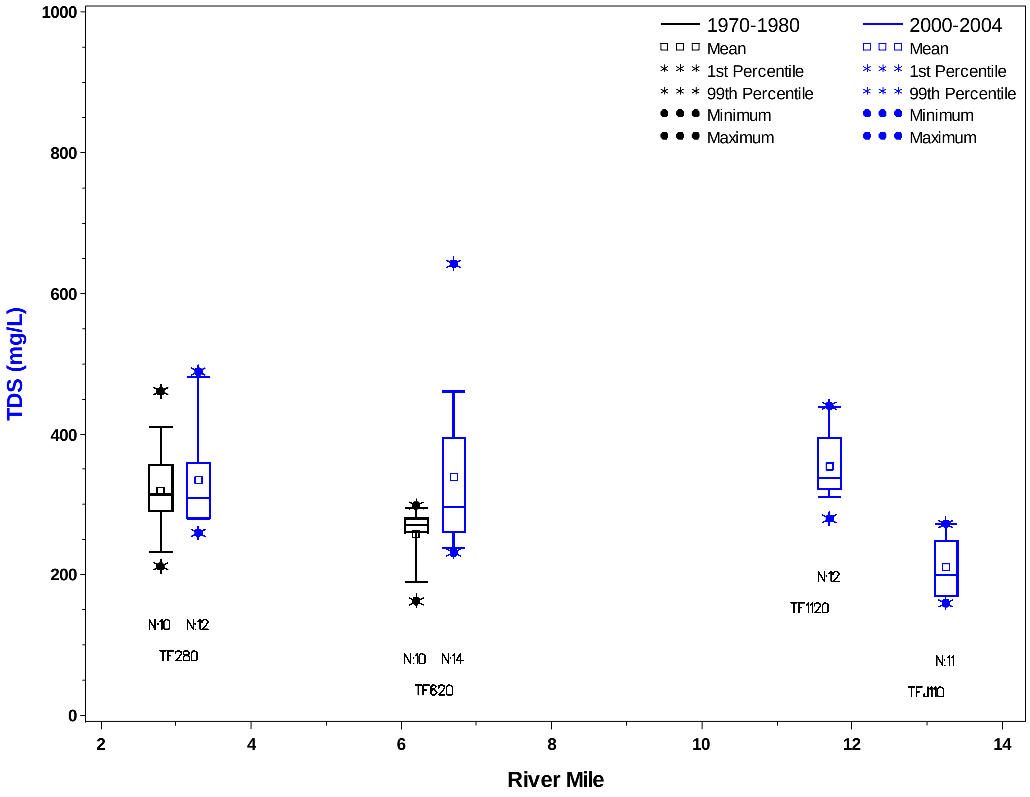


Figure A-20 Paired Modified Tukey Diagrams for Total Dissolved Solids Dry Weather

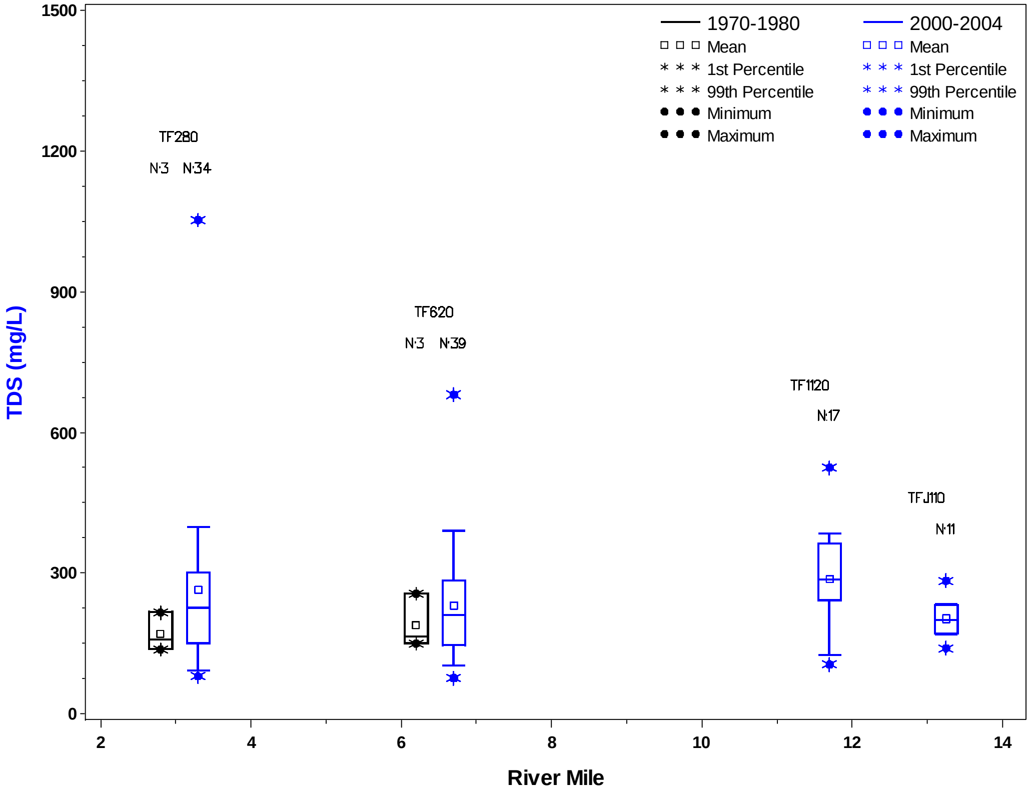


Figure A-21 Paired Modified Tukey Diagrams for Total Dissolved Solids Wet Weather

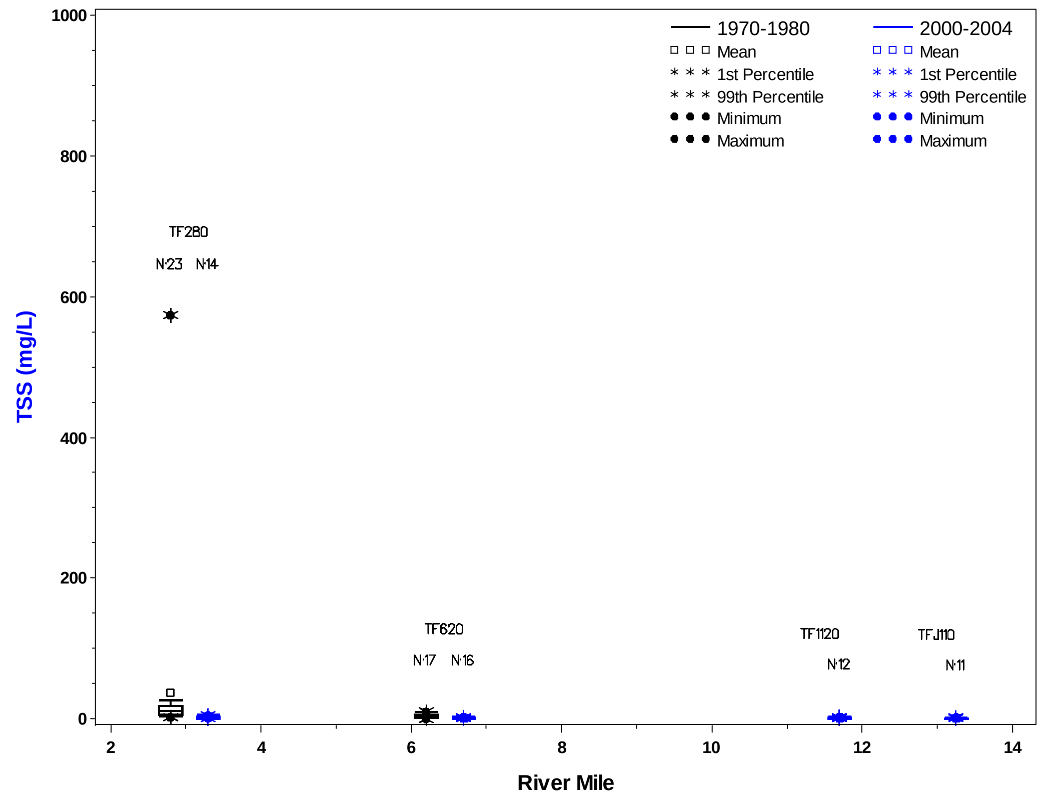


Figure A-22 Paired Modified Tukey Diagrams for Total Suspended Solids Dry Weather

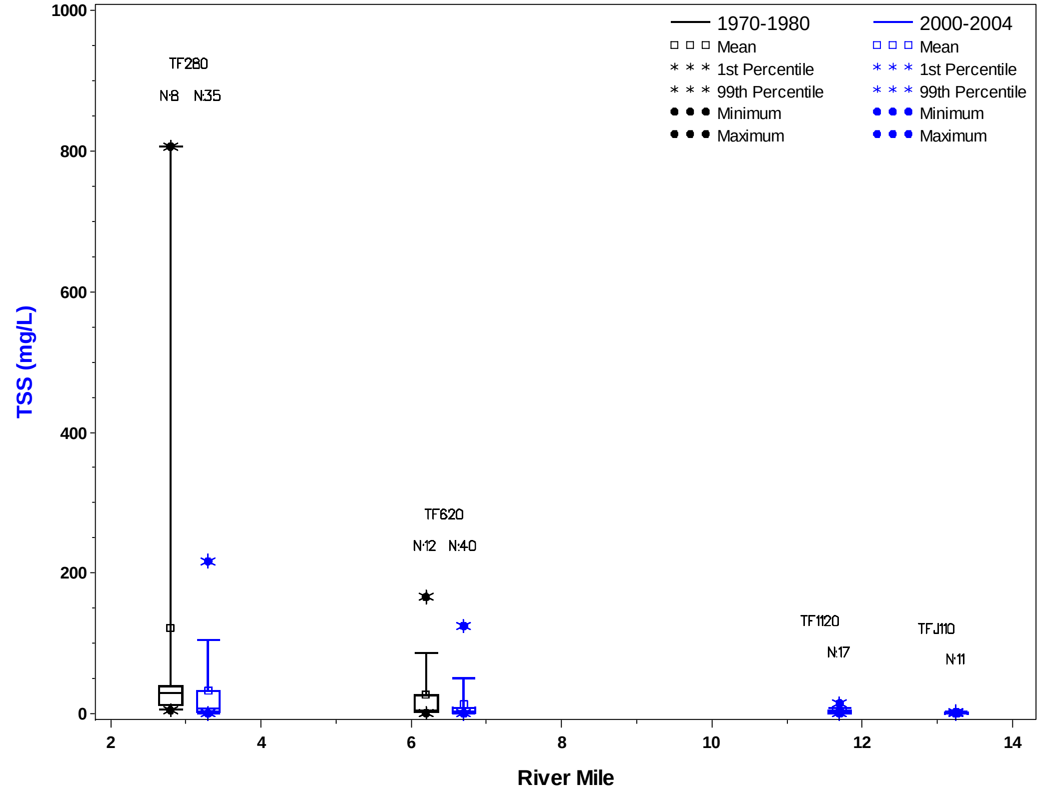


Figure A-23 Paired Modified Tukey Diagrams for Total Suspended Solids Wet Weather

Appendix B: Sonde Data Protocol for the Tookany/Tacony-Frankford Creek

DO Acceptance:
The large number of measurements made by the continuous sampling equipment serves to characterize DO throughout the diurnal cycle under a range of flow conditions. The equipment produces 96 observations of DO every 24 hours, but cost and quality control are more challenging compared to discrete sampling. A variety of procedures are followed before, during, and immediately after deployment to help insure quality and identify problems that may affect DO data quality. These procedures are outlined in detail in the main body of "YSI 6600 Sondes to Monitor Water Quality in Streams" and are summarized below.

- Pre-deployment and post-deployment laboratory validation checks are performed on all parameters. The probes are tested in solutions of known concentrations as established by standard laboratory testing procedures. Instruments are deployed and data is initially accepted if probe measurements are within a certain tolerance of the standards.

- Field personnel fill out standardized forms to note conditions and events that may have an effect on data quality. Examples include debris or sediment obstructing the probe, debris obstructing free flow of water around the instrument, or instrument failure such as a battery failure.

- Beginning in the fall of 2001, field measurements are taken of DO, pH, and specific conductance at deployment and retrieval. Measurements are taken as close to the probe locations as possible, and the data is added to the pre- and post-deployment validation checks when determining whether data is initially accepted.

- BLS personnel prepare time series plots and make preliminary determinations of whether data fall within reasonable ranges and patterns. BLS staff recommends acceptance of data at this point provided they pass the criteria discussed above.

These four items represent initial screens for poor quality data; they identify instances where probes do not accurately measure conditions in the immediate vicinity of the instrument. However, suspended sediment, debris, and biofouling can all affect the microenvironment in the immediate vicinity of the instrument, causing data to be collected that does not represent overall conditions in the water column. For this reason, additional procedures are needed to distinguish data that is sufficiently representative to be included in analyses from data that is not representative.

Table B-1 summarizes a system that assigns points to data based on the presence of characteristics that are indicative of reliable data. Data analysis suggests that conditions that lead to unreliable data are present primarily during and after wet weather and depend on the intensity of the runoff event. For this reason, the continuous data is biased toward dry weather conditions although they do represent some wet weather events.

Table B-1 Criteria Applied to Determine Sonde DO Data Reliability

CRITERIA (Accept data with 5 or more points.)	**CHARACTERISTICS OF Chapter 1 HIGHER RELIABILITY DATA**	⟷	**CHARACTERISTICS OF LOWER RELIABILITY DATA**
VALIDATION CHECKS	The data pass all field and laboratory validation checks within 1.0 mg/L. PROCEED TO NEXT STEP.	Does not apply.	The data do not pass one or more validation checks. REJECT THE DATA.
PROBE FAILURE	The data never drop to zero for two or more days. PROCEED TO NEXT STEP.	The data drop to zero for two days or more, but recover later in the deployment. PROCEED TO NEXT STEP.	The data drop abruptly to zero and remain there for the duration of the deployment. REJECT THE DATA.
SITE CONDITIONS	Field notes do not document any conditions that may cause instrument failure. (+2 POINTS)	Field notes indicate light to moderate obstruction by debris, sediment, and/or biofouling. (+1 POINT)	Field notes indicate moderate to extensive obstruction by debris, sediment, and/or biofouling. (+0 POINTS)
NOISE	The data pattern is smooth, without sudden and erratic changes. (+2 POINTS)	Data are slightly to moderately noisy, but the underlying pattern is readily apparent. (+1 POINT)	The data are extremely noisy. (+0 POINTS)
IF diurnal pattern is evident…	The diurnal pattern is relatively constant in dry weather and has an amplitude of less than 4 mg/L. (+2 POINTS)	The diurnal amplitude is less than 4 mg/L, but it changes over the course of the deployment by a factor of 2 or more. This may indicate algae accumulation. (+1 POINT)	The diurnal amplitude is greater than 4 mg/L. (+0 points)
IF redundant observations are available…	Both sets of data are similar and display characteristics of high quality data. (+2 POINTS for one data set; discard the other).	Only one data set displays multiple characteristics of low quality data. (+1 POINTS for the higher quality data set; discard the other).	Both data sets display multiple characteristics of low quality data. (+0 POINTS)

Explanation of acceptance/rejection:
The primary objective in this part of the update is to identify which data is usable and which is not. The most important comment that can be made is that we are not trying to reject data that doesn't seem to fit the "usual" pattern (diurnal). Instead we are trying to reject data that seems to have been caused by mechanical failure. Therefore it is important to realize exactly what is usable and what is useless. The first place to look for this is in the original excel file that supplied the data. Check the charts that are in the file and look for any red comments about mechanical failure. If this is the case, then the data should be rejected in those regions. The Excel file "TF_Acceptance_Criteria.xls" has a series of worksheets which help decide if the data should be rejected or not. Looking at the plot, decide on an appropriate number of sections that are needed. For example, if there seems to be a section of questionable data between 2 sections of good data, you would need 3 sections. Make a copy of one of the templates depending on the sections required and rename the sheet for the respective deployment. Complete the sheet to help gauge if the data should be rejected or not.

How to select which regions to reject:

- Open the TaconyFrankford Database :"**TaconyFrankford.mdb**".
- Open the sheet called **"RejectedDates"**.
- For each region you wish to reject, enter the deployment, start dtime to reject and end dtime to stop rejecting.
- For single point rejections, enter the same dtime for start and stop.
- For multiple rejection ranges for the same deployment, use the same deployment number and add a new record with more rejection times.
- Update the "**TF_Acceptance_Criteria**" worksheet. Add a new worksheet for each new deployment using the template sheets in the front. For 2 rejection regions use Template2, for 3 use Temp3 etc.
- Fill in the proper point values as was described above.

DO Flagging:

Program 5 – "update do flag optimized.vb" - Module inside database

- This program takes the rejected date ranges and flags the TF_Sonde table accordingly.
- Run the module, if there are any errors, read the comments in the program. You may comment out the **fillw1** query.
- Export the table **"TF_Sonde"** with the export query. Output is **"TF_Export_Sonde.csv".**
- Rerun the program **DOPlots.sas.** Output will be several graphics files.

Check the graphs for consistency

Appendix C: Rejected Continuous DO Monitoring Data Intervals

Site	Start Date/Time	End Date/Time
TF280	3/21/2001 14:30	3/26/2001 15:30
TF760	5/3/2001 11:00	5/17/2001 14:00
TF1120	5/21/2001 16:00	6/4/2001 16:00
TF760	5/22/2001 11:30	6/5/2001 11:30
TF1120	8/20/2001 1:00	8/29/2001 10:45
TF280	8/19/2001 20:15	8/29/2001 10:15
TF500	8/19/2001 20:15	8/29/2001 9:45
TF620	8/20/2001 1:45	8/29/2001 10:30
TF760	8/20/2001 1:45	8/29/2001 9:30
TF1120	6/26/2001 14:45	7/3/2001 10:45
TFM000	7/13/2001 12:00	7/18/2001 14:00
TFM000	11/22/2002 1:30	12/1/2002 13:30
TF280	9/25/2002 10:00	10/9/2002 9:00
TF500	10/26/2002 0:45	10/30/2002 12:15
TF500	11/21/2002 22:31	11/26/2002 15:31
TF500	9/14/2002 20:15	9/25/2002 14:00
TF620	10/11/2002 9:31	10/17/2002 11:46
TF620	11/5/2002 18:30	11/8/2002 7:45
TF620	11/11/2002 0:15	11/19/2002 8:00
TF760	10/26/2002 2:16	10/29/2002 14:31
TF760	9/27/2002 7:31	10/1/2002 15:01
TF975	11/10/2002 16:16	11/19/2002 8:01
TF975	9/14/2002 16:31	9/25/2002 15:16
TF1120	10/11/2002 21:01	10/17/2002 11:46
TF1120	3/4/2003 10:30	3/4/2003 11:45
TF280	3/6/2003 12:15	3/7/2003 11:45
TF280	3/20/2003 20:15	3/21/2003 11:00
TF280	4/9/2003 0:01	4/15/2003 11:46
TF280	4/11/2003 0:15	4/15/2003 11:30
TF280	4/26/2003 0:15	4/29/2003 12:30
TF280	4/29/2003 12:45	5/3/2003 17:45
TF280	5/6/2003 18:15	5/9/2003 11:45
TF280	5/13/2003 0:15	5/13/2003 11:45
TF280	5/6/2003 0:15	5/9/2003 13:45
TF280	5/13/2003 0:15	5/13/2003 11:45
TF280	5/16/2003 15:15	5/18/2003 5:45
TF280	5/20/2003 0:15	5/20/2003 11:15
TF280	5/30/2003 14:30	6/12/2003 14:00
TF280	5/30/2003 14:00	6/2/2003 11:45
TF280	6/7/2003 12:15	6/7/2003 21:45
TF620	6/17/2003 16:15	6/18/2003 11:45
TF620	6/20/2003 0:15	6/20/2003 13:45
TF620	6/17/2003 19:00	6/18/2003 11:45
TF620	6/20/2003 0:15	6/20/2003 13:45
TF620	7/8/2003 15:31	7/8/2003 15:31

TF620	7/9/2003 13:16	7/11/2003 15:31
Site	**Start Date/Time**	**End Date/Time**
TF620	7/12/2003 17:01	7/14/2003 13:16
TF975	7/9/2003 15:45	7/11/2003 13:30
TF975	7/12/2003 17:15	7/14/2003 13:15
TF975	4/11/2003 0:15	4/15/2003 9:30
TF975	4/27/2003 0:15	4/29/2003 10:15
TF975	5/2/2003 18:15	5/3/2003 12:45
TF975	4/11/2003 0:15	4/15/2003 10:00
TF1120	4/26/2003 0:15	4/29/2003 11:15
TF1120	5/5/2003 12:01	5/13/2003 10:46
TF1120	4/9/2003 0:01	4/10/2003 11:46
TF1120	4/11/2003 9:01	4/15/2003 10:31
TF1120	5/2/2003 12:01	5/3/2003 11:46
TF280	9/27/2003 14:15	9/30/2003 11:00
TF280	10/14/2003 20:15	10/15/2003 16:30
TF280	10/14/2003 18:15	10/15/2003 16:45
TF280	11/5/2003 18:15	11/10/2003 12:45
TF620	11/12/2003 3:15	11/13/2003 14:45
TF620	11/13/2003 12:15	11/13/2003 15:15
TF620	11/13/2003 12:01	11/13/2003 15:46
TF975	11/13/2003 12:15	11/13/2003 16:00
TF975	3/31/2004 0:46	4/4/2004 7:16
TF1120	4/12/2004 18:46	4/15/2004 5:46
TF1120	4/26/2004 0:46	4/27/2004 8:46
TF280	5/3/2004 1:31	5/4/2004 9:00
TF620	5/9/2004 22:31	5/10/2004 13:16
TF975	5/15/2004 23:16	5/18/2004 11:01
TF1120	5/18/2004 11:16	6/1/2004 13:31
TF280	6/5/2004 8:16	6/7/2004 9:46
TF620	6/15/2004 18:01	6/17/2004 9:31
TF975	6/22/2004 18:46	6/29/2004 9:31
TF1120	6/15/2004 18:01	6/17/2004 9:31
TF280	6/22/2004 18:46	6/29/2004 9:16
TF620	5/15/2004 20:01	5/18/2004 11:31
TF975	6/28/2004 0:16	6/29/2004 9:46
TF1120	3/31/2004 12:16	4/2/2004 11:01
TF280	5/10/2004 0:00	5/10/2004 14:00
TF280	5/15/2004 23:00	5/18/2004 12:00
TF280	5/31/2004 17:31	6/1/2004 14:16
TF280	6/14/2004 14:46	6/29/2004 10:16
TF280	4/13/2004 0:16	4/15/2004 7:01
TF280	6/1/2004 11:46	6/14/2004 16:01
TF280	6/14/2004 16:01	6/29/2004 10:45
TF280	5/12/2004 19:31	5/12/2004 19:31
TF280	6/14/2004 15:31	6/29/2004 11:01
TF620	3/20/2003 9:00	3/21/2003 11:00
TF620	6/29/2004 9:30	7/15/2004 13:15

TF620	6/29/2004 9:31	7/15/2004 13:16
Site	**Start Date/Time**	**End Date/Time**
TF620	7/12/2004 8:16	7/15/2004 14:01
TF620	7/10/2004 5:31	7/10/2004 5:31
TF620	7/18/2004 11:31	7/18/2004 14:46
TF620	7/28/2004 21:31	7/30/2004 9:46
TF620	7/27/2004 16:16	7/28/2004 1:16
TF975	7/23/2004 13:31	7/27/2004 21:46
TF975	8/1/2004 7:46	8/5/2004 9:31
TF975	7/29/2004 0:00	8/13/2004 0:00
TF975	8/16/2004 8:16	8/17/2004 14:16
TF975	8/21/2004 14:46	8/24/2004 14:30
TF975	8/31/2004 5:00	9/1/2004 10:31
TF975	7/29/2004 0:00	8/13/2004 0:00
TF1120	8/11/2004 19:31	8/12/2004 9:31
TF1120	9/8/2004 10:01	9/15/2004 10:01
TF1120	9/17/2004 22:16	9/20/2004 10:31
TF1120	9/8/2004 9:31	9/15/2004 10:46
TF1120	9/18/2004 3:01	9/20/2004 11:01
TF1120		
TF1120		
TFJ110		
TFJ110		
TFJ110		
TFJ110		
TFJ110		
TFJ110		
TFJ110		
TFM000		
TFM000		
TFM000		
TFM000		
TFM000		
TFM000		
TFM000		
TFM000		
TF280		
TF280		
TF500		
TF620		
TF280		
TF500		
TF620		
TF280		
TF280		
TF280		
TF500		
TF500		

TF500		
TF620		
TF620		
Site	**Start Date/Time**	**End Date/Time**
TF620		
TF280		
TF500		
TF620		
TF280		
TF500		
TF620		

Appendix D: Statistical Outliers and samples affected by contamination

Sample_ID	Parameter	Value	Date	Site	Units	Reason
HWQ7126126-3	Total Suspended Solids	574	7/12/1971	TF280	mg/L	Outlier
DW000706-0050	Aluminum	<.001	7/6/2000	TF620	mg/L	Outlier
DW000706-0050	Calcium	0.06675	7/6/2000	TF620	mg/L	Outlier
DW000706-0050	Cadmium	<.001	7/6/2000	TF620	mg/L	Outlier
DW000706-0050	Chromium	0.00115	7/6/2000	TF620	mg/L	Outlier
DW000706-0050	Copper	<.001	7/6/2000	TF620	mg/L	Outlier
DW000706-0050	Iron	0.0224	7/6/2000	TF620	mg/L	Outlier
DW000706-0050	Magnesium	0.01679	7/6/2000	TF620	mg/L	Outlier
DW000706-0050	Manganese	<.001	7/6/2000	TF620	mg/L	Outlier
DW000706-0050	Lead	<.001	7/6/2000	TF620	mg/L	Outlier
DW000706-0050	Total Phosphorus	0.01847	7/6/2000	TF620	mg/L	Outlier
DW000706-0050	Zinc	0.01034	7/6/2000	TF620	mg/L	Outlier
DW000706-0051	Cadmium Dissolved	<.001	7/6/2000	TFJ110	mg/L	Outlier
DW000706-0051	Dissolved Iron	0.02335	7/6/2000	TFJ110	mg/L	Outlier
DW000706-0052	Ammonia	<.1	7/6/2000	TF280	mg/L as N	Outlier
DW000706-0052	TKN	<.4	7/6/2000	TF280	mg/L	Outlier
DW040712-0056	Aluminum	<.05	7/12/2004	TF280	mg/L	Outlier
DW040712-0056	Calcium	0.121	7/12/2004	TF280	mg/L	Outlier
DW040712-0056	Cadmium	<.001	7/12/2004	TF280	mg/L	Outlier
DW040712-0056	Chromium	<.001	7/12/2004	TF280	mg/L	Outlier
DW040712-0056	Copper	0.004	7/12/2004	TF280	mg/L	Outlier
DW040712-0056	Cadmium Dissolved	<.001	7/12/2004	TF280	mg/L	Outlier
DW040712-0056	Chromium Dissolved	<.001	7/12/2004	TF280	mg/L	Outlier
DW040712-0056	Copper Dissolved	0.002	7/12/2004	TF280	mg/L	Outlier
DW040712-0056	Iron Dissolved	<.05	7/12/2004	TF280	mg/L	Outlier
DW040712-0056	Lead Dissolved	<.001	7/12/2004	TF280	mg/L	Outlier
DW040712-0056	Zinc Dissolved	0.016	7/12/2004	TF280	mg/L	Outlier
DW040712-0056	Iron	<.05	7/12/2004	TF280	mg/L	Outlier
DW040712-0056	Hardness	<.71	7/12/2004	TF280	mg/L	Outlier
DW040712-0056	Magnesium	<.1	7/12/2004	TF280	mg/L	Outlier
DW040712-0056	Manganese	<.01	7/12/2004	TF280	mg/L	Outlier
DW040712-0056	Lead	<.001	7/12/2004	TF280	mg/L	Outlier
DW040712-0056	Sodium	0.102	7/12/2004	TF280	mg/L	Outlier
DW040712-0056	Total Phosphorus	<.05	7/12/2004	TF280	mg/L	Outlier
DW040712-0056	Zinc	0.037	7/12/2004	TF280	mg/L	Outlier
DW040707-0068	Copper Dissolved	0.003	7/7/2004	TFJ010	mg/L	Outlier

Sample_ID	Parameter	Value	Date	Site	Units	Reason
DW040819-0057	Copper Dissolved	0.006	8/19/2004	TF500	mg/L	Outlier
DW040429-0060	Zinc	0.013	4/29/2004	TF280	mg/L	Contamination Suspected
DW040429-0060	Zinc Dissolved	0.041	4/29/2004	TF280	mg/L	Contamination Suspected
DW040429-0061	Zinc	0.011	4/29/2004	TF500	mg/L	Contamination Suspected
DW040429-0061	Zinc Dissolved	0.231	4/29/2004	TF500	mg/L	Contamination Suspected
DW040429-0062	Zinc	0.012	4/29/2004	TF620	mg/L	Contamination Suspected
DW040429-0062	Zinc Dissolved	0.044	4/29/2004	TF620	mg/L	Contamination Suspected
DW040429-0063	Zinc	0.015	4/29/2004	TF760	mg/L	Contamination Suspected
DW040429-0063	Zinc Dissolved	0.234	4/29/2004	TF760	mg/L	Contamination Suspected
DW040429-0065	Zinc	0.032	4/29/2004	TFM006	mg/L	Contamination Suspected
DW040429-0065	Zinc Dissolved	0.057	4/29/2004	TFM006	mg/L	Contamination Suspected
DW040429-0066	Zinc	0.015	4/29/2004	TF975	mg/L	Contamination Suspected
DW040429-0066	Zinc Dissolved	0.093	4/29/2004	TF975	mg/L	Contamination Suspected
DW040429-0067	Zinc	0.023	4/29/2004	TF1120	mg/L	Contamination Suspected
DW040429-0067	Zinc Dissolved	0.075	4/29/2004	TF1120	mg/L	Contamination Suspected
DW040429-0068	Zinc	0.008	4/29/2004	TFJ110	mg/L	Contamination Suspected
DW040429-0068	Zinc Dissolved	0.013	4/29/2004	TFJ110	mg/L	Contamination Suspected
DW040506-0062	Zinc	0.016	5/6/2004	TF280	mg/L	Contamination Suspected
DW040506-0062	Zinc Dissolved	0.058	5/6/2004	TF280	mg/L	Contamination Suspected
DW040506-0063	Zinc	0.021	5/6/2004	TF500	mg/L	Contamination Suspected
DW040506-0063	Zinc Dissolved	0.053	5/6/2004	TF500	mg/L	Contamination Suspected
DW040506-0064	Zinc	0.017	5/6/2004	TF620	mg/L	Contamination Suspected
DW040506-0064	Zinc Dissolved	0.046	5/6/2004	TF620	mg/L	Contamination Suspected
DW040506-0065	Zinc	0.014	5/6/2004	TF760	mg/L	Contamination Suspected

Sample_ID	Parameter	Value	Date	Site	Units	Reason
DW040506-0065	Zinc Dissolved	0.015	5/6/2004	TF760	mg/L	Contamination Suspected
DW040506-0066	Zinc	0.033	5/6/2004	TFM006	mg/L	Contamination Suspected
DW040506-0066	Zinc Dissolved	0.026	5/6/2004	TFM006	mg/L	Contamination Suspected
DW040506-0067	Zinc	0.015	5/6/2004	TF975	mg/L	Contamination Suspected
DW040506-0067	Zinc Dissolved	0.016	5/6/2004	TF975	mg/L	Contamination Suspected
DW040506-0068	Zinc	0.013	5/6/2004	TF1120	mg/L	Contamination Suspected
DW040506-0068	Zinc Dissolved	0.017	5/6/2004	TF1120	mg/L	Contamination Suspected
DW040506-0069	Zinc	0.008	5/6/2004	TFJ110	mg/L	Contamination Suspected
DW040506-0069	Zinc Dissolved	0.009	5/6/2004	TFJ110	mg/L	Contamination Suspected
DW040513-0070	Zinc	0.01	5/13/2004	TF280	mg/L	Contamination Suspected
DW040513-0070	Zinc Dissolved	0.041	5/13/2004	TF280	mg/L	Contamination Suspected
DW040513-0071	Zinc	0.012	5/13/2004	TF500	mg/L	Contamination Suspected
DW040513-0071	Zinc Dissolved	0.042	5/13/2004	TF500	mg/L	Contamination Suspected
DW040513-0072	Zinc	0.012	5/13/2004	TF620	mg/L	Contamination Suspected
DW040513-0072	Zinc Dissolved	0.04	5/13/2004	TF620	mg/L	Contamination Suspected
DW040513-0073	Zinc	0.012	5/13/2004	TF760	mg/L	Contamination Suspected
DW040513-0073	Zinc Dissolved	0.177	5/13/2004	TF760	mg/L	Contamination Suspected
DW040513-0074	Zinc	0.012	5/13/2004	TF975	mg/L	Contamination Suspected
DW040513-0074	Zinc Dissolved	< 0.005	5/13/2004	TF975	mg/L	Contamination Suspected
DW040513-0075	Zinc	0.012	5/13/2004	TF1120	mg/L	Contamination Suspected
DW040513-0075	Zinc Dissolved	0.236	5/13/2004	TF1120	mg/L	Contamination Suspected
DW040513-0076	Zinc	0.015	5/13/2004	TFM006	mg/L	Contamination Suspected
DW040513-0076	Zinc Dissolved	0.046	5/13/2004	TFM006	mg/L	Contamination Suspected
DW040513-0077	Zinc	0.006	5/13/2004	TFJ110	mg/L	Contamination Suspected

Sample_ID	Parameter	Value	Date	Site	Units	Reason
DW040513-0077	Zinc Dissolved	0.223	5/13/2004	TFJ110	mg/L	Contamination Suspected
DW040920-0049	Zinc	0.036	9/18/2004	TF280	mg/L	Contamination Suspected
DW040920-0049	Zinc Dissolved	0.244	9/18/2004	TF280	mg/L	Contamination Suspected
DW040920-0050	Zinc	0.029	9/18/2004	TF280	mg/L	Contamination Suspected
DW040920-0050	Zinc Dissolved	0.176	9/18/2004	TF280	mg/L	Contamination Suspected
DW040920-0051	Zinc	0.034	9/18/2004	TF280	mg/L	Contamination Suspected
DW040920-0051	Zinc Dissolved	0.244	9/18/2004	TF280	mg/L	Contamination Suspected
DW040920-0052	Zinc	0.032	9/18/2004	TF280	mg/L	Contamination Suspected
DW040920-0052	Zinc Dissolved	0.238	9/18/2004	TF280	mg/L	Contamination Suspected
DW040920-0053	Zinc	0.035	9/18/2004	TF280	mg/L	Contamination Suspected
DW040920-0053	Zinc Dissolved	0.249	9/18/2004	TF280	mg/L	Contamination Suspected
DW040920-0054	Zinc	0.042	9/18/2004	TF280	mg/L	Contamination Suspected
DW040920-0054	Zinc Dissolved	0.237	9/18/2004	TF280	mg/L	Contamination Suspected
DW040920-0055	Zinc	0.041	9/18/2004	TF280	mg/L	Contamination Suspected
DW040920-0055	Zinc Dissolved	0.229	9/18/2004	TF280	mg/L	Contamination Suspected
DW040920-0056	Zinc	0.181	9/18/2004	TF280	mg/L	Contamination Suspected
DW040920-0056	Zinc Dissolved	0.184	9/18/2004	TF280	mg/L	Contamination Suspected

Appendix E: The diurnal oxygen-curve method for estimating primary productivity and community metabolism in the Tookany-Tacony-Frankford Creek

The diurnal oxygen-curve method for estimating primary productivity and community metabolism in streams (USGS 1987) was applied for single station analysis to TTF using continuous sonde DO, Temperature, and level data. This approach provides an estimate of gross primary productivity and community respiration by estimating the total amount of oxygen produced and consumed over a 24-hour period. It assumes that the daytime respiration rate varies linearly with time from pre-dawn to post-dusk. The net consumption or production of oxygen in the stream is estimated from measured DO concentration changes over time using finite difference methods. The measured DO concentrations and subsequent rates of DO change are adjusted for atmospheric reaeration rates which are estimated to be directly proportional to the DO saturation deficit at the measured temperature. The reaeration rate constant was estimated as a function of average stream cross-sectional velocity and hydraulic radius using the Churchill-Elmore-Buckingham formula (Churchill 1962) given by equation E1.

$$k_2 = 5.026\,(V^{9.69})\,(R^{-1.673}) \qquad \text{(E1)}$$

- V is the average stream cross-sectional velocity (ft/s)
- R is the hydraulic radius (ft)
- k_2 is the reaeration rate constant (day^{-1}) at $20^{o}C$

The reaeration rate constant was adjusted for temperature (T) using:

$$K = 1.024^{(T-20)}\,k_2 \qquad \text{(E2)}$$

And, the reaeration rate was estimated by:

$$D_a = K\,(C_s - C_o) \qquad \text{(E3)}$$

- Where Da is the change in DO due to reaeration in mg / l / hour
- C_s is the DO saturation concentration at measured water temperature
- C_o is the measured DO concentration
- K is the temperature adjusted reaeration rate constant from equation (E2)

Note that in shallow turbulent streams the time needed to achieve equilibrium between the atmosphere and water may be too short for the diurnal oxygen-curve method to be used reliably (Britton 1987).

Stream cross-sectional velocity was estimated using rating curves and sonde depth measurements corrected for atmospheric pressure and adjusted for sensor offset based on relative baseflow values at the USGS stream gauge station at Frankford Creek and Castor Avenue. The rating curves were developed by field measurement over the dry weather flow regime at cross-sections near each monitoring location.

Night-time respiration rate was estimated directly from measured changes in DO concentration over time and adjusted for atmospheric reaertion rates as described above. During daytime, however, photosynthesis and respiration together account for observed changes in adjusted DO concentrations over time. Daytime respiration, therefore, was estimated to vary linearly from early morning to late evening and gross productivity determined by difference from changes in measured DO concentrations. Productivity and respiration rates estimated in this manner for site TF280 on April 30 and May 1, 2003 are shown in Figure E1. Gross daily oxygen production and consumption, expressed in mg/l, were determined by numerical integration of these rates over time seen as the area between the curves and the zero rate of DO change line in Figure E1. In addition, net daily productivity and production respiration ratio (P:R) were determined.

Productivity and respiration estimates were determined in this manner using only complete days of accepted sonde data collected to date. Each accepted day was then characterized by the number of days since the last rainfall recorded at any PWD raingage station surrounding the watershed, and only dry days with 2 or more days since the last rainfall were used in further analyses. In addition, “post” and “pre” rainfall days were identified as having either 3 to 5 and more than eight days, respectively, since the last rainfall.

In order to characterize community metabolism and better understand the role of periphytic algae between sites along the TTF creek and across seasons, various statistical analyses of productivity and respiration estimates were performed. The results of these analyses are presented in figures E2 through E5. It can be readily seen that peak metabolism rates occur during the springtime across all sites.

In addition, comparisons of “pre” and “post” storm metabolism were performed across seasons for each site. These results are presented in figures E6 through E21. There appears to be potentially significant reductions in gross productivity, gross respiration, and to a lesser extent P:R ratio between “pre” and “post” storm estimates taken during the fall samplings. Further investigation is needed.

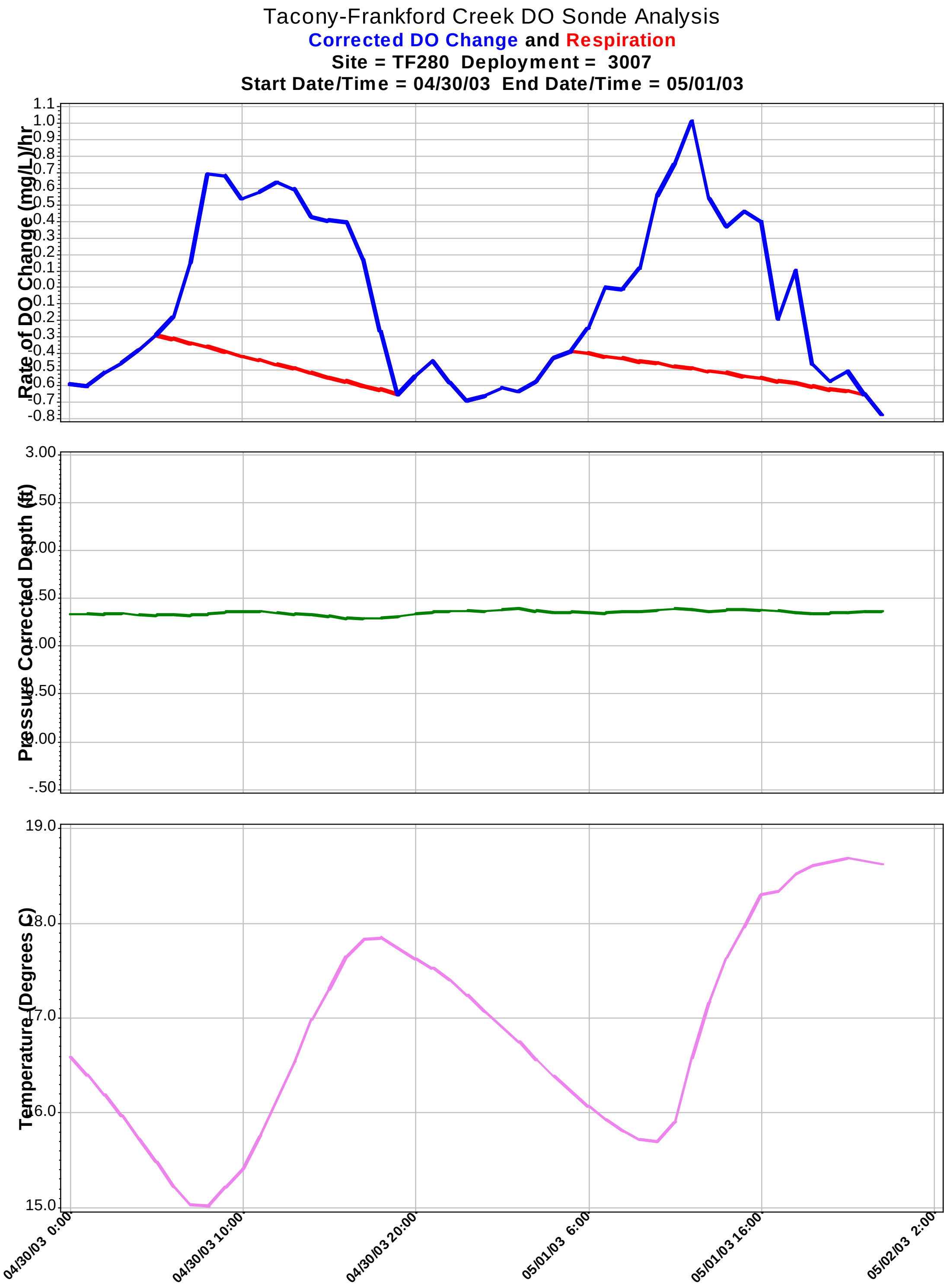
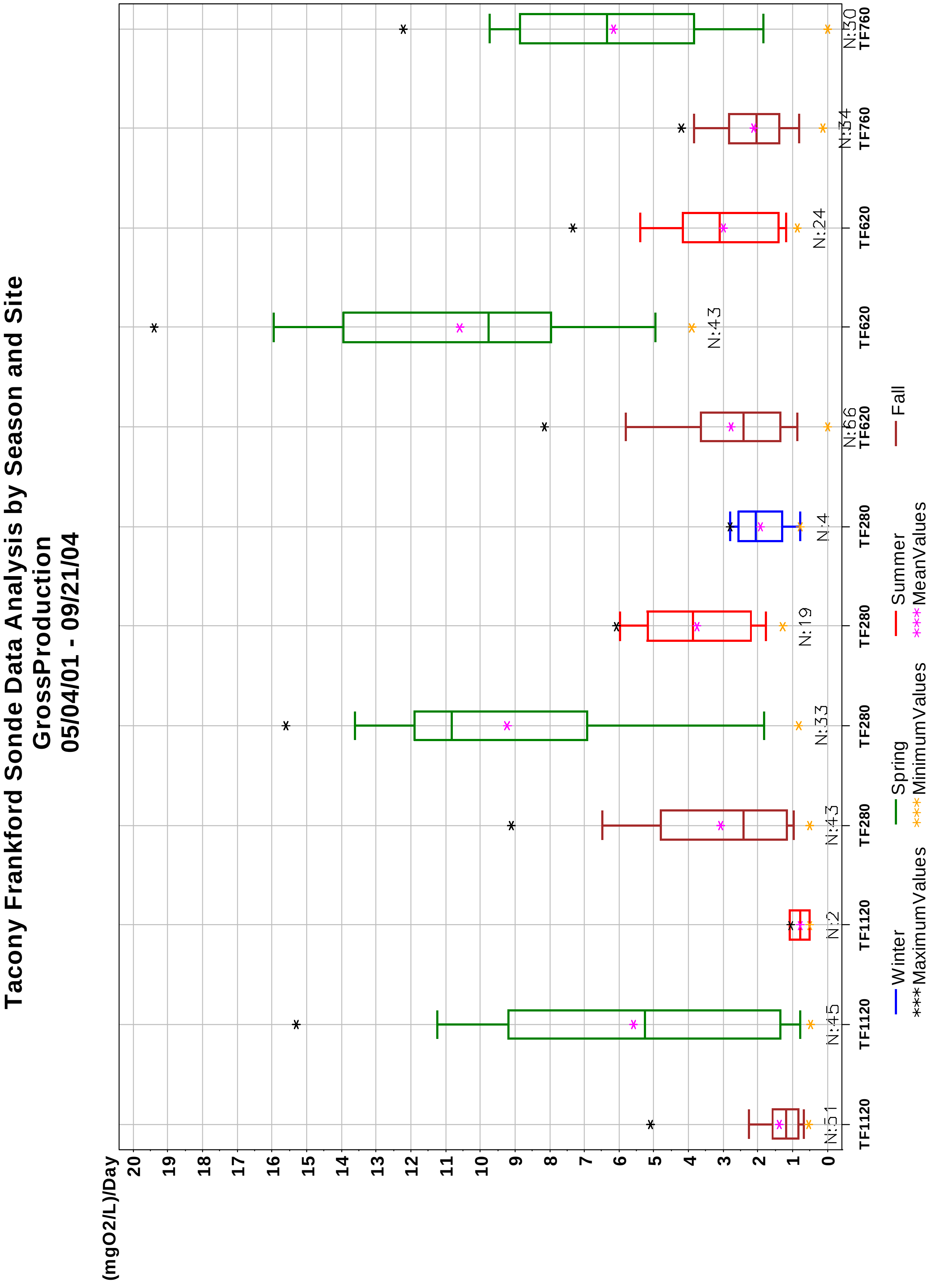
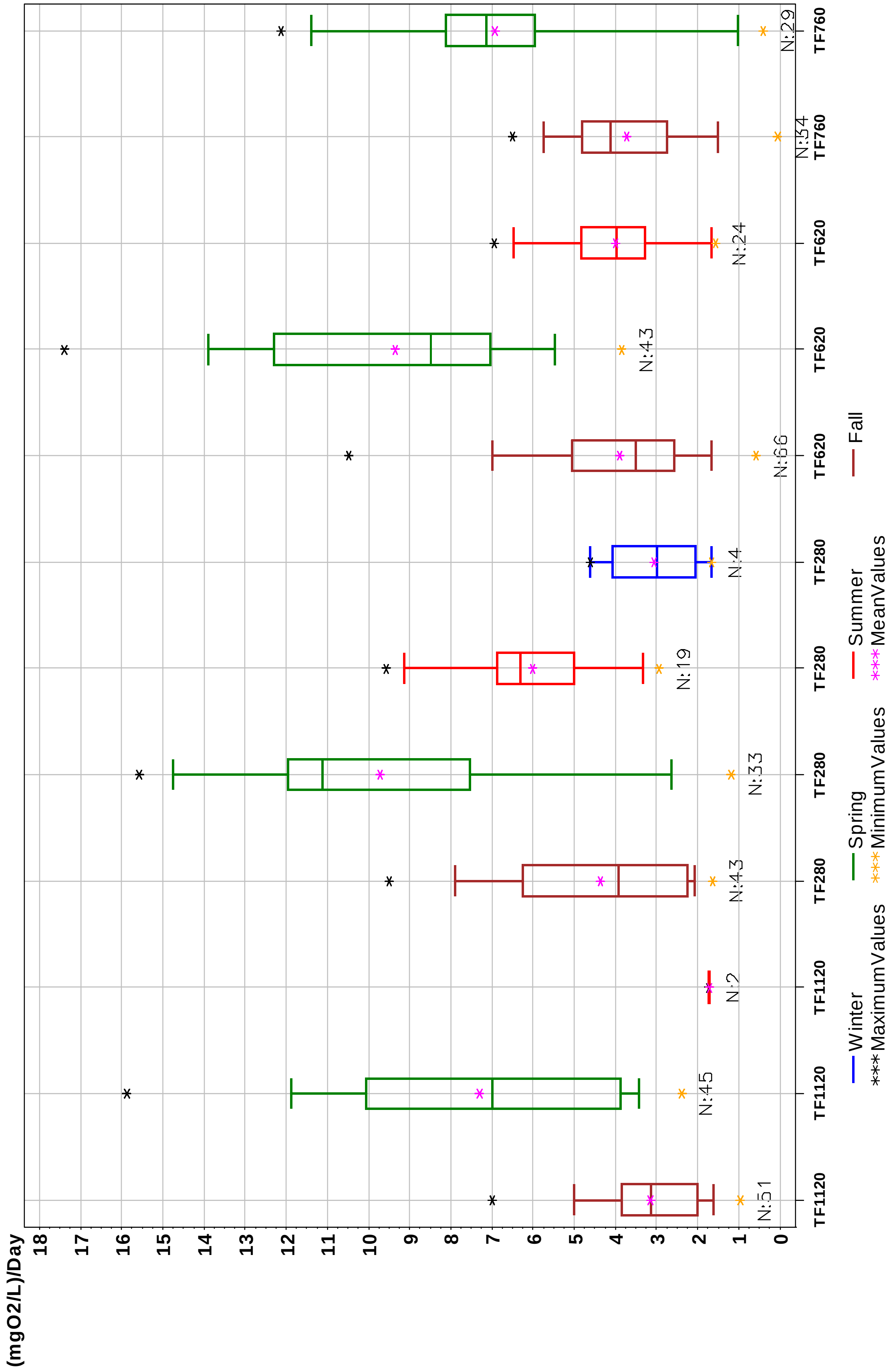


Figure E1: TTF continuous monitoring results at site TF280 for April 30 and May 1, 2003 (Top) Corrected rate of DO change and estimated daytime respiration (Middle) Pressure corrected sonde depth (Bottom) sonde Temperature measurement.

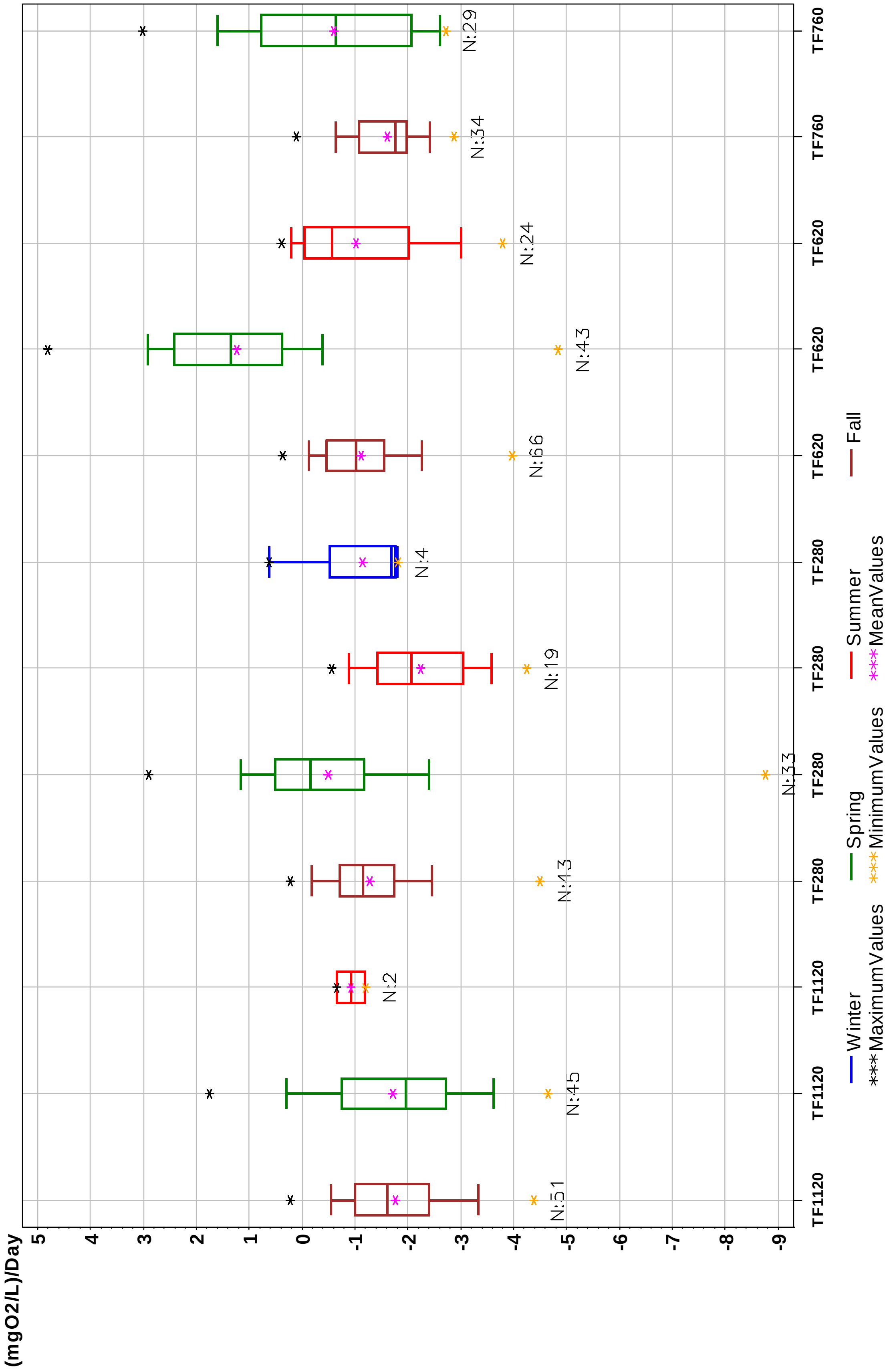
Figures E2 through E5: Comparison of statistical analysis results showing seasonal variations in gross productivity, gross respiration, net productivity, and P:R ratios across TTF monitoring locations.


Tacony Frankford Sonde Data Analysis by Season and Site
GrossProduction
05/04/01 - 09/21/04
(mgO2/L)/Day
20
19
18
17
16
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
0
TF1120
TF1120
TF1120
TF280
TF280
TF280
TF280
TF620
TF620
TF620
TF760
TF760
N:51
N:45
N:2
N:43
N:33
N:19
N:4
N:66
N:43
N:24
N:34
N:30
Winter
Spring
Summer
Fall
MaximumValues
MinimumValues
MeanValues

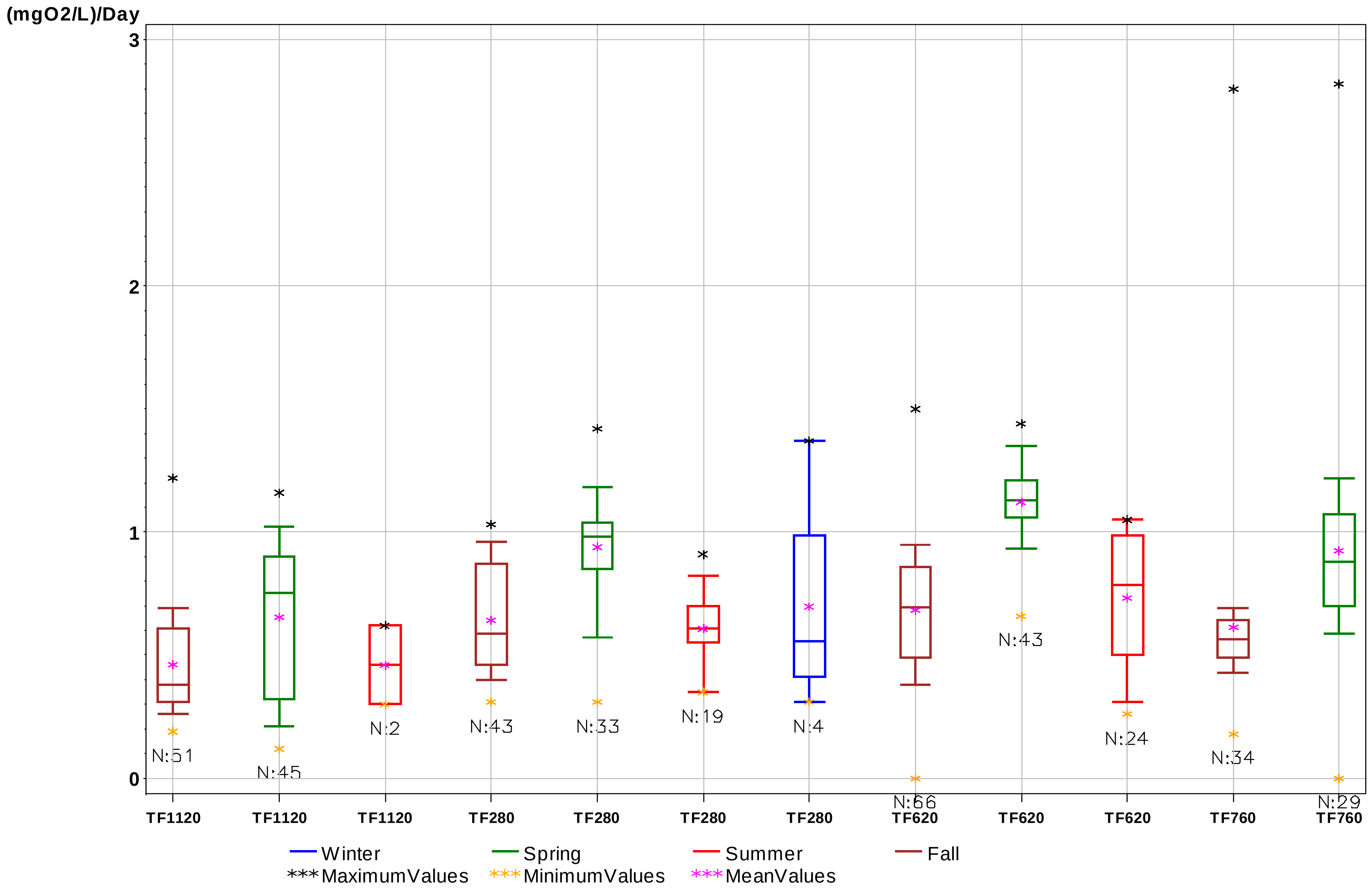


Tacony Frankford Sonde Data Analysis by Season and Site
GrossRespiration
05/04/01 - 09/21/04

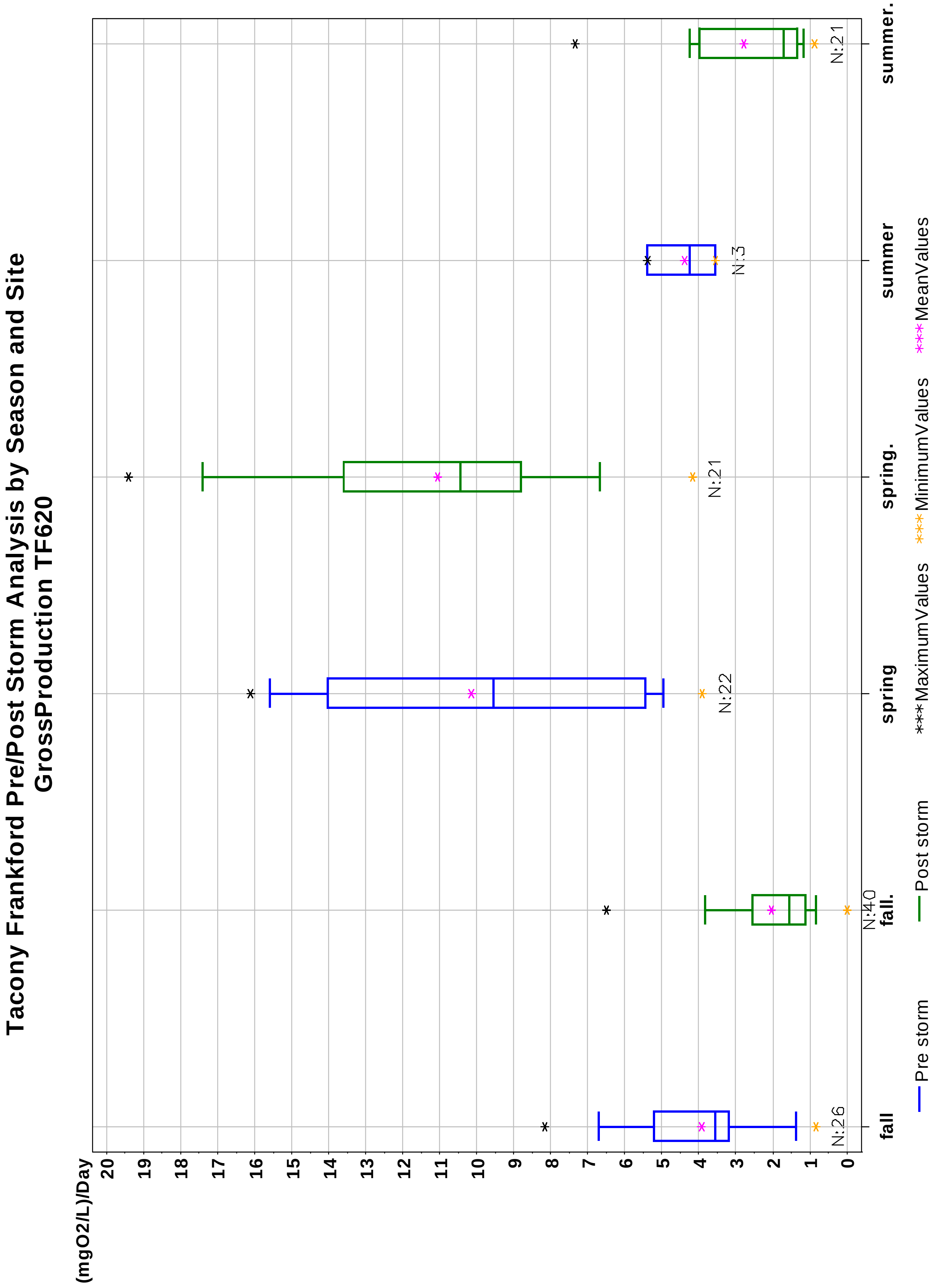
Tacony Frankford Sonde Data Analysis by Season and Site
NetProduction
05/04/01 - 09/21/04



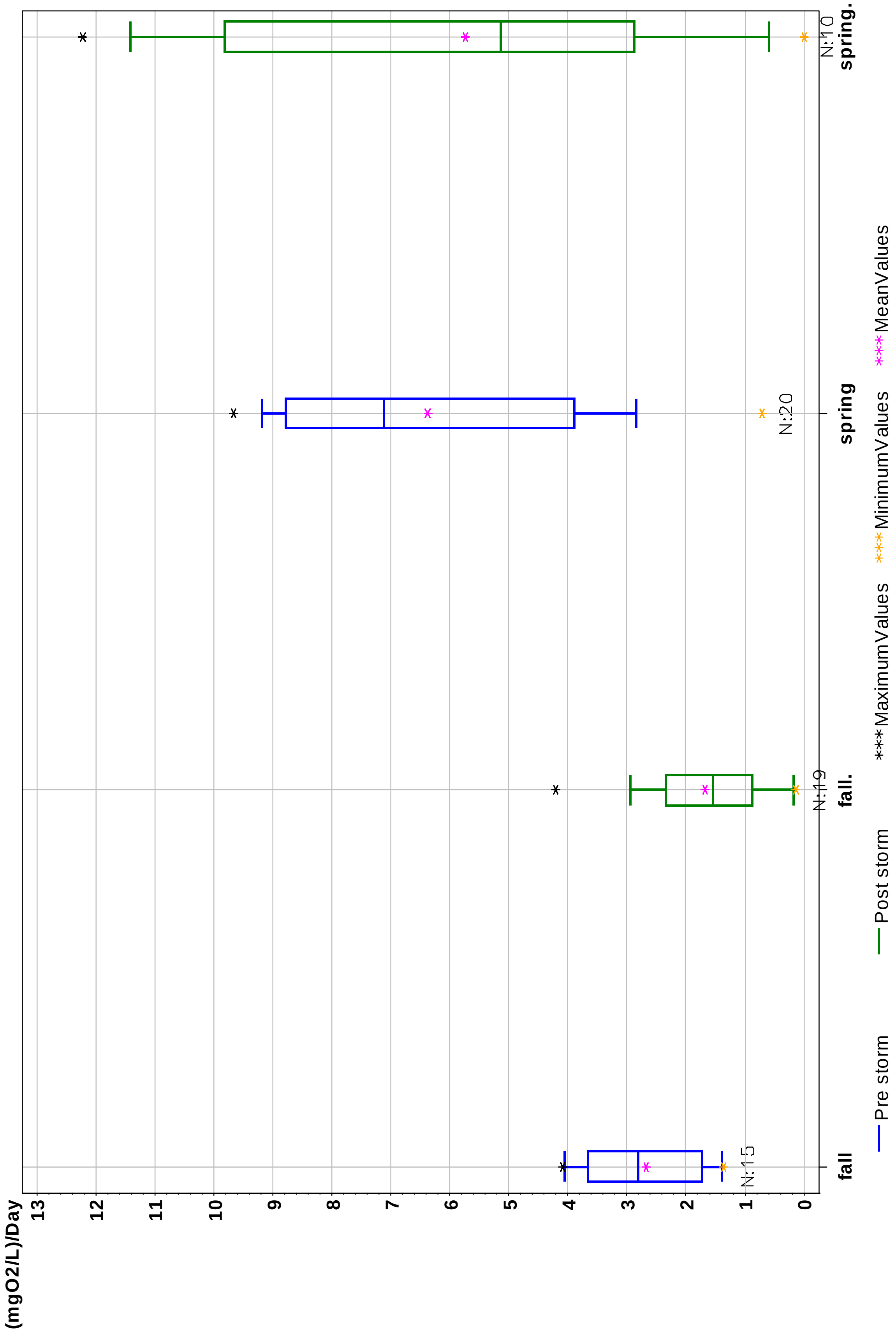
Tacony Frankford Sonde Data Analysis by Season and Site
PRRatio
05/04/01 - 09/21/04

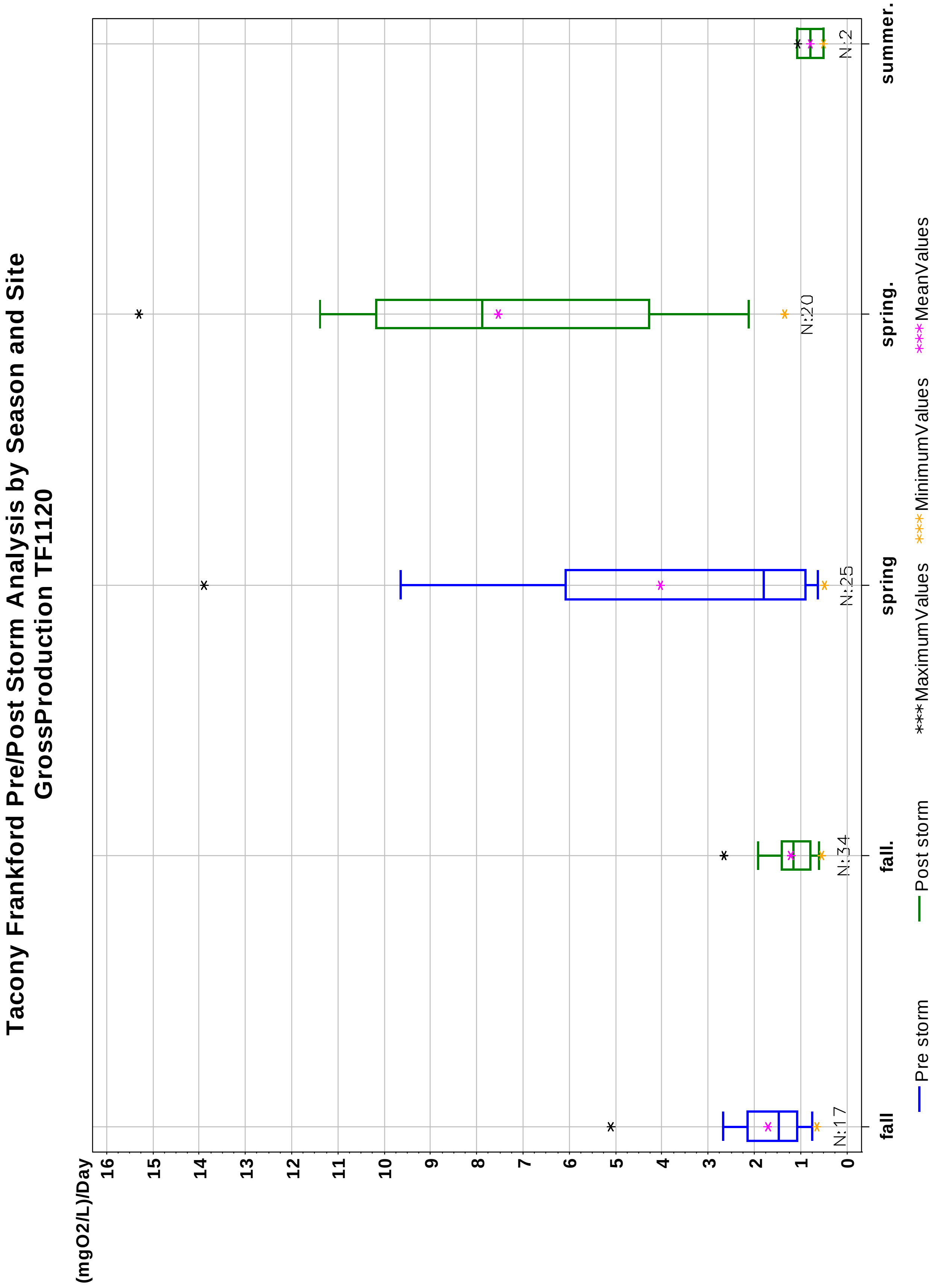


Figures E6 through E21: Comparison of statistical analysis results for “pre” and “post” storm monitoring showing seasonal variations in gross productivity, gross respiration, net productivity, and P:R ratios for each TTF monitoring location.

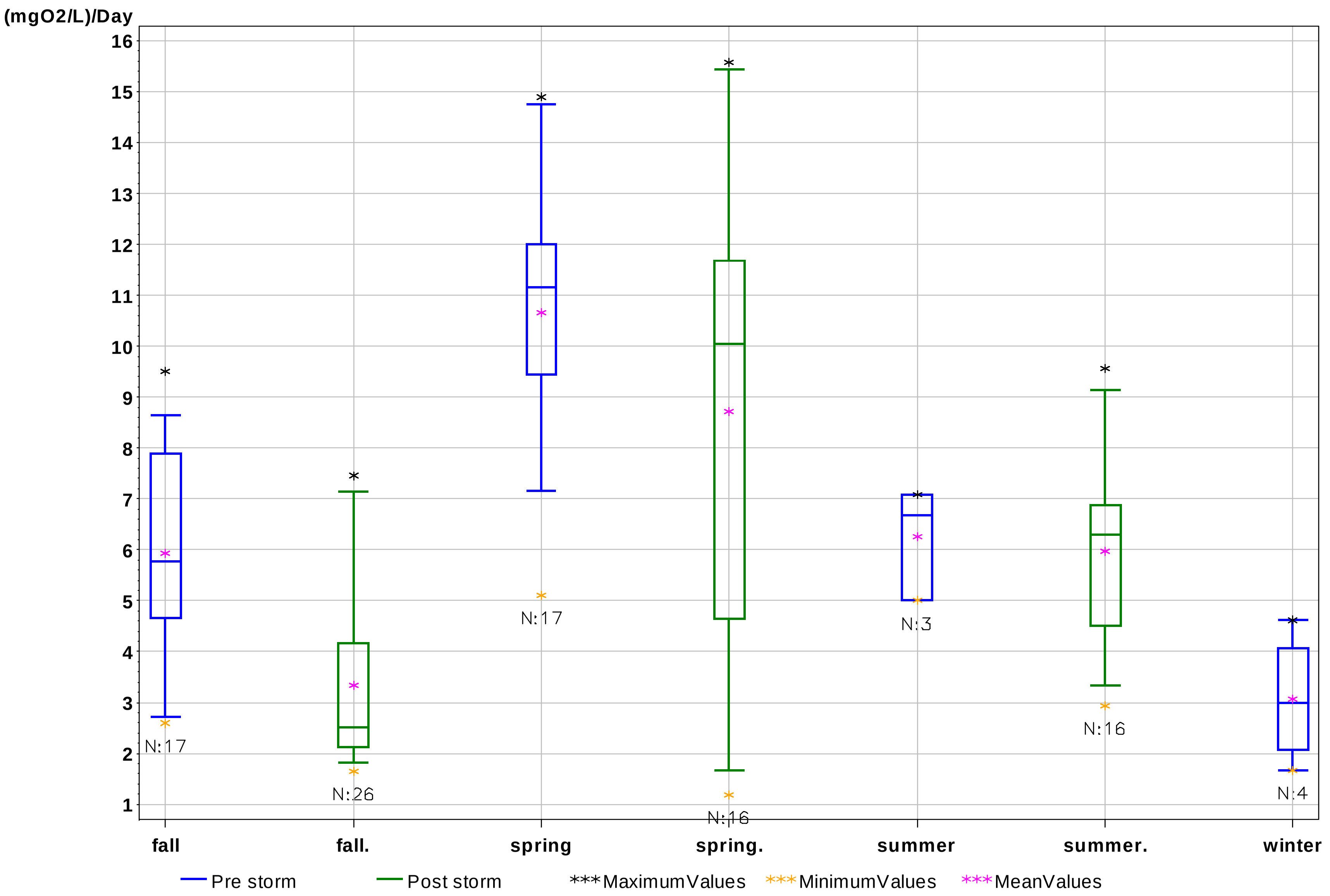

Tacony Frankford Pre/Post Storm Analysis by Season and Site
GrossProduction TF620
(mgO2/L)/Day
20
19
18
17
16
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
0
N:26
N:40
N:22
N:21
N:3
N:21
fall
fall.
spring
spring.
summer
summer.
Pre storm
Post storm
*** MaximumValues
*** MinimumValues
*** MeanValues

Tacony Frankford Pre/Post Storm Analysis by Season and Site
GrossProduction TF975

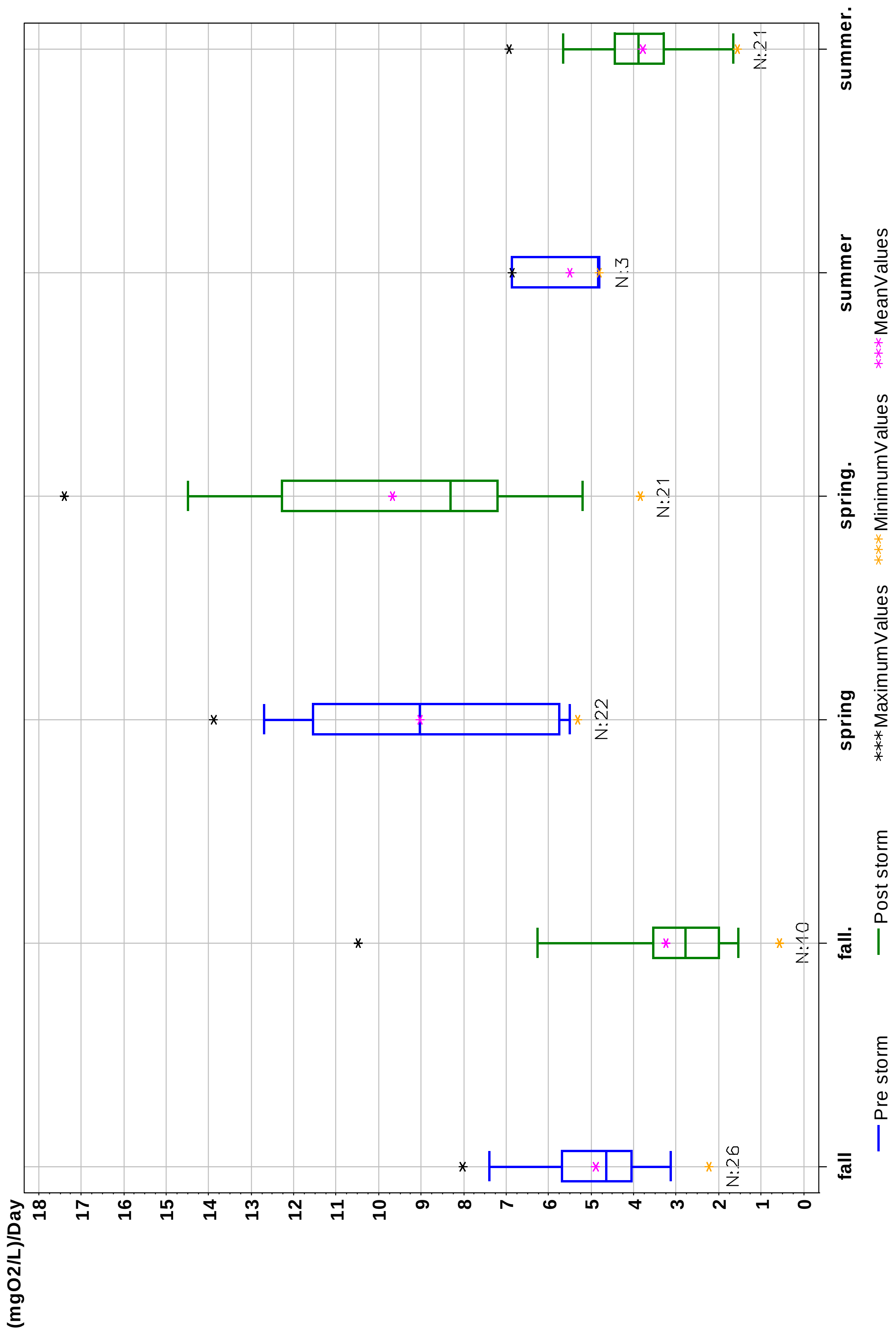


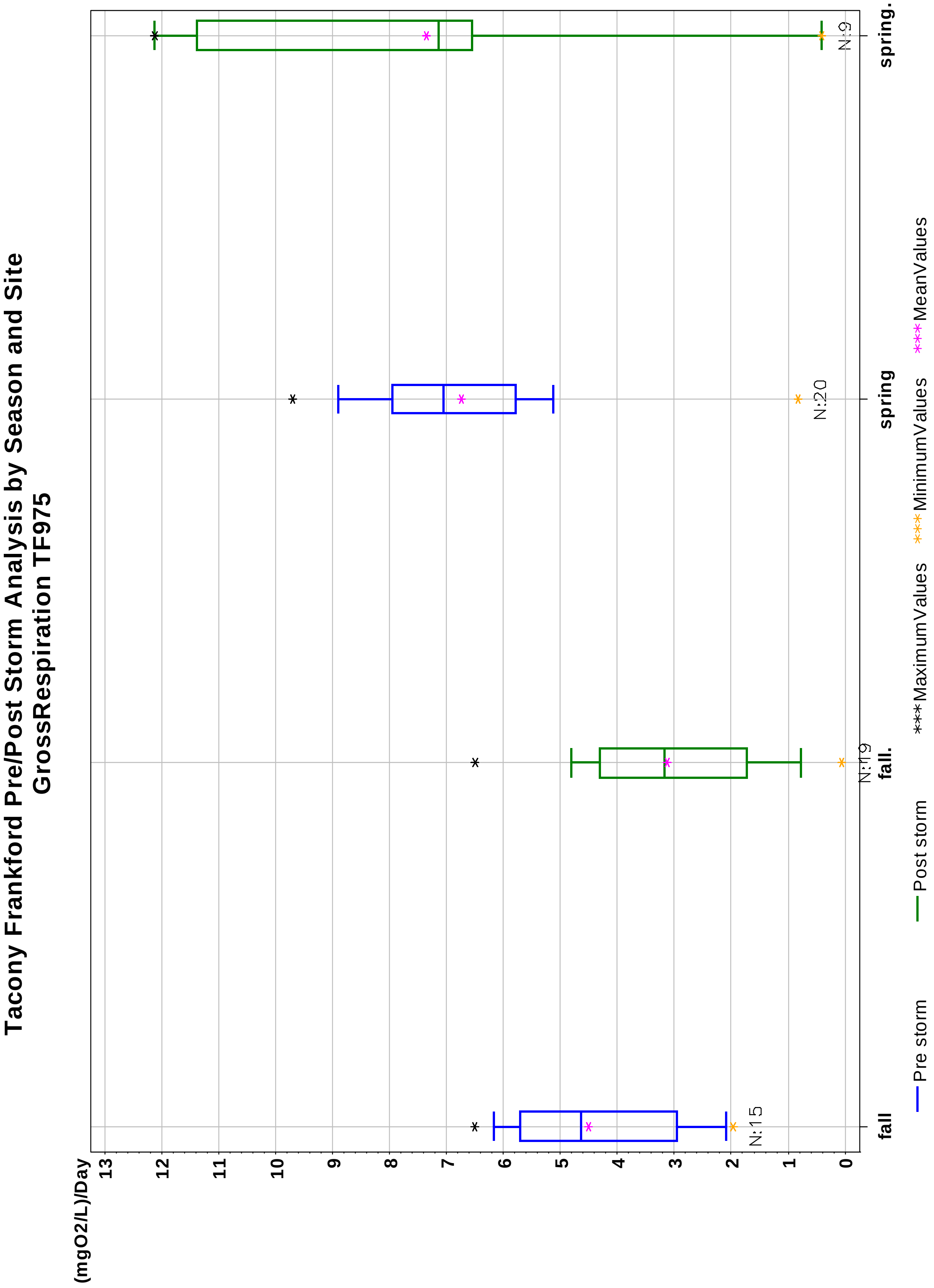

Tacony Frankford Pre/Post Storm Analysis by Season and Site
GrossProduction TF1120
(mgO2/L)/Day
16
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
0
N:17
N:34
N:25
N:20
N:2
fall
fall.
spring
spring.
summer.
Pre storm
Post storm
*** MaximumValues
*** MinimumValues
*** MeanValues

Tacony Frankford Pre/Post Storm Analysis by Season and Site
GrossRespiration TF280



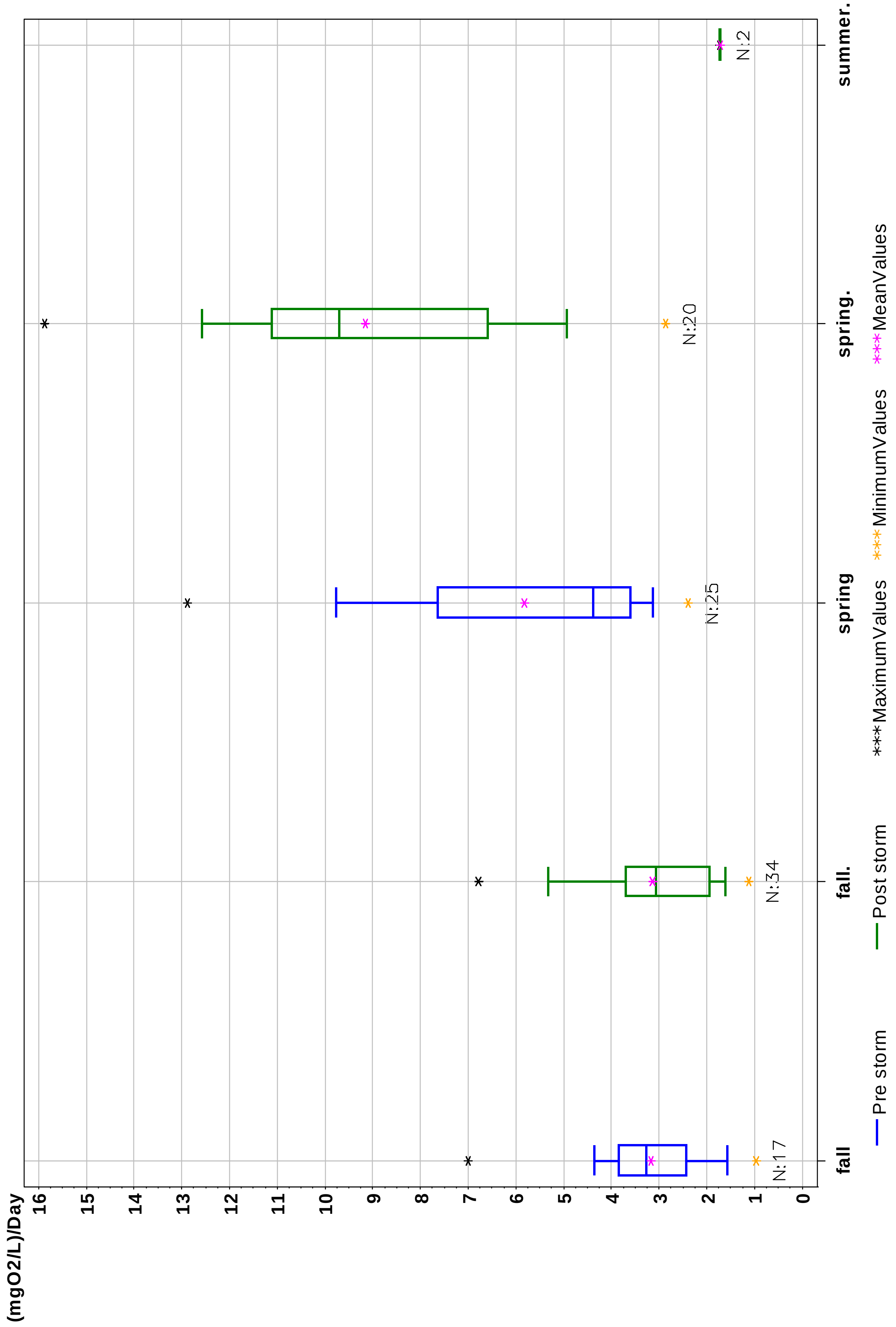
Tacony Frankford Pre/Post Storm Analysis by Season and Site
GrossRespiration TF620

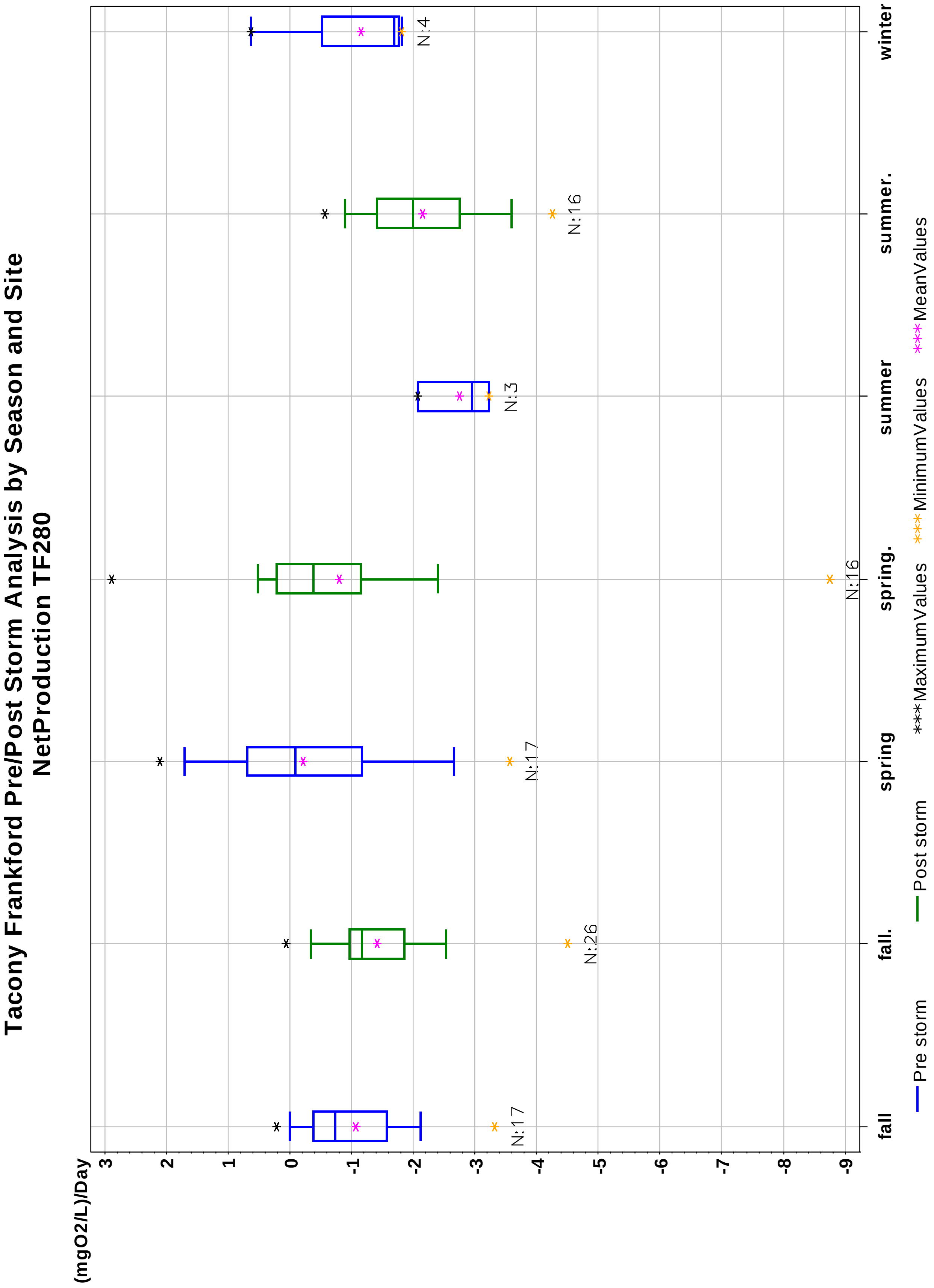




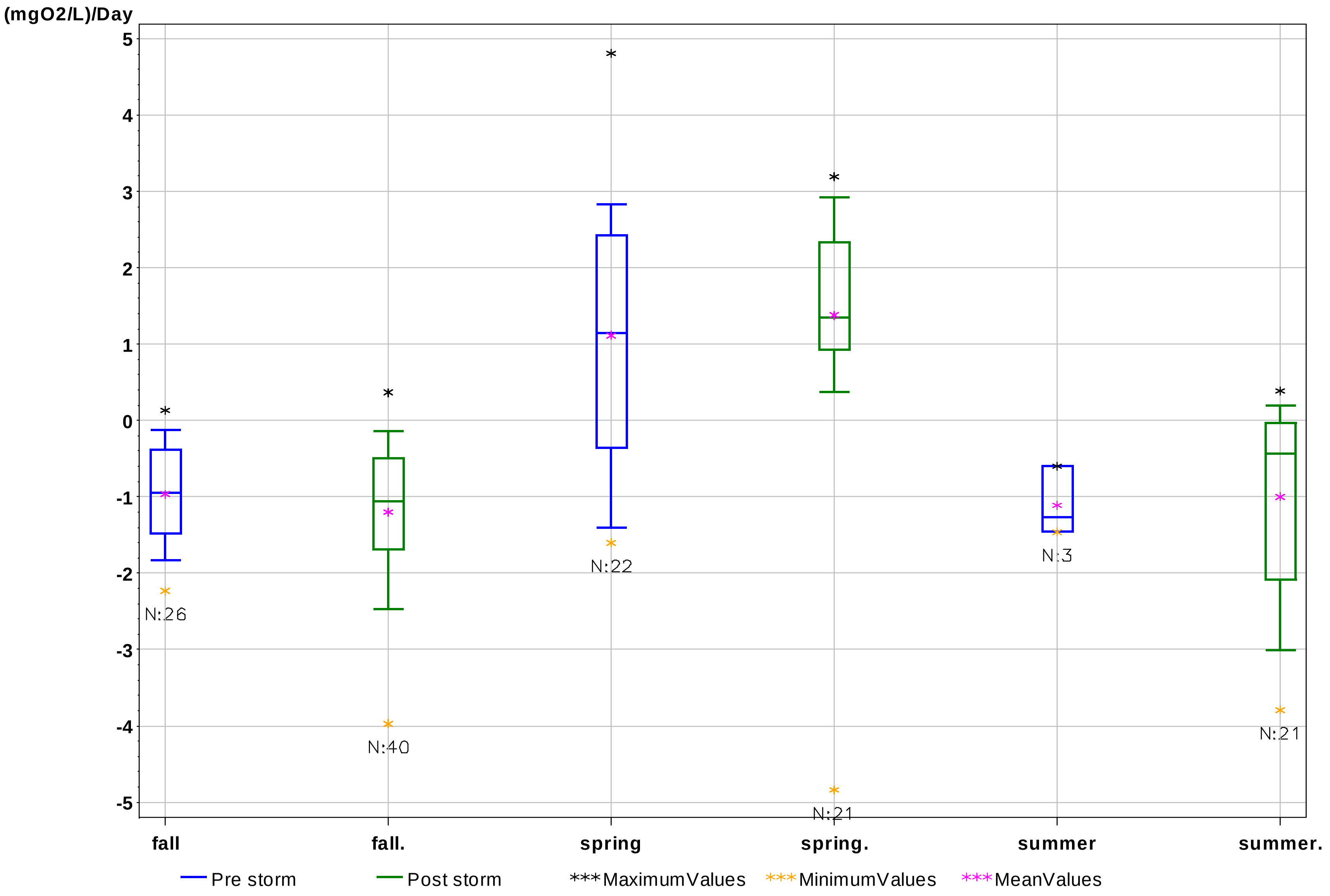
Tacony Frankford Pre/Post Storm Analysis by Season and Site
GrossRespiration TF975

Tacony Frankford Pre/Post Storm Analysis by Season and Site
GrossRespiration TF1120

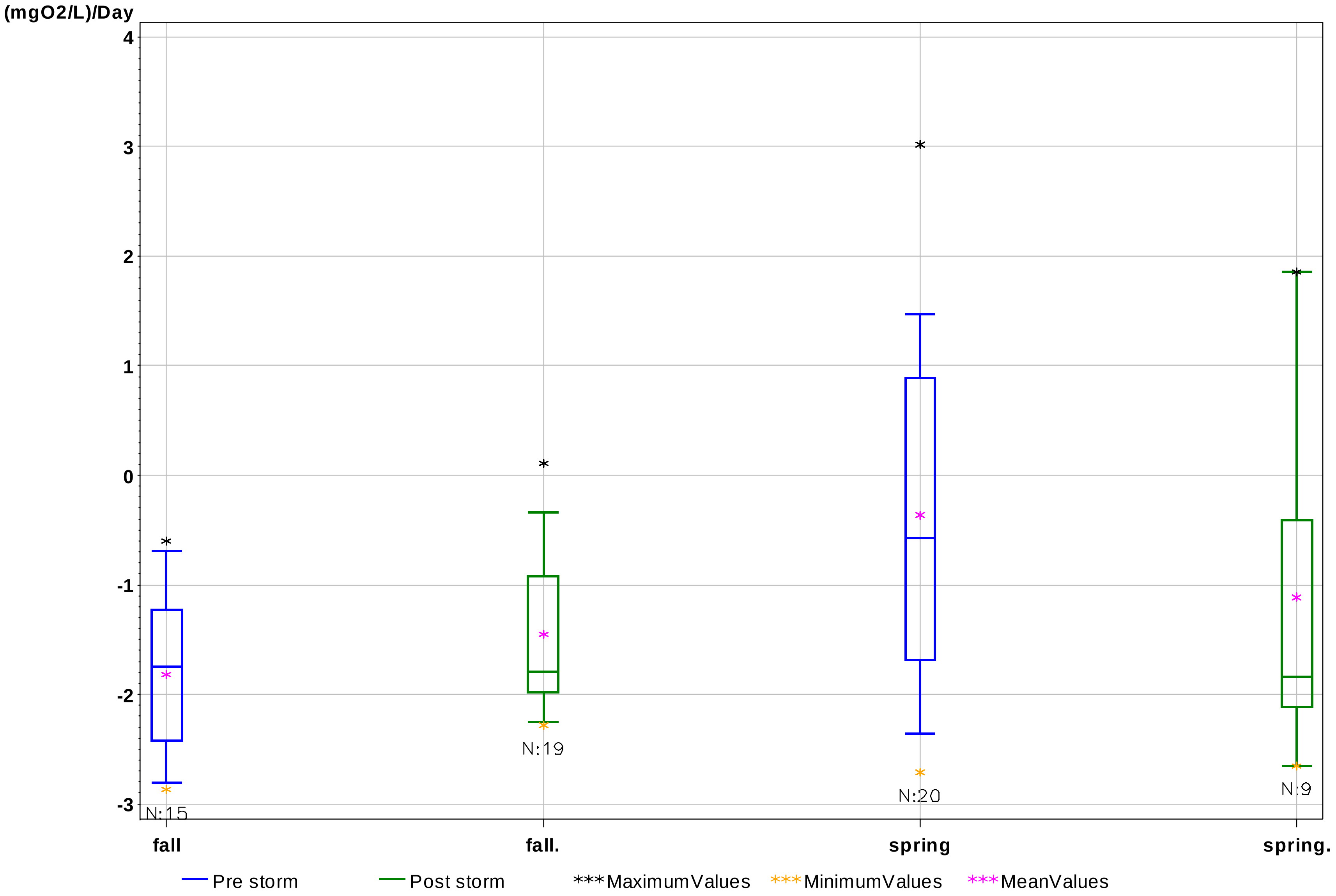


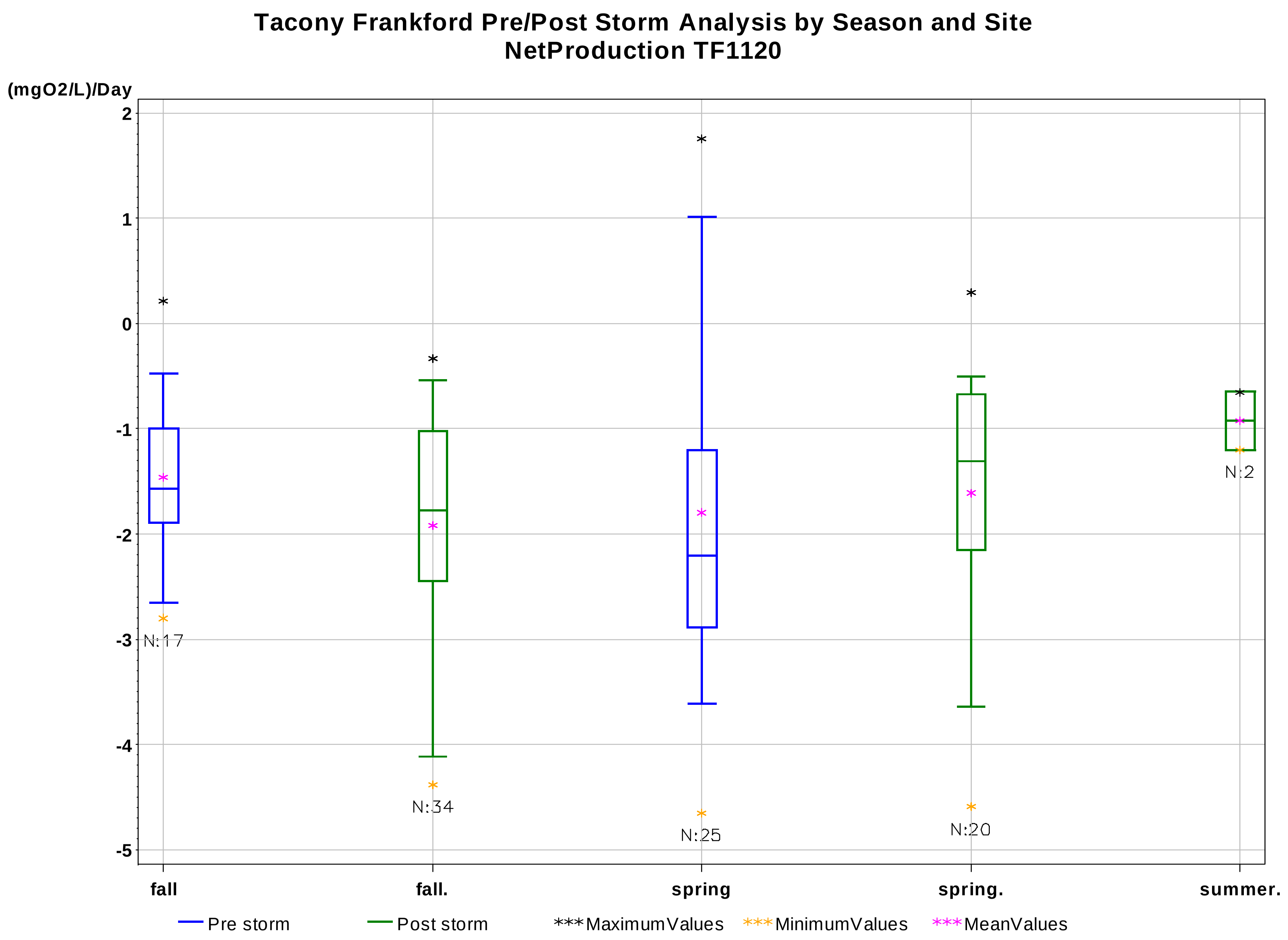

Tacony Frankford Pre/Post Storm Analysis by Season and Site
NetProduction TF280

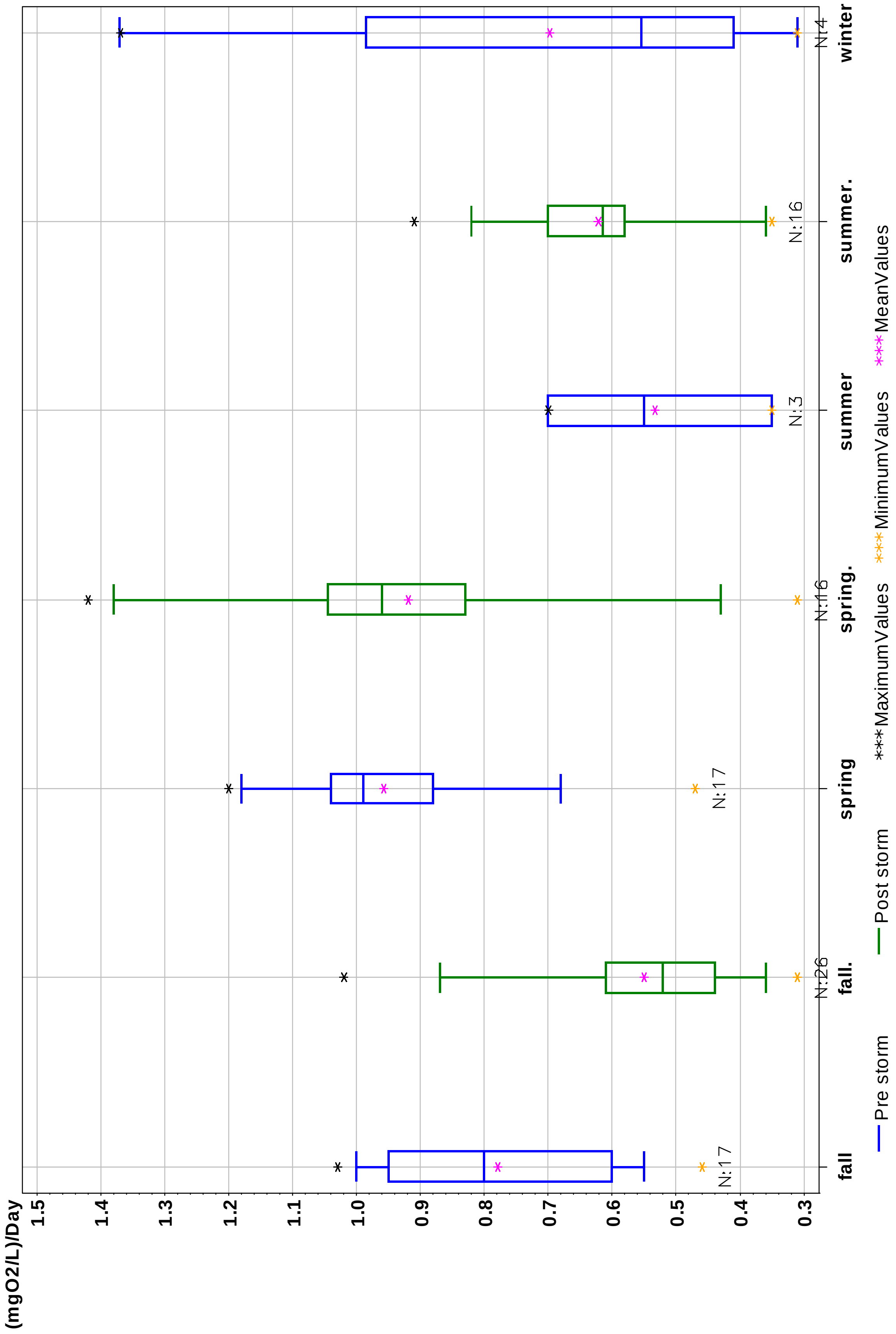
Tacony Frankford Pre/Post Storm Analysis by Season and Site
NetProduction TF620



Tacony Frankford Pre/Post Storm Analysis by Season and Site
NetProduction TF975

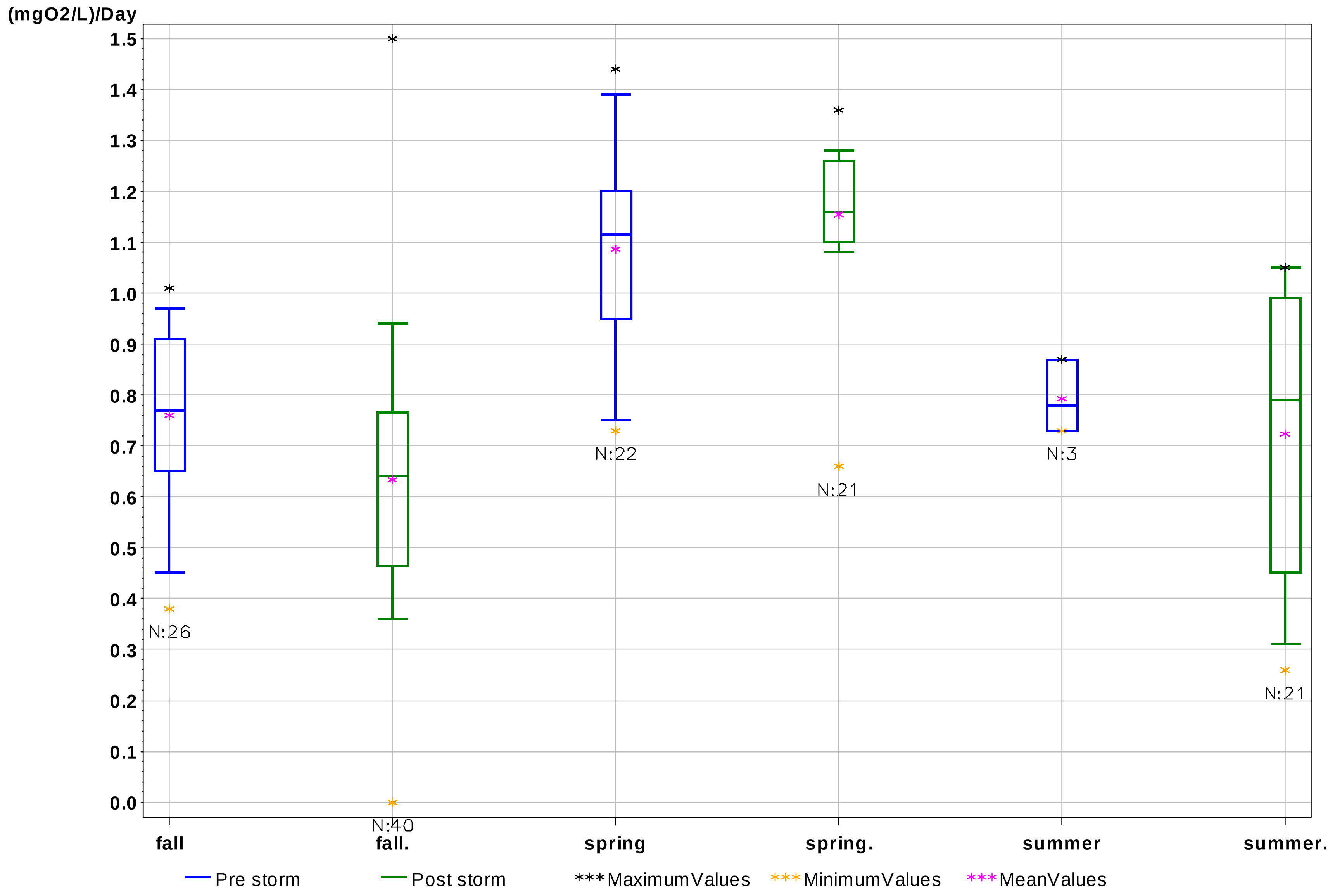


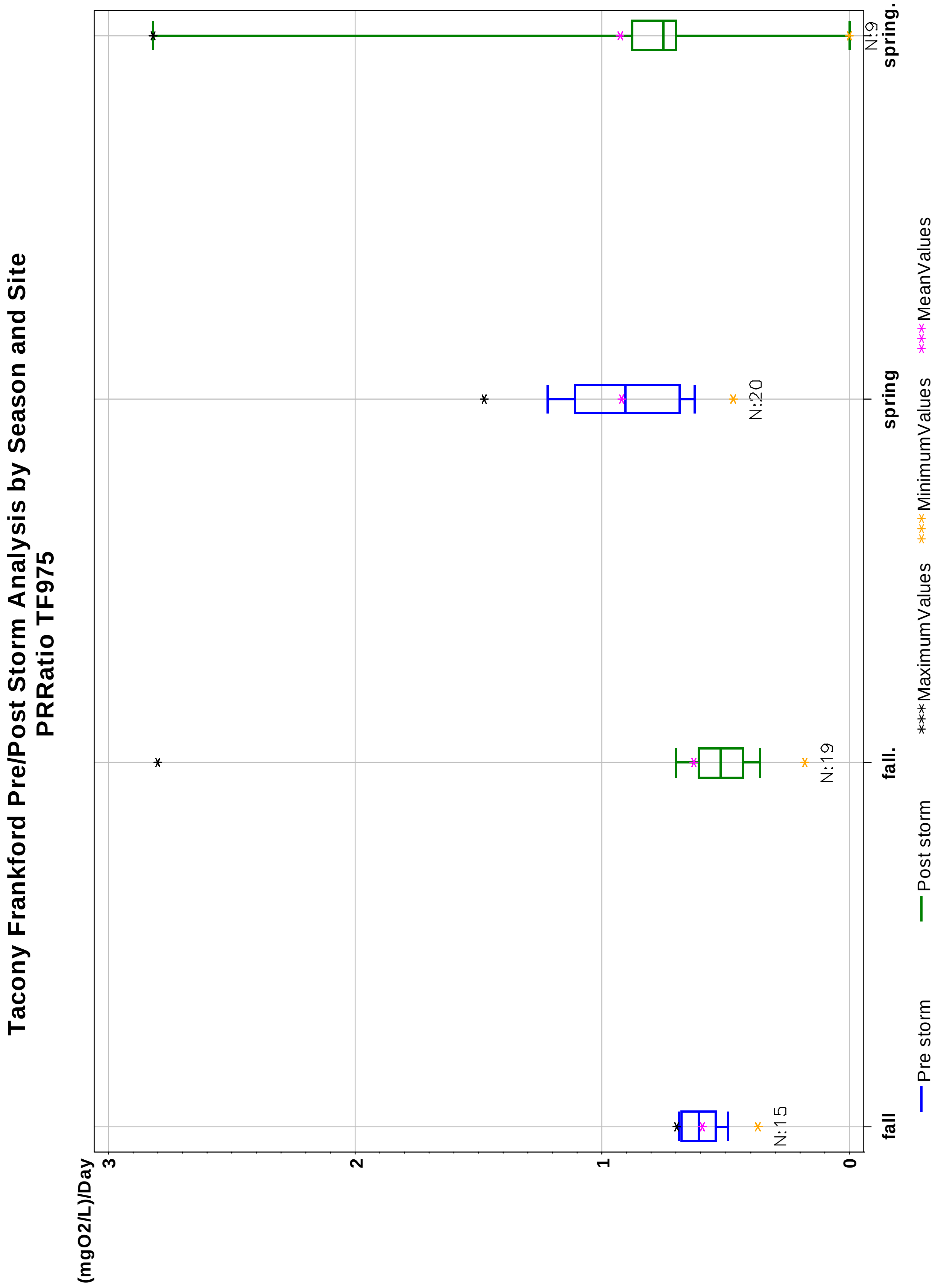

Tacony Frankford Pre/Post Storm Analysis by Season and Site
NetProduction TF1120
(mgO2/L)/Day
2
1
0
-1
-2
-3
-4
-5
N:17
N:34
N:25
N:20
N:2
fall
fall.
spring
spring.
summer.
Pre storm
Post storm
***MaximumValues
***MinimumValues
***MeanValues

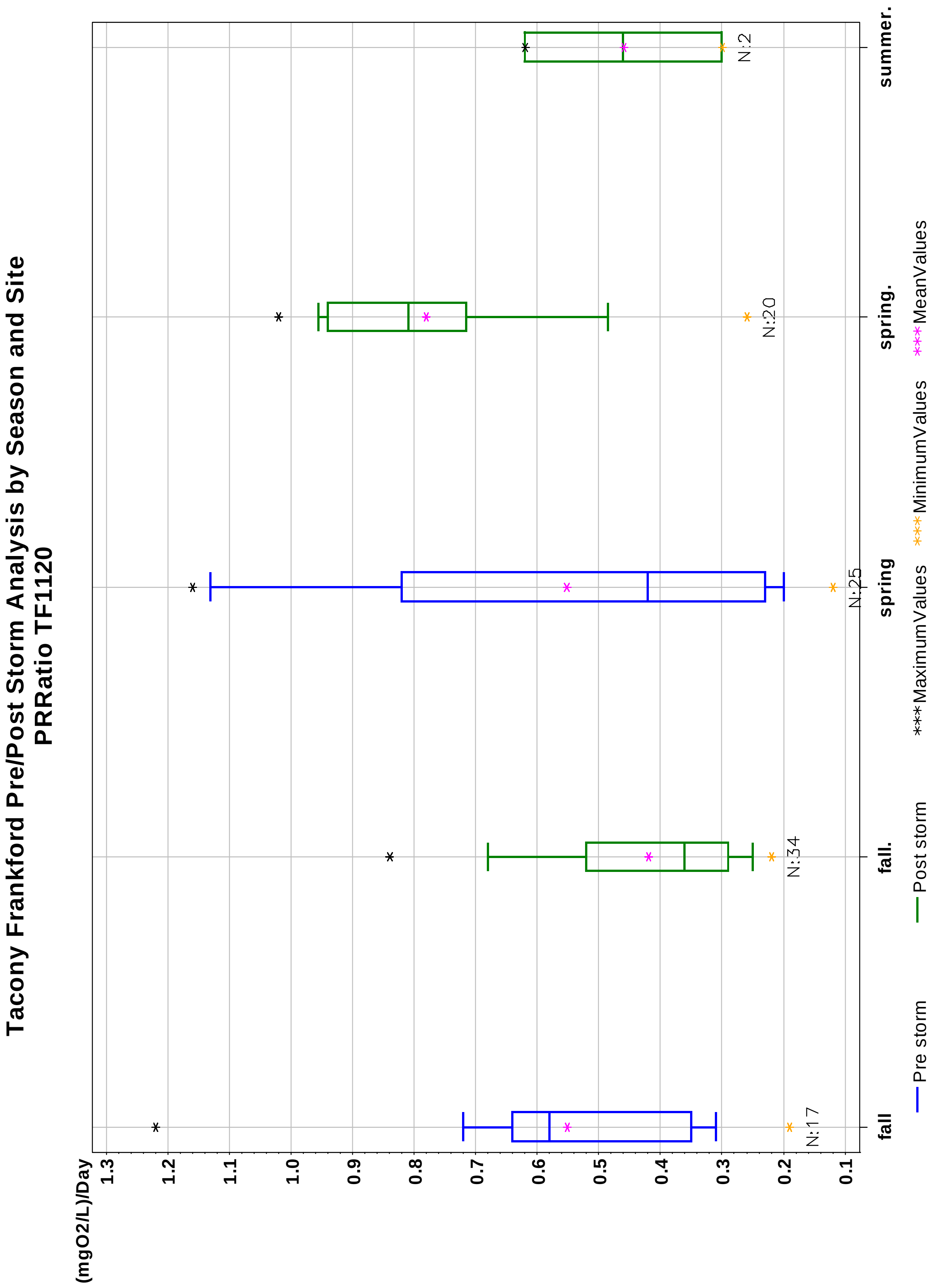


Tacony Frankford Pre/Post Storm Analysis by Season and Site
PRRatio TF280

Tacony Frankford Pre/Post Storm Analysis by Season and Site
PRRatio TF620




Tacony Frankford Pre/Post Storm Analysis by Season and Site
PRRatio TF975
(mgO2/L)/Day
3
2
1
0
N:15
N:19
N:20
N:9
fall
fall.
spring
spring.
Pre storm
Post storm
*** MaximumValues
*** MinimumValues
*** MeanValues



Tacony Frankford Pre/Post Storm Analysis by Season and Site
PRRatio TF1120

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http://permanent.access.gpo.gov/waterusgsgov/water.usgs.gov/pubs/twri/twri5a4/html/pdf.html

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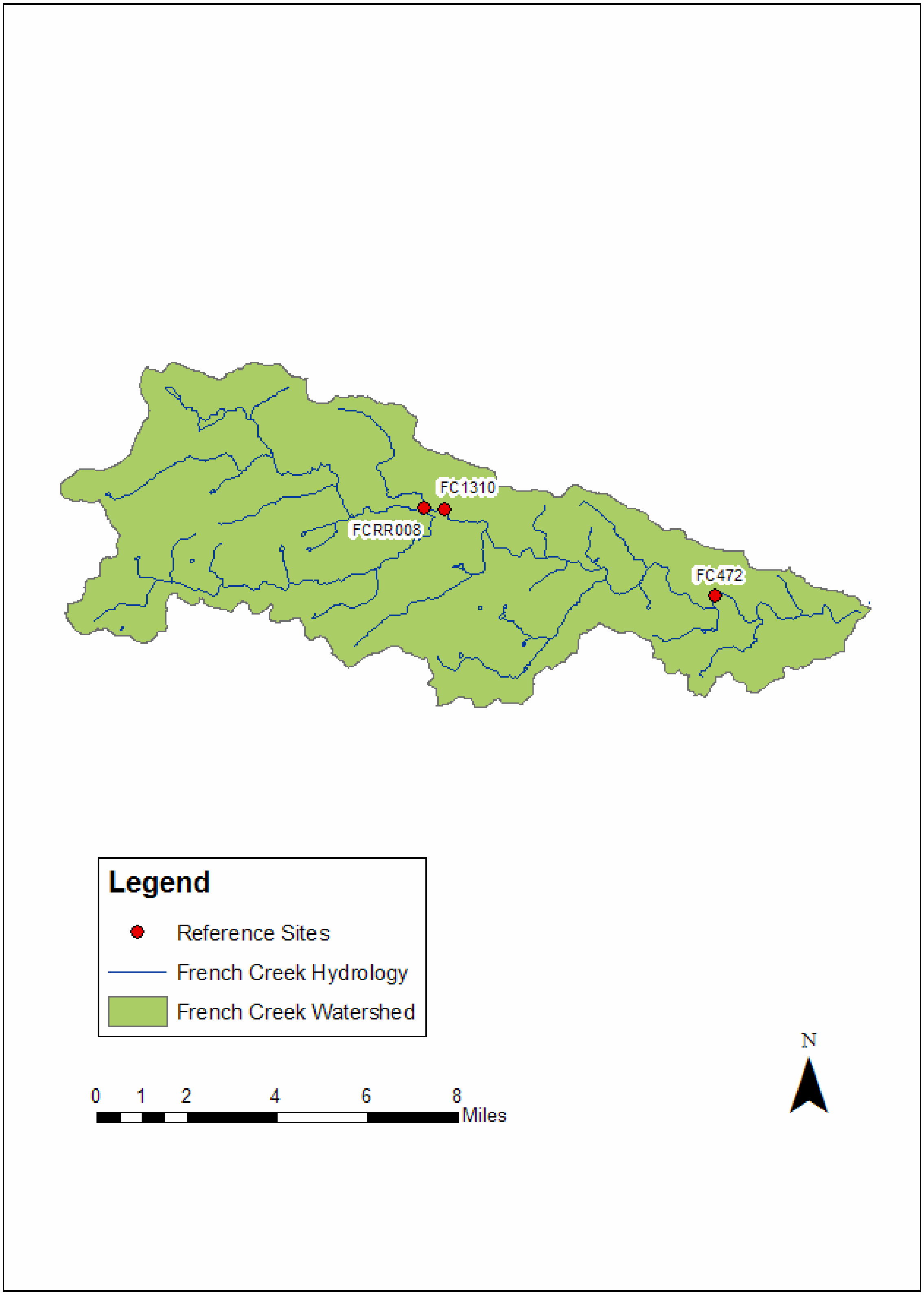
Churchill, M. A., Elmore H. L., Buckingham, R.A., 1962, The prediction of stream reaeration rates, Journal of the Sanitary Engineering Division Proceedings of the American Society of Civil Engineers, v 88, no. SA-4, p 1-46.

O'Connell, Richard L., Thomas, Nelson A., 1965, Effect of Benthic Algea on Stream Dissolved Oxygen, Journal of the Sanitary Engineering Division Proceedings of the American Society of Civil Engineers, no. SA-3, p 1-16.

Appendix F: Reference Site Locations



Appendix I All Chlorophyll data collected from Tookany/Tacony-Frankford Watershed 2000-2005

Samples in **bold font** are periphyton samples

Sam_ID	DateTime	Site	Parameter	Value	Units	Wet/Dry
DW000629-0046	6/29/2000 8:40	TF280	Chlorophyll a (approx)	6.23	ug/L	1
DW000629-0050	6/29/2000 8:57	TF975	Chlorophyll a (approx)	3.03	ug/L	1
DW000629-0047	6/29/2000 9:20	TF500	Chlorophyll a (approx)	5.26	ug/L	1
DW000629-0051	6/29/2000 9:30	TF1120	Chlorophyll a (approx)	1.39	ug/L	1
DW000629-0052	6/29/2000 9:57	TFJ110	Chlorophyll a (approx)	1.58	ug/L	1
DW000629-0048	6/29/2000 10:00	TF620	Chlorophyll a (approx)	3.97	ug/L	1
DW000629-0049	6/29/2000 10:30	TF760	Chlorophyll a (approx)	3.72	ug/L	1
DW000706-0043	7/6/2000 8:30	TF280	Chlorophyll a (approx)	10.85	ug/L	0
DW000706-0047	7/6/2000 9:05	TF975	Chlorophyll a (approx)	1.96	ug/L	0
DW000706-0044	7/6/2000 9:10	TF500	Chlorophyll a (approx)	4.06	ug/L	0
DW000706-0048	7/6/2000 9:39	TF1120	Chlorophyll a (approx)	0.71	ug/L	0
DW000706-0045	7/6/2000 9:45	TF620	Chlorophyll a (approx)	3.13	ug/L	0
DW000706-0046	7/6/2000 10:20	TF760	Chlorophyll a (approx)	3.49	ug/L	0
DW000810-00□3	8/10/2000 8:25	TF280	Chlorophyll a (approx)	2.19	ug/L	1
DW000810-0039	8/10/2000 8:40	TF975	Chlorophyll a (approx)	0.84	ug/L	1
DW000810-0044	8/10/2000 9:30	TF500	Chlorophyll a (approx)	2.94	ug/L	1
DW000810-0045	8/10/2000 9:55	TF620	Chlorophyll a (approx)	2.25	ug/L	1
DW000810-0046	8/10/2000 10:25	TF760	Chlorophyll a (approx)	5.13	ug/L	1
DW000831-0044	8/31/2000 8:54	TF975	Chlorophyll a (approx)	2.06	ug/L	0
DW000831-0047	8/31/2000 9:05	TF280	Chlorophyll a (approx)	15.66	ug/L	0
DW000831-0045	8/31/2000 9:30	TF1120	Chlorophyll a (approx)	1.99	ug/L	0
DW000831-0048	8/31/2000 9:50	TF500	Chlorophyll a (approx)	4.99	ug/L	0
DW000831-0049	8/31/2000 10:25	TF620	Chlorophyll a (approx)	4.48	ug/L	0
DW000831-0050	8/31/2000 11:00	TF760	Chlorophyll a (approx)	4.25	ug/L	0
DW000914-0041	9/14/2000 7:55	TF280	Chlorophyll a (approx)	2.87	ug/L	0
DW000914-0038	9/14/2000 8:14	TF975	Chlorophyll a (approx)	1.38	ug/L	0
DW000914-0042	9/14/2000 8:45	TF500	Chlorophyll a (approx)	2.64	ug/L	0
DW000914-0039	9/14/2000 8:55	TF1120	Chlorophyll a (approx)	2.93	ug/L	0
DW000914-0043	9/14/2000 9:20	TF620	Chlorophyll a (approx)	1.94	ug/L	0
DW000914-0040	9/14/2000 9:25	TFJ110	Chlorophyll a (approx)	0.75	ug/L	0
DW000914-0044	9/14/2000 9:50	TF760	Chlorophyll a (approx)	1.88	ug/L	0
DW000928-0042	9/28/2000 8:45	TF280	Chlorophyll a (approx)	0.77	ug/L	0
DW000928-0039	9/28/2000 8:55	TF975	Chlorophyll a (approx)	0.59	ug/L	0
DW000928-0040	9/28/2000 9:30	TF1120	Chlorophyll a (approx)	2.57	ug/L	0
DW000928-0041	9/28/2000 10:10	TFJ110	Chlorophyll a (approx)	0.85	ug/L	0
DW000928-0045	9/28/2000 10:40	TF760	Chlorophyll a (approx)	0.55	ug/L	0
DW001012-0048	10/12/2000 8:40	TF280	Chlorophyll a (approx)	1.17	ug/L	0
DW001012-0049	10/12/2000 9:35	TF500	Chlorophyll a (approx)	1.03	ug/L	0
DW001012-0053	10/12/2000 9:55	TF975	Chlorophyll a (approx)	1.04	ug/L	0
DW001012-0050	10/12/2000 10:10	TF620	Chlorophyll a (approx)	1.02	ug/L	0
DW001012-0054	10/12/2000 10:33	TF1120	Chlorophyll a (approx)	0.85	ug/L	0
DW001012-0051	10/12/2000 10:40	TF760	Chlorophyll a (approx)	1.16	ug/L	0
DW001026-0085	10/26/2000 8:45	TF280	Chlorophyll a (approx)	3.07	ug/L	0
DW001026-0089	10/26/2000 9:25	TF975	Chlorophyll a (approx)	1.14	ug/L	0

Sam_ID	DateTime	Site	Parameter	Value	Units	Wet/Dry
DW001026-0090	10/26/2000 9:25	TF1120	Chlorophyll a (approx)	0.57	ug/L	0
DW001026-0086	10/26/2000 9:40	TF500	Chlorophyll a (approx)	2.65	ug/L	0
DW001026-0087	10/26/2000 10:15	TF620	Chlorophyll a (approx)	2.10	ug/L	0
DW001026-0088	10/26/2000 10:40	TF760	Chlorophyll a (approx)	2.02	ug/L	0
DW001109-0054	11/9/2000 8:55	TF280	Chlorophyll a (approx)	4.32	ug/L	0
DW001109-0055	11/9/2000 9:25	TF500	Chlorophyll a (approx)	6.65	ug/L	0
DW001109-0067	11/9/2000 9:57	TF975	Chlorophyll a (approx)	3.34	ug/L	0
DW001109-0056	11/9/2000 10:05	TF620	Chlorophyll a (approx)	3.95	ug/L	0
DW001109-0068	11/9/2000 10:40	TF1120	Chlorophyll a (approx)	9.59	ug/L	0
DW001109-0057	11/9/2000 10:50	TF760	Chlorophyll a (approx)	1.12	ug/L	0
DW001109-0069	11/9/2000 11:18	TFJ110	Chlorophyll a (approx)	0.63	ug/L	0
DW010319-0061	3/19/2001 13:45	TF280	Chlorophyll a (approx)	2.10	ug/L	0
DW010321-0055	3/21/2001 10:35	TF280	Chlorophyll a (approx)	2.93	ug/L	1
DW010321-0057	3/21/2001 12:35	TF280	Chlorophyll a (approx)	4.50	ug/L	1
DW010321-0078	3/21/2001 16:35	TF280	Chlorophyll a (approx)	20.75	ug/L	1
DW010321-0079	3/21/2001 18:35	TF280	Chlorophyll a (approx)	75.62	ug/L	1
DW010322-0038	3/22/2001 8:35	TF280	Chlorophyll a (approx)	4.44	ug/L	1
DW010322-0048	3/22/2001 12:50	TF280	Chlorophyll a (approx)	3.58	ug/L	1
DW010322-0049	3/22/2001 16:35	TF280	Chlorophyll a (approx)	2.80	ug/L	1
DW010323-0052	3/23/2001 9:55	TF280	Chlorophyll a (approx)	2.22	ug/L	1
DW010521-0060	5/21/2001 10:30	TF280	Chlorophyll a (approx)	16.04	ug/L	1
DW010521-0061	5/21/2001 11:25	TF500	Chlorophyll a (approx)	24.88	ug/L	1
DW010521-0062	5/21/2001 11:55	TF760	Chlorophyll a (approx)	18.08	ug/L	1
DW010522-0045	5/22/2001 11:05	TF280	Chlorophyll a (approx)	31.54	ug/L	1
DW010522-0053	5/22/2001 12:14	TF500	Chlorophyll a (approx)	16.72	ug/L	1
DW010522-0056	5/22/2001 12:41	TF760	Chlorophyll a (approx)	5.56	ug/L	1
DW010523-0059	5/23/2001 9:00	TF280	Chlorophyll a (approx)	4.36	ug/L	1
DW010523-0060	5/23/2001 9:42	TF500	Chlorophyll a (approx)	4.80	ug/L	1
DW010523-0061	5/23/2001 10:18	TF760	Chlorophyll a (approx)	3.44	ug/L	1
DW021016-0091	10/16/2002 11:45	TF620	Chlorophyll a (approx)	1.37	ug/L	1
DW021016-0092	10/16/2002 12:20	TF1120	Chlorophyll a (approx)	1.21	ug/L	1
DW021030-0058	10/30/2002 7:45	TF620	Chlorophyll a (approx)	1.35	ug/L	1
DW021030-0055	10/30/2002 8:35	TF500	Chlorophyll a (approx)	1.48	ug/L	1
DW021030-0067	10/30/2002 12:05	TF760	Chlorophyll a (approx)	1.28	ug/L	1
DW021030-0064	10/30/2002 12:30	TF500	Chlorophyll a (approx)	1.44	ug/L	1
DW021031-0053	10/30/2002 16:20	TF760	Chlorophyll a (approx)	2.21	ug/L	1
DW021031-0052	10/30/2002 16:25	TF620	Chlorophyll a (approx)	1.92	ug/L	1
DW021031-0051	10/30/2002 16:50	TF500	Chlorophyll a (approx)	1.26	ug/L	1
DW021031-0054	10/30/2002 16:50	TF975	Chlorophyll a (approx)	3.31	ug/L	1
DW021031-0058	10/31/2002 10:10	TF760	Chlorophyll a (approx)	1.42	ug/L	1
DW021112-0060	11/12/2002 12:00	TF620	Chlorophyll a (approx)	4.73	ug/L	1
DW021112-0061	11/12/2002 12:30	TF975	Chlorophyll a (approx)	11.00	ug/L	1
DW021113-0059	11/13/2002 11:55	TF620	Chlorophyll a (approx)	1.94	ug/L	1
DW040819-0070	**8/19/2004 0:00**	**TF280**	**Chlorophyll a (approx)**	**70.26**	**mg/sqmeter**	**3**
DW040819-0069	**8/19/2004 0:00**	**TF280**	**Chlorophyll a (approx)**	**47.62**	**mg/sqmeter**	**3**
DW040819-0069	**8/19/2004 0:00**	**TF280**	**Chlorophyll a (approx)**	**47.62**	**mg/sqmeter**	**3**
DW040819-0070	**8/19/2004 0:00**	**TF280**	**Chlorophyll a (approx)**	**70.26**	**mg/sqmeter**	**3**

Sam_ID	DateTime	Site	Parameter	Value	Units	Wet/Dry
DW040819-0068	**8/19/2004 0:00**	**TF280**	**Chlorophyll a (approx)**	**40.53**	**mg/sqmeter**	**3**
DW040819-0067	**8/19/2004 0:00**	**TF280**	**Chlorophyll a (approx)**	**30.06**	**mg/sqmeter**	**3**
DW040819-0066	**8/19/2004 0:00**	**TF280**	**Chlorophyll a (approx)**	**57.93**	**mg/sqmeter**	**3**
DW040819-0071	**8/19/2004 0:00**	**TF280**	**Chlorophyll a (approx)**	**17.39**	**mg/sqmeter**	**3**
DW040819-0066	**8/19/2004 0:00**	**TF280**	**Chlorophyll a (approx)**	**57.93**	**mg/sqmeter**	**3**
DW040819-0084	**8/19/2004 0:00**	**TF680**	**Chlorophyll a (approx)**	**96.38**	**mg/sqmeter**	**3**
DW040819-0081	**8/19/2004 0:00**	**TF680**	**Chlorophyll a (approx)**	**84.20**	**mg/sqmeter**	**3**
DW040819-0086	**8/19/2004 0:00**	**TF680**	**Chlorophyll a (approx)**	**96.58**	**mg/sqmeter**	**3**
DW040819-0086	**8/19/2004 0:00**	**TF680**	**Chlorophyll a (approx)**	**96.58**	**mg/sqmeter**	**3**
DW040819-0085	**8/19/2004 0:00**	**TF680**	**Chlorophyll a (approx)**	**143.71**	**mg/sqmeter**	**3**
DW040819-0084	**8/19/2004 0:00**	**TF680**	**Chlorophyll a (approx)**	**96.38**	**mg/sqmeter**	**3**
DW040819-0083	**8/19/2004 0:00**	**TF680**	**Chlorophyll a (approx)**	**123.68**	**mg/sqmeter**	**3**
DW040819-0082	**8/19/2004 0:00**	**TF680**	**Chlorophyll a (approx)**	**154.40**	**mg/sqmeter**	**3**
DW040819-0081	**8/19/2004 0:00**	**TF680**	**Chlorophyll a (approx)**	**84.20**	**mg/sqmeter**	**3**
DW040819-0076	**8/19/2004 0:00**	**TF500**	**Chlorophyll a (approx)**	**59.94**	**mg/sqmeter**	**3**
DW040819-0074	**8/19/2004 0:00**	**TF500**	**Chlorophyll a (approx)**	**38.26**	**mg/sqmeter**	**3**
DW040819-0076	**8/19/2004 0:00**	**TF500**	**Chlorophyll a (approx)**	**59.94**	**mg/sqmeter**	**3**
DW040819-0075	**8/19/2004 0:00**	**TF500**	**Chlorophyll a (approx)**	**24.92**	**mg/sqmeter**	**3**
DW040819-0080	**8/19/2004 0:00**	**TF680**	**Chlorophyll a (approx)**	**96.73**	**mg/sqmeter**	**3**
DW040819-0072	**8/19/2004 0:00**	**TF280**	**Chlorophyll a (approx)**	**18.97**	**mg/sqmeter**	**3**
DW040819-0080	**8/19/2004 0:00**	**TF680**	**Chlorophyll a (approx)**	**96.73**	**mg/sqmeter**	**3**
DW040819-0073	**8/19/2004 0:00**	**TF280**	**Chlorophyll a (approx)**	**55.51**	**mg/sqmeter**	**3**
DW040819-0073	**8/19/2004 0:00**	**TF280**	**Chlorophyll a (approx)**	**55.51**	**mg/sqmeter**	**3**
DW040819-0077	**8/19/2004 0:00**	**TF500**	**Chlorophyll a (approx)**	**21.75**	**mg/sqmeter**	**3**
DW040819-0079	**8/19/2004 0:00**	**TF680**	**Chlorophyll a (approx)**	**139.24**	**mg/sqmeter**	**3**
DW040819-0079	**8/19/2004 0:00**	**TF680**	**Chlorophyll a (approx)**	**139.24**	**mg/sqmeter**	**3**
DW040819-0078	**8/19/2004 0:00**	**TF500**	**Chlorophyll a (approx)**	**29.48**	**mg/sqmeter**	**3**
DW040823-0058	**8/23/2004 10:45**	**TF280**	**Chlorophyll a (approx)**	**17.88**	**mg/sqmeter**	**1**
DW040823-0062	**8/23/2004 10:45**	**TF280**	**Chlorophyll a (approx)**	**39.19**	**mg/sqmeter**	**1**
DW040823-0061	**8/23/2004 10:45**	**TF280**	**Chlorophyll a (approx)**	**35.82**	**mg/sqmeter**	**1**
DW040823-0061	**8/23/2004 10:45**	**TF280**	**Chlorophyll a (approx)**	**35.82**	**mg/sqmeter**	**1**
DW040823-0060	**8/23/2004 10:45**	**TF280**	**Chlorophyll a (approx)**	**25.40**	**mg/sqmeter**	**1**
DW040823-0059	**8/23/2004 10:45**	**TF280**	**Chlorophyll a (approx)**	**30.73**	**mg/sqmeter**	**1**
DW040823-0063	8/23/2004 10:45	TF280	Chlorophyll a (approx)	2.78	ug/L	1
DW040823-0069	**8/23/2004 12:00**	**TF680**	**Chlorophyll a (approx)**	**151.42**	**mg/sqmeter**	**1**
DW040823-0068	**8/23/2004 12:00**	**TF680**	**Chlorophyll a (approx)**	**92.24**	**mg/sqmeter**	**1**
DW040823-0067	**8/23/2004 12:00**	**TF680**	**Chlorophyll a (approx)**	**117.10**	**mg/sqmeter**	**1**
DW040823-0066	**8/23/2004 12:00**	**TF680**	**Chlorophyll a (approx)**	**112.20**	**mg/sqmeter**	**1**
DW040823-0066	**8/23/2004 12:00**	**TF680**	**Chlorophyll a (approx)**	**112.20**	**mg/sqmeter**	**1**
DW040823-0065	**8/23/2004 12:00**	**TF680**	**Chlorophyll a (approx)**	**104.45**	**mg/sqmeter**	**1**
DW040823-0065	**8/23/2004 12:00**	**TF680**	**Chlorophyll a (approx)**	**104.45**	**mg/sqmeter**	**1**
DW040823-0070	8/23/2004 12:00	TF680	Chlorophyll a (approx)	2.69	ug/L	1
DW040826-0070	**8/26/2004 10:00**	**TF280**	**Chlorophyll a (approx)**	**78.45**	**mg/sqmeter**	**0**
DW040826-0073	**8/26/2004 10:00**	**TF280**	**Chlorophyll a (approx)**	**37.36**	**mg/sqmeter**	**0**
DW040826-0068	**8/26/2004 10:00**	**TF280**	**Chlorophyll a (approx)**	**37.56**	**mg/sqmeter**	**0**
DW040826-0068	**8/26/2004 10:00**	**TF280**	**Chlorophyll a (approx)**	**37.56**	**mg/sqmeter**	**0**
DW040826-0074	**8/26/2004 10:00**	**TF280**	**Chlorophyll a (approx)**	**18.74**	**mg/sqmeter**	**0**

Sam_ID	DateTime	Site	Parameter	Value	Units	Wet/Dry
DW040826-0071	**8/26/2004 10:00**	**TF280**	**Chlorophyll a (approx)**	**28.59**	**mg/sqmeter**	**0**
DW040826-0070	**8/26/2004 10:00**	**TF280**	**Chlorophyll a (approx)**	**78.45**	**mg/sqmeter**	**0**
DW040826-0075	8/26/2004 10:00	TF280	Chlorophyll a (approx)	2.09	ug/L	0
DW040826-0077	**8/26/2004 12:00**	**TF680**	**Chlorophyll a (approx)**	**175.64**	**mg/sqmeter**	**0**
DW040826-0076	**8/26/2004 12:00**	**TF680**	**Chlorophyll a (approx)**	**124.08**	**mg/sqmeter**	**0**
DW040826-0078	**8/26/2004 12:00**	**TF680**	**Chlorophyll a (approx)**	**100.75**	**mg/sqmeter**	**0**
DW040826-0080	**8/26/2004 12:00**	**TF680**	**Chlorophyll a (approx)**	**112.21**	**mg/sqmeter**	**0**
DW040826-0081	**8/26/2004 12:00**	**TF680**	**Chlorophyll a (approx)**	**126.93**	**mg/sqmeter**	**0**
DW040826-0081	**8/26/2004 12:00**	**TF680**	**Chlorophyll a (approx)**	**126.93**	**mg/sqmeter**	**0**
DW040909-0067	**9/8/2004 10:30**	**TF680**	**Chlorophyll a (approx)**	**31.64**	**mg/sqmeter**	**1**
DW040909-0068	**9/8/2004 10:30**	**TF680**	**Chlorophyll a (approx)**	**40.59**	**mg/sqmeter**	**1**
DW040909-0067	**9/8/2004 10:30**	**TF680**	**Chlorophyll a (approx)**	**31.64**	**mg/sqmeter**	**1**
DW040909-0066	**9/8/2004 10:30**	**TF680**	**Chlorophyll a (approx)**	**39.19**	**mg/sqmeter**	**1**
DW040909-0074	**9/8/2004 10:30**	**TF680**	**Chlorophyll a (approx)**	**41.55**	**mg/sqmeter**	**1**
DW040909-0073	**9/8/2004 10:30**	**TF680**	**Chlorophyll a (approx)**	**43.89**	**mg/sqmeter**	**1**
DW040909-0072	**9/8/2004 10:30**	**TF680**	**Chlorophyll a (approx)**	**81.97**	**mg/sqmeter**	**1**
DW040909-0070	**9/8/2004 10:30**	**TF680**	**Chlorophyll a (approx)**	**67.68**	**mg/sqmeter**	**1**
DW040909-0073	**9/8/2004 10:30**	**TF680**	**Chlorophyll a (approx)**	**43.89**	**mg/sqmeter**	**1**
DW040909-0071	**9/8/2004 10:30**	**TF680**	**Chlorophyll a (approx)**	**73.89**	**mg/sqmeter**	**1**
DW040909-0070	**9/8/2004 10:30**	**TF680**	**Chlorophyll a (approx)**	**67.68**	**mg/sqmeter**	**1**
DW040909-0069	**9/8/2004 10:30**	**TF680**	**Chlorophyll a (approx)**	**27.43**	**mg/sqmeter**	**1**
DW040909-0068	**9/8/2004 10:30**	**TF680**	**Chlorophyll a (approx)**	**40.59**	**mg/sqmeter**	**1**
DW040909-0071	**9/8/2004 10:30**	**TF680**	**Chlorophyll a (approx)**	**73.89**	**mg/sqmeter**	**1**
DW040913-0081	**9/13/2004 13:00**	**TF680**	**Chlorophyll a (approx)**	**144.74**	**mg/sqmeter**	**0**
DW040913-0080	**9/13/2004 13:00**	**TF680**	**Chlorophyll a (approx)**	**100.86**	**mg/sqmeter**	**0**
DW040913-0079	**9/13/2004 13:00**	**TF680**	**Chlorophyll a (approx)**	**57.86**	**mg/sqmeter**	**0**
DW040913-0082	**9/13/2004 13:00**	**TF680**	**Chlorophyll a (approx)**	**50.93**	**mg/sqmeter**	**0**
DW040913-0076	**9/13/2004 13:00**	**TF680**	**Chlorophyll a (approx)**	**105.72**	**mg/sqmeter**	**0**
DW040913-0075	**9/13/2004 13:00**	**TF680**	**Chlorophyll a (approx)**	**150.77**	**mg/sqmeter**	**0**
DW040913-0077	**9/13/2004 13:00**	**TF680**	**Chlorophyll a (approx)**	**93.84**	**mg/sqmeter**	**0**
DW040913-0078	**9/13/2004 13:00**	**TF680**	**Chlorophyll a (approx)**	**83.93**	**mg/sqmeter**	**0**
DW040913-0068	**9/13/2004 14:00**	**TF280**	**Chlorophyll a (approx)**	**43.09**	**mg/sqmeter**	**0**
DW040913-0072	**9/13/2004 14:00**	**TF280**	**Chlorophyll a (approx)**	**65.13**	**mg/sqmeter**	**0**
DW040913-0066	**9/13/2004 14:00**	**TF280**	**Chlorophyll a (approx)**	**65.34**	**mg/sqmeter**	**0**
DW040913-0071	**9/13/2004 14:00**	**TF280**	**Chlorophyll a (approx)**	**70.75**	**mg/sqmeter**	**0**
DW040913-0070	**9/13/2004 14:00**	**TF280**	**Chlorophyll a (approx)**	**43.97**	**mg/sqmeter**	**0**
DW040913-0069	**9/13/2004 14:00**	**TF280**	**Chlorophyll a (approx)**	**34.81**	**mg/sqmeter**	**0**
DW040913-0074	**9/13/2004 14:00**	**TF280**	**Chlorophyll a (approx)**	**27.08**	**mg/sqmeter**	**0**
DW040913-0073	**9/13/2004 14:00**	**TF280**	**Chlorophyll a (approx)**	**47.77**	**mg/sqmeter**	**0**
DW040917-0085	**9/17/2004 10:45**	**TF280**	**Chlorophyll a (approx)**	**118.93**	**mg/sqmeter**	**0**
DW040917-0086	**9/17/2004 10:45**	**TF280**	**Chlorophyll a (approx)**	**77.10**	**mg/sqmeter**	**0**
DW040917-0087	**9/17/2004 10:45**	**TF280**	**Chlorophyll a (approx)**	**89.27**	**mg/sqmeter**	**0**
DW040917-0088	**9/17/2004 10:45**	**TF280**	**Chlorophyll a (approx)**	**68.71**	**mg/sqmeter**	**0**
DW040917-0084	**9/17/2004 10:45**	**TF280**	**Chlorophyll a (approx)**	**28.42**	**mg/sqmeter**	**0**
DW040917-0083	**9/17/2004 10:45**	**TF280**	**Chlorophyll a (approx)**	**46.49**	**mg/sqmeter**	**0**
DW040917-0081	**9/17/2004 10:45**	**TF280**	**Chlorophyll a (approx)**	**43.72**	**mg/sqmeter**	**0**
DW040917-0082	**9/17/2004 10:45**	**TF280**	**Chlorophyll a (approx)**	**40.93**	**mg/sqmeter**	**0**

Sam_ID	DateTime	Site	Parameter	Value	Units	Wet/Dry
DW040917-0089	9/17/2004 10:45	TF280	Chlorophyll a (approx)	2.81	ug/L	0
DW040917-0095	**9/17/2004 12:00**	**TF680**	**Chlorophyll a (approx)**	**130.06**	**mg/sqmeter**	**0**
DW040917-0097	**9/17/2004 12:00**	**TF680**	**Chlorophyll a (approx)**	**122.21**	**mg/sqmeter**	**0**
DW040917-0094	**9/17/2004 12:00**	**TF680**	**Chlorophyll a (approx)**	**120.29**	**mg/sqmeter**	**0**
DW040917-0096	**9/17/2004 12:00**	**TF680**	**Chlorophyll a (approx)**	**101.43**	**mg/sqmeter**	**0**
DW040917-0090	**9/17/2004 12:00**	**TF680**	**Chlorophyll a (approx)**	**74.32**	**mg/sqmeter**	**0**
DW040917-0091	**9/17/2004 12:00**	**TF680**	**Chlorophyll a (approx)**	**82.73**	**mg/sqmeter**	**0**
DW040917-0092	**9/17/2004 12:00**	**TF680**	**Chlorophyll a (approx)**	**65.95**	**mg/sqmeter**	**0**
DW040917-0093	**9/17/2004 12:00**	**TF680**	**Chlorophyll a (approx)**	**58.40**	**mg/sqmeter**	**0**

Appendix J: List of Terms

a priori	latin, literally “from the former”; describing a hypothesis made without prior knowledge, before experimentation, or based upon assumption
Acute	describing an effect or response, such as toxicity, that is measured or occurs over a relatively short amount of time; not chronic
Adaptive management	Process of continually monitoring progress and adjusting the approach
Algae	any of a number of several groups of single-celled or multi-cellular organisms, all of which lack leaves, roots, flowers, and other organ structures that characterize higher plants.
Ammonia/ Ammonium	a Nitrogen-containing molecule that exists naturally in both gaseous (NH3) and ionized (NH_4+) forms. The gaseous form is corrosive and toxic, while the ionized form is a usable source of nitrogen for plant growth. Ammonia may be produced by decomposition of nitrogen-containing molecules such as proteins.
Amphipoda	an order of small, shrimp-like crustaceans
Anadromous	describes fishes that migrate from salt water to fresh water to spawn or reproduce
Anoxic	lacking oxygen; especially water lacking dissolved oxygen
Anthropogenic	man-made or human in origin; influenced by mankind
Aquatic	relating to water, particularly freshwater
Aquifer	An underground geologic feature containing water
Autotroph/ Autotrophic	Describes organisms that can produce their own food, such as plants, algae or certain specialized bacteria.
Bankfull discharge	The high flow stage of a fluvial system distinguished by the highest stage elevation a stream can reach before spilling over. In fluvial geomorphology, the bankfull stage is used to describe the flow stage that is most important in shaping the stream channel. Often defined as the flow with recurrence interval 1.3-1.5 years on average, but urbanization tends to decrease this interval.
Baseflow	flow in a stream that is not influenced by precipitation
Basic	alkaline; containing oxide or hydroxyl ions; not acidic

Benthic	Used to describe aquatic organisms living at the bottom of a body of water
Benthic macroinvertebrates	Aquatic insect larvae that live on stream bottom. Because of a short lifespan and relative immobility, they reflect the chemical and physical characteristics of a stream and chronic sources of pollution.
Bioaccumulation	describes the condition or process through which living things concentrate substances, such as toxins, in excess of ambient concentrations
Bioassessment	an evaluation technique that uses measures of the structure, condition, or distribution of biological communities
Bioavailable	describes a substance, such as a pollutant, that can be taken up or incorporated by living things.
Bioindicator	an organism that exhibits sensitivity or tolerance of environmental conditions and may be used in assessing an environmental condition, such as water pollution
Biotic	living, relating to life or biology
BMP -	Best Management Practice – Also called a "management option," BMP is a technique, measure, or structural control that addresses one or more objectives (e.g., a detention basin that gets built, an ordinance that gets passed, and an educational program that gets implemented).
BOD	biological or biochemical oxygen demand, an empirical test procedure that measures the ability of a water sample to deplete oxygen
BOD_{30}	a BOD test that is carried out over 30days
BOD_5	a BOD test that is carried out over 5 days
Caddisfly	an insect of the order Trichoptera, a group of insects usually having an aquatic life stage which are generally sensitive to organic pollution. Often used as a bioindicator of organic pollution.
Cadmium	(Cd) a toxic heavy metal element
Calcium	(Ca) a metallic element found in limestone and numerous naturally occurring compounds
$CaCO_3$	Calcium Carbonate
Catadromous	describes fishes that migrate from fresh water to salt water to spawn or reproduce

Cation	a positively charged ion. Common cations in streamwater are Calcium (Ca) and Magnesium (Mg)
Catchment	see Drainage area
CBOD	carbonaceous oxygen demand; a BOD test in which oxidation of nitrogen is inhibited
CCD	County Conservation District(s)
CCTV	Closed Circuit Television
Channelization	the process of modifying the natural course of a stream in order to make it flow into or along a restricted path
Chlorophyll	any of a group of green pigments necessary for photosynthesis, concentrations of which are used as a surrogate measurement of producer biomass
Chl-*a*	chlorophyll-α, a form of chlorophyll that is found universally in autotrophic organisms
Chironomid	a midge; a small fly of the family Chironomidae, many of which are used as bioindicators of water pollution
Chromium	(Cr) a heavy metal element, occurring naturally in trivalent [CrIII] and hexavalent [CrIV] forms. The latter form is highly toxic
Chronic	describing an effect or response, such as toxicity, that occurs or can be measured over a relatively long period of time; not acute
Cladocera/ Cladoceran	an order of microcrustaceans that are common zooplankton in fresh water and used in toxicity testing
Clay	inorganic sediment particles smaller than 0.002mm
CO_3^{2-}	carbonate ion
Cobble	a stream particle with diameter between 64 and 256mm
Coliform	of or relating to the bacilli (bacteria) that inhabit the intestines of warm-blooded animals
Collector-gatherer	a functional feeding group of aquatic organisms characterized by feeding upon particulate matter that is gathered or manipulated rather than filtered from flowing water by specialized appendage or apparatus
Conductance/	a measure of the ability of a water sample to conduct an electric current; a

Conductivity	measure of dissolved ionic strength
Copper	an essential metallic nutrient that can be toxic in relatively small concentrations
Criterion	an established standard, such as concentration of a pollutant, that is limited or regulated by law
Crustacea/ Crustacean	a class of arthropods that includes shrimp, crabs, crayfish and many types of zooplankton
CSO	Combined Sewer Overflow
CSS	Combined Sewer System
Culvert	a metal, concrete, or plastic pipe that allows water to flow under a road or any other obstruction
CWA	Clean Water Act –Federal Amendment that authorizes EPA to implement pollution control programs and set water quality standards for all contaminants in surface waters. "The Act made it unlawful for any person to discharge any pollutant from a point source into navigable waters, unless a permit was obtained under its provisions. It also funded the construction of sewage treatment plants under the construction grants program and recognized the need for planning to address the critical problems posed by nonpoint source pollution." (EPA website)
CWA Section 104(b)(3) Program	Promotes the coordination and acceleration of research, investigations, experiments, training, demonstrations, surveys, and studies relating to the causes, effects, extent, prevention, reduction and elimination of pollution.
CWA Section 208 Wastewater Planning	Intended to encourage and facilitate the development and implementation of area-wide waste treatment management plans.
CWA Section 319(b) Non-point Source Management Program	Designed to address mine drainage, agricultural runoff, construction/urban runoff, hydrologic and habitat modifications, on-lot wastewater systems, and silviculture.
Daphnia	a genus of small cladoceran; common in ponds/lakes, used in toxicity testing
DCIA	Directly Connected Impervious Area
Deamination	a stage in the decomposition of protein in which amine groups are removed, usually through hydrolysis; produces ammonia

Decomposition	decay; process through which a complex substance, such as dead organic matter, is broken down into smaller molecules
Defective lateral	a plumbing problem in which a lateral pipe is damaged, potentially leading to sanitary waste in a storm sewer and the receiving water body
Designation/ Designated Use	describes the uses a waterbody is intended to support, such as stocking trout for recreational fishing
Detection limit/ Method Detection Limit (MDL)	the smallest amount of a substance that can be measured with a laboratory technique or instrument (see method reporting limit)
Diatom	Single-celled alga of the class bacillariophyceae, having a cell wall composed of silica. Diatoms are primary producers in streams and lakes.
Diffusion	spontaneous, random movement of molecules that tends to result in equalization of concentrations over time as net movement occurs from areas of greater concentration to areas of lower concentration
Diluent/Dilutant	a thinning agent, such as water, which reduces the concentration of a solution. Pollution may be diluted by streamwater.
Dilute/Dilution	the process through which a solution is made less concentrated through the addition of a diluent/dilutant
Discharge	Flow; a measure of the volume of water flowing through a defined area in a given time. Discharge is often abbreviated as Q, and measured in cubic feet per second (cfs)
Dissolve	cause to pass into solution. In laboratory testing, substances may be considered dissolved if they pass through a 0.45µm filter
Diurnal	Relating to or occurring in a 24-hour period; daily.
DO	Dissolved Oxygen
Drainage area	The area of land that drains to a particular body of water or site on a waterbody.
DRBC	Delaware River Basin Commission
DVRPC	Delaware Valley Regional Planning Commission
DWO	Dry-Weather Outlet - connector pipe between a CSO regulator and interceptor sewer.
Dynamic	relating to conditions that change or are in motion; not static

E. coli	a common rod-shaped bacterium that is found in the intestinal tract of warm blooded animals. Used as an indicator of contamination by feces/sewage.
EACs	Environmental Advisory Councils
Ecoregion	a relatively large area of land characterized by a unique set of communities, physical, and climatological characteristics
Ecosystem	a collection of living things and their environment
Ecotoxicology	the study of environmental toxins
Effluent	outflow of liquid waste, such as discharge from a sewage treatment plant
Empirical	of or related to direct observation; not theoretical
Encapsulated	enclosed or covered, such a stream that has been built into a sewer
Endogenous	coming from or produced wholly from within, such as an enzyme produced by bacteria
E.P.A.	United States Environmental Protection Agency
EPT	(Ephemeroptera + Plecoptera + Trichoptera) three insect orders that are generally sensitive to organic pollution and are used to measure stream water quality
Epifaunal	of or relating to stream surfaces upon which attached alga and other living things may grow or find shelter
Epiphyte	a type of plant or algae that grows upon another plant or algae
Equilibrium	a steady state or condition in which opposing influences balance one another out
Erosion	the process by which soil particles are removed or displaced, usually by wind or water
Estuary	a body of water intermediate between an ocean and river, usually tidal and highly productive
ET	Evapotranspiration – the sum of water vapor evaporation from the earth's surface and transpiration from plants.
Eutrophic	characterized by abundant or overabundant life, such as a stream or river that is nutrient enriched and has dense growth of algae or aquatic vegetation

Eutrophication	the process through which a waterbody comes to have an overabundance of life, usually caused by nutrient enrichment
EVAMIX	A multi-criteria evaluation program to help choose objectively between various alternatives
FGM	Fluvial Geomorphology is the study of a stream's interactions with the local climate, geology, topography, vegetation, and land use; the study of how a river carves its channel within its landscape.
Filamentous	characterized by an elongated, sometimes repeating growth pattern, such as that exhibited by some types of green and blue-green algae
Filterer-collector	a functional feeding group of aquatic organisms characterized by feeding upon particulate matter that is filtered from flowing water by specialized appendage or apparatus, such as a silken net
Fluvial	of or relating to flowing waters, especially rivers
Floatables	Waterborne waste material and debris (e.g., plastics, polystyrene, paper) that float at or below the water surface.
Functional feeding group	a group of aquatic organisms defined by a common feeding strategy, such as predation on other living things
Generalist	describes a species that tolerates a broad range of environmental conditions
Geometric mean	A measure of the central tendency of a set of numbers defined as the product of all numbers of the set raised to a power equal to the reciprocal of the total number of members of the set. The geometric mean is always smaller than the Arithmetic mean
GIS	Geographic Information Systems
H_2CO_3	Carbonic acid
Handheld DO	Dissolved oxygen readings taken with a handheld meter.
Hardness	a measure of the concentration of Calcium and Magnesium ions in water
HCO_3-	Bicarbonate ion
Heterotrophic	describes organisms that cannot synthesize their own food through photosynthesis or other chemical means
Hexavalent	having valence number 6, such as hexavalent Chromium, a toxic metal
Hilsenhoff Biotic	A biological index of stream health that employs a scale of sensitivity of

Index (HBI)	macroinvertebrates to organic pollution
HNO_3	nitric acid, a source of atmospheric nitrogen pollution and acid rain
HSI	Habitat Suitability Indices
Humic	derived from decomposing organic matter, such as leaf litter.
Hydraulic	of or relating to forces exerted by a fluid, often water, under pressure
Hydrograph	A graphical representation of the change in stage or discharge of a stream as a function of time
Hydrolysis	a chemical reaction in which water reacts with another molecule, often resulting in new compounds. The breakdown of urea is a hydrolytic reaction
Hyetograph	a graphical representation of rainfall intensity as a function of time
IDD&E	Illicit Discharge, Detection, and Elimination – one of the six minimum control measures required of permittees under the Phase II NPDES Stormwater Regulations. Program steps include developing maps of municipal separate storm sewer system outfalls and receiving waterbodies; prohibiting illicit discharges via PADEP-approved ordinance; implementing an IDD&E Program that includes a field screening program and procedures, and elimination of illicit discharges; conducting public awareness and reporting program. A similar program is being followed by PWD in the Long Term Control Plan (LTCP) for CSOs.
Illicit connection	An illegal sewer connection, particularly connection of a sanitary sewer, household or industrial waste pipe to a storm sewer. Illicit connections may result in sewage or other pollution inputs to receiving waterbodies.
Impairment	weakening, damage, or instability, such as the effects caused by pollution
Impervious	incapable of being penetrated, such as a surface that does not absorb water
in situ	Latin, literally “in place”, refers to types of measurements and observations made directly in the natural environment, such as a water quality instrument installed in a stream
Index/Indices	A number, ratio, or value on a scale of measurement that can reveal differences between observations or reveal changes over time. Numerous indices are used to assess the health of aquatic communities, such as the Hilsenhoff Biotic Index or HBI

Infrastructure	The basic system of utilities and services needed to support a society. Structures such as culverts, pipes, bridges, dams, and flood control measures can cause instability of streams and affect aquatic habitats.
Inimical	harmful; injurious
Insoluble	unable to pass into solution
Instantaneous	immediate; occurring, such as a change, quickly. Some continuous water quality parameters are observed instantaneously
Invertebrates	animals, such as insects and crustaceans, that lack backbones (vertebrae)
Ion	an atom or molecule that has lost or gained an electron or electrons, resulting in a charged state
IPM	Integrated Pest Management
Iron	(Fe) a common metallic element; an essential nutrient that may be toxic in relatively large concentrations. Iron can cause problems with taste and color of drinking water.
Kjeldahl nitrogen test	a laboratory procedure for determining the concentration of ammonia and organically-bound nitrogen in a water sample
Kruskal-Wallis ANOVA	a non-parametric test that can be used to compare sample means when the assumptions of parametric statistics are not met
Larva/larvae	Immature life stage of an invertebrate, such as a beetle or fly. Many insects that have aquatic larval stages are used as bioindicators of water pollution.
LD50	in toxicity testing, an endpoint, such as toxin concentration, where 50% of the test organisms die over a specified exposure interval
Lentic	of or relating to still water, such as lakes, ponds, or bogs
LID	Low-Impact Development (similar to "better site design" and "conservation site design")
Ligand	An atom or molecule that can form a bond with a one or more central atoms (usually metals), forming a complex. Naturally occurring ligands compete with gill surface interaction sites for metals and metallic ions, reducing metal toxicity
Lotic	of or relating to flowing water, such as streams and rivers
LTCP	Long-Term CSO Control Plan – part of the EPA's CSO Control Policy for

	regulation of CSOs under NPDES that guides municipalities, state, and federal permitting agencies in reaching full compliance with the CWA.
Macroinvertebrates	Macroinvertebrates are invertebrate animals that can be seen without the aid of a microscope.
Macronutrient	a nutrient, such as nitrogen or phosphorus, needed in relatively large amounts for biological growth
Magnesium (Mg)	a common cation that contributes to hardness in water
Mainstem	the main flow or central channel of a stream drainage network into which tributaries flow
Manganese	a relatively common metallic element; an essential nutrient that may be toxic in relatively large concentrations
Mayfly	Aquatic insect of the order Ephemeroptera. Mayflies are recognized as being generally sensitive to pollution and are used as indicators of water pollution
Mean/ Arithmetic mean	average; a measure of the central tendency of a set of numbers equal to the sum of all members of a set divided by the number of members of the set
Median	In descriptive statistics, the value in a set of numbers for which half the members of the set are greater and half are smaller. In some instances, the median value may be more informative than the arithmetic mean if a small number of extreme values tends to skew the mean
Mesotrophic	characterized by a moderate amount of biological growth; not eutrophic
Metabolism	all the biochemical processes exhibited by a living organism
Methemoglobinemia	A medical condition in which the oxygen carrying capacity of hemoglobin is disrupted by a faulty gene or exposure to toxins. Infants are especially susceptible to methemoglobinemia due to exposure to nitrates, a condition termed “blue baby syndrome”
mhos	A unit of electrical conductance; a measure of the ability to pass electric current. Water itself is an insulator, but dissolved ions increase its ability to conduct electricity
Microcrustacean	A crustacean that is not readily visible to the unaided eye
Microgram (µg)	A unit of mass equivalent to 1/1,000,000 of a gram
Microhabitat	Fine scale habitat, features of which are important to small living things

Micronutrient	A nutrient, such as a trace metal, needed in relatively small concentrations for biological growth. Micronutrients may limit growth if macronutrients are very abundant
Microorganism	An organism, such as a bacterium or alga, that is observable only under magnification
Microsiemen (µS)	A unit of electrical conductance, Microsiemens/cm is a common unit of measure in water chemistry.
Minnow	Any of a number of species of fish, typically small, of the family Cyprinidae. Minnows are an important link in the aquatic ecosystem, consuming invertebrates and being preyed upon by larger fish
Model	A useful representation, such as a computer simulation, that can be used to simplify and study systems and processes
MPC	Municipalities Planning Code
MRL	Method reporting limit, a measure of the accuracy of a laboratory procedure that takes actual test conditions and characteristics of the environmental sample into account. MRLs are always smaller than method detection limits (MDLs) and may change from laboratory to laboratory or from day to day depending upon the actual performance of an instrument or technique
MS4	Municipal Separate Storm Sewer System
NH_3	Ammonia (gaseous, un-ionized)
NH_4+	Ammonium ion
Nitrate (NO_3)	An oxidized form of Nitrogen; an essential plant nutrient. Elevated Nitrate concentration may result in eutrophication of water bodies and in very great concentrations may be toxic (see methemoglobinemia)
Nitrification	Process of converting ammonia to nitrite and nitrate in the presence of oxygen, especially by the action of naturally occurring bacteria
Nitrite (NO_2-)	An oxidized ion of nitrogen; an intermediate form in the reaction that converts ammonia to nitrate. Nitrite is usually not available for plant growth
Nitrogen	A macronutrient needed for biological growth. Inert nitrogen gas makes up a large portion of the Earth's atmosphere
NLREEP	Natural Lands Restoration and Environmental Education Program (a unit of Philadelphia's Fairmount Park Commission)

NOAA	National Oceanic and Atmospheric Administration
Nonferrous	not containing iron; especially metals and alloys that do not contain iron
Nonparametric statistics	a collection of statistical analysis tools, used when the data to be analyzed do not meet the assumptions of parametric statistics, such as homogeneity of variances
Non-point source pollution	Pollution that comes from a diffuse source such as atmospheric deposition, stormwater runoff from pasture and crop land, or individual on-lot domestic sewage systems discharging through shallow groundwater.
Non-structural BMPs	These BMPs will require no operation or maintenance. Examples are use of open space and vegetated buffers in development design, minimization of soil disturbance and compaction during construction, and minimization of directly-connected impervious areas.
NPDES	National Pollutant Discharge Elimination System
NPDES Phase I	The stormwater management component of the NPDES program instituted in 1990, which addressed the storm runoff sources most threatening to water quality. Under this phase, industrial activity, and construction sites within large communities (population 100,000 or more) are required to obtain permits for the storm water leaving the site.
NPDES Phase II	Additional stormwater management regulations enacted in 1999, applying to smaller communities and construction sites.
NRCS	Natural Resource Conservation Service
NTU	nephelometric turbidity units; a unit of measure describing the light scattering properties of a water sample
Nutrient	An element or molecule needed for biological growth. When nutrients such as phosphorus are present in great concentrations, biological growth (algae in particular) can become overabundant, causing problems for aquatic ecosystems
Oligotrophic	characterized by a relatively small amount of biological growth
OLDS	On-Lot sewage Disposal Systems
O&M	Operations and Maintenance
OOW	PWD’s Office of Watersheds
Orthophosphate	a dissolved, inorganic form of phosphorus, available as a nutrient for

(OPO_4)	plant growth; soluble reactive phosphorus
Outfall	a pipe or other structure that discharges flow, such as treated sewage effluent or stormwater, to receiving waters
Outlier	in statistics, a data point or observation that is far away from the rest of the data. Statistical techniques can be used to identify and remove outliers from a data set, if desired
Oxidation	chemical process in which a molecule or atom reacts with oxygen or generally, a reaction in which an atom loses electrons and increases in valence state; the opposite of a reduction reaction
Oxygen	an element, common in Earth's atmosphere and dissolved in water, necessary for most forms of complex animal and plant life
PA Act 167	Stormwater Management Act
PA Act 537	Sewage Facilities Planning Act
PADCNR	Pennsylvania Department of Conservation and Natural Resources
PADEP	Pennsylvania Department of Environmental Protection
Parameter	A chemical constituent or physical characteristic of water quality (*e.g.*, dissolved oxygen is a chemical constituent, temperature is a physical characteristic)
Parametric statistics	a collection of powerful statistical tools that assume certain qualities of the data being analyzed, such as homogeneity of variances
Parasite	a functional feeding group of aquatic organisms characterized by feeding usually upon bodily fluids of other organisms, rather than direct predation and consumption. The organism that is fed upon need not die due to the effects of feeding
PEC	Pennsylvania Environmental Council
Periphyton	collectively, the algae growing upon stream surfaces; a group or growth form of algae defined by a bottom or surficial growth habit
PFBC	Pennsylvania Fish and Boat Commission
Phenolics	Any of a group of aromatic compounds having at least one hydroxl group**.** Phenolics in surface waters generally originate from industry and are toxic in relatively small concentrations.
Phosphatases	any of a group of enzymes, such as those produced by some algae, that can convert or liberate phosphorus from an organically bound to soluble, usable form

Phosphate	An oxidized form of phosphorus, which may be organic or inorganic. Inorganic phosphates are generally more likely to be available as nutrients for biological growth
Photosynthesis	A set of chemical reactions in which plants and other organisms, such as blue-green algae, can synthesize their own food using light and inorganic carbon. Photosynthetic activity in water increases dissolved oxygen concentration during daylight hours.
Physicochemical	physical and chemical properties of water; a term used to group water quality parameters of interest
Phytoplankton	collectively, algae suspended in water; a group or growth form of algae defined by passive or active suspension in the water column
PO_4	phosphate
Point source	Pollution discharged from a single point, defined in the CWA as "any discernable, confined and discrete conveyance, including but not limited to any pipe, ditch, channel, tunnel, conduit, well, discrete fissure, container, rolling stock, concentrated animal feeding operation, vessel, or other floating craft from which pollutants are or may be discharged."
Potassium (K)	an elemental macronutrient required for biological growth
POTW	Publicly Owned Treatment Works
PRD	Planned Residential Development
Predator	a functional feeding group of aquatic organisms characterized by actively feeding upon captured prey
Preferenda/ preferendum	a preferred environmental condition, such as the temperature range an organism will tend to occupy when presented with a gradient
Producers	collectively, the components of an ecosystem, predominantly plants and plant-like living things, that make their own food by chemical means from inorganic building blocks; the base of the food chain
Productivity	a measure of the amount of biological growth that occurs in an ecosystem
PWD	Philadelphia Water Department
QA/QC	Quality Assurance/Quality Control
RBP	Rapid Bioassessment Protocol (developed by the EPA) a standard method to assess aquatic health through fish and macroinvertebrate diversity (EPA Website).

RBPIII	(Rapid Bioassessment Protocol III) EPA approved technique for evaluating macroinvertebrate communities of a river or stream
RBPV	(Rapid Bioassessment Protocol V) EPA approved technique for evaluating the fish communities of a river or stream
RCP	PA DCNR’s Rivers Conservation Planning Program
Reach	a segment of a stream as defined by the study being undertaken
Recoverable	a substance, such as a metal, that can be removed, dissolved or taken away in a chemical reaction or physical process
Redfield ratio	an approximation of the relative molar concentrations of the most common elements (Carbon, Nitrogen, and Phosphorus) present in organic matter, usually expressed as 106:16:1
Reduction	a reaction in which an atom or molecule gains electrons, decreasing valence state; not oxidation
Reference	A condition or value used for comparison. Many types of biological assessment techniques require comparison to references
Regulator	in sewer infrastructure, a physical gate, valve, or other control structure that routes flow between two or more receiving pipes, usually one of which terminates in a CSO
Replicate	additional sample(s) or observation(s) which can be used to measure the accuracy or repeatability (precision) of an experimental result
Respiration	biological metabolic process in which a large molecule is broken into smaller pieces to yield usable energy. Aerobic respiration, the efficient respiration reaction favored by complex living things, requires oxygen.
Riffle	a reach of stream that is characterized by shallow, fast moving water broken by the presence of rocks and boulders
Riparian	related to, within, or near a river or its banks
Riparian corridor	The area of land along the bank or shoreline of a body of water (EPA website).
Riparian woodlands	Woodlands that grow within the riparian corridor.
RTC	Real Time Control - a dynamic system of hydraulic controls to provide additional storage and reduce overflows from a combined sewer system
Run	a reach of stream that is characterized by smooth flowing water

Runoff	generally, precipitation that is not absorbed by surfaces or evaporated, but allowed to flow over the surface to a receiving body of water
Scraper	a functional feeding group of aquatic organisms characterized by feeding upon living attached material, usually algae, by means of a specialized scraping apparatus or mouthparts
Sediment	particles, especially inorganic soil particles, that settle upon stream surfaces
SEO	Sewage Enforcement Officers (designated by PADEP)
Seston/Sestonic	of or relating to the collection of inorganic and organic particles that settle to the bottom of a body of water; usually used to describe the predominantly organic detrital particles that settle to the bottom of a lake or pond.
Shear	generally, the physical force applied perpendicularly or at an angle to a surface, such as the hydraulic force applied to stream banks and surfaces by flowing water
Shredder	a functional feeding group of stream invertebrates that consume coarse particulate matter, such as leaves
Sinuosity	a measure of the degree to which a stream, viewed from above, deviates from a linear path, expressed as the ratio of stream length between two points divided by the valley length, or point-to-point distance between the same two points
Slough	to scour or remove from a surface, such as the removal of surficial algae by physical hydraulic force
Significant	when describing the results of scientific or experimental study, describes a comparison or relationship that has been determined to be more likely real than related to randomness or chance to a stated degree of confidence
Silt/Siltation	Inorganic sediment particles between 3.9 and 62.5 µm in diameter. also the process of being covered by or embedded in silt
SOD	sediment oxygen demand; a measure of the oxygen depleting capabilities of decomposing organic material and oxidizable inorganic material in sediment, often expressed as a mass of oxygen per unit area over time
Soluble/Solubility	The quality or state of being able to pass into solution. In water chemistry analysis, a substance may be considered soluble or dissolved if it passes through a 0.45µm filter
Sonde	a continuous water quality monitoring instrument

Speciation	the process of distinguishing between different forms of a substance through analytical or chemical means; or the process through which a substance is converted to two or more different forms
Species	the level of biological taxonomic classification at which living things are separated from one another by the ability to reproduce yielding fertile offspring
SRP	soluble reactive phosphorus; see orthophosphate
SSA	Separate-Sewered Area stormwater runoff
SSET	Sewer Scanner and Evaluation Technology
SSMS	Sanitary Sewer Management System
SSO	Sanitary Sewer Overflow
Stage	level of a stream's water surface, as measured on a gauge or reference datum
Stonefly	An insect of the order Plecoptera, a group of insects usually having an aquatic life stage which are generally sensitive to organic pollution. Often used as a bioindicator of organic pollution.
STORET	USEPA's water quality database (STOrage and RETrieval)
Stormwater Management Program Protocol ("Protocol")	PADEP guidance for implementing the requirements of the NPDES Phase II stormwater regulations
Structural BMPs	These BMPS will require proper operation and maintenance. Examples include wet ponds, grassed swales, infiltration basins and bioretention areas.
Substrate	a surface upon which living things grow; commonly, the bottom of a stream or river
Supersaturation	the condition in which a substance, such as dissolved oxygen, is dissolved in a solvent in a concentration exceeding the usual maximum concentration for the solute under given conditions. When algae are very abundant, they may increase dissolved oxygen concentration to the point of supersaturation
SWMM	Storm Water Management Model
Taxon/taxa	a distinct unit of biological taxonomic organization, such as a family or species

TDR	Transfer of Development Rights
Temporal	of or relating to time, such as a change observed over time
TIGER	Topologically Integrated Geographic Encoding and Referencing (U.S. Census database)
Tipulid	cranefly; an insect of the family Tipulidae, of which many secies are aquatic or semi-aquatic as larvae
TMDL program	Total Maximum Daily Load program - EPA/PADEP program for limiting and allocating discharges of a pollutant within a watershed.
TOC	total organic carbon
Toxic/toxicity	describing a substance that is harmful, able to cause injury or death; also the concentration at which a substance may cause injury or death
Transpiration	The process by which water vapor passes through the membrane or pores of plants to the atmosphere.
Trivalent	having valence 3, such as Cr[III], a non toxic, trace nutrient form of Chromium
Trophic	describing or relating to food, food type, or the process through which a living thing acquires food
TSS	Total Suspended Solids
TTFIWMP	The Tookany/Tacony-Frankford Integrated Watershed Management Plan
Turbidity	a measure of the light scattering properties of water
UA	Urban Areas
UAA	Use Attainability Analysis
Unimpaired	natural, unmolested; describing an unaltered or undisturbed state
Urea	a nitrogen-containing breakdown product of protein metabolism
USDA	United States Department of Agriculture
USGS	United States Geological Survey
Velocity	a vector quantity that describes speed in a stated direction or along an axis
Vertebrate	a complex living thing having a backbone (vertebrae)

Violation	an instance or time period during which a regulated water quality parameter was exceeded
Watershed	The area of land draining to a stream, river, or other water body. Watershed boundaries are established where any precipitation falling within the boundary will drain to a single water body. Precipitation falling outside the boundary will drain to a different watershed. These boundaries are typically formed on high elevation ridges. The water bodies formed from the watershed drainage are usually at the lowest elevation in the watershed. Watersheds can also be called drainage basins.
WLA	waste load allocation
WMP	Watershed Management Plan
WQS	Water Quality Standards
WRAS	PADEP's Watershed Restoration Action Strategy

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Supplemental Documentation
Volume 13

TTF Integrated Watershed Management Plan

Updated: September 1, 2009

Tookany/Tacony-Frankford Integrated Watershed Management Plan

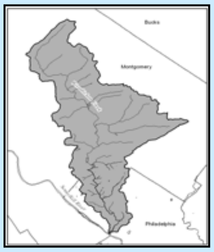
December 2005

Prepared by:

Philadelphia Water Department
Tookany/Tacony-Frankford Watershed Partnership

Cobbs Watershed

Tookany/Tacony-Frankford Watershed



Wissahickon Watershed

Pennypack Watershed

Poquessing Watershed

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TTFIWMP User Guide

Below is a brief orientation to the type of content found in each section of this report. These "snapshots" are repeated on the first page of each section as well.

Section 1: Background

Details the reasons for developing the Tookany/Tacony-Frankford Integrated Watershed Management Plan, or TTFIWMP, and the purposes the plan is intended to serve. Provides an orientation to various facets of the TTF Watershed itself (geographical, ecological, historical, cultural, etc.), and describes the TTF Partnership, which was involved throughout the plan's development and will be instrumental to its implementation. Finally, the overall watershed planning and regulatory framework is outlined in Sections 1.4 – 1.7.

Section 2: Integrated Watershed Management for the TTF Watershed

Describes the watershed planning approach behind the TTFIWMP. Outlines the types of existing and new data that were assembled and analyzed, as well as the process for modeling stormwater flow under various scenarios. Introduces several key concepts of the TTFIWMP: the overall goals and objectives (detailed in Section 3), the 21 watershed "indicators" (Section 4); and the screening of numerous methods, or "management options," for meeting the goals (Section 7). In addition, introduces the approach of setting multiple strategies – Targets A, B, and C – for promoting successful implementation of the TTFIWMP.

Section 3: Goals and Objectives

Describes the process for setting overall watershed goals for the TTFIWMP, as well as numerous objectives for helping to reach those goals. The seven prioritized goals, referenced throughout this document, are useful for evaluating the wide range of possible management options for implementing the plan.

Section 4: Watershed Indicators: TTF Study Results

Details the 21 measurable "watershed indicators" that were created in order to assess historic and current conditions, and to track progress as the TTFIWMP is implemented over time. The information presented can serve as a basis for understanding the state of the TTF Watershed, its relative environmental quality, and trends in the management of factors that influence its quality.

Section 5: Problem Definition and Analysis

The watershed indicators described in Section 4 are used both to characterize the current state of the TTF Watershed, and to set a baseline for future comparison. Section 5 identifies the wide range of potential problems that have been identified in the watershed, and describes the analysis tools used to define them.

Section 6: Causes of Impairment

Discusses the causes of the various watershed problems identified through field study, stakeholders input, modeling, and data analysis. This section forms the link between the problem analysis presented in Section 5, and the identification of alternative solutions, or management options, presented in Section 7.

Section 7: Development and Screening of Management Options

Summarizes a comprehensive list of stormwater and watershed corrective measures, or "management options," that the TTF Watershed Partnership judged to be potentially applicable to their watershed. This list serves as the starting point for the screening and evaluation steps (Section 7.2) that lead to the array of recommendations contained in the Implementation Guidelines (Section 8).

Section 8: Implementation Guidelines

Presents guidelines for watershed-wide implementation of the management options identified by the Tookany/Tacony-Frankford Watershed Partnership as best meeting the goals and objectives of the TTF Integrated Watershed Management Plan. Following extensive screening and evaluation (described in Section 7), only those options that are likely to be cost-effective and feasible under the specific conditions found in the TTF Watershed are carried over and included in these guidelines. The section begins with tips on how to navigate the information presented.

Section 9: Cost and Institutional Analysis

Presents cost estimates for the various recommended management options, and for the full set of Implementation Guidelines (from Section 8). Those cost estimates are then broken down by county and by municipality within the TTF Watershed. Finally, the section outlines the primary roles and responsibilities for the various levels of stakeholders in the implementation of the TTFIWMP.

Executive Summary

Tookany/Tacony-Frankford Integrated Watershed Management Plan (TTFIWMP)

Foreword

This plan presents a logical and affordable roadmap for the restoration and protection of the beneficial and designated uses of the Tookany/Tacony-Frankford Creek basin. The Tookany/Tacony-Frankford Integrated Watershed Management Plan (TTFIWMP) is based on extensive physical, chemical, and biological assessments. It explores the nature, causes, severity, and opportunities for control of water quality impairments in the TTF Watershed. The primary intent of this planning process is to improve the environmental health and safe enjoyment of the Tookany/Tacony-Frankford Creek by sharing resources and through cooperation among residents and other stakeholders in the watershed.

The goals of the initiative are to protect, enhance, and restore the beneficial uses of the Tookany/Tacony-Frankford waterway and its riparian areas. This plan recommends appropriate remedial measures for the Tookany/Tacony-Frankford Creek basin and a financial commitment to initiate implementation of recommendations right away. This planning process has sought to provide the impetus for stakeholders of the Tookany/Tacony-Frankford basin to follow suit.

The Philadelphia Water Department conducted a comprehensive, multi-year assessment of the Tookany/Tacony-Frankford Watershed (see Figure E.1). Results of the watershed-wide assessment suggests that at some times during dry weather periods, bacteria contamination of the Tookany/Tacony-Frankford's waters prevents the achievement of water quality standards that would support swimming or other forms of primary contact recreation in the creek. (For a detailed account of the assessment methodology and data results, see the 2004 Tookany/Tacony-Frankford Comprehensive Characterization Report.) Stream aesthetics, accessibility, and safety are compromised due a number of factors, including litter and illegal dumping, trash from stormwater discharges, channelization of portions of the stream, and bank deterioration along stream corridors. The existing aquatic and riparian habitats have been degraded by urban runoff, limiting the diversity of fish and other aquatic life and preventing the development of healthy living resource conditions necessary to support recreational activities such as fishing. Wet weather water quality is limited by bacteria discharged from combined and separate storm sewers. High rates of urban runoff cause flooding during larger storms, and flood flows that erode the stream banks and bottoms and have subsequently exposed and compromised utility infrastructure.

The good news is that measurable progress can be made towards restoring the legislated designated uses of the stream. To this end, this plan provides a commitment from the Philadelphia Water Department to an investment strategy for achieving definable levels of environmental return in the Tookany/Tacony-Frankford Creek basin. It is estimated that significant progress towards improving the various areas of environmental concern can be made for an investment of less than $290 per household per year over a 20-year horizon.

The plan proposes that the upstream municipalities of Montgomery County in the Tookany/Tacony-Frankford basin make similar financial commitments to implementation in order to ensure the restoration and preservation of the waters that flow through and from their communities, helping to shape their quality of life along the way. A significant portion of this funding is directed towards work that reflects the widely recognized national need to renew our water resources infrastructure. It is proposed that a combination of Federal, state and local government, along with private funding, be brought to bear in order to implement this plan watershed-wide. The Philadelphia Water Department has expended over $1 million for the development of the plan, and will commit an additional $2-3 million per year or more towards implementing its recommendations over the next 20 years.

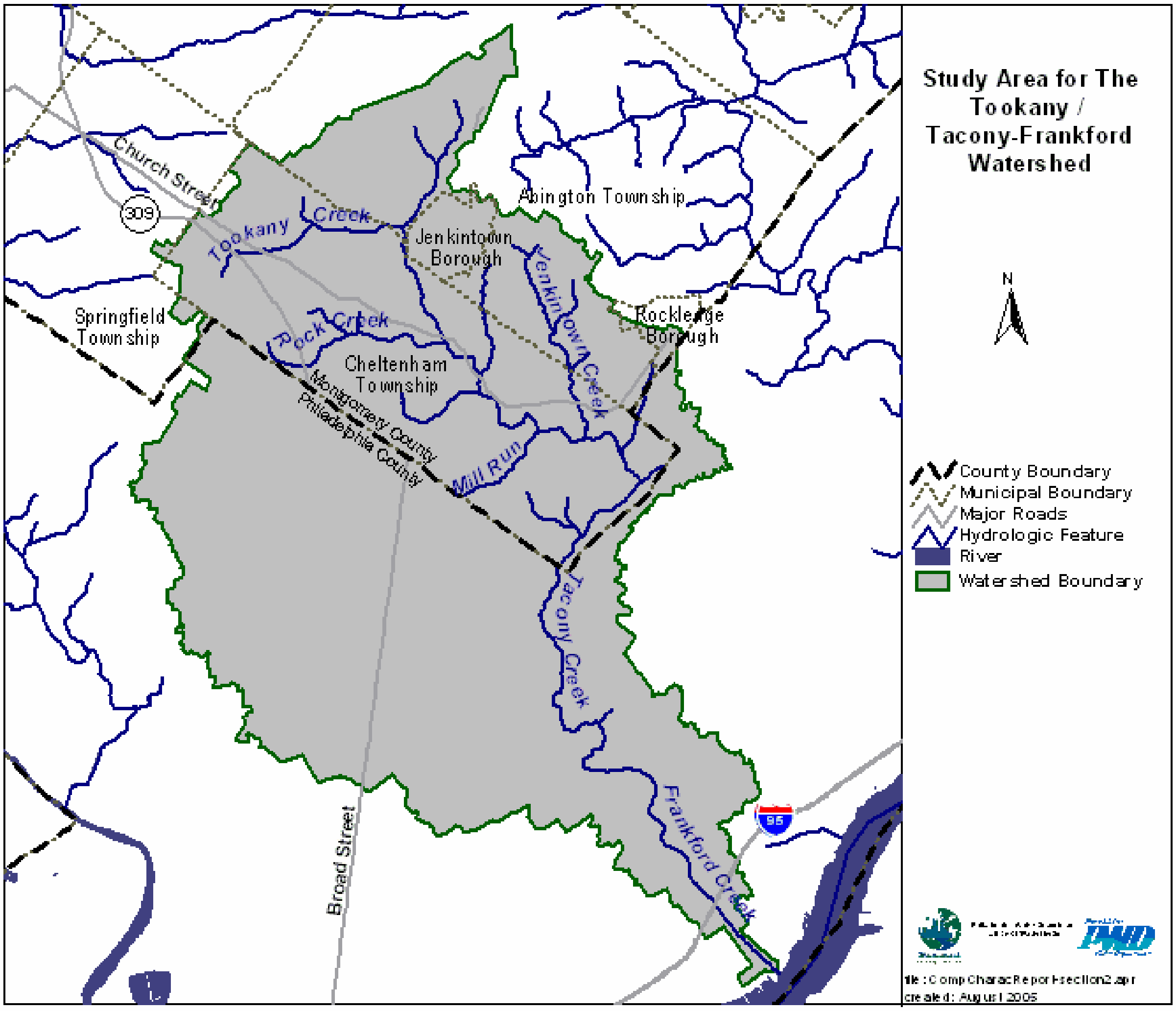


Figure E.1 Tookany/Tacony-Frankford Watershed

Background

Stewardship of a river must be built around the needs of the community. It will grow by making visible the critical way the health of the watershed is integral to basic quality of life issues. Once the seeds of stewardship have been planted, members of the community can be recruited to take action in protecting their watershed.

In 2000, PWD acted as the municipal sponsor of the Tookany/Tacony-Frankford Watershed Partnership, an exciting and groundbreaking effort to connect residents, businesses, and government as neighbors and stewards of the watershed. PWD hired the Pennsylvania Environmental Council (PEC), a well-respected, non-profit institution with a reputation for supporting watershed-based, holistic planning in the form of smart growth planning, as the facilitator and outreach coordinator of this partnership. PEC pulled together a diverse representation of the watershed including municipalities, “friends” groups, educators, agencies, residents, and other nonprofit organizations for participation in this planning process. Since then, the Partnership has been active in developing a vision for the watershed and guiding and supporting subsequent planning activities within the Tookany/Tacony-Frankford watershed.

The mission of the TTF Partnership was summarized as follows:

- To increase public understanding of the importance of a clean and healthy watershed.
- To instill a sense of appreciation and stewardship among residents for the natural environment.
- To improve and enhance our parks, streams, and surrounding communities in the Tookany/Tacony-Frankford Watershed.

With this Tookany/Tacony-Frankford Integrated Watershed Management Plan, PWD, supported by the TTF Partnership, has now completed the multi-year watershed planning effort intended to lead to the restoration of the Watershed as one that can boast fishable, swimmable, and enjoyable streams.

The main purposes of the plan, as articulated by the stakeholders, are: to mitigate wet weather impacts caused by urban stormwater runoff and combined sewer overflow (CSO); to identify ways to improve water quality, aesthetics, and recreational opportunities in dry weather; and to restore living resources in the stream and along the stream corridor. PWD placed a high priority on the development of the TTFIWMP because it represents one of the three major components of the City of Philadelphia’s CSO Long Term Control Plan strategy. This component entails a substantial commitment from the City to watershed planning to identify long term improvements throughout its watersheds, including any additional CSO controls that will result in an improvement of water quality and, ultimately, the attainment of water quality standards.

PWD was not alone in this planning effort. Significant support from other agencies has helped to fund various components of the plan and helped to better integrate this effort with other regulatory programs. The U.S. EPA provided funding under its Wetland Program Grant to help assess existing wetlands within the Tookany/Tacony-Frankford Watershed and provide basic data for developing wetland restoration projects. Through the Act 167 Stormwater Management Program, PA DEP provided funding to PWD for modeling and analysis to support stormwater planning, as well as to initiate the creation of an Act 167 Plan for this watershed. Finally, initial planning efforts and the development of planning goals were embodied in two Rivers Conservation Plans (one for the Montgomery County portion and one for Philadelphia portion of the watershed) funded by PA DCNR.

Plan Goals

Considerable stakeholder input towards developing watershed goals was sought from the beginning of this planning effort. Stakeholder input was primarily organized through the Partnership; through a weighting and evaluation process, consensus on a set of planning goals and objectives was achieved. In addition, the plan sought to integrate goals derived from other relevant regulatory programs and both Rivers Conservation Plans to more fully achieve the ideal of integrated water resource planning. The resulting integrated planning goals, and their relation to the major regulatory programs, are summarized in Table E.1.

Table E.1 Regulatory Support for Stakeholder Goals for the Tookany/Tacony-Frankford Watershed

Goal Description	Act 167 Stormwater	Act 537 Sewage Facilities	TMDL Program	NPDES Stormwater	CSO Program	RCPs
1. Streamflow and Living Resources. Improve stream habitat and integrity of aquatic life.	X		X	X	X	X
2. Instream Flow Conditions. Reduce the impact of urbanized flow on living resources.	X				X	X
3. Water Quality and Pollutant Loads. Improve dry and wet weather stream quality to reduce the effects on public health and aquatic life.		X	X	X	X	X
4. Stream Corridors. Protect and restore stream corridors, buffers, floodplains, and natural habitats including wetlands.						X
5. Flooding. Identify flood prone areas and decrease flooding by similar measures intended to support Goals 1, 2, and 4.	X					X
6. Quality of Life. Enhance community environmental quality of life (protect open space, access and recreation, security, aesthetics, historical/cultural resources).	X	X	X	X	X	X
7. Stewardship, Communication, and Coordination. Foster community stewardship and improve inter-municipal, inter-county, state-local, and stakeholder cooperation and coordination on a watershed basis.	X	X	X	X	X	X

Planning Approach

Once the Partnership had established the goals and objectives for the TTFIWMP, a planning approach was designed to achieve the desired results through a cooperative effort between the City of Philadelphia and upstream municipalities. The approach has four main elements:

- Data collection, organization, and analysis
- Systems description
- Problem identification and development of plan objectives
- Strategies, policies, and approaches

Watershed Status and Problem Identification

An integral part of this plan is the assessment and description of existing conditions within the watershed and stream. This assessment has identified specific problem areas, while establishing a "watershed baseline" from which we can measure our future progress as recommendations are implemented. Based upon these existing conditions, a series of "watershed indicators" were developed so that as implementation occurs in the coming years, progress can be quantified. "Indicators" are specifically designed to be measurable. For the TTF Watershed, 21 indicators (discussed in Section 4) were used for assessing current conditions and will be revisited annually to measure progress.

Through the extensive field studies, modeling, and data analysis, the highest priority problems in the Tookany/Tacony-Frankford Creek were identified, and the means for addressing the problems were developed. Given that the Tookany/Tacony-Frankford Watershed is highly urbanized with both CSOs and significant stormwater flows, some of the highest priority problems included:

Dry Weather Water Quality and Aesthetics

- Water quality concerns including high fecal coliform during dry weather
- Potential dry weather sewage flows in separate sewered areas
- Trash-filled, unsightly streams that discourage residential use
- Safety concerns along streams and stream corridors

Healthy Living Resources

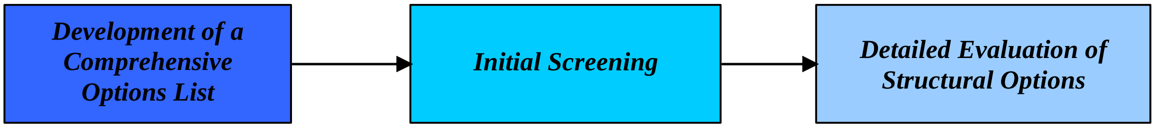
- Degraded aquatic and riparian habitats
- Loss of wetlands
- Channelized stream sections
- Limited diversity of fish and other aquatic life
- Periodic, localized occurrences of low dissolved oxygen in downstream areas
- Wide diurnal swings in dissolved oxygen
- Utility infrastructure threatened by bank and streambed erosion
- Limited public awareness and sense of stewardship for the creek

Wet Weather Water Quality and Quantity

- Water quality concerns including high fecal coliform, and nutrients and metals during wet weather flows
- CSO impacts on water quality and stream channels
- Little volume control and treatment of stormwater flows in separate sewered areas

Development and Screening of Management Options

Lists of options were developed as potential "solutions" to address the identified problems and to meet each of the goals and objectives established for the Tookany/Tacony-Frankford Watershed. Only those options deemed feasible and practical for the TTF Watershed were considered in the final list of management options. Options were developed and evaluated in three steps:



Since the plan cannot prescribe actions to be undertaken by all the participants in the planning process, recommendations and guidelines for implementation were developed. Modeling and other analyses were used to help recommend an approach for municipalities. Ultimately, it will be up to the TTF Partnership and the Montgomery County municipalities to turn these recommendations into a watershed-wide implementation plan.

Implementation Approach

In developing a recommended watershed management alternative and discussing goals and objectives with stakeholders, it became clear that implementation could best be achieved by defining three distinct targets to meet the overall plan objectives. Targets A and B were defined so that they could be fully met with full implementation of a limited set of options. For Target C, it was agreed to set interim objectives, recommend measures to achieve the interim objectives, implement those controls, and monitor and reassess the effectiveness of the plan in meeting the objectives.

Target A: Dry Weather Water Quality and Aesthetics

The first target is to meet water quality standards in the stream during dry weather flows. Target A was defined for Tookany/Tacony-Frankford Creek with a focus on trash removal and litter prevention, and the elimination of sources of sewage discharge during dry weather.

Sewers must be assessed to identify segments in need of rehabilitation, particularly where leakage is directly flowing into the stream. In separate sewered areas, a detection program for potential cross-connections is needed in order to eliminate dry weather flows.

Target A is also associated with improving the esthetic quality of the stream so that it can be viewed and treasured as a resource. Stream clean-ups are a way to achieve this while also involving residents and volunteers in the process.

Target B: Healthy Living Resources

Improvements to the number, health, and diversity of benthic macroinvertebrate and fish species in the Tookany/Tacony-Frankford Creek will require investment in habitat improvement and measures to provide the opportunity for organisms to avoid high velocities during storms. Improving the ability of an urban stream to support viable habitat and fish populations must focus primarily on the elimination or remediation of the more obvious impacts of urbanization. These include loss of riparian habitat, eroding and undercut banks, scoured streambed or excessive silt deposits, channelized and armored sections, trash buildup, and invasive species.

Target B is focused on improving the instream conditions of the Tookany/Tacony-Frankford Creek. Implementation projects are aimed at habitat improvements as well as measures to provide the opportunity for organisms to avoid high velocities during storms. Improvements to the number, health, and diversity of the benthic macroinvertebrate and fish species are anticipated as a result of these measures.

Target C: Wet Weather Water Quality and Quantity

The third target is to restore water quality to meet fishable and swimmable criteria during wet weather and address flooding issues. Improving water quality and flow conditions during and immediately following storms is the most difficult target to meet in the urban environment. The only rational approach to achieve this target must include stepped implementation with interim targets for reducing wet weather pollutant loads and stormwater flows, along with monitoring for the efficacy of control measures.

Initial load reduction goals for parameters such as stormwater flow, metals, total suspended solids, and bacteria were set in conjunction with the stakeholders. Based on preliminary work by PWD, a 20% reduction has emerged as a challenging but achievable interim goal.

Implementation Guidelines

All management options were thoroughly screened and evaluated using a variety of approaches, including computer simulation modeling and cost-effectiveness. This resulted in the selection of only those options appropriate and deemed effective for the particular conditions found in the Tookany/Tacony-Frankford Watershed. The Implementation Guidelines (Section 8) seek to present the options in such a way that each major stakeholder or responsible party understands what is expected. The guidelines are designed such that, if implementation follows the recommendations, all plan objectives associated with Targets A and B will be fully met, and the interim objectives for Target C will be met or even exceeded.

In Section 8, each recommended option is fully described, and a recommended level of implementation is provided. Where possible, locations for on-the-ground implementation are indicated.

Implementation Plans

The Implementation Guidelines presented in this document are intended to present a long-range vision for implementation over the upcoming 20-year horizon, and to be used as a reference by parties creating actual Implementation Plans in the future. Such plans will be designed to provide a detailed blueprint for specific tasks during a shorter planning period. Detailed planning for implementation of the TTFIWMP will be broken into four sequential 5-year periods to cover our 20-year implementation horizon.

The Philadelphia Water Department has created and committed to a detailed 5-year Implementation Plan for the portion of the Tookany/Tacony-Frankford Watershed within the City of Philadelphia (see summary in Appendix E). This plan has been designed to begin in 2006 and run through 2011; however, many recommended projects had already been initiated prior to 2006.

Planning Level Costs

Planning-level cost estimates have been developed for the majority of the options recommended. Because actual costs are highly dependent on site specific conditions and the extent to which implementation occurs, cost estimates are only approximate. These estimates are useful, however, in providing order of magnitude funding needs, and also as a comparison to potential costs associated with more traditional approaches to CSO control (e.g., large scale storage tanks designed to reach the 85% capture goal).

Estimated costs to PWD are separated from those to outside agencies (primarily municipalities) by apportioning costs based on ownership of facilities or simply by the relative areas of the watershed within and outside of Philadelphia City limits. “Cost per acre” values (Table E.2) are provided as a simple measure of the way costs are apportioned in the tables. Actual costs will depend on the exact mix of options ultimately implemented.

Table E.2 Total Watershed Plan Cost

Total		Philadelphia		Montgomery County	
Annual Cost	One-Time	Annual Cost	One-Time	Annual Cost	One-Time
$6,172,000	$148,459,000	$3,532,000	$68,839,000	$2,637,000	$79,625,000
$290/ac	$7,060/ac	$290/ac	$5,650/ac	$300/ac	$9,000/ac

The affordability of the costs associated with this plan was also analyzed. The results of this analysis are presented in Table E.3 for Philadelphia and for the combined suburban communities comprising the remainder of the watershed. For Philadelphia, the affordability calculation indicates that the incremental cost of the Tookany/Tacony-Frankford improvements would be approximately $10 per household per year, representing 0.03% of median household income. For the combined suburban communities, the cost would be $157 per household per year, representing 0.26% of the weighted median household income for those areas. Both of these values are well within U.S. EPA affordability guidelines, and represent relatively limited increases in the current rates being paid for water, sewer, and stormwater in Philadelphia.

The overall impact on affordability would need to be evaluated in the context of all the programs comprising water quality improvement within a given community. For example, residents of Philadelphia will ultimately help pay for management programs in five or more watersheds, while residents of Cheltenham, for example, will pay only for this one program. Because residents of Philadelphia will ultimately pay for improvements in a number of watersheds, the total cost per household in Philadelphia likely will be similar to the cost for households in the suburban communities.

Table E.3 Incremental Affordability Measure

		Philadelphia	Suburban Communities *(Combined)*
1	**One-time cost (annualized)**	$3,338,000	$3,875,000
2	**Annual cost**	$2,598,733	$2,268,386
3	**Total annual cost associated with TTFIWMP**	$5,936,733	$6,143,386
4	**Cost per acre in watershed**	$487	$694
5	**2000 MHI (median household income)**	$30,746	$59,621
6	**Estimated annual sewer user charge***	$343	$250
7	**WMP cost per household in watershed (in entire municipalities)**	$52.53 ($10.06)	$258.93 ($157.00)
8	**WMP cost as % of MHI in watershed (in entire municipalities)**	0.17% (0.03%)	0.43% (0.26%)
9	**Existing sewer cost + TTFIWMP cost in watershed (in entire municipalities)**	1.59% (1.15%)	0.62% (0.46%)

** The sewer user charge in Philadelphia includes a stormwater collection and treatment fee. Stormwater-related charges outside Philadelphia were not investigated.*

Tables E.4 and E.5 provide data to help communities outside Philadelphia place projected TTFIWMP costs in a local context. Table E.4 expresses estimated costs for communities per acre and per household inside the watershed boundaries; Table E.5 presents costs within the boundaries of all municipalities that intersect the watershed. These cost tables are but one illustration of a possible cost distribution, and are provided to help municipalities decide what funding and institutional mechanisms may be most appropriate given local conditions.

Table E.4 Distribution of Costs among Rate Payers in Tookany/Tacony-Frankford Watershed in Communities Outside Philadelphia

	Abington	Cheltenham	Jenkintown	Philadelphia	Rockledge
Municipality area in watershed (ac)	2,712	5,691	367	12,178	81
Area of municipality in watershed (% of municipality total)	27%	98%	99%	13%	37%
Households in municipality and watershed	7,147	14,218	2,013	113,022	348
Annual cost associated with TTFIWMP	$807,899	$1,695,749	$109,277	$3,532,000	$24,075
Cost per acre (within watershed)	$297.95	$297.95	$297.95	$290.03	$297.95
Cost per household (within watershed)	$113.04	$119.27	$54.29	$31.25	$69.18
Median household income ($/year)	$59,921	$61,713	$47,743	$30,746	$47,958
Cost per household (% of MHI)	0.19%	0.19%	0.11%	0.10%	0.14%

Table E.5 Distribution among All Rate Payers in Communities Outside Philadelphia

	Abington	Cheltenham	Jenkintown	Philadelphia	Rockledge
Municipality area (ac)	9,893	5,779	369	91,287	219
Watershed area in municipality (ac)	2,712	5,691	367	12,178	81
Watershed area in municipality (% of watershed total)	12.9%	27.1%	1.7%	57.9%	0.4%
Households in municipality	21,690	14,346	2,035	590,071	1,060
Annual cost associated with TTFIWMP	$807,899	$1,695,749	$109,277	$3,532,000	$24,075
Cost per acre (whole municipality)	$81.66	$293.42	$296.36	$38.69	$109.91
Cost per household (whole municipality)	$37.25	$118.20	$53.70	$5.99	$22.71
Median household income ($/year)	$59,921	$61,713	$47,743	$30,746	$47,958
Cost per household (% of MHI)	0.06%	0.19%	0.11%	0.02%	0.05%

Section 1
Background

This section details the reasons for developing the Tookany/Tacony-Frankford Integrated Watershed Management Plan, or TTFIWMP, and the purposes the plan is intended to serve. It provides an orientation to various facets of the TTF Watershed itself (geographical, ecological, historical, cultural, etc.), and it describes the TTF Partnership, which was involved throughout the plan's development and will be instrumental to its implementation. Finally, the overall watershed planning and regulatory framework is outlined in Sections 1.4 – 1.7.

The Tookany/Tacony-Frankford Integrated Watershed Management Plan (TTFIWMP) is based on a carefully developed approach to meet the challenges of watershed management in an urban setting. It is designed to meet the goals and objectives of numerous water resources related regulations and programs, and it utilizes adaptive management approaches to prescribe implementation recommendations. Its focus is on attaining priority environmental goals in a phased approach, making use of the consolidated goals of the numerous existing programs that directly or indirectly require watershed planning.

1.1 What Is a Watershed and Why a Plan?

Consider this vision, as presented by the Tacony-Frankford River Conservation Plan:

> *"Welcome to our world – a world that includes a Tacony Creek that is beautiful and full of life. A world that boasts a Tacony Creek Park and a host of community green spaces that make the heart leap at the beauty of nature. A world that offers the residents of the watershed opportunities to bike, run and play at its recreation centers and parks. A world that recognizes that a community that values and protects its natural spaces is a community that will economically and culturally thrive."*

A watershed is a natural formation including land and communities connected by the drainage area of a water body (Figure 1.1). Simply said, the health of a stream depends on the quality of the land surrounding it, which in turn relies on the people charged with the care for that land. How do we care for an urban watershed? By addressing practices of the past, including paving the land and piping the stormwater, which took place as the area was urbanized. These practices were deemed an important step in development at the time, but they have had a devastating impact on the natural environment. As scientific knowledge and values have changed over time, we have realized that we can have both a vibrant community and healthy natural resources, and that the two can reinforce one another.

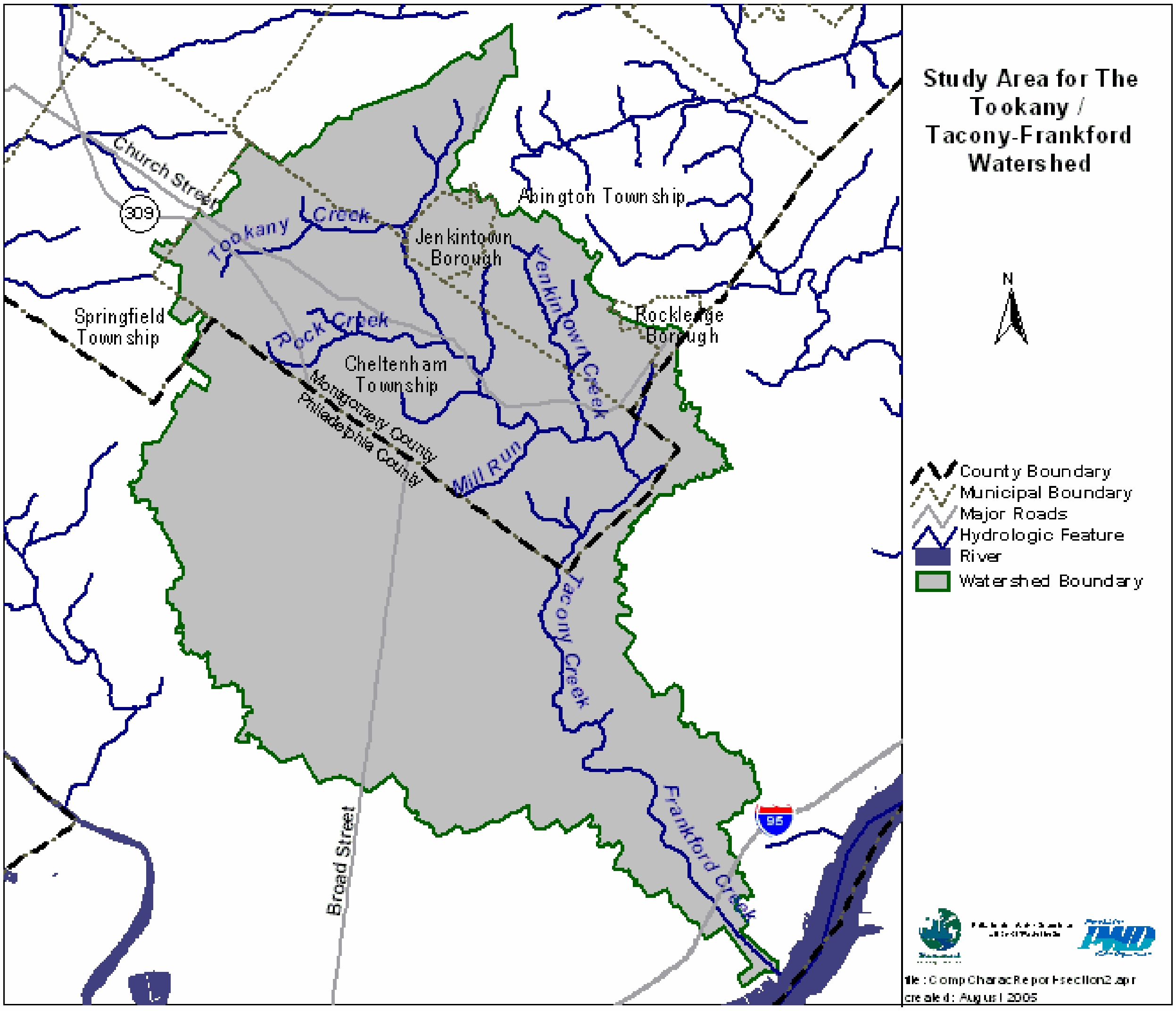


Figure 1.1 Tookany/Tacony-Frankford Watershed Study Area

An integrated watershed management plan is a long-term road map designed to achieve these twin goals of a healthy community and healthy natural resources. An integrated plan embraces the laws designed to save our streams, preserves the streams’ ecology, and enhances the parkland and riparian buffers that shelter these streams. The plan also reaches out to include the best of municipal and conservation planning that strives to ensure that growth within the watershed occurs with particular care to the environment. Most importantly, the plan incorporates a diversity of people who live, work, and dream in all areas of the watershed. People provide the catalyst for change, the energy to create the plan, and the vigilance to sustain the plan. These people, the stakeholders, become the watershed’s guardians – the keepers of the integrated plan.

The Tookany/Tacony-Frankford Partnership has provided a forum for stakeholders to work together to develop strategies that embrace our dual focus of improving stream water quality as well as the quality of life in our communities. Stakeholders care with their minds, hearts, and hands. TTF stakeholders include various government agencies – regulatory agencies, whose jobs empower them to guard the quality of our rivers and streams, as well as counties and municipalities, separate political entities bound together by nature. Stakeholders also include all those groups – nonprofit groups, neighborhood groups, religious groups, and schools – who define themselves as environmental advocates. Finally, stakeholders include concerned citizens who care about the state of their natural environment and their own quality of life.

Stakeholders have come together to discuss visions for the watershed. They shared thoughts of what they would like to see in our streams, parks, and neighborhoods. They are passionate about the possibilities – of revived aquatic and plant life, of streams that flow naturally, of parks that appear lush and inviting, of wetlands, and of meadows and woods that abound with wildlife. Together, we decide that our visions must become a reality.

The TTF Partnership discussed priorities and the actions necessary to make our initiative a successful one. These actions have become our strategy, and they address our desire to improve our water and land environment through a number of avenues. The TTFIWMP is built upon the foundation of environmental regulations, already in place and providing the impetus for stakeholders to work together to meet watershed goals. The plan's framework includes a number of elements – innovative land use controls and best management practices, improvements to piping and other conveyance systems, restoration of damaged stream corridors, and education and public awareness. These components, like good building materials, can result in a solid, sustainable structure, a plan that will result in a healthier and greener environment.

Stakeholders are committed to implementing the plan while canvassing for funds to nurture and sustain it, and they look to our governments and to stakeholders to contribute the dollars, expertise, and people to make their vision a reality. We will review our plan on a regular basis to ensure that it remains vital and to measure incremental successes that place us on the path of achieving our long-term goals. We share our plan with the residents of the watershed, showing how it works, and how each of them plays a part in its success. We empower them to share in our vision of a vital, dynamic watershed.

We look for solutions on the land where rainfall drains to our waterways, in the underground infrastructure that carries rainwater and wastewater away, and in and along our streams where natural ecosystems should thrive. As champions of our water resources, we believe this approach benefits not only our water environment, but also the region's physical, social, and economic environment.

1.2 Brief History of the Tookany/Tacony-Frankford Watershed

As part of both River Conservation Planning (RCP) initiatives, the Tookany/Tacony-Frankford Watershed Partnership has compiled a brief history of the watershed, including Tookany Creek. Portions of this history are reproduced here exactly as they appear in the RCPs.

Prior to the European settlement in the early 1600s, the area that is now Philadelphia was inhabited by the Lenape Indian tribe. The Lenape people, referred to as Delaware Indians by European Settlers, considered themselves the "original people." Lee Sultzman, in his *History of Delaware,* indicates that there was a widespread belief among native peoples that the Lenape were the original tribe of Algonquin speaking peoples to inhabit the area.

The Unami bank of Lenapes occupied the territory of Pennsylvania and New Jersey from Staten Island to just south of Philadelphia. The Unamis were not a politically cohesive group, but shared common language and cultural characteristics.

The Lenape people lived in villages and depended on agricultural crops such as squash and corn as their primary source of sustenance. Men of the tribe supplemented the tribe's diet through hunting and fishing. Tribal government consisted of three sachems or captains that represented the three matrilineal clans that comprised Lenape society. The head chief was always from the Turtle clan, although the position was elected and not strictly hereditary. The other two clans were the Wolf and Turkey clans.

First contact between the Lenape and Europeans (primarily Dutch explorers) occurred in the early 1600s. The Tacony-Frankford Watershed was colonized in the mid seventeenth century by different groups of immigrants. Swedes and Finns traveling up the Delaware River were the first European inhabitants of the Tacony Creek Valley, while Germans fleeing religious persecution settled in the western portion of the watershed in what is now Germantown. In 1664, the land that is southeastern Pennsylvania was surrendered to the English by the Dutch. In 1681, King Charles II of England granted William Penn 40,000 acres of land in the Delaware Valley as repayment for a debt owed to Penn's father. The entire Tookany/Tacony-Frankford Watershed lies within the area of this land grant. With the establishment of Penn's colony, English settlers flocked to the region, establishing homesteads, plantations, and towns.

The Tacony Creek and surrounding valley was primarily developed as an area of agriculture and milling operations. The Tacony Creek was dammed several times for mills and become a center for industrial operations during the late eighteenth and early nineteenth centuries. Expansion of the city in the late 1800s converted farmland into residential neighborhoods. Active agriculture persisted in the upper watershed until the early 1900s. Land for the Tacony Creek Park was purchased by the city in 1915, while land was being consumed for the need for new housing. The park was added to in 1939, and now occupies 302 acres. High-density housing characterizes the development of the area after the 1940s.

1.3 Watershed Description and Demographics

The Tookany/Tacony-Frankford Watershed is defined as the land area that drains to the Delaware River via that variously named creek. The Tookany/Tacony-Frankford study area includes parts of Montgomery County and a portion of Philadelphia County and covers a total of approximately 29 square miles, or about 20,000 acres. Figure 1.1 includes the watershed boundaries, hydrologic features, and political boundaries. The creek is referred to as the Tookany Creek until it enters Philadelphia at Cheltenham Avenue. It is then called the Tacony Creek from that Montgomery County border until the confluence with the historical Wingohocking Creek in Juniata Park. The section of stream from Juniata Park to the Delaware River is referred to as the Frankford Creek, and is underlain by a concrete channel.

The streams in the western portion of the watershed are contained in pipes and combined sewer infrastructure. Historic streams, including the Wingohocking Creek, Rock Run, and Little Tacony Creek, were encapsulated in combined sewers to facilitate the development of this watershed in the early twentieth century. Combined sewers convey sanitary waste, as well as stormwater to the city's wastewater treatment facilities. The total number of stream miles in this study is 14.4 miles in the mainstem creek and approximately 31.9 miles of encapsulated tributaries.

The drainage area is highly urbanized both in the lower reaches, which are primarily located in Philadelphia County, and in the upper reaches; however, that upper portion, included mainly in Montgomery County, is characterized by a more varying mixture of land uses. The population of the entire drainage area, based on 2000 census data, is approximately 331,400 people. This yields an average population density of approximately 16 -17 persons/acre.

In addition to CSO discharges to Frankford Creek from the City of Philadelphia, the drainage area receives a significant amount of point and non-point source discharges that impact water quality. According to the USGS data for the study area, the breakdown by sewer type is as follows: combined sewer areas make up 9,800 acres, or 47% of the drainage area; separate sewers, including areas outside of the City of Philadelphia, account for 9,200 acres or 44% of the drainage area; and non-contributing sewers make up 1,900 acres or 9% of the drainage area.

The waters in the drainage area receive point source discharges including CSOs and other urban and suburban stormwater, sanitary sewer overflows, and industrial storm, process, and cooling waters. Non-point sources in the basin include atmospheric deposition, overland runoff from urban and suburban areas, and potentially some remaining individual on-lot domestic sewage systems discharging through shallow groundwater.

In a relatively undisturbed watershed, the watershed boundaries follow topographic high points or contours. The U.S. Geological Survey (USGS) has further subdivided the Tookany/Tacony-Frankford Watershed based on topography, as shown in Figure 1.2. These USGS subwatersheds are determined from the land area draining to a particular point of interest, such as a stream confluence or gauging site. These boundaries allow initial determinations of drainage areas and modeling elements. However, it is important in the urban environment to include the effects of man-made changes to natural drainage patterns. In the Philadelphia portion of the watershed, drainage areas were adjusted to account for the combined sewer system drainage boundaries.

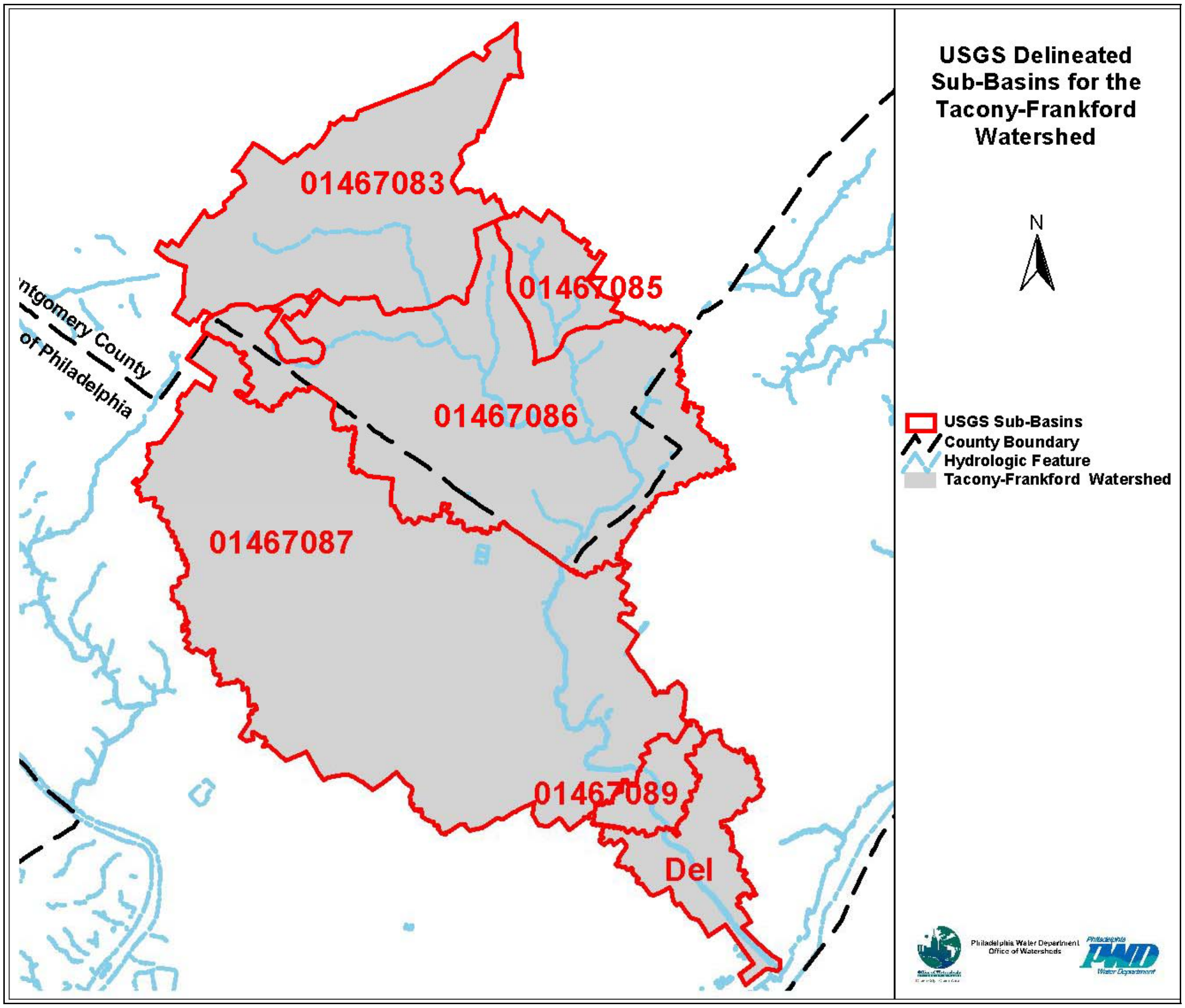


Figure 1.2 USGS Topographic Subwatersheds of the Tookany/Tacony-Frankford Watershed

Geology and Soils

Geology and soils play a role in the hydrology, water quality, and ecology of a watershed. The middle and upper reaches of the study area are in the Northern Piedmont Ecoregion (EPA Enviromapper). The Piedmont is characterized by ridges, hills, and deep narrow valleys. Elevation can vary from 40 feet at the fall line to 400 feet at the ridge tops. The topography of the study area is level except for steep slopes along the banks of the Tacony Creek. This section of the watershed is generally underlain by metamorphic and igneous geologic formations, predominately the Wissahickon Formation with small areas of gneiss and hornblende. These formations are exposed where the Tacony Creek has eroded overlying sediments to the bedrock (PA DEP 2001).

The lower portion of the watershed lies within the Middle Atlantic Coastal Plain Ecoregion. This is an area of low relief. Historically, the coastal plain in the city of Philadelphia was tidal marsh. These marshes were filled and paved over for urban development (PA DEP 2001). The topography of the coastal plain is gently sloping with elevations from 0 to 40 feet above sea level. The coastal plain is mainly comprised of unconsolidated sand and clay. These sands and clays are represented by the Pennsauken Formation, which was deposited in the Cretaceous period, and unconsolidated sand and clay (Trenton Gravel) deposited during the current quaternary geologic period.

Figure 1.3 displays a map of the geologic formations within the study area. The following are generalized descriptions of the geologic formations:

- **Wissahickon formation:** Typically a phyllite comprised of quartz, feldspar, muscovite, and chlorite. Moderately resistant to weathering. Fractures in platy patterns.
- **Mafic Gneiss, horneblend bearing:** Medium to fine grained, dark colored calcic plagioclase, hyperthene, augite, and quartz. Highly resistant to weathering.
- **Pennsauken formation:** Sand and gravel yellow to dark reddish brown, mostly comprised of quartz, quartzite, and chert. Deeply weathered floodplain formation.
- **Bryn Mawr formation:** White, yellow, and brown gravel and sand. Deeply weathered formation.
- **Quaternary deposits (Trenton gravel):** Unconsolidated sand and clays deposited by the Delaware River during the current geologic period.

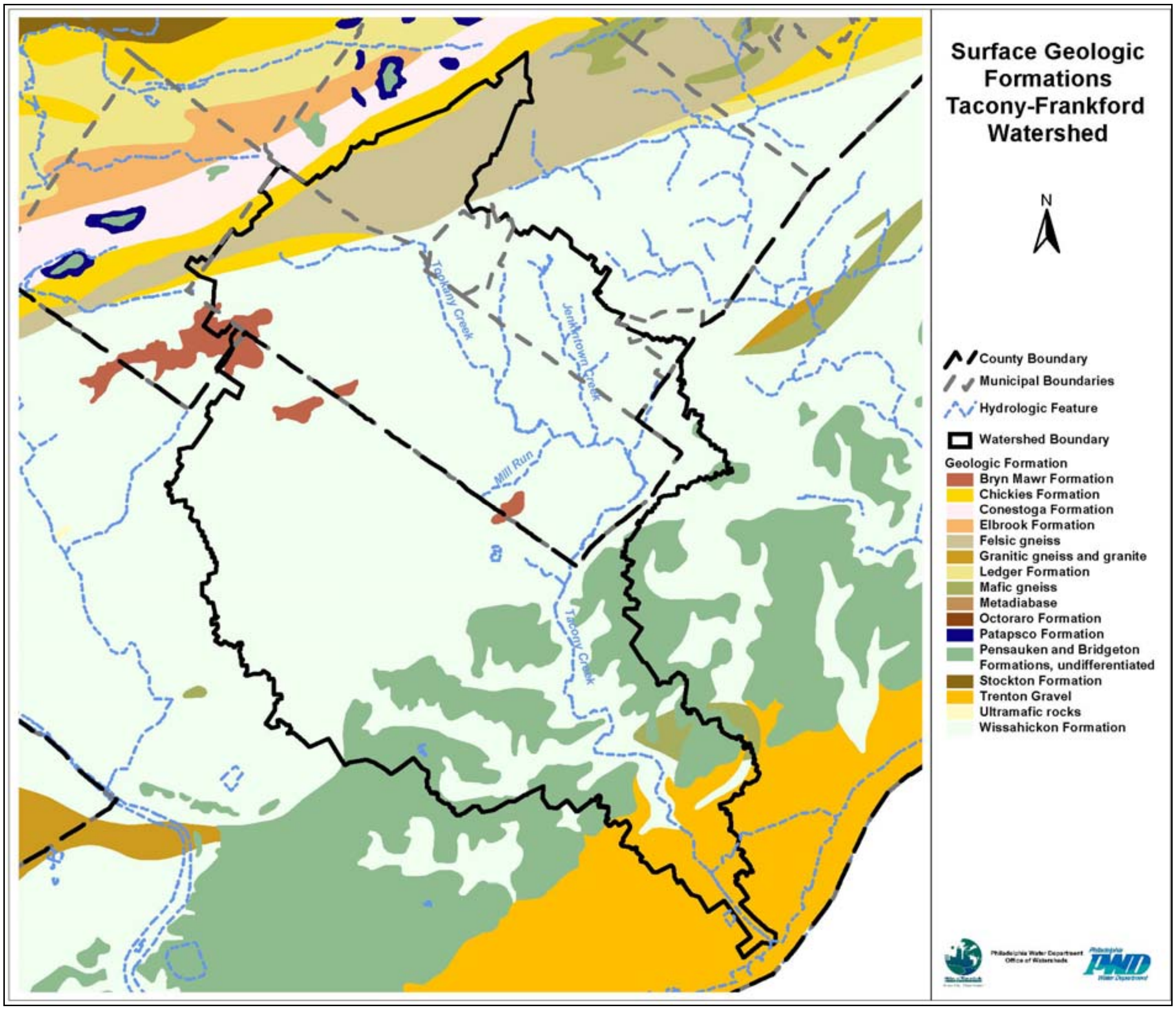


Figure 1.3 Surface Geologic Formations of the Tookany/Tacony-Frankford Watershed

Soils in the United States have been assigned to Hydrologic Soil Groups (HSG). The assigned groups are listed in Natural Resources Conservation Service Field Office Technical Guides, published soil surveys, and local, state, and national soil databases. The Hydrologic Soil Groups, as defined by NRCS engineers, are A, B, C, D, and dual groups A/D, B/D, and C/D.

Soils in hydrologic group A have low runoff potential. These soils have a high rate of infiltration when thoroughly wet. The depth to any restrictive layer is greater than 100 cm (40 inches) and to a permanent water table is deeper than 150 cm (5 feet).

Soils that have a moderate rate of infiltration when thoroughly wet are in hydrologic group B. Water movement through these soils is moderately rapid. The depth to any restrictive layer is greater than 50 cm (20 inches) and to a permanent water table is deeper than 60 cm (2 feet).

Hydrologic group C soils have a slow rate of infiltration when thoroughly wet. Water movement through these soils is moderate or moderately slow; they generally have a restrictive layer that impedes the downward movement of water. The depth to the restrictive layer is greater than 50 cm (20 inches) and to a permanent water table is deeper than 60 cm (2 feet).

Soils in hydrologic group D have a high runoff potential. These soils have a very slow infiltration rate when thoroughly wet. Water movement through the soil is slow or very slow. A restrictive layer of nearly impervious material may be within 50 cm (20 inches) of the soil surface and the depth to a permanent water table is shallower than 60 cm (2 feet).

Dual Hydrologic Soil Groups (A/D, B/D, and C/D) are given for certain wet soils that could be adequately drained. The first letter applies to the drained and the second to the undrained condition. Soils are assigned to dual groups if the depth to a permanent water table is the sole criteria for assigning a soil to hydrologic group D.

The HSG rating can be useful in assessing the ability of the soils in an area to recharge stormwater or to accept recharge of treated wastewater or to allow for effective use of septic systems. Figure 1.4 shows the hydrologic soil groups in the study area. The map indicates that most of the study area contains soil in the hydrologic category B, with some areas at the downstream end shown as category C. This means that most of the study area has soils that have a moderate to high rates of infiltration when thoroughly wet, and water movement through these soils is generally rapid. This has implications for the design of stormwater infiltration systems, and also affects the amount of water that needs to be infiltrated in newly developing areas to maintain predevelopment or natural infiltration rates. The HSG classification is also used when doing stormwater runoff calculations for site development design, and was used in this study in developing the SWMM model runoff calculations.

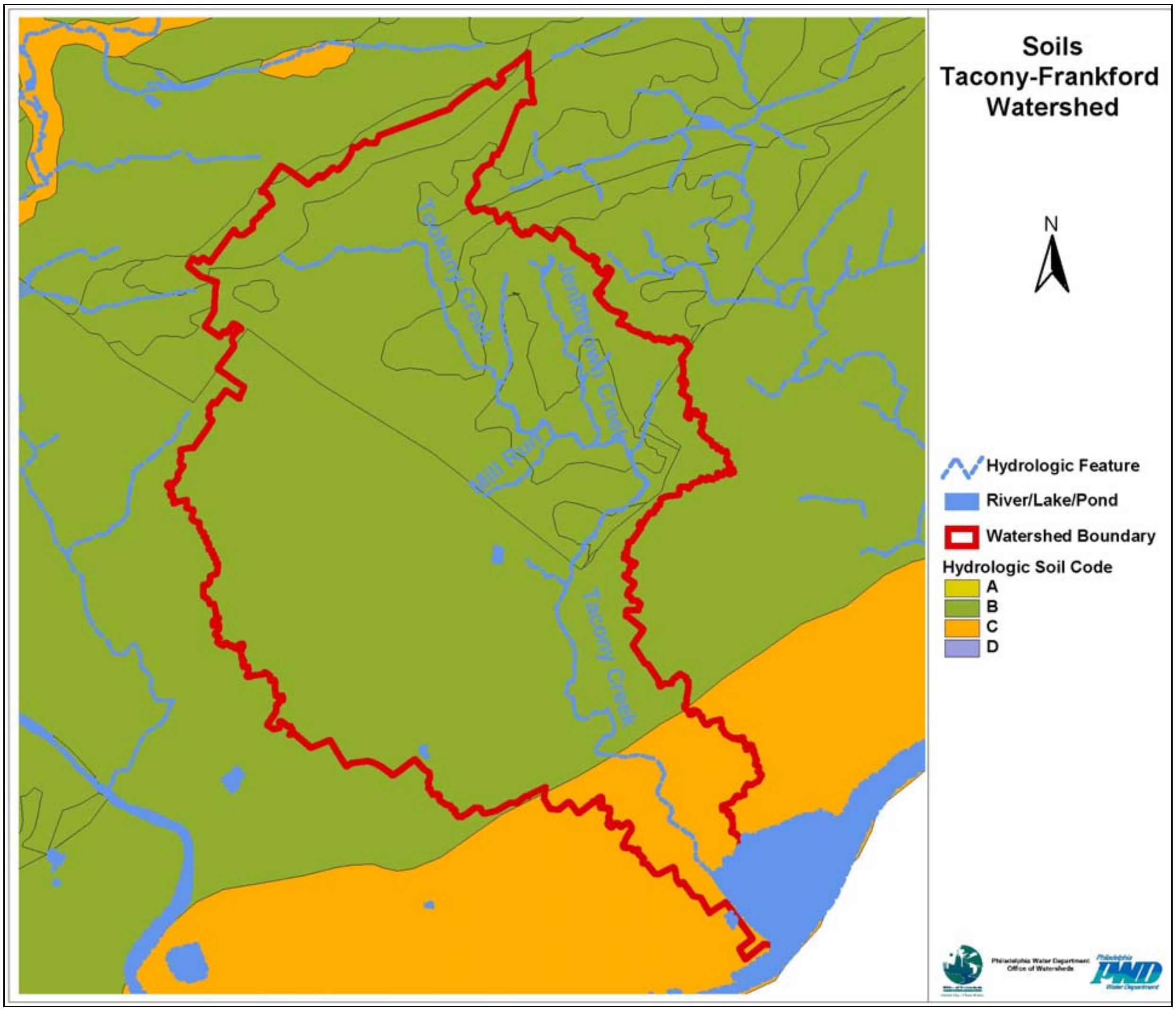


Figure 1.4 Hydrologic Soil Groups in the Tookany/Tacony-Frankford Watershed

Demographic Information

Population density and other demographic information in the watershed are available from the results of the 2000 Census. Approximately 357,104 people live within the drainage area of the Tookany/Tacony-Frankford Creek. Figure 1.5 shows the population density in the watershed at the census block level. Spatial trends in population correspond closely to land use, with multiple-family row homes displaying the greatest population density of 20 people per acre or more, single-family homes displaying a lower density, and other land use types displaying the lowest density. In addition to population data, the U.S. Census Bureau provides a range of socioeconomic data that are often useful in watershed planning and general planning studies. Median household income and mean home value (Figures 1.6 and 1.7) are two of the many sample datasets provided.

The population density of a residential area is related closely to its imperviousness and thus to the quantity and quality of runoff produced. Figure 1.5 depicts the population density in people per acre for the watershed area.

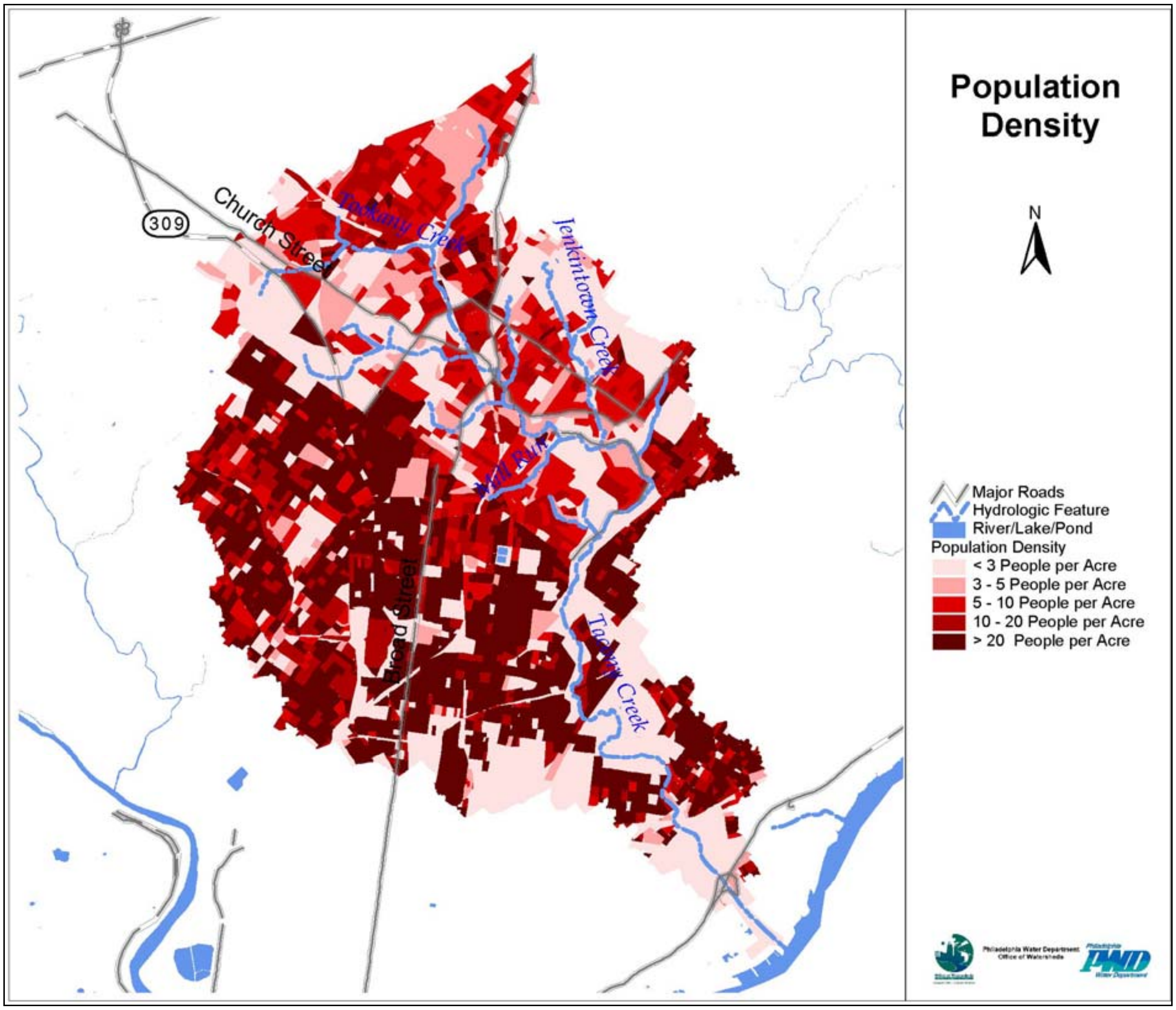


Figure 1.5 Population Density of the Tookany/Tacony-Frankford Watershed (Source: 2000 US Census)

Within the Tookany/Tacony-Frankford drainage area, based on 2000 census data, are 357,104 people. Represented by county, this corresponds to 59,456 people in the Montgomery County portion and 297,648 people in the Philadelphia County portion. The average population/acre in each county is determined to be 7 people/acre for Montgomery County and 24 people/acre for Philadelphia County. Based on this quantitative data and the visual data from the figure above, it is evident that Philadelphia County is more heavily populated than Montgomery County. Therefore, the combination of contributions from both counties yields an overall average (area-weighted) population density of approximately 17 persons/acre.

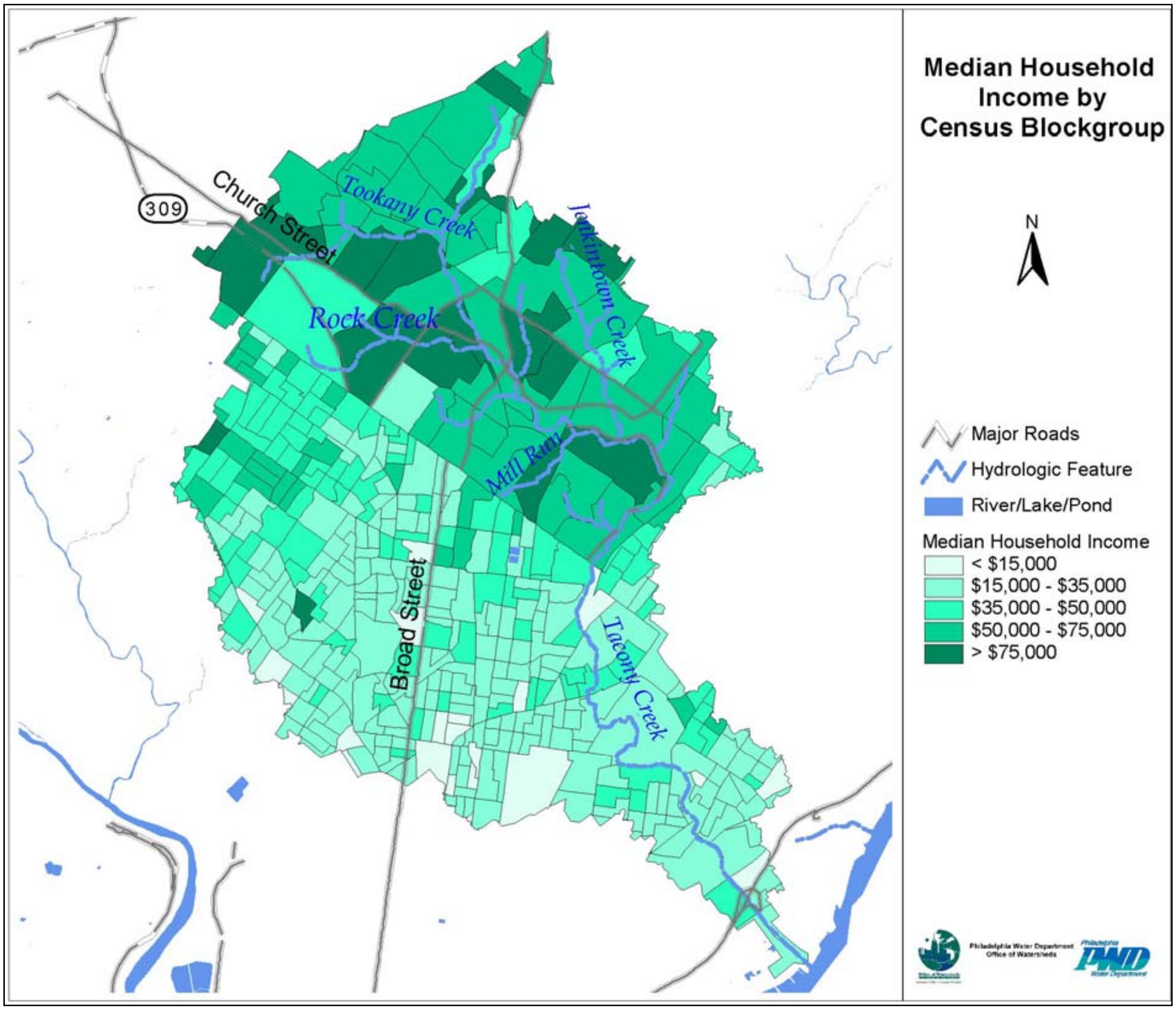


Figure 1.6 Median Household Income in the Tookany/Tacony-Frankford Watershed (Source: 2000 US Census)

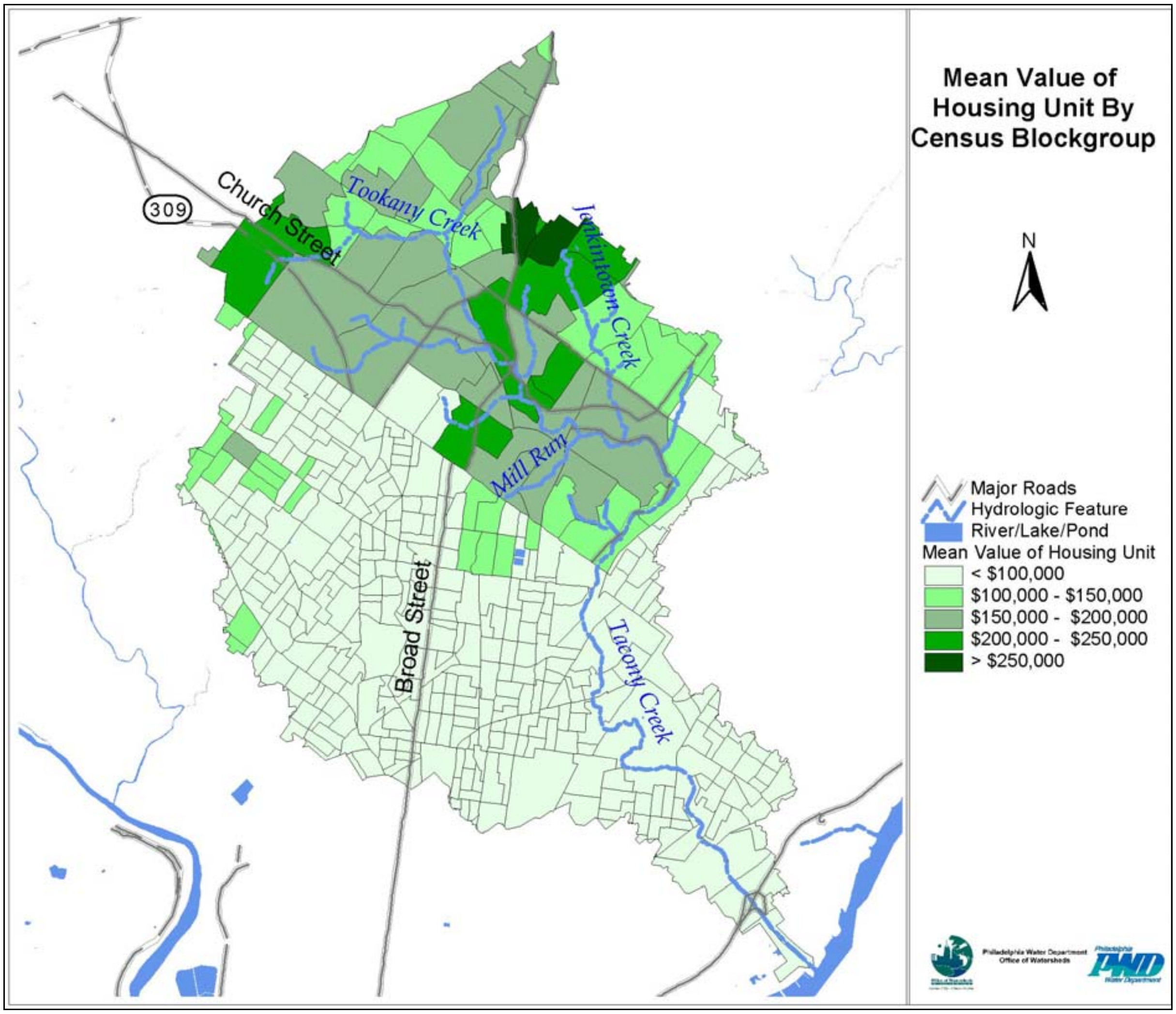


Figure 1.7 Mean Home Value in the Tookany/Tacony-Frankford Watershed (Source: 2000 US Census)

Figure 1.8, below, shows numerical population change, based on municipality areas within the watershed, from the 1990 to year 2000 census. This graph shows that all municipalities except Cheltenham have experienced slight losses in population and also a loss in population watershed-wide.

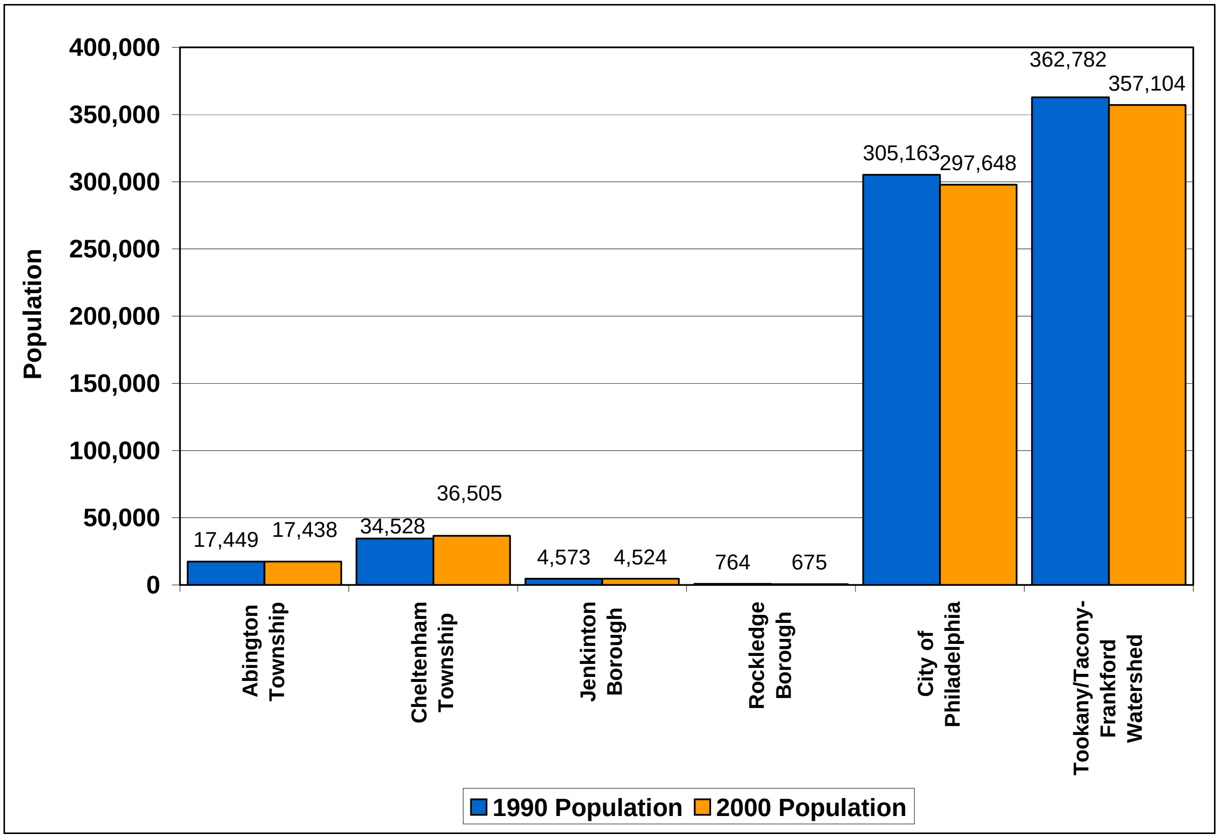


Figure 1.8 Population Change 1990-2000 in Tookany/Tacony-Frankford Watershed (Source: 2000 US Census)

1.4 Comprehensive Planning and the Regulatory Framework

In many states, numerous federal and state regulations and programs are aimed at improving the water quality and flow patterns in urban streams, while at the same time reducing flooding. Pennsylvania is no exception; the U.S. EPA and the Pennsylvania Department of Environmental Protection (PA DEP) have a complex regulatory framework for managing water resources with frequently overlapping demands and requirements. There are five major regulatory programs that contain significant elements related to watershed management in the Tookany/Tacony-Frankford Watershed. These are:

- the NPDES Phase I and Phase II stormwater regulations to control pollution due to stormwater discharges from municipal stormwater systems;
- the stormwater management PA Act 167 to address management of stormwater runoff quantity particularly in developing areas;
- PA Act 537 sewage facilities planning to protect and prevent contamination of groundwater and surface water by developing proper sewage disposal plans;
- the TMDL process to improve water quality on impaired streams and water bodies; and
- EPA's Combined Sewer Overflow (CSO) Control Policy to minimize mixed sewage and stormwater overflowing directly into streams.

Each of these programs, described on the pages that follow, provides guidelines that are transformed into a series of planning objectives within the watershed management planning process, leading directly to the selection of watershed management options to address those objectives.

1.4.1 NPDES Stormwater Rules

In response to the 1987 Amendments to the Clean Water Act (CWA), the Environmental Protection Agency (EPA) developed Phase I of the NPDES Stormwater Program in 1990. Phase I required NPDES (National Pollutant Discharge Elimination System) permits for all stormwater discharging from storm sewers (MS4s) of medium and large urban areas with populations of 100,000 or more. It also required permits from eleven categories of industrial activity, including construction activities that disturb five or more acres of land. Permit coverage can be either under an individually tailored NPDES permit (used by MS4s and some industrial facilities) or a general NPDES permit (used by most industrial facilities and construction sites).

Phase II of the NPDES Stormwater Program was published in November 1999. The Phase II regulation requires NPDES permit coverage, mostly general permits, for stormwater discharges from most small-urbanized areas (small MS4s) and construction activities that disturb from 1 to 5 acres of land. A list of affected communities has been published in the Federal Register.

There are six "minimum control measures" (MCMs) that communities must implement as part of a municipal stormwater management program whose goal is Phase II compliance. These are:

1. **Public Education and Outreach:** Distributing educational materials and performing outreach to inform citizens about the impacts polluted stormwater runoff discharges can have on water quality.
2. **Public Participation and Involvement:** Providing opportunities for citizens to participate in program development and implementation, including effectively publicizing public hearings and/or encouraging citizen representatives to be part of a stormwater management panel.
3. **Illicit Discharge Detection and Elimination:** Developing and implementing a plan to detect and eliminate illicit discharges to the storm sewer system. Includes the developing of a system map as well as informing the community about hazards associated with illegal discharges and improper waste disposal.
4. **Construction Site Runoff Control:** Developing, implementing, and enforcing an erosion and sediment control program for construction activities that disturb one or more acres of land (controls could include for example, silt fences, and temporary stormwater detention ponds).
5. **Post Construction Runoff Control:** Developing, implementing, and enforcing a program to address discharges of post-construction stormwater runoff from new development and redevelopment areas. Applicable controls could include preventative actions such as protecting sensitive areas (e.g., wetlands) or the use of structural BMPs such as grassed swales or porous pavement.
6. **Pollution Prevention/Good Housekeeping:** Developing and implementing a program with the goal of preventing or reducing pollutant runoff from municipal operations. The program must include municipal staff training on pollution prevention measures and techniques (e.g., regular street sweeping, reduction in the use of pesticides or street salt, and frequent catch-basin cleaning).

The EPA has listed the following municipalities within the Tookany/Tacony-Frankford watershed for inclusion in the Phase II program: Cheltenham Township, Jenkintown Borough, and Rockledge Borough. The permit cycle for these permits started in 2003.

1.4.2 Act 167 Stormwater Management

The Stormwater Management Act 167 of 1978 is administered by PADEP and is designed to address the inadequate management of accelerated stormwater runoff resulting from development. An Act 167 plan must address a wide range of hydrologic impacts due to development on a watershed basis, and include such considerations as tributary timing, flow volume reduction, base flow augmentation, water quality control, and ecological protection. Watershed runoff modeling is usually a critical component of the study, with modeled hydrologic responses to 2, 5, 10, 25, 50, and 100-year storms.

The primary purposes of Act 167 are to:

- Encourage planning and management of stormwater runoff;
- Authorize a comprehensive program of stormwater management designed to preserve and restore the flood carrying capacity of Commonwealth streams;
- Preserve natural stormwater runoff regimes;
- Protect and conserve groundwater.

Act 167 requires that each county – in consultation with affected municipalities – prepare and adopt a stormwater management plan for each watershed that falls wholly or partially within the county. The Act focuses on reduction of stormwater runoff quantities, rather than on water quality. Each stormwater plan will include, but is not limited to:

- A survey of existing runoff characteristics in small as well as large storms, including the impact of soils, slopes, vegetation, and existing development;
- A survey of existing significant obstructions and their capacities;
- An assessment of projected and alternative land development patterns in the watershed, and the potential impact of runoff quantity, velocity, and quality;
- An analysis of present and projected development in flood hazard areas, and its sensitivity to damages from future flooding or increased runoff;
- A survey of existing drainage problems and proposed solutions;
- A review of existing and proposed stormwater collection systems and their impacts;
- An assessment of alternative runoff control techniques and their efficiency in the particular watershed;
- An identification of existing and proposed state, federal, and local flood control projects located in the watershed and their design capacities;
- A designation of those areas to be served by stormwater collection and control facilities within a 10-year period;
- An estimate of the design capacity and costs of such facilities;
- A schedule and proposed methods for financing the development, construction, and operation of the facilities;

- An identification of the existing or proposed institutional arrangements to implement and operate the facilities;
- An identification of floodplains within the watershed;
- Standards for the control of stormwater runoff from existing and new development which are necessary to minimize dangers to property and life;
- Priorities for implementation of action within each plan;
- Provisions for periodically reviewing, revising, and updating the plan.

After adoption and approval of a stormwater plan, the location, design, and construction within the watershed of stormwater management systems, flood control projects, subdivisions and major land developments, highways, and transportation facilities must all be conducted in a manner consistent with the approved plan.

An Act 167 Plan is under preparation for the Tookany/Tacony-Frankford Creek watershed by Cheltenham Township with assistance from Philadelphia and Montgomery Counties.

1.4.3 Act 537 Sewage Facilities Planning

Act 537, enacted by the Pennsylvania Legislature in 1966, requires every municipality in the state to develop and maintain an up-to-date sewage facilities plan. The Act requires proper planning of all types of sewage facilities, permitting of individual and community on-lot disposal systems, and uniform standards of design.

The main purpose of a municipality's sewage facilities plan is to correct existing sewage disposal problems including malfunctioning on-lot septic systems, overloaded treatment plants or sewer lines, and improper sewer connections. The program is also designed to prevent future sewer problems and to protect the groundwater and surface water of the locality. To meet these objectives, PADEP uses the Official Sewage Planning requirements of Act 537 that prevent and eliminate pollution of the waters of the Commonwealth by coordinating planning for the sanitary disposal of sewage with a comprehensive program of water quality management.

Official plans contain comprehensive information, including:

- Planning objectives and needs;
- Physical description of planning area;
- Evaluation of existing wastewater treatment and conveyance systems;
- Evaluation of wastewater treatment needs.

Currently, all of the municipalities in the watershed have an Act 537 Plan, which provides for the resolution of existing sewage disposal problems, future sewage disposal needs of new land development, and future sewage disposal needs of the municipality. As of December 2005, Abington Township's Act 537 Plan is more than 5 years old and Philadelphia's is more than 10 years old. However, some plans are older than 30 years: Cheltenham, Rockledge, and Jenkintown boroughs. Also, the plans vary in their level of detail.

1.4.4 Impairment Designations and the TMDL Process

Section 303(d) of the Clean Water Act and the U.S. EPA's Water Quality Planning and Management Regulations (40 CFR Part 130) provide a framework for watershed planning based on Total Maximum Daily Loads. TMDLs are the sum of individual waste load allocations (point sources) and load allocations (non-point sources) plus a margin of safety. They establish a link between water quality standards and water quality based controls. The objective of TMDLs is to allocate allowable loads among different pollutant sources so that the appropriate control actions can be taken and water quality standards achieved.

The basic steps in the water quality based approach to TMDLs include:

- Identification of the water quality-limited waters and the quality parameters of concern;
- Prioritizing the locations by ranking and targeting;
- Establishing the TMDL;
- Implementing the control actions;
- Assessment of the control actions.

Pennsylvania has listed water quality-limited waters according to point and non-point sources for toxic, conventional (BOD, TSS, fecal coliform, oil, and grease), and non-conventional (ammonia, chlorine, and iron) pollutants. Streams that are listed under Section 303(d) of the CWA are particularly targeted for improvement. The Tacony Creek Watershed is within Subbasin 03J, which also includes Jenkintown Creek, Mill Run, and Chester Creek watersheds. Within the Tookany-Tacony/Frankford Watershed, the following stream segments are listed as impaired (Figure 1.9):

- 13.4 miles of Tookany Creek and 13.0 miles of tributaries outside of Philadelphia are impaired due to habitat modification, siltation, and water/flow variability from urban runoff and storm sewers.
- 3.1 miles of Tacony-Frankford Creek inside the City are impaired due to habitat modification, siltation, and water/flow variability from urban runoff and storm sewers.
- The tidal portion of the creek (illustrated in blue) flowing toward the confluence with the Delaware River has not been assessed.

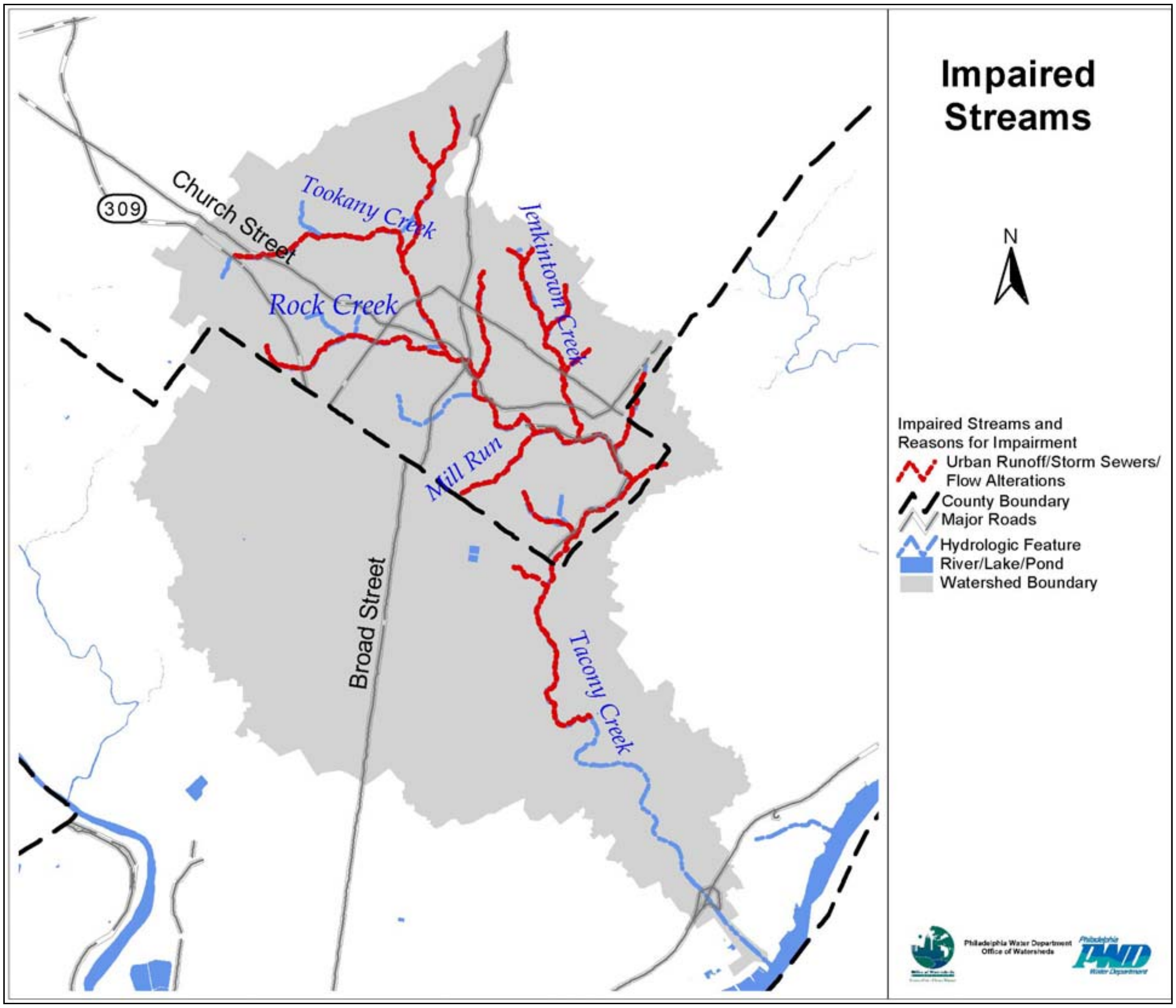


Figure 1.9 Impaired Streams in the Tookany/Tacony-Frankford Watershed

The next step in the statewide TMDL process includes prioritization of the list and the development of TMDLs for high-priority water bodies. It is this phase of the TMDL process that is of interest to the integrated watershed planning process.

Prioritization must take into account the severity of the pollution and the designated uses of the water body. It should consider the following:

- Risks pertaining to human health and aquatic life;
- Degree of public interest and support;
- Recreational, economic, and aesthetic importance;
- Vulnerability or fragility of the aquatic habitat.
- New permit applications for discharges or revisions to existing permits;
- Court orders and decisions;
- National policies and priorities.

TMDL development requires the quantification of pollutant sources and the allocation of maximum discharge loads to contributing point and non-point sources in order to attain water quality standards. TMDLs are best developed on a watershed basis in order to efficiently and effectively manage the quality of the water. The TMDL process may be developed using a phased approach that includes monitoring requirements and it generally includes the following five activities:

- Selection of the pollutants;
- Evaluation of the water body's assimilative capacity;
- Assessment of the pollutants discharged from all sources;
- Predictive analysis of the water body's response to pollution and determination of the total allowable pollutant load;
- Allocation (with a margin of safety) of the allowable pollutant load among the different sources.

The National Pollutant Discharge Elimination System's (NPDES) permitting process is used to implement control measures to limit effluent from point sources. In the case of non-point sources, state and local laws can be used to implement best management practices (BMPs), as well as Section 319 state management programs. These programs must be coordinated in order to effectively achieve the required non-point source reductions.

1.4.5 Combined Sewer Overflow (CSO) Control Policy

EPA's CSO Control Policy, published in 1994, provides the national framework for regulation of CSOs under NPDES. The policy guides municipalities and state and federal permitting agencies in meeting the pollution control goals of the CWA in as flexible and cost-effective a manner as possible. As part of the program, communities serviced by combined sewer systems are required to develop CSO Long-Term Control Plans (LTCPs) that will result in full compliance with the CWA, including attainment of water quality standards.

As the first step under the CSO policy, nine technology-based minimum controls are required; these are measures that can reduce the prevalence and impacts of CSOs and that are not expected to require significant engineering studies or major construction.

- Proper operation and regular maintenance programs for the sewer system and the CSOs;
- Maximum use of the collection system for storage;
- Review and modification of pretreatment requirements to assure CSO impacts are minimized;
- Maximization of flow to the publicly owned treatment works for treatment;
- Prohibition of CSOs during dry weather;
- Control of solid and floatable materials in CSOs;
- Pollution prevention;
- Public notification to ensure that the public receives adequate notification of CSO occurrences and CSO impacts;
- Monitoring to effectively characterize CSO impacts and the efficacy of CSO controls.

In the longer term, the CSO policy includes four requirements to ensure that the CSO systems meet the pollution control goals and local environmental objectives in a cost-effective manner:

- Clear levels of control to meet health and environmental objectives;
- Flexibility to consider the site-specific nature of CSOs and find the most cost-effective way to control them;
- Phased implementation of CSO controls to accommodate a community's financial capability;
- Review and revision of water quality standards during the development of CSO control plans to reflect the site-specific wet weather impacts of CSOs.

One of the three major components of the City of Philadelphia’s CSO LTCP strategy involves a substantial commitment by the City to watershed planning to identify long term improvements throughout its watersheds, including any necessary additional CSO controls, which will result in further improvements in water quality and, ultimately, the attainment of water quality standards. The need for this watershed initiative is rooted in the fact that insufficient physical, chemical, and biological information currently exists on the nature and causes of water quality impairments, sources of pollution, and appropriate remedial measures. Because of this deficiency, at the time the CSO LTCP was developed, it was impossible to determine what needed to be done for additional CSO control or control of other wet weather sources throughout the watershed. This deficiency, especially with respect to the effects of wet weather discharges and receiving water dynamics, was increasingly recognized nationwide and led to a broader recognition of the need for watershed-based planning and management to properly define water quality standards and goals. In its LTCP, PWD suggested that the National CSO Policy, state and federal permitting and water quality management authorities, cities, environmental groups, and industry all recognized that effective long-term water quality management could be accomplished only through watershed-based planning.

The CSO Control Policy acknowledges the importance of watershed planning in the long term control of CSOs by encouraging the permit writer "... to evaluate water pollution control needs on a watershed management basis and coordinate CSO control efforts with other point and non-point source control activities" (1.B). The watershed approach is also discussed in the section of the CSO Control Policy addressing the demonstration approach to CSO control (II.B.4.b, and Chapter 3 of the U.S. EPA Guidance for Long Term Control Planning), which, in recommending that NPDES permitting authorities allow a demonstration of attainment of water quality standards (WQS), provides for consideration of natural background conditions and pollution sources other than CSOs.

The EPA Long Term Control Planning Guidance suggests that EPA is committed to supporting the implementation of a comprehensive watershed management approach. EPA has convened a Watershed Management Policy Committee consisting of senior managers to oversee the reorientation of all EPA water programs to support watershed approaches.

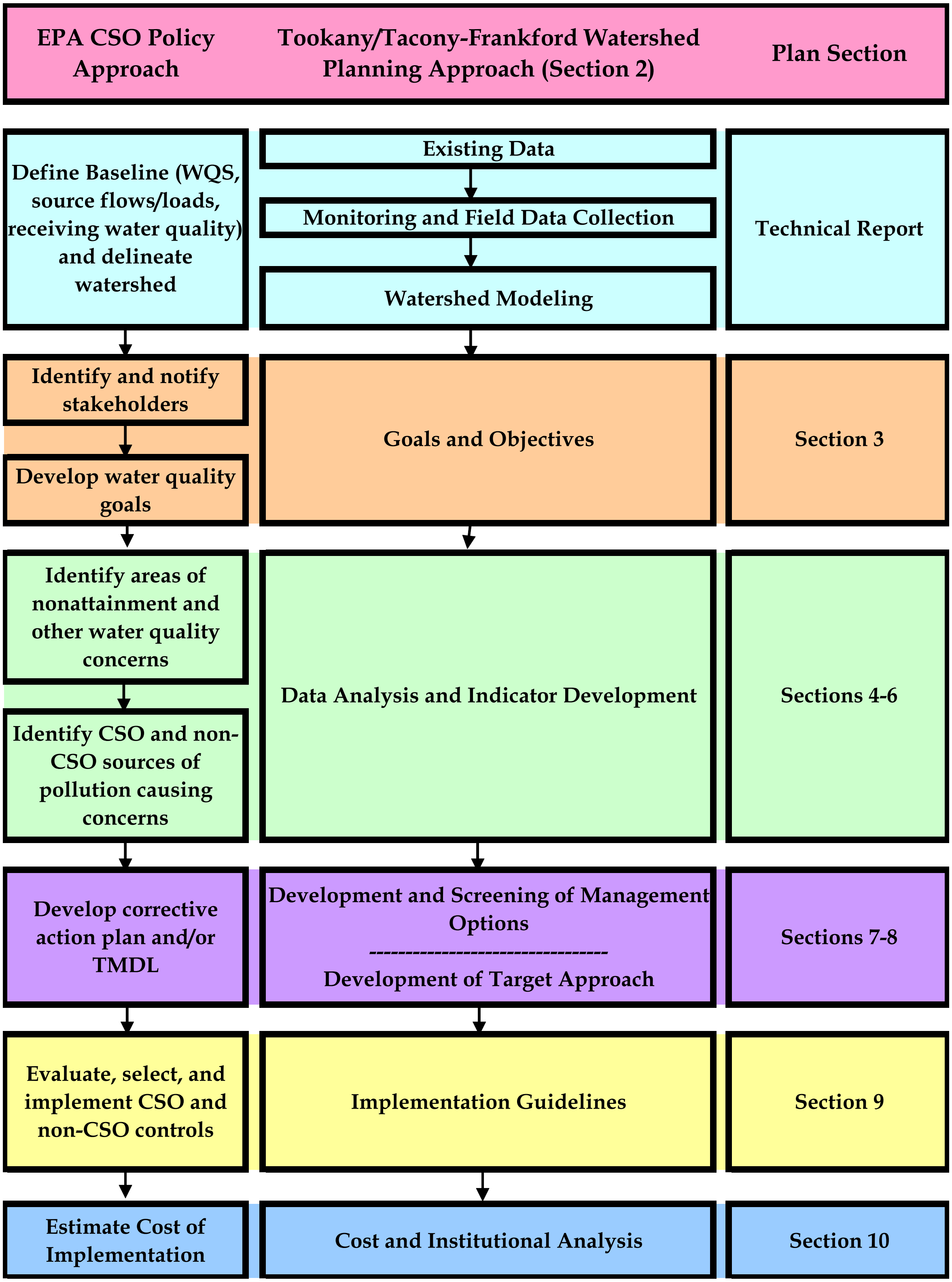
Of particular importance to CSO control planning and management is the NPDES Watershed Strategy. This strategy outlines national objectives and implementation activities to integrate the NPDES program into the broader watershed protection approach. The strategy also supports the development of basin management as part of an overall watershed management approach.

The Long Term Control Planning Guidance suggests that the sources of watershed pollution and impairment, in addition to CSOs, are varied and include other point source discharges; discharges from storm drains; overland runoff; habitat destruction; land use activities, such as agriculture and construction; erosion; septic systems; and landfills. The benefits to implementing a watershed approach are significant and include:

- Consideration of all important sources of pollution or impairment;
- Closer ties to receiving waters;
- Greater flexibility;
- Greater cost effectiveness (through coordination of monitoring programs, for example);
- Fostering of prevention as well as control;
- Fairer allocation of resources and responsibilities.

The Guidance notes that the major advantage of using a watershed-based approach to develop an LTCP is that it allows the site-specific determination of the relative impacts of CSOs and non-CSO sources of pollution on water quality. For some receiving water reaches within a watershed, CSOs could be less significant contributors to nonattainment than stormwater or upstream sources. In such cases, a large expenditure on CSO control could result in negligible improvement in water quality.

The EPA LTCP Guidance outlines a conceptual framework for conducting CSO planning in a watershed context (Figure 1.10). The approach is intended to identify CSO controls for each receiving water segment based on the concepts of watershed management and use attainability. The Tookany/Tacony-Frankford Watershed planning approach outlined in this document is conceptually identical. It moved from data collection through analysis and modeling to arrive at a set of recommended measures or options designed to meet the goals and objectives agreed upon through the stakeholder process. Figure 1.10 also identifies which section of this TTF Integrated Watershed Management Plan documents each step in the process.



EPA CSO Policy Approach	Tookany/Tacony-Frankford Watershed Planning Approach (Section 2)	Plan Section
Define Baseline (WQS, source flows/loads, receiving water quality) and delineate watershed	Existing Data Monitoring and Field Data Collection Watershed Modeling	Technical Report
Identify and notify stakeholders Develop water quality goals	Goals and Objectives	Section 3
Identify areas of nonattainment and other water quality concerns Identify CSO and non-CSO sources of pollution causing concerns	Data Analysis and Indicator Development	Sections 4-6
Develop corrective action plan and/or TMDL	Development and Screening of Management Options -------------------------------- Development of Target Approach	Sections 7-8
Evaluate, select, and implement CSO and non-CSO controls	Implementation Guidelines	Section 9
Estimate Cost of Implementation	Cost and Institutional Analysis	Section 10

Figure 1.10 Tookany/Tacony-Frankford Planning Approach
Watershed-Based CSO Control Planning Approach for a Receiving Water Segment – from U.S. EPA Guidance for Long Term Control Plan (1995)

1.5 Overlapping Aspects of Regulatory Programs

Integrated watershed planning includes various tasks, ranging from monitoring and resource assessment to technology evaluation and public participation. The scope and importance of each task varies for each watershed, depending on site-specific factors such as environmental features of the watershed, regulatory factors such as the need to revise permits or complete TMDLs, available funding, extent of previous work, land use, and the size and degree of urbanization of watershed.

There are numerous activities required by each of the five programs mentioned above, and those activities demand a wide range of data collection. Table 1.1 gives an overview of the types of data required under each program, and Table 1.2 shows the corresponding types of activities required. Both tables highlight the fact that the task performed or the data collected under one program is often identical or very similar to the work done under other programs. It is clear that significant savings can be achieved through coordination of the programs and the development of one comprehensive plan for a watershed that meets all five program needs.

Table 1.1 Overview of Data Collection Required by Watershed Programs

Data Collection	Act 167 Stormwater	Act 537 Sewage Facilities	TMDL Program	NPDES Stormwater	CSO Program	RCPs
Geographic data (political, transportation, topographic, hydrographic, land use, etc.)	**X**	**X**	**X**	**X**	**X**	**X**
Economic and demographic		**X**		**X**	**X**	**X**
Meteorological	**X**	**X**	**X**	**X**	**X**	
Hydrologic characteristics	**X**	**X**	**X**	**X**	**X**	**X**
Designated uses and impaired water bodies			**X**	**X**	**X**	**X**
Water quality		**X**	**X**	**X**	**X**	**X**
Biological and habitat assessment			**X**	**X**	**X**	**X**
Floodplains and flooding issues	**X**					**X**
Point sources / Potential sources		**X**	**X**	**X**	**X**	**X**
Non-point sources of pollution			**X**	**X**		**X**
Sewer system performance and CSO	**X**	**X**	**X**	**X**	**X**	
Storm drainage system	**X**			**X**	**X**	
Historical and cultural resources	**X**					**X**

Table 1.2 Overview of Planning Tasks Required by Watershed Programs

Planning Tasks	Act 167 Stormwater	Act 537 Sewage Facilities	TMDL Program	NPDES Stormwater	CSO Program	RCPs
Preliminary reconnaissance survey						
Existing data collection and assessment	X	X	X	X	X	X
Preliminary water quality assessment		X	X		X	X
Present / Future land use and resource mapping	X	X	X		X	X
Inventory of point and non-point sources		X	X	X		X
Definition of regulatory issues and requirements			X		X	
Preliminary biological habitat assessment			X	X		X
Preliminary problem assessment	X	X	X		X	X
Public Involvement	X	X	X	X	X	X
Individual Watershed Plan						
Survey of runoff characteristics for storm events	X		X		X	
Survey of drainage problems, flood plains, drainage structures	X			X		X
Mapping of point sources, sewer system	X		X	X	X	
Monitoring, sampling, and bioassessment			X		X	
QA/QC and data evaluation	X	X	X	X	X	X
Sewer system modeling		X			X	
Watershed modeling	X		X		X	
Water body modeling	X		X			
Problem definition and goal setting	X	X	X	X	X	X
Identification and evaluation of runoff, flood control measures	X			X		
Identification of Combined Sewer Overflow				X	X	
Identification and evaluation of pollution control measures		X	X	X	X	
Economic assessment and funding requirements	X	X	X	X	X	X
Public involvement	X	X	X	X	X	X
Development of a Watershed Management Plan	X	X	X	X	X	X*

**Note: An RCP includes some but not all elements of an integrated watershed management plan.*

Watershed-based planning is now the preferred approach on both the federal and state level. General water quality and water quantity goals have been established at a state level, and the next step is to develop specific goals for each watershed. Table 1.3 shows the watershed planning goals for Tookany/Tacony-Frankford Creek and how they correspond to many of the overlapping goals of the five major regulatory programs.

Table 1.3 Overview of the Statement of Goals of the Watershed Programs

Goal Description	Act 167 Stormwater	Act 537 Sewage Facilities	TMDL Program	NPDES Stormwater	CSO Program	RCPs
1. Streamflow and Living Resources. Improve stream habitat and integrity of aquatic life.	X		X	X	X	X
2. Instream Flow Conditions. Reduce the impact of urbanized flow on living resources.	X				X	X
3. Water Quality and Pollutant Loads. Improve dry and wet weather stream quality to reduce the effects on public health and aquatic life.		X	X	X	X	X
4. Stream Corridors. Protect and restore stream corridors, buffers, floodplains, and natural habitats including wetlands.						X
5. Flooding. Identify flood prone areas and decrease flooding by similar measures intended to support Goals 1, 2, and 4.	X					X
6. Quality of Life. Enhance community environmental quality of life (protect open space, access and recreation, security, aesthetics, historical/cultural resources).	X	X	X	X	X	X
7. Stewardship, Communication, and Coordination. Foster community stewardship and improve inter-municipal, inter-county, state-local, and stakeholder cooperation and coordination on a watershed basis.	X	X	X	X	X	X

1.6 Other Relevant Programs

Other programs, both regulatory and non-regulatory, influence the watershed management planning approach and are briefly described under this section.

1.6.1 Rivers Conservation Program (RCP)

One significant non-regulatory program is the PA Department of Conservation and Natural Resources' (DCNR) Rivers Conservation Program (RCP), which was developed to conserve and enhance stream resources by implementing locally initiated plans.

The program provides technical and financial assistance to municipalities and stream support groups for the conservation of local streams. Generally, the RCP plans intend to assess the river's resources, identify potential threats, and recommend restoration/maintenance options. That involves the statement of goals to be accomplished and the listing of recommendations for the development and implementation of the plan.

The goals and recommendations from an RCP can be an important building block for an integrated watershed management plan (IWMP). The programs are similar in structure and approach; they have the same geographic scope, require overlapping data collection; and they involve the statement of goals and listing of recommendations. However, an RCP is narrower in scope than an IWMP and focuses more on quality of life along the stream corridor rather than on regulatory compliance. The RCP for the Tookany Watershed was completed in October 2003 by Abington Township, Cheltenham Township, Jenkintown Borough, and Rockledge Borough. The Tookany/Tacony-Frankford Watershed Partnership completed the Tacony-Frankford RCP in February 2004. The goals and objectives from both RCPs are incorporated into this TTF Integrated Watershed Management Plan.

1.6.2 Summary of Other Programs

Other relevant programs that have been incorporated or that may affect the watershed management program are listed on Table 1.4.

Table 1.4 Other Programs that May Influence the Watershed Management Plan

Sanitary Sewer Overflow (SSO) Policy Requires revisions to the NPDES permit regulations to improve the operation of municipal sanitary sewer collection systems, eliminate the occurrence of sewer overflows, and provide more effective public notification when overflows do occur.
PA DEP On-Lot Sewage Disposal Regulations Require local agencies to administer a permitting program for the installation of on-lot sewage disposal systems.
PENNVEST State Revolving Fund Program Provides funding for sewer, stormwater, and water projects throughout the Commonwealth.
Delaware River Basin Commission (DRBC) Programs Regulate both groundwater and surface water use for withdrawals greater than 100,000 gpd based on average 30-day use in a large portion of the study area, which drains to the Delaware River.
Delaware Valley Regional Planning Commission (DVRPC) Programs Address transportation, land use, and environmental protection issues in addition to economic development. Also provide services in planning analysis, data collection, and mapping.
PA DCNR Greenways Program An Action Plan for Creating Connections is designed to provide a coordinated and strategic approach to creating connections through the establishment of greenways in the state.
CWA Section 104(b)(3) Program Promotes the coordination and acceleration of research, investigations, experiments, training, demonstrations, surveys, and studies relating to the causes, effects, extent, prevention, reduction, and elimination of pollution.
CWA Section 208 Wastewater Planning Intended to encourage and facilitate the development and implementation of area-wide waste treatment management plans.
CWA Section 319(b) Non-point Source Management Program Designed to address mine drainage, agricultural runoff, construction/urban runoff, hydrologic and habitat modifications, on-lot wastewater systems, and silviculture.

1.7 Regulatory Agency and Stakeholder Partnerships

Beginning in 2000, PWD acted as the municipal sponsor of the Tookany/Tacony-Frankford Watershed Partnership, an exciting and groundbreaking effort to connect residents, businesses, and government as neighbors and stewards of the watershed. PWD hired the Pennsylvania Environmental Council (PEC), a well-respected, non-profit institution with a reputation for supporting watershed-based, holistic planning, as facilitator and outreach coordinator of this partnership. PEC pulled together diverse representatives from the watershed: municipalities, "friends" groups, educators, citizens, agencies, and watershed organizations.

Within the partnership there were originally two standing committees: the Public Participation and Outreach Committee and the Technical Advisory Committee. The partnership as a whole was called together for general planning status updates and what were called "focus group" meetings, which were initiated to elicit input on the management planning process. Additionally, in 2004 a third committee called the Structure Committee was initiated. Generally, partnership meetings were devoted to education about watershed concepts and to understanding the visions and concerns of participants as they related to their communities' environmental health. The TTF Partnership participated in the selection and prioritization of goals and objectives for this watershed management plan.

The Public Participation Committee was open to all partnership members. It consisted largely of watershed organizations, educators, residents, and educational non-profits. The committee established a number of projects to raise general awareness about watershed issues and to recruit further partnership membership. Projects included two watershed surveys (as a part of the two River Conservation Planning initiatives), a large-scale public event celebrating "the return of the Great Blue Heron" to the watershed area, a stream signage program, a rain barrel implementation program, clean-ups, participation in Philadelphia Cares Day, and many more.

The Technical Committee was also open to all members of the partnership, though the participants consisted mainly of representatives from local, state, and federal government agencies. This committee reviewed the technical documents produced by PWD, including a watershed reconnaissance of past and existing water quality studies, a current water quality sampling and modeling report, a sediment pollutant loading report, and a bioassessment summary. This technical data is essential for justifying and prioritizing the goals and objectives of the watershed management plan.

The Structure Committee was born out of a recommendation of the Public Participation Committee. It had become apparent to the partnership that in order to fully realize their watershed vision and to move forward with implementation of the recommendations put forth by the TTFIWMP, they would need to evaluate their own organizational structure for its feasibility in making this possible. The result of a series of Structure Committee meetings was that the Tookany/Tacony-Frankford Watershed Partnership evolved into an independent nonprofit watershed organization, with a mission of implementing the recommendations of the TTFIWMP. To view a copy of the new Tookany/Tacony-Frankford Watershed Partnership 501(c)3 bylaws, see Appendix C.

The role of the TTF Partnership will continue to evolve and become more critical to implementation of the plan.

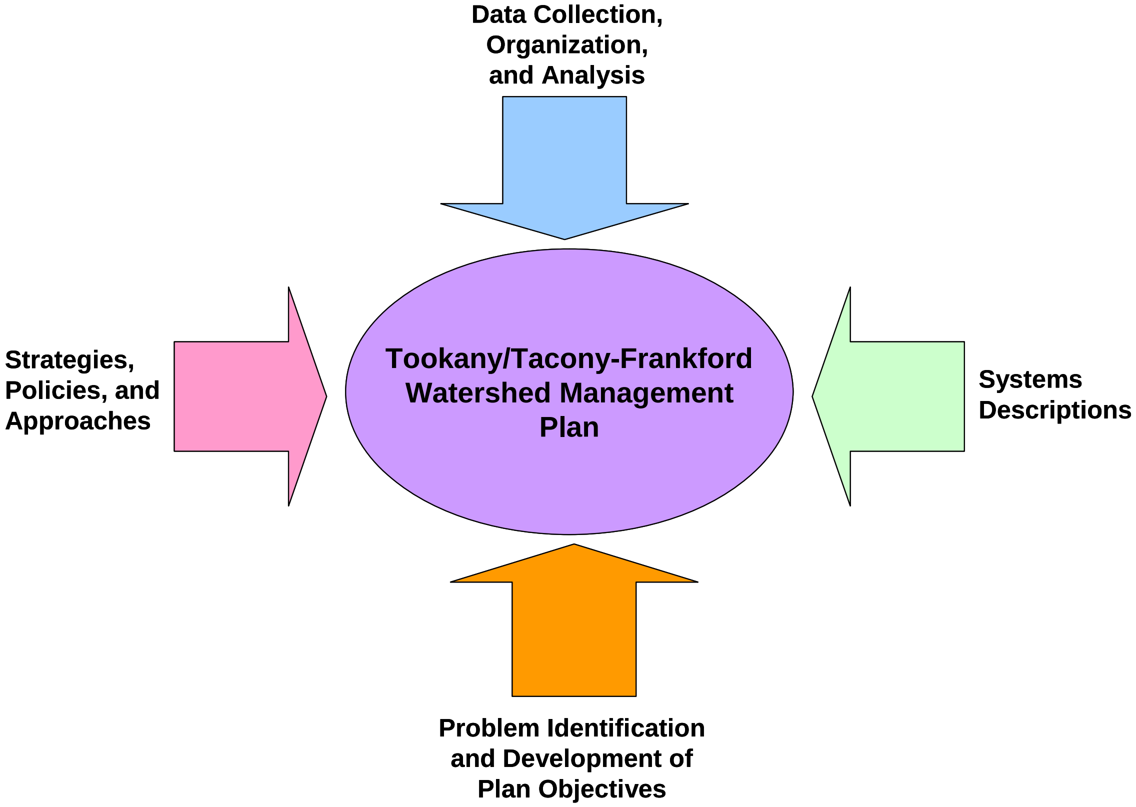
Section 2
Integrated Watershed Management for the Tookany/Tacony-Frankford Watershed

This section describes the watershed planning approach behind the TTFIWMP. It outlines the types of existing and new data that were assembled and analyzed, as well as the process for modeling stormwater flow under various scenarios. Several key concepts of the TTFIWMP are introduced: the overall goals and objectives (detailed in Section 3), the 21 watershed "indicators" (Section 4); and the screening of numerous methods, or "management options," for meeting the goals (Section 7). In addition, this section introduces the approach of setting multiple strategies – Targets A, B, and C – for promoting successful implementation of the TTFIWMP.

The watershed planning approach that serves as the framework for the Tookany/Tacony-Frankford Integrated Watershed Management Plan (TTFIWMP) contains many of the activities included in Philadelphia's CSO Long Term Control Plan and coordinates each of the five regulatory programs discussed in Section 1.4.

2.1 General Planning Approach

The general approach followed for the TTFIWMP has four major elements, as illustrated below, each with multiple tasks specific to the planning efforts within the TTF Watershed.



Data Collection, Organization, and Analysis

The initial step in the planning process is the collection and organization of existing data on surface water hydrology and quality, wastewater collection and treatment, combined sewer overflows, stormwater control, land use, stream habitat and biological conditions, and historic and cultural resources. In addition, existing rules, regulations, and guidelines pertaining to watershed management at federal, state, basin commission, county, and municipal levels also are examined for coherence and completeness in facilitating the achievement of watershed planning goals.

Data are collected by many agencies and organizations in various forms, ranging from reports to databases and Geographic Information System (GIS) files. Field data collection efforts were undertaken prior to the study, and expanded once data gaps were identified.

Systems Description

The planning approach for an urban stream must focus on the relationship between the natural watershed systems (both groundwater and surface water) and the constructed systems related to land use that influence the hydrologic cycle, such as water supply, wastewater collection and treatment, and stormwater collection. A critical step in the planning process is to examine this relationship in all its complexity and to explore the adequacy of the existing regulatory structure at the federal, state, county, and municipal level to properly manage these natural and built systems. In urban watersheds, the natural systems are, by definition, influenced by the altered environment, and existing conditions reflect these influences. It is not, however, always obvious which constructed systems are having the most influence, and what that influence is. Analyzing and understanding the water resources and water supply/wastewater/stormwater facilities and their interrelationship provides a sound basis for subsequent planning, leading to the development of a realistic set of planning objectives.

Problem Identification and Development of Plan Objectives

Existing problems and issues of water quality, stream habitat, and streamflow related to the urbanization of the watershed can be identified through analyses of:

- Prior studies and assessments;
- Existing data;
- New field data;
- Stakeholder input.

Problems and issues identified through data analysis must be compared with problems and issues brought forward by stakeholders. An initial list of problems and issues then are transformed into a preliminary set of goals and objectives. These goals and objectives may reveal data gaps and may require additional data collection and analysis. Ultimately, with stakeholder collaboration, a final list of goals and objectives is established that truly reflects the conditions of the watershed. These goals and objectives are prioritized by the stakeholders based on the results of the data analysis.

The priority of objectives becomes the basis for developing a recommended alternative. Potential constraints on implementation require that the objectives be broken down into phased targets, in which an alternative is developed to meet interim objectives. In this way, the effectiveness of implementation can be monitored, and targets adjusted, as more is learned about the watershed, its physical characteristics, and evolving water quality regulations.

Strategies, Policies, and Approaches

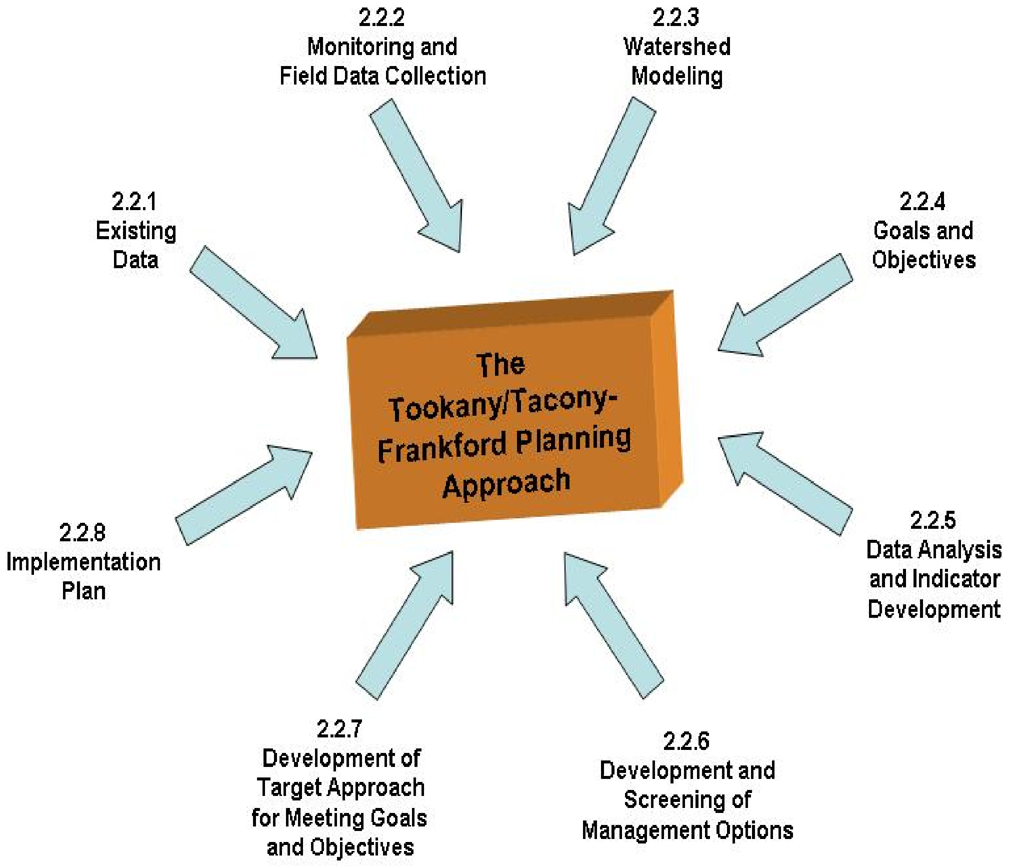
Once end targets and interim targets are established, with a clear list of associated planning objectives based on sound scientific analysis and consensus among stakeholders, a recommended alternative can be developed to meet the agreed upon targets and objectives. This alternative combines selected options from among the many suggested municipal actions, recommendations on water supply and wastewater collection system improvements, potential measures to protect water quality from point sources, best management practices for stormwater control, measures to control sanitary and combined sewer overflows, changes to land use and zoning, stream channel and streambank restoration measures, etc.

Section 8 of this plan provides Implementation Guidelines on how best to combine the many options in a coherent fashion within the context of the watershed-wide management objectives. The plan is designed to provide an implementation process and guidelines to achieve the stated objectives over a specified period of time.

2.2 The Tookany/Tacony-Frankford Planning Approach

As mentioned above, the approach and specific tasks for the TTFIWMP are intended to meet the criteria of the five major regulatory programs discussed in Section 1.4.

In order to establish environmental goals and identify the indicators that measure progress toward these goals, the Tookany/Tacony-Frankford planning strategy utilizes the "plan-do-check-review" methodology often called the "adaptive management approach." To satisfy the five elements included in this procedure, the Tookany/Tacony-Frankford planning process moved from data collection and analysis to plan development in an organized manner, with constant interaction with the established stakeholder groups. The primary data collection, analysis, and technical planning activities of the TTFIWMP are outlined below, and the stakeholder process is discussed in Section 3.



2.2.1 Existing Data

PWD assembled relevant existing data and information collected in the past by other agencies and by prior studies. Several types of geographic and physical data were collected.

Geographic and Demographic Data

The base map for the project study area was prepared from U.S. Census Bureaus TIGER (Topologically Integrated Geographic Encoding and Referencing) database. These files contain local and state political boundaries, rivers and waterways, roads and railroads, and census block and block group boundaries for demographic analysis.

Meteorological Data

In addition to U.S. Census data, meteorological data was gathered to analyze streamflow responses to seasonal changes, climate variation, and storms, and to model stormwater flows. Long-term rainfall data was obtained from the National Oceanic and Atmospheric Administration's rainfall gauge at the Philadelphia International Airport. This gauge has over 100 years of hourly precipitation data, from 1902 through the present. In addition to this long-term rainfall gauge, the PWD CSO Program has over 10 years of 15-minute rainfall data from 24 rain gauges. Ten of these gauges are in the vicinity of the TTF Watershed. The available rainfall data for each gauge is summarized in Table 2.1, and Figure 2.1 shows their locations (next page). Data from each gauge was analyzed for accuracy and completeness and then subjected to statistical analyses to check for changes in the gauge location or physical layout, as well as to explore correlations among gauges to identify potential over- or under-catch trends.

Rain Gauge Data: PWD maintains a database of 15-minute accumulated precipitation depths collected from its county-wide 24 tipping bucket rain gauge network for the period 1990 to the present. The uncorrected, 2.5-minute accumulated, 0.01 inch tip count, rain gauge data is subjected to preliminary quality assurance and quality control procedures. Identification and flagging of bad or missing data is performed for each rainfall event on a monthly basis by visual inspection comparing 15-minute accumulated measurements at nearby gauges and looking for patterns of obvious gauge failures, including plugged gauges and erratic tipping. Next, a bias adjustment procedure is performed to normalize systematic rain gauge biases across the network. Finally, all data flagged as bad or missing is filled with data from up to five nearby gauges using inverse-distance-squared weighting. A continuous rainfall record at each gauge location is thereby produced for use in continuous hydrologic model simulations.

Radar Rainfall Data: Gauge calibrated radar rainfall estimates have been obtained from Vieux and Associates for seven wet weather events sampled during 2003. The spatial resolution of this data is approximately 1km x 1km grid covering the extended watershed area. The 15-minute accumulated rainfall depths are derived from the National Weather Service's Mount Holly, NJ, level 2 radar reflectivity data that has been calibrated to PWD's rain gauge data using mean field bias adjustment. Mean field bias adjustment preserves the average rainfall depth measured at the rain gauges along with the spatial distribution represented by the radar reflectivity data.

Representative Wet Weather Year: A representative year of rainfall data was constructed to more easily evaluate the effectiveness of stormwater management options. This was done by comparing the 100-year hourly rainfall record from the NOAA Philadelphia International

Airport rain gauge station to individual quarterly records for the years 1991 through 2002. Each quarter year was evaluated against the long term record by comparing total quarterly rainfall along with the cumulative distributions of rainfall intensities and storm total depths. The resulting representative year was constructed using data from quarter 1 of 1997, quarter 2 of 1998, quarter 3 of 1996, and quarter 4 of 1997.

Table 2.1 Rainfall Data Available for the Tookany/Tacony-Frankford Watershed Gauges

Gauge Name	Available Data
RG-07	1991-2003
RG-08	1991-2001, 2003
RG-10	1991-2001
RG-11	1991-2000, 2002-2003
RG-13	1991-1998, 2001-2003
RG-14	1991-1998, 2001
RG-17	1991, 1993-2003
RG-18	1992-2003
RG-19	1991-2003

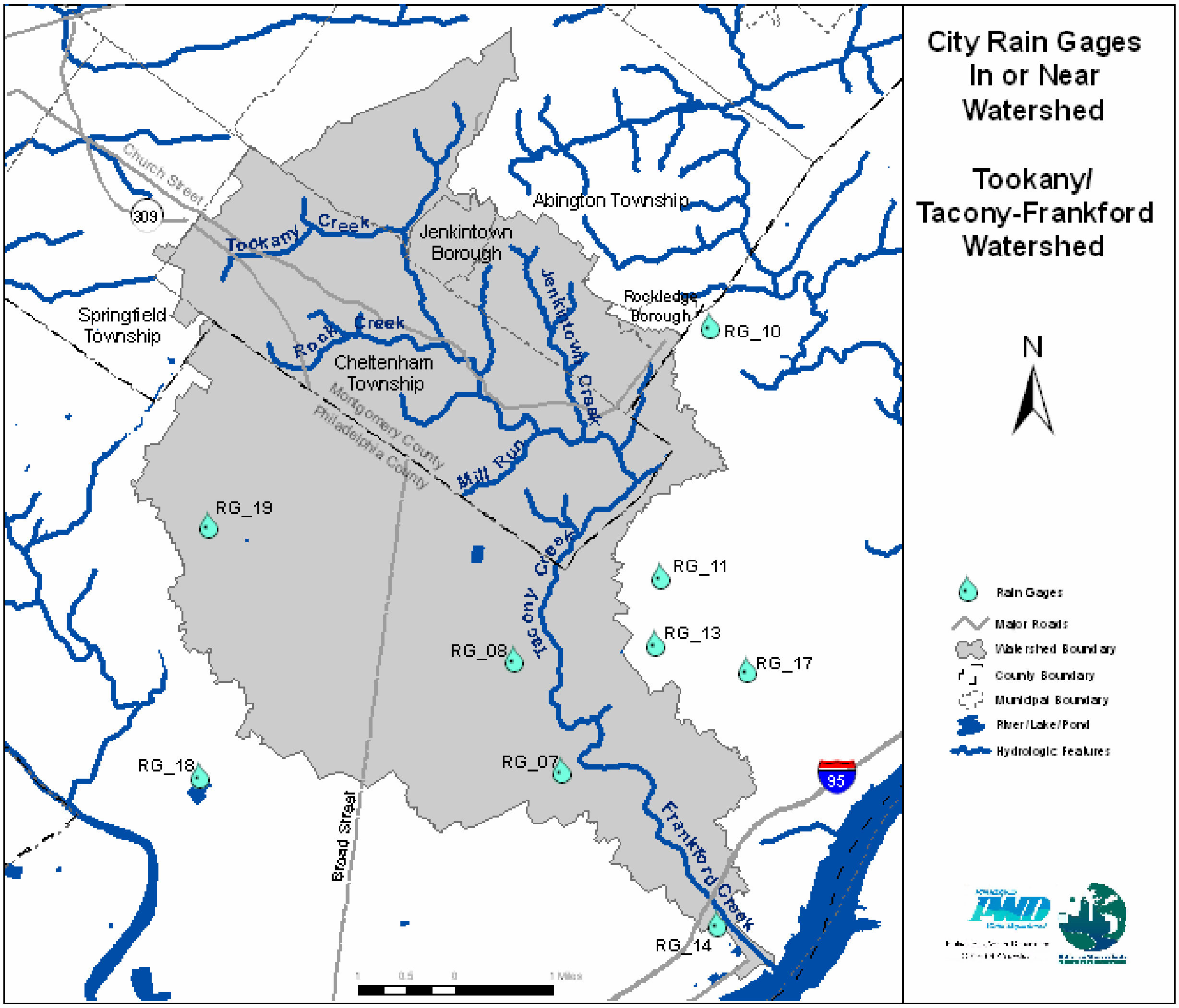


Figure 2.1 City Rain Gauges in or near the Tookany/Tacony-Frankford Watershed

Land Use

Land use information for the Tookany/Tacony-Frankford Watershed was obtained from the Delaware Valley Regional Planning Commission (DVRPC) for Montgomery and Philadelphia counties. The DVRPC land use maps are based on aerial photography from March through May of 1995. The residential areas were updated based on the 2000 Census populations. A useful representation of the existing land use information for hydrologic analyses was developed as shown in Figure 2.2.

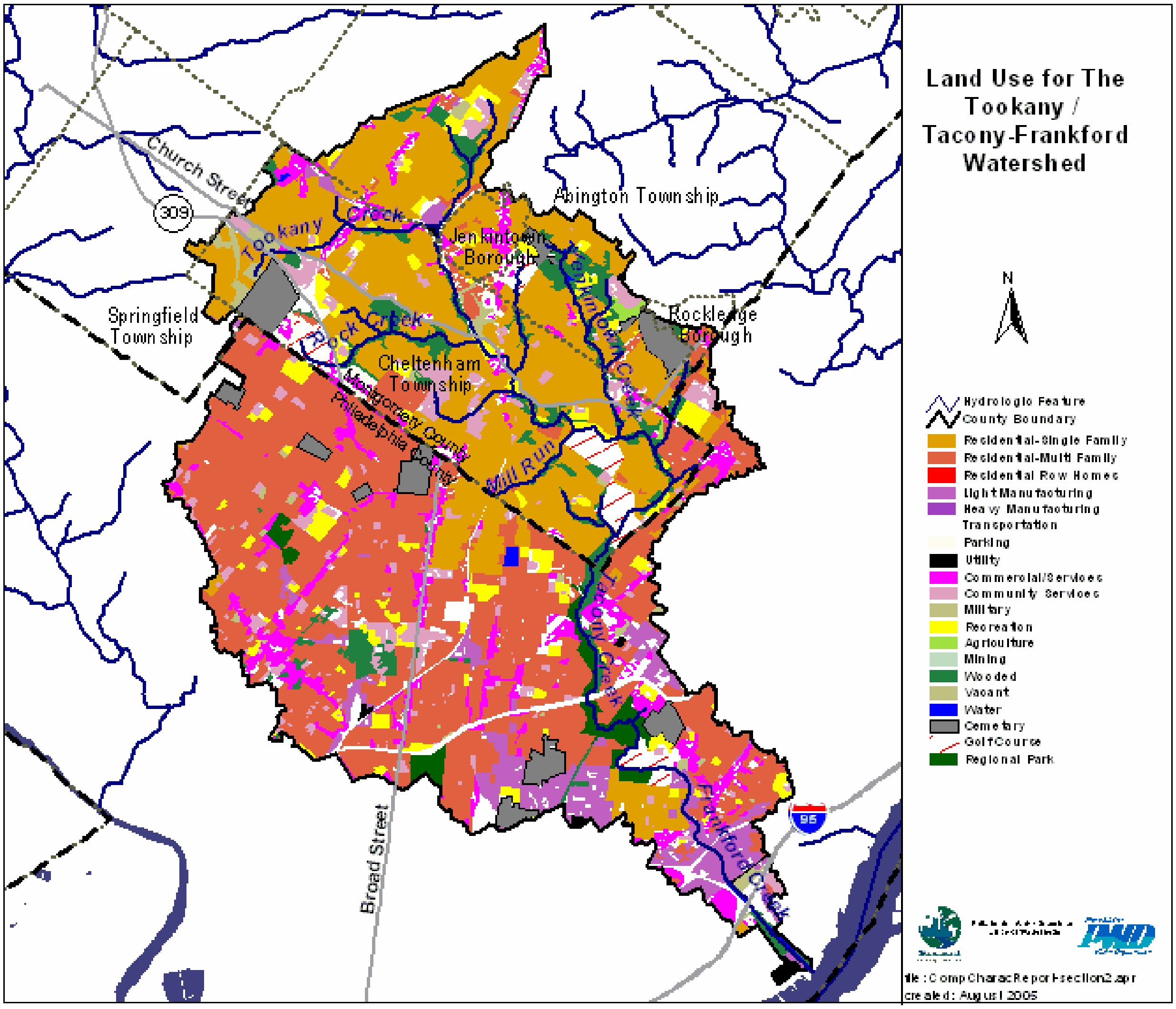


Figure 2.2 Land Use Map for the Tookany/Tacony-Frankford Watershed (Source: DVRPC)

Streamflow

During the 1960s, the United States Geological Survey (USGS), in cooperation with PWD, established streamflow-gauging stations at five locations in the Tookany/Tacony-Frankford Watershed. While only one of these gauges still is active today, the two to three decades of historic record they provided is invaluable in characterizing the hydrologic response of the watershed. The locations of the gauges are listed in Table 2.2 and shown in Figure 2.3, below. Daily streamflow records from the gauges were analyzed, and baseflow separation performed to identify patterns along the stream of baseflow and stormwater runoff. (The results of these analyses are presented in Section 4.2.1 and Section 5.2.)

Water Quality

In the early 1970s, the Philadelphia Water Department began a study in cooperation with the U.S. Geological Survey (USGS) titled, "Urbanization of the Philadelphia Area Streams." The purpose of this study was to quantify the pollutant loads in some of Philadelphia's streams and document any degradation in water quality due to urbanization. The study included three sampling sites in the headwaters and two on the main stem of Tacony-Frankford Creek (see Figure 2.3, next page). Monthly discrete water quality samples were collected at each site and analyzed for a variety of water quality parameters between 1970 and 1980. The USGS established streamflow gauging stations at five locations in the Tacony-Frankford Watershed, partially as a result of its participation in the Cooperative Program. The majority of the data currently available from STORET, U.S. EPA's water quality database, was collected as part of this study.

Table 2.2 USGS Gauges and Periods of Record

Gauge No.	Name	Drainage Area (sq. mi.)	Period of Record
01467089	Frankford Creek at Torresdale Ave.	33.8	10/1/65 - 9/30/81, 5/14/82 - 6/29/82
01467087	Frankford Creek at Castor Ave.*	30.4	7/1/82 - 9/30/98
01467086	Tacony Creek at County Line	16.6	10/1/65 - 11/17/88
01467085	Jenkintown Creek At Elkins Park	1.17	10/01/73 - 9/30/78
01467083	Tacony Creek near Jenkintown	5.25	10/1/73 - 9/30/78

** currently operating gauge*

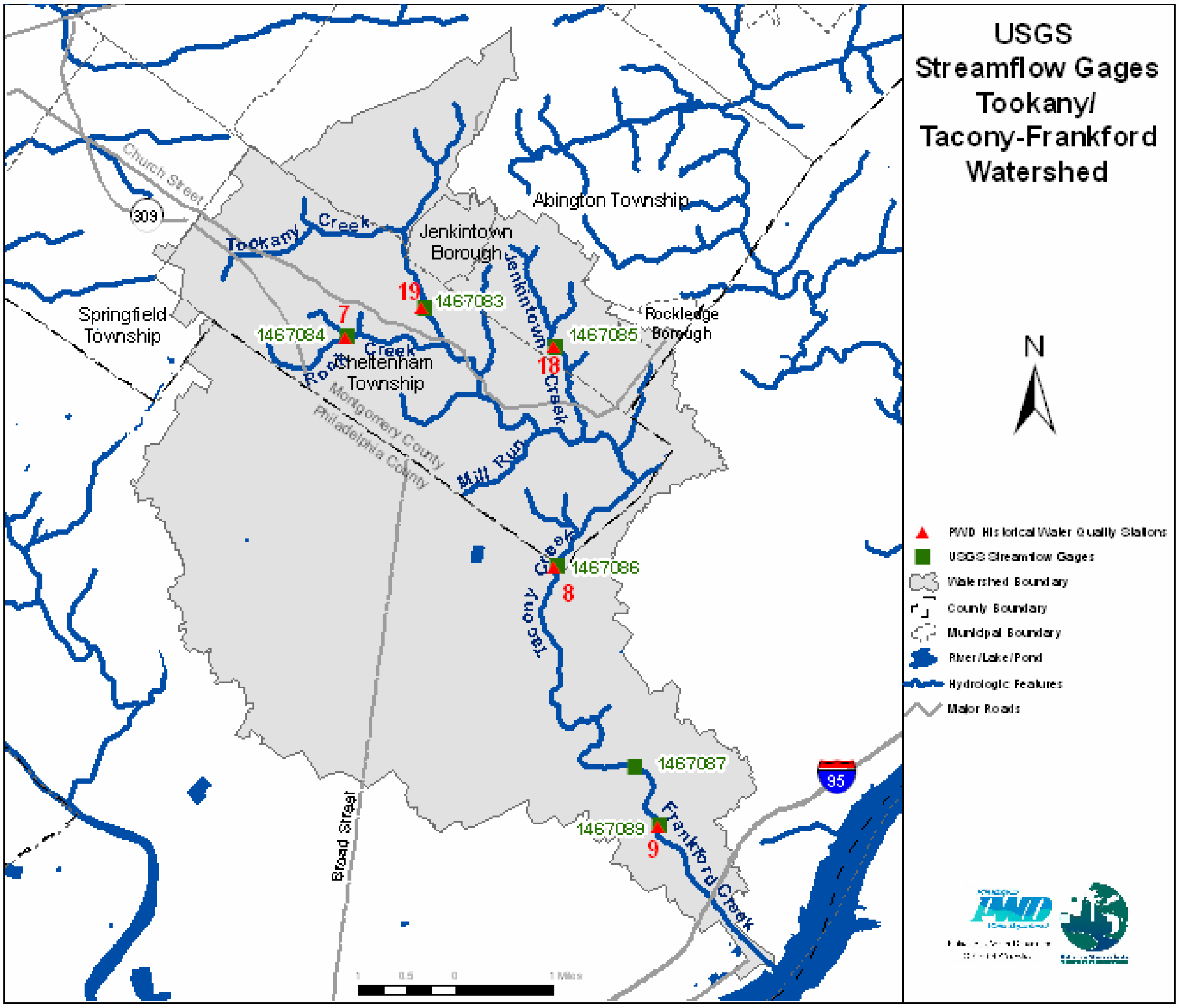


Figure 2.3 PWD/USGS Cooperative Program Water Quality and Streamflow Stations in the Tookany/Tacony-Frankford Watershed

2.2.2 Monitoring and Field Data Collection

To supplement existing data, PWD conducted an extensive sampling and monitoring program to characterize conditions in the TTF Watershed. The program was designed to document the condition of aquatic resources, to provide information for the planning process needed to meet EPA and PA DEP regulatory requirements, and to monitor trends as implementation proceeds.

Water Quality Sampling

PWD performed three types of sampling at eight sites (Figure 2.4). Discrete sampling was done from June 2000 through July 2003. Wet weather sampling involved collecting discrete samples before and during 12 wet weather events from March 2001 through October 2003, allowing the characterization of water quality responses to stormwater runoff and sanitary and combined sewer overflows. The third type of sampling was continuous monitoring, carried out by YSI 6600 and 600 XLM Sondes, shallow depth continuous water quality monitors, and probes that record dissolved oxygen, pH, and turbidity. The equipment was deployed to three locations periodically for a number of days to collect continuous data samples and observe water quality fluctuations. The Sonde data for the Tookany/Tacony-Frankford Watershed includes over 80 deployments.

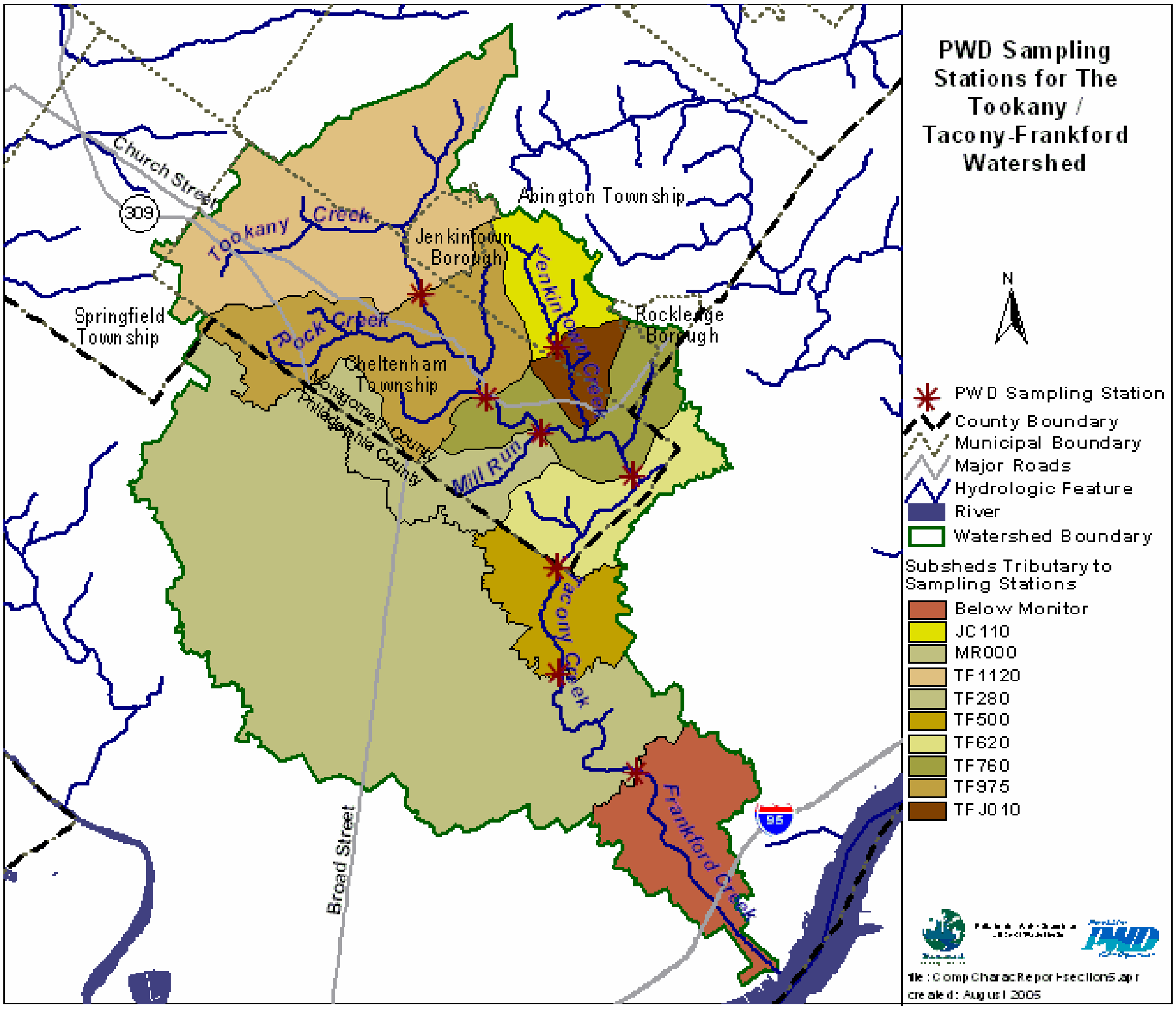


Figure 2.4 Water Quality Monitoring Locations in the Tookany/Tacony-Frankford Watershed

Biological Monitoring

Biological monitoring is a useful means of detecting anthropogenic impacts to the aquatic community. Resident biota (e.g., benthic macroinvertebrates, fish, and periphyton) in a water body are natural monitors of environmental quality and can reveal the effects of episodic and cumulative pollution and habitat alteration (Plafkin et. al. 1989, Barbour et al. 1995). The Philadelphia Water Department's Office of Watersheds and Bureau of Laboratory Services, along with the Philadelphia Academy of Natural Sciences and the Pennsylvania Department of Environmental Protection have been developing a preliminary biological database to assess the aquatic integrity of the Tookany/Tacony-Frankford Watershed. During the winter of 2000-2001, the Philadelphia Water Department conducted biological assessments (Rapid Bioassessment Protocols III and V) at seven non-tidal locations along the Tacony-Frankford Watershed to investigate the various point and non-point source stressors. Macroinvertebrate and ichthyfauna monitoring was conducted at specific locations within the watershed. Geographical Information Systems (GIS) databases and watershed maps were constructed to provide accurate locations of the sampling sites.

An ichthyfauna (fish) assessment occurred at four sampling stations on the mainstem of the Tookany/Tacony-Frankford Creek. Six metrics were used to assess the quality of the fish assemblages in the study stream.

1. Species richness
2. Species diversity
3. Trophic composition relationships
4. Pollution tolerance levels
5. Disease and parasite abundance/severity
6. Introduced (exotic) species

In addition to the fish assessment, the results of a PA DEP Rapid Bioassessment Protocol (RBP) assessment of seven sites in the Tookany/Tacony-Frankford Watershed were also compiled. PA DEP biologists used a combination of habitat and biological assessments to evaluate the Tookany/Tacony-Frankford under the Unassessed Waters Program. Biological surveys included kick screen sampling of benthic macroinvertebrates, which were identified by family and by their tolerance to pollution. Benthic macroinvertebrates mainly are aquatic insect larvae that live on the stream bottom. Since they are short-lived and relatively immobile, they reflect the chemical and physical characteristics of a stream and chronic sources of pollution. The biological integrity and benthic community composition was determined using U.S. EPA guidelines for RBP III.

Upon completion of the total biological scoring criteria, each site was compared to a reference site according to its drainage area and geomorphological attributes. The reference site chosen was French Creek, located at Coventry Road Bridge, South Coventry Township, Chester County. The comparison of the biological assessment of each site with the reference site was designed to create a baseline for monitoring trends in benthic community structure that might be attributable to improvement or worsening of conditions over time. Several Biological Condition Categories were developed:

- Non-impaired
- Slightly impaired
- Moderately impaired
- Severely impaired

Habitat Assessment

Habitat assessments evaluate how deeply the stream substrate is embedded, the degree of streambank erosion, the condition of riparian vegetation, and the amount of sedimentation. Data from the PA DEP surveys were available for the Tookany/Tacony-Frankford Creek. Habitat assessments at seven non-tidal sites were completed based on the Stream Classification Guidelines for Wisconsin (Ball, 1982) and Methods of Evaluating Stream, Riparian, and Biotic Conditions (Platts et al., 1983). Reference conditions were used to normalize the assessment to the Tookany/Tacony-Frankford (mainstream) "best attainable" situation. Habitat parameters were separated into three principal categories to characterize the site:

- Primary or microscale habitat
- Secondary or macroscale habitat (stream channel)
- Tertiary or riparian and bank structure

Resource based Habitat Suitability Indices (HSI) were developed to add aquatic life-based habitat and flow requirement criteria to the watershed assessment. HSIs integrate the expected effects of a variety of physicochemical and hydrological variables on a target species of environmental or economic concern. Data is used to construct sets of suitability index curves, each of which relates a habitat parameter to its suitability for the species of interest. Curves rate habitat variables on a scale of 0 to 1.0, and were developed to measure food and cover, water quality, and reproduction (e.g., substrate type, percent pools, percent cover, depth of pools, pH, DO, turbidity, temperature).

Fluvial Geomorphological Assessment

For the Tacony Creek Watershed, members of the Philadelphia Water Department performed a fluvial geomorphological (FGM) assessment which included baseline determination of stream stability and habitat parameters. The measurement of geomorphic parameters and physical and hydraulic relationships were performed at both Level I and Level II using the Rosgen classification methodology (D.L. Rosgen Applied River Morphology 1996).

Level I: Desktop survey included desktop delineation of the stream using generalized major stream types based on available topographic information, geological maps, soils maps, and aerial photographs. The purpose of the inventory was to provide an initial framework for organizing and targeting subsequent field assessments of important reaches where problems are known to occur or are anticipated to occur. Available topographic information, geological maps, soils maps, and aerial photographs were reviewed.

Level II: Reach stream survey was performed for approximately 30 miles of stream including the Main Stem Tookany/Tacony-Frankford Creek and 14 tributaries within the Watershed. A field team consisting of engineers and biologists walked the designated lengths of each stream and tributary and estimated several parameters related to channel morphology:

- Bankfull elevations/widths
- Floodprone elevations/widths
- Bankfull/Floodprone discharges
- Entrenchment ratios
- Width/Depth ratios
- Sinuosity
- Channel/Water surface slopes
- Channel materials (pebble count) – D50's
- Meander pattern
- Rosgen stream types
- Velocities
- Shear stresses

Wetland Study Method

Wetlands play a significant role in ecosystem health and water quality in a watershed. For this reason, two wetland field investigations were conducted to characterize the presence and condition of wetlands in the Tookany/Tacony-Frankford Watershed. Potential wetlands within Philadelphia were evaluated in July of 2001, and potential wetlands in Montgomery County were evaluated in August 2003. The wetland field investigation was designed to survey existing wetlands, evaluate potential wetland enhancement actions, and identify potential wetland creation sites.

The field investigation plan was developed based on orthophoto basemaps, and indicator information such as National Wetlands Inventory (NWI) mapping, hydric soil information, Fairmount Park Commission (FPC) mapping, and Delaware Valley Regional Planning Commission (DVRPC) existing open space mapping.

The wetland field investigation evaluated the hydrology, vegetation, soils, general location, estimated acreage, and landscape position of the wetlands in the riparian corridors. Although wetlands were not delineated, all identified wetlands within the watershed met the criteria for jurisdictional wetlands as described in the 1987 *U.S. Army Corps of Engineers* (USACE) *Wetlands Delineation Manual* (Environmental Laboratory 1987). Where possible, significant and representative points were mapped using global positioning systems (GPS).

Existing wetlands located during the field survey were also evaluated for existing wetland functions using the Oregon Assessment Method. The *Oregon Freshwater Wetland Assessment Methodology* (Roth, et al. 1996) and the Human Disturbance Gradient (Gernes and Helgen, 2002) were applied to each wetland location. The Oregon Assessment Method values were calculated for Wildlife Habitat, Fish Habitat, Water Quality, Hydrologic Control, and Sensitivity to Future

Impact. An additional function, termed Wetland Improvement, was evaluated using relevant questions from other areas of the Oregon Assessment Method. The Wetland Improvement Function was intended to reflect field observations that the potential for wetland enhancement may exist without a significant buffer, so long as there was sufficient access to create the enhancement.

Water quality is a factor of both the Oregon Assessment Method and the Human Disturbance Gradient (HDG). A combination of field observations, including the location of the wetland and waterway within the watershed or sub-watershed, as well as the PA DEP's *2002 Section 303(d) List of Impaired Waterbodies* (PA DEP 2002) was used as a measure of water quality. Four PWD monitoring stations within the Tookany/Tacony-Frankford Watershed that assess chemical, macroinvertebrate, and fish habitat data also contributed data to the Oregon and HDG analyses.

Where applicable, the redirection of outlets was considered in determining sites for streambank restoration and/or wetland restoration. Existing undeveloped areas were considered as potential wetland creation sites; factors included proximity to a waterway, the presence of stormwater outlets, the presence of existing wetlands nearby, whether these wetlands would be negatively impacted by the creation of additional wetland, and construction access and physical limitations of the site.

2.2.3 Watershed Modeling

An important tool for developing the watershed plan is a hydrologic and hydraulic model of the stream and stormwater system. In most streams in the eastern U.S., stormwater flows can range from less than 30% of total annual streamflow in less-developed watersheds to over 70% in highly urbanized settings. Modeling of stormwater flows is, therefore, a critical component of a watershed management plan. The model should, at a minimum, be built to provide storm-by-storm flows to the streams as well as estimates of pollutant loads carried by the stormwater reaching the streams.

A Stormwater Management Model (SWMM) was built for the entire Tookany/Tacony-Frankford Watershed. SWMM is a comprehensive set of mathematical models originally developed for the simulation of urban runoff quantity and quality in storm, sanitary, and combined sewer systems. The model subdivides the watershed into approximately 300 subwatersheds and estimates flow and pollutant loading from each land use type within each of the subwatersheds. It simulates the hydraulics of combined sewers, the open channel of the creek itself, and the floodplain. Thus, the model is useful for simulation of stormwater runoff quantity and quality, combined sewer overflow, and streamflow. The model was calibrated by comparing stormwater runoff to estimated runoff, calculated through hydrograph separation at the USGS gauges in the watershed. Model simulations included:

- Existing conditions using a long-term rainfall record from Philadelphia Airport;
- Annual average pollutant loads for key pollutants found in stormwater. The list of pollutants includes parameters such as nitrate, phosphorus, total suspended solids, heavy metals, biochemical oxygen demand, and dissolved oxygen;
- Numerous simulations to test the effectiveness of various BMPs within the Tookany/Tacony-Frankford Watershed. Effectiveness was judged based on reductions in stormwater discharges, CSOs, and reduced pollutant loading during wet weather.

The model results helped identify areas where stormwater runoff or pollutant loads are particularly high and in need of control. Model flow results, in combination with the results of the fluvial geomorphic assessment, provided excellent tools for identifying areas of the watershed that are undergoing stormwater-related stress and an efficient way of developing alternative integrated watershed management approaches, particularly with regard to the Wet Weather “Target C” objective (described in Section 2.2.7).

2.2.4 Goals and Objectives

Early in the planning process, project goals and objectives were developed in conjunction with the stakeholders. In general, goals represent consensus on a series of "wishes" for the watershed. Seven project goals were established that encompass the full spectrum of goals from all the relevant regulatory programs as well as the River Conservation Plans (as summarized in Table 1.3). A significant effort was made to consolidate the various goals into a single, coherent set that avoids overlap and is organized into clear categories:

1. Streamflow and Living Resources
2. Instream Flow Conditions
3. Water Quality and Pollutant Loads
4. Stream Corridors
5. Flooding
6. Quality of Life
7. Stewardship, Communication, and Coordination

Once the preliminary set of goals was established, a series of associated objectives was developed. Objectives translate the goals into measurable quantities; "indicators" (described below) are the means of measuring progress toward those objectives. This relationship is the link between the more general project goals and the indicators developed to assess the watershed and to track future improvement.

The preliminary planning goals and objectives were presented to stakeholders for initial review. However, the final, prioritized goals and objectives were subjected to final review and approval when the data analysis and modeling work were completed. (See Section 3 for more detail.)

2.2.5 Data Analysis and Indicator Development

An integral part of this plan is the assessment and description of existing conditions within the watershed and stream. This assessment has identified specific problem areas, while establishing a "watershed baseline" from which we can measure our future progress as recommendations are implemented. Based upon these existing conditions, a series of "watershed indicators" were developed so that as implementation occurs in the coming years, progress can be quantified. These indicators were developed to represent the results of the data collection efforts and the data analysis and modeling. An indicator is a measurable quantity that characterizes the current state of at least one aspect of watershed health. Every indicator is directly linked to one or more project objectives. Thus, they serve to describe the current conditions, and provide a clear method of monitoring progress and achievement of objectives as watershed management strategies are implemented over time.

The 21 indicators selected for their potential use in assessing both current conditions and future progress in improving conditions are listed in Table 2.3 (next page) and discussed in detail in Section 4.

Table 2.3 Tookany/Tacony-Frankford Watershed Indicators

The Land Use and Stream Health Relationship

Indicators	
1	Land Use and Impervious Cover

Flow Conditions and Living Resources

Indicators	
2	Streamflow
3	Stream Channels and Aquatic Habitat
4	Restoration and Demonstration Projects
5	Fish
6	Benthic Macroinvertebrates

Water Quality

Indicators	
7	Effects on Public Health (Bacteria)
8	Effects on Public Health (Metals and Fish Consumption)
9	Effects on Aquatic Life (Dissolved Oxygen)

Pollutants and Their Sources

Indicators	
10	Point Sources
11	Non-point Sources

The Stream Corridor

Indicators	
12	Riparian Corridor
13	Wetlands and Riparian Woodlands
14	Wildlife

Quality of Life

Indicators	
15	Flooding
16	Public Understanding and Community Stewardship
17	School-Based Education
18	Recreational Use and Aesthetics
19	Local Government Stewardship
20	Business and Institutional Stewardship
21	Cultural and Historic Resources

2.2.6 Development and Screening of Management Options

Clear, measurable objectives provided the guidance for developing options designed to meet the project goals. A "management option" is a technique, measure, or structural control that addresses one or more objectives (e.g., a detention basin that gets built, an ordinance that gets passed, an educational program that gets implemented).

The following example clarifies the difference among a goal, an objective, and a management option.

> **Goal**: Improve water quality.
>
> **Objective:** Maintain dissolved oxygen levels above 5 mg/L.
>
> **Management Option:** Eliminate deep, poorly mixed plunge pools where low DO is detected.

Lists of management options were developed to meet each of the goals and objectives established for the Tookany/Tacony-Frankford Watershed. Only those options deemed feasible and practical were considered in the final list of management options. Options were developed and evaluated in three steps:

1. **Development of a Comprehensive Options List.** Virtually all options applicable in the urban environment were collected. These options were identified from a variety of sources, including other watershed plans, demonstration programs, regulatory programs, literature, and professional experience.
2. **Initial Screening.** Some options could be eliminated as impractical for reasons of cost, space required, or other considerations. Options that already were implemented, were mandated by one of the programs, or were agreed to be vital, were identified for definite implementation. The remaining options were screened for applicability to the TTF Watershed and for their relative cost and the degree to which they met the project objectives. Only the most cost-effective options were considered further.
3. **Detailed Evaluation of Structural Options.** Structural best management practices (BMPs) for stormwater and combined sewage were subjected to a modeling analysis. Effects on runoff volume, overflow volume, peak stream velocity, and pollutant loads were evaluated at various levels of coverage.

Detailed evaluation of structural options (step 3) used the SWMM model to assess the effectiveness of each option and used planning-level cost estimates of each option. All options that had an effect on CSOs or stormwater-related pollutant loads were modeled at several degrees of implementation. Graphs of effectiveness versus degree of implementation were developed, and the results were then combined with more accurate cost estimates to provide guidance on selecting effective options or combinations of options.

2.2.7 Development of Target Approach for Meeting Goals and Objectives

In developing a recommended watershed management alternative and discussing goals and objectives with stakeholders, it became clear that implementation could best be achieved by defining three distinct targets to meet the overall plan objectives. Targets A and B were defined so that they could be fully met with a limited set of options that are fully implemented. Target C fit better with an adaptive management approach. In other words, it was agreed to set interim objectives, recommend measures to achieve the interim objectives, implement those controls, and reassess the capability to meet the objectives or agree to raise the bar to more complete achievement of the final objectives.

These three targets represent groups of objectives that each focus on a different problem related to the urban stream system. They can be thought of as different parts of the overall goal of fishable and swimmable waters through improved water quality, more natural flow patterns, and restored aquatic and riparian habitat. The targets are specifically designed to help focus plan implementation.

By defining these targets, and designing the recommended alternative to address the targets simultaneously, the plan will have a greater likelihood of success. It also will result in realizing some of the objectives within a relatively short time frame, providing positive incentive to the communities and agencies involved in the restoration, and more immediate benefits to the people living in the watershed.

The targets for the Tookany/Tacony-Frankford Integrated Watershed Management Plan are defined as follows:

Target A: Dry Weather Water Quality and Aesthetics

Target A was defined for Tookany/Tacony-Frankford Creek with a focus on trash removal and litter prevention, and the elimination of sources of sewage discharge during dry weather. Streams should be aesthetically appealing (look and smell good), be accessible to the public, and be an amenity to the community. Access and interaction with the stream during dry weather has the highest priority, because dry weather flows occur about 60-65% of the time during the course of a year on the Tookany/Tacony-Frankford Creek. These are also the times when the public is most likely to be near or in contact with the stream. The water quality of the stream in dry weather, particularly with respect to bacteria, should be similar to background concentrations in groundwater.

In many urban streams, monitoring indicates that the water quality rarely meets the standard for bacteria, and occasionally exhibits dissolved oxygen (DO) problems, even during baseflow or dry weather conditions. Thus, the first target focuses on dry weather water quality, coupled with the visual aesthetics of the stream, primarily the removal of trash and the elimination of illegal dumping so often associated with degraded, urban waterways. Target A also includes a range of regulatory and nonstructural options that address both water quality and quantity concerns. Because the options under consideration are aimed at the total elimination of dry weather sources of trash and sewage, virtually all options related to this target were included in the implementation plan.

Target B: Healthy Living Resources

Based on the results of the water quality monitoring, habitat assessment, and biological monitoring, water quality was not identified as the primary cause of the low diversity and impaired nature of the fish population in the stream. Improvements to the number, health, and diversity of the benthic macroinvertebrate and fish species in the Tookany/Tacony-Frankford Creek need to focus on habitat improvement and the opportunity for organisms to avoid high velocities during storms. Fluvial geomorphological studies, wetland and streambank restoration/creation projects, and stream modeling should be combined with continued biological monitoring to ensure that correct procedures are implemented to increase habitat heterogeneity within the aquatic ecosystem.

Improving the ability of an urban stream to support viable habitat and fish populations focuses primarily on the elimination or remediation of the more obvious impacts of urbanization on the stream. These include loss of riparian habitat, eroding and undercut banks, scoured streambed or excessive silt deposits, channelized and armored stream sections, trash buildup, and invasive species. Thus, the primary tool to accomplish Target B is stream restoration.

Restoration will focus on improving channel stability, improving instream and riparian habitat, providing refuges for fish from high velocity conditions during storms, and managing land within the stream corridor. Restoration strategies include:

- Bank stabilization, including boulder structures, bioengineering, root wads, plantings, and log and woody structures;
- Bed stabilization, including rock/log vanes with grade control, rock/log cross vanes, and using naturally occurring boulders and bedrock;
- Realignment and relocation, used only on severely degraded stream sections;
- Dam and debris removal;
- Reforestation, with priority to floodplains, steep slopes, and wetlands;
- Invasive species management to increase biodiversity;
- Wetland creation, often used in conjunction with stream realignment to improve floodplain areas subject to annual flooding;
- Forest preservation;
- Fish holding areas, with low- to no-current zones created to provide fish with places to hold position during high flows.

Stream restoration measures to meet Target B were identified, and all options required to meet the target are planned for implementation.

Target C: Wet Weather Water Quality and Quantity

The third target is to restore water quality to meet fishable and swimmable criteria during wet weather. Improving water quality and flow conditions during and after storms is the most difficult target to meet in the urban environment. Because wet weather conditions on Tookany/Tacony-Frankford Creek occur to some degree about 35-40% of the time during the year, measures to improve wet weather quality have a somewhat lower priority than measures designed to address dry weather water quality. During wet weather, extreme increases in streamflow are common, accompanied by short-term changes in water quality. Stormwater generally does not cause immediate DO problems.

A comprehensive watershed management approach must also address flooding issues. Where water quality and quantity problems exist, options may be identified that address both. Any BMP that increases infiltration or detains flow will help decrease the frequency of damaging floods; however, the size of such structures may need to be increased in areas where flooding is a major concern. (Reductions in the frequency of erosive flows and velocities also will help protect the investment in stream restoration made as part of the Target B.)

Target C must be approached somewhat differently from Targets A and B. Full achievement of this target means meeting all water quality standards during wet weather, as well as eliminating all flooding. Meeting these goals will be difficult. It will be expensive and will require a long-term effort. The only rational approach to achieve this target must include stepped implementation with interim goals for reducing wet weather pollutant loads and stormwater flows, along with monitoring for the efficacy of control measures.

Initial load reduction targets for parameters such as metals, total suspended solids (TSS), and bacteria were set in conjunction with the stakeholders. Based on preliminary work by PWD, a 20% reduction is a challenging but achievable initial interim target.

It is expected that changes to the approach, and even to the desired results, will occur as measures are implemented and results are monitored. This process of continually monitoring progress and adjusting the approach is known as "adaptive management." The NPDES permit programs for stormwater and CSO outfalls can lead to a cycle of monitoring, planning, and implementation that helps define a time frame to this process.

2.2.8 Implementation Plan

Implementation plan guidelines were developed to provide Philadelphia and the upstream municipalities with a blueprint for improving water quality and habitat conditions. The guidelines (detailed in Section 8) include:

- Specific recommendations and a schedule for meeting Target A objectives;
- Specific recommendations and a schedule for meeting Target B objectives;
- Guidance on which BMPs or mixes of BMPs are most effective in Tookany/Tacony-Frankford Creek for meeting Target C objectives;
- Guidance on the needed degree of implementation to achieve Target C objectives;
- Guidance on areas of the watershed where BMPs would be most effective;
- Recommendations on Target C options for the CSO areas and separate storm sewer areas;
- Planning level cost estimates for implementation.

Section 3
Goals and Objectives

This section describes the process for setting overall watershed goals for the TTFIWMP, as well as numerous objectives for helping to reach those goals. The seven prioritized goals, referenced throughout this document, are useful for evaluating the wide range of possible "management options" for implementing the plan.

Developing a focused and prioritized list of goals (general) and objectives (specific, measurable) is critical to a successful planning process. Goals and objectives need to be:

- initially developed by stakeholders and regulatory agencies;
- analyzed and informed by the watershed data collection, analysis, and modeling carried out by the project team;
- finalized by the project team and stakeholders;
- prioritized by the stakeholders.

3.1 Stakeholder Goal Setting Process

Considerable stakeholder input toward developing watershed goals was sought from the beginning of this planning effort. Responses were summarized, and additional stakeholder input organized through further contacts with the stakeholders.

Tookany/Tacony-Frankford Partnership Mission Statement

The mission for the Tookany/Tacony-Frankford planning effort, developed by the stakeholders, is to improve the environmental health and safe enjoyment of the Tookany/Tacony-Frankford Watershed by sharing resources through cooperation of the residents and other stakeholders in the watershed. The goals of the initiative are to protect, enhance, and restore the beneficial uses of the Tookany/Tacony-Frankford waterways and riparian areas. Watershed management seeks to mitigate the adverse physical, biological, and chemical impacts of land uses as surface and groundwater are transported throughout the watershed to the waterways. The TTF Partnership seeks to achieve higher levels of environmental improvement by sharing information and resources.

Goals of Related Studies and Programs

Other studies have already provided a list of goals. Generally, the goals in this section are those identified through the Rivers Conservation Planning process, supplemented by those goals that are required as a result of various environmental regulatory requirements. Additional goals identified in the Tookany/Tacony-Frankford stakeholder meetings were also included once consensus was established.

Existing goals included:

- Aquatic life designated use attainment goal (warm water fishery)
- Public health: Contact recreation (bacteria, noxious plants)
- Aesthetics: Visual and olfactory conditions (noxious plants, bank erosion, litter, odor, etc.)
- Riparian corridors
- Wetlands, woodlands, and meadows
- Wildlife
- Act 167 plan goals
- Act 537 goals
- TMDL-related goals
- NPDES program goals (including stormwater management and CSO control)
- Environmental Futures Program goals
- River Conservation Plan goals

3.2 Consolidated Watershed Planning Goals and Objectives

The large list of goals from the existing stakeholder process needed to be organized. This was accomplished by consolidating goals from various sources into a coherent set for the integrated plan. Other considerations included stakeholders' desire to restore the living resources, and the preference for achieving goals through innovative, land-based, low-impact, and cost-effective management options. Consensus was reached around the following seven goals. Under each goal, more specific objectives are listed.

Goal 1 – Streamflow and Living Resources. Improve stream habitat and integrity of aquatic life.

- Improve quantitative measures of fishery health.
- Improve quantitative measures of benthic macroinvertebrate quality.
- Adapt or develop quantitative measures of attached algae to assess current stream conditions.
- Improve migratory fish passage.
- Increase miles of stable stream banks and stream channels by reducing deposition and scour.

Goal 2 – Instream Flow Conditions. Reduce the impact of urbanized flow on living resources.

- Increase baseflow as a percentage of total flow.
- Increase groundwater recharge.
- Prevent increases in the stormwater flow peaks in future development/redevelopment areas.
- Reduce directly connected impervious cover in developed and new development areas.
- Revise municipal codes to encourage new development and redevelopment using responsible stormwater management techniques.
- Reduce the frequency of occurrence of bankfull flow.

Goal 3 – Water Quality and Pollutant Loads. Improve dry and wet weather stream quality to reduce the effects on public health and aquatic life.

- Develop a phased approach to meeting appropriate water quality criteria in dry weather and wet weather.
- Work with regulatory agencies to re-evaluate designated uses.
- Prevent fish consumption advisories.
- Decrease loads of targeted water quality parameters from stormwater.
- Identify and eliminate SSOs and storm sewer cross-connections.
- Minimize CSO volume and frequency.
- Decrease inputs of floatables, debris, and litter from all sources.
- Increase "Inflow & Infiltration" studies, sewer cleanings, and inspections.
- Eliminate septic tank failures.

Goal 4 – Stream Corridors. Protect and restore stream corridors, buffers, floodplains, and natural habitats including wetlands.

- Maximize open space and habitat by responsibly managing new development and redevelopment of existing, vacant, and abandoned lands.
- Inventory and protect existing wetlands.

- Identify and pursue opportunities for wetland enhancement and wetland creation for stormwater treatment.
- Improve floodplain conditions through restoration or improvement of the connections between streams and their floodplains.
- Protect and restore riparian and upland habitats along stream corridors with native species.

Goal 5 – Flooding. Identify flood prone areas and decrease flooding by similar measures intended to support Goals 1, 2, and 4.

- Reduce the effects and frequency of out-of-bank flooding through management of stormwater.
- Remediate stream-related flooding in known problem areas without increasing the problem in other areas.
- Increase regular storm drain maintenance and cleaning programs throughout the watershed.
- Incorporate sound floodplain management principles in flood planning.
- Minimize the effects of structural floodway and stream encroachments with regard to sediment load and natural streamflow.

Goal 6 – Quality of Life. Enhance community environmental quality of life.

- Increase community green and open space.
- Increase community access and recreational activities in city parks and streams (e.g., by increasing miles of greenways and trails along stream corridors).
- Increase the public sense of security along stream corridors (e.g., by lighting, signage, park maintenance, increased police presence).
- Improve and protect aesthetics along stream corridors (e.g., by litter/graffiti removal, enforcement against illegal practices such as dumping, controls on ATV use).
- Identify and protect historical and cultural resources along stream corridors.

Goal 7 – Stewardship, Communication, and Coordination. Foster community stewardship and improve inter-municipal, inter-county, state-local, and stakeholder cooperation and coordination on a watershed basis.

- Increase public awareness of the value of streams to the community.
- Improve public, business, and institutional awareness of and accountability for activities that affect water quality.
- Encourage and support establishment of watershed organizations, EACs, and the like, to bear the watershed banner.
- Engage local officials and planners.
- Increase volunteer participation in implementing management options.
- Increase school-based education.

3.3 Goals Prioritization

The goals and objectives represent the collective ideas of the stakeholders on what the watershed management plan should achieve. Not all goals, however, are of equal importance. It is helpful to elicit from the stakeholders a collective opinion on the relative importance of each goal for the Tookany/Tacony-Frankford Watershed. Because the achievement of goals is a key aspect of measuring the effectiveness of the management plan, some numerical representation of the importance of each goal is useful.

To develop a set of numerical weights that represent the importance of each goal relative to the other goals, a workshop was held in May 2003, with participation from members of the partnership. The goal of the workshop was to drive towards a consensus on a numerical set of weights that best represent the collective opinion on the importance of each goal. Each participant filled in a worksheet weighting each of the seven goals with the percentage that described the individual contribution of each goal to the overall goal of watershed management. These sheets provided a variety of opinions on how the goals should be weighted, and served as a guide to a discussion on the relative importance of each goal. Through the group discussion, a consensus set of goal weights was developed that best represents the importance of each goal as defined by the stakeholders. Table 3.1 shows the weights assigned to each goal. The weights represent a percentage of the overall importance of each goal relative to all goals.

Table 3.1 Stakeholder Priorities as Weights for Goals

1. Streamflow and Living Resources. Improve stream habitat and integrity of aquatic life.	**15**
2. Instream Flow Conditions. Reduce the impact of urbanized flow on living resources.	**15**
3. Water Quality and Pollutant Loads. Improve dry and wet weather stream quality to reduce the effects on public health and aquatic life.	**20**
4. Stream Corridors. Protect and restore stream corridors, buffers, floodplains, and natural habitats including wetlands.	**15**
5. Flooding. Identify flood prone areas and decrease flooding by similar measures intended to support Goals 1, 2, and 4.	**5**
6. Quality of Life. Enhance community environmental quality of life (protect open space, access and recreation, security, aesthetics, historical/cultural resources).	**10**
7. Stewardship, Communication, and Coordination. Foster community stewardship and improve inter-municipal, inter-county, state-local, and stakeholder cooperation and coordination on a watershed basis.	**20**

The weights assigned to each goal were important in screening and evaluating the many possible alternative water management approaches to arrive at the recommended options.

The workshop participants also offered their opinions on the relative priority – high, medium, or low – of each of the objectives within the goals. A consensus building process was not attempted for all of the objectives, however, since these play a lesser role in the overall evaluation.

Section 4
Watershed Indicators: TTF Study Results

This section details the 21 measurable "watershed indicators" that were created in order to assess historic and current conditions, and to track progress as the TTFIWMP is implemented over time. The information presented can serve as a basis for understanding the state of the TTF Watershed, its relative environmental quality, and trends in the management of factors that influence its quality.

This section summarizes the results of the numerous recent studies of the Tookany/Tacony-Frankford Watershed. When available, results are included for the combined Montgomery County (Tookany) and Philadelphia County (Tacony-Frankford) portions of the watershed; however, several studies have provided more detailed information within Philadelphia. These assessments have identified problem areas for future focus, while establishing a "watershed baseline" from which we can measure our progress as recommendations are implemented. The 21 indicators fall into six broad categories, covered in the following sections:

Section 4.1	**The Land Use and Stream Health Relationship**
Section 4.1.1	Indicator 1: Land Use and Impervious Cover
Section 4.2	**Flow Conditions and Living Resources**
Section 4.2.1	Indicator 2: Streamflow
Section 4.2.2	Indicator 3: Stream Channels and Aquatic Habitat
Section 4.2.3	Indicator 4: Restoration and Demonstration Projects
Section 4.2.4	Indicator 5: Fish
Section 4.2.5	Indicator 6: Benthic Macroinvertebrates
Section 4.3	**Water Quality**
Section 4.3.1	Indicator 7: Effects on Public Health (Bacteria)
Section 4.3.2	Indicator 8: Effects on Public Health (Metals and Fish Consumption)
Section 4.3.3	Indicator 9: Effects on Aquatic Life (Dissolved Oxygen)
Section 4.4	**Pollutants**
Section 4.4.1	Indicator 10: Point Sources
Section 4.4.2	Indicator 11: Non-point Sources
Section 4.5	**The Stream Corridor**
Section 4.5.1	Indicator 12: Riparian Corridor
Section 4.5.2	Indicator 13: Wetlands and Woodlands
Section 4.5.3	Indicator 14: Wildlife
Section 4.6	**Quality of Life**
Section 4.6.1	Indicator 15: Flooding
Section 4.6.2	Indicator 16: Public Understanding and Community Stewardship
Section 4.6.3	Indicator 17: School-Based Education
Section 4.6.4	Indicator 18: Recreational Use and Aesthetics
Section 4.6.5	Indicator 19: Local Government Stewardship
Section 4.6.6	Indicator 20: Business and Institutional Stewardship
Section 4.6.7	Indicator 21: Cultural and Historic Resources

4.1 The Land Use and Stream Health Relationship

Urbanization of natural lands affects watershed hydrology, water quality, stream stability, and ecology.

4.1.1 Indicator 1: Land Use and Impervious Cover

One of the primary indicators of watershed health is the percent of impervious cover in the watershed. Based on numerous research efforts, studies, and observations, a general categorization of watersheds has been widely applied to watershed management based on percent impervious cover (Schueler 1995). Table 4.1 summarizes several of the impacts of traditional development on streams and watersheds, most of which are created by the addition of impervious cover across portions of the land surface.

Table 4.1 Impervious Cover as an Indicator of Stream Health (Schueler 1995)

Characteristic	Sensitive	Degrading	Non-Supporting
Percent Impervious Cover	0% to 10%	11% to 25%	26% to 100%
Channel Stability	Stable	Unstable	Highly Unstable
Water Quality	Good to Excellent	Fair to Good	Fair to Poor
Stream Biodiversity	Good to Excellent	Fair to Good	Poor
Pollutants of Concern	Sediment and temperature only	Also nutrients and metals	Also bacteria

This indicator measures:

- **GIS-estimated impervious cover of each municipality (% of total area)**
- **Model-estimated Directly Connected Impervious Area (DCIA) of each subwatershed (% of total area)**
- **Open space in each municipality (% of total area)**
- **Publicly-owned land in each municipality (% of total area)**
- **Vacant land**

Where We Were:

By 1820, the majority of the woodland in the watershed had been cut down for use as fuel and for construction. After this time, the land use of the watershed began to change drastically. During the 1890s, there were transportation improvements which brought to the watershed new industries that were seeking to take advantage of the growing riverfront industrial community. Streets were laid, and roads, houses, churches, and stores were built. During the 19th and early 20th centuries, the Tookany/Tacony-Frankford Watershed became an industrial center for textile production. Many mills and factories were built in the flood plains of the stream and the tributaries. In the early 20th century, in order to protect the creek from further pollution, the City of Philadelphia set aside hundreds of acres of parkland along the creek, called the Fairmount Park System, which included Juniata Park and Tacony Creek Park in the Tacony-Frankford Watershed.

Since World War II, half a million people have left Philadelphia, which has increased the amount of vacant land within the city. The incentives for construction of single homes in the suburbs created a flight of people out of the city, leaving many building and lots vacant and untended. These abandoned properties decrease the value of homes within the neighborhood and are a drain on city resources.

<u>Where We Are</u>:

The geographic breakdown of land use within the Tookany/Tacony-Frankford watershed was displayed in Figure 2-2; the spatial distribution of land use is shown here in Figure 4.1. Land use within the watershed is predominantly residential (around 59% of total land use). Headwater regions located in Montgomery County are dominated by single-family residences (26.5% of the total watershed), while mid-portions of the watershed located in the City of Philadelphia are predominantly multi-family residential, such as row or cluster housing (32.9% of the total watershed). The lower portions of the watershed are characterized mainly by industrial facilities (4.9% of the total watershed) and multi-family residential. The section of Tookany/Tacony-Frankford Watershed within the City of Philadelphia is dominated by urban land uses. Furthermore, the lack of a well-defined riparian corridor and forested regions within the watershed is evident, with only 5.8% of land attributed to parklands and natural surfaces and 5.1% classified as wooded regions.

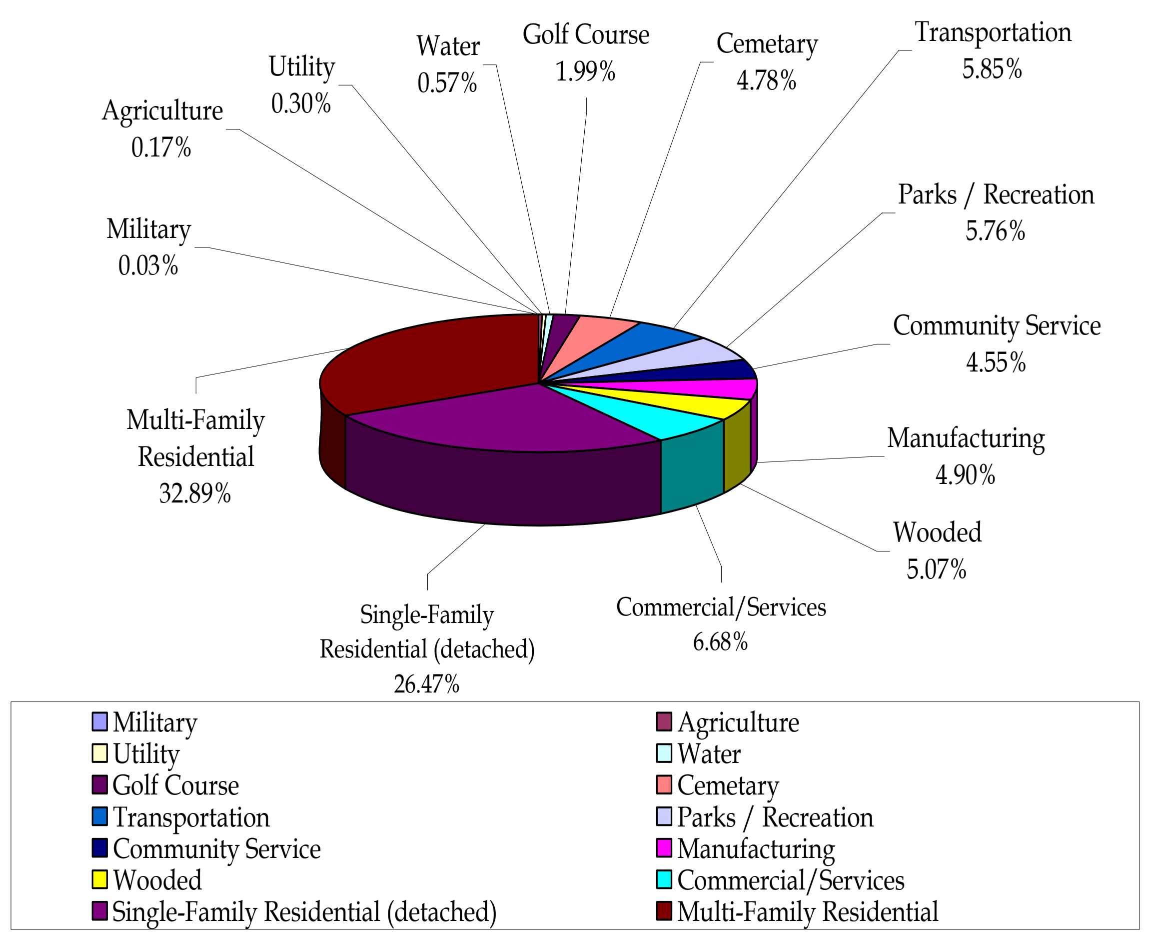


Figure 4.1 Land Use Breakdown in Tacony-Frankford Watershed

As seen in Table 4.2, Abington Township has the lowest percentage of impervious cover in the watershed, with just under 32% of their land within the watershed listed as impervious. Philadelphia has the highest percent impervious, with more than 47% of the land within the watershed listed as impervious. The entire watershed is at a level where stream channels are highly unstable, water quality is either fair or poor, and there is poor stream biodiversity (Table

4.1). Many of the pollutants associated with watersheds at this level of percent impervious cover include sediment, temperature, nutrients, metals, and bacteria.

Table 4.2 Breakdown of % Imperviousness by Municipality (within watershed boundaries)

Municipality	County	Total Area Within Watershed (acres)	% Impervious
Abington	Montgomery	2,661	31.9%
Cheltenham	Montgomery	5,609	32.6%
Rockledge	Montgomery	97	35.3%
Springfield	Montgomery	66	38.0%
Jenkintown	Montgomery	332	43.5%
Philadelphia	Philadelphia	12,161	47.3%

From the land use data, the part of each municipality that lies within the watershed was analyzed to determine the percentage of open space and publicly owned land. The watershed on a whole averages about 17% open space and 19% publicly owned land. As seen in Table 4.3, the amount of open space varies by municipality within the watersheds, with Jenkintown with as little as 3.5% open space and Rockledge with as much as 30% of their land within the watershed as open space. Included in our open space calculation were categories such as agriculture, cemeteries, golf courses, regional parks, urban recreation areas, water, wetlands, and wooded areas. The percentage of publicly owned land varied greatly depending on municipality, with the small portion of Springfield that lies within the watershed having 8% of this area publicly owned, while Rockledge had the most publicly owned land at almost 28% of the total acreage within the watershed. Publicly owned land included cemeteries, commercial, transportation, regional parks, urban recreation areas, water, and wetlands.

Table 4.3 Estimated Open Space and Publicly Owned Land

Municipality	County	Total Area Within Watershed (acres)	Publicly Owned (% of total)	Open Space (% of total)
Abington	Montgomery	2,661	17.2%	27.0%
Cheltenham	Montgomery	5,609	15.0%	23.6%
Rockledge	Montgomery	97	27.9%	30.6%
Springfield	Montgomery	66	8.1%	5.9%
Jenkintown	Montgomery	332	20.5%	3.5%
Philadelphia	Philadelphia	12,161	25.9%	14.4%

The City of Philadelphia began the Neighborhood Transformation Initiative (NTI) in 2001; the goal of the program is revitalizing Philadelphia neighborhoods. The NTI includes a vacant lot program that cleans and maintains vacant lots throughout the City. The program includes the removal of debris from vacant lots, and when possible, the transformation of some of them into green space. Through the NTI program, 31,000 of the City's vacant lots were cleaned at least once and 33,950 tons of debris was removed. Additionally, as of June 2003, the City had "greened" 470 vacant parcels of land (over 13 acres). Figure 4.2 displays the vacant lands within the Tookany/Tacony-Frankford Watershed. Another aspect of NTI is the demolition of dangerous vacant buildings. From 2000-2003, more that 4100 vacant buildings were demolished in Philadelphia.

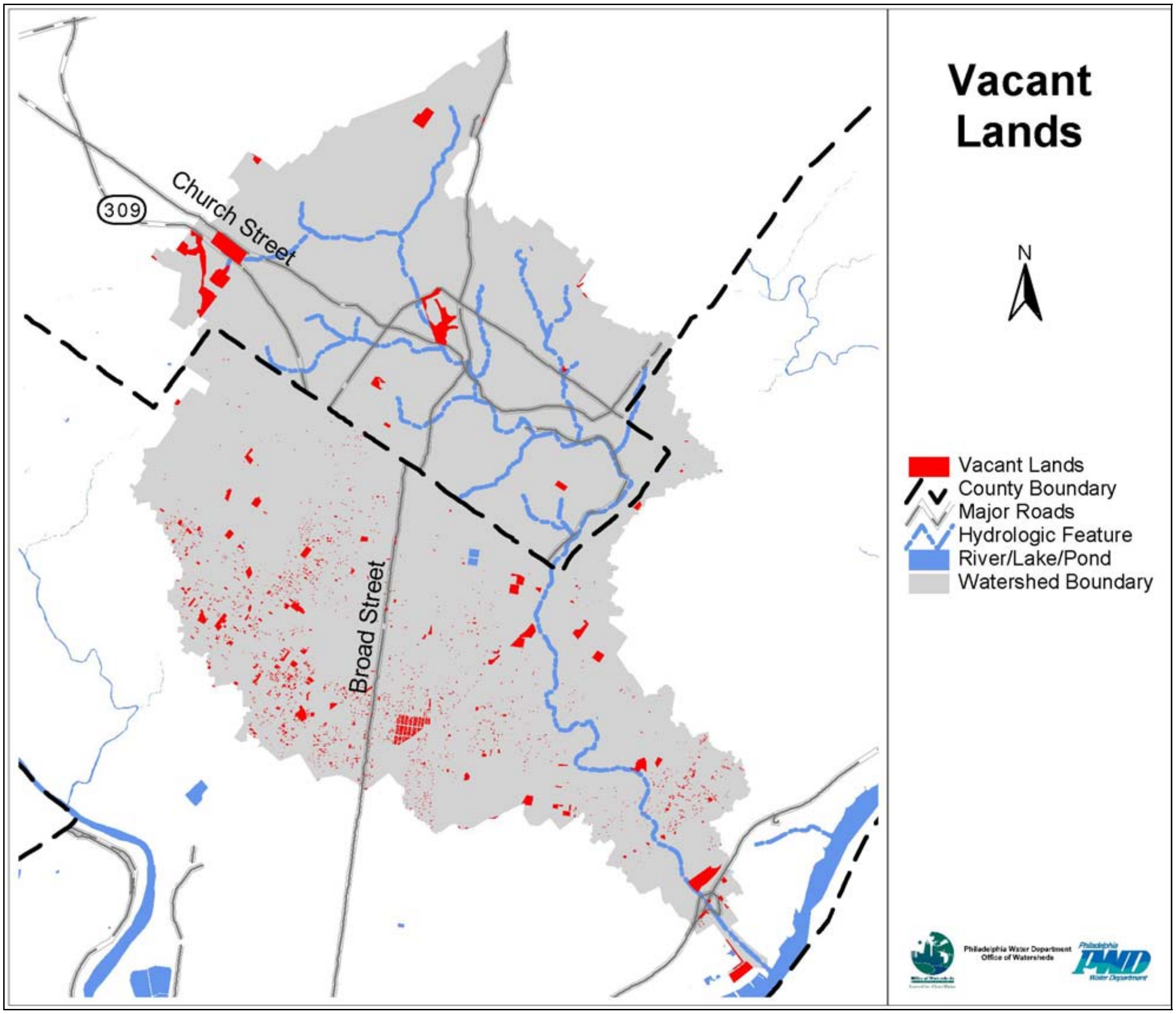


Figure 4.2 Vacant Lands in the Tookany/Tacony-Frankford Watershed

4.2 Flow Conditions and Living Resources

Urbanized land uses affect stormwater runoff, streamflow, the shape of stream banks and channels, water quality, and aquatic habitat and ecosystems.

4.2.1 Indicator 2: Streamflow

Increases in impervious cover affect stream hydrology in a variety of ways:

- Increased magnitude and frequency of severe floods;
- Increased frequency of erosive bankfull and sub-bankfull floods;
- Reduced groundwater recharge leading to reduced baseflow;
- Higher flow velocities during storm events.

This indicator measures:

- **Average annual baseflow (% of total flow)**
- **Average annual baseflow (% of annual precipitation)**
- **Average annual stormwater runoff (% of annual precipitation)**

As discussed in Indicator 1, the entire watershed is highly urbanized and contains a large proportion of impervious cover. The hydrologic impact of urbanization can be observed through analysis of streamflow data taken from USGS gauges on the Tacony-Frankford Creek. In addition, data from French Creek in Chester County provides a picture of a nearby, less-developed watershed to utilize for comparison as a “reference stream.”

<u>Where We Were</u>:
The analysis below represents a long-term period of record for each stream gauge. It is difficult to establish a trend over time, but an attempt will be made when the watershed is reassessed.

<u>Where We Are</u>:
Streamflow data were separated into two main components: baseflow and stormwater runoff. In perennial streams, baseflow is the portion of streamflow caused by groundwater inflow and streamflow will be present in both dry and wet weather conditions. The stormwater runoff component is the portion of streamflow that is contributed during wet weather as a result of excess stormwater runoff flowing over the land surface and through the storm drainage system to the creek.

The results of a hydrograph decomposition analysis support the relationship between land use and hydrology discussed above. In Table 4.4, the results for the Tacony-Frankford Creek analysis are compared with that of French Creek, our unimpaired reference stream, and the Darby Creek, a stream in a mixed urban and suburban watershed similar to the Tookany/Tacony-Frankford. The table demonstrates how the three chosen statistics help describe the hydrologic condition of the streams, ranging from rural to highly urbanized. Results for French Creek are somewhat typical of an undeveloped watershed, with baseflow comprising 64% of mean annual streamflow and stormwater only 17% of annual precipitation.

Table 4.4 Summary of Hydrograph Separation Results over the Period of Record

	Baseflow (% of total flow)	Baseflow (% of precip.)	Stormwater Runoff (% of precip.)
French Creek 01475127	64	31	17
Darby Creek 01475510	62	34	21
Tacony Creek 01467086	58	29	21
Frankford Creek 01467087	38	17	27

The Frankford Creek gauge represents most of the urbanized area in the Tookany/Tacony-Frankford watershed. At this gauge, the stormwater component of streamflow is a much greater percentage of total annual streamflow (62%), and baseflow represents a much smaller percentage of total annual streamflow (only 38%). These results confirm that Tacony-Frankford is a highly urbanized stream. Figure 4.3 displays the hydrograph decomposition for the Frankford Creek USGS gauge for a six month period in 2000. The daily baseflow is estimated and plotted on top of the total flow. The area above the baseflow curve indicates the daily runoff. Storm events can be seen clearly by the peaks in runoff.

The Tacony Creek USGS gauge, representing the headwaters of the Tacony-Frankford watershed, exhibits behavior intermediate between the two extremes. However, the statistics suggest that it is more urbanized than the Darby Creek watershed, another urbanized watershed in Philadelphia.

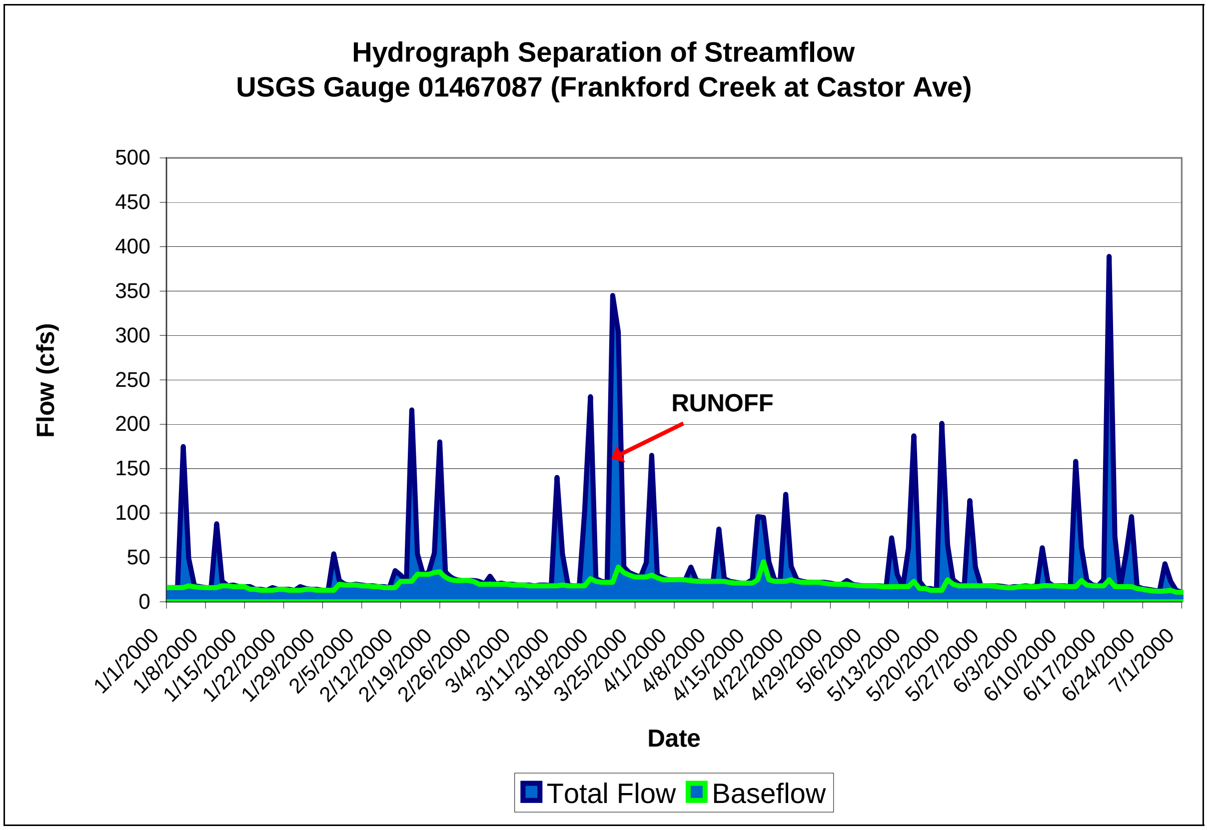


Figure 4.3 Hydrograph Separation at Frankford Creek gauge (USGS gauge 01467087)

4.2.2 Indicator 3: Stream Channels and Aquatic Habitat

Stream life (fish, invertebrates, and plants) require physical habitat features that allow them to feed, reproduce, and seek shelter during periods of high flow. In the urban environment where significant erosion and deposition occur, these areas often are not available (Figure 4.4).

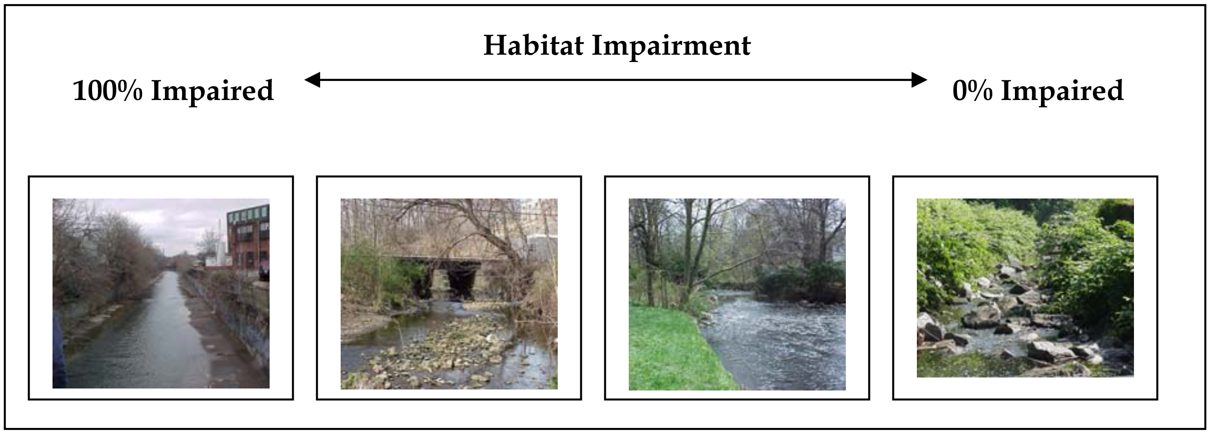


Figure 4.4 Photo Comparison of Impaired and Unimpaired Habitats

Fluvial geomorphology (FGM) is the study of landforms associated with river channels and the processes that form them. The Rosgen classification system was used to assess the physical channel conditions. The Rosgen classification system was developed by Dave Rosgen and assigns a channel type based on channel slope, width-to-depth ratio, bed material, entrenchment ratio, and sinuosity. This classification system is based primarily on the appearance of a stream in combination with a number of delineative criteria associated with the stream's morphology.

This indicator measures:

- **Habitat score relative to reference condition at various sites**
- **Channel type and expected trend**

<u>Where We Were</u>:
There is no historical data available for this indicator. Habitat and stream channels most likely degraded over a long period of time as development took place within the watershed. A trend will be established the next time this area is reassessed.

<u>Where We Are</u>:
Habitat assessments were performed at the seven sites where benthic macroinvertebrate community assessments were completed. Each site was assessed on habitat conditions for Epifaunal Substrate/Available Cover, Pool Substrate Characterization, Pool Variability, Sediment Deposition, Embeddedness, Velocity/Depth Regime, Frequency of Riffles (or bends), Channel Flow Status, Channel Alteration, Channel Sinuosity, Bank Stability, Vegetative Protection, and Riparian Vegetative Zone Width. Habitat assessments are scored in comparison with a healthy stream, as a percentage of the expected diversity found in an unimpaired reach. The results show two sites found to be "Partially Supporting," and the other five sites found to be "Non-Supporting"(Table 4.5 and Figure 4.5). This is a clear indication of the impacts of urbanization on the stream habitat.

Table 4.5 Habitat Assessment Scores

Site	Score	Percent Comparison	Assessment Category
TF 280	108.5	52%	Non-Supporting
TF 500	97	47%	Non-Supporting
TF 620	147.5	71%	Partially Supporting
TFM 000	91	44%	Non-Supporting
TF 975	122	59%	Non-Supporting
TF 1120	120.5	58%	Non-Supporting
TFJ110	128	70%	Partially Supporting

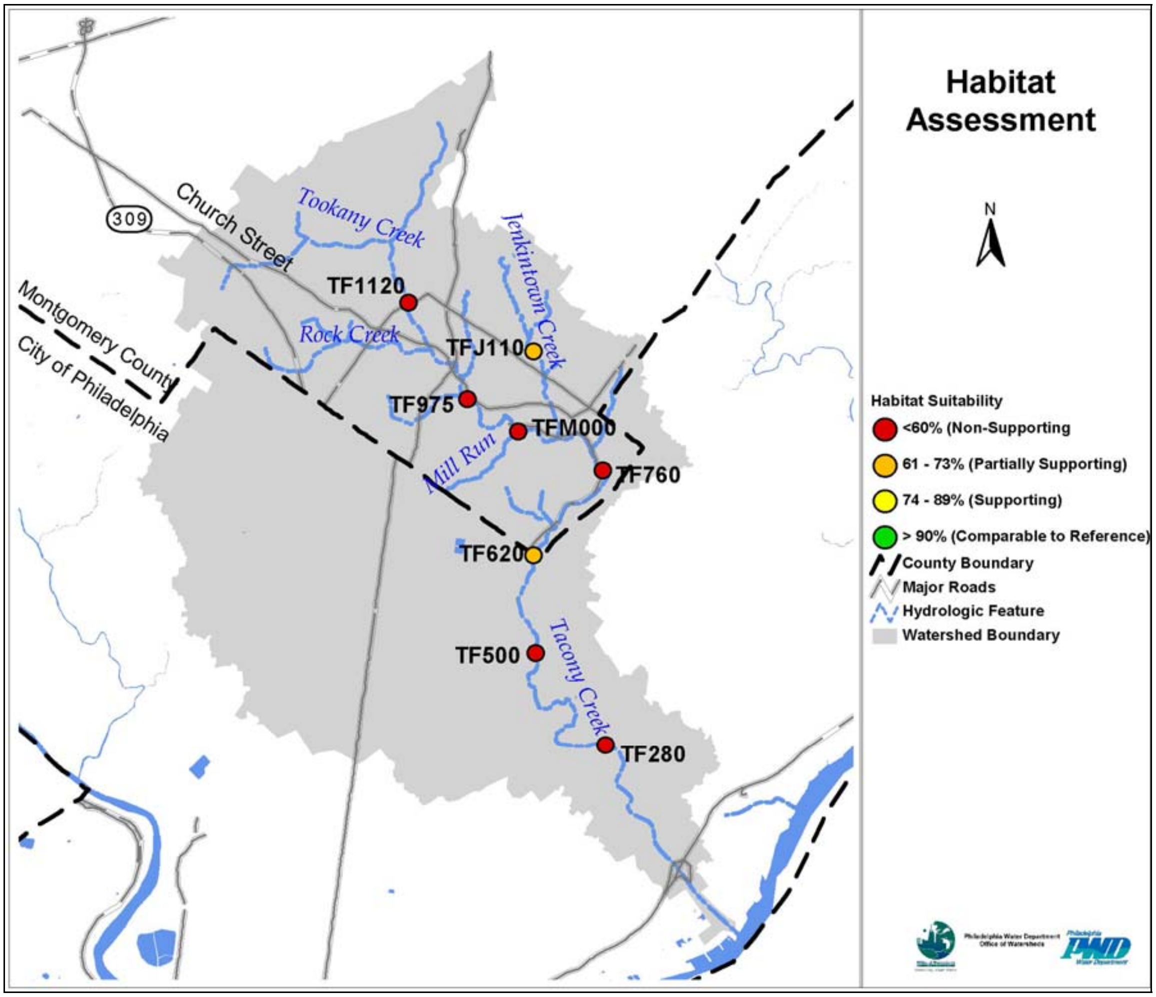


Figure 4.5 Tookany/Tacony-Frankford Watershed Habitat Assessment

4.2.3 Indicator 4: Restoration and Demonstration Projects

Funding for watersheds and water–related projects has been increasing throughout the country in recent years. Grants are being issued to complete various types of projects throughout the state of Pennsylvania. The Growing Greener program has been an enormous source of environmental funding over the last few years and has become the largest single investment of state funds in Pennsylvania's history. There are also many other organizations and governmental agencies offering grant money and technical assistance for communities and other associations to accomplish their environmental projects for improving our watersheds. Figure 4.6 is one example of a stream reach that is planned for eventual restoration.

This indicator measures:

- **Lists of completed, in progress, and planned projects**

Figure 4.6 Streambank Restoration in the Tookany/Tacony Frankford Creek

<u>Where We Were</u>:

There is no historical data available for this indicator. The number of restoration and other environmental projects in this watershed has increased with the introduction of the Growing Greener program and other funding programs.

<u>Where We Are</u>:

There has been a flurry of environmental projects in the Tookany/Tacony-Frankford Watershed over the past few years. There has been an influx of grant monies from programs such as the Growing Greener Program and the League of Women's Voters. The types of projects that are underway or have been completed include wetlands assessment, technical assistance, demonstration projects, education, watershed planning, property acquisition, and restoration projects. A list of many of the grants for environmental projects in the Tacony-Frankford Watershed issued from 1999 to 2004 has been assembled. Table 4.6 represents a profile of the grants received and the projects being performed. The list includes 20 projects either completely or partially in the watershed with a total amount of over $1.7 million in grants received.

One example project conducted by the TTF Partnership was the Rain Barrel Implementation Project. This project demonstrated the use of rain barrels as a method to reduce stormwater runoff. The rain barrel project enlisted members of the communities in and around Philadelphia, as well as several environmental organizations to install rain barrels on their personal property or on the property of their organization. This project included an educational component that consisted of instruction on the assembly and maintenance of the rain barrel, as well as the uses and benefits. The primary goal was to implement an individual "property-level" Best Management Practice (BMP) to help reduce the volume of stormwater reaching the receiving stream and to increase the length of time it takes the stormwater to reach the receiving stream.

Table 4.6 Grants Awarded in the Tookany/Tacony-Frankford Watershed

Funding Agency	Funding Program	Year	Lead Agency	Project Title	Amount Awarded	Project Description
PA League of Women Voters	Watershed Education for Pollution Prevention Projects	1999	Awbury Arboretum	Tacony- Frankford Watershed Lesson	$3,000	To develop a watershed education program, including brochures and lessons plans, about the Tacony-Frankford Watershed. The program will include the theme of Backyard Conservation and will be targeted at school age children who visit Awbury Arboretum.
DCNR	Rivers Conservation Program	1999	Cheltenham Township	Tookany Creek River Conservation Plan	$25,000	To prepare a River Conservation Plan for the Tookany Creek watershed from its headwaters to the Montgomery/Philadelphia county line.
DEP	Growing Greener	1999	Awbury Arboretum	Tacony-Frankford watershed education initiative	$13,000	To implement a new watershed-protection education initiative which aims to greatly increase the public's awareness of the Tacony-Frankford Watershed.
DCNR	Rivers Conservation Program	2001	Philadelphia Water Department	Tacony-Frankford Watershed River Conservation Plan	$100,000	To develop a River Conservation Plan for the Philadelphia County portion of the Tacony-Frankford watershed.
EPA	Five Star Restoration Challenge Grant Program	2001	Township of Cheltenham	Tookany Park Streambank Restoration	$15,000	The project will revitalize and restore one section of flood-ravaged Tookany Creek. Along with this comprehensive creekside restoration, the project will develop watershed information and a training manual for middle school students about issues related to the Tookany Creek Watershed. Partial funding for this grant is provided by Lockheed Martin Corporation.
DCNR	Growing Greener	2001	Fairmount Park Commission	Acquisition of the Delaware River/ Kensington Tacony Trail	$350,000	To acquire 16 acres of rail line property to develop the Delaware River/Kensington Tacony Trail.
DEP	Growing Greener	2002	Awbury Arboretum	Awbury Arboretum watershed restoration project	$42,000	This project will redirect stormwater runoff from adjacent properties; remove obstructions to the flow from two natural springs; daylight a stretch of stream; enhance existing meadow; and restore degraded areas with native plantings.

Funding Agency	Funding Program	Year	Lead Agency	Project Title	Amount Awarded	Project Description
DEP	Growing Greener	2002	Philadelphia Water Department	Rain barrel Implementation project	$28,000	To install rain barrels on properties of the communities comprising the Tacony-Frankford Watershed as a method of reduction of stormwater runoff. This project includes an educational component that consists of instruction on the assembly and maintenance of the rain barrel, as well as the uses and benefits.
EPA	Five Star Restoration Challenge Grant Program	2002	Township of Cheltenham	Tookany Park Streambank Restoration II	$10,000	The project will continue efforts to revitalize and restore one section of flood-ravaged Tookany Creek. Along with this comprehensive creekside restoration, the project will develop watershed information and a training manual for middle school students about issues related to the Tookany Creek Watershed. Partial funding for this grant is provided by EPA Region III and Lockheed Martin Corporation.
NFWF	Foundation Grants	2002	Township of Cheltenham	Tookany Park Streambank Restoration	$10,000	Continue efforts to revitalize and restore one section of flood-ravaged Tookany Creek in Pennsylvania. Project will also develop a watershed information and a training manual for middle school students about issues related to the Tookany Creek watershed.
DEP - CZM	CNPP	2002	Pennsylvania Environmental Council	Kensington & Tacony Trail Pre-Acquisition & Development	$50,000	Complete all pre-acquisition activities as well as develop appropriate communications and stakeholder educational materials describing the importance of the trail for recreational activity and coastal zone access.
DEP	Growing Greener	2003	Township of Cheltenham	Streambank restoration on Tookany Creek	$100,000	Streambank restoration on Tookany Creek.
DEP	Growing Greener	2003	Philadelphia Water Department	Restore Tacony Creek using natural channel design	$25,000	The primary goal of this project is to identify and document existing stream conditions of the Tacony Creek stream corridor near Whitaker Avenue in Northern Philadelphia.
DEP - CZM	CNPP	2004	Township of Cheltenham	Tookany Creek stabilization and restoration	$50,000	For stabilization and restoration of 3,900 feet of streambank along the Tookany Creek in a Cheltenham Township riparian park. The project will use bioengineering techniques and non-structural best management practices.
DEP	Act 167	2002	Philadelphia Water Department	Tacony-Frankford Act 167 SW Plan Phase I	$15,000	Preparation and submission of a Scope of Study to DEP for a watershed stormwater plan.
EPA	Wetland Program Development Grants	2002	Philadelphia Water Department	Southeast Regional Wetland Inventory and Water Quality Improvement Initiative	$250,000	This project is to expand Philadelphia Water Department's existing wetland inventory and assessment program to define opportunities for wetland protection and enhancement for four watersheds in the Southeast region of the commonwealth of Pennsylvania. *(includes other watersheds)*

Funding Agency	**Funding Program**	**Year**	**Lead Agency**	**Project Title**	**Amount Awarded**	**Project Description**
DEP	Act 167	2004	Philadelphia Water Department	Tacony-Frankford Act 167 SW Plan Phase II	$363,000	Preparation and adoption of the detailed watershed stormwater plan; includes modified Level 2 FGM assessment.
DEP	Growing Greener	2003		Norris Square Civic Association Mercado	$140,000	Build a green roof and rain garden at the Mercado.
USACE	Southeastern Pennsylvania Environmental Assistance Program	2000	City of Philadelphia	Logan Sinking Homes Study	$150,000	Sinking homes in the Logan neighborhood – The focus of the project was to gather and develop data to perform a preliminary analysis of the potential magnitude, extent, and scope of the problem and its possible causes.
DEP	Growing Greener	2003	City of Philadelphia	Technical Assistance Grant	$232,000	This project provides a wide range of assistance to community-based conservation efforts in urban settings of Southeastern Pennsylvania. *(includes other watersheds)*
					$1,739,000	

4.2.4 Indicator 5: Fish

Fish are good indicators of stream health because their presence requires favorable environmental conditions within a certain range of streamflow, water temperature, water quality, and channel habitat. Abundance and diversity of fish are indicators of good water quality. The number of pollution tolerant fish and the presence of fish with abnormalities will indicate degraded or poor water quality. Having a large percentage of the fish population made up of pollution tolerant species is undesirable because it is an indication of habitat deterioration and water quality degradation.

This indicator measures:

- **Abundance and pollution tolerance of species found at various sites**
- **Fish community integrity relative to reference condition at various sites**
- **Whether stream meets criteria for trout-stocking**

Where We Were:

There is no historical data available for this indicator. A trend will be established the next time this area is reassessed.

Where We Are:

A biological assessment of the Tookany/Tacony-Frankford Watershed was completed in 2001 by the Philadelphia Water Department, with fish assessments at four locations on the main stem of the creek. The biological assessment locations are named according to river mile (where TF 0 is where the Tookany/Tacony-Frankford meets the Delaware River, and TF 280 is 2.8 miles upstream from that point), and the four locations with fish assessments completed are TF 280, TF 620, TF 975, and TF 1120. The fish assessments looked at a variety of quantitative and qualitative analyses including species richness, species diversity, trophic composition relationships, pollution tolerance levels, Modified Index of Well-Being (MIWB), biomass per unit area, and species descriptions.

The pollution tolerance metric identifies the abundance of tolerant, moderately tolerant and pollution intolerant individuals at the study site. Figure 4.7 shows the percentage of the total number of fish at each site, by their tolerance level. Both pollution tolerant and moderately tolerant species were found at each site, with pollution tolerant species being the predominant at every site. No pollution intolerant species were found during the fish assessment.

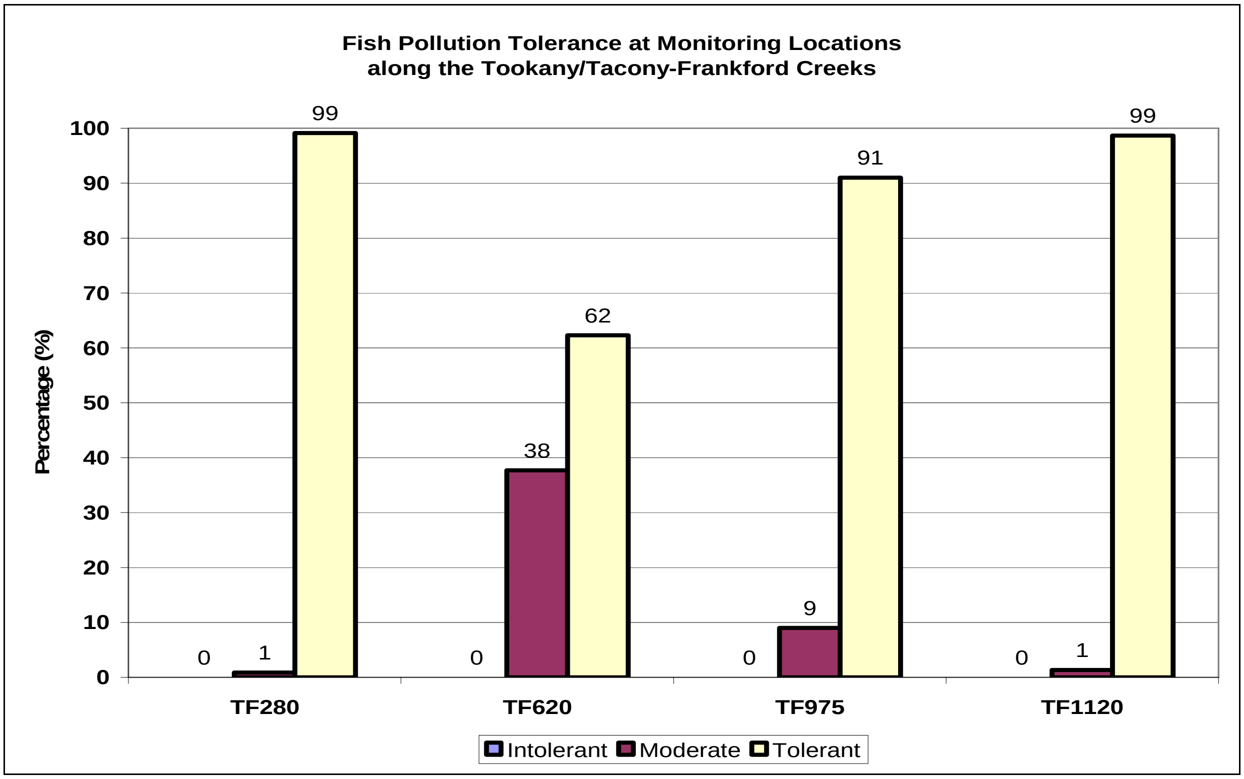


Figure 4.7 Fish Tolerance at Specific Monitoring Sites

Also, sites were classified based on their fish community integrity and compared to a reference condition. On a rating scale of poor, marginal, fair, and optimal, sites TF 280 and TF1120 received ratings of poor and sites TF 620 and TF 975 received ratings of marginal (Figure 4.8). Follow-up baseline assessments are planned every five years for this watershed, with the latest assessment completed in 2005, to be revisited next in 2010.

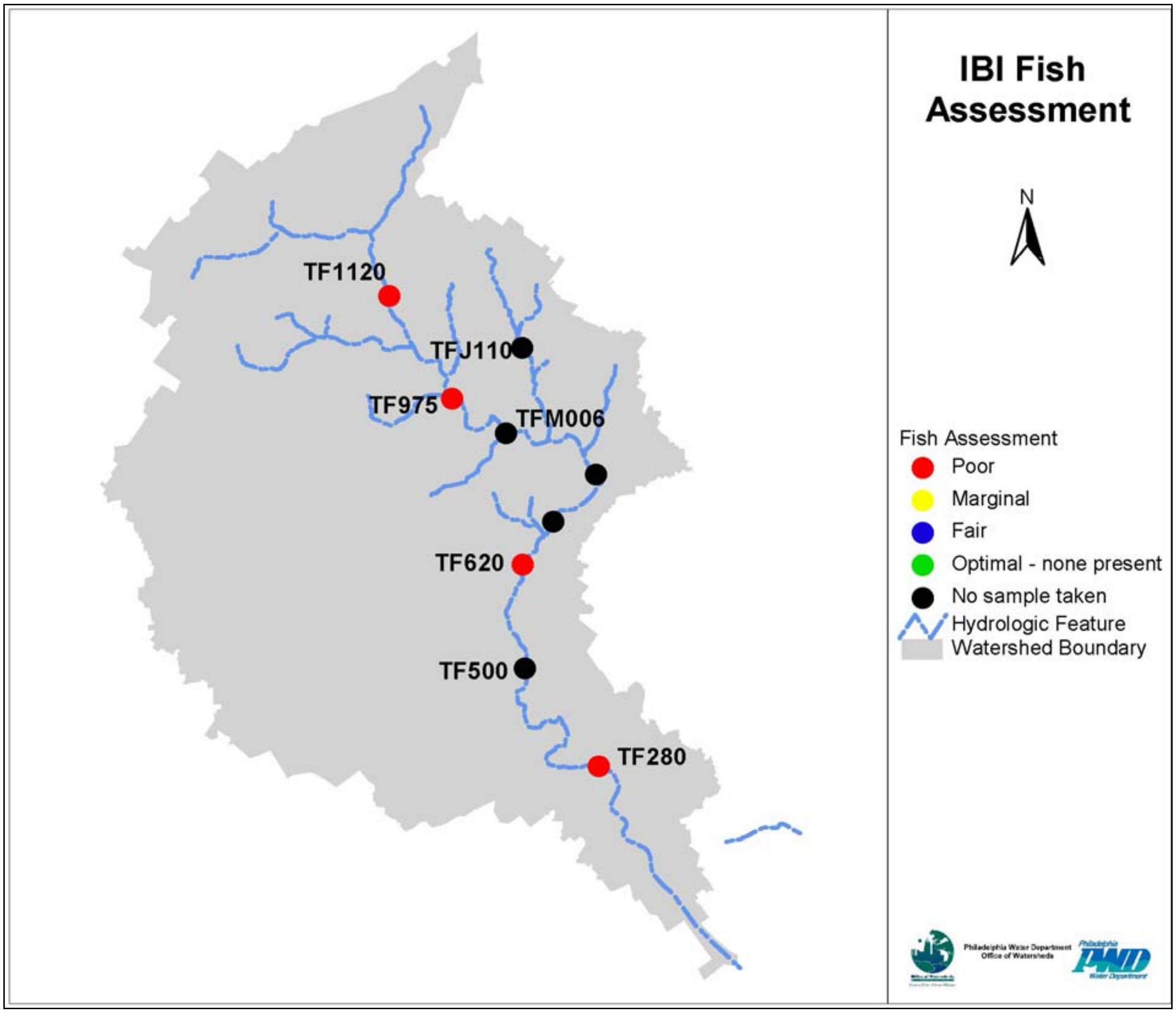


Figure 4.8 Tookany/Tacony-Frankford Fish Assessment (Philadelphia Water Department, 2001)

There were a total of 14 different species found in the watershed, some in more abundance then others. A breakdown of the relative abundance of each species at each assessment site can be seen in Figure 4.9, along with the pollution tolerance category of each fish species.

Pennsylvania Fish and Boat Commission biologists are continuously monitoring the Commonwealth’s waters and adding and removing lengths of streams to be trout-stocked. Factors to determine whether a stream is stocked are water quality, public access, use, and a variety of other factors. There are no stream lengths in the Tookany-Tacony-Frankford Watershed that meet the criteria qualifying them to be stocked with trout by the Fish & Boat Commission.

	Site #					
Species	**TF 280**	**TF 620**	**TF 975**	**TF 1120**	**Pollution Tolerance**	**Picture**
American Eel	R	R	R	R	M	
Common Shiner	N	R	R	N	M	
Redbreast Sunfish	N	R	N	N	M	
Spottail Shiner	N	R	R	N	M	
Swallowtail Shiner	N	R	N	N	M	
Bluegill	N	R	N	N	M	
Satinfin Shiner	N	R	C	A	M	
Banded Killifish	R	R	N	N	T	
Blacknose Dace	N	R	C	A	T	
Brown Bullhead Catfish	R	R	N	N	T	
Creek Chub	N	N	R	R	T	
Fathead Minnow	N	R	N	N	T	
Mummichog	A	N	N	N	T	
White Sucker	N	C	C	N	T	

Species Abundance	**Symbol**	%
Abundant	A	60% -100%
Common	C	30% - 60%
Rare	R	0% - 30%
None	N	0
Pollution Tolerance	**Symbol**	
Moderate	M	
Tolerant	T	

Figure 4.9 Fish Types and Abundance

4.2.5 Indicator 6: Benthic Macroinvertebrates

The community of organisms on the bottom of water bodies is a good indicator of long-term water quality and the overall health of an aquatic system. Organisms inhabiting the stream bottom play roles in the aquatic ecosystem similar to the ones terrestrial small plant and animal species play in land-based communities. Benthic macroinvertebrate communities respond to changes in the aquatic environment and often provide an indication of concerns or evidence of successful restoration projects. Figure 4.10 is an example of a benthic macroinvertebrate.

This indicator measures:

- **State designation of attained and unattained reaches**
- **Benthic macroinvertebrate community integrity relative to reference condition at various sites**

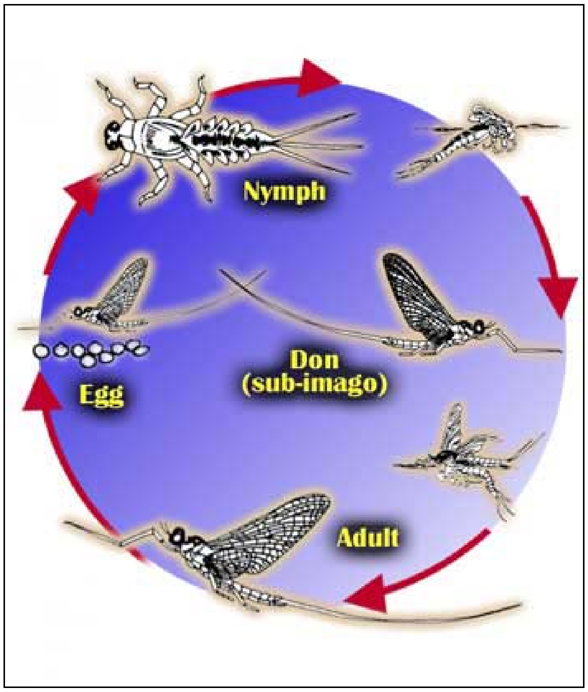


Figure 4.10 Life Cycle of a Mayfly

<u>Where We Were</u>:
There is no historical data available for this indicator. A trend will be established when this area is reassessed.

<u>Where We Are</u>:
The Pennsylvania DEP assesses the water quality of water bodies throughout the state and categorizes them according to their water quality status attainment. The assessments are found in the Pennsylvania Integrated Water Quality Monitoring and Assessment Report. Water bodies that do not meet water quality standards are designated as "impaired" and those that meet the designated water quality standards are designated as "attained."

Table 4.7 summarizes the impairments for the Tookany/Tacony-Frankford Creek. The tidal portion of the watershed, Frankford Creek (4.11 miles), has not been assessed since it is not wadeable, and therefore has no established procedure for assessment. The remaining streams in the watershed, including the main branch Tacony, Jenkintown, and East Branch Jenkintown Creek, all were placed in the category of "Streams Impaired by Pollution Not Requiring a TMDL." Figure 4.11 shows the delineation of the sections identified as attained, not attained (impaired), and unassessed. The streams were assessed for aquatic life, and the main source for impairment was identified as Urban Runoff/Storm Sewers. The main causes for impairment were identified as Flow Alterations, Other Habitat Alterations, and Water/Flow Variability.

Table 4.7 Descriptions of Impairment Causes and Sources (from the Commonwealth Of Pennsylvania Assessment and Listing Methodology for the 2004 Integrated Water Quality Monitoring and Assessment Report)

Impairment Cause / Source	Description
Urban Runoff / Storm Sewers	Runoff from impervious or urban areas to surface waters from precipitation, snowmelt, and subsurface drainage, and may be conveyed by storm sewers. The most obvious probable causes of impairment associated with this source are habitat removal caused by bank erosion, or streambed scouring, or smothering of habitat by siltation. Other probable causes are oils and grease, metals, pathogens, and nutrients.
Flow Alterations	Changes in hydrologic regime as a result of water regulation (including dams without or with insufficient minimum releases), or dewatering as a result of bedrock fracturing from mining activities, or lack of base flow due to reduced rain water infiltration in urban areas, or reduction in base flow caused by ground water withdrawals.
Other Habitat Alterations	Habitat changes due to severe bank erosion, removal or lack of riparian vegetation, and concrete channels and streambeds.
Water / Flow Variability	Changes in hydrologic regime caused by water releases, increased surface runoff from impervious surfaces during storm events, scouring, and drought. Results in unstable environment for macroinvertebrates and fishes. Habitat alterations include stream widening, substrate paving, shallower pools, etc.

The biological assessment of the Tookany/Tacony-Frankford Watershed completed in 2000-2001 by the Philadelphia Water Department looked at macroinvertebrates in the streams and collected data which led to a biological condition score. The macroinvertebrate assessments took place at all seven monitoring sites in the watershed, identified as TF 280, TF 500, TFM0000, TF 620, TF 975, TFJ 110, and TF 1120. Each site is given a biological score based on conditions in the stream – such as Taxa Richness, Taxa Comparison, Hilsenhoff Biotic Index (modified), Modified EPT Taxa, Percent Modified Mayflies, Dominant Family, Ratio of Scrapers/ Filter Collectors, Ratio of Shredders/Total, Community Loss Index, Biological Quality, Biological Assessment, Habitat Quality, and Habitat Assessment – and then compared to a reference stream. Every site in this watershed received a rating of either moderately impaired or severely impaired (Figure 4.11 and Table 4.8). The impaired benthic macroinvertebrate community is a result of habitat deterioration and episodic water quality degradation throughout the entire watershed. Increases in flow, sediment deposition, and scouring in the Tacony-Frankford Creek have impeded reproductive and feeding strategies of many species of macroinvertebrates.

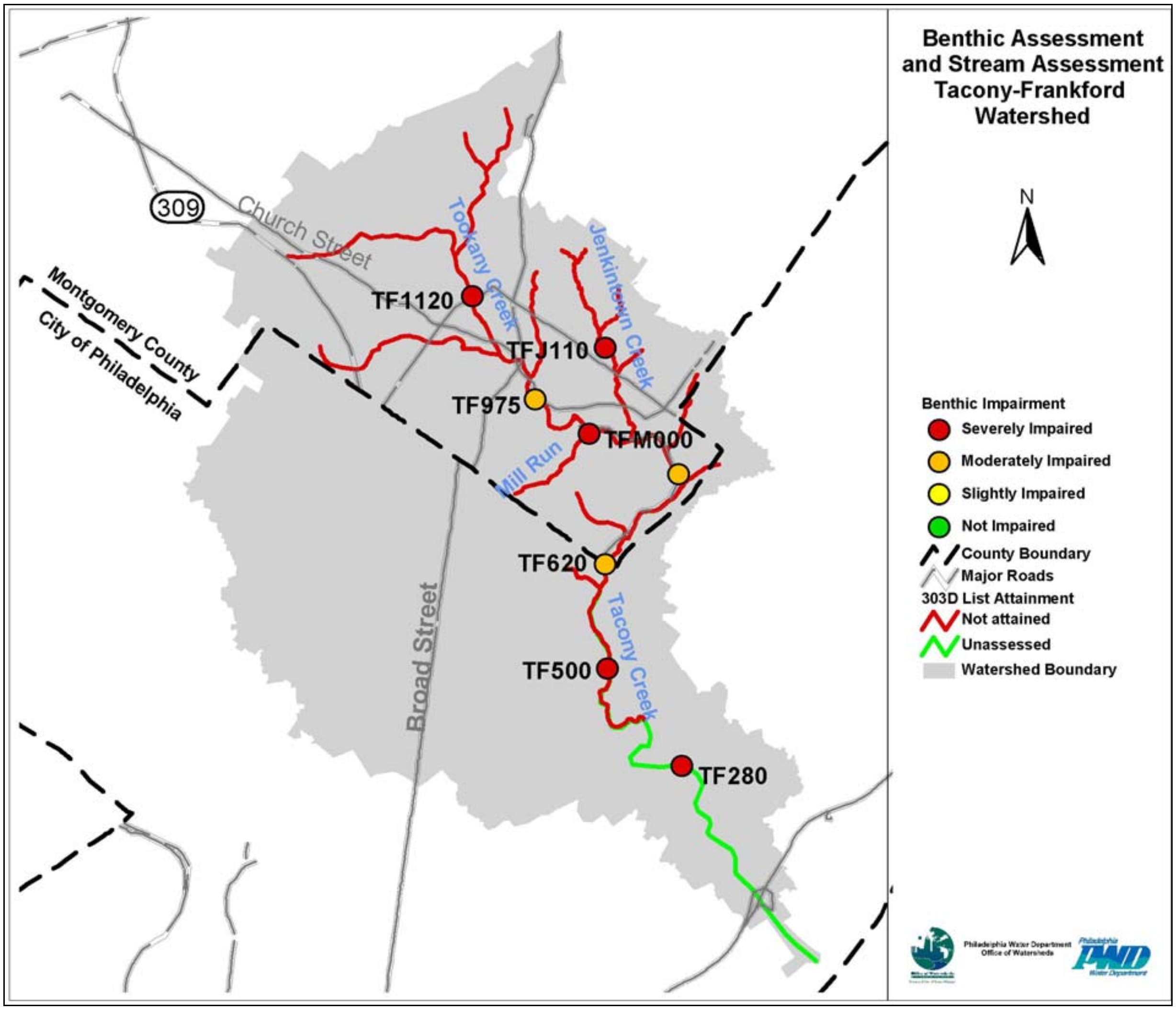


Figure 4.11 Benthic Macroinvertebrate Community Assessment Sites and Impaired Reaches

Table 4.8 Biological Condition Category as Percent Comparison to a Reference Score

% Comparison to Reference Score *	Biological Condition Category	Attributes
>83%	Nonimpaired	Comparable to the best situation within an ecoregion. Balanced trophic structure. Optimum community structure for stream size and habitat quality.
54-79%	Slightly impaired	Community structure less than expected. Species composition and dominance lower than expected due to loss of some intolerant forms. Percent contribution of tolerant forms increases.
21-50%	Moderately impaired	Fewer species due to loss of most intolerant forms. Reduction in EPT index.
<17%	Severely impaired	Few species present. If high densities of organisms, then dominated by one or two taxa.

** Scores that fall between score ranges are assigned based on best professional judgment*

4.3 Water Quality

The following three indicators for assessing watershed health and tracking changes concern factors that influence water quality conditions.

4.3.1 Indicator 7: Effects on Public Health (Bacteria)

Fecal contamination may originate from both human and animal sources and poses a threat to human health. Stormwater runoff transports waste from pets, livestock, and other animals to surface waters. Wet weather sewer overflows (SSOs and CSOs) introduce domestic wastewater constituents to surface water. Illegal or accidental cross-connection of sanitary sewers to storm sewers may also result in discharges of raw wastewater to the creek. Additionally, septic systems release some bacteria to surface waters, but these inputs are generally small.

Fecal coliform bacteria are abundant in the intestines of warm blooded animals, including humans. Fecal coliform is a fairly accurate indicator of harmful bacteria in natural water, drinking water, and wastewater. Measures taken to reduce the input of fecal coliform to natural waters are likely to reduce other microorganisms found in sewage and surface runoff as well.

The water quality standard for fecal coliform is as follows: during the swimming season (May through September), the maximum level shall be a geometric mean of 200 per 100 mL based on five consecutive samples, each collected on a different day; for the remainder of the year, the maximum level shall be a geometric mean of 2000 per 100 mL based on five such samples.

This indicator measures:

- **Percent of fecal coliform samples meeting state standards at various sites**

<u>Where We Were</u>:
Approximately 100 samples of fecal coliform were taken between 1970 and 1980 at five different sites. For samples taken in the headwaters in Tacony and Jenkintown Creeks, approximately one-half to two-thirds met the current standard. For samples taken in Rock Creek and on the main stem at the Philadelphia-Montgomery county line, only one-quarter of the samples met the standard. At the most downstream site at Castor Avenue, less than 15% of samples taken met the standard. Conditions under wet weather are not significantly worse than dry weather, suggesting that dry weather inputs were the main source of bacteria in the stream.

<u>Where We Are</u>:
Samples were collected between June 2000 and October 2003 at seven sites in the watershed. Table 4.9 compares the data collected to water quality standards. At each of three of the seven sites, roughly half of dry weather samples met the standard. At the remaining four sites, no more than one-quarter of dry weather samples met the standard. And in wet weather, fewer than one-tenth of all samples taken at each of the seven sites met the water quality standard.

The two sites on the lower main stem were sampled in both the historical and 2000–2003 periods and can be directly compared. Over time, the percent of samples meeting the standard in dry weather improved slightly at both the main stem county-line site and the Castor Avenue site. There was a decrease in the percentage of samples meeting the standard from the historical data to current data at the two main stem sites, suggesting that wet weather conditions may have declined over time.

Table 4.9 Percent of Samples Meeting Bacteria Standards

Site	Percent of Samples that Meet the Standard					
	Historical			Current		
	All Data	Dry Weather	Wet Weather	All Data	Dry Weather	Wet Weather
19	60%	67%	50%			
18	55%	67%	38%			
7	27%	29%	24%			
8 / TF620	35%	39%	29%	24%	44%	9%
9 / TF280	13%	14%	12%	12%	23%	6%
TF1120				8%	18%	3%
TF500				26%	45%	8%
TF760				29%	50%	8%
TF975				10%	25%	3%
TF680				2%	8%	0%

Criteria			
Lower Limit		Upper Limit	
67%	<= % meeting <=	100%	GREEN
33%	<= % meeting <=	67%	YELLOW
0%	<= % meeting <=	33%	RED

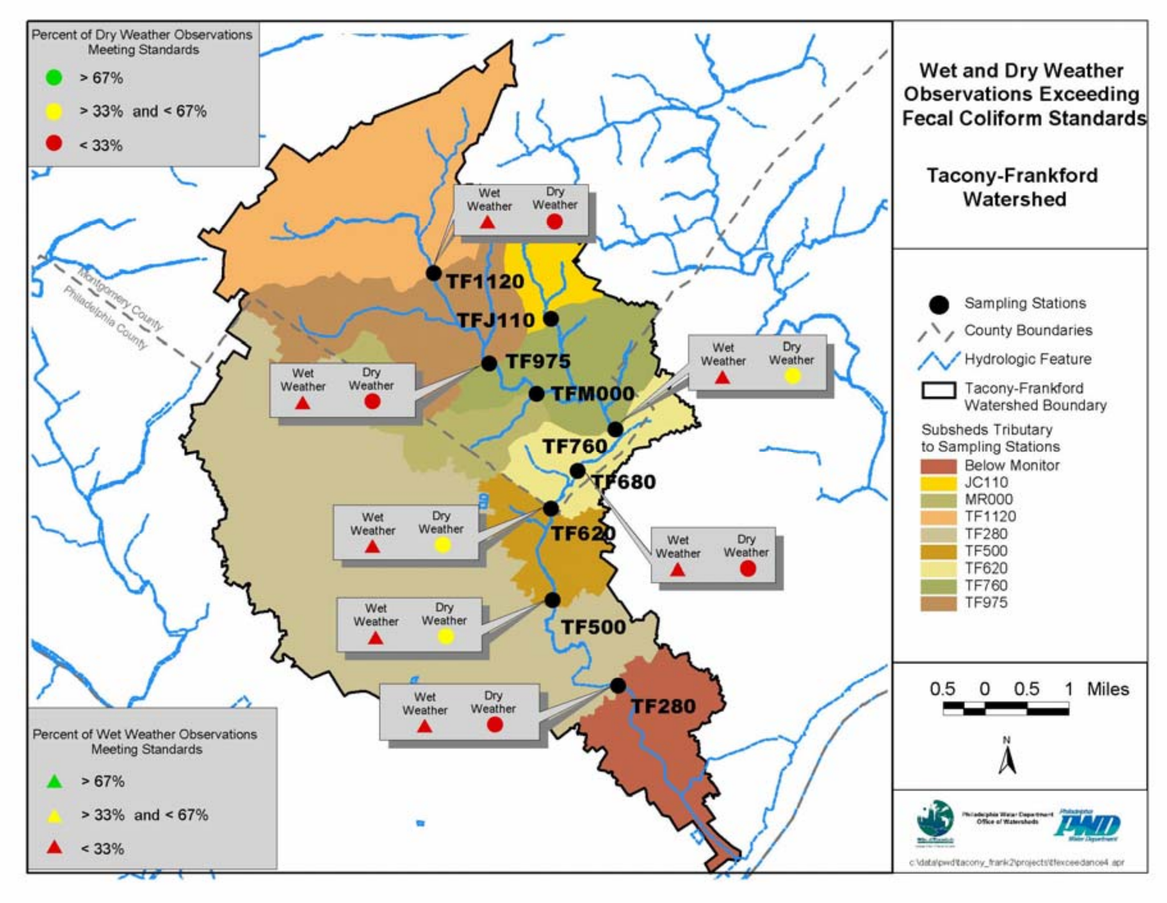


Figure 4.12 Current Water Quality Data for Fecal Coliform

4.3.2 Indicator 8: Effects on Public Health (Metals and Fish Consumption)

Toxic substances, including metals (such as mercury) and organic substances (such as PCBs), are sometimes introduced into the aquatic environment due to human activity. These substances exist in some sediments as a result of historical discharges, are introduced to the atmosphere through burning of fossil fuels, and are deposited on the land surface through industrial and transportation activities. Precipitation and surface runoff introduce small concentrations of these substances to surface waters. Over time, fish ingest the toxic chemicals from the water they live in and the food they eat, in some cases developing harmful concentrations in their tissues. Because toxic substances in the environment can affect aquatic life and humans who eat fish, the PA DEP has set maximum allowable concentrations for the water column. The standards based on aquatic life protection are generally strict. In addition, the DEP samples fish tissue and issues advisories designed to warn the public about species that may contain toxic chemicals. These contaminants can build up in the human body over time, possibly leading to health effects.

This indicator measures:

- **Areas with fish consumption advisories (graphical)**
- **Percent of aluminum (Al), cadmium (Cd), chromium (Cr), copper (Cu), lead (Pb), and zinc (Zn) samples meeting state standards at various sites**

Where We Were:

Pennsylvania updates its fish consumption advisories at least yearly. Table 4.10 shows the Fish Consumption Advisory for 2003. This advisory applies only to tributaries of the Delaware River such as the Tacony-Frankford, only to the head of tide, which can be seen on Figure 4.13.

Table 4.10 Commonwealth of Pennsylvania Public Health Advisory – 2003 Fish Consumption

Water Body	Area Under Advisory	Species	Meal Frequency	Contaminant
Delaware River and Estuary, including all tributaries to head of tide and the Schuylkill River to the Fairmount Dam (Bucks, Philadelphia, and Delaware counties)	Yardley to PA/Delaware state line	White perch, Flathead catfish, Striped bass, Carp	1 meal/month	PCB
		Channel catfish	6 meals/year	PCB
		American eel	Do Not Eat	PCB
		Smallmouth bass	2 meals/month	Mercury

Historical information on concentrations of toxins in fish tissue is not readily available. Data on some metals was collected in the 1970s, and can be compared to current water quality standards. Approximately 60 samples were collected at each of three sites between 1970 and 1980 for lead, cadmium, chromium, copper, and zinc together. Metals concentrations frequently exceeded standards at the observation sites, in both dry and wet weather. With the exception of Site 7 during wet weather, which met the standard 82% of the time, samples from all three sites during both dry and wet weather only met that standard roughly 50-60% of the time (Table 4.12).

Where We Are:

The 2004 Fish Consumption Advisory (Table 4.11) recommended limiting consumption of white perch, flathead catfish, striped bass, carp, channel catfish, and American eel due to PCB contamination in an area that includes the Tacony-Frankford Creek, up to the head of tide (area below TF 280, Figure 4.13). The only change seen from the previous year's advisory was that an advisory for mercury in smallmouth bass was lifted.

Table 4.11 Commonwealth of Pennsylvania Public Health Advisory – 2004 Fish Consumption

Waterway	Area Under Advisory	Species	Meal Frequency	Contaminant
Delaware River and Estuary, including the tidal portion of all PA tributaries and the Schuylkill River to the Fairmount Dam (Bucks, Philadelphia, & Delaware Co.)	Yardley to PA/Delaware state line	White perch, flathead catfish, striped bass, carp	1 meal/month	PCB
		Channel catfish	6 meals/year	
		American eel	Do Not Eat	

Samples collected between June 2000 and October 2003 at seven sites were tested for aluminum, cadmium, chromium, copper, lead, and zinc (Figure 4.13 and Table 4.12). At each site, at least 90% of dry weather samples met the standard for each metal, with the exception of copper at two sites; 100% of samples met the dry weather standard for lead and cadmium; and at two upstream sites, every sample met all dry weather metal standards. Wet weather data varied from site to site and for the individual metals, but the samples usually met the standard less than 90% of the time.

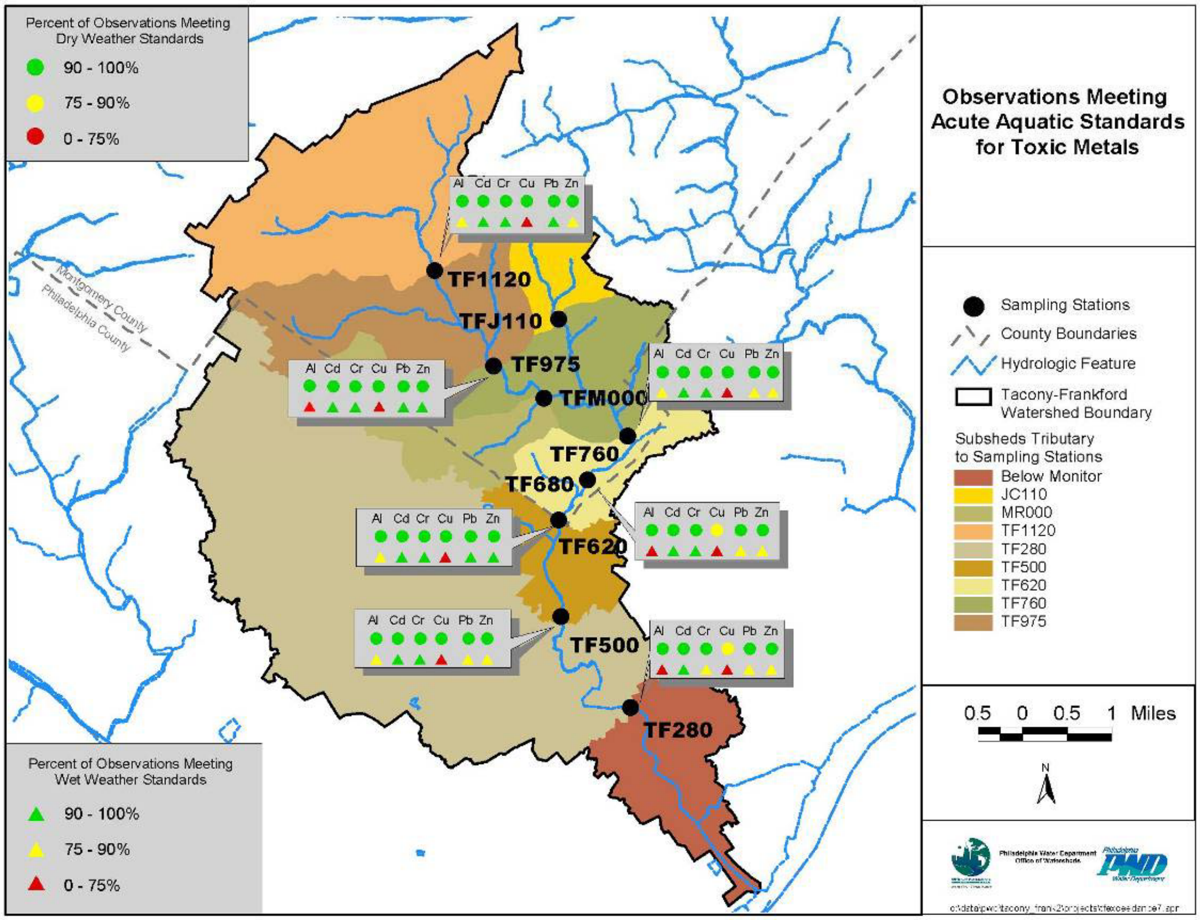


Figure 4.13 Current Metals Water Quality Data with Fish Consumption Advisory Areas

Of the three sites for which historical data exist, two of those sites also have corresponding current data. At both of the sites, the percent of samples meeting the water quality standard has increased dramatically over the last 20 to 30 years, in both wet and dry weather. Historical data showed dry weather samples met the standard an average of 50% of the time; current data shows an average at those two sites of meeting the standard 98% of the time. With wet weather sampling, the average increased from around 60% to 82% of the samples meeting the standard.

Table 4.12 Percent of Samples Meeting Toxic Metals Standards

	Percent of Samples that Meet the Standard					
	Historical			**Current**		
Site	**All Data**	**Dry Weather**	**Wet Weather**	**All Data**	**Dry Weather**	**Wet Weather**
19						
18						
7	58%	48%	82%			
8 / TF620	55%	52%	61%	93%	99%	88%
9 / TF280	50%	47%	59%	84%	97%	76%
TF1120				90%	100%	84%
TF500				87%	99%	75%
TF760				91%	100%	82%
TF975				89%	98%	83%
TF680				86%	97%	80%

Criteria			
Lower Limit		Upper Limit	
90%	<= % meeting <=	100%	GREEN
75%	<= % meeting <=	90%	YELLOW
0%	<= % meeting <=	75%	RED

4.3.3 Indicator 9: Effects on Aquatic Life (Dissolved Oxygen)

Just as humans require oxygen gas for respiration, most aquatic organisms require dissolved oxygen (DO). Oxygen dissolves in water through air-water interaction at the surface of the flow and through photosynthesis of plants and algae. At the same time, DO is depleted through the respiration of microorganisms, animals, plants, and algae. In a healthy system, the balance between oxygen-depleting and oxygen-providing processes maintains DO at a level that allows aquatic organisms to survive and flourish. In a less healthy system, dissolved oxygen may be depleted below levels needed by aquatic organisms. The minimum dissolved oxygen concentration required by many common fish species found in rivers and streams is approximately 5 mg/L. The PA DEP has set a water quality standard, or minimum allowable concentration, of 5 mg/L as a daily average and 4 mg/L as an instantaneous value for the Tookany/Tacony-Frankford Creek.

This indicator measures:

- **Percent of DO samples meeting state standards at various sites**

Where We Were:

Discrete samples of DO were taken at five sites in the watershed in the 1970s and 1980s. At all five sites, 100% of the wet weather samples met the average minimum standard. Dry weather samples met the standard 100% of the time at three of the sites, and met the standard 95% and 98% of the time at the remaining two sites.

Where We Are:

Both discrete and continuous samples were collected between 2000 and 2003 (see Figures 4.14 and 4.15). Discrete samples produce a single DO value at the time the sample is taken; continuous monitoring measures DO over the entire photic period, including the night when DO is lowest due to algal respiration. Both the discrete and continuous samples suggest that dissolved oxygen is rarely below the standard under dry or wet conditions. At each of the seven sites where discrete samples were taken, 100% of the discrete samples taken in both wet weather and dry weather met both the average minimum standard and the instantaneous minimum standard, with the exception of one site downstream, TF280. At this site, 4 out of 19 samples were below the average minimum standard in dry weather and 2 out of 19 samples were below the instantaneous minimum standard in dry weather. No discrete samples at any of the sites were below the standard in wet weather.

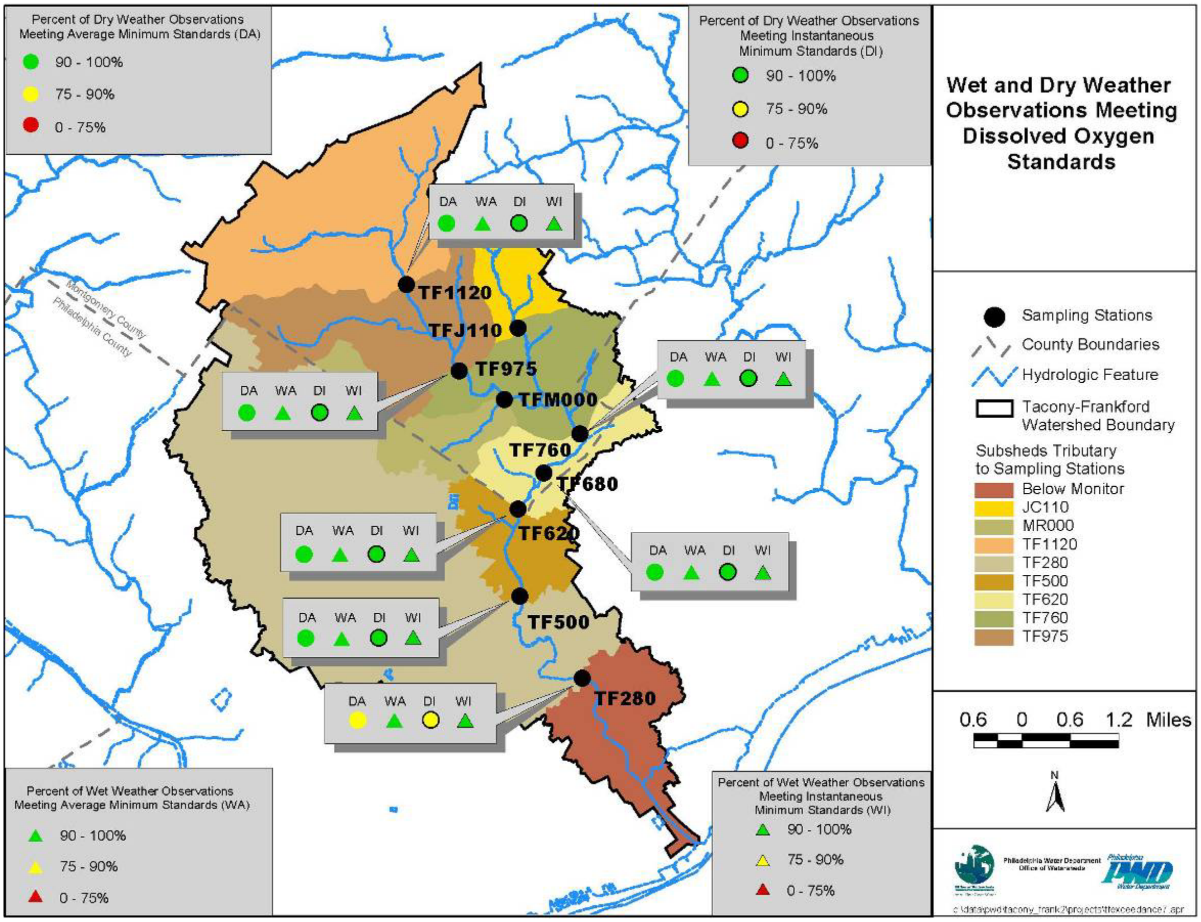


Figure 4.14 Current Water Quality Discrete Data for Dissolved Oxygen

With the continuous samples, 100% of the samples taken at each of six sites at which discrete sampling occurred met the DO daily mean standard, except for at site TF280. At least 90% of the samples at each site met the DO daily minimum standard. Again, for the DO daily minimum standard, site TF280 shows the highest number of samples that do not meet the standard. Overall, 100% of the discrete samples met the standard for DO daily mean and 94% of the samples met the standard for DO daily minimum.

The continuous Sonde data collected shows more than 2% of the readings below the DO daily minimum near the downstream end of the watershed and just upstream of the City boundary. Figure 4.15 displays the Sonde DO data compared to the daily minimum standard.

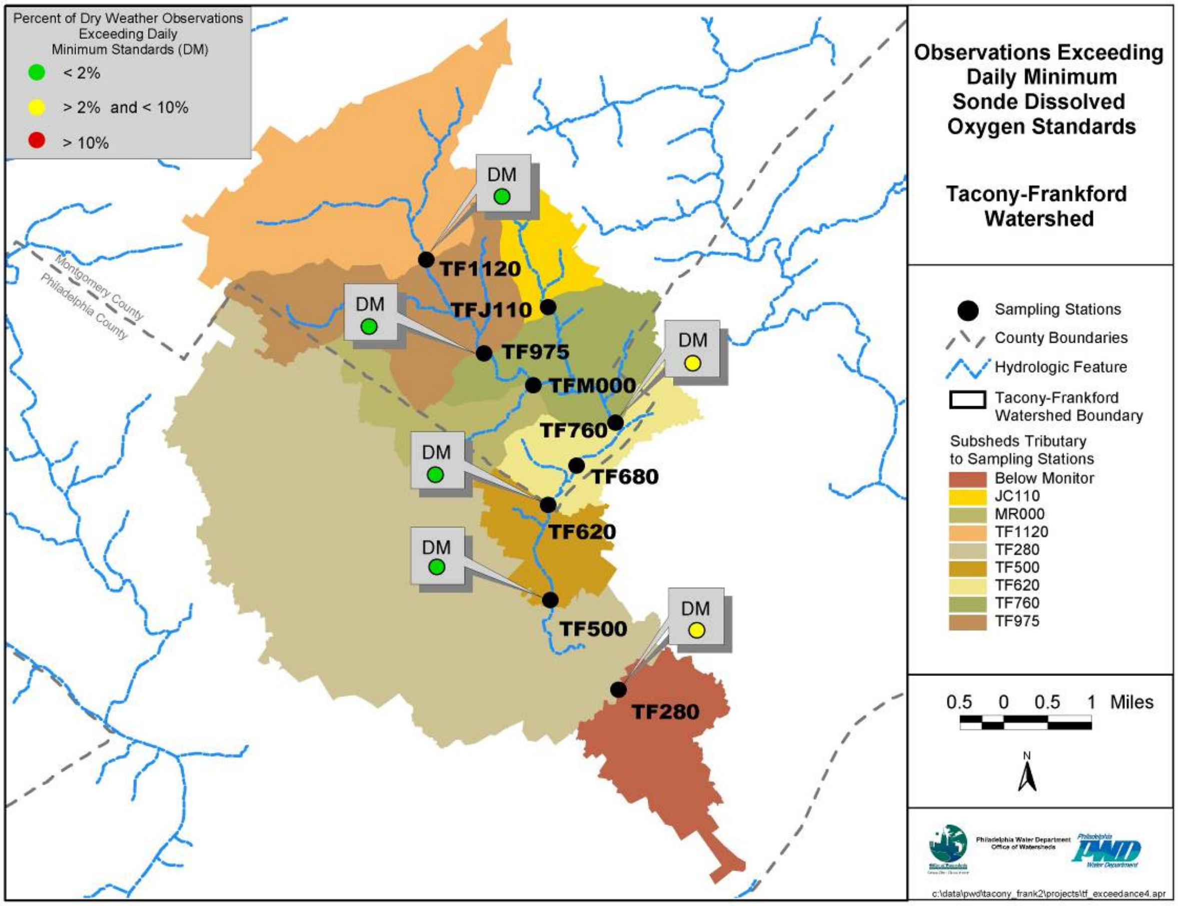


Figure 4.15 Current Water Quality Continuous Data for Dissolved Oxygen

Comparing the current data with historical data for two sites in the watershed, TF280 and TF 620, the number of samples not meeting the average minimum standard has increased. Historically, 100% of wet weather samples met the standard at both sites, which is consistent with current sampling results. With dry weather samples, the results have remained fairly consistent at site TF620 with 98% of samples meeting the standard historically and 100% of the samples meeting the standard currently. At site TF280, dry weather sampling results show a decrease in the number of samples meeting the standard. Historically, 95% of dry weather samples met the standard at this site while currently only 79% of the samples are meeting the standard.

4.4 Pollutants

The following two watershed indicators categorize pollutants broadly by their sources: "point" and "non-point."

4.4.1 Indicator 10: Point Sources

A point source is any point where pollutants enter the water, such as a pipe, channel, or ditch (Figures 4.16 to 4.18). Point source discharges can include treated municipal wastewater, combined sewer overflows (CSOs), separate sanitary overflows (SSOs), industrial process water, municipal separate storm sewer system (MS4) discharges, and/or cooling waters. Point sources are regulated under the Clean Water Act by the National Pollutant Discharge Elimination System (NPDES).

Figure 4.16 Stormwater Outfall

Figure 4.17 CSO Outfall

Figure 4.18 Municipal Wastewater Treatment Plant

A municipal separate storm sewer system (MS4) collects stormwater runoff from the land surface and discharges it directly to a receiving stream.

Combined sewer systems use one pipe to convey sanitary sewage and stormwater runoff to a combined sewage regulator chamber. The regulator captures all of the sanitary sewage in dry weather, and some of the combined sewage in wet weather, and sends it to a wastewater treatment plant. The balance of the wet weather flow is discharged to an area water body through a CSO outfall.

Sanitary Sewer Overflows (SSOs) occur when a municipal separate sanitary sewer system becomes overcharged in wet weather and overflows unintentionally to an area water body.

Municipal Wastewater Treatment Plants are facilities that process municipal sanitary waste and industrial and commercial discharges to the sewer system. These facilities treat the waste stream and discharge it to a local stream.

Industrial processes use water in manufacturing, power generation, or other activities to produce a product. The by-products from the process can be discharged to area waterways with varying levels of treatment.

This indicator measures:

- **Number of industrial and municipal point sources permitted to discharge to water bodies (if available, number meeting permit requirements)**
- **Estimated annual percent capture of combined sewage**
- **Model-estimated pollutant contributions of industrial/municipal, CSO, and stormwater outfalls**

Where We Were:

Point source discharges from treatment plants and industrial facilities were a priority for increased control during the 1970s and 1980s as secondary wastewater treatment requirements and industrial pre-treatment regulations were imposed. Historical data indicated that there were three facilities in the watershed with National Pollutant Discharge Elimination System (NPDES) Permits.

Historical SSO and CSO discharges are not well documented, and there is only limited current data on SSOs. However, it can be inferred from water quality data that dry weather sewage discharges were much more common in the past (see Indicator 8). It is reasonable to conclude that the frequency and volume of CSO discharges in the Philadelphia portion of the Tacony-Frankford Watershed have decreased over the past 20 years due to improved sewer maintenance and CSO control measures (discussed in detail later in this section).

Where We Are:

Active Industrial and Municipal Point Source Dischargers

Current facilities with NPDES permits to discharge to the Tookany, Tacony, Frankford, and Baeder creeks are believed to be SPS Technologies, Allegheny Iron Radiation, Bayway Refining Company, Roadway Express, BFI Waste Services Of Pa, S D Richman Sons Incorporated, and Sunoco Incorporated Frankford Plant. The Philadelphia Water Department is also permitted for its CSO outfalls. The permit for one facility, Biello Auto Parts Inc, that was once listed as active has expired. All municipalities in the watershed – Abington, Jenkintown, Rockledge, Cheltenham, Springfield, and Philadelphia – have MS4 permits, which all large, medium, and regulated small municipal separate storm sewer systems need in order to discharge pollutants.

Estimated Annual Percent Capture of Combined Sewage

Portions of Philadelphia County, including 47% of the Tookany/Tacony-Frankford Creek Watershed, are serviced by combined sewer. The City of Philadelphia has 31 regulator structures within the watershed, as shown in Figure 4.19. Since the 1980s, PWD has made significant progress in reducing CSO discharges to the Tacony-Frankford Creek. As required under EPA's CSO Control Policy, PWD has developed and implemented a CSO Long Term Control Plan (LTCP) to improve and preserve the water environment in the Philadelphia area. Table 4.13 lists estimated capture percentages for regulator structures in the Tacony-Frankford Watershed, based on the modeling results listed in PWD's CSO Annual Reports.

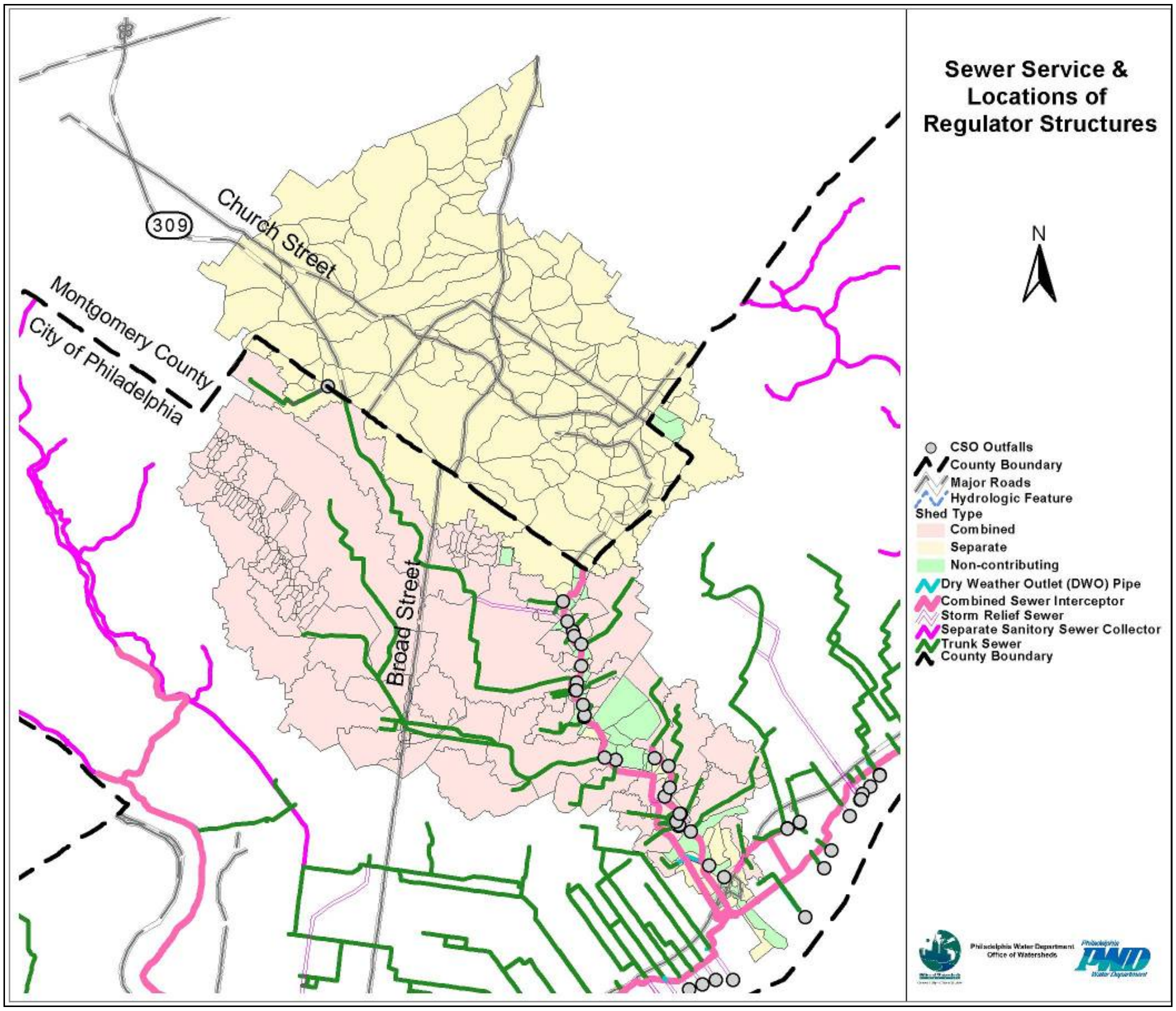


Figure 4.19 Types of Sewer Service and Locations of Regulator Structures

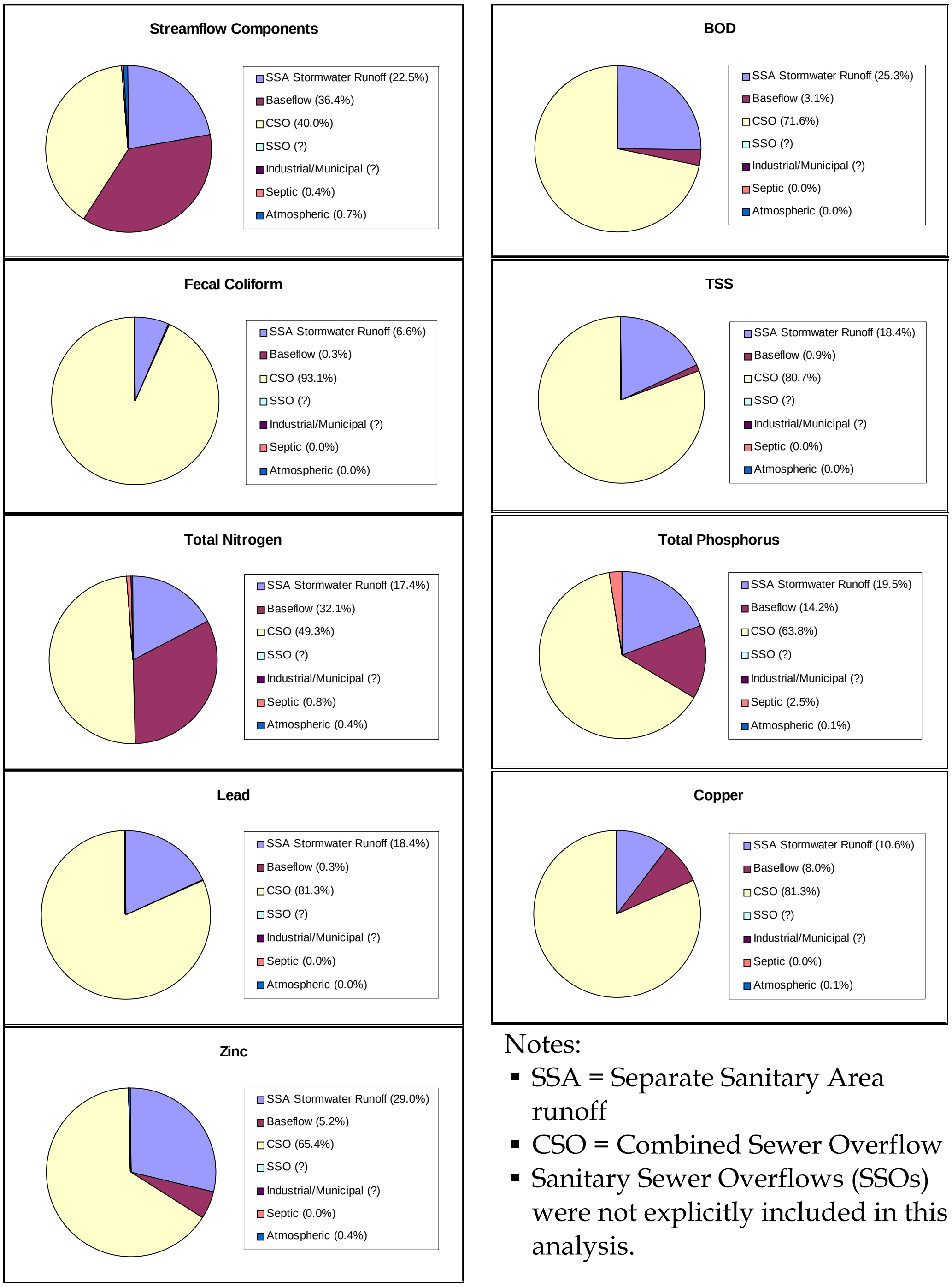
A capture percentage is defined as the percentage of combined sewage (mixed sanitary sewage and stormwater) that is sent to a treatment plant during rainfall events over the course of a year. 85% capture is considered to be an ultimate goal for many communities, as they implement CSO Long Term Control Plans (since it is not possible to capture and treat large storms). It is important to note that percent capture for a given year is strongly dependent on the frequency and magnitude of rainfall events during that year. The five years of data listed in Table 4.13 are not sufficient to determine whether an increasing or decreasing trend has taken place. However, as the amount of data increases throughout implementation of the Long Term Control Plan, it will ultimately be possible to evaluate the effectiveness of the control measures

Table 4.13 Estimated Annual Combined Sewage Capture Percentages

Year	Precipitation (in)	Capture (%) – Lowest and Highest Structure	
		Tacony	Upper Frankford Low Level
2003	46.72	43 - 45	64 - 65
2002	34.11	59 - 64	76 - 79
2001	30.62	51 - 53	70 - 72
2000	43.26	40 - 42	58 - 60
1999	48.6	39 – 40	57 - 59

Model-Estimated Pollutant Contributions of Different Sources

Estimated annual pollutant contributions to the Tookany/Tacony-Frankford Creek are shown below. CSO is the largest source associated with urban and suburban runoff, including nutrients such as phosphorus and metals such as lead. Stormwater outfalls are a smaller but significant source of these constituents. CSO discharges are the main source of fecal coliform. Permitted industrial and municipal point source discharges make up less than 1% of annual streamflow in both systems. SSOs are thought to occur in both watersheds but have not been well documented.



Notes:
- SSA = Separate Sanitary Area runoff
- CSO = Combined Sewer Overflow
- Sanitary Sewer Overflows (SSOs) were not explicitly included in this analysis.

Figure 4.20 Annual Pollutant Contribution

Spatial distributions of model-based constituent loads are shown in Figures 4.21 through 4.28. The darker areas represent areas of higher loads per acre per year. For BOD, a significant amount is within the City from combined-sewered areas. Highest fecal coliform estimates are found in the City portion of the watershed. Metals (lead and zinc) are generally higher in the more urbanized areas of the watershed. Total suspended solids (TSS) loads follow a similar trend to metals. Nutrients (phosphorus and nitrogen) have significant contributions throughout the watershed, with the highest near the Philadelphia County line. (For more information about modeling used to estimate this annual loading to the Tookany/Tacony-Frankford Creek, see Section 9 of the Tookany/Tacony-Frankford Watershed Comprehensive Characterization Report, 2005.)

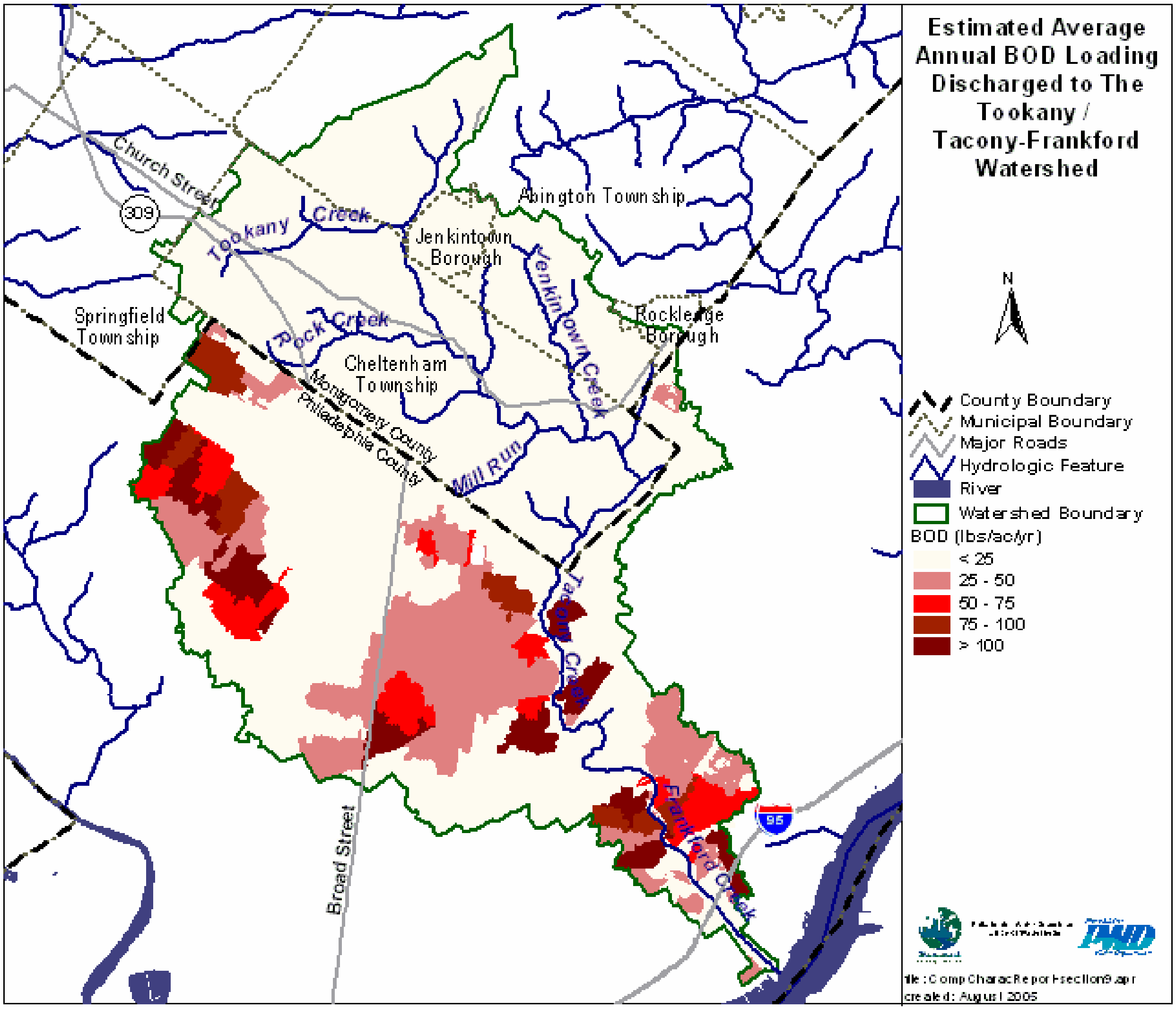


Figure 4.21 Estimated Annual BOD Loading to the Tookany/Tacony-Frankford Creek

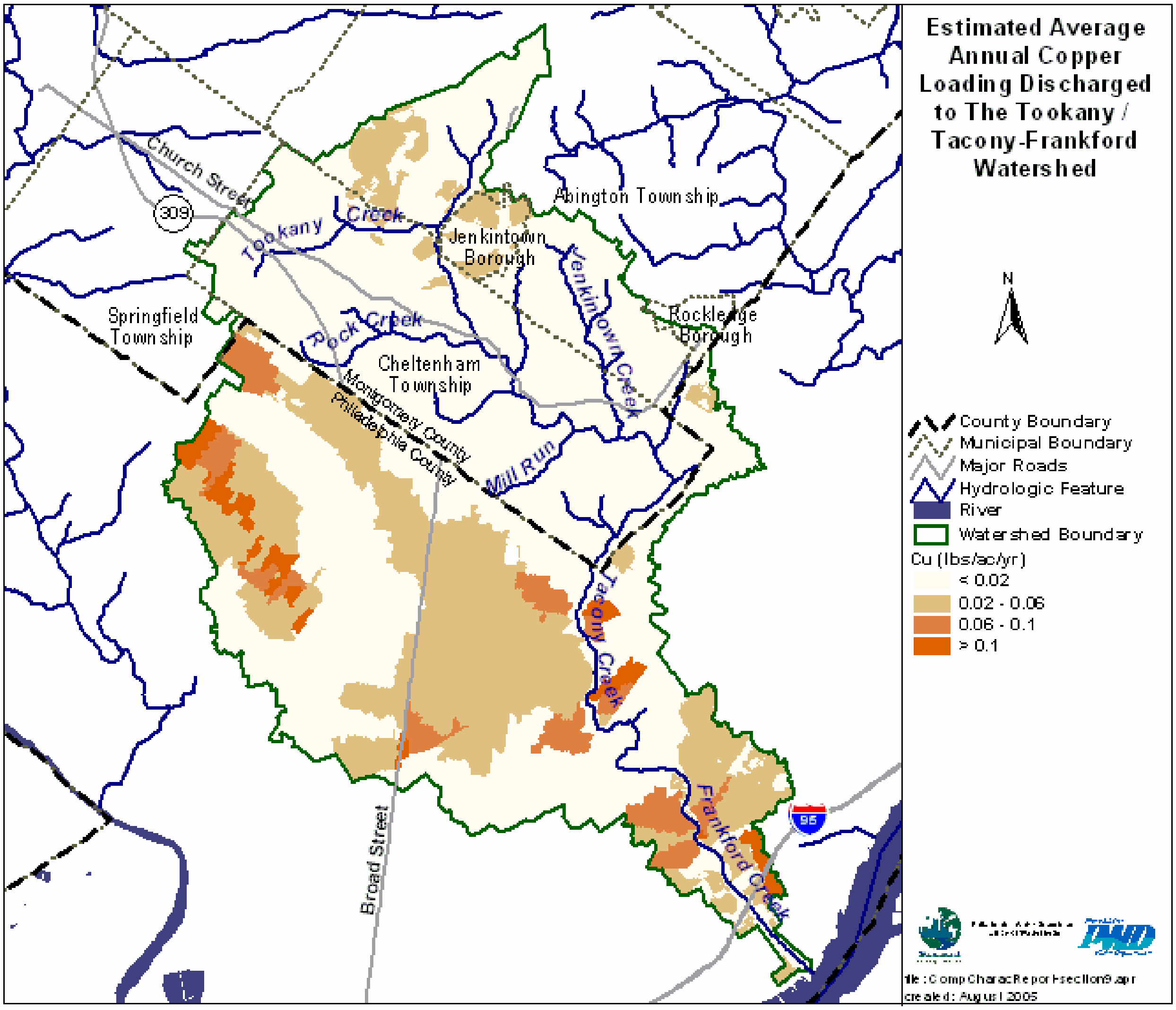


Figure 4.22 Estimated Annual Copper Loading to the Tookany-Tacony-Frankford Watershed

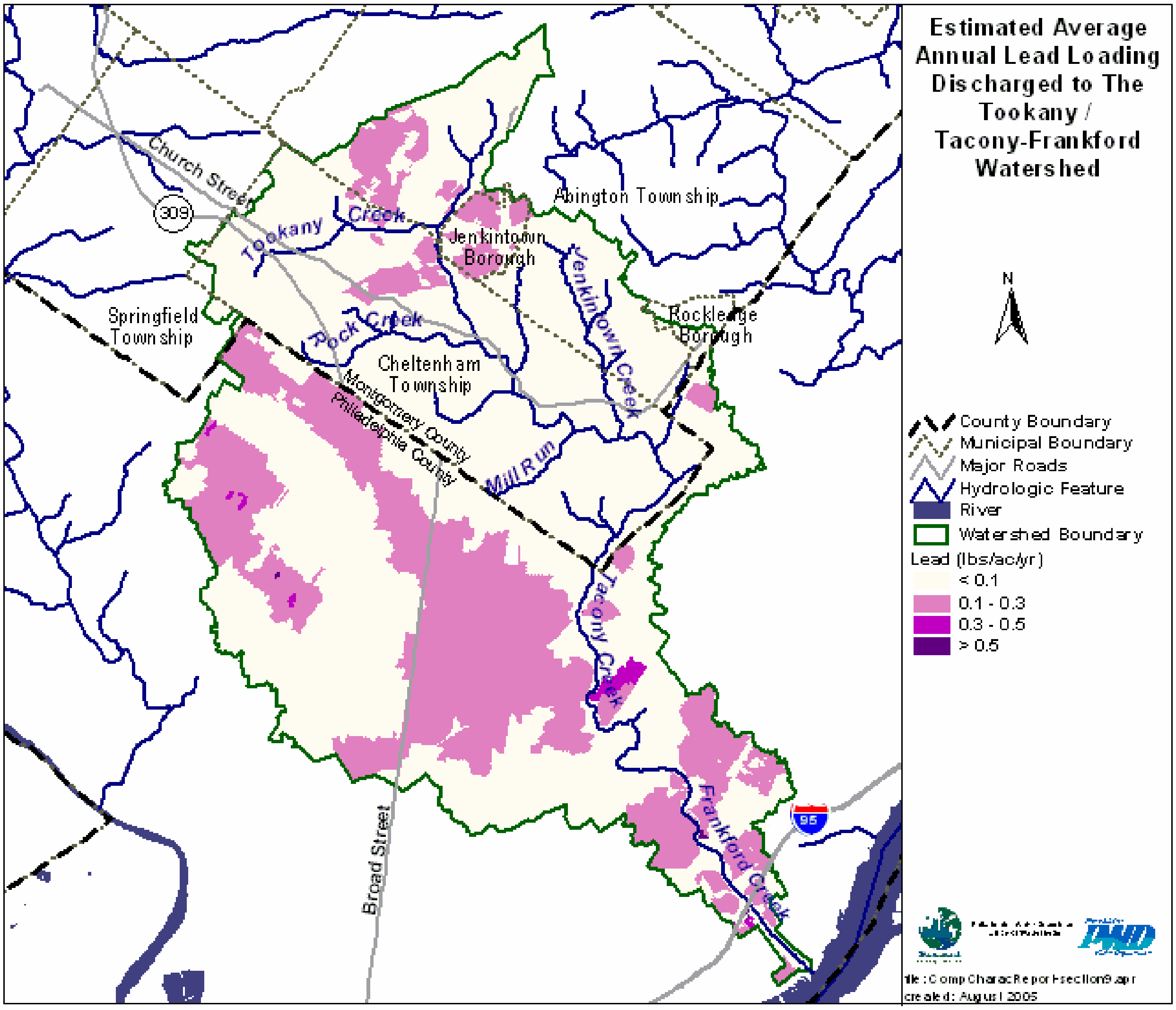


Figure 4.23 Estimated Annual Lead Loading to the Tookany/Tacony-Frankford Creek

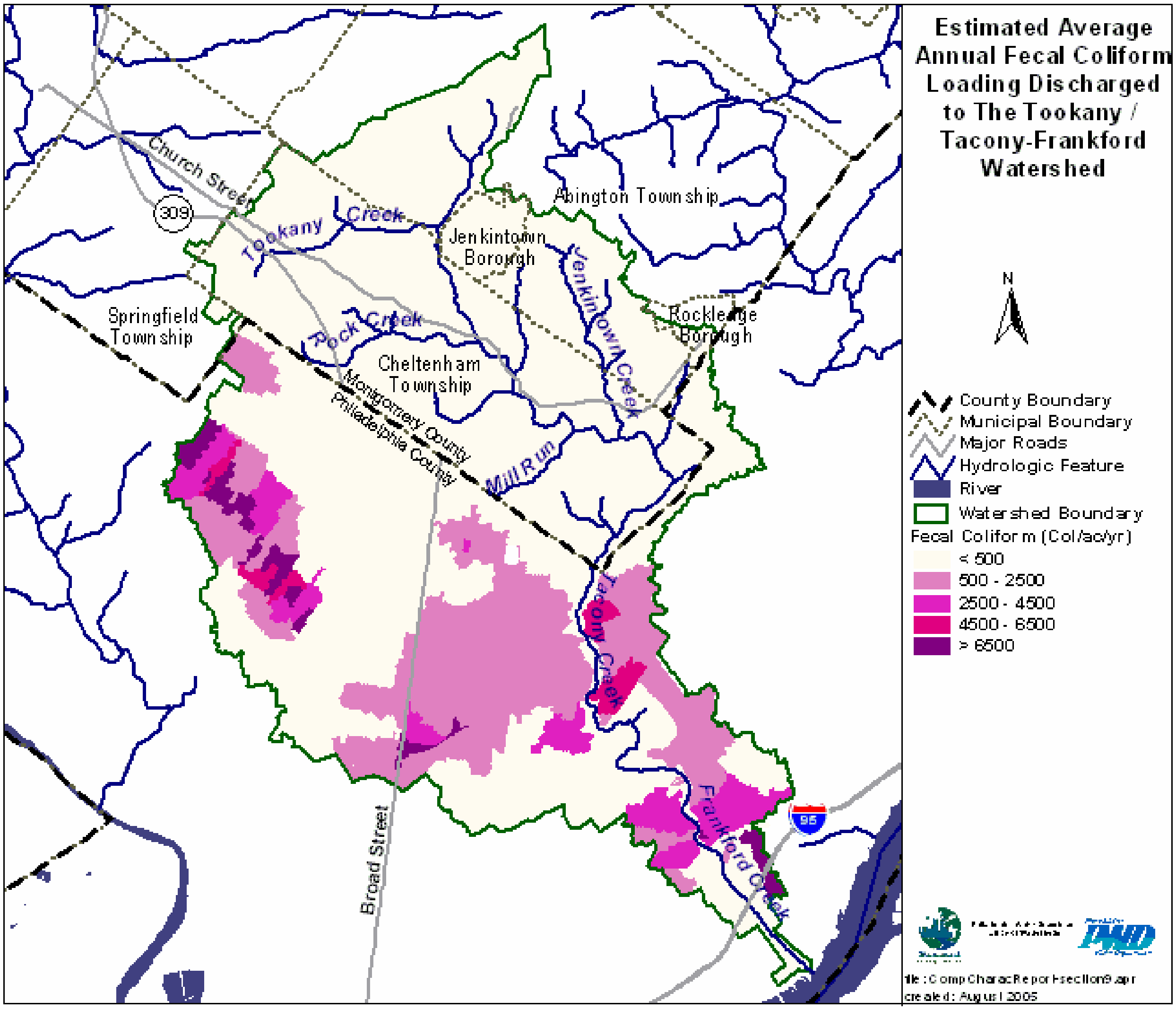


Figure 4.24 Estimated Annual Fecal Loading to the Tookany/Tacony-Frankford Creek

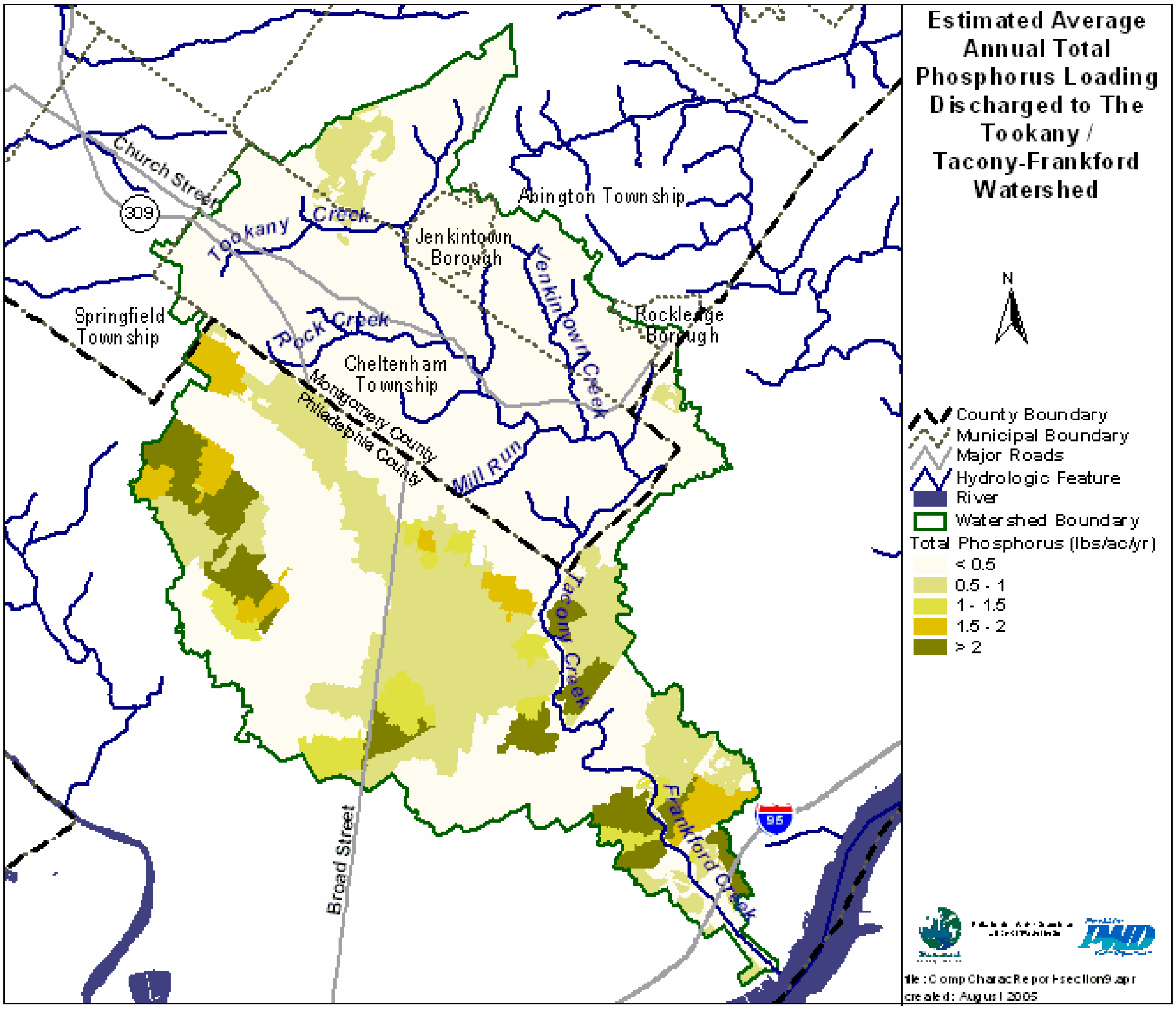


Figure 4.25 Estimated Annual Phosphorus Loading to the Tookany/Tacony-Frankford Creek

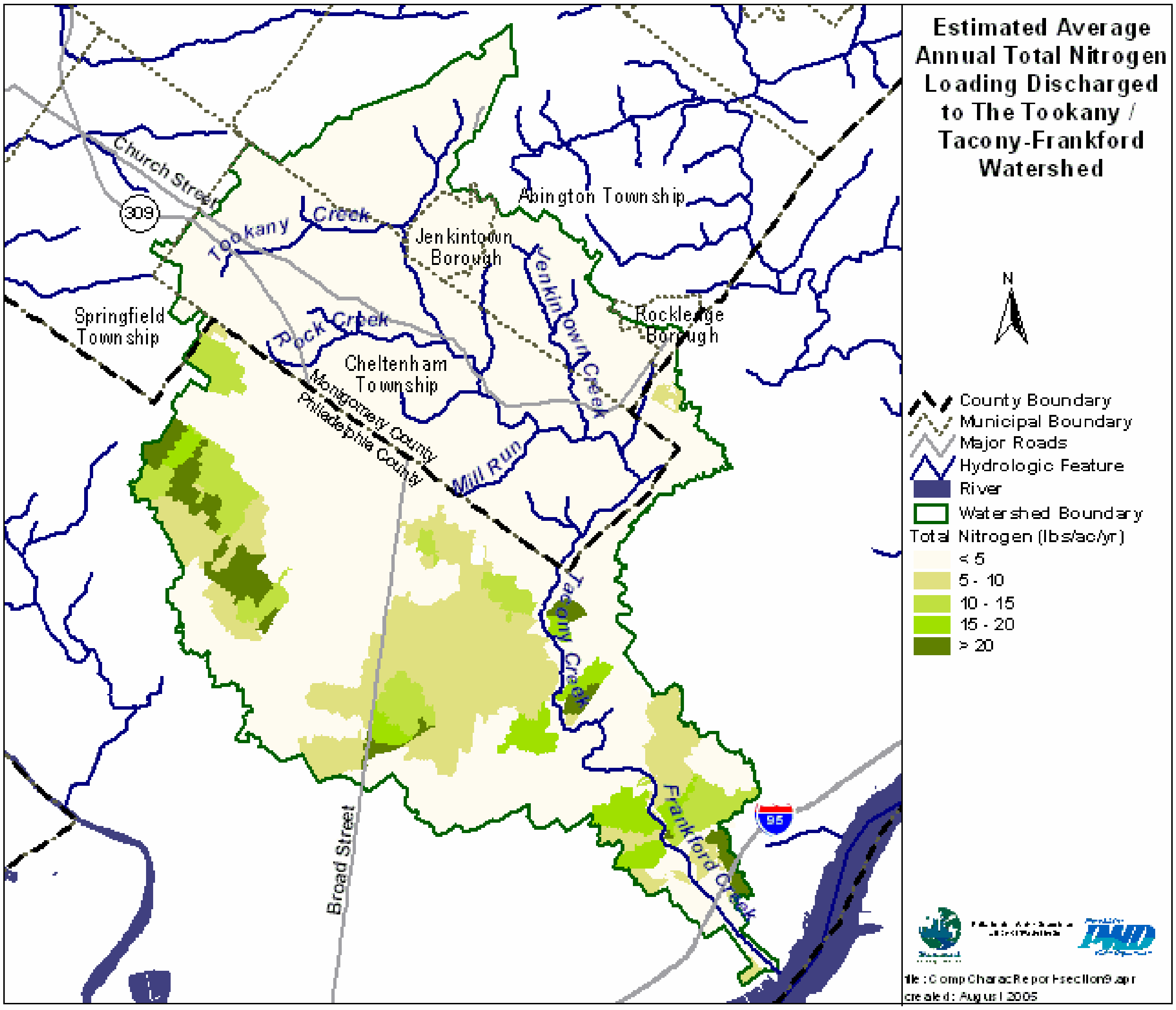


Figure 4.26 Estimated Annual Nitrogen Loading to the Tookany/Tacony-Frankford Creek

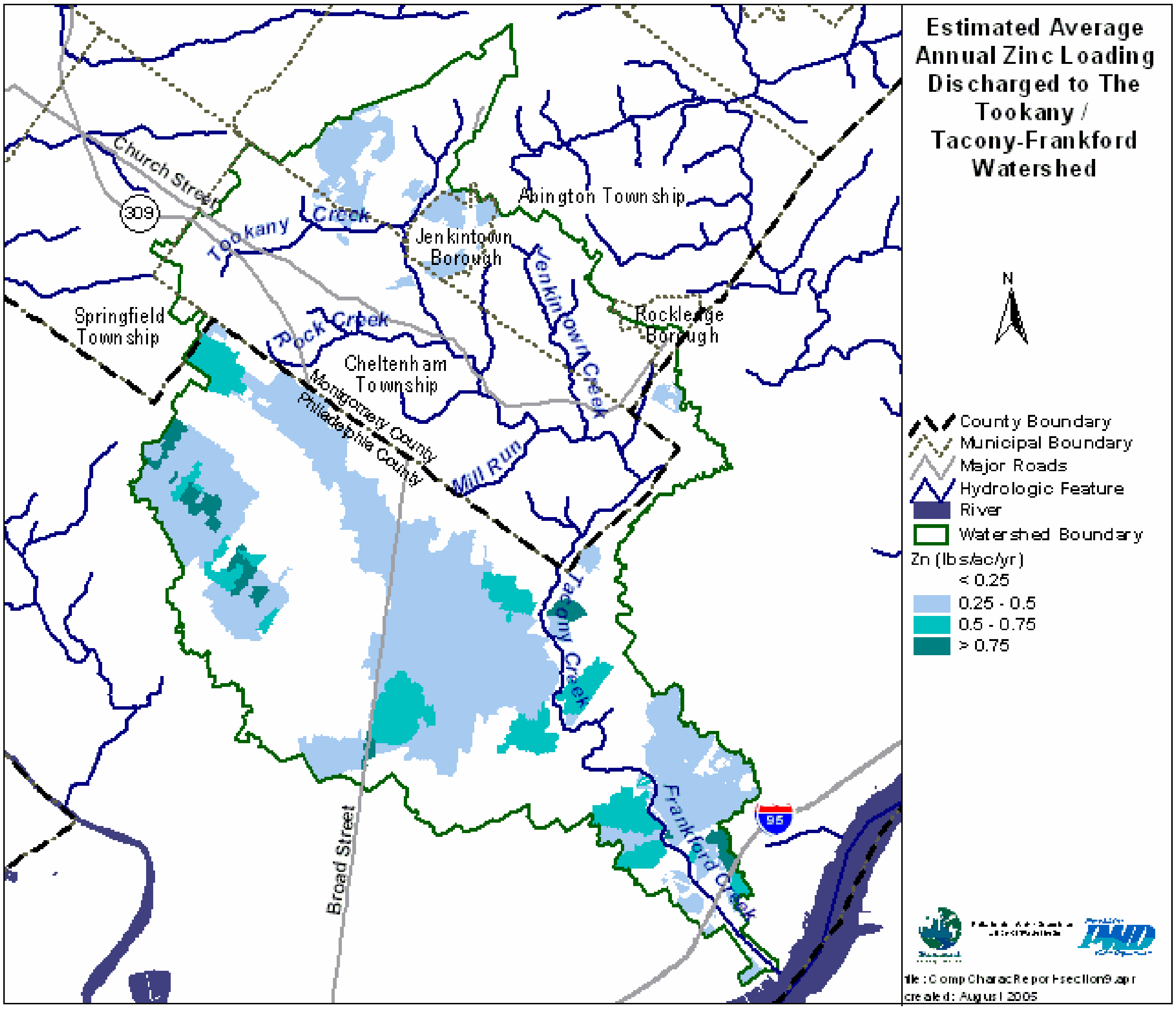


Figure 4.27 Estimated Annual Zinc Loading to the Tookany/Tacony-Frankford Creek

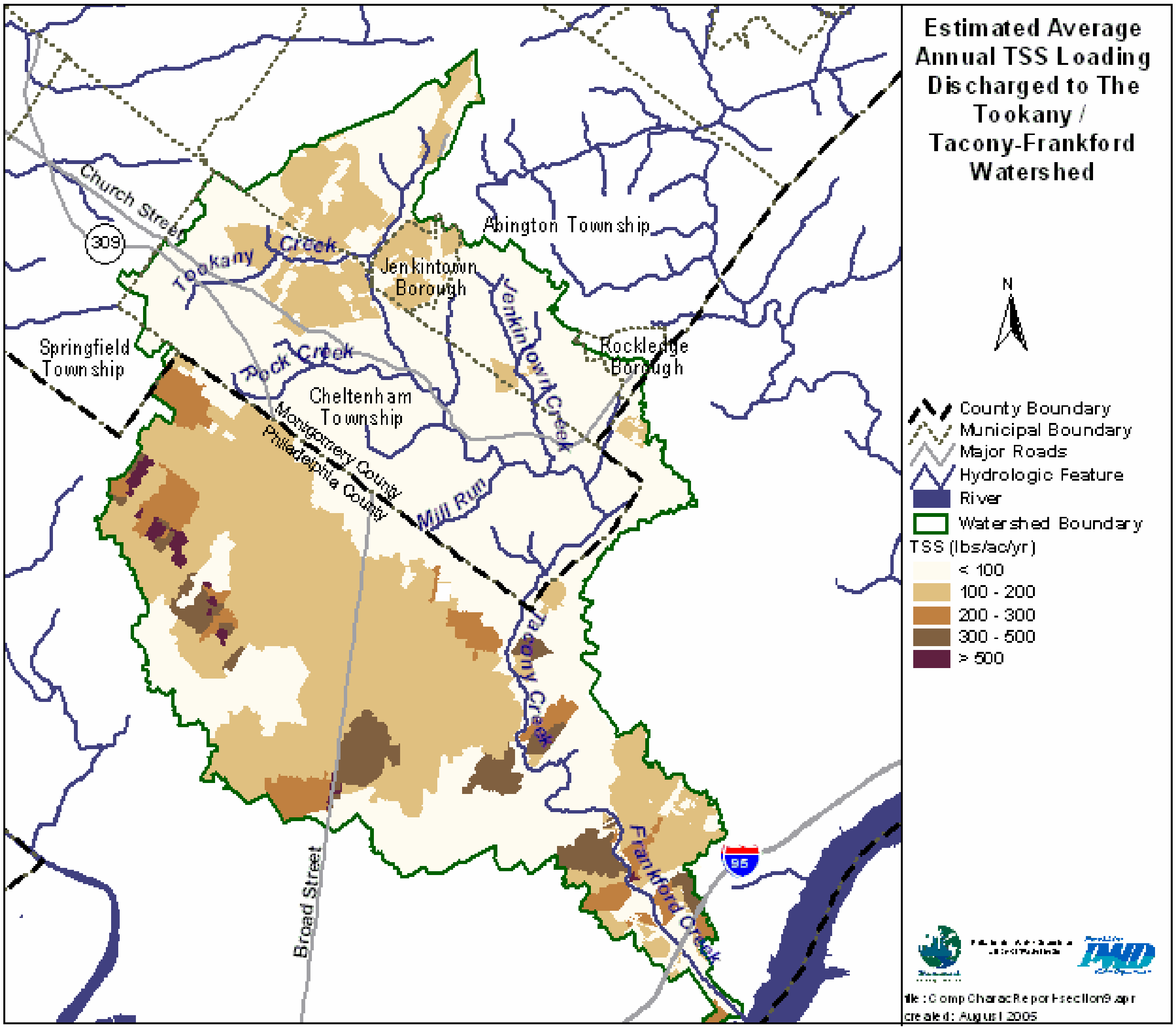


Figure 4.28 Estimated Annual TSS Loading to the Tookany/Tacony-Frankford Creek

4.4.2 Indicator 11: Non-point Sources

Non-point source pollution is any source of water contamination not associated with a distinct discharge point. This type of pollution is a leading cause of water quality degradation in the United States. Non-point sources include atmospheric deposition, stormwater runoff from pasture and crop land, and individual on-lot domestic sewage systems discharging through shallow groundwater. Stormwater from urban and suburban areas is considered a point source for regulatory purposes because it is collected in a pipe system and discharged at a single point.

Figure 4.29 Pasture Land

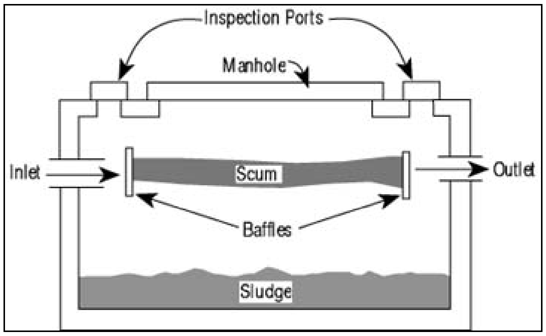


Figure 4.30 Septic System
Source: Ohio State University Extension

Agricultural activity is a major source of non-point source pollution in many areas. Animal manure and fertilizers applied to crops may lead to pollutant inputs to surface water and groundwater.

A properly sited and maintained **septic system** should not result in inputs of nutrients to groundwater. However, failing septic systems are common and can result in nutrient inputs to shallow groundwater and ultimately to stream baseflow.

Background concentrations of some water quality constituents are present in groundwater and may be transferred to stream baseflow. Some constituents may be introduced through agricultural activity or failing septic systems, while others may be present as a result of local geology.

This indicator measures:

- **Model-estimated percent of total pollutant loads contributed by septic tanks**
- **Evidence that sanitary sewers are leaking during dry weather, or are in direct contact with the stream**

<u>Where We Were</u>:

Since most point sources were addressed in the 1970s and 1980s, regulatory agencies have been turning attention towards controlling non-point sources of pollution. Many of these sources began to be addressed during the 1990s.

<u>Where We Are</u>:

Non-point sources in the Tookany/Tacony-Frankford Watershed include atmospheric deposition, stormwater runoff from a very small amount of agricultural land, background concentrations in groundwater, and individual on-lot disposal systems (OLDS) discharging through shallow groundwater. The number of septic tanks within the watershed is hard to accurately quantify. According to 1990 census data, about 1075 septic tanks were present in the watershed; however, this is believed to be a high estimate of the actual number. Figure 4.31 shows the septic areas within the watershed. Based on modeling estimates (Figures 4.32 and 4.33), septic tanks contribute less than 1% of total nitrogen and 2.5% of phosphorus loads. Atmospheric loads to wetlands and open water were estimated to be less than 1%. Background groundwater concentrations of total nitrogen were a large source of loading through stream baseflow at over 30%. Dry weather contributions from leaking sanitary sewers could not be estimated based on current data; however, evidence that leaking is occurring is presented below.

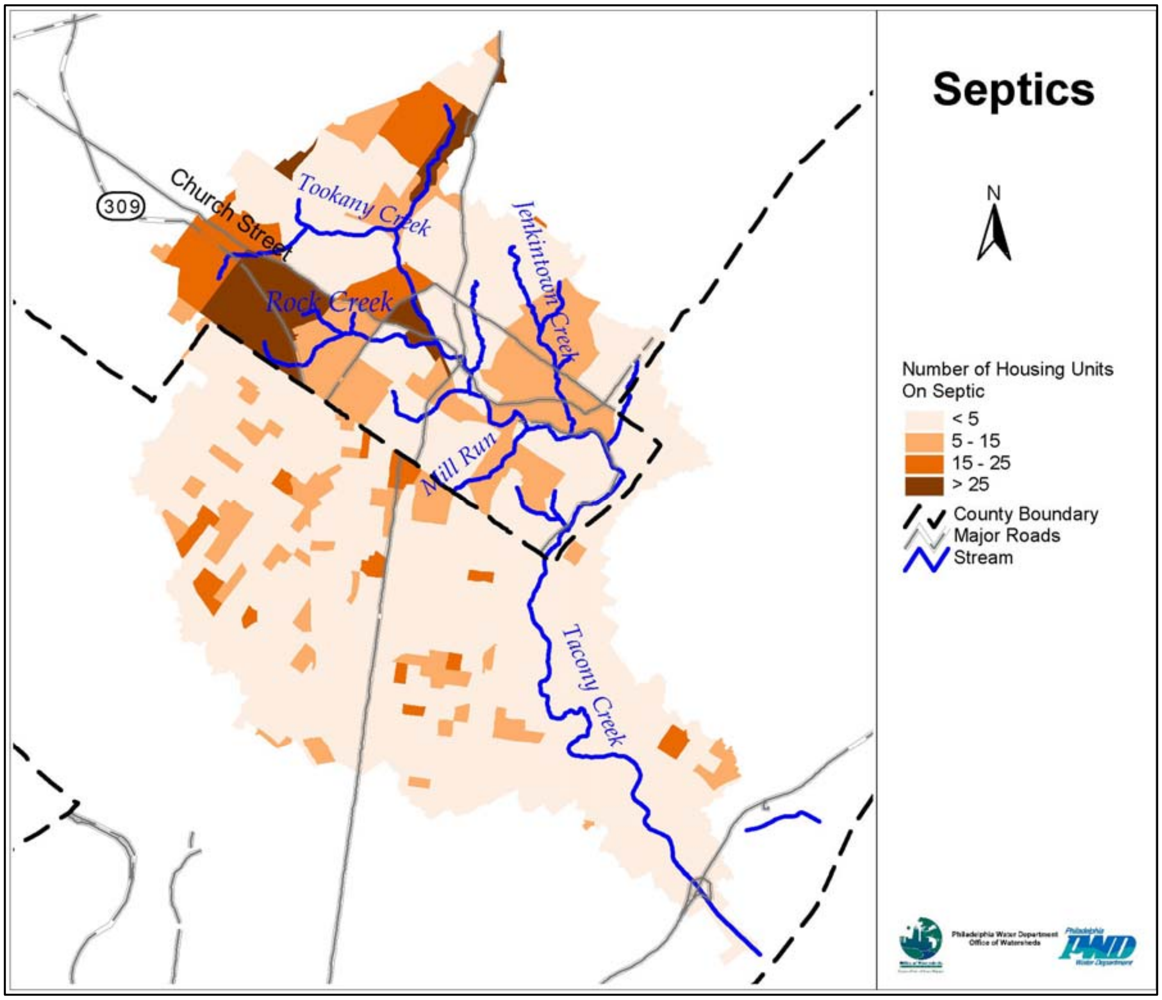


Figure 4.31 Septic Housing Units in the Tookany/Tacony-Frankford Watershed

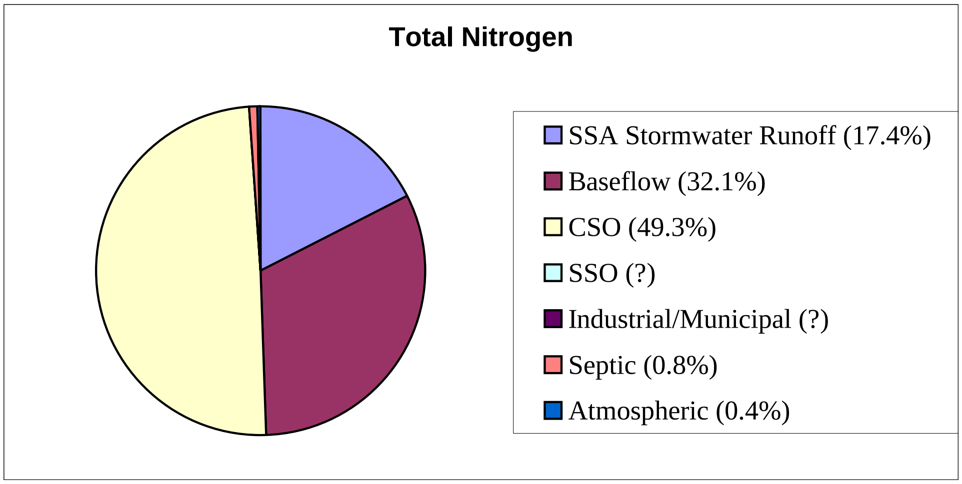


Figure 4.32 Estimated Nitrogen Inputs

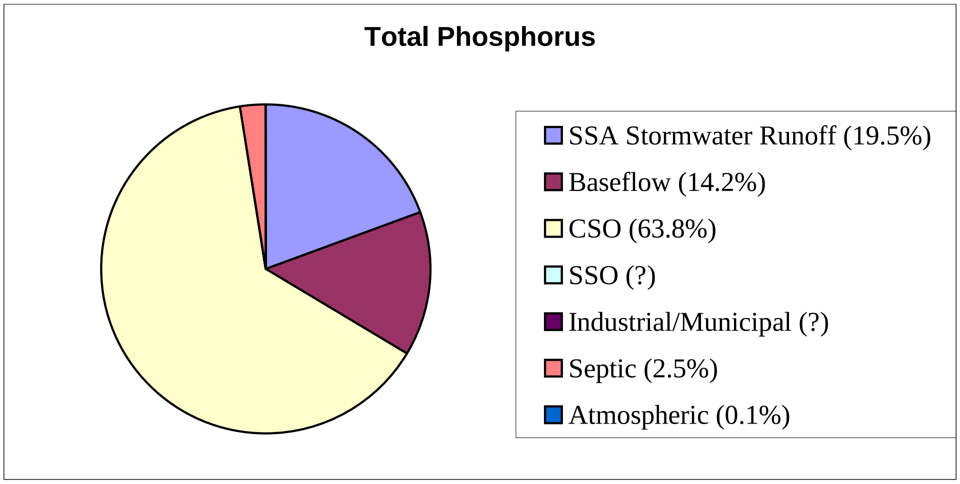


Figure 4.33 Estimated Phosphorus Inputs

4.5 Stream Corridor

The next three indicators of watershed health address environmental features of the lands immediately surrounding the waterway.

4.5.1 Indicator 12: Riparian Corridor

The riparian areas buffering streams, rivers, lakes, and other water bodies are especially sensitive watershed zones. In their naturally vegetated and undisturbed state, floodplains and riparian areas provide stormwater management and flood control functions, providing both water quantity and water quality benefits.

This indicator measures:

- **Miles of stream with a minimum buffer of 50 feet and 50 percent canopy cover**

Figure 4.34 Riparian Corridor in Jenkintown

<u>Where We Were</u>:
There is no historical data available for this indicator. A trend will be established the next time this area is reassessed.

<u>Where We Are</u>:
In the Tacony Creek Park, riparian zones no longer function as they should due to a loss of native community assemblages, which has had a deleterious effect on the riparian zone's ability to efficiently sequester pollutants and stormwater runoff. Japanese knotweed, an exotic plant species, has invaded the banks of the creek and contributes to the vulnerability of the banks to erosion during storms. There are currently volunteer efforts underway to eradicate this species from riparian zones, but it still persists. The riparian areas along the creeks in the Fairmount Park System are superior in quality compared to most of the areas in the watershed, which have almost completely lost their riparian buffers.

Buffers along stream corridors can be an important factor in enhancing stream habitat and preventing erosion. In 2002, the Heritage Conservancy was funded to develop a rapid assessment method to identify and map sections of stream lacking riparian forest buffers. The conservancy assessed watersheds in southeastern Pennsylvania and mapped waterways lacking riparian forest buffers. Interpretation of 1" = 200' black-and-white high altitude aerial photographs and videotape from helicopter flyovers were used to determine the presence or absence of a forested buffer for 975 miles of stream. For this analysis, a stream bank was classified as having a forested buffer if it was determined to have a 50 foot wide buffer of trees and 50 percent canopy cover. Each stream bank was analyzed independently. Table 4.14 shows that there are about 8½ miles of stream within the watershed that are lacking forested riparian buffers on one or both banks, which amounts to about one-third of the stream miles assessed.

Table 4.14 Lack of Riparian Forested Buffer

Riparian Buffer	Length (Stream Miles)
Buffer Lacking on One Bank	5.4
Buffer Lacking on Both Banks	3.1
Total Miles Lacking Buffer	8.5
Total Miles Assessed	27.3
% of stream lacking buffer	31.1%

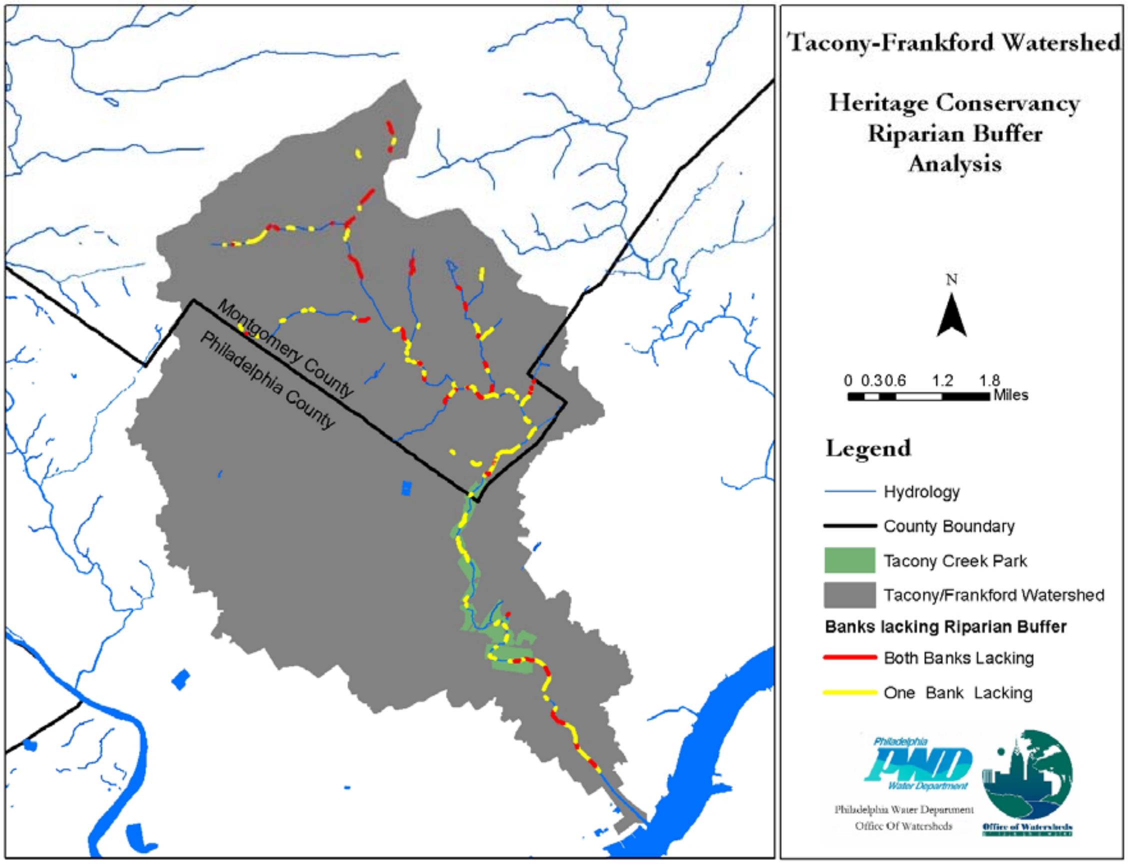


Figure 4.35 Heritage Conservancy's Forested Riparian Buffer Analysis (2002)

4.5.2 Indicator 13: Wetlands and Riparian Woodlands

Wetlands and riparian woodlands are important natural filters for pollutants in stormwater. They increase diversity of vegetation while providing feeding and nesting habitat for birds and animals. They are important in preventing slope erosion and mitigating flood peaks by slowing runoff, and they promote natural infiltration of rainfall and groundwater recharge.

The most significant functions that wetlands perform are:

- Wildlife habitat
- Fish habitat
- Water quality improvement (nutrient and toxicant reduction)
- Hydrologic (flood flow) modification
- Groundwater recharge

The location and size of a wetland influence the functions it can perform. For example, the geographic location may determine its habitat functions, and the location of a wetland within a watershed can influence its hydrologic and water-quality functions. Many factors determine how well a wetland will perform these functions – such as the size and type of wetland, the quantity and quality of water entering the wetland, and the disturbances or alteration within the wetland or in the surrounding ecosystem.

Wetlands of the Tookany/Tacony-Frankford Watershed were evaluated for the first four of the functions listed above, and were further studied to understand the degree to which they have experienced disturbance and their potential for enhancement and improvement, where they have experienced disturbance. Figure 4.36 shows a typical wetland in the watershed.

This indicator measures:

- **Approximate area of wetland in the watershed**
- **Area of riparian buffer along waterways**
- **The quality of (and disturbance to) the wetlands**
- **The ability of the wetland and woodlands to improve water quality**

Figure 4.36 Example of a Wetland Area

Where We Were:

There is little data available about the historical presence of wetlands and riparian woodlands in the watershed. The Fairmount Park Commission (FPC) compiled some information regarding historic wetlands in their 1999 Natural Lands Restoration Master Plan. FPC reported that Philadelphia had an abundance of wetlands along the Delaware and Schuylkill Rivers in pre-Colonial times. These included a variety of inter-tidal channels, marshes and mudflats, and gravel bars. Much of the south and southwestern parts of the city, including what is now FDR Park, were a mix of tidal channels and marshes. Non-tidal wetlands were present inland from the tidal marshes and along streams (FPC, 1999).

Urban and suburban development has resulted in the piping of historic streams, destruction of wetlands, and deforestation and modification of historic floodplains. Stormwater is piped directly to waterways, and no longer flows overland through vegetation, wetlands, and woodlands. Also, because stormwater runoff frequently flows over impervious surfaces and is then piped to the streams, the flow and volume of runoff is intensified. Stream channels of the watershed exhibit many effects of urbanization: degradation of the stream channel (including overwidening), bank erosion, loss of sinuosity, loss of the floodplain-stream connection, and loss/degradation of aquatic habitat. Because most stormwater is piped directly to the channel of the waterways of the Tookany/Tacony-Frankford Watershed and does not flow over land, there is no longer a source of water input to maintain many of the wetlands that once existed.

Extensive development in the Tookany/Tacony-Frankford Watershed has resulted in conversion of natural riparian lands to residential, institutional, and active recreational land use. Primary land uses in the watershed, for the most part, preclude the existence of natural vegetated areas due to the high density of development. For example, 33% of the residential land uses are row or multi-family homes, which typically have relatively little vegetated open area that might control, improve, and recharge stormwater runoff.

In summary, the number and area of wetlands and riparian woodlands in the Tookany/Tacony-Frankford Watershed have declined significantly over time as a result of development close to the stream edges, changes to the floodplain from concentrated stormwater flows, and routing of nearly all stormwater flow into pipes.

Where We Are:

The Tookany/Tacony-Frankford Watershed is 21,000 acres in size, or about 31 square miles. The watershed is nearly totally developed: 87% (18,200 acres) of the watershed now hosts residences, businesses, industries, and utilities.

Land use data indicates that only 13% of the Tookany/Tacony-Frankford Watershed land area is non-urbanized (e.g., agriculture, cemetery, recreation, woodland), and only 5% of the watershed land area remains as woodland (1,060 acres). The undeveloped riparian corridor, which comprises the undeveloped land directly adjacent to the Tookany/Tacony-Frankford waterways, totals about 3.3% (685 acres) of the watershed land area. The undeveloped riparian corridor is illustrated in Figure 4.37. About one-third of the total woodland is located within the Tookany/Tacony-Frankford undeveloped riparian corridor. (Also see Indicator 1: Land Use and Impervious Cover.)

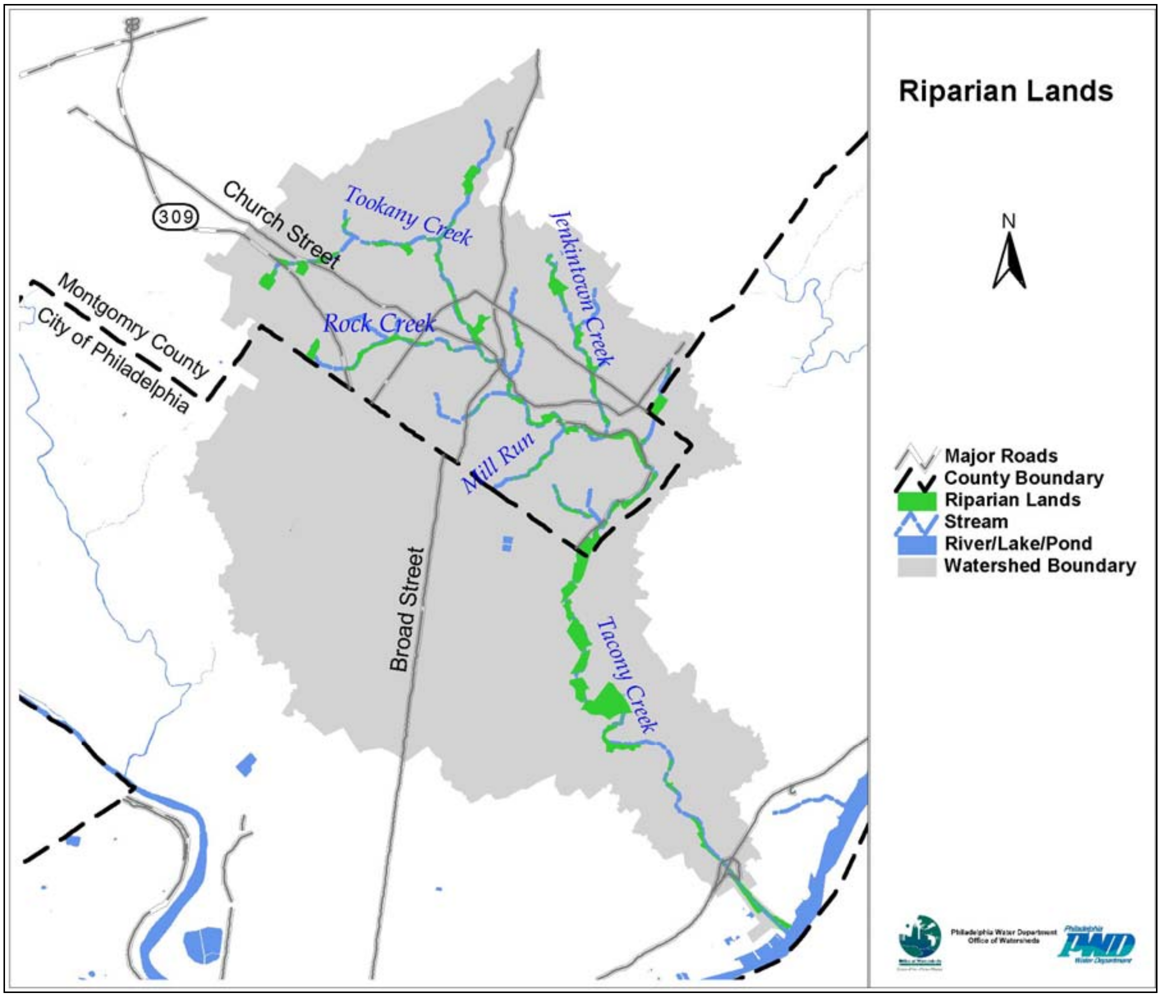


Figure 4.37 Undeveloped Riparian Lands in the Tookany/Tacony-Frankford Watershed

Forested areas in the Tookany/Tacony-Frankford Watershed are generally more contiguous within the Fairmount Park lands, where several large areas of woodland are found. In upstream areas, where there is greater urban encroachment in the riparian corridor, wooded areas are more fragmented, creating habitat for exotic, aggressive tree species. Regrowth of understory and herbaceous layers is usually limited once these non-indigenous species become established. Exotic control, replanting, and trash removal are components of riparian woodlands restoration.

A field study conducted by the Philadelphia Water Department found only small, scattered wetlands remaining along the riparian corridor (see Figure 4.38 and Tables 4.15 and 4.16). The estimated area of these remnants is roughly 15 acres (based on field survey, not jurisdictional mapping), which means wetlands are present in only 2.2% of the undeveloped riparian lands. Wetland communities of native vegetation are also scarce along the riparian corridor.

If runoff from the developed parts of the watershed could be settled and filtered by flowing through a restored riparian corridor, a substantial portion of the total solids in the stormwater could be removed before it reached the creek. However, most stormwater in the watershed is piped directly to the stream channel, bypassing the wetlands and riparian woodlands that could improve water quality through detention, trapping sediment, and recharge. Much of the woodland along the creek and its tributaries is now largely public open space (or in some cases, privately owned residential yards). Return of these lands to their original stormwater functions requires a public discussion and decision-making process for resolving competing uses for riparian lands (which currently include active and passive recreation).

As noted above, the total area of wetland in the watershed is small considering the 29 miles of waterways. Field investigation found only about 24 wetlands, totaling approximately 15 acres, along the creek and its tributaries. The wetlands range in size from 0.01 acre to approximately 2.5 acres. Most are very small: 13 of the 24 wetlands surveyed were less than one-quarter acre in size, and all but two of those were in the upstream Montgomery County reaches.

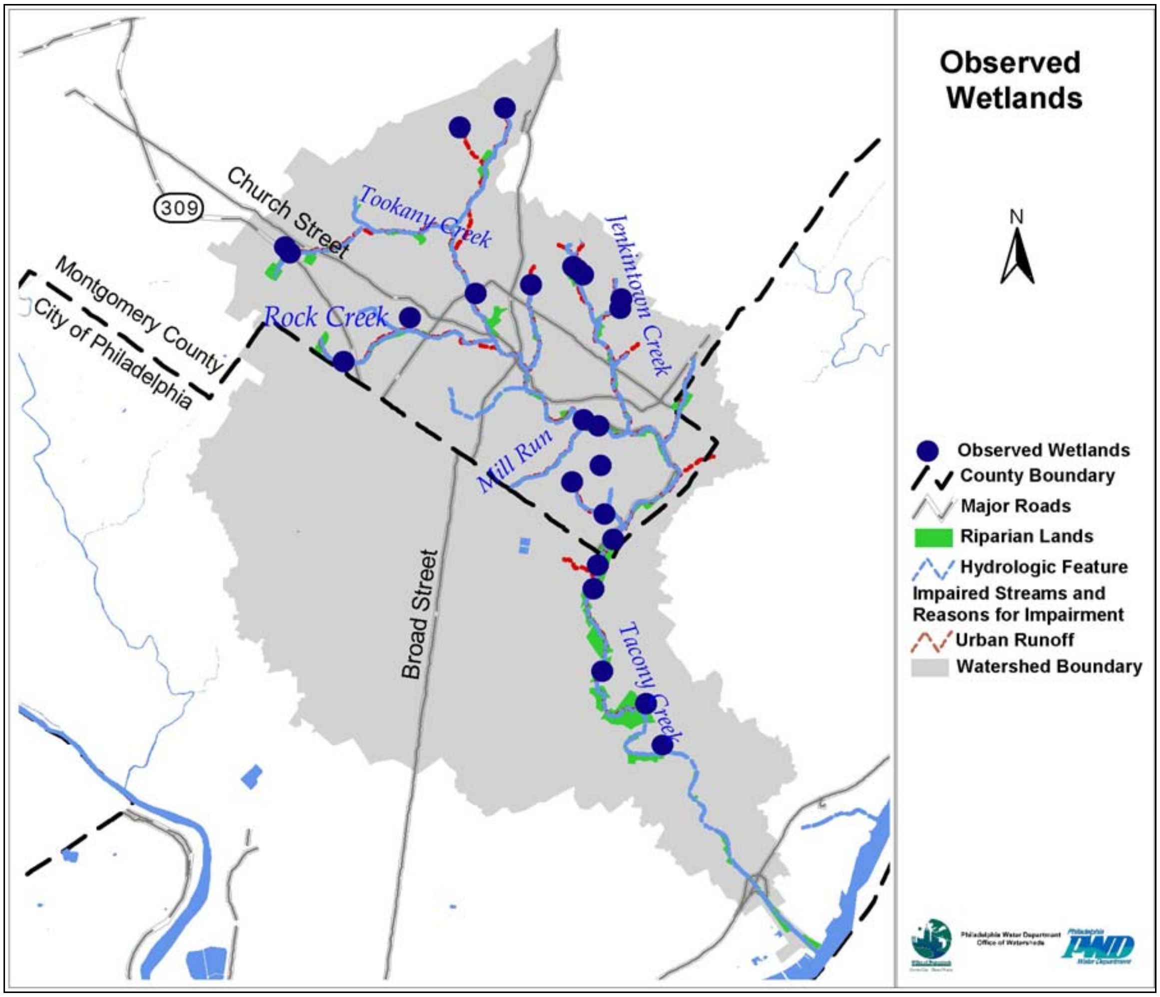


Figure 4.38 PWD Field Surveyed Wetlands (2002 – 2003)

Table 4.15 Estimated Wetland Area by County

County	Total Area (ac)	Woodlands (% of total)	Wetlands (% of total)
Montgomery	8,915	9%	0.20%
Philadelphia	12,178	2%	0.05%

Table 4.16 Estimated Wetland Area in the Tookany/Tacony-Frankford Watershed Area

Wetland	Location	County	Approximate Area (ac)
TF01-00612-W	Oak Lane and Brookfield Road	Philadelphia	0.25
TF-06190-W(E)	Crescentville Road and Godfrey Ave.	Philadelphia	1.4
TF-05911-W(E)	Adams Ave. at Tacony Creek	Philadelphia	0.01
TF-04933 -W(E)	Tabor Ave. at Tacony Creek	Philadelphia	2.5
TF-03968-W(E)	Friends Hospital and Oaklin Cemetery	Philadelphia	2.5
TF-02947-W(E)	Juniata Golf Course, Cayuga Street	Philadelphia	0.5
TF-06509-W	Tookany Creek Parkway, church parking lot	Montgomery	0.01
TF01-00295-W(E)	Hilldale Rd. & Boncouer Rd.	Montgomery	0.02
TF01-0805-W(E)	Parkview Rd. & Front St.	Montgomery	0.03
TF-14056-W(E)	Waverly Rd. at Holy Sepulchre Cemetery	Montgomery	1.7
TF-08853-W	Ashbourne Country Club	Montgomery	0.03
TF-09016-W(E)	Tacony Creek Parkway	Montgomery	0.4
TF-11331-W(E)	Bryer Estates, Washington Ln. and Township Line Rd.	Montgomery	0.8
TF03-001050-W(E)	Abington Country Club, Meetinghouse Rd.	Montgomery	0.4
TFR-00140-W(E)	Curtis Arboretum, Church Rd	Montgomery	0.02
TFJ-01855-W(E)	Alverthorpe Park	Montgomery	0.15
TFJ-01776-W(E)	Alverthorpe Park	Montgomery	0.06
TFJ-01737-W(E)	Alverthorpe Park	Montgomery	0.07
TF04-01071-W(E)	Abington High School	Montgomery	1
TF04-01561-W(E)	Abington Junior High School	Montgomery	0.2
TFEJ-00429-W(E)	Manor Junior College	Montgomery	2.4
TFEJ-00363-W	McKinley Elementary School	Montgomery	0.5
TF-14014-W(E)	Holy Sepulchre Cemetery	Montgomery	0.1
TFR-01887-W(E)	Cedarbrook Country Club	Montgomery	0.2
TOTAL # Wetlands	**24**		
TOTAL WETLAND ACREAGE	**15.25**		

Functional Assessment of Wetlands

The Tookany/Tacony-Frankford Watershed wetlands were evaluated for their value as wildlife and fish habitat, potential for water quality improvement (nutrient and toxicant reduction), and potential for hydrologic (flood flow) modification. Nearly all wetlands in the watershed exhibit impaired functions that indicate extensive disturbance and deterioration.

Results of the wetland functional field assessments (Table 4.17) indicate that the remaining wetlands in the TTF Watershed are degraded, and do not serve as high quality habitats or perform many of their water quality improvement or ecological functions. If stormwater was redirected to the small areas of remaining wetlands, rather than being rerouted directly to the Tookany/Tacony-Frankford Creek, water quality improvement would be minimal given the current compromised conditions of most of the wetlands. The water quality improvement potential for surveyed wetlands is mapped in Figure 4.39, and illustrates the extensively compromised ability of wetlands to perform their natural water quality improvement functions.

Table 4.17 Wetland Functional Assessment Results (based on 24 wetland locations)

Function	Number of Wetlands with Stated Condition
Wildlife Habitat	
Diverse Habitat	10
Moderate	14
Fish Habitat	
Intact Habitat	6
Degraded	12
Lost / Not Present	6
Water Quality Improvement	
Intact Function	3
Degraded	21
Hydrologic Connection to Stream	
Intact Connection	16
Degraded	7
Lost / Not Present	1

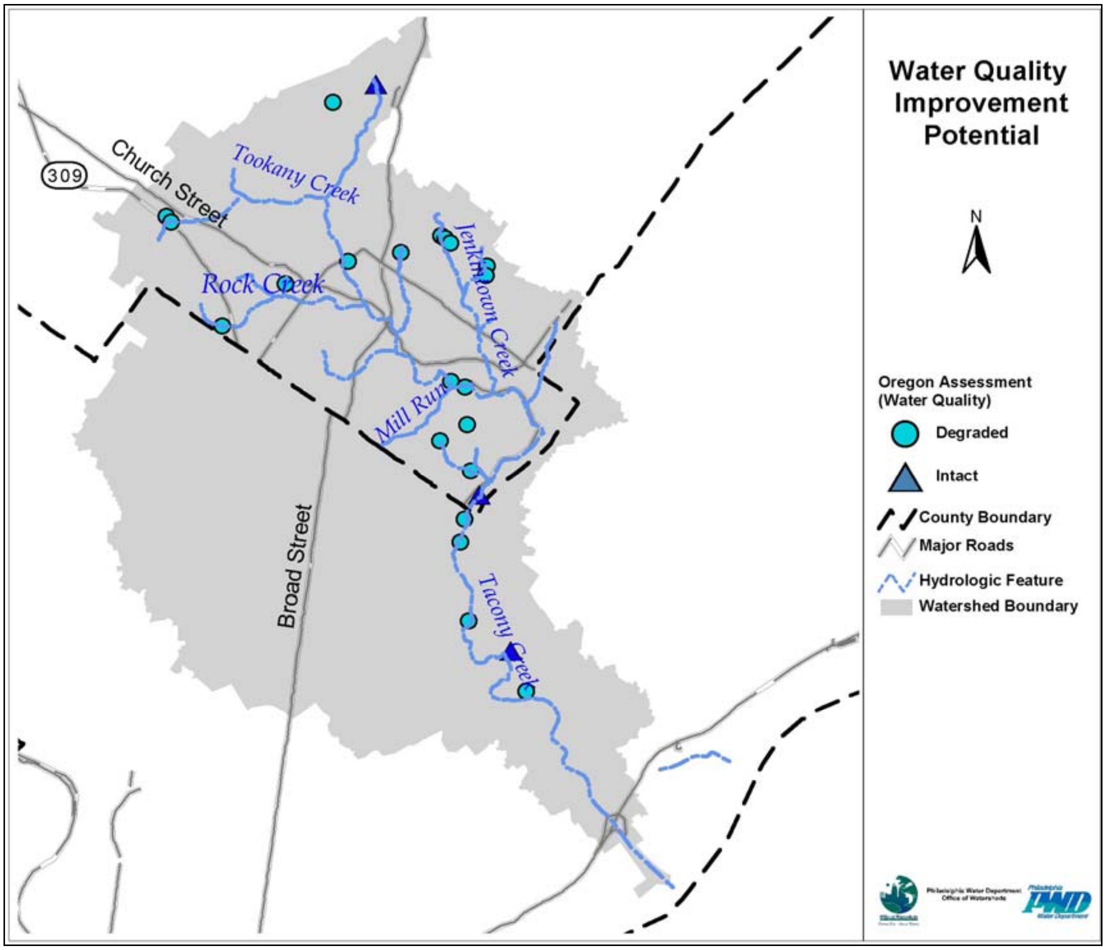


Figure 4.39 Results of Tookany/Tacony-Frankford Creek Functional Assessments for the Water Quality Improvement Function (2002 – 2003)

Human Disturbance of Wetlands

The wetlands that exist along the riparian corridor have been extensively disturbed by urbanization and the related hydrologic alterations to natural overland stormwater flows. A human disturbance score was calculated for each wetland based on several factors: disturbance to the immediate and intermediate wetland buffer zone; habitat alteration (specifically to soils and vegetation); hydrologic alteration (draining and disconnection from the surface drainage network); and chemical pollution from runoff, dumping, and spills.

Table 4.18 Wetland Human Disturbance Gradient Results

Human Disturbance Gradient Rank	Number of Wetlands
Moderately Low Disturbance	10
Moderately High Disturbance	12
Highly Disturbed	2

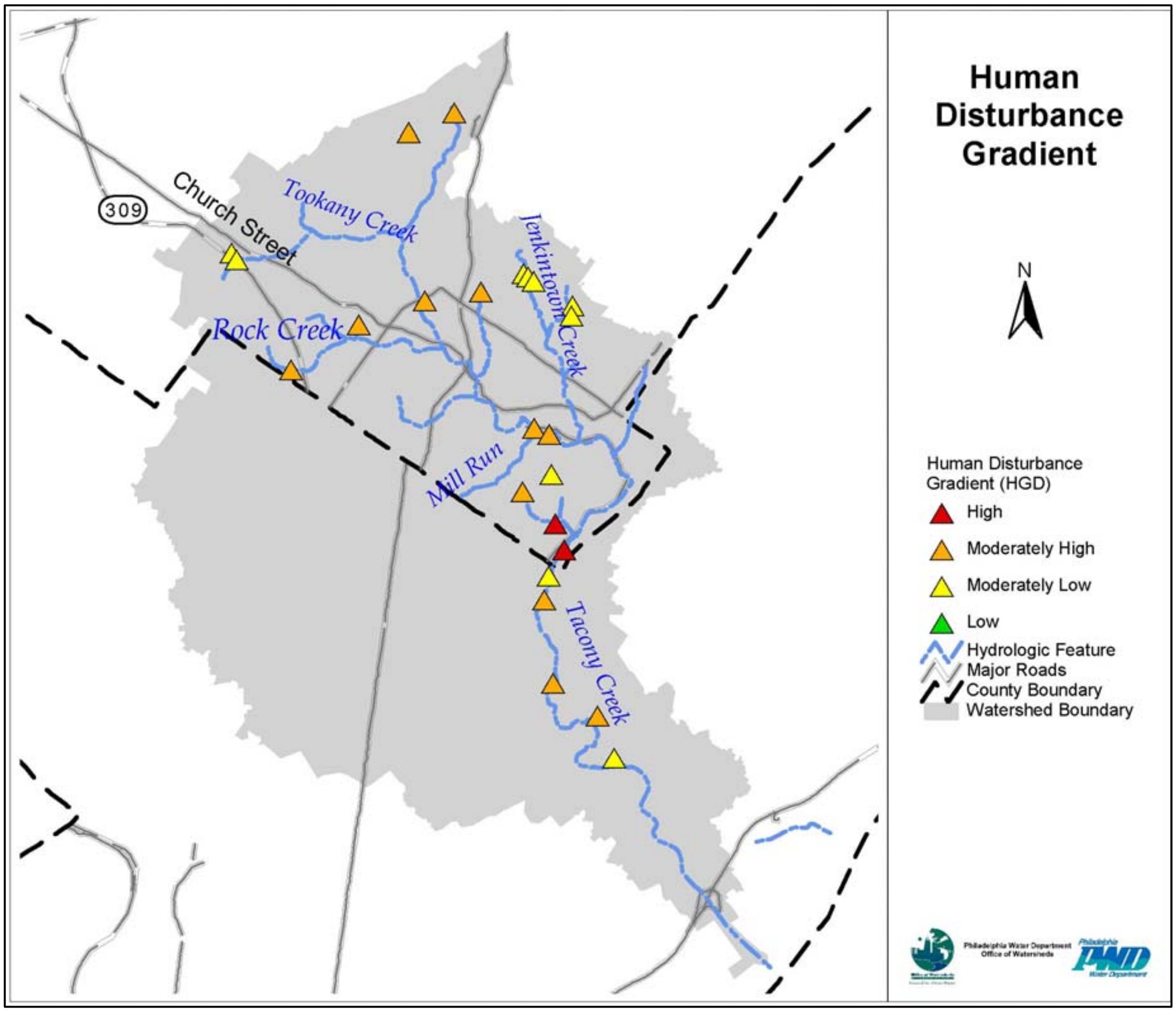


Figure 4.40 Human Disturbance Gradient Scores for Wetland Assessments (2002 – 2003)

4.5.3 Indicator 14: Wildlife

Wildlife includes birds, amphibians, and other animals that make their home in the watershed. Quality and diversity of wildlife habitats are also indicators of watershed health. Many species have specific habitat requirements. Their presence or absence indicates the health of the habitats. For example, healthy, naturally reproducing amphibian communities indicate the presence of appropriate habitats.

This indicator measures:

- **Species inventory**
- **Identification of any threatened and endangered species**

Figure 4.41 Photo of a Baltimore Oriole in Tacony Creek Park

<u>Where We Were</u>:
There is not much information on birds, reptiles, amphibians or mollusk species in Tacony Creek Park before the census was completed in 1998.

<u>Where We Are</u>:
In the Montgomery County section of the watershed, although no formal survey has been completed, there have been reported sightings of northern water snakes, garter snakes, box turtles, and several species of salamanders and frogs.

The Tookany section of the watershed has abundant geese and deer populations. These two animals can act as pests when their populations go unchecked.

In the Philadelphia portion of the watershed, a census was completed in 1998 in Tacony Creek Park (Figure 4.42). It was determined that the Park lacked healthy bird habitat. There were only 39 species of birds, 36 of which are probable breeders in Tacony Creek Park. 20 of these 39 species are indicator species, and only several individuals of each indicator species were found (Table 4.19).

The 1998 inventory found mollusks at six sites, two native Holarctic species, one native North American species and two introduced species. When looking at reptiles and amphibians, bullfrogs and green frogs are common along the creek. Isolated occurrences of two-lined salamanders, a northern red salamander, and northern brown snakes were found. No turtles were documented, though remains of a wood turtle were found. It is believed that a longer study would reveal more reptiles and amphibian species in this Park.

There are no known Pennsylvania Natural Heritage Program (PNHP) – formerly Pennsylvania Natural Diversity Inventory (PNDI) - species within the watershed.

Table 4.19 Park-Specific List of Individual Bird Indicator Species Observed in 1998 in Tacony Creek Park

Species ID	#	Species ID	#
Acadian Flycatcher	1	Eastern Towhee	2
Baltimore Oriole	12	Eastern Woodpewee	2
Barn Swallow	3	Great Crested Flycatcher	2
Belted Kingfisher	2	Great Egret	1
Black-crowned Night-heron	1	House Wren	3
Blue-gray Gnatcatcher	1	Orchard Oriole	1
Carolina Wren	3	Red-eyed Vireo	7
Common Yellowthroat	1	Redwinged Blackbird	1
Eastern Kingbird	4	Warbling Vireo	4
Eastern Phoebe	1	Wood Thrush	6
Total # of Species			**20**
Total # of Birds			**78**

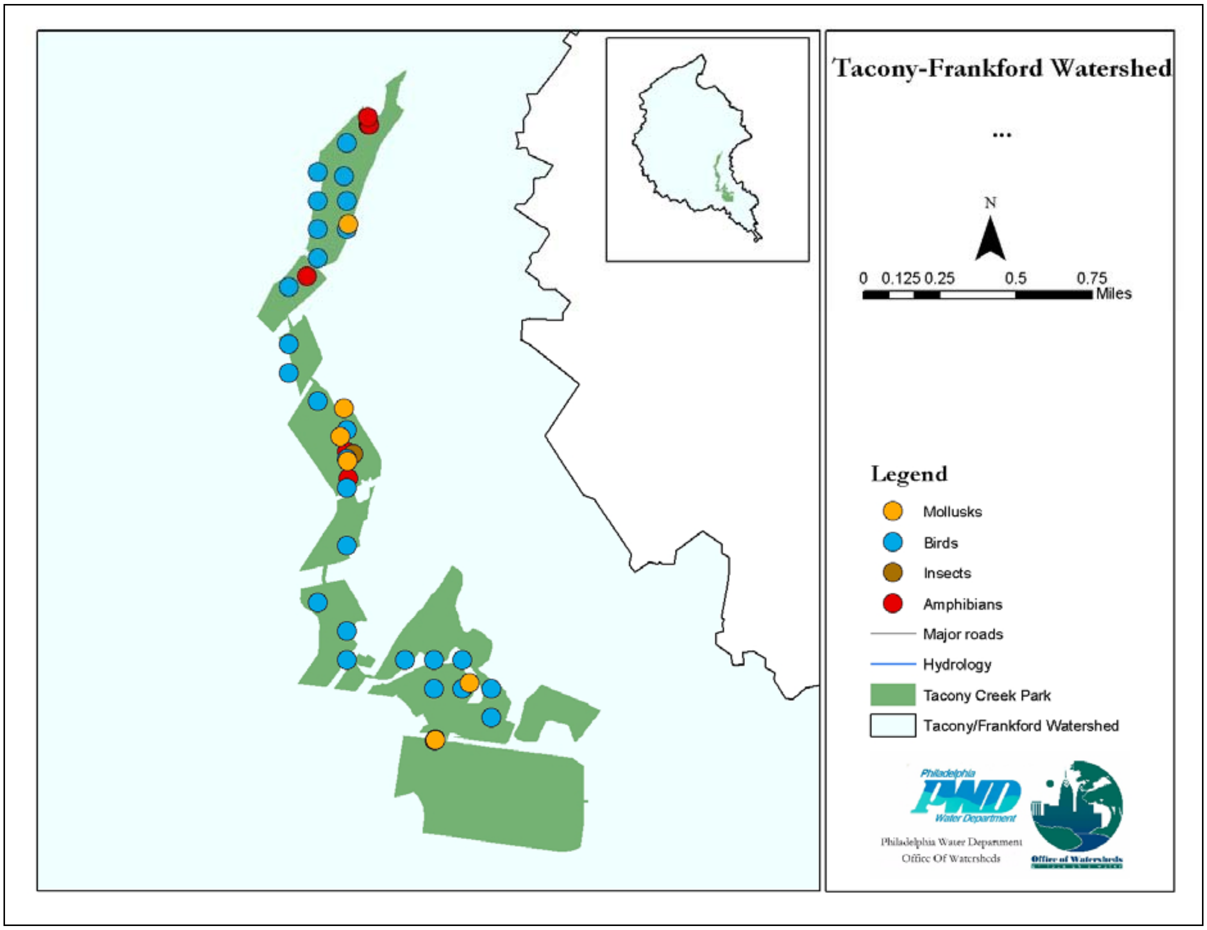


Figure 4.42 Species Locations Found During Tacony Creek Park Survey

4.6 Quality of Life

This group of watershed indicators relate to factors that affect the daily lives of people who live, work, or dream within the Tookany/Tacony-Frankford community.

4.6.1 Indicator 15: Flooding

Impervious cover and improperly sized or maintained drainage systems in urban watersheds occasionally lead to flooding. Act 167, the Stormwater Management Act of 1978, requires each county in Pennsylvania to prepare and adopt a stormwater management plan for each designated watershed in the county. An official plan provides a mechanism for municipalities to plan for and manage increased runoff associated with possible future development and land use change.

This indicator measures:

- **Areas susceptible to flooding along Tookany/Tacony-Frankford Creek**

Where We Were:
Frequent, serious flooding has not been a major concern in the Tookany/Tacony-Frankford watershed for many years since the stream was channelized. Floodplain mapping studies were conducted by FEMA to establish flood insurance rates for Montgomery County and for Philadelphia County in 1996. These studies include anecdotal evidence of major flooding during tropical storms.

Where We Are:
FEMA studies include stream cross-sections at major road crossings. Figure 4.43 identifies several road crossings where bridge decks are in the 100-year floodplain. As an example, several pictures were taken from the storm on August 1, 2004. The locations of the photos are along the Tacony Creek near Adams Avenue. Figures 4.44 through 4.46 indicate that extensive flooding occurred near the bridge, almost overtopping the bridge. Considerable debris was trapped at the culverts, shown in the photos after the stormflows had subsided.

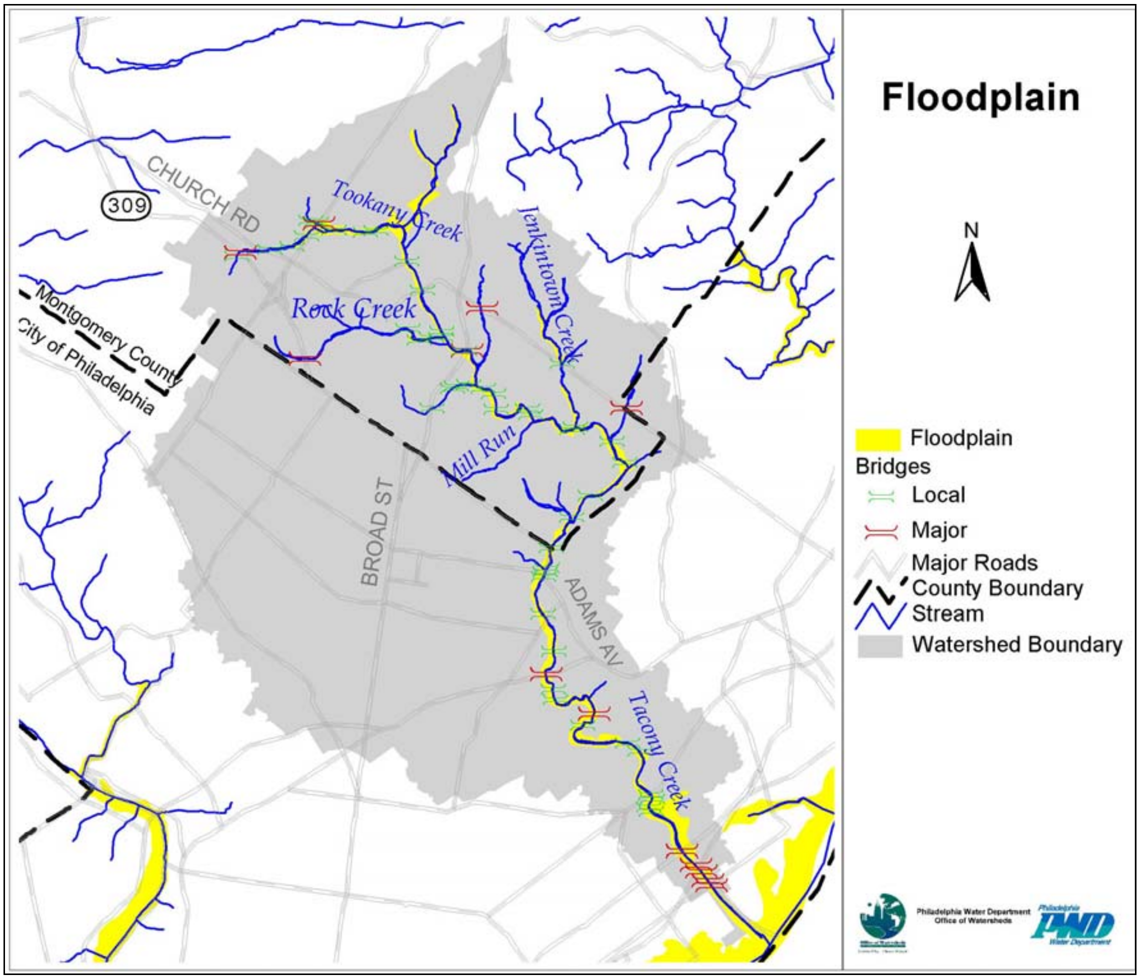


Figure 4.43 Estimated Flood-Prone Areas in the Tookany/Tacony-Frankford Watershed

Figure 4.44 Adams Avenue during August 1, 2004 Storm

Figure 4.45 Tacony Creek near the County Border during August 1, 2004 Storm

Figure 4.46 Adams Avenue after August 1, 2004 Storm

4.6.2 Indicator 16: Public Understanding and Community Stewardship

Because a connection to the natural world and its waterways is less apparent in some communities of the Tookany/Tacony-Frankford Watershed, the notion of environmental stewardship does not always top the list of daily priorities for many residents. Stewardship, therefore, must be built around the needs of the community as users of the watershed, as well as by making visible the critical ways in which the health of the watershed is integral to basic quality of life issues. Once this connection has been established, members of the community can be recruited to take action in protecting their watershed. Within this context, citizens need to 1) become aware of the meaning of the term "watershed" and understand the watershed in which they live, 2) become informed about the actions they can take to improve watershed health and 3) move from understanding into action and stewardship. Citizens must also remain informed of the progress made as implementation occurs.

Stakeholders are those who care with their minds and hearts because they already understand their vital connection to the environmental health of their community. The watershed stakeholders include state and federal regulators, those whose jobs empower them to guard the quality of our rivers and streams. The stakeholders include all of the municipalities, separate entities on paper yet bound together by nature including: neighborhood groups, religious groups, schools, and all groups who define themselves as environmental advocates.

This indicator measures:

- **Number of responses to surveys**
- **Number of newspaper stories and letters to the editor about watershed-related issues**
- **Changes in membership in the Tookany/Tacony-Frankford Watershed Partnership**
- **Participation in local environmental stewardship projects**

<u>Where We Were</u>:

A historical baseline has not been established for this indicator. Progress will be assessed next time this plan is updated.

<u>Where We Are</u>:

<u>Surveys</u>

As a part of the Rivers Conservation Planning Program, surveys of residents' understanding of their watershed were conducted by PWD and the Pennsylvania Environmental Council (PEC) for the Philadelphia portion of the watershed and by Heritage Conservancy for the Montgomery County portion of the watershed. The Philadelphia County survey was disseminated in 2002 and can be viewed in Appendix B (Survey 1). The Montgomery County survey was distributed in 2001 and can be viewed in Appendix B (Survey 2). It is evident from the results of both sets of surveys that there is an interest and desire on behalf of the residents to better manage the Tookany/Tacony-Frankford Watershed and to revitalize its creeks. It is also apparent that watershed education and outreach for the residents in both counties are necessary as reflected by a number of the answers in the surveys, in addition to the low response rate on both the Philadelphia County and Montgomery County surveys. A summary of the results of the Tookany survey (Montgomery) is listed at the end of this section. The results of the Tacony-Frankford (Philadelphia) survey and an analysis of the survey results follow (Figure 4.48).

The Tacony-Frankford survey was created with several goals in mind: 1) to provide baseline information on resident knowledge of watershed issues, 2) to understand the residents' hopes and concerns for the Tacony-Frankford Creek, and 3) to educate these residents about the impacts of their actions on the creek. The timeframe for the Tacony-Frankford survey to be completed and returned was approximately seven months. The distribution of the survey was broad, with roughly 800 surveys placed within 16 libraries, 600 surveys distributed through community contacts, 150 distributed at community presentations, and an additional 275 sent to high school teachers at 11 Philadelphia high schools, for a rough total of 1,875 surveys disseminated throughout the watershed. Although there was a low response rate with only 71 completed surveys returned, the surveys did cover a broad area of the watershed. Of the returned surveys, 18 zip codes spanning 31 neighborhoods were represented (Figure 4.47).

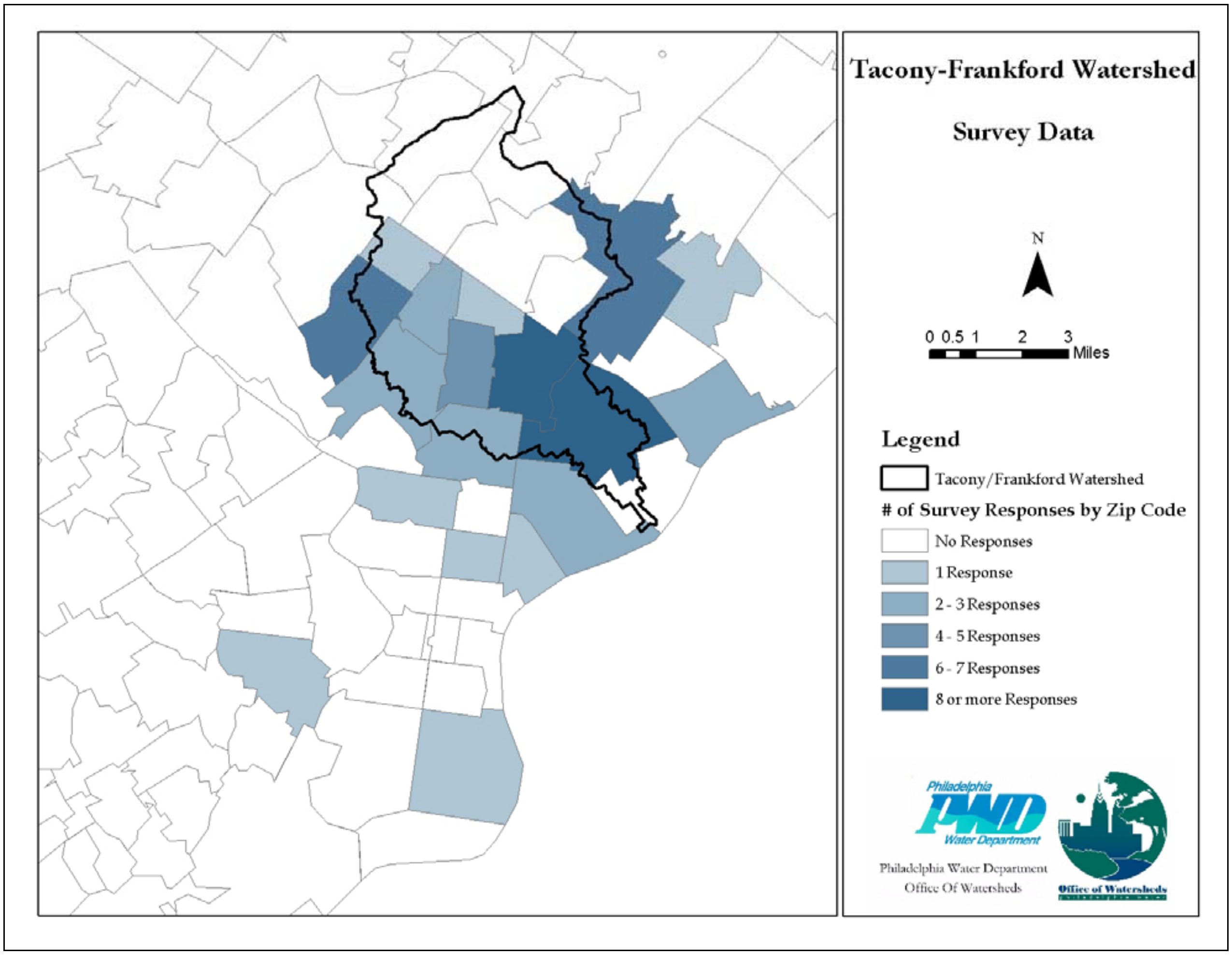


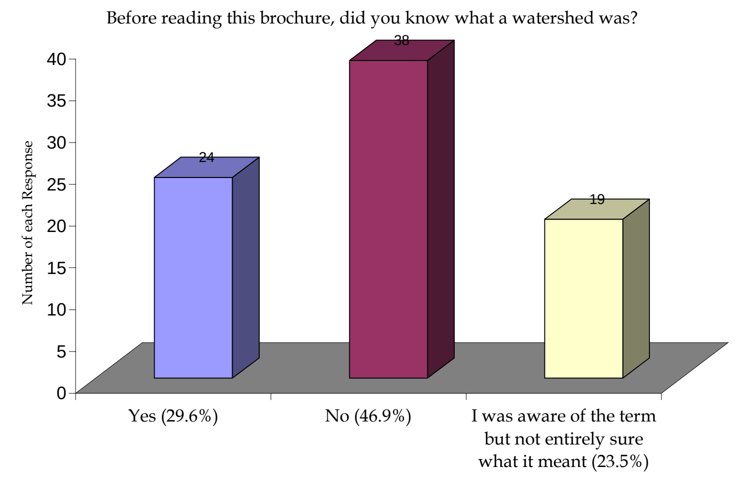
Figure 4.47 Neighborhoods of Respondents to Tacony-Frankford River Conservation Plan Watershed Survey

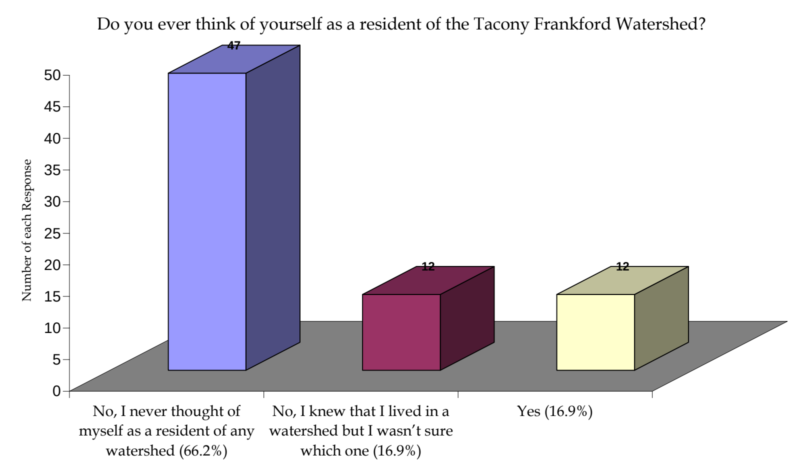
Results indicate that the majority of residents responding to the Tacony-Frankford survey did not have prior knowledge of the definition of the term "watershed" before reading the brochure. Additionally, only 30% of respondents (21 total responses) thought of themselves as residents of the Tacony-Frankford Watershed.

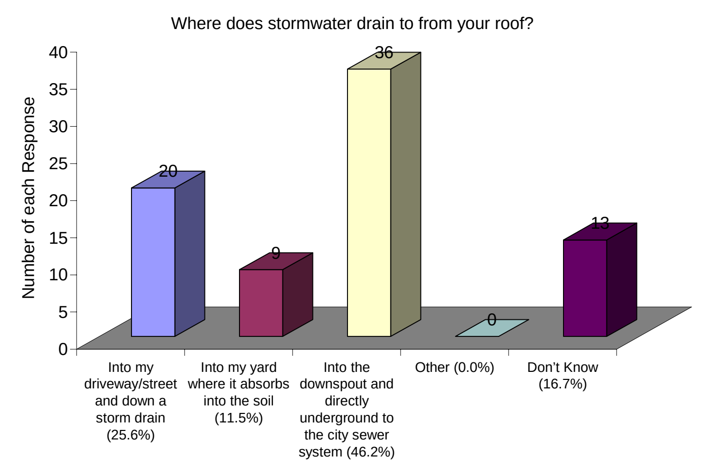
Sixty four percent (64%) of the Tacony-Frankford survey responses (43 respondents) indicate that residents rarely, if ever, spend recreational time along the creek. Also, more than half of the respondents perceive the water quality of the Tacony-Frankford Creek as poor. The surveyed residents have identified trash and litter in the streams as the most significant source of pollution to the watershed. Sedimentation was ranked as the second most significant source of pollution and illegal dumping ranked third. When asked where money should be directed for the purpose of enhancing the greater community, the answer most frequently rated as most important was the "cleaning of the water in the creek." The removal of trash from the creek area ranked second, and increased safety and security in parks ranked third.

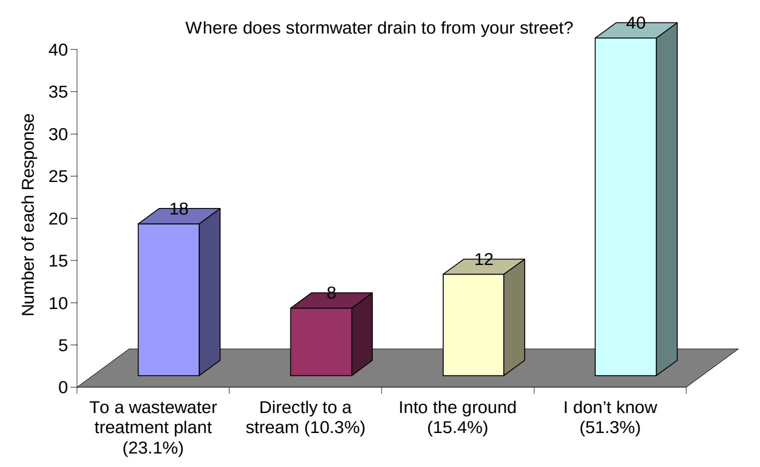
Once the Tacony-Frankford survey results were broken down into two age groups, respondents 18 years and over, and respondents under the age of 18, additional interesting results emerged. Of the 48 individuals surveyed that were 18 years and over, 35 % responded that they knew what a watershed was, and 23% had at least heard of the term before. In contrast, only 6% of the 17 respondents in the category of "under the age of 18 years" knew what a watershed was, although 35% of them claimed to have at least heard the term before.

When asked about the amount of recreational time spent along the Tacony-Frankford Creek, of those under the age of 18, only 12% (2 of the respondents) claimed to spend any time at all along the creek, and then only a few times a year. It seems that residents in the "18 years and over" category have been more likely to make use of the areas along the creek, with 39% (19) of them having visited the area at least a few times a year. Of the 45 respondents who do spend time in the parks, 53% go there to walk, the most frequent recreational activity in the area.


Before reading this brochure, did you know what a watershed was?
Number of each Response
0
5
10
15
20
25
30
35
40
24
38
19
Yes (29.6%)
No (46.9%)
I was aware of the term but not entirely sure what it meant (23.5%)


Do you ever think of yourself as a resident of the Tacony Frankford Watershed?
Number of each Response
0
5
10
15
20
25
30
35
40
45
50
47
12
12
No, I never thought of myself as a resident of any watershed (66.2%)
No, I knew that I lived in a watershed but I wasn't sure which one (16.9%)
Yes (16.9%)


Where does stormwater drain to from your roof?
Number of each Response
0
5
10
15
20
25
30
35
40
20
9
36
0
13
Into my driveway/street and down a storm drain (25.6%)
Into my yard where it absorbs into the soil (11.5%)
Into the downspout and directly underground to the city sewer system (46.2%)
Other (0.0%)
Don't Know (16.7%)


Where does stormwater drain to from your street?
Number of each Response
0
5
10
15
20
25
30
35
40
18
8
12
40
To a wastewater treatment plant (23.1%)
Directly to a stream (10.3%)
Into the ground (15.4%)
I don't know (51.3%)

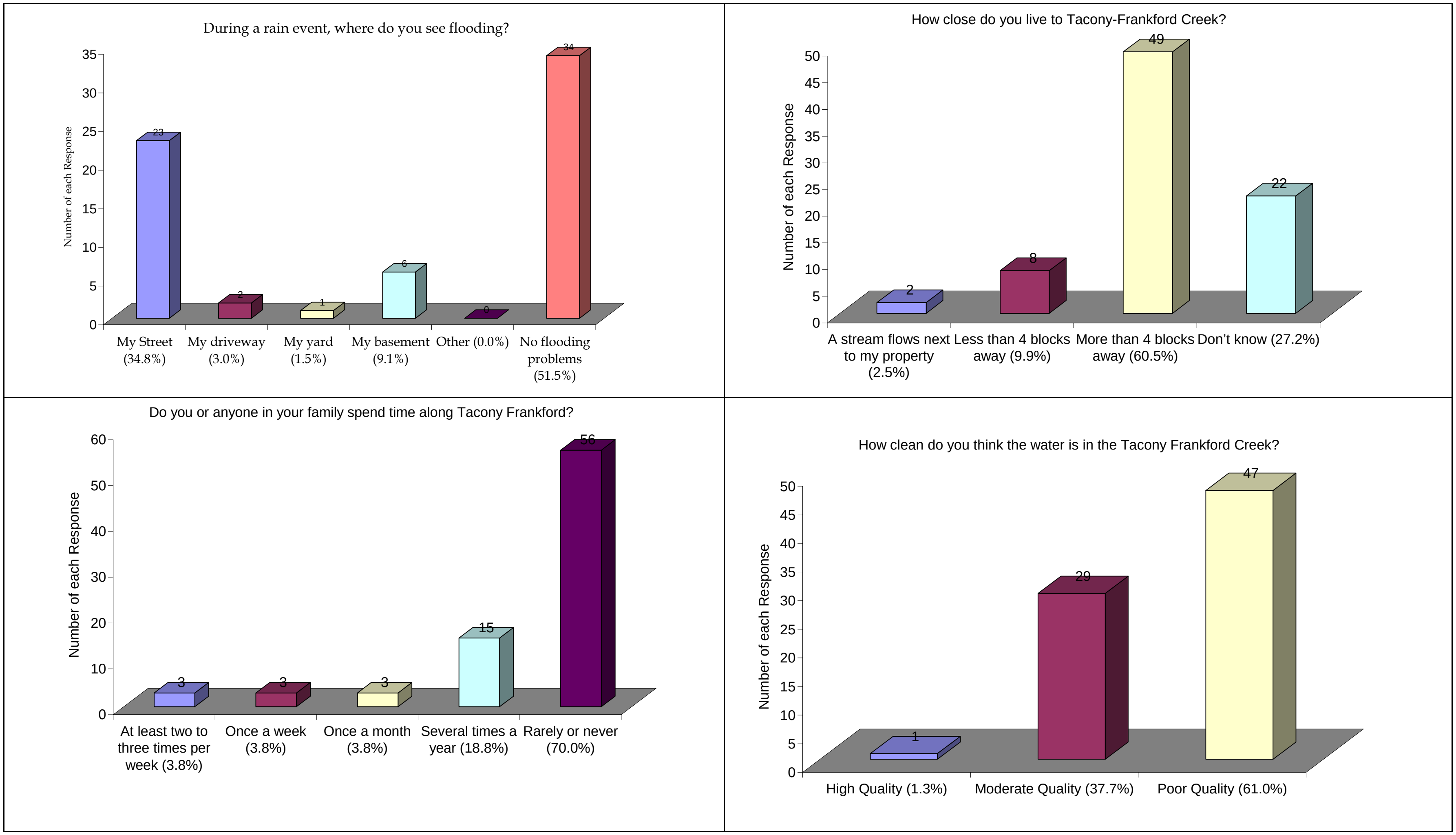


Figure 4.48 Tacony-Frankford Resident Survey Results

For the Tookany survey, 147 (15%) questionnaires were returned out of the 1,000 that were randomly disseminated to the four Montgomery County municipalities. Out of the 147 completed surveys, 101 were returned from Cheltenham County residents. Below is a summary of the Tookany survey results as listed in the "Tookany Creek Watershed Management Plan."

Tookany Creek Survey Results

- The majority (90%) think that the Tookany Creek is an important natural and scenic resource.
- A majority recommended preservation of undeveloped land, preservation of historic resources, preservation of scenic character, protection of wildlife habitat, municipal ordinances that preserve forested land, improvement of water quality, and education.
- A majority also recommended discouraging residential development, shopping centers, retail development, and other commercial and industrial development.
- The main issues that respondents feel need to be addressed are trash, water pollution, and flooding.
- One-half (51%) of respondents said they use the Tookany Creek or its tributaries for nature walks. 29% use it for biking and hiking, 22% use it for jogging, and a small percentage use it for fishing (8%). Respondents participate in the above activities about five times per month.
- When asked what improvements they would like to see, comments included more parking, trails for biking, walking, signage, safety, and better maintenance in general.
- If there were better access to the creeks, more than half would use the creek and its tributaries more.
- 77% feel that municipalities should be responsible for increased conservation and management; 65% feel it should be a county park system responsibility.
- 44% said the money for these projects should come from municipal bonds, and 77% said it should come from federal, state, or private grants.
- When asked to rank eight priority projects, most projects were in the low to average ranking. About one-third (32%) said they want stronger land use ordinances to regulate how land is used along stream corridors, one-third (31%) want streambank restoration to filter pollutants, and 17% indicated that they would want a tree replacement program and physical improvements to reduce flooding.
- Most respondents want education and land use regulations to conserve and protect creek corridors.
- Prior to this survey, 65% of people had not heard about any conservation efforts along the Tookany Creek, and those who did (20%) had read it in the newspaper.
- More than one-half of the respondents (55%) would like to receive written updates on the progress of the TTFIWMP.
- Only 3% of respondents own creek front property.

- Half of the respondents said they do not want to serve on a volunteer coalition or volunteer to participate in a streambank restoration.

Articles

The media greatly influence community perception and may indicate, via public reaction, which events and issues are important to the community. Through an examination of newspaper clipping articles and "letters to the editor" in local weekly and daily papers that serve the Tookany/Tacony-Frankford Watershed, 15 articles specific to the watershed or the TTF Partnership have been identified since 2000.

In the fall of 2002, the Tookany/Tacony-Frankford Watershed Partnership initiated what they called the Tookany/Tacony-Frankford Newspaper Series. They wrote a series of six articles about their watershed history and current issues that were printed on a bi-weekly basis in local newspapers. These six articles (listed below) can be found on the TTF Partnership website at www.phillywater.org/tacony-frankford/Education/education.htm:

1) *Restoring Our Watershed Means Healthier, Safer Communities*
2) *Demographics/ History/ Development of the Tacony-Frankford*
3) *Recent Watershed History*
4) *Natural Amenities*
5) *Challenges*
6) *"What's going on in your Watershed?"*

Membership

Attendance at meetings held by watershed-related groups is another way to gauge interest among citizens. Some 37 stakeholders (Table 4.20) have attended or participated in meetings sponsored by the Tookany/Tacony-Frankford Partnership and other watershed-related forums.

Table 4.20 Organizations/Agencies Represented at TTF Partnership Meetings

Abington Township Environmental Advisory Council (EAC)
Awbury Arboretum
Cardone Industries
CDM
Central East Middle School
Centro Nueva Creacion
Cheltenham Township
City Year Philadelphia
Delaware Riverkeeper Network
Delaware Valley Earth Force
Earthright
Edison / Fareira High School
Fairmount Park Commission
Frankford Group Ministry
FrankfordStyle Community Arts Organization
Friends of High School Park
Friends of Tacony Creek Park
Friends of Pennypack Park
Glenside Green
Heritage Conservancy
LaSalle University
Melrose Park Neighbors Association
Montgomery County Planning Commission
National Park Service Rivers & Trails
PA Department of Conservation and Natural Resources
PA Department of Environmental Protection
Pennsylvania Environmental Council
Pennsylvania Horticultural Society, Philadelphia Green Program
Philadelphia City Planning Commission
Philadelphia Police Department
Philadelphia Water Department, Office of Watersheds
Rohm & Haas Co.
Senior Environmental Corps
Tookany Creek Watershed Management Plan Steering Committee
U.S. Army Corp of Engineers
U.S. Environmental Protection Agency
U.S. Environmental Protection Agency (*VISTA)

Stewardship

Members of the Tookany/Tacony-Frankford Watershed Partnership have been active in participating in and leading local stewardship projects throughout the watershed. Volunteer groups host stream clean-ups and coordinate restoration projects, such as the planting of native vegetation along the creek's riparian corridors. Partnership members have led rain barrel workshops at their homes and in their communities as a means to educate local residents about the impacts of stormwater runoff and the use of rain barrels as stormwater controls. PWD (on behalf of the TTF Partnership) and the Montgomery County Conservation District have each sponsored rain barrel projects in overlapping areas of this watershed, resulting in the installation of 215 rain barrels in the Tookany/Tacony-Frankford Watershed from the PWD program and 35 rain barrels in the Tookany section of the watershed from the Montgomery County program.

In order to broaden community support and involvement throughout the watershed, Partnership members also coordinated various public events. Self-guided watershed tours and Visual Stream Assessments were sponsored as a way to familiarize residents with the watershed area. The Wingohocking Mystery Tour, which follows the route of the now sewered Wingohocking stream, the largest tributary to the Tacony-Frankford Creek, has now been held annually since 2002. The Return of the Great Blue Heron Day was organized in spring of 2003 to celebrate and bring attention to the good work being done in the watershed that has made it possible to see wildlife return to portions of this region. An overwhelmingly well attended invasive plants workshop was hosted in 2004 in the Tacony Creek Park. This workshop educated stakeholders about types of invasive species and options for removing these plants without damaging the surrounding plant life. An urban streams restoration workshop was held in January 2004 at The Franklin Institute, featuring an urban streams restoration expert who discussed the types of restoration solutions that could be applied in an urban stream such as the Tookany/Tacony-Frankford. The workshop was such a success that it inspired a more detailed follow-up program: the Urban Watersheds Revitalization Conference, a two-day event held in January 2005 at the Franklin Institute.

4.6.3 Indicator 17: School-Based Education

School-aged children of today are the watershed stewards of the future. For that reason, school-based education is an integral component of the long-term health of the watershed. School-based education takes many forms, from lesson plans within the classroom to hands-on activities outside of the classroom such as field trips to the Tookany/Tacony- Frankford Creek and direct involvement in actual restoration projects.

Figure 4.49 Students Collecting Insects in the TTF watershed

Being engaged in actual restoration projects, either through service learning, after-school clubs, or as part of lesson plans translates lessons into action. There are several ways to measure the success of school-based education programs, and each depends on the other.

This indicator measures:

- **Survey of schools on whether they have environmental or watershed management curriculum**
- **Number of schools participating in local environmental stewardship projects**

Where We Were:

A historical baseline has not been established for this indicator. Progress will be assessed next time this plan is updated.

Where We Are:

To date, there are various schools in the watershed that have incorporated environmental or watershed management into the curricula. Furthermore, there are schools that have led local stewardship projects that involve, for example, the creation of a wetland on-campus, participation in a streambank restoration project, and the installation of rain barrels on-campus. Students throughout the watershed also submitted 24 logo entries into the Tookany/Tacony-Frankford Partnership Logo Contest. The winning school's logo became the TTF Partnership's emblem.

In Montgomery County, there are at least seven schools that incorporate environmental and watershed lesson plans into their curricula. These schools include Cheltenham Elementary, Myers Elementary, Wyncote Elementary, Glenside Elementary, Elkins Park Middle School, Cedarbrook Middle School, and Cheltenham High School. In Philadelphia, there are at least 10 schools integrating watershed and environmental education into their curricula. Five of the schools listed below participate in watershed and environmental education programs offered at nearby Awbury Arboretum, while other schools develop their own stewardship projects in their local neighborhoods. Schools in Philadelphia that have incorporated watershed and environmental education into their curricula include Edison Fareira High School, Frankford High School, Grover Washington Junior High School, Hill-Freedman Middle School, Ada Lewis Middle School, Henry R. Edmunds Middle School, Germantown Settlement Charter School, Fulton Elementary School, Hopkinson Elementary, and Holy Innocents Parish Elementary.

The Academic Standards for Science and Technology and Environment and Ecology became a core requirement of the public school curriculum in January 2002 and testing on these topics commenced for the first time in spring 2003 as part of the Pennsylvania System of School Assessment (PSSA). The standards establish the basic elements of what students should know and be able to accomplish at the end of grades 4, 7, 10, and 12. Section 4.1 of these standards is dedicated to watersheds and wetlands. The goals for this topic area are for students to gain knowledge about water cycles, the role of watersheds, physical factors, characteristics and functions of wetlands, and the impacts of watersheds and wetlands. A scope and sequence has been predetermined for each of the aforementioned grades.

4.6.4 Indicator 18: Recreational Use and Aesthetics

People seem to be innately drawn to water and areas of natural beauty. Not surprisingly, park and recreational areas are often centered on scenic water features, such as lakes or rivers. Indeed, many acres of parkland are already established along the Tookany/Tacony-Frankford Creek (see Figure 4.51). However, many miles of the creek are not accessible to the public. If the public has no way to get to the stream, it is less likely to be enjoyed. Parks, and the waterways that flow through them, serve many functions; some obvious and others unseen. For instance, parks and waterways are areas of active and passive recreation. Active recreation includes football, baseball, and canoeing, while passive recreation implies that areas are intended for quiet contemplation or conversation, an essential respite from the concrete and asphalt of the urban world. Natural amenities, when protected and preserved, elevate the quality of life for residents by providing a myriad of recreational, educational, and other activities, in addition to enhancing the market value of homes and institutions.

This indicator measures:

- **Stream accessibility for the Tookany/Tacony-Frankford Creek and its tributaries**
- **Tons of trash removed from the creek and buffer areas**
- **Miles of trails**

Where We Were:

A historical baseline has not been established for this indicator. Progress will be assessed next time this plan is updated.

Where We Are:

Stream Accessibility

An accessibility indicator was developed to determine the degree to which a community is able to reach their waterways (Table 4.21 and Figure 4.50). Accessibility was determined on a scale from 0 through 5, with zero representing a particular segment of a stream that is inaccessible and 5 representing a completely accessible stream segment. The greater the availability of parking, trails, and public recreational land adjacent to the stream, the higher the accessibility rating given to that reach of stream. A segment of a stream running through a private, industrial, or commercial site was given a rating of 0. A segment of a stream running through a public park that has parking and trails leading to the stream was given an accessibility rating of 5. The number of stream miles and the percentage of the total stream miles with each particular accessibility rating were calculated. Fifteen percent of the waterways within the Tacony-Frankford Watershed were given a “Completely Accessible” rating. An additional 20% of the stream miles were rated as “Highly” or “Somewhat Accessible.”

Table 4.21 Accessibility by Stream Miles

Accessibility Rating	Length (miles)	Description	% of Stream Miles
0	3.70	Not Accessible	8%
1	10.50	Minimally Accessible	24%
2	15.28	Moderately Accessible	34%
3	6.11	Somewhat Accessible	14%
4	2.26	Highly Accessible	5%
5	6.48	Completely Accessible	15%

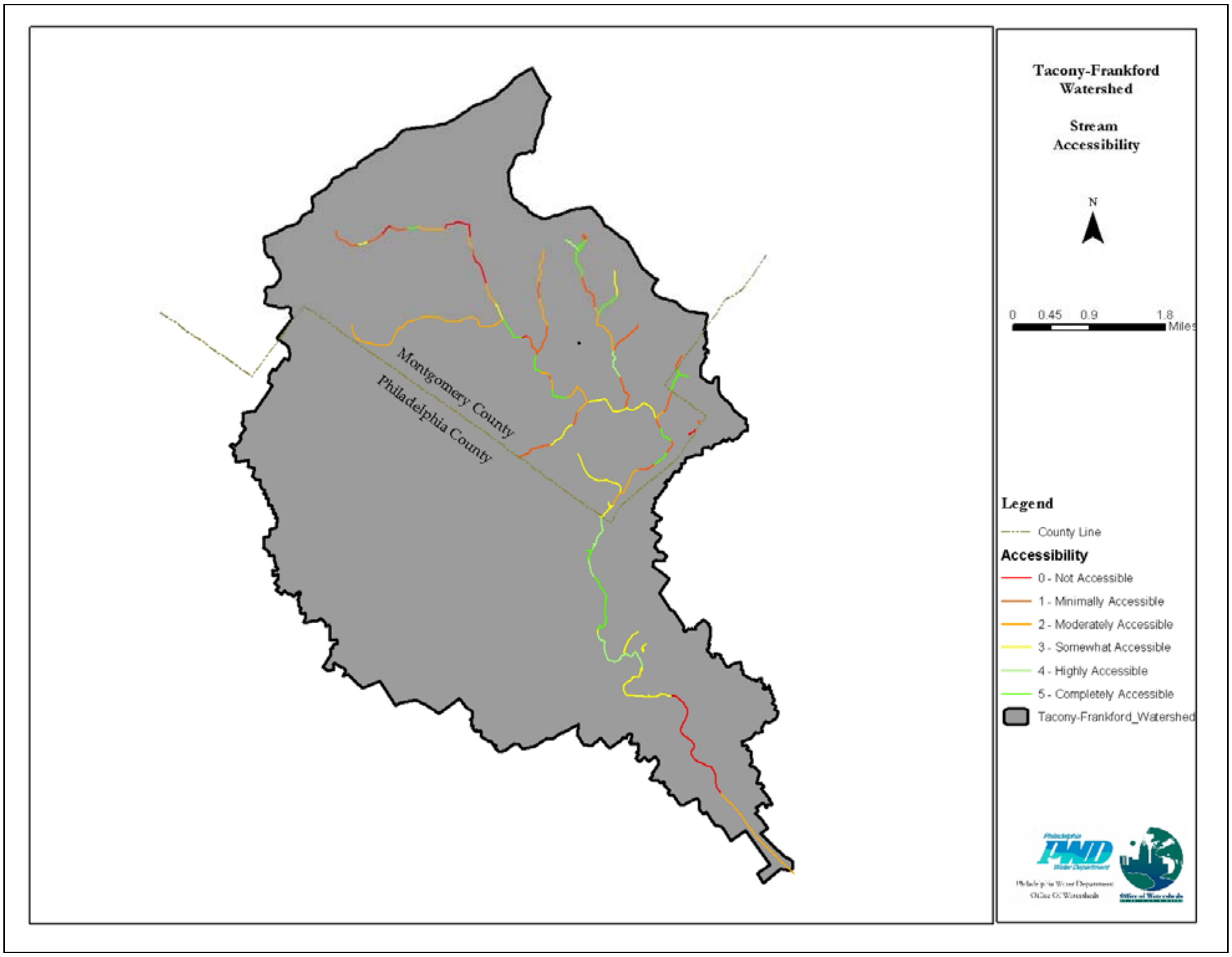


Figure 4.50 Stream Accessibility and Parks in Tacony-Frankford Watershed (2004)

Trash Removal

Maintenance records indicate that 78.45 tons of trash and debris were removed from creeks and riparian buffers in Philadelphia between July 2003 and July 2004 by the Philadelphia Water Department's Waterways Restoration Unit (WRU). The WRU is dedicated to removing large trash and debris – cars, appliances, shopping carts – from our streams in addition to restoring streambanks and streambeds that have been eroded as a result of pipe outfalls. The WRU partners with the Fairmount Park Commission and dedicated volunteers throughout Philadelphia on clean-up and restoration efforts.

Miles of Trails

Burlholme Park and Tacony Creek Park offers residents the opportunity to walk trails along the creek in the watershed. Burlholme's trails parallel an unnamed tributary to the Tookany Creek as it flows into Cheltenham Township. Tacony Creek Park has an extensive trail network along the Tacony Creek, including a trail that extends the length of the park. These trails are the most tangible connection that city residents have to this watershed. Other parks that have walking trails include Awbury Arboretum, Fern Hill, Wister Woods, Kemble, and Fisher Park.

There are 43.8 miles of bike paths within the Tacony Frankford watershed. Most of the bike paths follow major thoroughfares.

The Parkland map (Figure 4.51) details bike routes and walking trails that contribute to the amount of open space within the watershed.

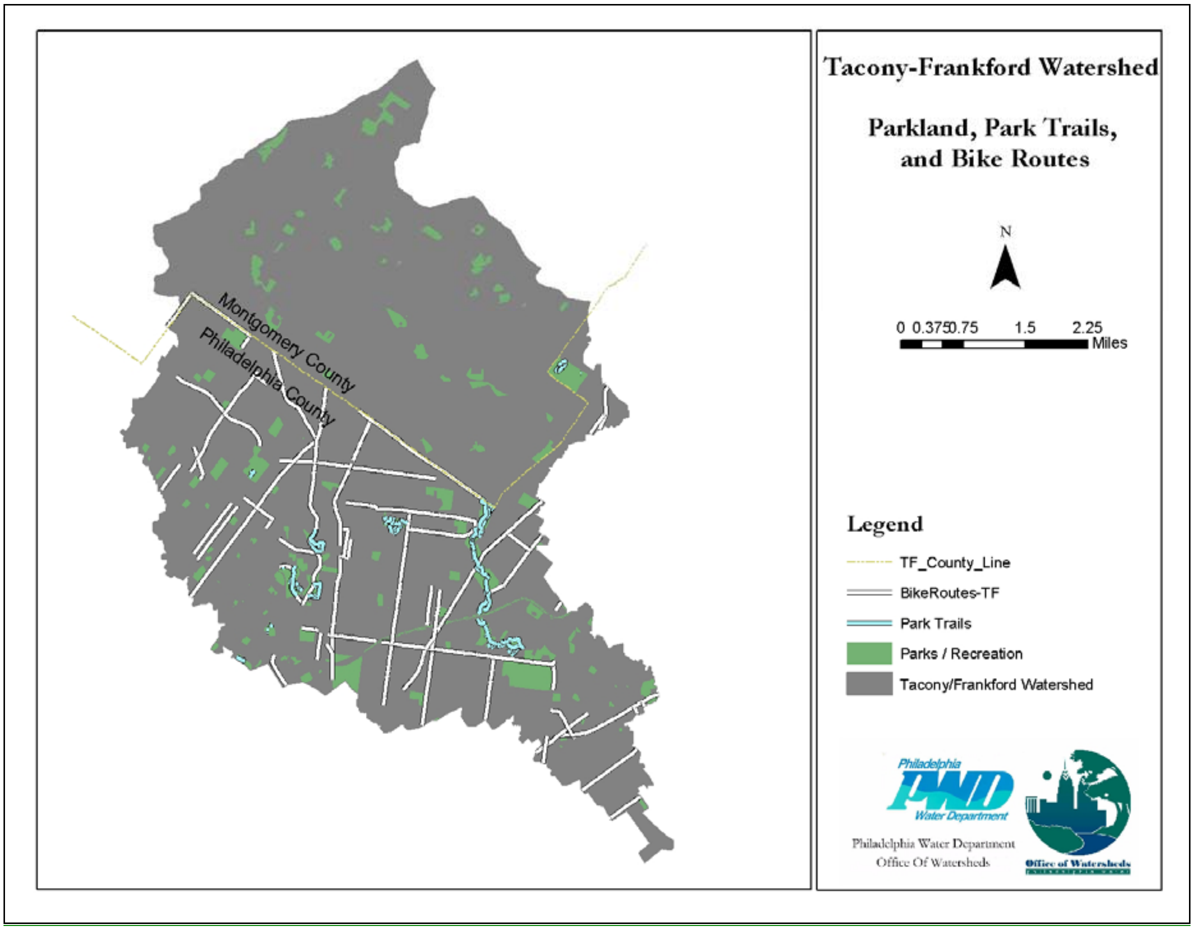


Figure 4.51 Parkland, Park Trails, and Bike Routes in the Tookany/Tacony-Frankford Watershed

4.6.5 Indicator 19: Local Government Stewardship

Local government leadership is essential to ensuring that improvements made under watershed restoration planning are sustainable. Local governments must also support, encourage, and complement the stewardship efforts of individuals, environmental groups, and businesses. A major goal is for local governments to work within their regulatory and statutory obligations while actively supporting the stewardship efforts within the watershed. It is also important that local governments implement voluntary actions to restore the watershed. Most importantly, to ensure the success of the watershed management plan, each local government within the watershed must embrace the goals and implementation strategies of the plan. A formal adoption of this plan would enhance its chance for success tremendously.

This indicator measures:

- **Municipalities participation in initiatives such as Act 167 planning, the TTF Partnership, River Conservation Plans (RCPs), and representation on the Board of the new 501(c)3 organization**
- **Age of sewage facilities (Act 537) plans**

<u>Where We Were</u>:
A historical baseline has not been established for this indicator. Progress will be assessed next time this plan is updated.

<u>Where We Are</u>:
To date, the Philadelphia Water Department and Cheltenham Township have received state grants to develop Act 167 Plans in the Tookany/Tacony-Frankford Watershed. Act 167 Plans require counties to prepare and adopt stormwater management plans for each designated watershed in a county. Consequently, PWD and four municipalities in the Montgomery County portion of the watershed have committed to participating in these plans. Those Montgomery County municipalities include Abington and Cheltenham townships, and the boroughs of Jenkintown and Rockledge (Figure 4.52).

Cheltenham Township is also leading an effort to explore the possibility of creating a watershed-wide Environmental Advisory Council (EAC) in collaboration with the other municipalities in Montgomery County. An EAC is a group of three to seven community residents, appointed by local elected officials, that advises the local planning commission, park and recreation board, and elected officials on the protection, conservation, management, promotion, and use of natural resources within its jurisdictional limits. Municipalities are authorized to establish EACs through Act 177 of 1996 (originally Act 148 of 1973).

As mentioned previously, PWD initiated the Tookany/Tacony-Frankford Watershed Partnership in 2000. The TTF Partnership represents a consortium of proactive environmental groups, municipal officials, community groups, government agencies, businesses, residents, and other stakeholders who have a vested interest in improving the Tookany/Tacony-Frankford Watershed. The Partnership formed various committees and has met periodically ever since.

Soon after the TTF Partnership was formed, a River Conservation Plan (RCP) for the Tacony-Frankford Watershed was developed by PWD and the Partnership members. The RCP Team was comprised of representatives from PWD, Frankford Group Ministry, Fairmount Park

Commission, Heritage Conservancy, and the Pennsylvania Environmental Council. In addition, the Plan was guided by an RCP Steering Committee, which included representatives from LaSalle University, the Philadelphia City Planning Commission, Frankford Community Development Corporation, Cheltenham Township, PA Department of Conservation and Natural Resources, Awbury Arboretum, National Park Service and Trails, Delaware Riverkeeper Network, Friends of Tacony Creek Park, 35th Police District, and the U.S. Army Corps of Engineers.

The Tookany RCP (referred to as the Tookany Creek Watershed Management Plan), led by Heritage Conservancy, was also developed by a diverse team of representatives. The RCP Steering Committee members were made up of officials from each municipality, in addition to representatives from Montgomery County Conservation District and Planning Commission, PECO Energy Company, PWD, and the Old York Road Historical Society.

Today, the Tacony-Frankford River Conservation Plan is complete and currently undergoing an approval process in order to be placed on the PA DCNR's Rivers Registry. The Tookany RCP is also complete and has been approved by the Montgomery County municipalities and listed on the Rivers Registry.

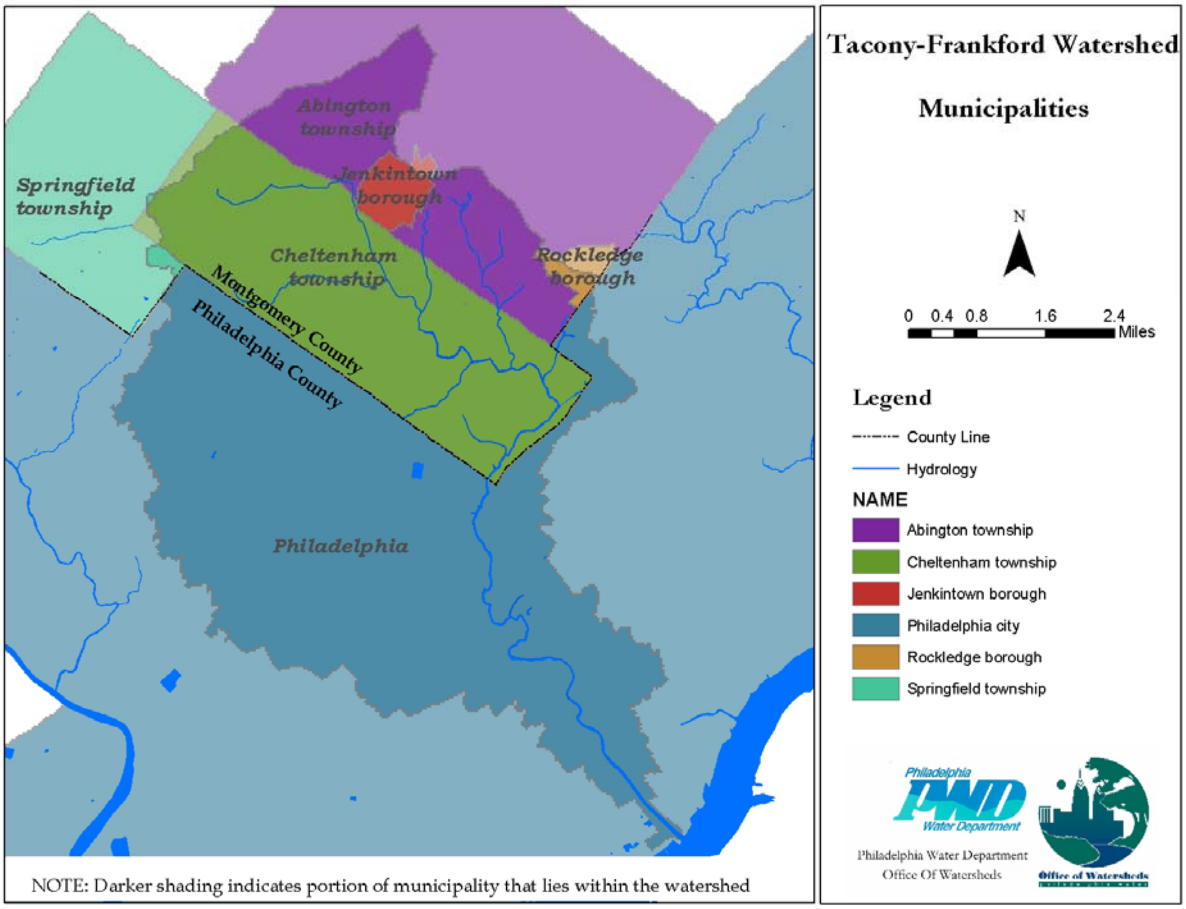
In 2003, a diverse group of Tookany/Tacony-Frankford Partnership members developed a committee to evaluate the group's organizational structure for effectiveness in plan implementation, in order to determine how to effectively guide the TTF Partnership's future progress. The Structure Committee expanded the goals of the Partnership and established the recommendation for transformation of the existing Partnership into an independent nonprofit watershed organization. It was decided that this would enable the Partnership to focus on coordinating the on-the-ground implementation of the recommendations in the TTFIWMP and to broaden community and political support for the revitalization of the watershed. The TTF Partnership was incorporated as an independent 501(c)3 organization in 2005. (See bylaws in Appendix C.)

Garnering political support from all municipal officials is an especially important priority for the TTF Partnership. Members of the Structure Committee included representatives from the Fairmount Park Commission, Awbury Arboretum, Cheltenham Township, Abington Environmental Advisory Council, Frankford Group Ministry, Friends of High School Park, Friends of Tacony Creek Park, Heritage Conservancy, Melrose Park Neighbors Association, Delaware Riverkeeper Network, Montgomery County Planning Commission, PA DEP, PA DCNR, and the U.S. Army Corps of Engineers. Many of those same entities, as well as various others, are represented on the board of directors of the newly incorporated nonprofit organization.

Currently, all of the municipalities in the watershed have an Act 537 Plan, which provides for the resolution of existing sewage disposal problems, future sewage disposal needs of new land development, and future sewage disposal needs of the municipality. However, some plans are newer and more detailed than others (Table 4.22).

Table 4.22 Act 537 Municipal Sewage Facilities Plans

Municipality	County	Plan Approval Date	Status (as of 12/2005)
Abington Township	Montgomery	12/16/99	Plan older than 5 years
Cheltenham Township	Montgomery	1/1/73	Plan older than 30 years
Jenkintown Borough	Montgomery	1/1/73	Plan older than 30 years
Philadelphia	Philadelphia	11/10/93	Plan older than 10 years
Rockledge Borough	Montgomery	1/1/73	Plan older than 30 years



NOTE: Darker shading indicates portion of municipality that lies within the watershed

Figure 4.52 Tookany/Tacony-Frankford Watershed Municipalities and Counties

4.6.6 Indicator 20: Business and Institutional Stewardship

Awareness of the role of businesses and institutions in watershed degradation and restoration is growing. Success of the watershed management plan will require stewardship on the part of stakeholders who represent the diversity of land uses in the watershed, including conservation groups, commercial, industrial, institutional, and residential users. The goal of the TTF Partnership is to have a proportional representation of these groups.

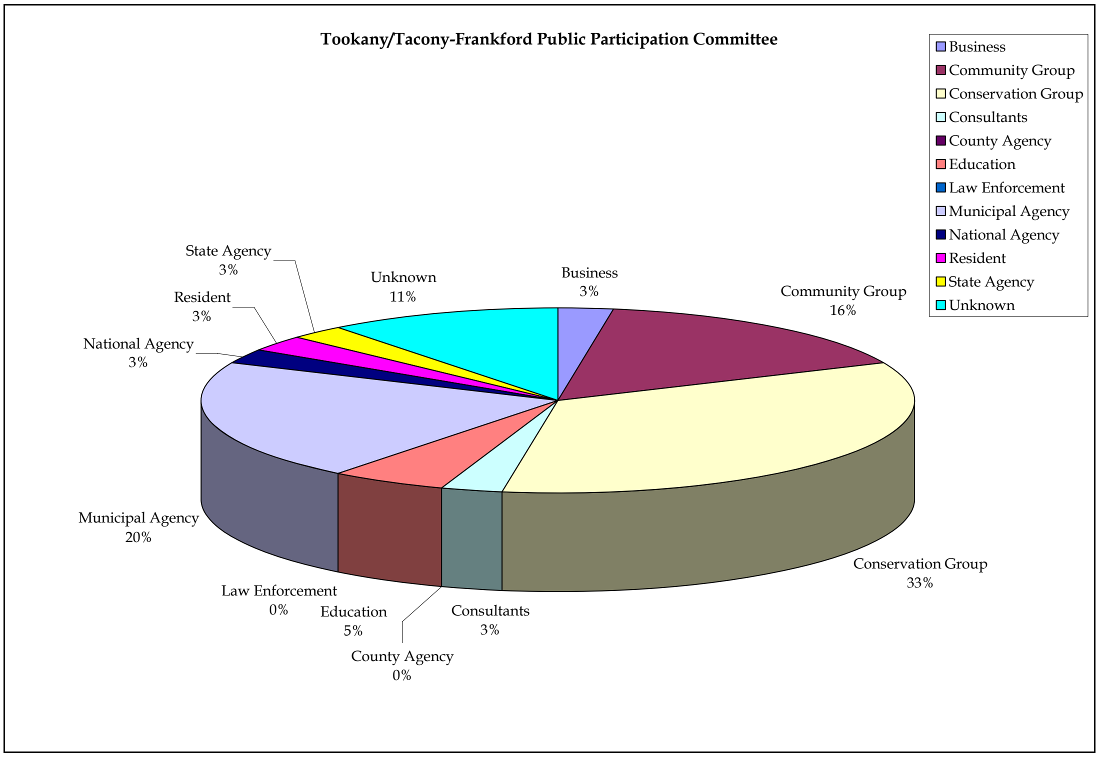
This indicator measures:

- **Breakdown of TTF Partnership committee participation by organization type**

<u>Where We Were</u>:
A historical baseline has not been established for this indicator. Progress will be assessed next time this plan is updated.

<u>Where We Are</u>:
Figure 4.53 illustrates the percentage of representatives of each type of group on the TTF Partnership's Technical and Public Participation Committees. To date, three business representatives have participated in Partnership meetings and events, as illustrated in the below charts. These business representatives included Rohm & Haas Co., Hankin Management, and Cardone Industries. These industries are all located near the creek.

Recently, PWD has developed a partnership with Shop Rite Supermarkets and the Pennsylvania Food Merchants Association (PFMA) to address the removal of shopping carts from local streams. Shop Rite has committed to sponsoring stream side clean-up events with students throughout the watershed.



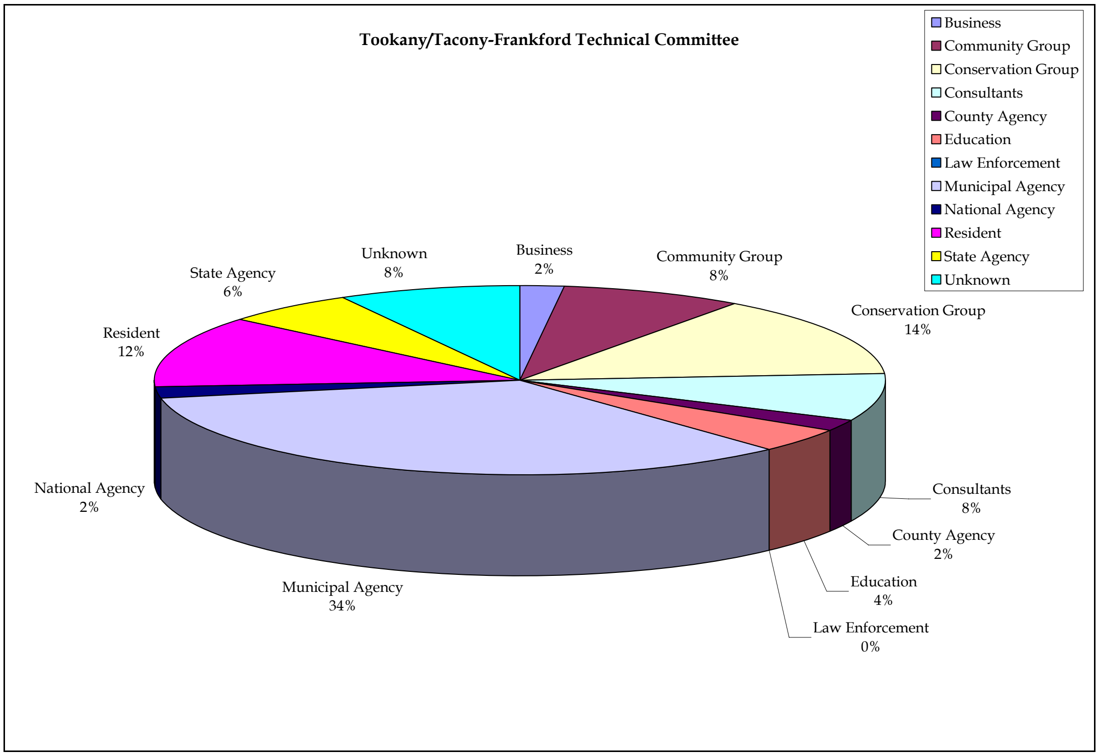


Figure 4.53 Distribution of Partnership Members' Affiliations (2003)

4.6.7 Indicator 21: Cultural and Historic Resources

Waterways have always been cradles of civilization, providing, among many other things, a means of travel and rich floodplain soils in which to cultivate crops. Waterways provided power for mills and fueled the beginnings of the industrial revolution. Consequently, historical and cultural resources are often concentrated in and along waterways. These resources enable us to better understand and appreciate different cultures and traditions, to recognize the struggles endured by our ancestors, and to comprehend the technologies of past generations; and they can be an invaluable tool to inform our understanding of present conditions.

This indicator measures:

- **National Register of Historic Places inventory**
- **National Register of Historic Districts inventory**
- **Number of nonprofit historical/cultural organizations**

Where We Were:
A historical baseline has not been established for this indicator. Progress will be assessed next time this plan is updated.

Where We Are:
Although it is hard to pinpoint the actual number of historic properties located in the watershed, it is approximated that 11 historic properties exist in the municipalities in the Tookany section of the watershed and approximately 46 historic properties exist in the Philadelphia section of the watershed. The Fairmount Park Commission has identified eight historic resources located in Tacony Creek Park. Additionally, six districts are identified as National Register Districts. The four National Register Historic Districts in Philadelphia include Awbury, Germantown, Friends Hospital, and Tulpehocken. The two Districts that exist in Montgomery County include La Mott Historic District with 40 resources, and Wyncote Historic District with 232 resources. The watershed is rich with numerous other historical, cultural, and social amenities throughout both counties, many of which are deemed eligible for listing on the National Registry by the Pennsylvania Historical and Museum Commission. The National Register was authorized by an Act of Congress in 1966 and serves as the nation's official list of cultural resources worthy of protection. The National Register is administered by the National Park Service of the U.S. Department of the Interior.

Furthermore, five nonprofit historical societies or cultural organizations exist to preserve the history and culture of the rich communities of the watershed: Germantown Historical Society, Historical Society of Frankford, Old York Road Historical Society, Ryerss Victorian Mansion, and the Settlement Music School. The City of Philadelphia also has the distinction of being an important destination for fugitive slaves seeking freedom in the North. There are numerous important Underground Railroad sites within the watershed. Two sites that are listed in Charles Blockson's *Hippocrene Guide to the Underground Railroad* are the John Johnson House in Germantown and the Campbell AME Church in Frankford.

Section 5
Problem Definition and Analysis

The watershed "indicators" described in Section 4 are used both to characterize the current state of the TTF Watershed, and to set a baseline for future comparison. Here, Section 5 identifies the wide range of potential problems that have been identified in the watershed, and describes the analysis tools used to define them.

Many of the problems in the TTF Watershed have been identified through the assessments carried out by the project team and others. Other problems were identified through stakeholder participation. Water quality problems were identified by taking samples and comparing results to water quality criteria. Several criteria were relevant to the analysis, many of which provided specific numeric standards with which to comply. Others were less specific, but nonetheless relevant. These are often referred to as narrative standards.

National water quality criteria include aesthetic qualities that protect the quality of streams. The criteria state:

"All waters free from substances attributable to wastewater or other discharges that:

(1) settle to form objectionable deposits;

(2) float as debris, scum, oil, or other matter to form a nuisance;

(3) produce objectionable color, odor, taste, or turbidity;

(4) injure or are toxic or produce adverse physiological responses in humans, animals or plants; and

(5) produce undesirable or nuisance aquatic life." (EPA, Goldbook, 1986)

Also, PA DEP's general water quality criteria state:

> (a) Water may not contain substances attributable to point or non-point source discharges in concentration or amounts sufficient to be inimical or harmful to the water uses to be protected or to human, animal, plant, or aquatic life.
>
> (b) In addition to other substances listed within or addressed by this chapter, specific substances to be controlled include, but are not limited to, floating materials, oil, grease, scum and substances which produce color, tastes, odors, turbidity or settle to form deposits. (PA DEP, Chapter 93 § 93.6.)

Some standards were related to the uses of the creek. The Tookany/Tacony-Frankford Creek's protected uses as designated by PA DEP are:

- Aquatic Life – Warm Water Fishes
- Water Supply – Potable Water Supply
- Recreation and Fish Consumption - Boating, Fishing, Water Contact Sports, and Esthetics

5.1 Visual Stream Assessment (Aesthetics and Narrative Criteria)

The Tacony-Frankford RCP Team and Tookany Creek Watershed Management Plan Steering Committee conducted visual assessments along the major tributaries and mainstem streams. These assessments provided a baseline inventory of the existing conditions along the stream corridor. The method utilized a modified version of the USDA's Visual Streambank Assessment Protocol. Members of these committees and volunteers conducted the visual stream assessments.

The visual assessments assisted in identification of problems and problem locations in the Tookany/Tacony-Frankford Watershed. Generally, the issues found in the watershed included:

- Erosion of creek banks (undercutting, exposed roots).
- Appearance of invasive species – Disturbed areas throughout the watershed are susceptible to invasion by non-native exotic vegetation. Japanese knotweed, kudzu, purple loosestrife, and multiflora rose were identified as issues within the watershed.
- Trash and debris – Along the creeks, there was an abundance of trash and debris.
- Illegal dumping – Dumping of trash, cars, and appliances are an issue for Tacony Creek Park and vacant land. Secluded open areas are especially susceptible to dumping. Sites of abandoned cars often become targets for fire. Illegal dumping ranges from trucks dumping construction materials and appliances to residents throwing trash directly into the creek.
- Illegal recreational activities (e.g., ATVs, swimming) – ATV use is illegal in Tacony Creek Park and has had a detrimental effect on the health of the park. Illegal trails disturb native vegetation and open habitat for invasives while contributing to erosion on slopes of the creek banks.
- Sewage and odors.
- Lack of riparian buffer – The lack of riparian buffer was observed on both public and private property. Native vegetation usually found in the riparian buffer often has been removed or mowed. Sections of the creeks where flooding has been problematic tend not to have riparian buffer areas, coupled with a high percentage of impervious surface.
- Exposed and eroded sewer and stormwater pipes.
- Instream flow obstructions.
- Chemical runoff which may include but is not limited to fertilizers, pesticides, herbicides, oil and grease, antifreeze, and industrial spills.
- Illicit and disconnected sewers.
- Lack of best management practices (BMPs).

Figure 5.1 displays the results of the visual stream assessments, with the locations of problems identified by stream reach.

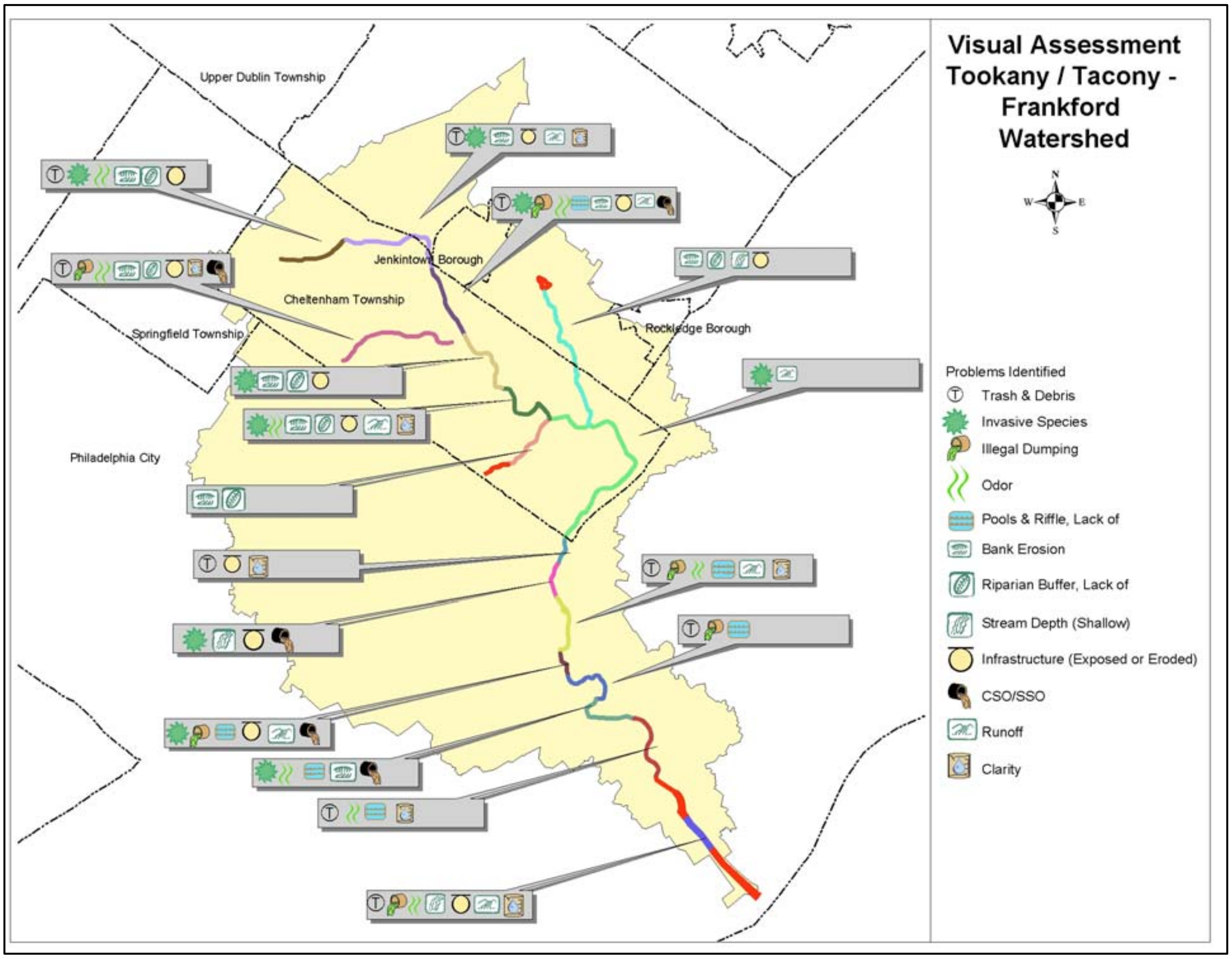


Figure 5.1 Summary of Visual Assessments

Various problems have been identified throughout the watershed. Evidence of streambank erosion was observed at all but one reach of the visually assessed streams. Trash and debris and invasive species were recorded at most reaches. There is no pattern with regards to the location of the reaches, with problems identified both in the city and outside the city.

5.2 Streamflow Analysis

Indicator 2, Streamflow, measures baseflow and runoff to analyze the impact of urbanization on watershed hydrology. As noted previously in Sections 2.2.1 and 4.2.1, the flow records at each of the USGS gauges in the Tookany/Tacony-Frankford Watershed were separated into runoff and baseflow components.

In Table 5.1, the results for Tacony-Frankford Creek are compared with French Creek, a rural stream, and Darby Creek, a stream in a mixed urban and suburban watershed. Results for French Creek are somewhat typical of an undeveloped watershed, with baseflow comprising 64% of mean annual streamflow and stormwater only 17% of annual precipitation.

At the Frankford Creek gauge, representing most of the urbanized Tacony-Frankford watershed, the stormwater component of streamflow is a much greater percentage of total annual streamflow (62%), and baseflow represents a much smaller percentage of total annual streamflow (only 38%). These results are indicative of a highly urbanized stream. The Tacony Creek USGS gauge, representing the headwaters of the Tacony-Frankford Watershed, exhibits a relationship between stormflow and baseflow that is between the two extremes.

Table 5.1 Summary of Hydrograph Separation Results over the Period of Record

USGS Gauge	Period of Record	Baseflow	Baseflow	Stormwater Runoff
		(% of Total Flow)	(% of Precip)	(% of Precip)
Tacony Creek near Jenkintown 01467083	10/1/73 - 9/30/78	56%	27%	21%
Rock Creek 01467084	5/1/71 – 9/30/78	46%	28%	33%
Jenkintown Creek 01467085	5/1/71 – 9/30/78	60%	27%	18%
Tacony Creek at County Line 01467086	10/1/65 - 11/17/88	58%	29%	21%
Frankford Creek at Castor Ave 01467087	7/1/82 - 9/30/03	38%	17%	27%
Frankford Creek at Torresdale Ave 01467089	10/1/65 - 9/30/81, 5/14/82 – 6/29/82	35%	17%	31%
French Creek 01475127	10/1/68 – 9/30/03	64%	31%	17%
Darby Creek 01475510	2/1/64 – 10/3/90	62%	34%	21%
Cobbs Creek 01475550	2/1/64 – 10/3/90	43%	19%	26%

5.3 Water Quality Analysis

As noted above, water uses relevant to the TTF Watershed include the following:

- Aquatic Life – Warm Water Fishes
- Water Supply – Potable Water Supply
- Recreation and Fish Consumption - Boating, Fishing, Water Contact Sports, and Esthetics

As described in Section 2.2.2, an analysis was conducted on the water quality data collected in the Tookany/Tacony-Frankford Watershed. A number of constituents, which are listed in Table 5.2, were used as indicators of watershed health in Section 4.3. Using the data collected from discrete wet and dry weather sampling, comparisons were made to water quality standards. National water quality standards and reference values were used if state water quality standards were not available. The water quality standards or reference values and their sources are also listed in Table 5.2.

The aquatic life criteria for metals were "established to control the toxic portion of a substance in the water column. Depending upon available data, aquatic life criteria for metals are expressed as either dissolved or total recoverable." (PA DEP, Chapter 16)

A color coding is used to indicate problems (red) and potential problems (yellow). Problems are identified if more than 10% of samples exceed the applied water quality standard or criteria. Potential problems are identified if between 2% and 10% of samples exceed the standard or criteria.

Table 5.2 Water Quality Standards and Reference Values

Parameter	Criteria	Water Quality Criteria or Reference Value	Source
Alkalinity	Minimum	20 mg/L	PA DEP
Aluminum	Aquatic Life Chronic Exposure Standard	87 mg/L (pH 6.5-9.0)	53FR33178
Aluminum	Aquatic Life Acute Exposure Standard	750 mg/L	PA DEP
Chlorophyll A	Reference reach frequency distribution approach for Ecoregion IX, subregion 64, 75th percentile	seasonal median: 3 ug/L, (Spectrophotometric)	EPA 822-B-00-019
Dissolved Cadmium	Aquatic Life Acute Exposure Standard	Hardness Dependent	PA DEP
	Aquatic Life Chronic Exposure Standard	Hardness Dependent	PA DEP
	Human Health Standard	10 mg/L	EPA Goldbook
Dissolved Chromium	Aquatic Life Acute Exposure Standard	16 mg/L	PA DEP
	Aquatic Life Chronic Exposure Standard	10 mg/L	PA DEP
Dissolved Copper	Aquatic Life Acute Exposure Standard	Hardness Dependent	PA DEP
	Aquatic Life Chronic Exposure Standard	Hardness Dependent	PA DEP
	Human Health Standard	1000 mg/L	EPA Goldbook
Dissolved Iron	Maximum	0.3 mg/L	PA DEP

Parameter	Criteria	Water Quality Criteria or Reference Value	Source
Dissolved Lead	Aquatic Life Acute Exposure Standard	Hardness Dependent	PA DEP
	Aquatic Life Chronic Exposure Standard	Hardness Dependent	PA DEP
	Human Health Standard	50 mg/L	EPA Goldbook
Dissolved Zinc	Aquatic Life Acute Exposure Standard	Hardness Dependent	PA DEP
	Aquatic Life Chronic Exposure Standard	Hardness Dependent	PA DEP
	Human Health Standard	5000 mg/L	EPA Goldbook
DO	Instantaneous Minimum	4 mg/L	PA DEP
	Average Minimum	5 mg/L	PA DEP
Fecal coliform	Maximum	Geometric Mean of 5 consecutive samples on different days within a 30 day period may not exceed 200/100mL (Summer) or 2000/100mL (Winter)	PA DEP
Fluoride	Maximum	2.0 mg/L	PA DEP
Iron	Maximum	1.5 mg/L	PA DEP
Manganese	Maximum	1.0 mg/L	PA DEP
NH3-N	Maximum	pH dependent	PA DEP
NO2+NO3	Nitrates – Human Health Consumption for water + organisms	10 mg/L	PA DEP
NO23-N	Maximum	10 mg/L	PA DEP
Periphyton Chlorophyll A		Ecoregion IX – 20.35 mg/m2	Goldbook
pH	Range	6.0 mg/L - 9.0 mg/L	PA DEP
Phenolics	Maximum	0.005 mg/L	PA DEP
TDS	Maximum	750 mg/L	PA DEP
Temperature		Varies w/ season. Additionally, waters may not result in a change by more than 2°F during a 1-hour period.	PA DEP
TKN	Maximum	Ecoregion IX, subregion 64 seasonal median: 0.675 mg/L	EPA 822-B-00-019
TN	Maximum	Ecoregion IX, subregion 64 seasonal median: 4.91 mg/L	EPA 822-B-00-019
TP	Maximum	Ecoregion IX, subregion 64 seasonal median: 140 ug/L	EPA 822-B-00-019
TSS	Maximum	25 mg/L	Other US states
Turbidity	Maximum	Ecoregion IX, subregion 64 seasonal median: 8.05 NTU	EPA 822-B-00-019

Based on a comparison of water quality sampling data with standards, criteria, or reference values, the problem and potential problem parameters have been identified and are discussed in this section. The issues have also been identified during wet and dry weather, if applicable.

5.3.1 Water Supply

The state's potable water supply criteria were applied to the Tookany/Tacony-Frankford Watershed. The criteria are listed above in Table 5.2. Comparisons between the water quality data and the criteria for water supply are listed in Table 5.3, which displays observed water quality exceedances of these criteria during dry and wet weather.

Table 5.3 Summary of Water Supply Criteria Exceedances

Parameter	Criteria	Dry			Wet		
		No. Obs.	**No. Exceed**	**% Exceed**	**No. Obs**	**No. Exceed**	**% Exceed**
Dissolved Iron (Fe)	Maximum	64	3	4.69	123	5	4.07
Fluorine (F)	Maximum	61	1	1.64	438	0	0.00
Manganese (Mn)	Maximum	90	0	0.00	461	9	1.95
Ammonia (NH_3)	Maximum	41	0	0.00	144	0	0.00
Nitrate-Nitrite (NO_2+NO_3)	Maximum	62	0	0.00	464	0	0.00
Total Dissolved Solids (TDS)	Maximum	36	0	0.00	144	2	1.39

Green – Parameter is not a problem *Yellow – Potential problem parameter* *Red – Problem parameter*

The results indicate dissolved iron, manganese, and total dissolved solids (TDS) as potential problem parameters. On the pages that follow, Figures 5.2 – 5.4 show the criteria comparison by monitoring location in the Tookany/Tacony-Frankford Watershed. Dissolved iron, prevalent in clay soils, has been identified to exceed the criteria more than 2% of the time in both dry and wet weather. Manganese appears to be a potential wet weather problem, and TDS a potential dry weather problem.

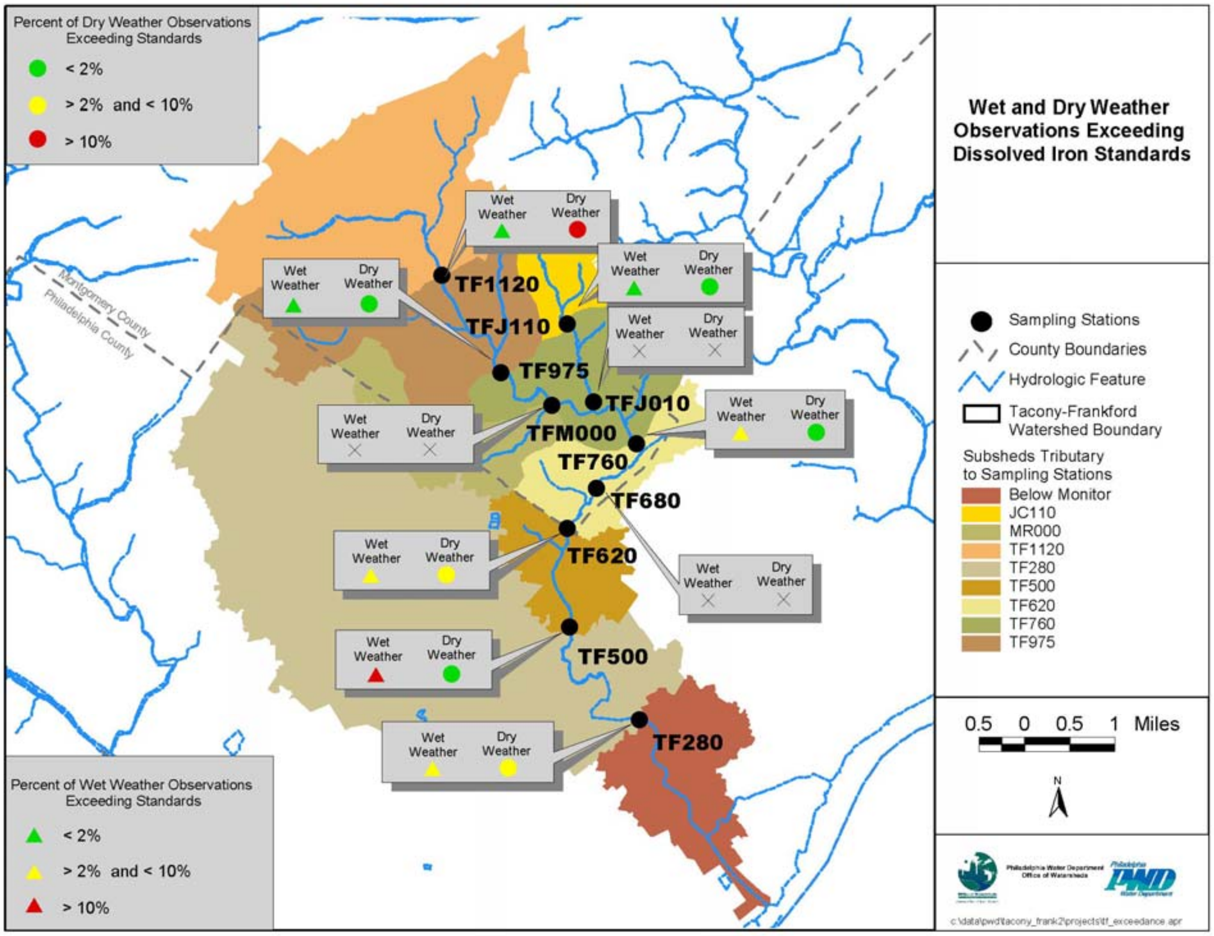


Figure 5.2 Water Supply Criteria for Dissolved Iron

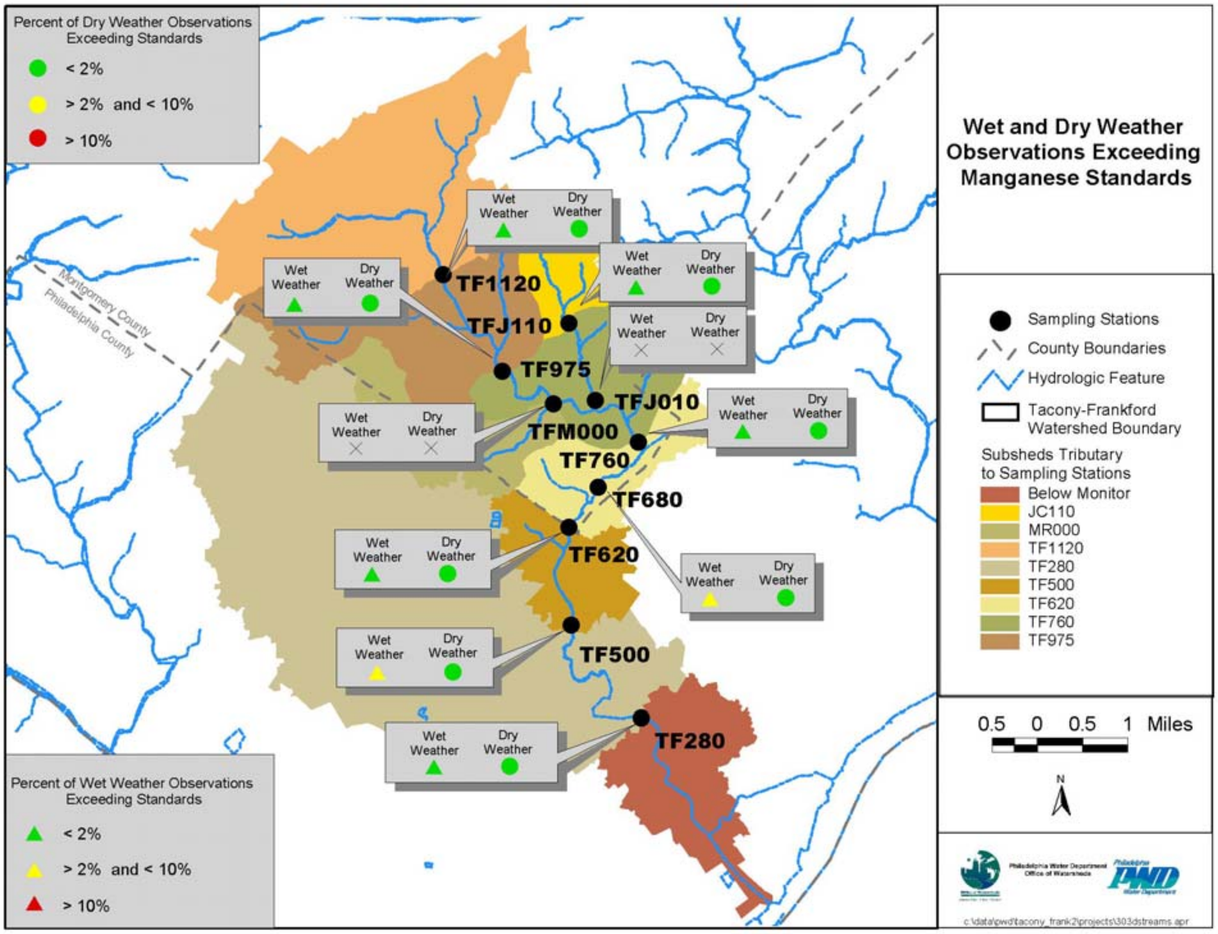


Figure 5.3 Water Supply Criteria for Manganese

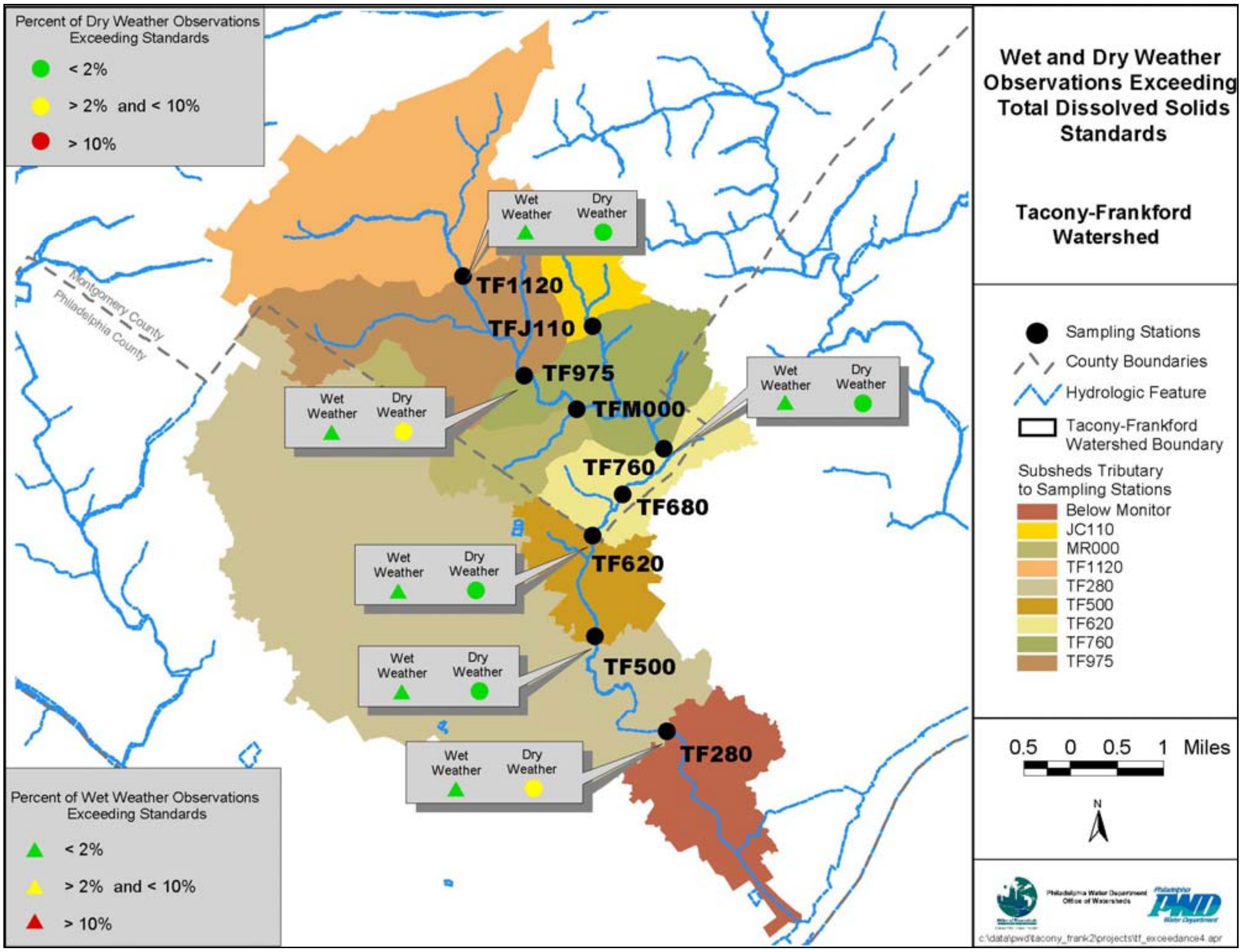


Figure 5.4 Water Supply Criteria for Total Dissolved Solids

5.3.2 Recreation and Fish Consumption

The protected and statewide water use for recreation and fish consumption applicable to the TTF Watershed is water contact sports. The specific water quality criterion for water contact is fecal coliform. Figure 5.5 displays comparisons at the monitoring locations with the criteria throughout the watershed. The data has been compared to the criteria during both swimming and non-swimming seasons. During the swimming season, fecal coliforms are identified as a problem. During the non-swimming season, they are characterized as a potential problem.

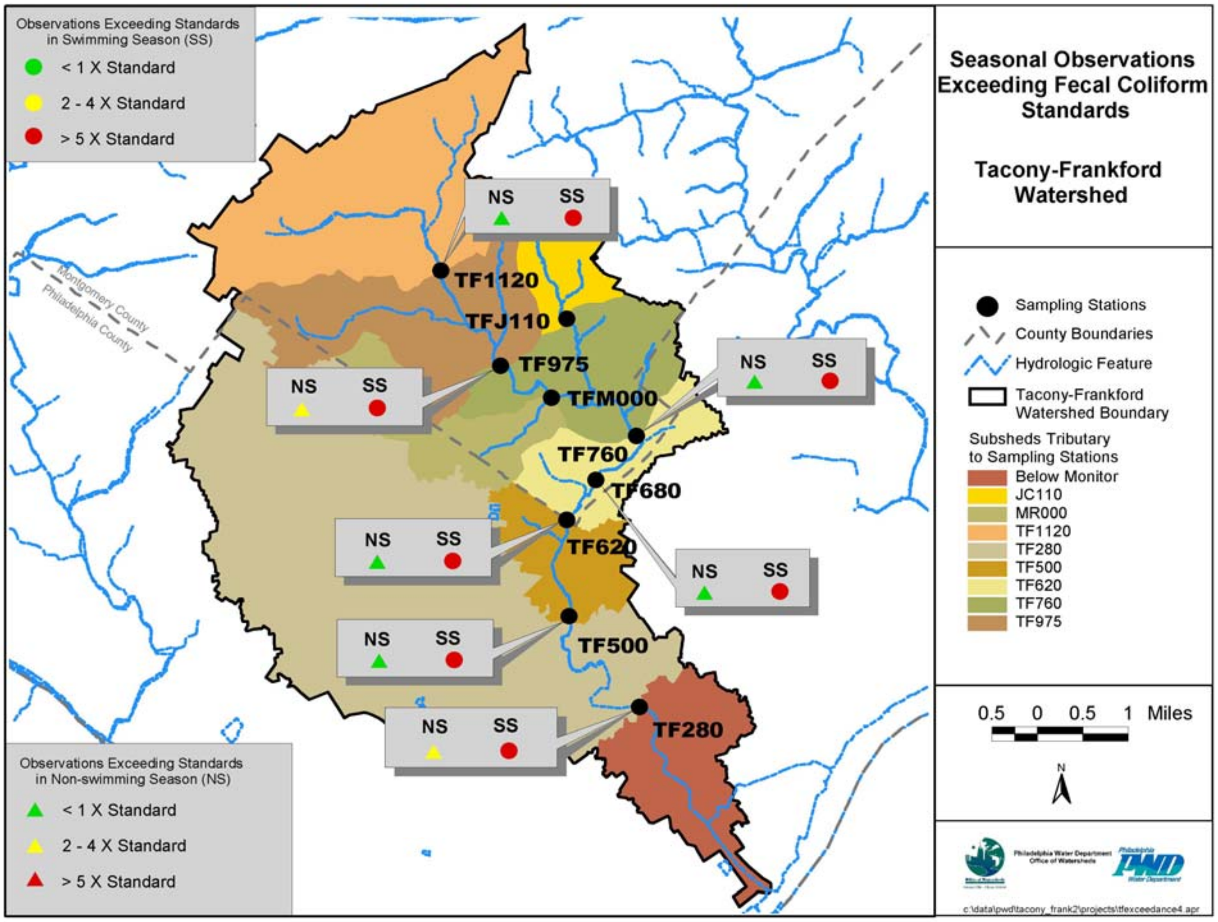


Figure 5.5 Water Contact Criteria for Fecal Coliform

Table 5.4 Summary of Recreation Criteria Exceedances

Season	Site	No. Obs.	No. Exceed	Percent Exc.
Nonswimming	TF500	1	1	100.00
	TF620	7	6	85.71
	TF760	1	0	0.00
	TF975	3	3	100.00
Swimming	TF1120	8	8	100.00
	TF280	7	7	100.00
	TF975	8	8	100.00

5.3.3 Human Health

The relevant human health criteria developed by EPA and PA DEP include exposure to toxic metals from drinking water and fish consumption. No problem parameters were identified among dissolved metals.

Table 5.5 Summary of Human Health Criteria Exceedances

Parameter	Criteria	Dry			Wet		
		No. Obs.	No. Exceed	% Exceed	No. Obs	No. Exceed	% Exceed
Dissolved Cadmium (Cd)	Human Health Maximum	37	0	0.00	118	0	0.00
Dissolved Copper (Cu)	Human Health Maximum	28	0	0.00	5	0	0.00
Dissolved Lead (Pb)	Human Health Maximum	19	0	0.00	N.A.	N.A.	N.A.
Dissolved Zinc (Zn)	Human Health Maximum	27	0	0.00	4	0	0.00
Nitrite (NO_3)	Human Health Maximum	62	0	0.00	464	0	0.00

Green – Parameter is not a problem *Yellow – Potential problem parameter* *Red – Problem parameter*

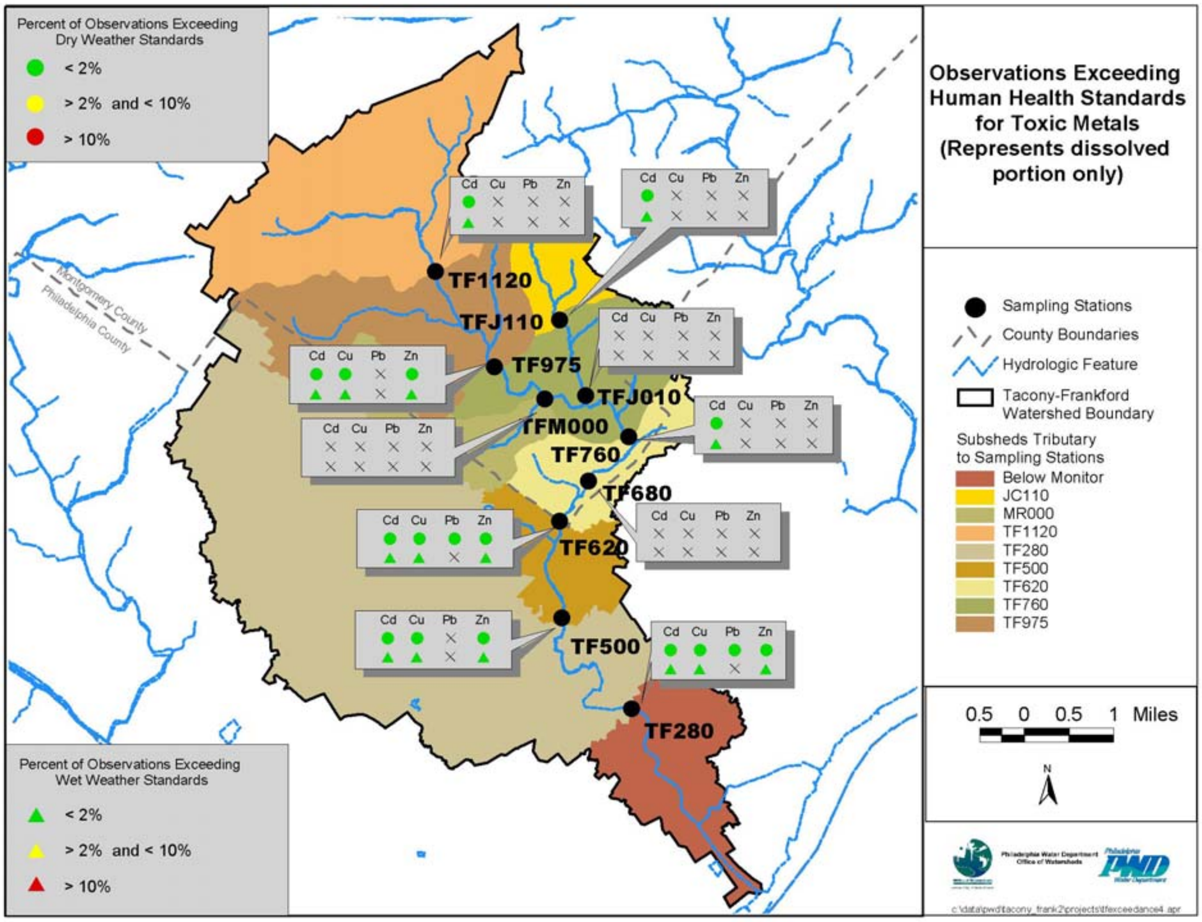


Figure 5.6 Spatial View of Human Health Criteria Exceedances

5.3.4 Aquatic Life

The criteria shown in Table 5.6 are designed to protect reproduction, growth, and survival of aquatic life from acute effects.

Table 5.6 Summary of Aquatic Life Acute Criteria Exceedances

Parameter	Criteria	Dry			Wet		
		No. Obs.	No. Exceed	% Exceed	No. Obs	No. Exceed	% Exceed
Al	Acute Maximum	78	0	0.00	402	77	19.15
Dissolved Cu	Acute Maximum	28	0	0.00	5	3	60.00
DO	Average Minimum (WWF)	59	2	3.39	143	2	1.40
DO	Instantaneous Minimum (WWF)	59	2	3.39	143	0	0.00
Dissolved Iron	Maximum (WWF)	64	3	4.69	123	5	4.07

Green – Parameter is not a problem   Yellow – Potential problem parameter   Red – Problem parameter

The above table suggests that there are a number of problem and potential problem parameters based on water quality criteria related to acute effects on aquatic life.

- During dry weather, only dissolved iron and dissolved oxygen (DO) are flagged as potential problems.
- During wet weather, aluminum and dissolved copper are flagged as problem parameters.
- During wet weather, dissolved iron is flagged as a potential problem.

Table 5.7 lists parameters that have been identified as problems because they exceed aquatic life chronic criteria. Since these are chronic, thus long term, exposure limits, they are not split into dry weather and wet weather results.

Table 5.7 Summary of Aquatic Life Chronic Criteria Exceedances

Parameter	Standard	No. Observations	No. Exceed	% Exceed
Al	Chronic Maximum	480	271	56.46
Dissolved Cd	Chronic Maximum	155	0	0.00
Dissolved Cu	Chronic Maximum	33	5	15.15
Dissolved Pb	Chronic Maximum	19	0	0.00
Dissolved Zn	Chronic Maximum	31	0	0.00

Green – Parameter is not a problem   Yellow – Potential problem parameter   Red – Problem parameter

Table 5.6 (at top of previous page) and Figure 5.7 (below) show the results of dissolved oxygen measurements. Both the figure and table suggest that, in general, dissolved oxygen is not a problem upstream of TF280. Within the tidal portion of the watershed below TF280, insufficient data exists to properly characterize the potentiality of a DO problem.

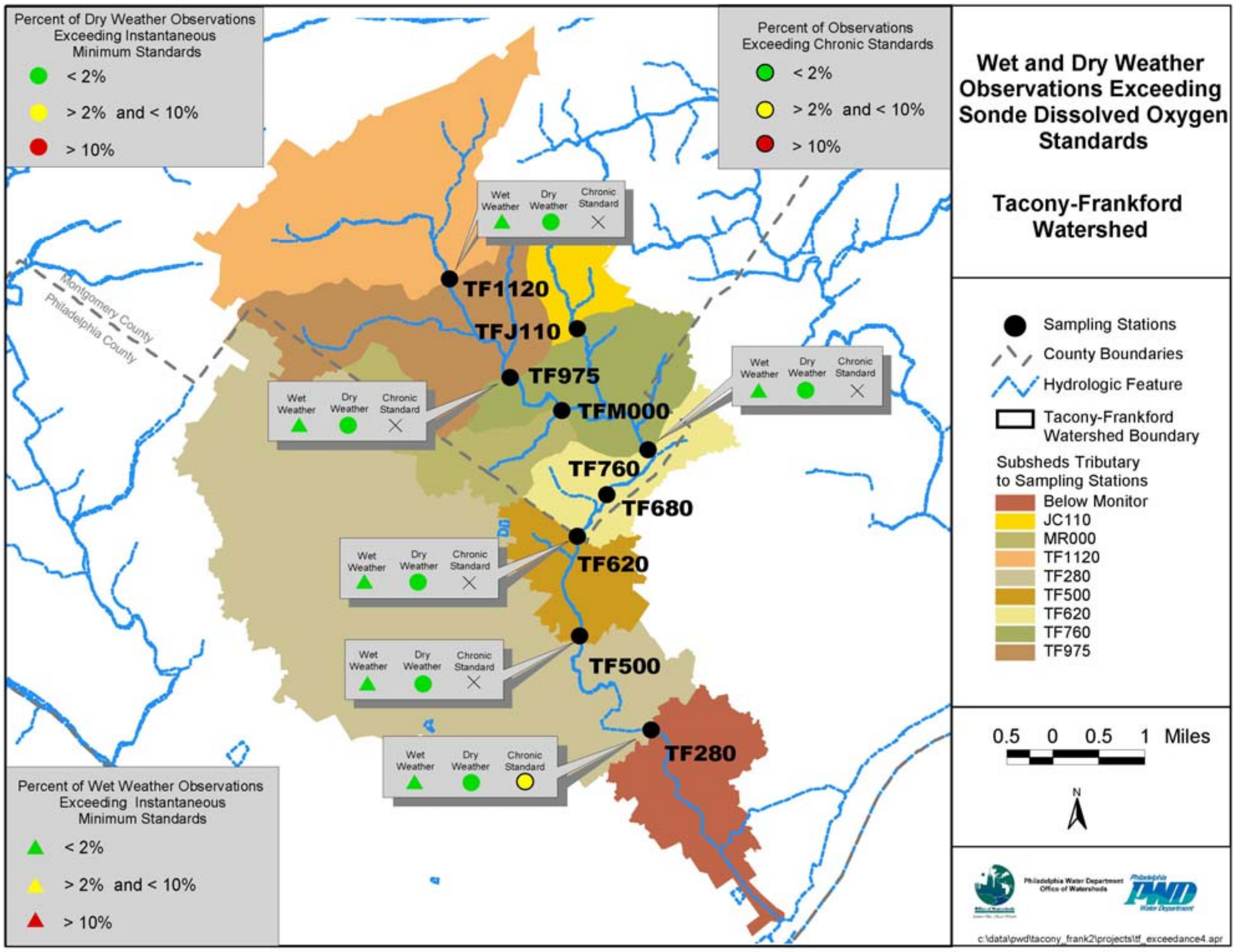


Figure 5.7 Spatial View of Dissolved Oxygen Exceedances in Wet and Dry Weather

Figure 5.8 shows dissolved oxygen measurements taken with one of the Sondes designed to take continuous DO measurements. Although the overall DO levels are adequate in this figure, the figure does point out a rather wide, diurnal fluctuation in DO, in this case over 6 mg/l. This suggests a great deal of biological activity. Although insufficient data exist at this point to indicate the fluctuations in DO are a potential problem, further investigation is important to determine the cause of these unusually wide, short term variations.

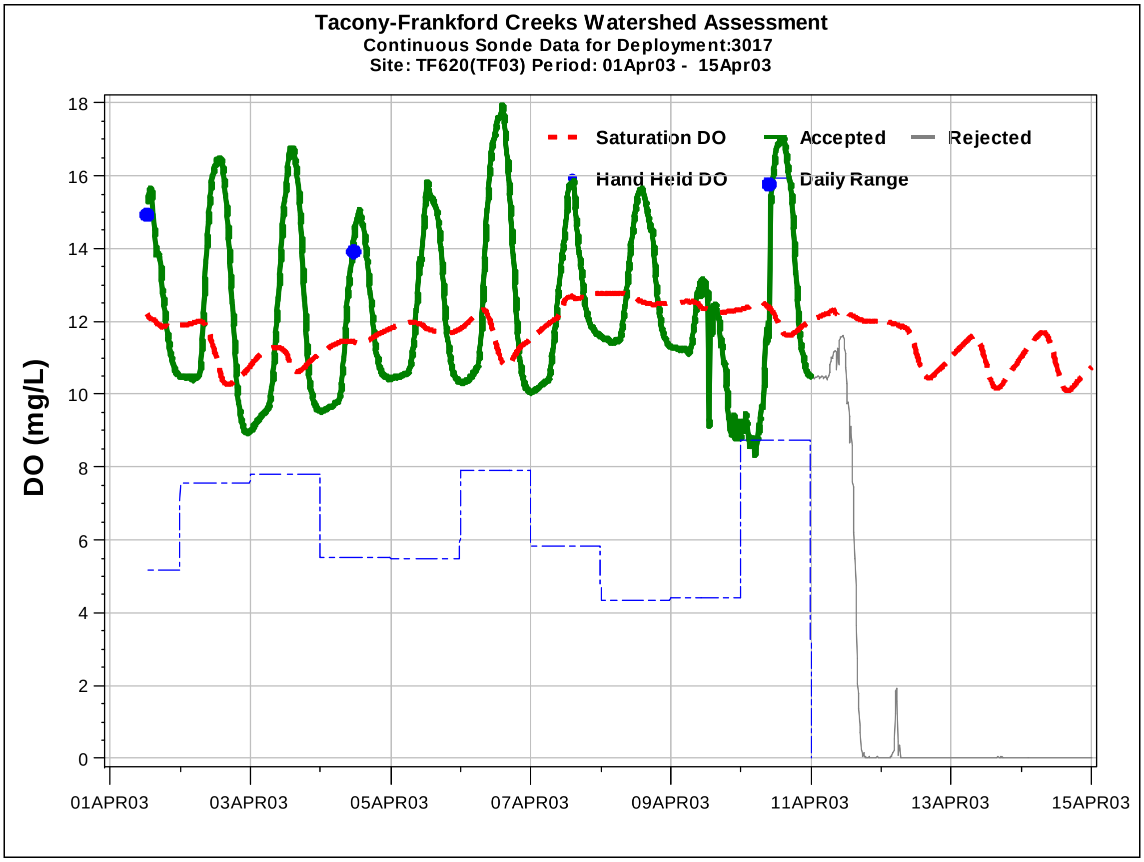


Figure 5.8 Time Series Plot of Dissolved Oxygen Exceedances in Wet and Dry Weather

Finally, Table 5.8 lists several other criteria that are related to aquatic life, but have no set regulatory limits. Criteria were established for this study as "flags of potential problems" using values relating to medians found through the U.S. EPA relevant to Ecoregion IX, subregion 64. As shown in the table, Chlorophyll A is high during both wet and dry weather, and is probably related to the above mentioned problem of large diurnal swings in DO. The nutrients nitrogen and phosphorus are also fairly high, possibly contributing to excessive algal growth. Turbidity and Total Suspended Solids are also quite high during wet weather, suggesting that bank and channel erosion may be occurring, as well as high wash loads of sediments in stormwater during rain events.

Table 5.8 Summary of Aquatic Life Criteria Exceedances

Parameter	Criteria	Dry			Wet		
		No. Obs.	No. Exceeds	% Exceed	No. Obs	No. Exceed	% Exceed
Chlorophyll A	Maximum	25	10	40.00	62	27	43.55
TKN	Maximum	55	5	9.09	404	225	55.69
TP	Maximum	67	8	11.94	451	165	36.59
TSS	Maximum	48	0	0.00	148	30	20.27
Turbidity	Maximum	61	1	1.64	441	148	33.56

Green – Parameter is not a problem *Yellow – Potential problem parameter* *Red – Problem parameter*

5.4 Potential Problem Parameter Summary

Based on the analysis, the problem and potential problem parameters are summarized below. The problem parameters are those constituents for which more than 10% of the samples exceed the standard. Parameters where the standards (or reference values) were exceeded over 2% of the time for all samples throughout the Tookany/Tacony-Frankford Watershed are listed as potential problems. Also, at the least, over 10% of parameter samples at one sampling location must exceed the standard to be considered a problem parameter.

In Table 5.9, the problem and potential problem parameters are listed by category. They are also broken down as either wet or dry weather problems, if applicable. For the metals, the listing is further broken down for chronic versus acute criteria.

Table 5.9 Summary of Problem and Potential Problem Parameters

Parameter	Standard	Dry	Wet	Chronic
Acute				
Al	Acute Maximum	🟩	🟧 ✓	🟩
Dissolved Cu	Acute Maximum	🟩	🟧 ✓	🟩
Chronic				
Al	Chronic Maximum	🟩	🟩	🟧 ✓
Dissolved Cu	Chronic Maximum	🟩	🟩	🟧 ✓
Water Supply				
Dissolved Fe	Maximum	🟨 ✓	🟨 ✓	🟩
Other Parameters based on reference values				
Chla	Maximum	🟧 ✓	🟧 ✓	🟩
Fe	Maximum	🟩	🟧 ✓	🟩
Phenolics	Maximum	🟩	🟧 ✓	🟩
TKN	Maximum	🟨 ✓	🟧 ✓	🟩
TP	Maximum	🟧 ✓	🟧 ✓	🟩
TSS	Maximum	🟩	🟧 ✓	🟩
Temp C	Maximum	🟩	🟨 ✓	🟩
Total Nitrogen	Maximum	🟩	🟨 ✓	🟩
Turbidity	Maximum	🟩	🟧 ✓	🟩
DO	Minimum	🟨 ✓	🟩	🟩
DO	Minimum Average	🟨 ✓	🟩	🟩

Green – Parameter is not a problem *Yellow – Potential problem parameter* *Red – Problem parameter*

5.5 Stream Ecology

The biological community of the TTF Watershed is heavily impacted by its urban surroundings. The impaired state of the creek is a result of habitat deterioration and water quality degradation. High levels of urbanization and development, and poor stream bank stability and flood control deeply influence the creek itself and the entire watershed. These factors have resulted in creek channelization, further inducing erosion and sedimentation problems. Natural water flows have been redirected to storm sewers and natural land surfaces replaced by block after block of impervious surfaces. Due to the changes in the hydrologic profile of the stream and watershed, storm events result in more concentrated runoff and cause more damage than they once did. Instead of percolating into the ground, stormwater is collected and rushed into an already unstable creek where it scours banks, fills pools, and covers riffles. The rushing water strips soil from the banks and deposits some of it over the embedded cobbles and takes the rest to the Delaware River, all the while holding on to the chemicals and pathogens collected on the city streets and in sewers. Figure 5.9 displays the results of the biological and habitat assessments.

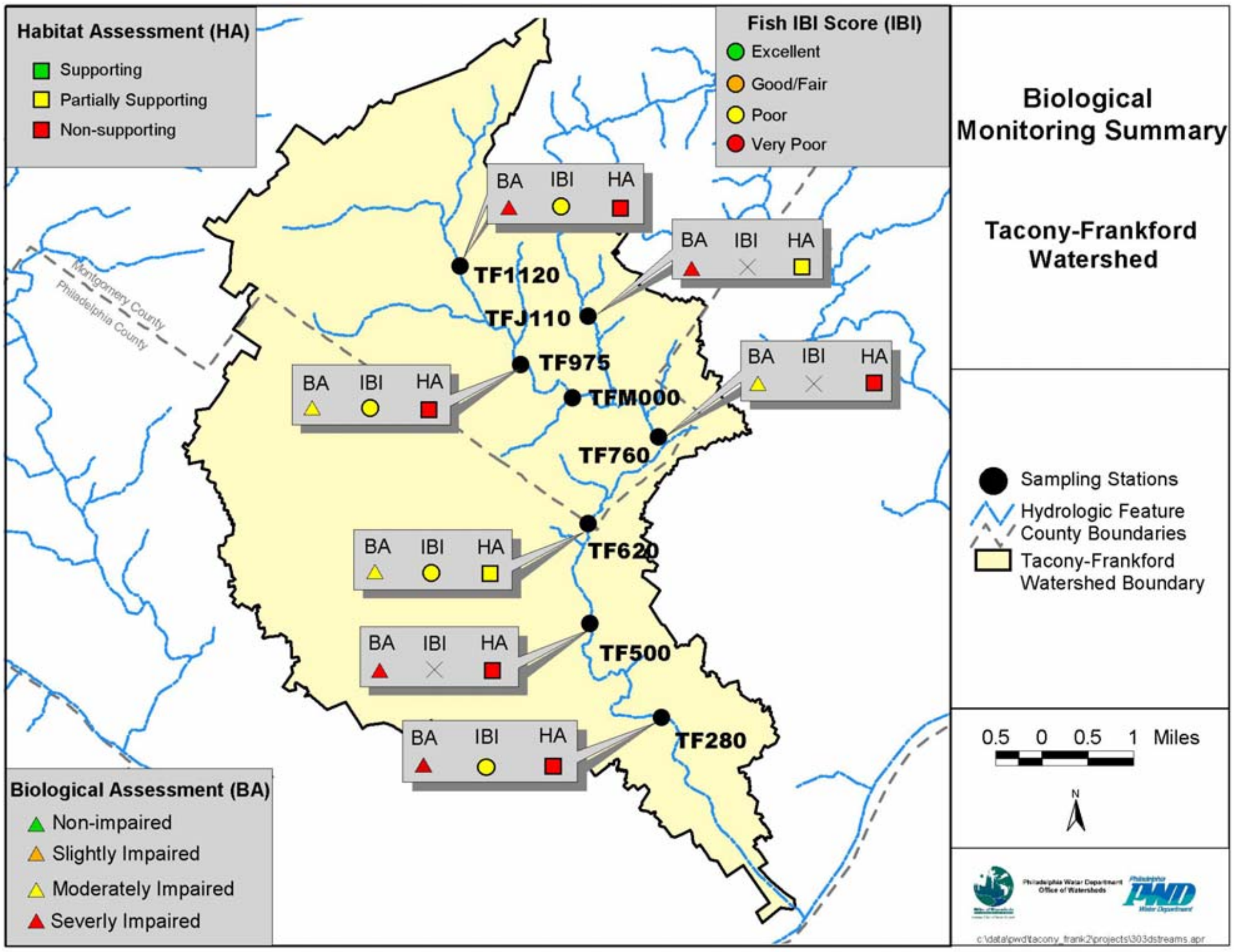


Figure 5.9 Tookany/Tacony-Frankford Biological Monitoring Summary

Biological monitoring indicates that the entire watershed suffers from impaired aquatic habitat and does not meet its designated use as a warm water fishery. As a result, the whole length of the Tacony-Frankford Creek and its tributaries were listed in PA DEP's 303d list of impaired waters in 1999. This impairment is due to severe water flow fluctuations, habitat alteration, point and non-point source (NPS) pollution from urban development, hydro-modification, and combined sewer overflows (CSOs) (PA DEP 2001). The tidal portion of the Frankford Creek remains unassessed because the biological assessment protocol is not applicable to tidal stream segments.

Habitat assessments of the Tacony-Frankford Watershed have determined much of the area to be non-supporting of a biological community. Eight sites within the watershed were assessed based on environmental features such as available vegetation and vegetative cover, riparian zones, stream bank stability, stream flow, riffles, pools, and other factors. Of these eight sites, six were determined to be lacking the attributes needed to support aquatic communities of organisms, while the other two were determined only capable of partially supporting aquatic communities.

Benthic macroinvertebrates rely heavily on stream riffles for at least part of their life cycle. Clinging to life in a riffle requires various adaptations, and most macroinvertebrates are not further prepared for the extreme hydrologic fluctuations that can occur in a channelized creek such as the Tookany/Tacony-Frankford. Increased stream velocities and sediment loads from eroding stream banks disrupt the benthic environment by alternately scouring the stream bottom of appropriately sized cobble substrate and burying those cobbles in sediment. Storm events lead to decreased species richness and evenness, which in turn changes the dynamics of feeding groups within the communities. Specialized feeders are greatly diminished, and generalists such as gatherer/collectors dominate the feeding community. Organisms well adapted to hydrologic extremes and to pollution also begin to dominate the communities. Of the eight sites evaluated for macroinvertebrate life, five were found to be severely impaired, and three were classified as moderately impaired. Only two of the sites were categorized as partially supporting of macroinvertebrate habitats, while the other six are non-supporting.

Like the benthic macroinvertebrate community, fish communities rely heavily on various habitats within a stream reach. An altered hydrologic profile in the stream leads to fewer offspring and decreased diversity in the fish community. The extreme flow conditions disrupt nesting habitats and routines for many species. Fish are also unable to rely on the presence of the calm pools and runs they often inhabit. A fish assessment of the Tookany/Tacony-Frankford Creek collected a total of 14 taxa, all of which being at least moderately tolerant of pollution. One of the sites evaluated had only three species of fish present. The low diversity and species richness is indicative of poor habitat and stream health.

5.6 Wetlands Assessment

As discussed in Section 4.5.2 (Indicator 13), the Philadelphia Water Department conducted an extensive wetlands assessment along the riparian corridor of the Tookany/Tacony-Frankford Watershed. Wetland indicators were used to identify possible wetland locations (e.g., soils, hydrology). Over 100 potential wetland locations were field evaluated, and 24 existing wetlands were identified. These wetlands were characterized using the Oregon Freshwater Wetland Assessment method, which evaluates how effectively a wetland performs the following functions: Wildlife Habitat, Fish Habitat, Water Quality, and Hydrologic Control.

The existing wetlands ranged in size from 0.01 to 2.5 acres. In total, only 15 acres of wetland (excluding open water) remain within the 685 acres that constitute the undeveloped riparian corridor of the Tookany/Tacony-Frankford Watershed, and most of those wetlands exhibit degraded wetland functions as a result of hydrologic disconnection from the waterways, encroachment, and invasive vegetation.

The most significant issues affecting wetlands are:

- Many wetlands have been lost to development;
- Remaining wetlands are not sufficiently inundated because stormwater is piped directly to streams;
- Wetlands are no longer hydrologically connected to the primary waterway;
- Wetlands have suffered encroachment and disturbance from urbanization;
- Wetland vegetative and wildlife diversity has been compromised by disturbance;
- Remaining wetlands are extensively compromised in terms of their water quality improvement function.

The extent of disturbance to the remaining wetlands is indicated by the degree to which the wetland functions have been degraded and the degree of human disturbance. The wetland field investigation produced ratings of the degree to which wetland functions have been compromised and the extent of human disturbance to the wetlands sites. This information is summarized in the tables and figures below.

Table 5.10 Wetland Functional Assessment Results for Tookany/Tacony-Frankford Creek Watershed (based on 24 wetland locations)

Function	***Number of Wetlands with Stated Condition***
Wildlife Habitat	
Diverse Habitat	10
Moderate Habitat	14
Fish Habitat	
Intact Habitat	6
Degraded	12
Lost / Not Present	6
Water Quality Improvement	
Intact Function	3
Degraded Function	21
Hydrologic Connection to Stream	
Intact Connection	16
Degraded Connection	7
Connection Lost / Not Present	1

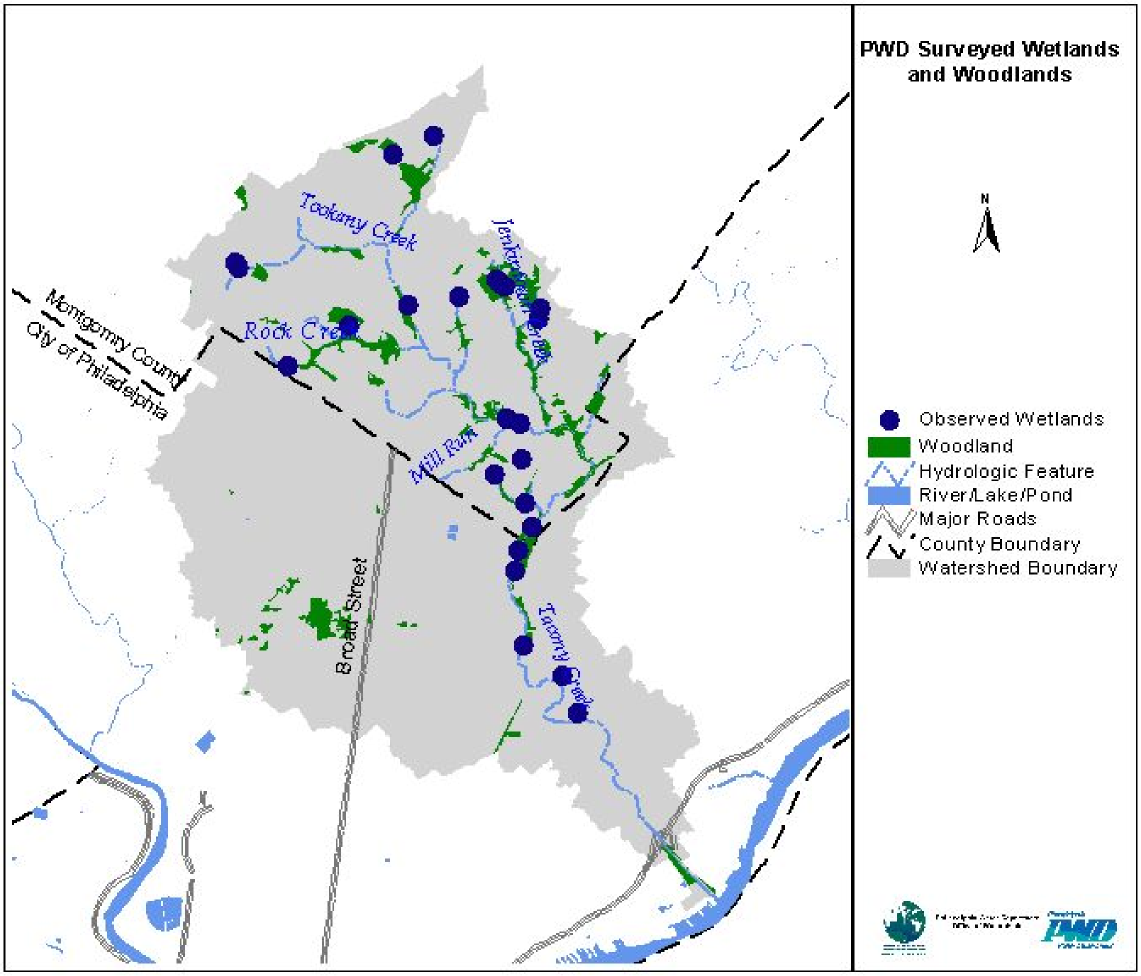


Figure 5.10 Location of Wetlands

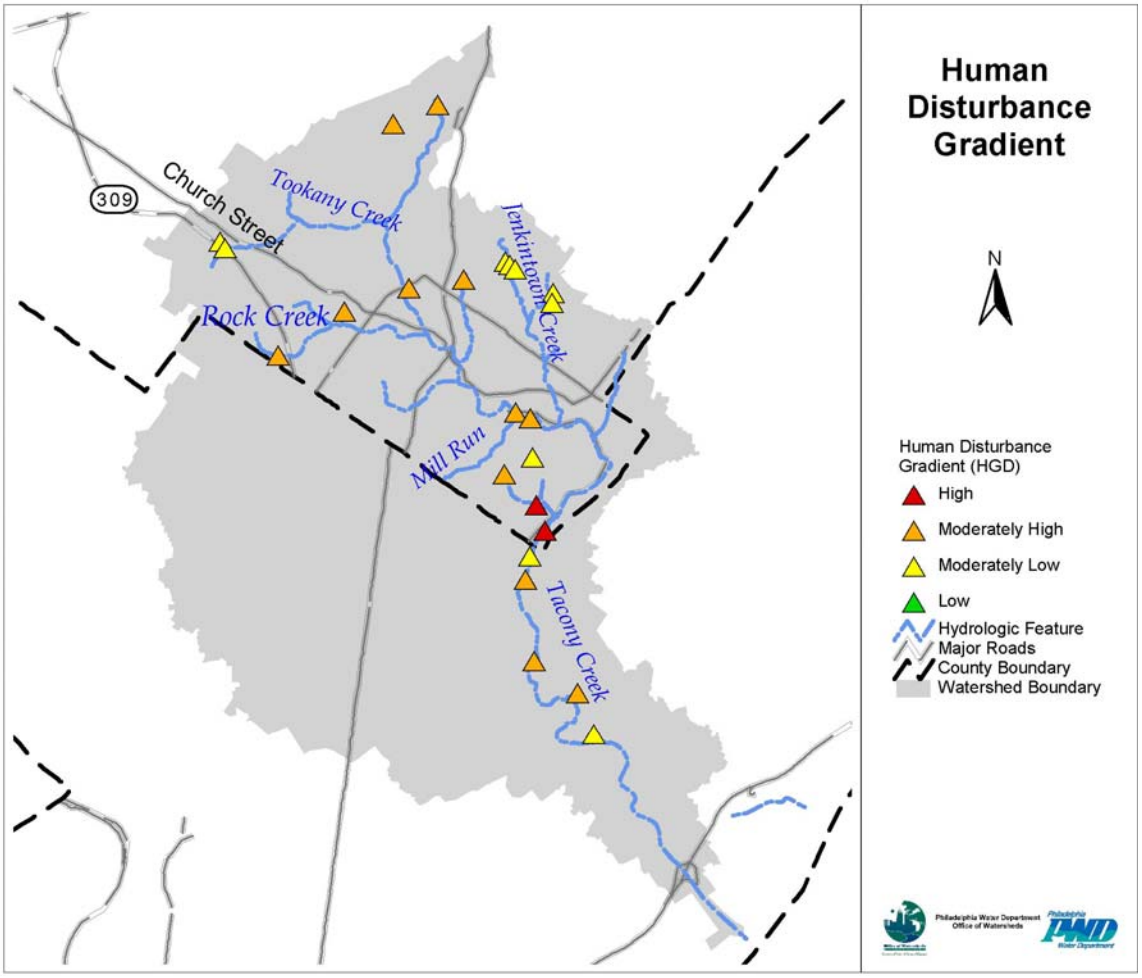


Figure 5.11 Rank of Human Disturbance Gradient

Table 5.11 Rank of Human Disturbance Gradient

Human Disturbance Gradient Rank	Number of Wetlands
Moderately Low Disturbance	10
Moderately High Disturbance	12
Highly Disturbed	2

5.7 Potential Problem Parameters and Planning Implications

Based on the comparisons to water quality criteria, the problem and potential problem parameters have been identified for the Tookany/Tacony-Frankford Watershed. Table 5.12 summarizes these parameters.

Table 5.12 Summary of Problem and Potential Problem Parameters

Parameter	**Dry Weather**	**Wet Weather**	**Chronic**
Fecal Coliform	🟥 ✓	🟥 ✓	
Chlorophyll A	🟥 ✓	🟥 ✓	
TKN	🟥 ✓	🟥 ✓	
TP	🟥 ✓	🟥 ✓	
Turbidity	🟥 ✓	🟥 ✓	
Cu	🟨 ✓	🟥 ✓	🟥 ✓
TSS	🟨 ✓	🟥 ✓	
Iron	🟩	🟥 ✓	
Zn	🟩	🟥 ✓	🟨 ✓
Al	🟩	🟥 ✓	🟥 ✓
Pb	🟩	🟥 ✓	🟥 ✓
Dissolved Fe	🟨 ✓	🟨 ✓	
Temperature	🟨 ✓	🟨 ✓	
DO	🟨 ✓	🟩	
TN	🟩	🟨 ✓	
Chromium			🟨 ✓

Green – Parameter is not a problem *Yellow – Potential problem parameter* *Red – Problem parameter*

The Tookany/Tacony-Frankford Watershed is faced with many challenges. Stormwater outfalls (SWOs) and combined sewer overflows (CSOs) have exacerbated problems within the watershed. Poor water quality and diurnal variations in levels of dissolved oxygen are added stresses on local fauna. Insufficient habitat combined with the highly variable stream flow makes it difficult to establish a diverse and healthy biotic community. An urban watershed must overcome many obstacles to establish meaningful habitat within and alongside a stream.

Table 5.13 (below) lists the indicators that directly link to water quality and aquatic habitat. The water quality sampling locations have been graded according to sampling results and watershed assessments. For most of the Tookany/Tacony-Frankford Watershed, the indicators have been marked as poor or very poor. Dissolved oxygen, important to maintaining aquatic life, has been identified as a potential problem in the downstream portion of the watershed area.

Table 5.13 Related Watershed Indicator Ratings by Sampling Location

	Indicator 1: Land Use and Impervious Cover	*Indicator 2: Streamflow*	*Indicator 3: Stream Channels and Aquatic Habitat*	*Indicator 5: Fish*	*Indicator 6: Benthos*	*Indicator 7: Effects on Public Health (Bacteria)*	*Indicator 8: Effects on Public Health (Metals and Fish Consumption)*	*Indicator 9 : Effects on Aquatic Life (Dissolved Oxygen)*	*Indicator 10: Point Sources*	*Indicator 11: Non-point Sources*	*Indicator 12: Riparian Corridor*	*Indicator 13: Wetlands and Woodlands*
TF280	●	◕	●	◕	●	●	●	◒	◒	●	●	●
TF500	●	◕	●	X	●	◕	◕	○	○	●	◒	◕
TF620	◕	◒	●	◕	◕	◒	◒	○	○	◒	●	◕
TF680	X	X	X	X	X	●	◕	○	○	◕	X	●
TF760	◕	◒	●	X	◕	◒	◒	○	◒	◒	◕	○
TF975	◕	◒	●	◕	◕	◕	◒	○	○	◒	◒	○
TF1120	◕	◒	●	◕	●	◒	◒	○	◒	◕	●	○
TFM000	◕	X	●	X	X	X	X	○	○	◒	◕	◕
TFJ110	◕	X	●	X	●	X	X	X	○	◒	◕	○

Very Poor	●
Poor	◕
Good/Fair	◒
Excellent	○

Results of the water quality sampling indicate that the water quality of the Tookany/Tacony-Frankford is impaired, with the problems associated primarily with wet weather conditions. Some problems have been identified during dry weather. Sources of bacterial contamination during dry weather may include inappropriate or illicit discharges from storm or sanitary sewerage systems. Detection of these sources is valuable to the management goals of the Tookany/Tacony-Frankford Watershed. Dry weather concentrations of nutrients may be attributed to treated wastewater effluent, over-watering of lawns and gardens, pet waste, and failing septic tanks.

In wet weather, the model-estimated pollutant loadings have identified contributions from different sources. Estimated annual pollutant contributions for the Tookany/Tacony-Frankford Watershed are discussed in Section 4.4. Permitted industrial and municipal point source discharges make up less than 1% of annual streamflow in both systems. SSOs are thought to occur in both watersheds but have not been well documented to date.

Section 6
Causes of Impairment

This section discusses the causes of the various watershed problems identified through field study, stakeholders input, modeling, and data analysis. It forms the link between the problem analysis presented in Section 5, and the identification of alternative solutions or "management options" presented in Section 7.

There are seven types of primary problems to be addressed. These include:

- Trash and dumping
- Erosion, sediment accumulation, and flow variability
- Instream sewer odors
- Lack of healthy riparian habitat
- Poor instream habitat and biological impairment
- Impaired wetlands
- Water quality concerns (metals, TSS, fecal coliform, DO)

In most cases, field studies and data analysis have identified one or more causes for the problem or impairment. In some cases, particularly regarding dissolved oxygen, further studies will be required before a full understanding of the problem is achieved. The high priority problems and their probable causes are discussed below, with recommendations for additional study where appropriate.

6.1 Trash and Dumping

Cause

The source of litter and dumped material is not hard to establish. Litter reaches the stream through careless behavior resulting from trash and litter accumulation in the streets. If not controlled, this accumulation will wash into the storm sewers or combined sewers and eventually be discharged into the streams. Once in the stream, it can get trapped along banks, or build up near flow obstructions such as bridge supports. In general, littering is not an intentional activity, but results from carelessness or lack of concern for its effect on the environment. Dumping, however, is a more deliberate act, and occurs when people gain access to the stream and dump waste material from the home or business directly into the stream. Dumping is generally done to avoid the costs associated with proper disposal. In either case, the cause of the buildup of litter and trash in the stream is clear, and can only be addressed through education and enforcement to eventually modify the behavior of people living and working in the watershed.

Further Studies

Some further study will be required to identify points along the stream that are most easily accessible by vehicle, and where illegal dumping has been a common practice in the past.

6.2 Erosion, Sediment Accumulation, and Flow Variability

Cause

Erosion of the channel bed and along the streambanks has been identified as a problem in many areas of the watershed. High levels of urbanization and development and poor stream bank stability deeply influence the Tookany/Tacony-Frankford Creek. Natural water flows from some portions of the creek have been redirected to storm sewers and replaced by block after block of impervious surfaces. Due to the changes in the hydrologic profile of the stream and watershed, storm events result in greater amounts of runoff and cause more damage than they once did. Instead of percolating into the ground, stormwater is collected and rushed into an already unstable creek where it scours banks, fills pools, and covers riffles. The rushing water strips soil from the banks and deposits some of it over the embedded cobbles and takes the rest to the Delaware River, all the while holding on to the chemicals and pathogens it collected on the city streets and in the sewers.

The cause of erosion can be traced primarily to the above mentioned flow variability, particularly to bankfull flow conditions that occur more frequently than in more natural watersheds due to the urbanized nature of the Tookany/Tacony-Frankford watershed. Sediment buildup can be caused either by streambed and streambank erosion, or by sediment washing into the creek from stormwater discharges. Note that flow variability has been identified as both a problem in itself, and as the cause of erosion and poor instream habitat (discussed below).

Further Studies

The flow variability is well established and understood, and does not require additional studies. The erosion problem has been generally identified through stream assessments. Further studies will be required, however, to prioritize areas undergoing erosion, and to more exactly identify the cause of erosion or sediment buildup for each reach of the river where erosion or deposition is occurring. These studies will be carried out during conceptual design of stream restoration measures.

6.3 Instream Sewer Odors

Cause

Sewer odors occur during dry weather when sewer lines leak into the stream, or when waste lines from homes or businesses are cross-connected to storm sewers in areas where the sanitary and storm sewer systems are separate. Odors also occur during wet weather, with the cause identified as combined sewer overflows (CSOs), or in areas of separate storm and sanitary sewers, through sanitary sewer overflows (SSOs).

Further Studies

Although the causes are well known, further studies will be required to pinpoint the location and cause of all dry weather sewer discharges in separate sewered areas, and to identify SSOs and opportunities for reduced CSOs during wet weather.

6.4 Lack of Healthy Riparian Habitat

Cause

The entire length of the Tookany/Tacony-Frankford Creek has been assessed, and the existence or absence of riparian buffers noted. The cause is usually obvious: Either development has encroached on the riparian buffer, leaving little or no room for a vegetated buffer, or the riparian area is open but poorly managed.

Further Studies

Additional studies will be required in developing a riparian buffer improvement program. These studies will primarily involve the identification of land ownership of riparian areas.

6.5 Poor Instream Habitat and Biological Impairment

Cause

Poor instream habitat has been identified as both a problem itself, as well as the cause of biological impairment found throughout the watershed. Stream channels in the Tookany/Tacony-Frankford Watershed exhibit many effects of urbanization, including over-widening, erosion, loss of sinuosity, loss of the floodplain, loss of stream connection, channel modification, and loss/degradation of aquatic habitat. Biological monitoring indicates that the whole Tookany/Tacony-Frankford Watershed suffers from impaired aquatic habitat and does not meet its designated use as a warm water fishery. As a result, the whole length of the non-tidal Tookany/Tacony-Frankford Creek and its tributaries were listed in PA DEP's 303d list of impaired waters in 1999. This impairment is due to severe water flow fluctuations, habitat alteration, point and non-point source pollution from urban development, hydromodification, and combined sewer overflows (PA DEP 2001). The tidal portion of the Frankford Creek remains unassessed because the biological assessment protocol is not applicable to tidal stream segments.

The biological community of the Tookany/Tacony-Frankford Watershed is heavily impacted by its urban surroundings. The impaired state of the creek is a result of habitat deterioration due to urbanized stormwater flow patterns and/or water quality degradation.

Benthic macroinvertebrates rely heavily on stream riffles for at least part of their life cycle. Clinging to life in a riffle requires various adaptations, and most macroinvertebrates are not prepared for the extreme hydrologic fluctuations that can occur in a channelized creek such as the Tookany/Tacony-Frankford. Increased stream velocities and sediment loads from eroding stream banks are disrupting the benthic environment by scouring the stream bottom of appropriately sized substrates. The cobble substrate has limited interstitial space, often filled by finer materials, for benthic macroinvertebrates to thrive. Storm events lead to decreased species richness and evenness, which in turn changes the dynamics of feeding groups within the communities. Specialized feeders are greatly diminished, and generalists such as gatherer/collectors dominate the feeding community.

Like the benthic macroinvertebrate community, fish communities rely heavily on various habitats within a stream reach. An altered hydrologic profile in the stream leads to fewer offspring and decreased diversity in the fish community. The extreme flow conditions disrupt nesting habitats and routines for many species. Fish are also unable to rely on the presence of the calm pools and runs they often inhabit.

Further Studies

Additional detailed studies will be required to better understand the degree of impairment and to pinpoint the causes of impairment for each stretch of the stream system. It is also critical to better understand the relative importance of the habitat impairment and the low dissolved oxygen conditions found in the downstream areas of the watershed as it relates to impaired benthic macroinvertebrate and fish communities. These studies must be completed prior to making detailed recommendations on habitat improvement.

6.6 Impaired Wetlands

Cause

Wetland assessments have identified the loss of wetlands and the impairment of remaining wetlands as a problem. The remaining wetlands were evaluated for their value as wildlife and fish habitat, and for their potential to improve water quality (nutrient and toxicant reduction) and temper the hydrologic regime (flood flow). Nearly all wetlands in the watershed exhibit impaired functions that indicate extensive disturbance and deterioration. Urban and suburban development has resulted in the piping of historic streams, destruction of wetlands, and deforestation and modification of historic floodplains. Stormwater is piped directly to waterways rather than flowing overland through vegetation, wetlands, and woodlands. Also, because stormwater runoff frequently flows over impervious surfaces, and is then piped to the streams, the flow and volume of runoff is intensified. Because most stormwater is piped directly to the waterways of the watershed, there is no longer a source of water to maintain many of the wetlands that once existed.

Further Studies

No further studies are anticipated, beyond those associated with the conceptual design of wetland enhancement or wetland creation at specific sites within the watershed.

6.7 Water Quality Concerns (Metals, TSS, Fecal Coliform, DO)

Cause

The primary water quality concerns were identified as elevated concentrations of some metals and Total Suspended Solids (TSS), particularly during wet weather events, high fecal coliform counts, particularly in wet weather, and low dissolved oxygen (DO) in downstream areas of the creek. The primary sources of contaminants are wet weather flows from separate and combined sewers, and some sewage flows during dry weather due to the connection of waste lines to a separate storm sewer, or to leaking combined sewer lines.

Stormwater running off of impervious areas can carry pollutants to the stream through the storm sewers and, during overflow events, through the combined sewer. Stormwater-borne pollutants can include litter, nutrients, metals, fecal coliform from pet wastes, pesticides used on lawns, and sediment. Non-point source pollution poses a threat to the water quality in the Tookany/Tacony–Frankford creek because of the volume of stormwater runoff and the concentrations of pollutants found in the stormwater.

A model was used to estimate runoff quantity and quality in storm, sanitary, and combined sewer systems and from each land use type within the subwatersheds. The list of pollutants simulated using the model included parameters such as nitrate and phosphorus, total suspended solids, heavy metals, and BOD (biological or biochemical oxygen demand). Although the source of pollutants is well established, the model results helped identify areas where stormwater runoff or pollutant loads are particularly high and in need of control.

Using lead and copper to represent metals in the Tookany/Tacony-Frankford watershed, the model-generated stormwater runoff loads are compared with the wet weather exceedance of the standards in Figures 6.1 and 6.2. The results show areas where higher loads are contributing to degraded stream water quality during wet weather, however, the lack of wet weather sampling data does not allow for comparison with runoff loads.

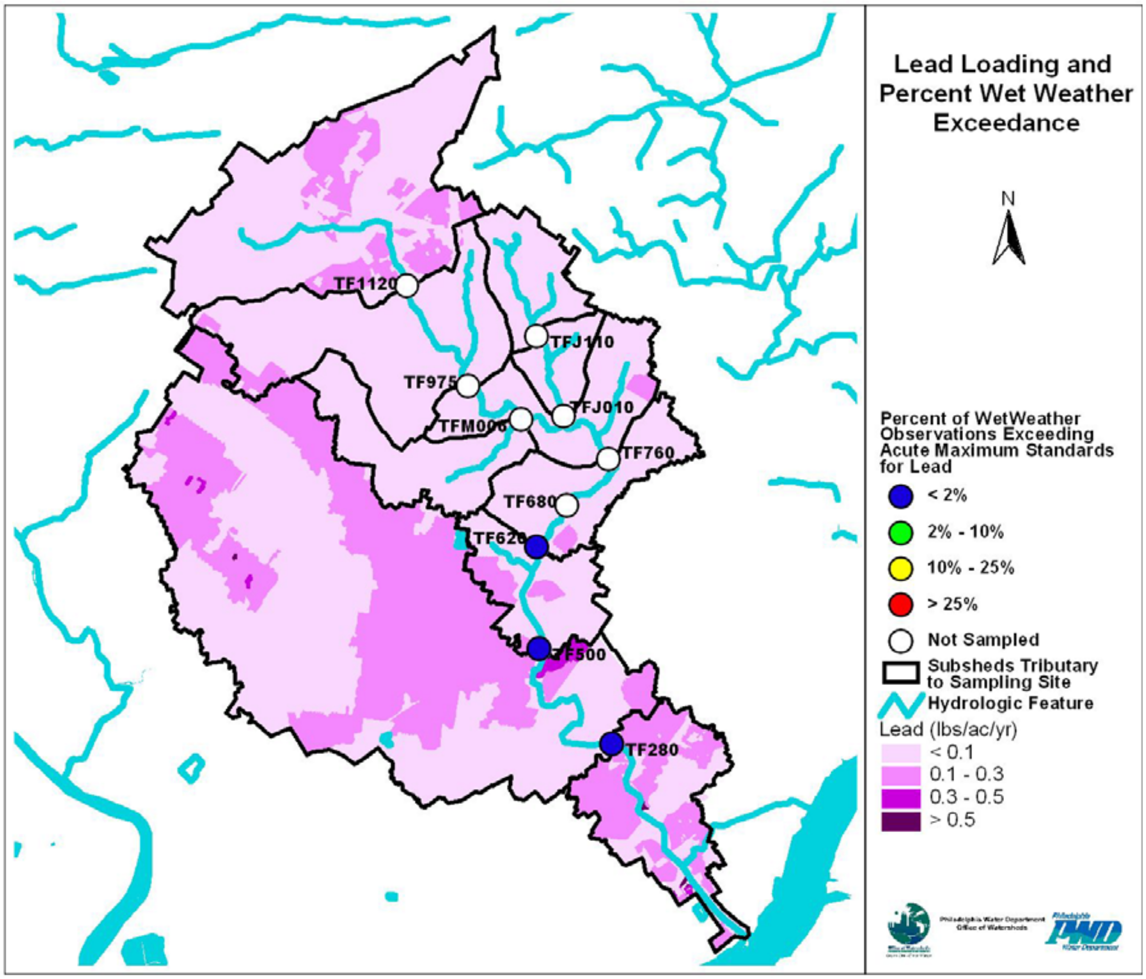


Figure 6.1 Lead Loading

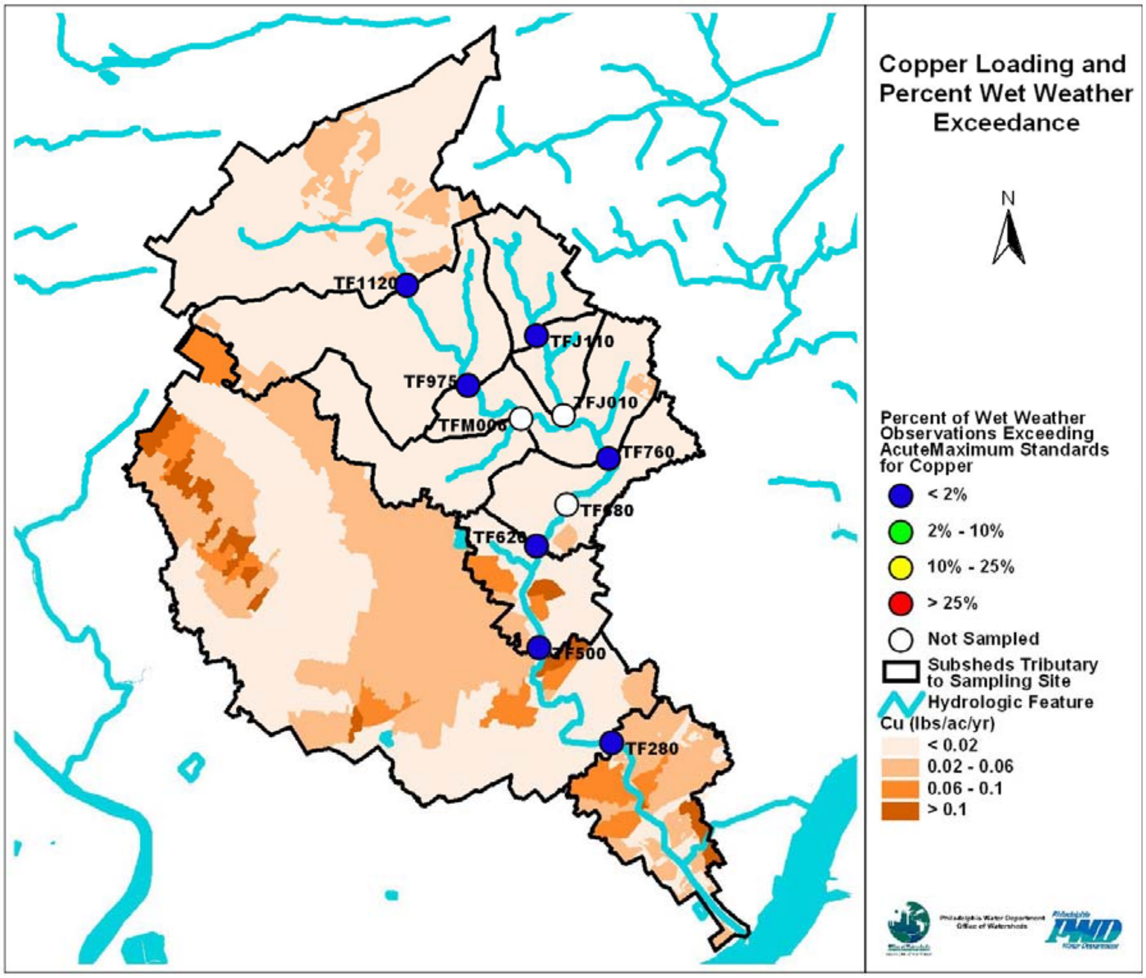


Figure 6.2 Copper Loading

CSO and stormwater discharges are the dominant sources of fecal coliform in the Tookany/Tacony-Frankford Watershed during wet weather. Figure 6.3 displays the spatial distribution of runoff loads for fecal coliform compared with the wet weather water quality. As indicated from the water quality data, fecal coliforms are a problem throughout the watershed.

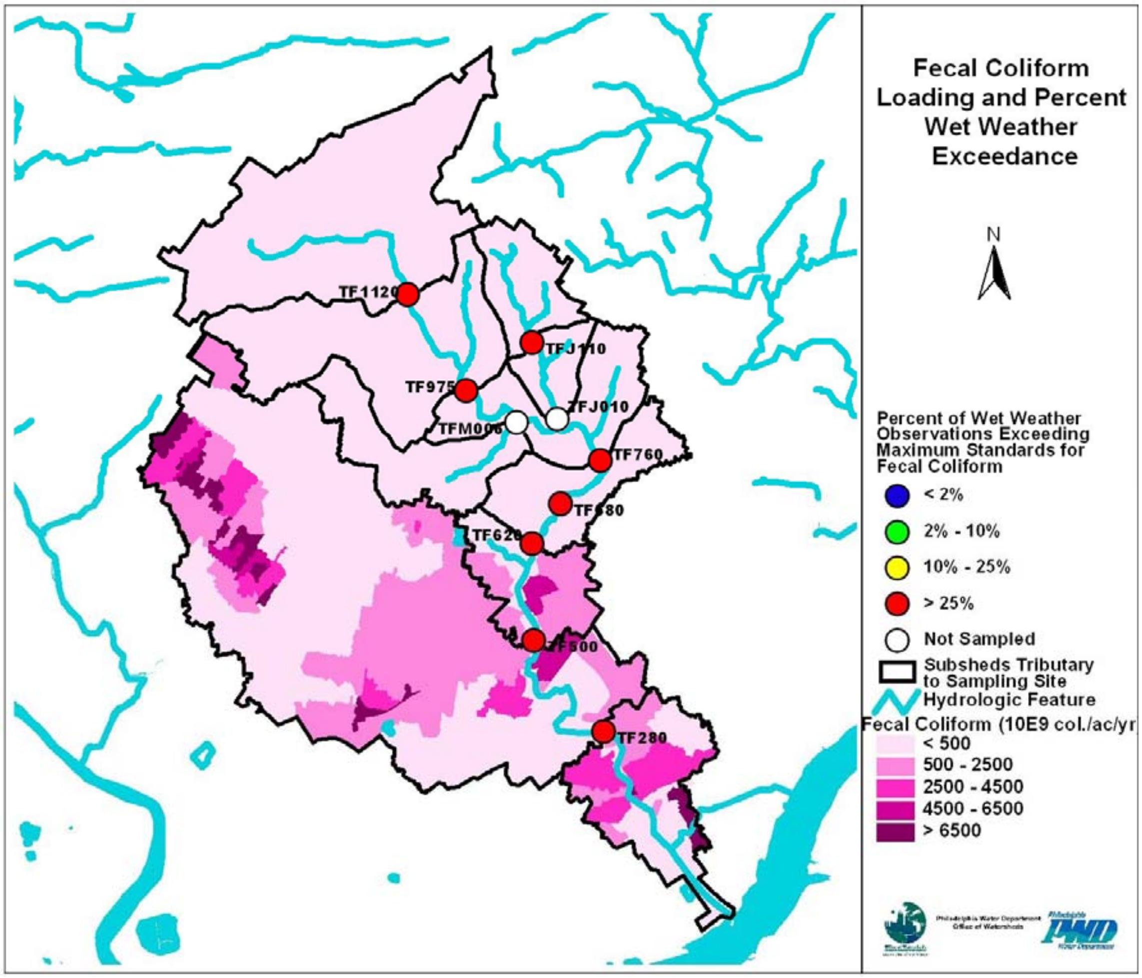


Figure 6.3 Fecal Coliform Loading

Figure 6.4 shows the model-estimated TSS loading and the wet weather sampling results. The pattern of sample results and model-estimated loads is a little less clear for TSS than for some of the other pollutants, with exceedances occurring both upstream and downstream, and loading more heavily weighted toward the urbanized, downstream portion of the watershed. This may indicate that stormwater runoff is not the only source of sediment, and that instream channel and bank erosion may also be a significant source. Additional studies would be necessary to further pinpoint the sources.

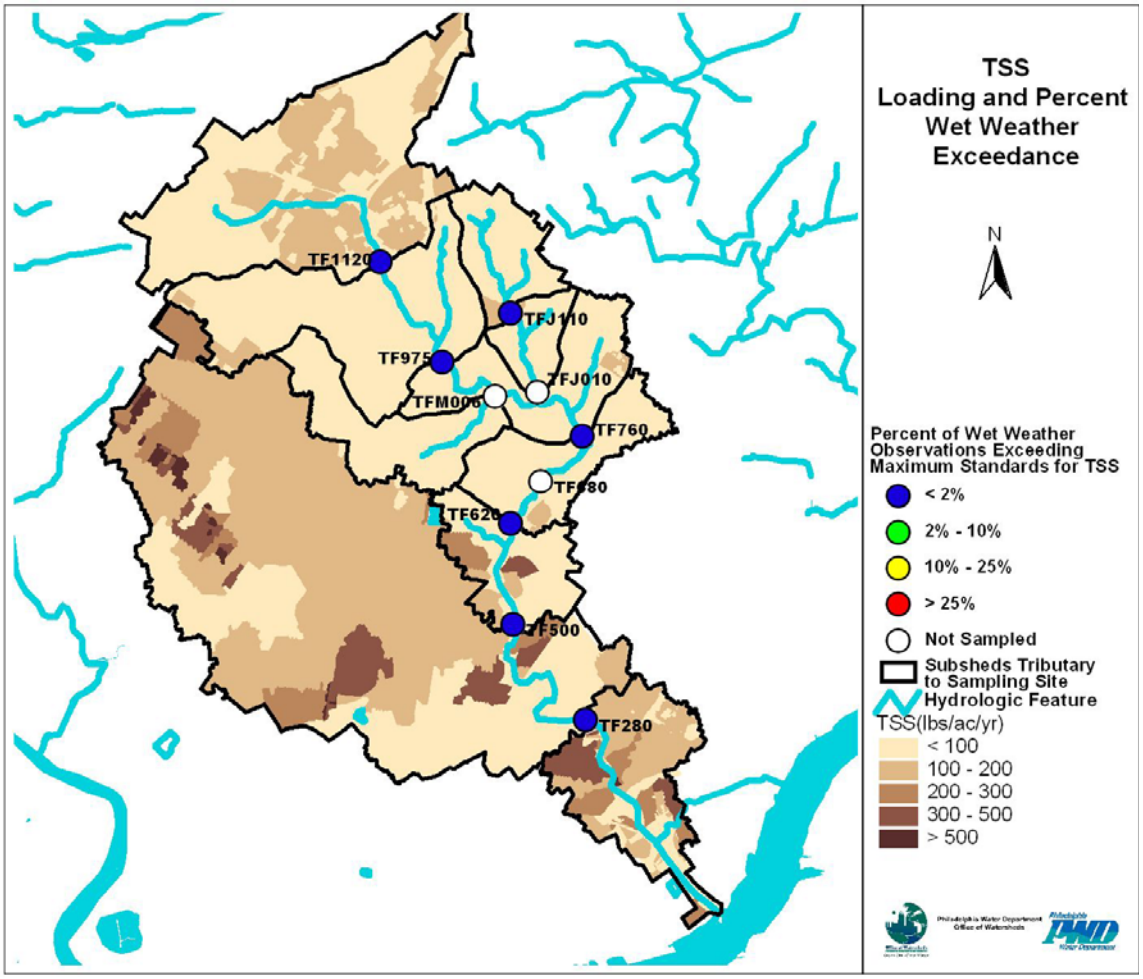


Figure 6.4 Total Suspended Solids Loading

CSOs are the largest source of pollutants associated with urban and suburban runoff, including nutrients such as phosphorus and metals such as lead, copper, and zinc. For the Tookany/ Tacony-Frankford Watershed, stormwater outfalls are a smaller but significant source of these constituents. (Figure 4.20 illustrated the model-estimated contributions for metals and fecal coliforms as percentages of the total estimated load.)

Low dissolved oxygen has been identified as a potential problem in the downstream section of the creek. In addition, unusually high diurnal fluctuations in DO have also been observed in the downstream sections. There are several potential causes of low DO. These include:

- High BOD loading during dry and wet weather;

- The existence of scour pools or pools upstream of dams that do not flush frequently enough, allowing anoxic conditions to occur;
- Excessive growth of attached algae that alternately produce and consume oxygen resulting in large diurnal fluctuations in DO;
- The buildup of organic material in the sediment that exerts high oxygen demand.

BOD (biological or biochemical demand) loading is a concern in the watershed. The BOD load estimates are shown in Figure 6.5. Sediments may store BOD, which may become re-suspended during storms, moving the area of DO deficit further downstream. Generally, the loads carried to the stream by stormwater are highest further downstream in the watershed.

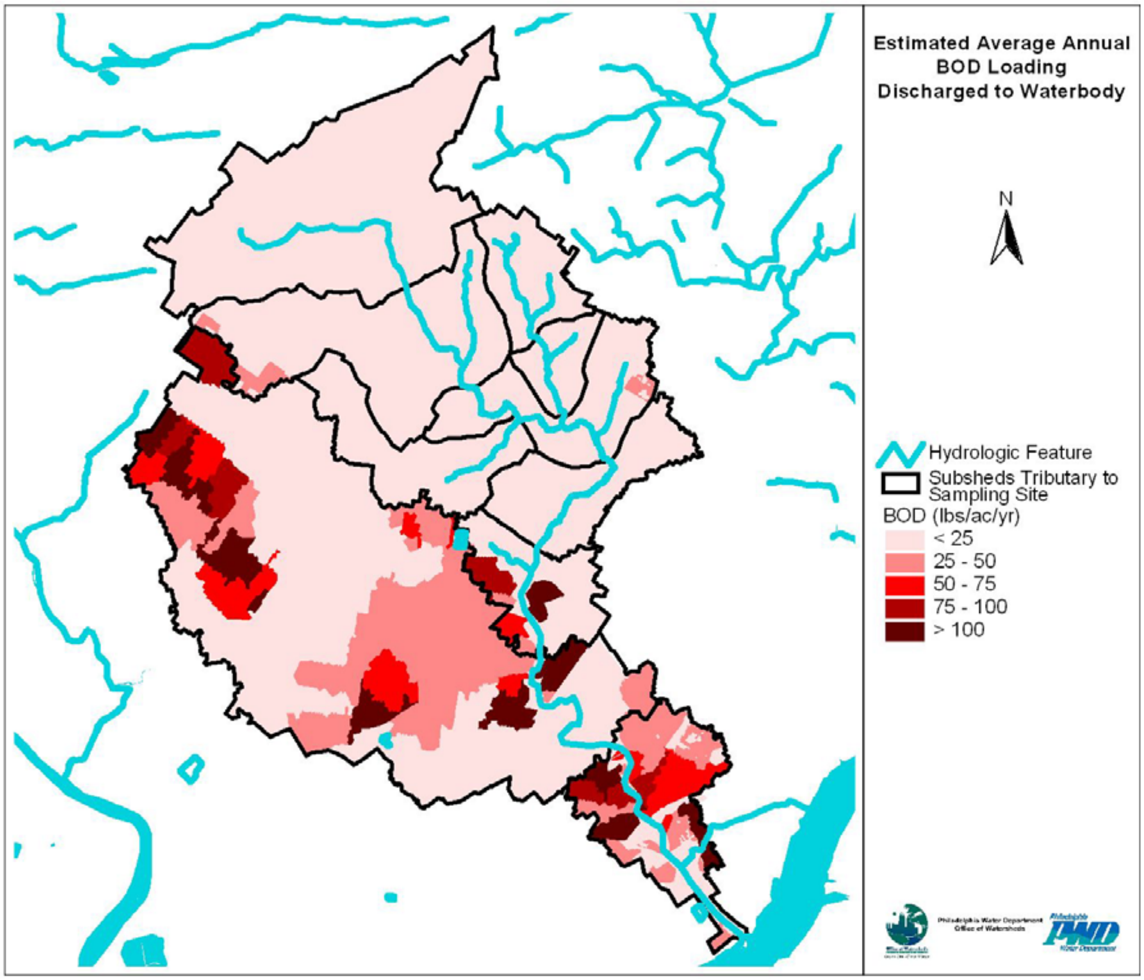


Figure 6.5 Total BOD Loading

Low DO is suspected in the area upstream of the dam at Adams Avenue. This may be caused by a combination of a deep pool that does not flush frequently, and high sediment oxygen demand.

<u>Further Studies</u>

The causes of TSS exceedances have been identified as stormwater discharges, CSOs, and instream erosion. The relative contributions of each, however, have not been adequately characterized. This will require additional analysis once the stream assessment data are available, combined with some additional modeling.

The causes of suspected DO problems in the Tookany/Tacony Frankford Watershed are not yet sufficiently understood, and will require further studies.

Studies should be carried out to:

- better understand the impact of attached algae on DO fluctuations (water quality modeling and field studies);
- identify areas where plunge pools and dams may be the cause of localized occurrences of low DO;
- assess the sediment oxygen demand and the BOD in the water column to better understand the relative contributions of each to low DO; and
- better assess sources of BOD during both dry and wet weather.

Section 7
Development and Screening of Management Options

This section summarizes a comprehensive list of stormwater and watershed corrective measures, or "management options," that the TTF Watershed Partnership judged to be potentially applicable to their watershed. This list serves as the starting point for the screening and evaluation steps (Section 7.2) that lead to the array of recommendations contained in the Implementation Guidelines (Section 8).

7.1 Menu of Options

A large amount of detailed information on these watershed management options is already available from existing sources. Rather than reproducing this information, this section provides references and links to these sources.

The options are grouped under the three targets introduced in Section 2 (with codes listed parenthetically for reference below and in the sections that follow):

Target A: Dry Weather Water Quality and Aesthetics
- Regulatory Approaches (AR1,2)
- Public Education and Volunteer Programs (AP1-3)
- Municipal Measures (AM1-7)
- Enhancing Stream Corridor Recreational and Cultural Resources (AO1)
- Monitoring, Reporting, and Further Study (AMR)

Target B: Healthy Living Resources
- Channel Stability and Aquatic Habitat Restoration (BM1-5)
- Lowland and Upland Restoration and Enhancement (BM6-9)
- Monitoring, Reporting, and Further Study (BMR)

Target C: Wet Weather Water Quality and Quantity
- Regulatory Approaches (CR1-9)
- Public Education and Volunteer Programs (CP1)
- Municipal Measures (CM1-9)
- Stormwater Management:
  - Source Control Measures (CS1-5)
  - Onsite and Regional Stormwater Control Facilities (CS6-16)
- Monitoring, Reporting, and Further Study (CMR)

7.1.1 Target A: Dry Weather Water Quality and Aesthetics

Target A is defined for Tookany/Tacony-Frankford Creek as focusing on trash removal and litter prevention, and the elimination of sources of sewage during dry weather. Streams should be aesthetically appealing (look and smell good), accessible to the public, and be an amenity to the community. Sewer odors occurring from dry weather sewer discharges in both combined and separate sewered areas should be remedied.

Regulatory Approaches

AR1 On-Lot Disposal (Septic System) Management
AR2 Pet Waste, Litter, and Dumping Ordinances

These typical pollution reduction and aesthetic ordinances are already in effect in many locations, and can be effective at controlling diffuse sources of pollutants. They are particularly important in urban watersheds; however, they must be consistently enforced to be effective.

Public Education and Volunteer Programs

AP1 Public Education
AP2 School-Based Education
AP3 Public Participation and Volunteer Programs

Municipal Measures

AM1 Capacity Management Operation and Maintenance (CMOM)
AM2 Inspection and Cleaning of Combined Sewers
AM3 Sanitary Sewer Rehabilitation
AM4 Combined Sewer Rehabilitation
AM5 Illicit Discharge, Detection, and Elimination (IDD&E)
AM6 Stream Cleanup and Maintenance
AM7 Household Hazardous Waste Collection

Enhancing Stream Corridor Recreational and Cultural Resources *(AO1)*

Preservation and enhancement of recreational and cultural resources may be integrated into comprehensive watershed management. These resources are part of the link between the human population and natural resources in a watershed. Strategies to provide access to water resources for recreational purposes encourage appreciation for and stewardship of these areas. Strategies to protect water-based historic structures should be implemented to insure that flooding and other impacts are avoided.

Monitoring, Reporting, and Further Study *(AMR)*

Monitoring and reporting under Target A include monitoring of progress toward achievement of objectives (as measured by indicators introduced in Section 4) and monitoring of implementation of recommended management measures. For example, Indicator 18 measures "tons of trash removed from streams and riparian areas" (a measure of option implementation) and derives a stream accessibility score for individual reaches of the creek (a measure of progress toward an objective).

7.1.2 Target B: Healthy Living Resources

Improving the ability of an urban stream to support viable habitat and fish populations focuses primarily on remediation of the more obvious impacts of urbanization on the stream. These impacts include loss of healthy riparian habitat, eroding and undercut banks, scoured streambed or excessive sediment deposits, channelized and armored stream sections, and invasive species. Encroaching development on the riparian buffer can leave little or no room for a vegetated buffer, while other open riparian areas are often left poorly managed. Biological monitoring indicates that the whole Tookany/Tacony-Frankford Watershed suffers from impaired aquatic habitat and does not meet its designated use as a warm water fishery. This impairment is due to severe water flow fluctuations, habitat alteration, point and non-point source pollution from urban development, hydromodification, and combined sewer overflows (PA DEP 2001).

The primary tool to address these problems is stream restoration. Restoration addresses poor instream habitat and biological impairment, focusing on improving channel stability, improving instream and riparian habitat, providing refuge that allows fish to avoid high velocity conditions during storms, and managing land within the stream corridor. Lowland restoration and enhancement addresses the problem of wetland loss and impairment. Nearly all wetlands in the watershed exhibit impaired functions that indicate extensive disturbance and deterioration.

The wet weather strategy includes both restoration of physical stream habitat and reduction of discharges from stormwater and combined sewage. These measures are complementary; stream restoration provides areas of lower flow where aquatic life can avoid higher flows, and discharge reduction helps limit velocities and protects the long-term investment in the restored stream. Targets B and C are intended to accomplish the restoration of physical stream habitat through control measures involving erosion, sediment accumulation, and flow variability.

Many of the stresses faced by aquatic life in urban streams are the result of alternating extremes of high and low flow, and the resulting sediment scour and deposition. While stormwater BMPs that promote infiltration do help to reduce these extremes, a recent modeling analysis conducted by PWD indicates that impervious cover would have to be reduced by half or more to have a significant effect. This result indicates that stream restoration measures may be a more feasible means of improving the aquatic habitat in the short term. Modern design techniques may create areas of reduced velocity where aquatic life is protected during high flow. Techniques appropriate to our area are summarized in “Guidelines for Natural Stream Channel Design for Pennsylvania Waterways,” by the Alliance for the Chesapeake Bay, March 2003. This publication is available online at http://www.acb-online.org/toolkits.cfm.

Channel Stability and Aquatic Habitat Restoration

BM1	Bed Stabilization and Habitat Restoration
BM2	Bank Stabilization and Habitat Restoration
BM3	Channel Realignment and Relocation
BM4	Plunge Pool Removal
BM5	Improvement of Fish Passage

Lowland and Upland Restoration and Enhancement

BM6	Wetland Improvement
BM7	Invasive Species Management
BM8	Biofiltration
BM9	Reforestation

Monitoring, Reporting, and Further Study ***(BMR)***

Monitoring and reporting under Target B includes monitoring of progress toward achievement of objectives (as measured by indicators introduced in Section 4) and monitoring of implementation of recommended management measures. For example, Indicator 3 measures the channel condition and trend for each reach of the stream. This indicator is both a measure of implementation and a measure of progress toward the goal of reducing streambank and stream channel deposition and scour to protect and restore the natural functions of aquatic habitat and ecosystems, streambanks, and stream channels.

7.1.3 Target C: Wet Weather Water Quality and Quantity

The third target is to restore water quality to meet fishable and swimmable criteria during wet weather. A comprehensive watershed management approach also must address flooding issues. The wet weather strategy includes both restoration of physical stream habitat and reduction of discharges from stormwater and combined sewage. These measures are complementary; stream restoration provides areas of lower flow where aquatic life can avoid higher flows, and discharge reduction helps limit velocities and protects the long-term investment in the restored stream. Targets B and C are intended to attend to restoration of physical stream habitat through control measures involving erosion, sediment accumulation, and flow variability.

Regulatory Approaches

CR1 Requiring Better Site Design in New Development
  - Open Space Preservation Plan
  - Stream Buffer/Corridor Protection Ordinance
  - Wetlands Protection Ordinance
  - Steep Slope Ordinance
  - Cluster Development Ordinance
  - Transfer of Development Rights Ordinance

CR2 Requiring Better Site Design in Redevelopment (may include options in CR1)
CR3 Stormwater and Floodplain Management
CR4 Industrial Stormwater Pollution Prevention
CR5 Construction Stormwater Pollution Prevention
CR6 Post-construction Stormwater Runoff Management
CR7 Pollution Trading
CR8 Use Review and Attainability Analysis
CR9 Watershed-Based Permitting

Following is a brief discussion of each of those nine regulatory approaches toward reaching Target C, as outlined above.

CR1&2 – Requiring Better Site Design in New Development and Redevelopment

The regulatory authority for controlling land use is vested in the municipalities through their ability to develop ordinances that regulate zoning and development practices. In areas that are undergoing development pressures, these ordinances are some of the most effective tools for watershed protection. In fully developed, urban watersheds such as the Tookany/Tacony-Frankford Creek Watershed, they are less effective, and are needed primarily to help improve conditions in areas that are re-developing.

A variety of approaches to environmentally responsible land use controls have been developed in recent years, and some are being implemented in the areas adjacent to Philadelphia that are undergoing rapid development. The Delaware Valley Regional Planning Commission (DVRPC) has collected information on these practices and local applications on their web site at http://www.dvrpc.org/planning/community/protectiontools.htm.

CR3 – Stormwater and Floodplain Management

Ordinances that deal directly with the way that stormwater is handled and floodplains are developed or re-developed are important in both developing and developed areas. Municipal ordinances for stormwater and floodplain management should be consistent with the "Comprehensive Stormwater Management Policy" (Document 392-0300-002) released by PA DEP in September 2002. This policy is intended "to more fully integrate post-construction stormwater planning requirements, emphasizing the use of ground water infiltration and volume and rate control best management practices (BMPs), into the existing NPDES permitting programs and the Stormwater Management Act ('Act 167') Planning Program." The comprehensive policy is available on PA DEP's web site at http://www.dep.state.pa.us/dep/deputate/watermgt/wc/Subjects/StormwaterManagement/GeneralInformation/default.htm.

In late 2004, the municipalities of the Tookany/Tacony Frankford Watershed embarked on the process of developing an Act 167 plan. This will include developing and adopting a model ordinance intended to satisfy the requirements of both the Act 167 and NPDES Phase II programs. This model ordinance may be based on a recently completed model ordinance developed for the Darby-Cobbs Watershed, adapted to meet the needs of the TTF Watershed.

CR4 – Industrial Stormwater Pollution Prevention

Industrial stormwater pollution prevention includes attention to the following measures:

- Good Housekeeping
- Preventive Maintenance
- Visual Inspections
- Spill Prevention and Response
- Employee Training
- Record Keeping and Reporting
- Fueling
- Maintaining Vehicles and Equipment
- Painting Vehicles and Equipment
- Washing Vehicles and Equipment
- Loading and Unloading Materials
- Liquid Storage in Above-Ground Tanks
- Industrial Waste Management and Outside Manufacturing
- Outside Storage of Raw Materials, By-Products, or Finished Products
- Salt Storage
- Flow Diversion
- Exposure Minimization Structures (dikes, drains, etc.)
- Erosion Prevention and Sediment Control
- Infiltration Practices

Detailed guidance on these industrial measures is available in EPA publication 832-R-92-006, "Storm Water Management for Industrial Activities: Developing Pollution Prevention Plans and Best Management Practices", released in September 1992. Municipalities may choose to adopt more stringent controls at the local level, or may work with state authorities to enforce the existing requirements. These measures are also appropriate for commercial and government operations involved in similar activities. The publication mentioned above is available online at http://nepis.epa.gov/pubtitleOW.htm.

CR5 – Construction Stormwater Pollution Prevention

Stormwater pollution prevention during construction activities includes attention to the following measures:

- Sediment and Erosion Control Practices
- Good Housekeeping
- Waste Disposal
- Minimizing Offsite Vehicle Tracking of Sediments
- Sanitary/Septic Disposal
- Material Management
- Spill Response
- Control of Allowable Non-Stormwater Discharges
- Maintenance and Inspection
- Stormwater Management

Detailed guidance on these measures is available in PA DEP publication 363-2134-008, "Erosion and Sediment Pollution Control Program Manual," released in April 2000. Municipalities may choose to adopt more stringent controls at the local level, or may work with state authorities to enforce the existing requirements. These measures are also appropriate for commercial and government operations involved in similar activities. The publication is available online at http://www.dep.state.pa.us/dep/deputate/watermgt/wc/Subjects/StormwaterManagement/GeneralInformation/default.htm.

CR6 – Post-construction Stormwater Runoff Management

Post-construction Stormwater Runoff Management is part of the NPDES Phase 2 stormwater management plan. (Options CR3 and CR6 have substantial overlap.)

CR7 – Pollution Trading

U.S. EPA is exploring market-based measures as a way of reaching targeted overall pollutant load reductions in a watershed. EPA's "Final Water Quality Trading Policy," released in January 2003, may be accessed at http://www.epa.gov/owow/watershed/trading/tradingpolicy.html. As this policy is adopted by the states and incorporated in regulations, it may increase incentives for cooperation and coordination between the municipalities and counties that share a watershed.

CR8 – Use Review and Attainability Analysis

U.S. EPA provides procedures for reviewing the applicability and attainability of designated uses. This process may be appropriate for urban watersheds like the Tookany/Tacony-Frankford. EPA document 833-R-01-002, "Coordinating CSO Long-Term Planning with Water Quality Standards Reviews," provides a framework for the process in areas served by combined sewers. The document is available at http://cfpub.epa.gov/npdes/cso/guidedocs.cfm.

CR9 – Watershed-Based Permitting

A holistic watershed management approach provides a framework for addressing all stressors within a hydrologically defined drainage basin instead of viewing individual sources in isolation. Within a broader watershed management system, the watershed-based permitting approach is a tool that can assist with implementation activities. The utility of this tool relies heavily on a detailed, integrated, and inclusive watershed planning process. Watershed planning includes monitoring and assessment activities that generate the data necessary for clear watershed goals to be established and permits to be designed to specifically address the goals. The policy statement and implementation guidance, "Watershed-Based National Pollutant Discharge Elimination System (NPDES) Permitting Implementation Guidance," finalized in 2004, are available at http://cfpub.epa.gov/npdes/wqbasedpermitting/wspermitting.cfm.

Public Education and Volunteer Programs

CP1 Public Education and Volunteer Programs

Municipal Measures

CM1 Sanitary Sewer Overflow Detection
CM2 Sanitary Sewer Overflow Elimination: Structural Measures
CM3 Reduction of Stormwater Inflow and Infiltration to Sanitary Sewers
CM4 Combined Sewer Overflow (CSO) Control Program
- Nine Minimum Controls
- Long Term CSO Control Plan
- Watershed-Based Planning

CM5 Catch Basin and Storm Inlet Maintenance
CM6 Street Sweeping
CM7 Responsible Landscaping Practices on Public Lands
CM8 Household Hazardous Waste Collection
CM9 Responsible Bridge and Roadway Maintenance

The first three measures above apply primarily to municipalities with separate sanitary sewer systems. The second measure, eliminating sanitary sewer overflow, is believed to be of critical importance in the Tookany/Tacony-Frankford Watershed. Inspection, cleaning, and when necessary, rehabilitation of aging sanitary sewers may be the single most important pollution reduction measure, and should be implemented immediately in this watershed. Reduction of pollutant loads due to stormwater may be of secondary importance if significant loads are being introduced by sanitary sewage.

Structural Stormwater Management Facilities

Detailed information on structural BMPs for stormwater management is available in various existing BMP manuals:

- PA DEP's Comprehensive Stormwater Management Policy (see links in Appendix A): http://www.dep.state.pa.us/dep/deputate/watermgt/wc/Subjects/StormwaterManagement/GeneralInformation/default.htm
- City of Philadelphia Stormwater BMP Manual: http://www.phillyriverinfo.org
- Center for Watershed Protection Stormwater Manager's Resource Center: http://www.stormwatercenter.net/
- Maryland Stormwater Design Manual: http://www.mde.state.md.us/Programs/WaterPrograms/SedimentandStormwater/stormwater_design/index.asp
- New Jersey: Best Management Practices for Control of Nonpoint Source Pollution: http://www.state.nj.us/dep/watershedmgt/bmpmanual.htm

Stormwater Management

Source Control Measures

CS1 Reducing Effective Impervious Cover Through Better Site Design
CS2 Porous Pavement and Subsurface Storage
CS3 Green Rooftops
CS4 Capturing Roof Runoff in Rain Barrels or Cisterns
CS5 Increasing Urban Tree Canopy

The first option above, reducing effective impervious cover, refers to a variety of measures, including encouraging homeowners to reduce the size of paved areas on their properties. Use of porous pavement is an alternative to reduction of paved areas. Rooftops represent a large proportion of the impervious area in highly urbanized watersheds such as the Tookany/Tacony-Frankford; constructing rooftop gardens over public and private buildings can be an effective structural measure to reduce urban runoff. Though this technology is catching on slowly in the United States, there are some examples in Southeastern Pennsylvania to look to as models.

The Tookany/Tacony-Frankford Partnership implemented a rain barrel pilot program. Rain barrels are inexpensive but need to be implemented throughout a watershed and drained between storms to be effective as a runoff reduction measure. It is also important that their owners are properly trained and committed to operate and maintain them. Cisterns are similar to rain barrels in function; they also must be drained on a regular basis to provide effective stormwater control.

Tree planting and urban reforestation programs provide hydrologic benefits in addition to quality of life improvements. Leaf surfaces intercept some rainfall that might otherwise fall on impervious surfaces. The rainfall then either evaporates or is conveyed more slowly to the ground along plant stems and trunks. Trees located over or near impervious cover provide the greatest stormwater control benefits.

Municipalities have the opportunity to provide incentives for private landowners to implement these innovative measures through ordinances, tax incentives, or a stormwater fee linked to impervious cover.

Stormwater Management

Onsite and Regional Stormwater Control Facilities

CS6 Maintaining/Retrofitting Existing Stormwater Structures
CS7 Modifying Catch Basins to Delay Stormwater Inflow
CS8 Retrofitting Existing Sewer Inlets with Dry Wells
CS9 Residential Dry Wells, Seepage Trenches, and Rain Gardens
CS10 Infiltration Basins
CS11 Vegetated Swales and Open Channels
CS12 Bioretention Basins and Porous Media Filtration
CS13 Treatment Wetlands: Onsite and Regional
CS14 Dry Detention Basins
CS15 Wet Retention Basins
CS16 BMPs for Highway Runoff (may include various structural options in this list)

The options listed above (CS6-16) are documented in the state manuals. Most of them may be implemented on the small scale of an individual property. Residential dry wells are an inexpensive way to infiltrate residential roof runoff and provide a benefit distributed over the watershed. Infiltration basins are similar but typically used on a larger scale requiring more land. Porous media filters and bioretention basins are most often used to detain, treat, and infiltrate parking lot runoff. Rain gardens are similar to bioretention and can be implemented in backyards or public land such as school grounds. Proper design and maintenance, along with an effective public relations campaign, can alleviate typical concerns about mosquito control and basement flooding.

Retrofit of existing sewer inlets with dry wells is an innovative option that, while expensive, may be attractive in a completely urbanized area with very little land available for traditional BMPs. Using this technology, existing catch basins are retrofitted to provide some measure of storage and infiltration. With full implementation and favorable soil conditions, the resulting outflows may resemble the pre-development condition. The City of Portland, Oregon, has implemented this approach and has provided some documentation in its Stormwater Management Manual (http://www.portlandonline.com/bes/index.cfm?c=35117).

Dry detention and wet retention basins are traditional BMPs that typically provide detention and treatment functions but only limited infiltration. Their design is extensively documented in the state manuals. Constructed wetlands, either onsite or regional, provide even greater detention and treatment functions; in addition, they may provide a cooling function and removal of some stormwater through evapotranspiration.

Monitoring, Reporting, and Further Study ***(CMR)***

Monitoring and reporting under Target C includes monitoring of progress toward achievement of objectives (as measured by indicators introduced in Section 4) and monitoring of implementation of recommended management measures. For example, Indicator 7 measures the percent of water quality samples where the state fecal coliform standard is met. This indicator is a measure of progress toward the goal of improved water quality in wet weather. Water Quality Concerns such as metals, TSS (total suspended solids), fecal coliform, and DO (dissolved oxygen) require further study to pinpoint sources. However, the problem can still be addressed (as most of the Target C options intend to do).

7.2 Screening of Options

The extensive lists of management options described above were developed to meet each of the goals and objectives established for the Tookany/Tacony-Frankford Watershed. Only those options deemed feasible and practical, however, were considered in the final list of management options. Options were evaluated in three steps:

> **1) Identification of Clearly Applicable Options (Section 7.2.1).** Some options were already being implemented or were mandated by a regulatory program. For some options, the planning team reached an early consensus that they were needed. These options did not require further evaluation.
>
> **2) Screening Based on Watershed Characterization (Section 7.2.2).** The extensive data analyses undertaken to characterize the watershed are summarized in Section 4 (Watershed Indicators: TTF Study Results), Section 5 (Problem Definition and Analysis), and Section 6 (Causes of Impairment). The results were used to evaluate the remaining options.
>
> **3) Detailed Evaluation of Structural Options (Section 7.2.3).** Structural best management practices (BMPs) for stormwater and combined sewage were subjected to a more rigorous modeling analysis. Effects on runoff volume, overflow volume, and pollutant loads were evaluated at various levels of coverage. That analysis is described in Section 7.3.

The table below lists the options chosen for each of those three evaluation steps.

Table 7.1 Options Chosen for Initial Screening and Detailed Evaluation

Option	Clearly Applicable	Screening	Detailed Model Evaluation
Target A	X*		
Target B	X		
Target C – Regulatory Approaches			
CR1 Requiring Better Site Design in New Development		X	
CR2 Requiring Better Site Design in Redevelopment	X		
CR3 Stormwater and Floodplain Management	X		
CR4 Industrial Stormwater Pollution Prevention	X		
CR5 Construction Stormwater Pollution Prevention	X		
CR6 Post-Construction Stormwater Runoff Management	X		
CR7 Pollution Trading		X	
CR8 Use Review and Attainability Analysis		X	
CR9 Watershed Based Permitting		X	
Target C – Public Education and Volunteer Programs			
CP1 Public Education and Volunteer Programs	X		
Target C – Municipal Measures			
CM1 Sanitary Sewer Overflow Detection	X		
CM2 Sanitary Sewer Overflow Elimination: Structural Measures	X		

* All Target A options except Option AM7, Household Hazardous Waste Collection, which was eliminated due to results of cost-benefit analysis.

(Continued on next page)

Table 7.1 Options Chosen for Initial Screening and Detailed Evaluation (continued)

Option	Clearly Applicable	Screening	Detailed Model Evaluation
CM3 Reduction of Stormwater Inflow and Infiltration to Sanitary Sewers	X		
CM4 Combined Sewer Overflow (CSO) Control Program	X*		X**
CM5 Catch Basin and Storm Inlet Maintenance	X		
CM6 Street Sweeping	X		
CM7 Responsible Landscaping Practices on Public Lands	X		
CM8 Household Hazardous Waste Collection	X		
CM9 Responsible Bridge and Roadway Maintenance	X		
Target C – Stormwater Management			
Source Control Measures			
CS1 Reducing Effective Impervious Cover Through Better Site Design			X
CS2 Porous Pavement and Subsurface Storage			X
CS3 Green Rooftops			X
CS4 Capturing Roof Runoff in Rain Barrels or Cisterns			X
CS5 Increasing Urban Tree Canopy	X		
Onsite and Regional Stormwater Control Facilities			
CS6 Maintaining/Retrofitting Existing Stormwater Structures		X	
CS7 Modifying Catch Basins to Delay Stormwater Inflow		X	
CS8 Retrofitting Existing Sewer Inlets With Dry Wells			X
CS9 Residential Dry Wells, Seepage Trenches, and Rain Gardens			X
CS10 Infiltration Basins			X
CS11 Vegetated Swales and Open Channels		X	
CS12 Bioretention Basins and Porous Media Filtration			X
CS13 Treatment Wetlands: Onsite and Regional			X
CS14 Dry Detention Basins		X	
CS15 Wet Retention Basins			X
CS16 BMPs for Highway Runoff		X	
Target C – Monitoring			
CMR Monitoring, Reporting, and Further Study	X		

** CSO program in place; model evaluation conducted to quantify benefits.

7.2.1 Clearly Applicable Options: Targets A, B, and C

Some options were already being implemented or were mandated by a regulatory program before preparation of the integrated plan began. For other options, the planning team reached an early consensus that they were needed. These options did not require further evaluation:

- **Virtually all Target A options.** Measures to reduce litter and improve recreational activities along the stream corridor are a clear priority of stakeholders. Due to deteriorating infrastructure and localized areas of low dissolved oxygen that have been identified in the creek, measures to eliminate dry weather sewage discharges are necessary. (Option AM7, Household Hazardous Waste Collection, was eliminated due to results of cost-benefit analysis.)

- **All Target B options.** The results of watershed characterization and experiences in other urban watersheds indicate that some restructuring of the streams and stream corridors will be required to restore designated uses.

- **Selected Target C options.** Regulatory approaches CR2 through CR6 are being addressed by the Pa. Act 167 planning program already underway in the TTF Watershed. Many of these measures are also required under the NPDES program. Public education and volunteer programs (Option CP1) are a critical component of any approach to integrated watershed management. In addition, most of the municipal measures listed under Target C, including the City of Philadelphia's Long Term CSO Control Program, are already being implemented in the watershed. Recommendations for these programs will be to continue or improve upon existing efforts.

7.2.2 Results of Target C Screening Based on Watershed Characterization

CR1 Requiring Better Site Design in New Development

Result: Not Recommended

Discussion:
Based on the analysis of land use and ownership presented in Section 4 (Indicator 1), the potential for new development in the TTF Watershed is limited. Concepts of low impact development may be applied on larger redevelopment sites (Option CR2), but extensive planning for new development is not necessary.

CR7 Pollution Trading

Result: Not Recommended

Discussion:
The Tookany/Tacony-Frankford Creek is currently listed by the PA DEP as impaired for one or more designated uses, not requiring a TMDL. Without a TMDL in place, the "driver" for initiating pollution trading does not exist. If a TMDL were to be enacted, the EPA's "Water Quality Trading Assessment Handbook" (EPA 841-B-04-001) could be used to provide an analytical framework to assess the conditions and water quality problems and determine whether water quality trading (WQT) could be effectively used.

CR8 Use Review and Attainability Analysis

CR9 Watershed Based Permitting

Result: Recommended for Further Study

Discussion:
The U.S. Environmental Protection Agency has endorsed these innovative options for improving the water resources environment in practical, sustainable, and cost-effective ways. Taken together, these three options represent a powerful opportunity for regulatory change in the watershed.

CS6 Maintaining/Retrofitting Existing Stormwater Structures

Result: Recommended

Discussion:
PWD performed an inventory of existing privately owned stormwater control basins in 2000. The results found seven confirmed structures within the Philadelphia portion of the watershed. Retrofit of existing basins, including maintenance and modification of outlet structures, can often increase the benefits from an older structure at minimal cost. This option is recommended and will be discussed in detail in the implementation section.

CS7 Modifying Catch Basins to Delay Stormwater Inflow

Result: Not Recommended

Discussion:
This option delays entry of stormwater runoff into street inlets and catch basins,

providing some level of detention while temporarily storing water on roadways. Based on discussions with stakeholders and local officials, this option is unpopular due to public perception. Other forms of detention are preferred.

CS11 Vegetated Swales and Open Channels

Result: Not Recommended

Discussion:
Vegetated swales and open channels are an attractive option as an alternative to traditional infrastructure in areas with new development. They are generally not applicable on smaller sites or on redevelopment sites. This option is not recommended except in very limited cases to be determined on a site-by-site basis.

CS14 Dry Detention Basins

Result: Not Recommended

Discussion:
Wet retention and infiltration basins are generally recommended over dry detention basins. Wet retention provides more effective water quality treatment in most cases. Dry extended detention ponds have only moderate pollutant removal when compared to other structural stormwater practices, and are ineffective at removing soluble pollutants. If a standing pool is not desired, designing for infiltration is recommended. This option is not recommended except in limited cases to be determined on a site-by-site basis.

CS16 BMPs for Highway Runoff

Result: Not Recommended

Discussion:
Transportation infrastructure in the watershed is dominated by city streets rather than highways. In most cases, there is not sufficient space available on roadway shoulders for significant storage to be created. In some cases, medians and islands in intersections may be appropriate for infiltration. These cases will be discussed under option CS12, Bioretention Basins and Porous Media Filtration.

7.2.3 Detailed Evaluation of Target C Structural Options

Structural options such as best management practices (BMPs) for stormwater and combined sewage were subjected to a rigorous modeling analysis. Effects on runoff volume, overflow volume, and pollutant loads were evaluated at various levels of coverage. In this way, the BMPs could be assessed for their cost-effectiveness when implemented in the TTF Watershed. BMPs that appear to cost-effectively decrease stormwater flows or combined sewer overflows, or significantly reduce pollutant loading during wet weather, were subjected to a series of model runs. BMPs were simulated at various levels of implementation within the watershed, and the results are represented graphically. For the assumed level of implementation, the results in terms of pollutant reduction and amount of stormwater treated were then combined with planning level cost estimates, and the options were subsequently ranked according to their cost effectiveness.

Figure 7.1 compares the effectiveness of the BMPs at volume removal (through infiltration and/or evapotranspiration) at their maximum feasible implementation levels. Two measures are capable of reducing total discharge to the receiving water (the sum of stormwater runoff and CSO) by more than 12%. Porous pavement with subsurface storage removes the volume primarily through infiltration, while real time control (RTC) reduces combined sewer overflow.

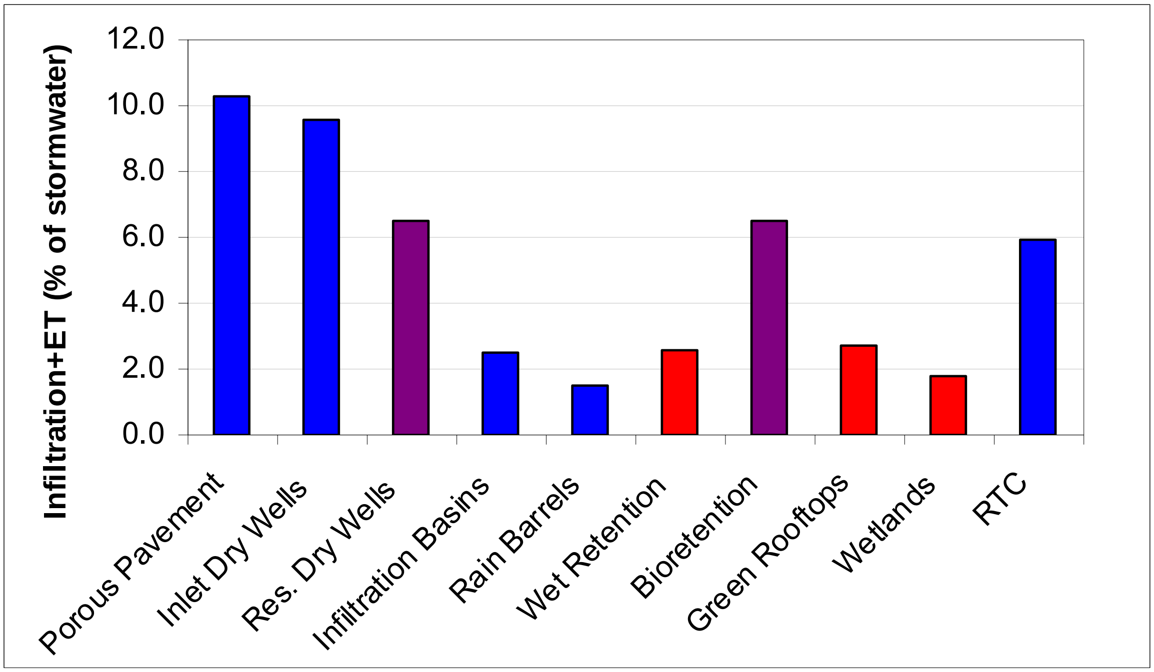


Figure 7.1 Potential Stormwater Volume Removal at Maximum Feasible Coverage

Figure 7.1 represents a range of impervious area draining to BMPs, from existing conditions (46% DCIA, or Directly Connected Impervious Area) to the maximum feasible coverage (varies by BMP). Levels of feasible coverage are chosen to be ambitious but realistic. For example, dry wells may not be technically feasible for all residences due to available space and other site constraints; for planning purposes, the maximum feasible level of coverage for the long term was assumed to be 25% for the TTF Watershed. Table 7.2 ranks the relative ability of each of the

BMPs to store stormwater, treat stormwater, or remove TSS, based on simulations of the maximum feasible level implementation of each of the BMPs. The rankings represent total volume and mass on a watershed basis over the one-year continuous simulation; they are a function of both technical effectiveness and feasible level of coverage. This ranking is independent of cost considerations.

Table 7.2 BMP Performance at Maximum Feasible Coverage

BMP Ranking	Potential Storage	Volume Removed	Load Reduction
Highest	Porous Pavement	Porous Pavement	Porous Pavement
	Wet Retention	Inlet Dry Wells	Res. Dry Wells
	Infiltration Basins	Bioretention	Bioretention
	Bioretention	Res. Dry Wells	Inlet Dry Wells
	Inlet Dry Wells	Real Time Control	Real Time Control
	Res. Dry Wells	Green Rooftops	Wet Retention
	Green Rooftops	Wet Retention	Infiltration Basins
	Wetlands	Infiltration Basins	Green Rooftops
	Rain Barrels	Wetlands	Wetlands
Lowest		Rain Barrels	Rain Barrels

Figure 7.2 shows the amount of storage that could be built in the TTF Watershed given the maximum feasible coverage for each BMP. At the simulated depth of 1 foot, subsurface storage under parking facilities represents approximately 45% of the storage that could feasibly be built. However, rain falling on the parking lot above the storage will not be sufficient to fill the storage. The full storage amount will be active only if additional runoff is directed into it. Infiltration and wet retention basins represent the second largest potential storage volume at approximately 15% of the total. Dry wells intercepting runoff from residential rooftops add 4%.

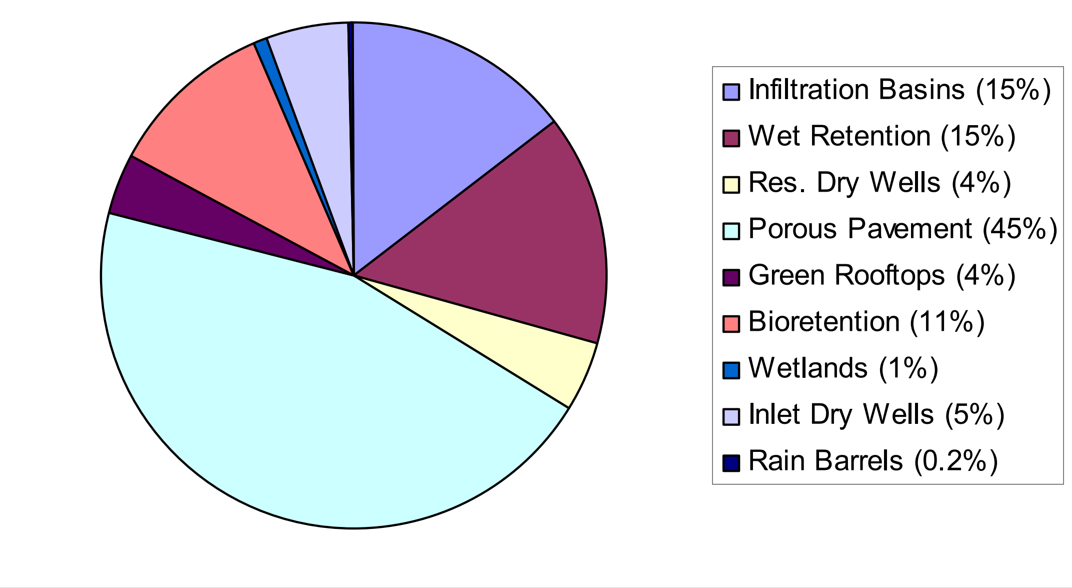


Figure 7.2 Maximum Storage Volume Feasible for Tookany/Tacony-Frankford Watershed

To gain some insight into the cost-effectiveness of various BMPs in the watershed under study, the precise hydraulic modeling results were combined with construction cost estimates. Literature values for costs of some BMPs are available in terms of storage volume. For others, literature values for cost in terms of area or operational unit were combined with model assumptions to obtain approximate costs. Operation and maintenance costs were not included in the current study.

While the hydrologic and hydraulic simulations were performed at a high level of precision, the costs used in this analysis were approximately order-of-magnitude in precision. The purpose of the cost-effectiveness analysis was to identify groups of BMPs that are highly effective, moderately effective, and of limited effectiveness in combined and separate-sewered areas. The values are specific to the climate, development pattern, soil conditions, and sewage systems in the Tookany/Tacony-Frankford Watershed. They are appropriate for long-term planning locally but are not recommended for detailed facilities cost estimating.

Model results were processed to produce relationships between storage volume, discharge reduction, load reduction, and cost. Some BMPs appear to be more efficient at pollutant removal, while others are more efficient at reducing the volume of stormwater reaching the stream; both are objectives of the TTFIWMP. Because the cost-load relationship is approximately linear, it is possible to present the results in the simplified form of approximate cost per gallon of discharge or pound of pollutant eliminated.

Subsurface storage facilities for combined sewage were examined as part of this study, but the cost-discharge and cost-load relationships were found to be nonlinear and could not be presented in the same form as the other results.

The results of the cost-effectiveness analysis are shown in Tables 7.3 and 7.4 (next page). Table 7.3 shows the estimated cost per gallon of stormwater treated and the cost per pound of TSS removed for simulations of feasible levels of implementation for each type of BMP under consideration. The results show that there is a wide range of costs, and that costs differ depending on whether a BMP is implemented in a CSO area or in an area served by separate storm sewers. Table 7.4 shows the list of options, ranked from most cost-effective to least cost-effective, grouped into highly effective, moderately effective, and least effective options.

Table 7.3 Planning-Level Cost-Effectiveness

	WATER QUALITY			WATER QUANTITY		
	TSS Removed			Volume Infiltrated/Evap/Captured		
BMP	Separate ($/lb)	Combined ($/lb)	Watershed ($/lb)	Separate ($/10^3 gal)	Combined ($/10^3 gal)	Watershed ($/10^3 gal)
Wetlands	3.07	1.43	1.80	3.02	1.38	1.75
Wet Retention	19.95	14.39	16.14	27.07	17.78	20.52
Rain Barrels	17.65	3.75	5.41	35.80	2.87	4.47
Inf. Basin	26.21	16.86	19.57	40.29	19.95	24.83
Real Time Control	N/A	5.98	N/A	N/A	4.20	N/A
Residential Dry Wells	19.40	11.47	13.64	44.91	10.38	14.81
Bioretention	42.46	22.09	27.16	60.95	20.86	28.03
Inlet Dry Wells	563.23	37.98	59.60	464.23	26.71	42.17
Green Rooftops	495.50	363.01	405.15	326.32	255.23	278.86
Porous Pavement	146.59	89.75	105.69	97.55	63.60	73.56

The most cost-effective discharge and pollutant reduction strategy is obtained by building the most inexpensive BMP to its maximum feasible level, followed by the next most inexpensive, until wet weather goals are met. Ultimately, other factors (e.g., public vs. private ownership, institutional arrangements for maintenance, degree and length of construction disturbance, feasibility of implementation, socio-political perceptions) must also be considered.

Table 7.4 Cost-Effectiveness of Options (High, Medium, Low)

WATER QUALITY		**WATER QUANTITY**	
TSS Removed		**Volume Infiltrated/Evaporated/Captured**	
Separate	Combined	Separate	Combined
Wetlands	Wetlands	Wetlands	Wetlands
Rain Barrels	Rain Barrels	Wet Retention	Rain Barrels
Residential Dry Wells	Real Time Control	Rain Barrels	Real Time Control
Wet Retention	Residential Dry Wells	Inf. Basin	Residential Dry Wells
Inf. Basin	Wet Retention	Residential Dry Wells	Wet Retention
Bioretention	Inf. Basin	Bioretention	Inf. Basin
Porous Pavement	Bioretention	Porous Pavement	Bioretention
Green Rooftops	Inlet Dry Wells	Green Rooftops	Inlet Dry Wells
Inlet Dry Wells	Porous Pavement	Inlet Dry Wells	Porous Pavement
	Green Rooftops		Green Rooftops

<u>The results of the simulations support a number of general conclusions</u> about the implementation of BMPs in the TTF Watershed. (**Note:** These numbered comments are referenced in summary Table 7.7, at end of Section 7.)

1. The cost of runoff volume reduction is higher in separate-sewered than in combined-sewered areas because temporary storage and release results in additional capture at CSO regulator structures. Larger cost differences between CSO and separate storm sewer

areas occur where evapotranspiration and/or infiltration are minor functions of the BMP (e.g., retrofitting sewer inlets with dry wells).

2. Generally speaking, if pollutant removal is significant for a given BMP, the cost difference between separate and CSO areas is smaller. One example is wetlands, due to water column pollutant attenuation.
3. Traditional BMPs like infiltration basins and wet retention basins can be effective where land is available. These facilities typically have much larger capacities, are regional in nature, and exhibit economies of scale. They are not thought to be practical alternatives for the TTF Watershed, but were included in our modeling simulations for completeness.
4. For the combined-sewered areas, real time control (RTC) is among the most competitive options in terms of both volume and load reduction. The RTC configuration being considered is highly specific to the TTF Watershed, and these results may not hold generally for other watersheds.
5. In highly urbanized areas, storage under parking facilities may be the only practical option to achieve large storage volumes. Porous pavement is one way to direct runoff from the parking lots themselves into the storage facility, while runoff from nearby rooftops can be piped into the facility.

The cost analysis of options in areas of separate storm sewers shows:

6. Wetlands and rain barrels are the most cost effective options for TSS removal on a cost per pound basis. Wetlands and wet retention are the most cost effective on a cost per gallon stormwater removed basis.
7. Dry wells in sewer inlets and green rooftops are particularly expensive for both TSS and discharge reduction. Porous pavement is expensive for TSS removal, but is more cost effective as a volume control measure.

The cost analysis of options in areas of combined sewers shows:

8. Wetlands, rain barrels, residential dry wells, and real time control are all relatively cost-effective options on the basis of cost-per-pound of TSS removed and cost-per-gallon of stormwater removed.
9. Green rooftops are the more expensive choice either on the basis of TSS removal or on the basis of dollars per gallon stormwater treated. Dry wells in sewer inlets are only moderately expensive in combined sewer areas (in contrast with separate sewer areas).
10. It is clear that the most expensive options in combined-sewered areas cost less than the most expensive options in separate-sewered areas. Because hydraulic detention is the most important mechanism in combined-sewered areas, there is less difference in cost-effectiveness between the different types of BMPs.
11. In combined areas, the regulator structures represent an investment already made in pollution reduction. Thus, money spent on stormwater BMPs results in greater load and volume reductions per additional dollar spent than in separate areas without stormwater controls. To meet an overall load reduction target in watersheds with both combined and separate areas, it may be more efficient to focus on the combined areas.

Table 7.5 lists ten measures, a feasible implementation level for each, and discharge and pollutant load reductions that are possible with each. These results may be used as a guide for individual municipalities or a watershed organization to select suitable BMPs.

Table 7.5 Maximum Feasible Discharge and Pollutant Reduction

Target C	Maximum Feasible Implementation	Volume Reduction		Pollutant Reduction
		CSO	Stormwater	
Municipal Measures				
CM4 Combined Sewer Overflow (CSO) Control Program				
● Real Time Control	2 sites	5.9%	N/A	6.1%
Structural Stormwater Management Facilities				
Source Control Measures				
CS1 Reducing Impervious Cover Through Better Site Design	1% reduction in DCIA	0.5%	0.5%	1.0%
CS2 Porous Pavement and Subsurface Storage	50% of parking lots	8.0%	3.3%	11.6%
CS3 Green Rooftops	5% of rooftops	1.8%	0.9%	2.7%
CS4 Capturing Roof Runoff in Rain Barrels or Cisterns	10% of homes	1.4%	0.1%	1.8%
CS5 Increasing Urban Tree Canopy	5% of watershed area	0.3%	0.3%	0.5%
Onsite and Regional Stormwater Control Facilities				
CS8 Retrofitting Existing Sewer Inlets with Dry Wells	100% of inlets	6.9%	0.3%	7.5%
CS9 Residential Dry Wells, Seepage Trenches, Rain Gardens	school grounds; 25% of homes	5.7%	0.8%	10.4%
CS12 Bioretention Basins and Porous Media Filtration	50% of parking lots	6.3%	2.1%	11.6%
CS13 Treatment Wetlands: Onsite and Regional	100% of identified potential	1.4%	0.4%	2.5%

Notes:
1) Volume reductions are % of total discharge (sum of CSO and stormwater).
2) “Maximum Feasible” considers technical feasibility and social acceptance, but not cost.

In spite of its cost, subsurface storage under parking lots is recommended because it is one of the few practical options in the most urban areas. Green rooftops are not recommended as a short-term management strategy due to the high cost and practical constraints they currently impose on private land owners. However, they may become more cost-effective in the future due to economies of scale and increased local availability of materials and expertise. For these reasons, the watershed planning team has recommended that local government implement demonstration projects on public buildings and consider incentives for private land owners. In the near term, the benefit of these projects will be primarily educational rather than technical.

While effectiveness and cost may be the two most important criteria used to assess and choose BMPs, feasibility and sociopolitical factors ultimately play a role. These factors were evaluated using a simpler method. Table 7.6 assigns a rating to assess the effect of each factor on the BMPs studied; the significance of the possible ratings is explained below.

Table 7.6 Evaluation Criteria Applied to Individual BMPs

	Technical Feasibility	Time to Implement	Legal Feasibility	Social/Political Support	Construction Disturbance	Maintenance
Real Time Control	●	●	●	●	●	●
Structural CSO Storage	●	◒	●	◒	○	○
Constructed Wetlands	●	●	○	◒	◒	◒
Rain Barrels	◒	◒	○	●	●	○
Residential Dry Wells	◒	◒	○	○	●	●
Bioretention/Porous Media Filter Systems	●	○	○	●	◒	◒
Green Rooftops	○	○	○	◒	○	○
Porous Pavement	◒	○	○	●	○	◒
Dry Wells in Sewer Inlets	◒	○	○	●	○	●

Legend

Excellent	●
Good/Fair	◒
Poor	○

Technical Feasibility

Excellent ●	The technology has been widely and successfully applied. Several local contractors will have experience with the technology.
Good/Fair ◒	The technology has been successfully applied in other cities or has been successfully demonstrated locally. At least one local contractor will have experience with the technology.
Poor ○	The technology has been applied in only a few pilot or demonstration programs. It may be impossible to find an experienced local contractor.

Length of Time to Implement

Excellent ●	The technology can be implemented in 2 years or less.
Good/Fair ◒	The technology can be implemented in 2 to 5 years.
Poor ○	The technology takes more than 5 years to implement.

Feasibility within the Legal Structure

Excellent ●	Existing laws require or provide an incentive for implementation. For example, measures proposed may overlap with the "six minimum controls" required by NPDES Phase II regulations.
Poor ○	Existing laws do not affect or do provide disincentives for different aspects of the plan. For example, a local ordinance may discourage infiltration.

Social/Political Support

Excellent ●	Overall, the measure proposed will be seen as positive by a majority of stakeholders (citizens, local governments, and non-profits).
Good/Fair ◒	The measure has both positive and negative aspects.
Poor ○	Overall, the measure proposed will be seen as negative by a majority of stakeholders (citizens, local governments, and non-profits).

Construction Disturbance

Excellent ●	Pavement removal is not required or is minimal. Effects on parking, traffic patterns, and noise are minimal. Rain barrels are one example.
Good/Fair ◒	Some pavement removal is required. Effects on parking, traffic patterns, and noise are moderate.
Poor ○	Construction will require removal of large amounts of pavement (streets, parking lots) and/or significantly affect parking, movement of people and vehicles, and the noise level. Examples include porous pavement and installation of dry wells in sewer inlets.

Maintenance – Cost and Institutional Considerations

Excellent ●	Maintenance can be performed through existing programs and existing funding. For example, maintenance of retrofit sewer inlets can be integrated into current sewer maintenance.
Good/Fair ◒	Private land owners will be responsible for minor maintenance chores (e.g., minor landscape maintenance for a bioretention basin that would have been a parking island anyway). Public agencies can handle maintenance with existing staff and budget, and/or will dedicate staff time to outreach, workshops, etc.
Poor ○	Existing public programs, staff, and funding will not cover maintenance, or maintenance will be a large burden on private land owners. Or, frequent maintenance is absolutely critical to BMP effectiveness, as with rain barrels.

7.3 Recommended Options

At the end of this section, Table 7.7 summarizes options recommended for full implementation, options recommended for conditional implementation, and options that are not recommended. Those recommended for conditional implementation include most of the structural stormwater and combined sewage management measures. (Note: Each "Conditional" recommendation in Table 7.7 is accompanied by a numbered reference to one or more of the various conclusions presented in Section 7.2.3, below Table 7.4.)

Target A: Options for Dry Weather Water Quality and Aesthetics

For the Tookany/Tacony-Frankford Creek, the focus of Target A is trash removal, litter prevention, and elimination of sources of sewage during dry weather. Because the options under consideration are aimed at the total elimination of trash and dry weather sources of sewage, no complex analysis was required to help define the program or assess its potential benefits. Virtually all options related to this target are recommended for implementation.

Streams should be aesthetically appealing (i.e., look and smell good), accessible to the public, and an amenity to the community. Access to and interaction with the stream during dry weather have the highest priority, because dry weather flows occur about 60-65% of the time during the course of a year, and is also the time when the public is most likely to be near or in contact with the stream. The water quality of the stream in dry weather, particularly with respect to bacteria, should be similar to background concentrations in groundwater. Many urban streams rarely meet water quality standards for bacteria, and urban streams often have significant BOD (biological or biochemical oxygen demand) problems, even during baseflow or dry weather conditions.

Target B: Options for Healthy Living Resources

Improving the ability of an urban stream to support viable habitat and fish populations focuses primarily on the elimination of the more obvious impacts of urbanization on the stream. These include loss of riparian habitat, eroding and undercut banks, scoured streambed or excessive silt deposits, channelized and armored stream sections, trash buildup, and invasive species. The primary tool to accomplish this is stream and stream corridor restoration. Restoration focuses on improving channel stability, improving instream and riparian habitat, providing refuges for fish from high velocity conditions during storms, and managing land within the stream corridor. Because designated uses in the stream cannot be restored without these options, all options grouped under Target B are recommended for implementation.

Target C: Options for Wet Weather Water Quality and Quantity

Improving water quality and flow conditions during and after storms is the most difficult target to meet in the urban environment. During wet weather, extreme increases in streamflow are common, accompanied by short term changes in water quality. Stormwater generally does not have DO (dissolved oxygen) problems, but sampling data indicate that concentrations of metals (such as copper, lead, and zinc) and bacteria do not meet water quality standards during wet weather. These pollutants are introduced by both stormwater and wet weather sewer overflows (CSOs and SSOs).

Target C options also must address flooding issues. Where water quality and quantity problems both exist, options must be identified that address both. Any BMP that increases infiltration or detains flow will help decrease the frequency of damaging floods; however, the size of such structures may need to be increased in areas where flooding is a major concern. Reductions in the frequency of erosive flows and velocities will also help protect the investment in stream restoration made as part of the implementation of Target B options.

Options recommended for Target C are divided into two groups, as shown in Table 7.7 below. The first group includes options recommended for ***full*** implementation. These options include a range of ordinances and regulatory measures and public education measures related to existing municipal infrastructure, selected source controls, and possibilities for pollution trading and use review. The municipal measures focus on the elimination of sanitary sewer overflows and the causes of overflows such as blockages and excessive infiltration.

The second group of Target C options includes structural measures designed to achieve specific, measurable discharge and pollutant load reductions. These options are recommended on a ***conditional*** basis, based on conclusions of screening and modeling studies. (As noted above, each of the “Conditional” recommendations is linked to one or more of the numbered conclusions listed in Section 7.2.3.)

Table 7.7 Summary of Recommended Options

Option	Recommended	Not Recommended	Conditional
Target A	X*		
Target B	X		
Target C – Regulatory Approaches			
CR1 Requiring Better Site Design in New Development		X	
CR2 Requiring Better Site Design in Redevelopment	X		
CR3 Stormwater and Floodplain Management	X		
CR4 Industrial Stormwater Pollution Prevention	X		
CR5 Construction Stormwater Pollution Prevention	X		
CR6 Post-Construction Stormwater Runoff Management	X		
CR7 Pollution Trading		X	
CR8 Use Review and Attainability Analysis	X		
CR9 Watershed Based Permitting	X		
Target C – Public Education and Volunteer Programs			
CP1 Public Education and Volunteer Programs	X		
Target C – Municipal Measures			
CM1 Sanitary Sewer Overflow Detection	X		
CM2 Sanitary Sewer Overflow Elimination: Structural Measures	X		
CM3 Reduction of Stormwater Inflow / Infiltration to Sanitary Sewers	X		
CM4 Combined Sewer Overflow (CSO) Control Program	X		
CM5 Catch Basin and Storm Inlet Maintenance	X		
CM6 Street Sweeping	X		
CM7 Responsible Landscaping Practices on Public Lands	X		
CM8 Household Hazardous Waste Collection	X		
CM9 Responsible Bridge and Roadway Maintenance	X		
Target C – Monitoring			
CMR Monitoring, Reporting, and Further Study	X		

* All Target A options except Option AM7, Household Hazardous Waste Collection, which was eliminated due to results of cost-benefit analysis.

(Continued on next page)

Table 7.7 Summary of Recommended Options (continued)

Option	Recommended	Not Recommended	Conditional*
Target C – Stormwater Management			
Source Control Measures			
CS1 Reducing Effective Impervious Cover Through Better Site Design	X		
CS2 Porous Pavement and Subsurface Storage			urban areas (5,7)
CS3 Green Rooftops			demonstration projects (7,9)
CS4 Capturing Roof Runoff in Rain Barrels or Cisterns			public relations campaign required (6,8)
CS5 Increasing Urban Tree Canopy	X		
Onsite and Regional Stormwater Control Facilities			
CS6 Maintaining/Retrofitting Existing Stormwater Structures	X		
CS7 Modifying Catch Basins to Delay Stormwater Inflow		X	
CS8 Retrofitting Existing Sewer Inlets With Dry Wells			CSO areas (1,7,9)
CS9 Residential Dry Wells, Seepage Trenches, and Rain Gardens			inexpensive in combined areas (8)
CS10 Infiltration Basins		X**	
CS11 Vegetated Swales and Open Channels		X	
CS12 Bioretention Basins and Porous Media Filtration			inexpensive in combined areas (7)
CS13 Treatment Wetlands: Onsite and Regional			site permitting (2,6,8)
CS14 Dry Detention Basins		X	
CS15 Wet Retention Basins		X**	
CS16 BMPs for Highway Runoff		X	

* **Note:** The parenthetical numbers under the “Conditional” column refer to the numbered conclusions of the BMP simulations, as listed in Section 7.2.3.

** Under the current conditions of the TTF Watershed, these measures are not recommended; however, in the event of large-scale redevelopment within the watershed, these BMPs could be considered.

Section 8
Implementation Guidelines

This section presents guidelines for watershed-wide implementation of the "management options" identified by the Tookany/Tacony-Frankford Watershed Partnership as best meeting the goals and objectives of the TTF Integrated Watershed Management Plan. Following extensive screening and evaluation (described in Section 7), only those options that are likely to be cost-effective and feasible under the specific conditions found in the TTF Watershed are carried over and included in these guidelines. The section begins with tips on how to navigate the information presented.

Navigating Section 8: Summary Tables and Boxes

Following the introductory information below and on the next page, three **summary tables** are presented. These tables categorize the recommended management options according to the agency or level of government responsible for carrying out each recommendation under current regulations: PA DEP, the City of Philadelphia, and the Montgomery County municipalities.

Sections 8.1, 8.2, and 8.3 are then devoted to presenting detailed information about each of those recommended options, grouped under Targets A, B, and C (introduced in Section 2.2.7 and discussed throughout this plan). Most of those options begin with a **summary box** that names (1) "What" the option involves, (2) "Who" is responsible, (3) "Where" the option is to be carried out, and (4) "When." In addition, each summary box lists the numbers of "Related Goals" and "Related Indicators," discussed in Sections 3 and 4, respectively. The summary box is followed by text, figures, and tables that further describe the option and the implementation approach being recommended.

Implementation Guidelines and Five-Year Plans

These guidelines present a long-range vision for implementation over a 20-year horizon, with the intent of meeting both Target A (Dry Weather Water Quality and Aesthetics) and Target B (Healthy Living Resources) within a 15-year planning horizon, while simultaneously proposing step-by-step implementation to meet Target C (Wet Weather Water Quality and Quantity), allowing for adaptive management over time. The guidelines provide information on location and degree to which implementation needs to be accomplished in order to meet the targets. Based upon these recommendations, PWD and the Tookany/Tacony-Frankford Watershed Partnership will prepare detailed, 5-year plans to carry out the recommended projects.

The Implementation Guidelines presented here are intended to offer a long-range vision for implementation over the upcoming 20-year horizon, and to be used as a reference by parties creating actual implementation plans in the future. The implementation plan is to be designed to provide a detailed blueprint for specific implementation tasks during the initial five-year period. Detailed planning for implementation of the TTFIWMP will be broken into four sequential five-year periods to cover the 20-year implementation horizon. The Philadelphia Water Department has created and committed to a detailed five-year Implementation Plan for the portion of the

Tookany/Tacony-Frankford Watershed within the City of Philadelphia (see summary in Appendix E). This plan has been designed to begin in 2006 and run through 2011; though the start date for the implementation period is in 2006, many projects have already been initiated.

The cost estimated for full implementation of the TTFIWMP in the Philadelphia portion of the watershed is roughly $18,000,000, to which PWD has committed staff and resources in the first five years. Detailed comparable costs for the first five years within the Montgomery County portion of the watershed have not yet been derived. A total estimated cost for watershed-wide implementation of this plan for the initial five-year period will be calculated by the Board of the Tookany/Tacony-Frankford Watershed Partnership once budgetary information for municipal implementation is available.

Role of the TTF Watershed Partnership in TTFIWMP Implementation

In the summer of 2005, the Tookany/Tacony-Frankford Watershed Partnership filed official incorporation papers in order to become a 501(c)3 nonprofit watershed organization. As noted in Article 2, Section 2.2 of the TTF Partnership By-Laws:

> *"The primary purposes of the Corporation are to carry out all activities allowable under Section 501(c)(3) of the Internal Revenue Code (or the corresponding section of any future Internal Revenue Law of the United States), including but not limited to: implement the Integrated Watershed Management Plan for the Tookany/Tacony-Frankford Watershed ("TTF Watershed"); improve stream habitat and integrity of aquatic life; reduce the impact of urbanized flow on living resources; improve dry and wet weather stream quality to reduce the effects on public health and aquatic life; protect and restore stream corridors, buffers, floodplains, and natural habitats including wetlands; identify flood prone areas and decrease flooding; enhance community environmental quality of life; foster community stewardship; and improve inter-municipal, inter-county, state-local and stakeholder cooperation and coordination on a watershed wide basis through dedicated public education and outreach."* (See Appendix C for complete By-Laws.)

This organization will strive to help the municipalities and other stakeholders throughout the watershed to realize the vision of a restored and vital Tookany/Tacony-Frankford Watershed.

Table 8.1 PA DEP Actions

Code	Option	Where	When
CR4	Industrial Stormwater Pollution Prevention	Industrial sites	Short-term
CR5	Construction Stormwater Pollution Prevention	Construction sites	Short-term
N.A.	Stewardship/Advocacy of Watershed Management Plan	Watershed-wide	Short-term
A/B/CMR	Monitoring, Reporting, and Further Study	Watershed-wide	Ongoing

Table 8.2 City of Philadelphia Actions

Code	Option	Where	When
AR2	Pet Waste, Litter, and Dumping Ordinances	Watershed-wide	Short-term
N.A.	Revised Stormwater Ordinance and BMP Manual	Watershed-wide	Short-term
AP1	Public Education	Watershed-wide	Short-term
AP2	School-Based Education	All schools	Short-term
AP3	Public Participation and Volunteer Programs	Watershed-wide	Short-term
AM2	Inspection and Cleaning of Combined Sewers	Watershed-wide	Short-term
AM4	Combined Sewer Rehabilitation	Combined-Sewered Areas	Medium-term
AM6	Stream Cleanup and Maintenance	Tookany/Tacony-Frankford Creek within or along City boundary	Short-term
AO1	Enhancing Stream Corridor Recreational and Cultural Resources	Along the stream corridor	Medium-term
BM1	Bed Stabilization and Habitat Restoration	Tookany/Tacony-Frankford Creek	Short-term
BM2	Bank Stabilization and Habitat Restoration	Middle section of Tookany/Tacony-Frankford Creek	Short-term
BM3	Channel Realignment and Relocation	Tookany/Tacony-Frankford Creek,	Short-term
BM4	Plunge Pool Removal	CSO and stormwater outfalls	Short-term
BM5	Improvement of Fish Passage	Tacony Creek Dams	Short-term
BM6	Wetland Creation	Riparian corridor	Short-term
BM7	Invasive Species Management	Riparian corridor	Short-term
BM9	Reforestation	Riparian corridor	Short-term
CR3	Stormwater and Floodplain Management	Watershed-wide	Short-term
CR6	Post-Construction Stormwater Runoff Management	Watershed-wide	Short-term
CM1	Sanitary Sewer Overflow Detection	Separate-Sewered Areas	Short-term
CM2	Sanitary Sewer Overflow Elimination: Structural Measures	Separate-Sewered Areas	Medium-term
CM4	CSO Control Program	Philadelphia combined sewer system	Short-term
CM5	Catch Basin and Storm Inlet Maintenance	All inlets	Short-term
CM6	Street Sweeping (Philadelphia Streets Department)	Streets and Parking Lots	Short-term
CM7	Responsible Landscaping on Public Lands	Green space	Short-term
CM9	Responsible Bridge and Roadway Maintenance	Roadways and bridges	Short-term
CM3	Green Rooftops	Appropriate public buildings chosen by PWD	Medium-term
CM4	Capturing Roof Runoff in Rain Barrels or Cisterns	Homes where dry wells are not feasible	Medium-term
CM5	Increasing Urban Tree Canopy	Watershed-wide	Medium-term
CS6	Maintaining/Retrofitting Existing Stormwater Structures	Watershed-wide	Short-term
CS8	Retrofitting Existing Sewer Inlets with Dry Wells	Inlets in combined-sewered areas	Long-term
CS9	Residential Dry Wells, Seepage Trenches, and Water Gardens	Homes and schools watershed-wide	Long-term
CS12	Bioretention Basins and Porous Media Filtration	Watershed-wide	Long-term
CS13	Treatment Wetlands: Onsite and Regional	Riparian corridor	Medium-term
A/B/CMR	Monitoring, Reporting, and Further Study	Watershed-wide	Ongoing

Table 8.3 Montgomery County Municipality Actions

Code	Option	Where	When
AR1	On-Lot Disposal (Septic System) Management	All areas with septic systems	Short-term
AR2	Pet Waste, Litter, and Dumping Ordinances	Watershed-wide	Short-term
AP1	Public Education	All Tookany/Tacony-Frankford Creek municipalities	Short-term
AP2	School-Based Education	All schools	Short-term
AP3	Public Participation and Volunteer Programs	All Tookany/Tacony-Frankford Creek municipalities	Short-term
AM1	Capacity Management Operation and Maintenance of Sanitary Sewers	Separate-Sewered Areas	Short-term
AM3	Sanitary Sewer Rehabilitation	Separate-Sewered Areas	Medium-term
AM5	Illicit Discharge, Detection, and Elimination (IDD&E)	All Tookany/Tacony-Frankford Creek municipalities	Short-term
AM6	Stream Cleanup and Maintenance	Tookany/Tacony-Frankford Creek within or along City boundary	Short-term
A01	Enhancing Stream Corridor Recreational and Cultural Resources	Along the stream corridor	Medium-term
BM1	Bed Stabilization and Habitat Restoration	Tookany/Tacony-Frankford Creek	Short-term
BM2	Bank Stabilization and Habitat Restoration	Middle section of Tookany/Tacony-Frankford Creek	Short-term
BM3	Channel Realignment and Relocation	Tookany/Tacony-Frankford Creek	Short-term
BM4	Plunge Pool Removal	Stormwater outfalls	Short-term
BM5	Improvement of Fish Passage	Dam locations	Short-term
BM6	Wetland Creation	Riparian corridor	Short-term
BM7	Invasive Species Management	Riparian corridor	Short-term
BM8	Biofiltration	Locations to be determined	
BM9	Reforestation	Riparian corridor	Short-term
CR2	Requiring Better Site Design in Redevelopment	Watershed-wide	Short-term
CR3	Stormwater and Floodplain Management	Watershed-wide	Short-term
CR6	Post-Construction Stormwater Runoff Management	Municipalities required to do Phase II permit	Short-term
CM1	Sanitary Sewer Overflow Detection	Separate-Sewered Areas	Ongoing program
CM3	Reduction of Stormwater Inflow and Infiltration to Sanitary Sewers	Separate-Sewered Areas	Medium-term
CM5	Catch Basin and Storm Inlet Maintenance	All inlets	Ongoing program
CM6	Street Sweeping	Streets and Parking Lots	Short-term
CM7	Responsible Landscaping on Public lands	Green space	Short-term
CM9	Responsible Bridge and Roadway Maintenance	Roadways and bridges	Short-term
CS2	Porous Pavement and Subsurface Storage	Parking lots watershed-wide	Long-term
CS4	Capturing Roof Runoff in Rain Barrels or Cisterns	Homes where dry wells are not feasible	Medium-term
CS5	Increasing Urban Tree Canopy	Watershed-wide	Medium-term
CS6	Maintaining/Retrofitting Existing Stormwater Structures	Watershed-wide	Short-term
CS9	Residential Dry Wells, Seepage Trenches, and Water Gardens	Homes and schools watershed-wide	Long-term
CS12	Bioretention Basins and Porous Media Filtration	Watershed-wide	Long-term
CS13	Treatment Wetlands: Onsite and Regional	Riparian corridor	Medium-term
A/B/CMR	Monitoring, Reporting, and Further Study	Watershed-wide	Ongoing

8.1 Target A: Dry Weather Water Quality and Aesthetics

Below are the recommended options for Target A. As explained in Section 7, virtually all Target A (and all Target B) options were recommended for implementation. These options are described in detail in the pages that follow.

Section 8.1.1 **Regulatory Approaches**

AR1	On-Lot Disposal (Septic System) Management
AR2	Pet Waste, Litter, and Dumping Ordinances

Section 8.1.2 **Public Education and Volunteer Programs**

AP1	Public Education
AP2	School-Based Education
AP3	Public Participation and Volunteer Programs

Section 8.1.3 **Municipal Measures**

AM1	Capacity Management Operation and Maintenance (CMOM)
AM2	Inspection and Cleaning of Combined Sewers
AM3	Sanitary Sewer Rehabilitation
AM4	Combined Sewer Rehabilitation
AM5	Illicit Discharge, Detection, and Elimination (IDD&E)
AM6	Stream Cleanup and Maintenance

Section 8.1.4 **Recreational and Cultural Resources**

AO1	Enhancing Stream Corridor Recreational and Cultural Resources

Section 8.1.5 **Monitoring and Reporting**

AMR	Monitoring, Reporting, and Further Study

8.1.1 Target A Options: Regulatory Approaches

On-Lot Disposal (Septic System) Management (AR1)

Related Goals: 3
Related Indicators: 7, 11, 19, 20

What	Who	Where	When
Septic tank management program required as part of the municipality's Official Act 537 Sewage Facilities Plan.	Municipalities through state certified Sewage Enforcement Officers (SEO). • All Act 537 plans should be updated as necessary.	All areas with septic systems (see Table 8.4).	Within next 5 years.

Septic tank management programs are currently required of all Pennsylvania municipalities as part of their Official Act 537 Sewage Facilities Plans. Keeping these plans up to date, including provisions related to operation and maintenance of on-lot sewage disposal systems (OLDS), is an important means of controlling the release of pathogens and nutrients within the watershed.

The Pennsylvania Sewage Facilities Act (Act 537) requires that all Commonwealth municipalities develop and implement comprehensive official plans that provide for resolution of existing sewage disposal problems, provide for future sewage disposal needs of new land development, and provide for future municipal sewage disposal needs. When a municipality adopts a plan, the plan is submitted for review and approval by the Pennsylvania Department of Environmental Protection. By regulation, the planning process is not final until an Act 537 Plan has been approved by PA DEP. Municipalities are required to revise (unless they are exempt from revising) the "Official Plan" if a new land development project is proposed or if unanticipated conditions or circumstances arise, making the base plan inadequate. There are two basic types of plan changes: "Plan revisions" resulting from new land development are completed using "planning modules" that are specific to individual projects; an "update revision" is used by municipalities to make broad changes to their Official Plan.

Act 537 planning has been a municipal requirement since July 1, 1967. Legally, all municipalities have an Act 537 Plan; however, some plans are newer and more detailed than others. A list of municipalities within the Tookany/Tacony-Frankford Creek Watershed indicating the status of their Act 537 Plans is presented in Table 8.4. Note that most of the plans are quite outdated. The municipalities are shown in Figure 8.1.

Table 8.4 Act 537 Municipal Sewage Facilities Plans

Municipality	County	Plan Approval Date	Status (as of 12/2005)
Abington Township	Montgomery	12/16/99	Plan older than 5 years
Cheltenham Township	Montgomery	1/1/73	Plan older than 30 years
Jenkintown Borough	Montgomery	1/1/73	Plan older than 30 years
Philadelphia	Philadelphia	11/10/93	Plan older than 10 years
Rockledge Borough	Montgomery	1/1/73	Plan older than 30 years

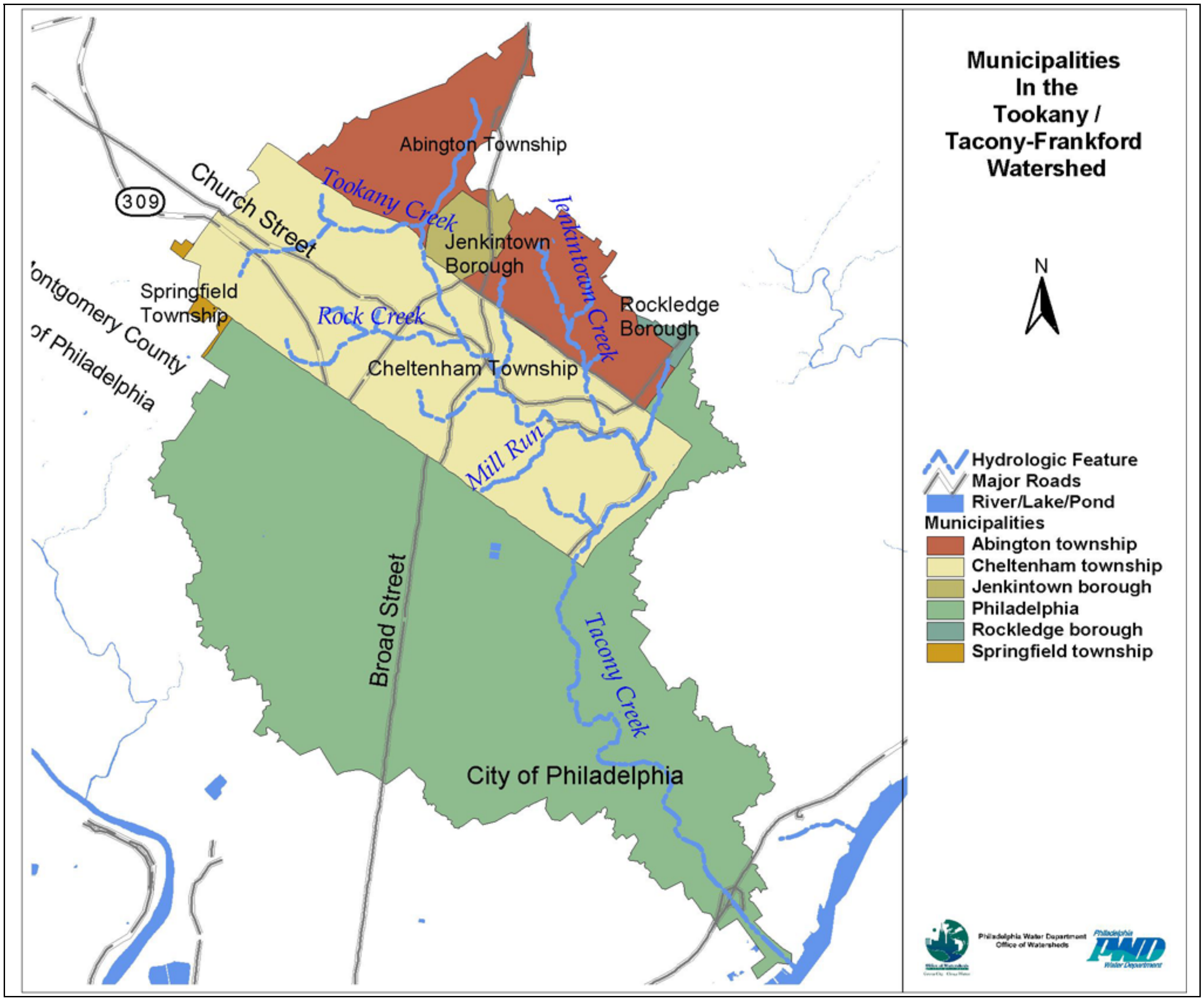


Figure 8.1 Tookany/Tacony-Frankford Watershed Municipalities

<u>**Relevant Provisions of Act 537**</u>

- All municipalities must develop and implement an official sewage plan that addresses their present and future sewage disposal needs. Local agencies are required to employ both primary and alternate Sewage Enforcement Officers (SEO) responsible for overseeing the daily operation of that agency's OLDS permitting program.
- Local agencies, through their SEO, approve or deny permits for construction of on-lot sewage disposal systems prior to system installation. The SEO is responsible for conducting soil profile testing, percolation testing, OLDS design review, and approving or denying OLDS permit applications.
- Local agencies, through their SEO, must manage the permitting program for individual on-lot disposal systems and community on-lot systems with design flows of 10,000 gallons-per-day or less.

- Municipalities are required to assure the proper operation and maintenance of sewage facilities within their borders.

Municipalities should maintain information on the location, type, and operational status of existing sewage facilities, as well as results of sanitary surveys. This information, however, is often incomplete. Septic tank data were included in the U.S. census through 1990, but were believed to be inaccurate and were not included in the 2000 census. County health departments may have information, and assessments have been attempted through voluntary questionnaires submitted by municipalities. These tasks have proven to be difficult but can be completed through perseverance.

Implementation of a Comprehensive Septic Tank Management Program

Each municipality shown in Table 8.4 should update its Act 537 Plan in the coming five-year period, as necessary.

Table 8.5 presents 1990 census sanitary survey results along with the area within the watershed. Better counts and, if appropriate, implementation of septic system management programs should be actively pursued in municipalities that have a large estimated number of septic systems and a high percentage of their total area within the watershed: Philadelphia, and Abington and Cheltenham townships.

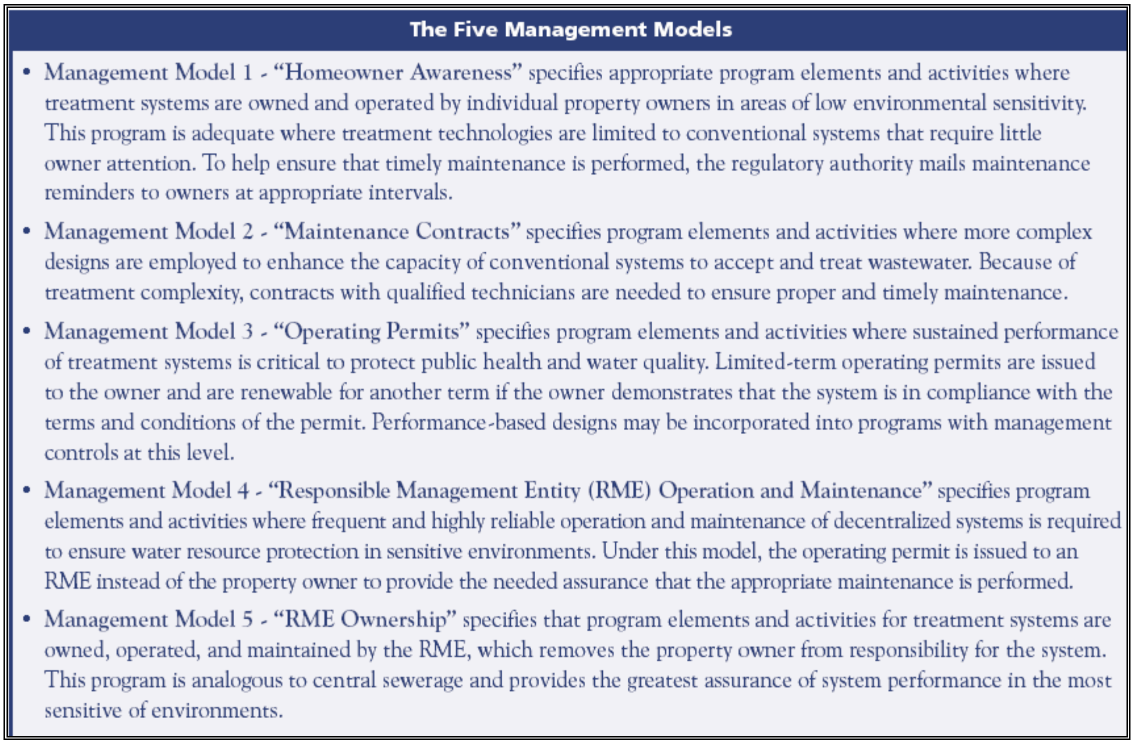
The implementation of comprehensive septic tank management programs in those three municipalities ideally will be consistently designed to provide degrees of protection based on an assessment of the environmental sensitivity of the area.

Table 8.5 Septic System Data from 1990 Census*

Municipality	Area (Acres)	Area in Watershed (Acres)	Percent of Area in Watershed (Acres)	Housing Units with Public Sewer	Housing Units with Septic Systems	Total Housing Units Occupied
Abington Township	9,893	2,712	12.9%	10,717	101	10,818
Cheltenham Township	5,779	5,691	27.0%	14,174	262	14,436
Jenkintown Borough	369	12,178	57.7%	2,072	0	2,072
Philadelphia City	91,287	367	1.7%	134,408	706	135,114
Rockledge Borough	219	81	0.4%	751	0	751
Springfield Township	4,352	65	0.3%	1,186	3	1,189

* Septic data is unavailable for 2000 Census.

The EPA has recently issued Voluntary National Guidelines for Management of Onsite and Clustered Wastewater Treatment Systems (EPA 832-B-03-001), covering all aspects of a comprehensive program, from design, inspection, and enforcement to public education and long-term planning. This document presents several different management models (see below) to choose from; division of responsibility and ownership between private land owners and public agencies varies between the different models. Municipalities should select that approach which best suits their conditions.



The Five Management Models

- Management Model 1 - "Homeowner Awareness" specifies appropriate program elements and activities where treatment systems are owned and operated by individual property owners in areas of low environmental sensitivity. This program is adequate where treatment technologies are limited to conventional systems that require little owner attention. To help ensure that timely maintenance is performed, the regulatory authority mails maintenance reminders to owners at appropriate intervals.
- Management Model 2 - "Maintenance Contracts" specifies program elements and activities where more complex designs are employed to enhance the capacity of conventional systems to accept and treat wastewater. Because of treatment complexity, contracts with qualified technicians are needed to ensure proper and timely maintenance.
- Management Model 3 - "Operating Permits" specifies program elements and activities where sustained performance of treatment systems is critical to protect public health and water quality. Limited-term operating permits are issued to the owner and are renewable for another term if the owner demonstrates that the system is in compliance with the terms and conditions of the permit. Performance-based designs may be incorporated into programs with management controls at this level.
- Management Model 4 - "Responsible Management Entity (RME) Operation and Maintenance" specifies program elements and activities where frequent and highly reliable operation and maintenance of decentralized systems is required to ensure water resource protection in sensitive environments. Under this model, the operating permit is issued to an RME instead of the property owner to provide the needed assurance that the appropriate maintenance is performed.
- Management Model 5 - "RME Ownership" specifies that program elements and activities for treatment systems are owned, operated, and maintained by the RME, which removes the property owner from responsibility for the system. This program is analogous to central sewerage and provides the greatest assurance of system performance in the most sensitive of environments.

Pet Waste, Litter, and Dumping Ordinances (AR2)

Related Goals: 3, 6, 7
Related Indicators: 7, 8, 9, 10, 11, 16, 17, 18, 19, 20

What	Who	Where	When
Adopt and enforce ordinance to require the removal of pet waste by the animal's owner within the municipality. Adopt and enforce ordinance to prohibit littering and dumping within the municipality.	See Table 8.6 (may not identify all municipalities with ordinance).	Entire watershed.	Within 5 years; update as needed.

A study was conducted to identify municipalities in the watershed that have adopted an ordinance to address removal of pet waste by the animal's owner and an ordinance that prohibits littering and dumping. The study verified existing ordinances related to pet waste, litter, and illegal dumping only in the City of Philadelphia; the study is believed to be comprehensive, but it is possible that additional ordinances exist that were not identified by the study. Table 8.6 shows the municipalities in the watershed that are known to have adopted pet waste and littering ordinances.

Table 8.6 Pet Waste and Littering Ordinances in the Tookany/Tacony-Frankford Watershed

Municipality	Pet Waste Ordinance	Littering and Dumping Ordinance
Abington Township		
Cheltenham Township		
Jenkintown Borough		
Philadelphia County	X	X
Rockledge Borough		

Source: www.ordinance.com, Delaware Valley Regional Planning Commission

Municipalities currently without ordinances are strongly encouraged to adopt them within the next two years. As an example of possible ordinance language, excerpts from Philadelphia County appear on the following page.

Pet Waste Ordinance	Littering and Dumping Ordinance
CHAPTER 10-100. Animals §10-105. Animals Committing Nuisances No person, having possession, custody or control of any animal, shall knowingly or negligently permit any dog or other animal to commit any nuisance upon any gutter, street, driveway, alley, curb or sidewalk in the City, or upon the floors or stairways of any building or place frequented by the public or used in common by the tenants, or upon the outside walls, walkways, driveways, alleys, curbs or stairways of any building abutting on a public street or park, or upon the grounds of any public park or public area, or upon any private property, including the property of the owner of such animal.	CHAPTER 10-700. REFUSE AND LITTERING §10-702. Litter in Public Places No person shall place or deposit litter in or upon any street, sidewalk or other public place within the City except in public receptacles or in authorized private receptacles.

Source: http://www.phila.gov/philacode/html/maintoc.htm , *The Philadelphia Code and Charter*

While pet waste and littering ordinances are enacted primarily for aesthetic purposes, reduction of pathogens and debris in stormwater, and thus in the Tookany/Tacony-Frankford Creek, can be reduced through their enforcement. Municipalities can assist residents in abiding by ordinances by placing trash cans in areas with higher pedestrian traffic. Plastic bags should be provided with trash cans in areas heavily used by dog owners, perhaps following the model established by the Partnership for the Delaware Estuary's "Dogi Pots" pet waste control program. Homeowners' associations should also be asked to notify residents of these ordinances and to provide trash cans and plastic bags in those neighborhoods as well.

8.1.2 Target A Options: Public Education and Volunteer Programs

Public Education (AP1) Related Goals: 4, 6, 7 Related Indicators: 16, 17, 18, 19, 20, 21			
What	Who	Where	When
Public Education Plan. Educational Program Implementation.	Municipalities on the Phase II List (see Table 8.7).	All municipalities in the TTF Watershed.	Short-term: first 5 years coinciding with the stormwater permit (see Table 8.8).

Public education about watershed management is an integral part of plan implementation. It will be designed to educate citizens on the importance of the watershed to the community, and on ways that individual behavior can impact water quality and the riparian and aquatic environment associated with Tookany/Tacony-Frankford Creek. In accordance with the TTFIWMP's stated purpose of integrating various existing programs, and to avoid duplication of effort, the recommended implementation plan follows the Stormwater Management Program Protocol to meet the six Minimum Control Measures required of municipal permittees under Phase II NPDES Stormwater Regulations (listed in Section 1.4.1 of this report, and found at 40 CFR § 122.26 – 123.35). In this way, implementation of these public education measures by municipalities will satisfy federal NPDES permit requirements for municipal separate storm sewer systems (MS4s), described in detail at 40 CFR §122.34.

Table 8.7 below lists the municipalities participating in the Phase II program that could work together with the City of Philadelphia on Public Education about watershed management issues. Assuming that a single, watershed-wide public education campaign focusing on all three Targets (A, B, and C) can be implemented, municipalities would meet their regulatory requirements while helping to implement the TTFIWMP, and avoiding the duplication of work with limited resources that would occur if each municipality were to initiate their own outreach campaign.

Table 8.7 Tookany/Tacony-Frankford Creek Municipalities on Phase I or II Stormwater List

Municipality	County	% of Muni. Area Drained by Watershed	% of Watershed within Muni.
Abington Township	Montgomery	27.41%	12.85%
Cheltenham Township	Montgomery	98.48%	26.98%
Jenkintown Borough	Montgomery	99.47%	1.74%
Rockledge Borough	Montgomery	36.89%	0.38%
Springfield Township	Montgomery	1.49%	0.31%

Public Education Plan

PWD and watershed municipalities should jointly develop a public education plan. The public education plan must target three audiences – homeowners, business owners, and developers – focusing on connections between their actions, stormwater runoff, and water quality. By the end of Year 1 of the permit cycle, cooperating municipalities should have a comprehensive plan in place that will help tap into the target audiences' existing communication channels to inform them about improving stormwater quality. During the following permit years, municipalities should monitor the effectiveness of the plan, and update it to ensure information about the target audiences is accurate.

PA DEP has guidelines for a public education plan. The plan should include an approach to collecting information on the three target audience categories. Municipalities should create a comprehensive inventory of the newsletters, newspapers, web sites, meetings, magazines, organizations, associations, etc. used by the target audiences. Cooperation of the municipalities with the assistance of the Tookany/Tacony-Frankford Watershed Partnership in gathering this information should help eliminate redundancy of effort. During the remaining years of the stormwater permit, municipalities are responsible for ensuring that information in the public education plan is accurate and current.

The River Conservation Plans (RCPs) recommend developing a comprehensive educational program for private land owners and businesses. A "do's and don'ts" format is suggested. The RCPs contain additional details and mapping for the following recommendations:

- Holy Sepulchre Cemetery to Ralph Morgan Park: Emphasize effect of land management practices on the creek.
- Washington Lane Underpass to Church Road: Focus on effects of land management on the creek. Target homeowners.
- High School Park to Ashbourne Road along the Tookany Creek Parkway: Emphasize infiltration BMPs.
- Unnamed Tributary in Glenside: Target homeowners, businesses, and SEPTA. Focus on rain barrels and riparian buffer zones.
- Baeder Creek Watershed: Focus on riparian buffer management and native species. Target land owners and apartment complexes.
- Rock Creek Watershed: Emphasize effect of land management practices on the creek.
- Mill Creek Watershed: Emphasize effect of land management practices on the creek.
- Leeches Run Watershed: Emphasize effect of land management practices on the creek. Target religious organizations and land owners.
- Township Line Road near Foxcroft Road to Main Stem: Focus on "no mow" zones, management of lawn waste, bank restoration, and invasive species.
- Township Line Road to Tookany Creek Parkway: Emphasize effect of land management practices on the creek.
- Rising Sun Avenue to Roosevelt Boulevard: Focus on illegal dumping.

- Castor Avenue to Erie Avenue: Emphasize effect of land management practices on the creek. Target local business owners, high school teachers, and students.
- Aramingo Avenue between Wheatsheaf Lane and Church Street: Emphasize effect of land management practices on the creek. Target local business owners, high school teachers, and students.
- Holy Sepulchre Cemetery to Ralph Morgan Park: Work with Bishop McDevitt to implement BMPs to focus on decreasing stormwater runoff from property.
- Wyncote Post Office to Washington Lane Underpass: PECO energy environmental department should be contacted for information regarding the results of studies being done in this area.
- Washington Lane Underpass to Church Road: The township should develop a dialogue and educate SEPTA regarding the needs of the bird sanctuary, the health of the creek, and railroad track safety.
- Eastern Branch of the Baeder Creek: Work with Abington Township School District to develop a land management plan. Focus on increasing on site infiltration.

In addition, other information relevant to watershed management should be included on topics such as:

- Improper Disposal to Storm Drains
- Automobile Maintenance
- Car Washing
- Animal Waste Collection
- Restorative Redevelopment: Public Education Aspects

Public Education Implementation

Once the public education plan is developed, it must be implemented. This means distributing educational materials provided by PA DEP or others that contain messages related to watershed (and stormwater) management. Municipalities can find educational materials needed to implement the educational program on the PA DEP website at http://www.dep.state.pa.us/dep/deputate/watermgt/wc/NPDSMS4/MS4CD/.

To fulfill NPDES stormwater permit requirements, municipalities should implement two phases of educational outreach. During the first stage, the focus is on raising the awareness of target audiences. In the second stage, municipalities should aim to educate the target audiences about the problems and potential solutions. PA DEP presents requirements in the stormwater permit for the "what" and "when" of this minimum measure component, but it does not specify the "how." Municipalities should use their Public Education Plan to determine the most effective means of getting educational materials into the hands of target audiences. Any additional educational activities should show compliance with this Minimum Control Measure. This includes educational activities by watershed groups, and certainly should make use of the existing Tookany/Tacony-Frankford Watershed Partnership activities.

In Year 1, municipalities are required to start raising target audience awareness. Raising awareness can be accomplished by use of PA DEP materials. PA DEP has made available copies of the pamphlet entitled "When It Rains, It Drains" (available on the PA DEP website, http://www.dep.state.pa.us/dep/deputate/watermgt/wc/NPDSMS4/MS4CD/).

This document addresses the issue of pollution related to stormwater runoff and activities that citizens can use to improve stormwater quality. It also provides an overview of a typical stormwater management program. Using the information on distribution channels in the Public Education Plan, municipalities should disseminate these pamphlets to all the target audience categories in the community.

In Year 2, municipalities should begin to educate all the target audiences. This includes distributing fact sheets to developers about their responsibilities under the state and federal stormwater regulations. To meet this requirement, municipalities should distribute the Fact Sheets prepared by PA DEP, and run a "stormwater ad" in local newspapers.

In addition to targeting developers, municipalities may distribute posters to schools, community organizations and institutions, and businesses. Topics such as responsible vehicle maintenance, household hazardous waste disposal, and pet waste are important to stormwater management. PA DEP has developed a series of posters that convey messages about these topics.

Another useful measure is storm drain stenciling. While not required by the Stormwater Management Program Protocol, any stenciling done by outside organizations may contribute to meeting permit requirements for this Minimum Control Measure.

Public education directors should check any links to PA DEP's stormwater website and update the links if necessary.

In Years 3-5, the implementation continues. This consists mainly of continuing with distribution of posters and fact sheets, and running additional ads in local newspapers.

The schedule for developing and implementing the plan to meet Phase II stormwater requirements is shown in Table 8.8.

Table 8.8 Schedule for Implementation of the Public Education Program

PERMIT YEAR	**Education Plan**	**Educational Program**
Year 1	Determine Target Audience. Develop Public Education Plan. Raise Target Audience Awareness.	• Disseminate materials to all target audiences using appropriate distribution channels. • Newspaper advertisement. • Other components of Plan.
Years 2-5	Implement the plan. Revise Plan as needed.	• Disseminate materials to all target audiences using appropriate distribution channels. • Newspaper advertisement. • Other components of Plan.

Source: PA DEP MS4 Stormwater Management Program Protocol, 2003

School-Based Education (AP2) Related Goals: 6, 7 Related Indicators: 17, 18, 21			
What	Who	Where	When
Implement PA Environmental Education Curriculum.	School districts, supported by municipal governments and non-profits.	All schools.	Short-term (within 5 years).

Besides requirements found in the MS4 Stormwater Management Program Protocol, another important aspect of public education is to reach children through school curricula.

School-based watershed education takes many forms, from lesson plans within the classroom, to hands-on activities outside of the classroom such as field trips to Tookany/Tacony-Frankford Creek and nearby nature centers, as well conducting actual restoration projects. Teacher training programs, developed to assist teachers in bringing watershed concepts to their students, are critical. Being engaged in actual restoration projects, whether through service learning, after school clubs, or integrated as a part of lesson plans helps to translate these lessons into actions.

Sources for lesson plans include the following:

- Incorporate the Pennsylvania Environmental Education Curriculum developed by PA DEP into middle school curricula. This curriculum introduces concepts in watersheds, wetlands, stormwater, drinking water, and water and air pollution.

- Use local examples of watershed protection and restoration to enhance the program, work with schools to provide watershed-based educational opportunities, including the Environmental Scholars Program, Tree Survey Project, Urban Watershed Program, Environmental Clubs, Learning Grove/Trail Development Project, Park Management Program, and Teacher Training Program.

The River Conservation Plans (RCPs) suggest that a statewide environmental education curriculum could spark the interest of younger members of the watershed therefore making them aware of the problems at an earlier age. This could include incorporating riparian buffer restoration with some of the mandatory ecology curriculum.

Public Participation and Volunteer Programs (AP3)

Related Goals: 3, 4, 5, 6, 7
Related Indicators: 10, 11, 12, 13, 14, 15, 16, 17, 18, 21

What	Who	Where	When
Public Participation. Volunteer Monitoring and Storm Drain Stenciling.	Municipalities.	All municipalities in the TTF Watershed.	First 5 years coinciding with the stormwater permit.

Public participation is another facet of implementation that must follow the PA DEP Stormwater Management Program Protocol to meet the six Minimum Control Measures required of municipal permittees under the Phase II NPDES Stormwater Regulations (listed in Section 1.4.1 of this report, and found at 40 CFR §§ 122.26 – 123.35). The public must participate in issues related to municipal actions to address stormwater impacts on water quality. This includes new planning initiatives, changes to ordinances and other local regulations. This requirement overlaps the public participation aspects of the watershed management plan, and suggests that a unified and coordinated approach between municipalities would be most efficient. All municipalities in the watershed (listed in Table 8.7) are required to have a public participation program. Again, the Tookany/Tacony-Frankford Watershed Partnership would be able to assist in fostering this coordination and performing public outreach.

Prior to adoption of any ordinance required under the PA DEP Stormwater Protocol, municipalities must provide adequate public notice and opportunities for public review and input, and hold hearings to obtain public feedback. This can be done in conjunction with normal public sessions of the municipal governing body. The notice must be published in a local newspaper of general circulation. Involving citizen groups, watershed organizations, and businesses as much as possible will obtain broad support for stormwater management efforts. The TTF Partnership itself is an obvious example of such inclusion, and can help municipalities to meet this requirement.

Although the actual public participation requirements can be met by following guidelines for Act 167 planning, it is recommended that municipalities go beyond the minimum. Some options for additional public participation are listed below.

- Develop a Public Involvement and Participation Plan: By the end of Year 1, a municipality may want to have a comprehensive plan in place that will guide your efforts to recruit volunteers and obtain participation at public meetings. This could be part of the Public Education Plan discussed above (see Option AP1).

- Produce strategies for recruiting participation from six categories of stakeholders: municipal employees, homeowners, businesses, schools, watershed associations and other volunteer groups, and developers.

- Develop a comprehensive stakeholder mailing list.

- Conduct Public Meetings: PA DEP suggests using a general stormwater public meeting to kick-off public education and participation efforts. This has already been done for the Tookany/Tacony-Frankford Partnership and Steering Committee, and municipalities are encouraged to make use of this. Invite representatives from all six stakeholder categories. It is important that all stakeholder interests have the opportunity to participate. Meeting agendas should include, but not be limited to, the overview presentation on the watershed management and stormwater program and time for questions from the audience.

An important aspect of public participation is the establishment of volunteer programs. There are many types of volunteer programs that can help manage stormwater and improve a community's water quality. The goal of the volunteer program is to obtain and sustain volunteer support that will aid watershed management efforts. To reach this goal, it is important to develop a program that reflects stakeholders' concerns and interests. Examples of volunteer programs are:

- **Volunteer Monitoring Program:** Municipalities should determine which type of assessment the program will undertake and develop a study design using the manual entitled "Designing Your Monitoring Program: A Technical Handbook for Community-Based Monitoring in Pennsylvania" as the basis for planning and implementing your monitoring program (PA DEP, 2001).

- **Storm Drain Stenciling Program:** Municipalities should establish procedures for storm drain stenciling and organize volunteers to carry out the program. PA DEP has provided resource materials in a References and Resources CD-ROM on developing and implementing a storm drain stenciling program.

- **Stream Cleanup and Restoration Activities:** Citizen participation in stream cleanups is a good way to get the community involved in keeping the streams free of trash and debris. In Philadelphia, stream cleanups can be coordinated with PWD's Waterways Restoration Unit. Other participatory activities can include support of riparian plantings during stream restoration activities.

The River Conservation Plans (RCPs) suggest that increased volunteer work will increase the general awareness regarding what citizen can do to keep the watershed free of problems. For example, at the Washington Lane Underpass to Church Road, a group could be organized to adopt the bird sanctuary area.

8.1.3 Target A Options: Municipal Measures

Capacity Management Operation and Maintenance (CMOM) (AM1)

Related Goals: 1, 2, 3
Related Indicators: 7, 9, 11

What	Who	Where	When
Program to manage and maintain sewer systems; plans in place to track SSOs and overflow response plan.	Separate Sewered Municipalities.	Separate Sanitary Sewer Areas.	Medium term: 5+ years.

Capacity, management, operation, and maintenance (CMOM) programs are recommended for all areas with separate sanitary sewer systems and are an important component of Target A because they help prevent dry weather discharges. Recommendations in this section cover both the dry and wet weather aspects of the program; recommendations that are specific to SSO abatement are included here for completeness and are referred to under Target C. The recommendations in this section are adapted from the "Consensus Recommendation of the SSO Federal Advisory Subcommittee," published in October 1999.

1) General Standards

- Properly manage, operate, and maintain, at all times, all parts of collection system. Perform maintenance and inspections using techniques similar to those recommended for combined sewers in Option AM2.
- Provide adequate capacity to convey base flows and peak flows for all parts of the collection system.
- Take all feasible steps to stop, and mitigate the impact of, sanitary sewer overflows in portions of the collection system.
- Provide notification to parties with a reasonable potential for exposure to pollutants associated with the overflow event.
- Develop a written summary of the CMOM program and make it, and the audit under section (5), available to any member of the public upon request.

2) Management Program

Develop a CMOM program to comply with the above general standards. If any element of this section is not appropriate or applicable for the CMOM program in question, it does not need to address the element, but a written summary must explain why that element is not applicable. The management program should consist of the following six components:

1. Goals
The program must identify in detail the major goals of the CMOM program consistent with the general standards identified above.

2. Organization
(A) Identify administrative and maintenance positions responsible for implementing measures in the CMOM program, including lines of authority by organization chart or similar document, and (B) establish the chain of communication for reporting SSOs from receipt of a complaint or other information to the person responsible for reporting to the NPDES authority.

3. Legal Authority
Include legal authority, through sewer use ordinances, service agreements or other legally binding documents, to:

(A) Control infiltration and connections from inflow sources;

(B) Require that sewers and connections be properly designed and constructed;

(C) Ensure proper installation, testing, and inspection of new and rehabilitated sewers (such as new or rehabilitated collector sewers and new or rehabilitated service laterals);

(D) Address flows from satellite municipal collection systems; and

(E) Implement the general and specific prohibitions of the national pretreatment program that you are subject to under 40 CFR 403.5.

4. Measures and Activities
The CMOM program must address the elements listed below that are appropriate and applicable to the sewer system and identify the person or position in the organization responsible for each element.

(A) Maintenance of facilities.

(B) Maintenance of a map of the collection system.

(C) Management of information and use of timely, relevant information to establish and prioritize appropriate CMOM activities, and to identify and illustrate trends in overflows.

(D) Routine preventive operation and maintenance activities.

(E) Assessment of the current capacity of the collection system and treatment facilities.

(F) Identification and prioritization of structural deficiencies and identification and implementation of short-term and long-term rehabilitation actions to address each deficiency.

(G) Appropriate training on a regular basis.

(H) Equipment and replacement parts inventories including identification of critical replacement parts.

5. Design and Performance Provisions
(A) Requirements and standards for the installation of new sewers, pumps, and other appurtenances, and for rehabilitation and repair projects.

(B) Procedures and specifications for inspecting and testing the installation of new sewers, pumps, and other appurtenances, and for rehabilitation and repair projects.

6. Monitoring, Measurement, and Program Modifications

Monitor the implementation and, where appropriate, measure the effectiveness of each element of the CMOM program. Program elements must be updated as appropriate based on monitoring or performance evaluations. The summary of the CMOM program should be modified as appropriate to keep it updated and accurate.

3) Overflow Response Plan

An overflow response plan should be developed and implemented that identifies measures to protect public health and the environment including, but not limited to, mechanisms to:

(i) Ensure that all overflows are made aware of (to the greatest extent possible);

(ii) Ensure that overflows are appropriately responded to, including ensuring that reports of overflows are immediately dispatched to appropriate personnel for investigation and appropriate response;

(iii) Ensure appropriate reporting pursuant to 40 CFR 122.42(e);

(iv) Ensure appropriate notification to the public, health agencies, and other impacted entities (e.g. water suppliers) pursuant to 40 CFR 122.42(h). The CMOM plan should identify the public health and other officials who will receive immediate notification;

(v) Ensure that appropriate personnel are aware of and follow the plan and are appropriately trained; and

(vi) Provide emergency operations.

4) System Evaluation and Capacity Assurance Plan

A plan should be prepared and implemented for system evaluation and capacity assurance if peak flow conditions are contributing to an SSO discharge unless either (1) already taken steps to correct the hydraulic deficiency or (2) the discharge meets the criteria of 122.42(g)(2). At a minimum the plan must include:

(i) *Evaluation:* Steps to evaluate those portions of the collection system which are experiencing or contributing to an SSO discharge caused by hydraulic deficiency or to noncompliance at a treatment plant. The evaluation should provide estimates of peak flows (including flows from SSOs that escape from the system) associated with conditions similar to those causing overflow events, provide estimates of the capacity of key system components, identify hydraulic deficiencies, including components of the system with limiting capacity and identify the major sources that contribute to the peak flows associated with overflow events.

(ii) *Capacity Enhancement Measures:* Establish short- and long-term actions to address each hydraulic deficiency including prioritization, alternative analysis, and a schedule.

(iii) *Plan Updates:* The plan should be updated to describe any significant change in proposed actions and/or implementation schedule. The plan should also be updated to reflect available information on the performance of measures that have been implemented.

5) CMOM Program Audits

As part of the NPDES permit application, an audit should be conducted, appropriate to the size of the system and the number of overflows, and a report submitted of such audit, evaluating the CMOM program and its compliance with this subsection, including its deficiencies and steps to respond to them.

6) Communications

The permittee should communicate on a regular basis with various interested parties on the implementation and performance of its CMOM program. The communication system should allow interested parties to provide input to the permittee as the CMOM program is developed and implemented.

Inspection and Cleaning of Combined Sewers (AM2)

Related Goals: 3, 4, 7
Related Indicators: 11, 19

What	Who	Where	When
Inspection activities, routine maintenance, monitoring activities.	PWD	Combined Sewered Areas (see Figure 8.3).	First 5 years coinciding with the stormwater permit.

Maintenance of sewers includes activities required to keep the system functioning as it was originally designed and constructed. Any reinvestment in the system, including routine maintenance, capital improvements for repair or rehabilitation, inspection activities, and monitoring activities are generally classified as maintenance.

An inspection program is vital to proper maintenance of a wastewater collection system. Without inspections, a maintenance program is difficult to design, since problems cannot be solved if they are not identified. Sewer inspections identify problems such as blocked, broken, or cracked pipes; tree roots growing into the sewer; sections of pipe that settle or shift so that pipe joints no longer match; and sediment and other material building up and causing pipes to break or collapse. The elements of an inspection program include flow monitoring, manhole inspections, smoke/dye testing, closed circuit television inspection, and private sector inspections. Private sector building inspection activities include inspection of area drains, downspouts, cleanouts, sump discharges, and other private sector inflow sources into the system.

In addition to inspection, routine maintenance must also include sewer cleaning, root removal/treatment, cleaning of mainline stoppages, cleaning of house service stoppages, and inspections and servicing of pump stations.

PWD is responsible for implementation of this option in the combined sewer areas of the Tookany/Tacony-Frankford Watershed, but municipalities with separate sewers should have similar permanent and active sewer maintenance programs in place under CMOM (see Option AM1). In Section 4.4.1, Figure 4.19 illustrated the areas where sanitary sewers and combined sewers exist. All municipalities in the watershed are responsible for sewer maintenance.

PWD has combined sewer maintenance responsibilities in the Tookany/Tacony-Frankford Watershed. CSO regulations (including the Nine Minimum Controls discussed in Section 1.4.5) have required that PWD carry out improved sewer maintenance. Some of the activities PWD is carrying out include the review and improvement of ongoing operation and maintenance programs, and comprehensive inspection and monitoring programs to characterize and report overflows and other conditions in the combined sewer system.

Sanitary Sewer Rehabilitation (AM3) Related Goals: 3 Related Indicators: 7, 11			
What	Who	Where	When
Perform major repairs or replacement on sections of sewer determined to be in poor condition.	All municipalities with separate sanitary sewer systems.	All municipalities with separate sanitary sewer systems.	Medium-term.

The CMOM and sewer inspection programs discussed in the two preceding sections may identify segments of sewer that are in poor condition and in need of major repair or replacement. The information in this section is adapted from fact sheets on the EPA web site: http://www.epa.gov/owm/mtb/rehabl.pdf.

Under the traditional method of sewer relief, a replacement or additional parallel sewer line is constructed by digging along the entire length of the existing pipeline. While these traditional methods of sewer rehabilitation require unearthing and replacing the deficient pipe (the dig-and-replace method), trenchless methods of rehabilitation use the existing pipe as a host for a new pipe or liner. Trenchless sewer rehabilitation techniques offer a method of correcting pipe deficiencies that requires less restoration and causes less disturbance and environmental degradation than the traditional dig and-replace method.

Trenchless Sewer Rehabilitation Methods:

- Pipe Bursting, or In-Line Expansion
- Sliplining
- Cured-In-Place Pipe
- Modified Cross Section Liner

These alternative techniques must be fully understood before they are applied. These four sewer rehabilitation methods are described further below:

Pipe Bursting or In-Line Expansion: Pipe bursting, or in-line expansion, is a method by which the existing pipe is forced outward and opened by a bursting tool. The Pipebursting™ method, patented by the British Gas Company in 1980, was successfully applied by the gas pipelines industry before its applicability was identified by other underground utility agencies. Over the last two decades, other methods of in-line expansion have been patented as well. During in-line expansion, the existing pipe is used as a guide for inserting the expansion head (part of the bursting tool). The expansion head, typically pulled by a cable rod and winch, increases the area available for the new pipe by pushing the existing pipe radially outward until it cracks. The bursting device pulls the new pipeline behind itself.

Sliplining: Sliplining is a well-established method of trenchless rehabilitation. During the sliplining process, a new liner of smaller diameter is placed inside the existing pipe. The annular space, or area between the existing pipe and the new pipe, is typically grouted to prevent leaks and to provide structural integrity.

Cured-In-Place Pipe: During the cured-in-place pipe (CIPP) renewal process, a flexible fabric liner, coated with a thermosetting resin, is inserted into the existing pipeline and cured to form a new liner. The liner is typically inserted into the existing pipe through an existing manhole. The fabric tube holds the resin in place until the tube is inserted in the pipe and ready to be cured. Commonly manufactured resins include unsaturated polyester, vinyl ester.

Modified Cross Section Lining: The modified cross section lining methods include deformed and reformed methods, sewagelining™, and rolldown. These methods either modify the pipe's cross sectional profile or reduce its cross sectional area so that the liner can be extruded through the existing pipe. The liner is subsequently expanded to conform to the existing pipe's size. Another method of obtaining a close fit between the new lining and existing pipe is to temporarily compress the new liner before it is drawn through the existing pipeline. The sewagelining™ and rolldown processes use chemical and mechanical means, respectively, to reduce the cross-sectional area of the new liner.

External Sewer Rehabilitation Methods (adapted from EPA/600/R-01/034)

External rehabilitation methods are performed from the above ground surface by excavating adjacent to the pipe, or the external region of the pipe is treated from inside the pipe through the wall. Some of the methods used include:

- External Point Repairs
- Chemical Grouting (Acrylamide Base Gel, Acrylic Base Gel)
- Cement Grouting (Cement, Microfine Cement, Compaction)

Internal Sewer Rehabilitation Methods

The basic internal sewer rehabilitation methods include:

Chemical Grouting: Internal grouting is the most commonly used method for sealing leaking joints in structurally sound sewer pipes. Chemical grouts do not stop leaks by filling cracks; they are forced through cracks and joints, and gel with surrounding soil, forming a waterproof collar around leaking pipes. This method is accomplished by sealing off an area with a "packer," air testing the segment, and pressure injecting a chemical grout for all segments which fail the air test. The three major types of chemical grout are: Acrylic, Acrylate, and Urethane.

Continuous Pipe: Insertion of a continuous pipe through the existing pipe (Polyethylene and Polypropylene).

Segmental: Short segments of new pipe are assembled to form a continuous line, and forced into the host pipe. Generally, this method is used on larger sized pipe and forced into the host pipe. (Polyethylene, Polyvinyl Chloride, Reinforced Plastic Mortar, Fiberglass Reinforced Plastic, Ductile Iron, Steel).

Fold and Form Pipe: This is similar to sliplining, except that the liner pipe is deformed in some manner to aid insertion into the existing pipe. Depending on the specific manufacturer, the liner pipe may be made of PVC or HDPE. One method of deforming the liner is to fold it into a "U" shape before insertion into the existing pipe. The pipe is then returned to its original circular shape using heated air or water, or using a rounded shaping device or mandrel. Ideally, there will be no void between the existing pipe and the liner pipe after expansion of the liner pipe with the shaping device. For the "U" shape liner, the resulting pipe liner is seamless and jointless.

Spiral Wound Pipe: This involves winding strips of PVC in a helical pattern to form a continuous liner on the inside of the existing pipe. The liner is then strengthened and supported with grout that is injected into the annular void between the existing pipe and the liner. A modified spiral method is also available that winds the liner pipe into a smaller diameter than the existing pipe, and then by slippage of the seams, the liner expands outward.

Combined Sewer Rehabilitation (AM4)

Related Goals: 3, 7
Related Indicators: 7, 8, 9, 10, 11, 19, 20

What	Who	Where	When
Perform major repairs or replacement on sections of sewer determined to be in poor condition.	PWD	Combined-Sewered Areas.	Medium-term.

Rehabilitation of combined sewers is conceptually similar to rehabilitation of separate sanitary sewers. Refer to Option AM3 above for information on specific techniques.

Illicit Discharge, Detection, and Elimination (IDD&E) (AM5) Related Goals: 3, 6, 7 Related Indicators: 7, 8, 9, 10, 11, 16, 19, 20			
What	Who	Where	When
IDD&E Program in conformance with Phase II Stormwater Permits and the LTCP for PWD.	All Municipalities required to do Phase II permit (see Table 8.7); PWD in CSO Areas.	All areas with a storm sewer or combined sewer (see Figure 8.3).	5-year program associated with stormwater permit (see Table 8.10).

In accordance with the Tookany/Tacony-Frankford Watershed Plan's stated purpose of integrating various existing programs, and to avoid duplication of effort, the recommended implementation plan follows the PA DEP Stormwater Management Program Protocol to meet the six minimum control measures required of municipal permittees under the Phase II NPDES Stormwater Regulations (listed in Section 1.4.1 of this report, and found at 40 CFR §§ 122.26 – 123.35). One of the six minimum controls is an IDD&E program. The IDD&E program can be summarized as consisting of the following steps:

- Develop map of municipal separate storm sewer system outfalls and receiving water bodies.
- Prohibit illicit discharges via PA DEP-approved ordinance.
- Implement an IDD&E Program that includes 1) field screening program and procedures and 2) elimination of illicit discharges.
- Conduct public awareness and reporting program (see Option AP1, "Public Education," in Section 8.1.2).

A similar approach to controlling dry weather flows is being followed by PWD under the Long Term Control Plan (LTCP) for CSOs.

Each step is explained in more detail below:

Develop an Outfall Map

The federal regulations define an outfall as "a point source as defined by 40 CFR 122.2 at the point where a municipal separate storm sewer discharges to waters of the United States." A "point source" is defined as "any discernable, confined, and discrete conveyance, including but not limited to any pipe, ditch, channel, tunnel, conduit, well, discrete fissure, container, rolling stock, concentrated animal feeding operation, vessel, or other floating craft from which pollutants are or may be discharged."

Many of the outfalls along Tookany/Tacony-Frankford Creek have already been located under the studies performed for the Tookany/Tacony-Frankford Creek RCP. Municipalities should work with PWD to develop a consistent set of outfall maps that meet the specific requirements of the Phase II program.

Illicit Discharge Ordinance

A model ordinance is available from PA DEP and should be used as is. PA DEP discourages changes to the model ordinance, because it has been prepared to meet the MS4 permit requirements. However, some municipalities already have good stormwater ordinances. Municipalities who do not wish to enact the model ordinance in its entirety must get approval from PA DEP to ensure that the MS4 permit requirements are met.

The model ordinance must be enacted in the first year of the permit term, except where a municipality commits to a multi-municipal, watershed-based program following the Stormwater Management Program Protocol, in which case the schedule is delayed one year. Subsequent to completion of the Act 167 Plan (or Plan Update), the ordinance must be modified to reflect Plan requirements. Regardless of the timing of the Act 167 Plan (or Plan Update) an ordinance must be enacted within the first two years of the permit term for all municipalities in the Tookany/Tacony-Frankford Watershed.

IDD&E Program

Following the PA DEP Protocol, the IDD&E Program must consist of the following three elements, which must be implemented according to the schedule shown below:

- Conduct Field Screening.
- Identify Source of Illicit Discharges.
- Develop and Implement a Strategy to Remove or Correct Illicit Discharges.

Field Screening: Field screening is necessary to identify source(s) of actual illicit discharges. Field screening must start in Year 2 of the permit. PA DEP provides a checklist that must be used when conducting field screening. Every outfall in priority areas must be screened two times a year. This activity can be accomplished concurrently with other existing field activities, such as regularly scheduled fire hydrant inspections, road repairs, landscaping activities, other field work conducted during county preparation of the Act 167 stormwater plan, etc.

Using a PA DEP supplied Checklist, the staff designated to conduct field screening collect visual data. The screening should be conducted at least 72 hours since the last precipitation event, and at least 48 hours should pass between the first screening at a particular outfall and the second screening at that outfall. If someone conducting the field screening discovers a dry-weather flow, they (or another designated individual with the proper training) must collect a sample of that flow for analysis. Such a discovery triggers the requirements under the other two program elements, below.

Identify Source of Illicit Discharges: The following IDD&E Program elements apply only if a dry-weather flow is identified during field screening activities in Years 2, 3, 4, and/or 5.

If field inspectors identify a dry-weather flow at an outfall during field screening, they should take two grab samples of the flow and analyze the samples for the characteristics and pollutants listed in the Table 8.9 below.

Table 8.9 Dry-Weather Flow Sampling Analysis Requirements

Characteristic/Pollutant	Method
Color	Visual observation
Odor	Visual observation
Turbidity	Visual observation
Sheen/scum	Visual observation
PH	In-field analysis
Total chlorine	In-field analysis
Total copper	In-field analysis
Total phenol	In-field analysis
Detergents/surfactants	In-field analysis
Flow	In-field measurement
Bacteria	Laboratory analysis

The data obtained from visual, in-field, and laboratory analyses will provide the information necessary to determine the source of the dry-weather flow or floatables. Based on the pollutants contained in the sample, it should be possible to determine if the source is from illegal dumping in a storm drain, a cross-connection, or a leak in a pipe. Potential sources of the dry-weather flow can be located by tracing the flow upstream using storm drain maps and by inspecting upgradient manholes and storm drains. If need be, a more focused test to pinpoint the source can be tried, such as dye testing, smoke testing, and television camera inspection.

Remove or Correct the Illicit Discharge: Once the source has been identified, municipalities need to determine if it is a case of improper dumping or if a property owner has an improper physical connection to the storm sewer system. This will help to select the most appropriate method for correcting or removing the discharge. If it is a case of improper dumping, the only recourse may be to conduct intensified education of residents living in and traveling through that area. If it is a case of an improper physical connection, the appropriate action can be taken to correct the discharge. A plan of action to eliminate illicit connections might include plugging discharge points or disconnecting and reconnecting lines.

If a violation is found, the property owner should be notified of the violation and given a timeframe for removal of the source. After that time has passed, the outfall can be screened to identify the dry weather discharge. The property should be visited a final time to confirm that the property owner removed or corrected the source. The results of all discussions, tests, and screenings should be documented for follow-up purposes. Progress evaluation of the municipal IDD&E program will depend on the ability to tabulate the number of illicit connections corrected and the status of those in the process of being corrected.

All municipalities within the Tookany/Tacony-Frankford Watershed that have a sanitary sewer system are required to carry out this program. Table 8.7 lists the municipalities, and Figure 8.3 shows the location of the sewered areas.

The PA DEP Protocol has laid out a very specific time table for completion of this program by the municipalities. The timing is shown in Table 8.10 below.

Table 8.10 Implementation Schedule for IDD&E Program

PERMIT YEAR	***IMPLEMENTATION SCHEDULE PERMIT REQUIREMENTS AND MEASURABLE GOALS***			
	Mapping	**Ordinance**	**Program**	**Education**
Year 1	Complete map of all outfalls.	Adopt and enact.	Screen Priority Areas. Take corrective actions to remove illicit discharges (as needed).	Presentation on IDD&E. Program and Ordinance during a public meeting. Distribute educational material (see Public Education and Outreach Minimum Measure).
Years 2 - 5	Establish priority areas for 25% of system.	Implement and enforce.	Screen Priority Areas. Take corrective actions to remove illicit discharges (as needed).	Distribute educational material (see Public Education and Outreach Minimum Measure).

The River Conservation Plans (RCPs) noted the following:

- <u>Rising Sun Avenue to Roosevelt Blvd</u>: Investigate exposed pipe at Tabor Road.

Stream Cleanup and Maintenance (AM6)

Related Goals: 1, 3, 4, 6, 7
Related Indicators: 3, 4, 5, 6, 10, 11, 15, 16, 17, 19, 20

What	Who	Where	When
Remove litter and heavy debris. Maintain habitat improvements (fish ladders, FGM, elimination of plunge pools).	PWD Waterways Restoration Unit; Fairmount Park volunteers and other volunteer groups.	Entire creek system.	Begin within 5 years; monthly maintenance schedule to be determined.

Keeping streams free of trash is a continuous activity. Fairmount Park volunteers alone have removed over 2,000 bags of trash from the stream corridor since 1998. Public education should help in reducing trash and debris reaching the streams; however, PWD and municipalities need to put into place a permanent maintenance schedule. PWD has implemented a permanent Waterways Restoration Unit. This team periodically removes trash and large debris from Tookany/Tacony-Frankford Creek on a rotating schedule. For reaches of stream within the City or along the City boundary, the team will focus on removal of litter and heavy debris, and maintenance of instream aquatic habitat improvement projects including fish ladders, fluvial geomorphologic restoration projects, and elimination of outfall plunge pools. For reaches of stream outside the City, municipalities should organize periodic stream cleanups using volunteer groups.

In addition to noting the specific trouble spots listed below, the River Conservation Plans (RCPs) recommend a general cleanup routine be established to conserve both the biological and aesthetical quality of the rivers. Any plans that reduce the amount of trash or illegal dumping would be considered essential. Local township volunteers can be of great assistance in this particular BMP.

- Wyncote Post Office to Washington Lane Underpass: Investigate dumping of construction material.
- Rock Creek Watershed: Monitor commercial areas for illegal dumping.
- Rising Sun Avenue to Roosevelt Boulevard: Erect a barricade to deter illegal dumping.
- Roosevelt Boulevard to Whitaker Avenue: Install a barrier to stop dumping at Whitaker Ave. Bridge.
- Whitaker Avenue to Wyoming Avenue: Erect a barricade to deter illegal dumping.
- Aramingo Avenue between Wheatsheaf Lane and Church Street: Install fence barrier at Aramingo Ave. overpass to stop illegal dumping.
- Holy Sepulchre Cemetery to Ralph Morgan Park: Conduct regular trash removal.
- Ralph Morgan Park to Greenwood Avenue: Clear debris blocking stormwater outlets and ask staff not to dump leaves in the creek.

- Greenwood Avenue to Wyncote Post Office: Routinely clear creek of trash and debris after storms.
- Wyncote Post Office to Washington Lane Underpass: Major cleanup required. SEPTA should be contacted to clean railroad debris.
- Washington Lane Underpass to Church Road: Remove trash, storm debris, and graffiti.
- High School Park to Ashbourne Road along the Tookany Creek Parkway: Conduct regular trash removal.
- Unnamed Tributary in Glenside: Clean up trash and storm debris along Tyson Ave. SEPTA should monitor culverts for blockage.
- Rock Creek Watershed: Continue to improve infrastructure that has a negative impact on water quality. Conduct regular trash removal.
- Abington Country Club to Township Line Road: Clean and maintain channelized portion of the creek on a regular basis.
- Township Line Road near Foxcroft Road to Main Stem (unnamed tributary): Clear entire reach of storm debris.
- Abington Friends School to Township Line Road: Regularly remove trash in the creek area.
- Township Line Road to Tookany Creek Parkway: Conduct regular trash/debris removal.
- Cheltenham Avenue to Adams Avenue: Clear creek of debris. Concentrate on woody debris at bridge. Evaluate trash pick-up schedule with Fairmount Park.
- Crescentville and Adams Avenues to Rising Sun Avenue: Conduct regular trash removal.
- Rising Sun Avenue to Roosevelt Boulevard: Conduct a massive trash removal, concentrating at the F Street site. Clear overgrown vegetation.
- Roosevelt Boulevard to Whitaker Avenue: Conduct massive trash removal of the whole segment.
- Wyoming Avenue to Castor Avenue: Conduct a trash cleanup. Contact Ferko Playground regarding trashcans and regular trash removal.
- Castor Avenue to Erie Avenue: Remove graffiti from walls and secure access areas.
- Aramingo Avenue between Wheatsheaf Lane and Church Street: Clear creek of all debris.
- Rohm & Haas, 5000 Richmond Street: Conduct trash removal at mouth of embankment.
- Intersection of Adams and Newtown Avenue: Investigate illegal dumpsite and install fencing.
- Driveway connecting Adams Ave to Godfrey Ave: Investigate illegal dumpsite and install fencing.
- Castor Avenue near Wyoming Avenue: Investigate illegal dumpsite and install fencing.
- I and Ramona: Investigate illegal dumpsite and install fencing.
- Awbury Arboretum: Investigate illegal dumpsite and install fencing.

8.1.4 Target A Options: Recreational and Cultural Resources

Enhancing Stream Corridor Recreational and Cultural Resources (AO1)

Related Goals: 4, 6, 7
Related Indicators: 16, 17, 18, 19, 20, 21

What	Who	Where	When
Establish and improve trails and greenways using measures recommended in the RCPs and the Fairmount Park Trails Master Plan. Protect historic sites listed in the RCPs.	Outside Philadelphia: partnership of Department of Conservation and Natural Resources (DCNR), county planning departments, and municipalities. Inside Philadelphia: Fairmount Park Commission.	See Figures 8.2.	Medium-term: 5-15 years.

Part of Target A addresses the accessibility of Tookany/Tacony-Frankford Creek. Once dry weather water quality and aesthetics have been improved, the recreational value of the Creek will be enhanced, and better accessibility becomes important. A stream accessibility analysis (Section 4.6.4, Indicator 18) illustrated that much of the headwaters and the downstream portion of the Tookany/Tacony-Frankford are inaccessible. The recommended actions focus primarily on improving access to public lands where recreational potential is greatest.

The River Conservation Plans (RCPs) recommend improving existing stream corridor recreation resources in order for the watershed to gain value as a civic asset. This goal can be achieved through building/repairing trails or by blocking disruptive activities (such as ATV use). Protecting historically significant items is also a recommendation. The RCPs noted in particular:

- Church Road at Chelten Hills Drive to Church Road near Ogontz Field: Remove millstones for historic display at Wall House.
- Rock Creek Watershed: Consider a trail or greenway along township-owned segments.
- Cheltenham Avenue to Adams Avenue: Repair trail erosion at benches. Recommend repair or removal of exercise stations.
- Crescentville and Adams Avenues to Rising Sun Avenue: Research and implement swimming deterrents.
- Whitaker Avenue to Wyoming Avenue: Create barriers to stop ATV use.
- Holy Sepulchre Cemetery to Ralph Morgan Park**:** Create a parks master plan for this area.

Fairmount Park's Natural Lands Restoration and Trails Master Plan contains specific recommendations for creating and enhancing trails in their park system. These are shown in Table 8.11 and Figure 8.2 on the pages that follow.

Table 8.11 Fairmount Park Trails Master Plan Recommendations

- Provide maximum support and development of positive volunteer educational and restoration efforts already in place.
- Eliminate redundant and problematic trails that are contributing to the ecological decline of the natural areas.
- Increase perceived safety by providing better trail sight lines and perimeter lighting.
- Create well-defined trail heads that have good transit and regional connections.
- Provide access points/gateways to adjacent neighborhoods.
- Provide interpretive and educational opportunities for the diverse ecological and cultural settings of the park.
- Provide for adequate parking and controlled access to the trails to eliminate/reduce likelihood of trails as entrance points for motorized vehicles (particularly ATV's and abandoned autos).
- Provide maintenance strategies and restoration solutions for eroded and degraded trails that will continue to be used.

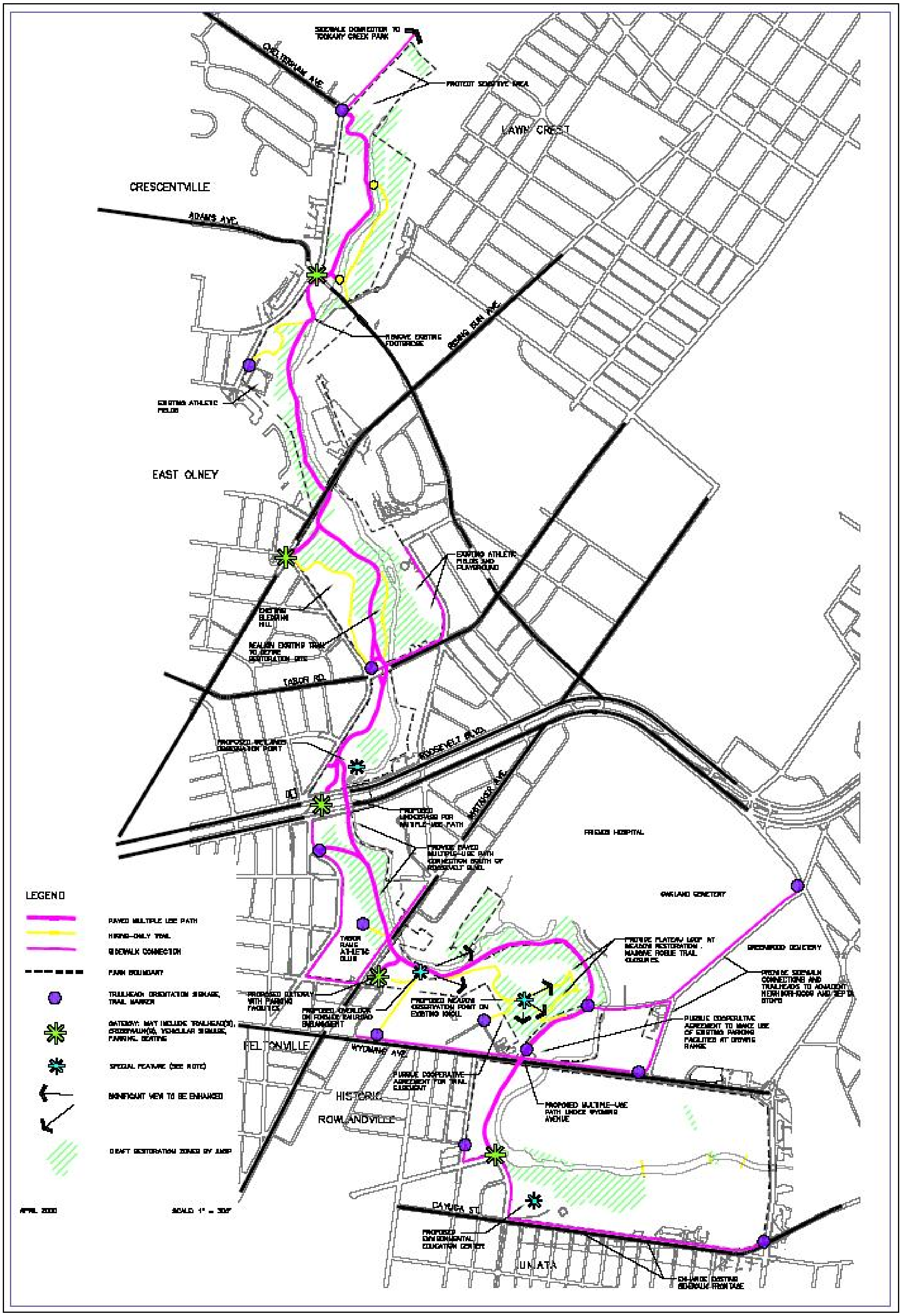


Figure 8.2 Fairmount Park's Proposed Trails Plan for Tookany/Tacony-Frankford Creek

8.1.5 Target A Options: Monitoring and Reporting

Monitoring, Reporting, and Further Study (AMR)

Related Goals:
Related Indicators: 16, 17, 18, 19, 20, 21

What	Who	Where	When
Monitor and collect data in areas where more information is needed to clarify the situation or establish a proper BMP.	PWD in CSO areas; municipal townships in separate sewered areas.	See Figure 8.3.	Short-term: 1-5 years.

The River Conservation Plans (RCPs) recommend monitoring sites where there is an unexpected substance, odor, or bacteria. A comprehensive water quality analysis is also recommended.

- <u>Ralph Morgan Park to Greenwood Avenue</u>: Identify the orange milky substance. Focus on water quality.
- <u>Wyncote Post Office to Washington Lane Underpass</u>: Investigate orange gel-like substance. Township to lead investigation.
- <u>Rock Creek Watershed</u>: Continue to monitor the areas with excessive coliform levels.
- <u>Rising Sun Avenue to Roosevelt Boulevard</u>: Target the cause of sewer odor and rectify.
- <u>Roosevelt Boulevard to Whitaker Avenue</u>: Target outfalls. Investigate possible disconnected sewer line.
- <u>Wyoming Avenue to Castor Avenue</u>: Target outfalls. Investigate sewage smells.
- <u>Aramingo Avenue between Wheatsheaf Lane and Church Street</u>: Investigate discharge from outfall pipe.

In the first five-year implementation plan, additional studies will be recommended to focus on dissolved oxygen, sources of fecal coliform, and the potential causes of large dissolved oxygen swings in the lower portion of the watershed.

8.2 Target B: Healthy Living Resources

Given the historic degradation of the water quality and ecology of Tookany/Tacony-Frankford Creek and its tributaries from urbanization, an interdependent set of corridor improvement actions are recommended. Because of that interdependent nature, this section begins with an overview that addresses various points common to many or all of the recommended Target B options. Following that overview, the individual options – all of which were recommended for implementation (as explained in Section 7) – are described in detail.

Section 8.2.1 **Overview: Stream and Riparian Corridor Improvement**

Section 8.2.2 **Channel Stability and Aquatic Habitat Restoration**

BM1	Bed Stabilization and Habitat Restoration
BM2	Bank Stabilization and Habitat Restoration
BM3	Channel Realignment and Relocation
BM4	Plunge Pool Removal
BM5	Improvement of Fish Passage

Section 8.2.3 **Lowland and Upland Restoration and Enhancement**

BM6	Wetland Creation and Enhancement
BM7	Invasive Species Management
BM8	Biofiltration
BM9	Reforestation

Section 8.2.4 **Monitoring and Reporting**

BMR	Monitoring, Reporting, and Further Study

8.2.1 Overview: Stream and Riparian Corridor Improvement

This Tookany/Tacony-Frankford Integrated Watershed Management Plan proposes a comprehensive stream and riparian corridor restoration strategy. The recommended actions presented throughout Section 8.2 – ranging from conservation of existing open spaces, to stream stabilization actions, to creation of new wetlands and biofiltration areas – together constitute a fully integrated riparian corridor improvement strategy that provides new habitat and water quality improvement. In the Philadelphia portion of the riparian corridor, this approach is intended to complement and expand the Fairmount Park Commission's Environmental Stewardship and Education Program.

These riparian corridor improvement actions, when implemented simultaneously, will result in improvements that span the waterway and riparian corridor. Thus, riparian corridor actions improve the ecology of the Tookany/Tacony-Frankford Creek landscape and optimize the ways in which the limited remaining open space can help improve water quality. The long-term benefits of an integrated riparian strategy significantly outweigh the short-term construction disturbances that are needed to implement the Tookany/Tacony-Frankford Creek riparian corridor improvements.

The riparian corridor is defined here as the land area that borders a stream and which directly affects and is affected by the water quality, including floodplains, shorelines, wetlands, and riparian forest. For the purposes of the Tookany/Tacony-Frankford Creek riparian corridor improvement strategy, the riparian area also includes the stream channel. Thus, the full undeveloped land and waterway area between the existing land development that surrounds the corridor will be considered for ecological improvement and for biofiltration functions that will improve water quality. Listed below are the options recommended for implementation across the corridor, from the lowest point in the landscape (the stream channel) to the highest (upland forest).

The most effective approach to riparian corridor improvement is to perform all the proposed streambed, streambank, wetland, and riparian upland improvements simultaneously along a reach, or stream section, to realize the synergy of the full set of landscape improvements. When one stream segment is completed, work would shift to the next priority location, section by section, for the length of the Tookany/Tacony-Frankford Creek corridor.

Implementing one set of corridor actions, for example, bed stabilization, without complementary actions, such as bank stabilization, will result in only limited success, because the aquatic and streamside land environments must function interactively to provide optimal stability. For this reason, the riparian corridor improvement strategy is both a short-term and long-term plan. Restoration activities in sections of the watershed that are in greatest need of improvement should be implemented early (targeting stream sections that are causing or contributing to water quality or ecological impairment first). For the Tookany/Tacony-Frankford Creek corridor, it is anticipated that significant improvements in water quality and ecology can be realized by addressing high priority locations that are principally upstream during the first 5 years, with sections downstream of Castor Ave. that require further evaluation of water quality issues receiving riparian corridor improvement during a second 10 year period (see Figure 8.4 and Table 8.12). It is important to note that the next step in implementing the riparian corridor improvement strategy is to develop a corridor improvement facilities plan, under which integrated designs are prepared for the full range of corridor improvements (e.g., bed and bank stabilization, and wetland creation and enhancement).

PWD recently performed stream assessments along the entire Tookany/Tacony-Frankford Creek corridor. The results of this study will provide more specific guidance on priority stream sections and recommended improvements.

The River Conservation Plans (RCPs) include the following recommendations for restoring buffer zones and undercut creek banks in an effort to control both stream contamination and flooding:

- Holy Sepulchre Cemetery to Ralph Morgan Park: Initiate plan to study geomorphology and sinuosity. Restore and enforce riparian buffer regulations. Conduct streambank stabilization.
- Ralph Morgan Park to Greenwood Avenue: Restore banks where there is severe undercutting. Plant creek banks to prevent washed out areas. Create "no-mow" zones. Remove a retaining wall, regrade, and plant the bank to facilitate a natural retaining basin. Relocate and replace the macadam walking path with natural material.
- Church Road at Chelten Hills Drive to Church Road near Ogontz Field: Possible relocation of playground equipment away from stream bank to promote healthier buffer zone. Check stability of rip-rap and stacked cement retaining wall. Restore and/or stabilize some of the undercut bank and root exposed trees.
- High School Park to Ashbourne Road along the Tookany Creek Parkway: Initiate plan to study local geomorphology and sinuosity. Conduct streambank stabilization.
- Unnamed Tributary in Glenside: Redesign, regrade, and plant banks along Grove Park. Create "no-mow" zone. Create riparian buffer zone, restore streambank along Waverly Rd. Formally name all unnamed tributaries.
- Baeder Creek Watershed: Consider removal of vertical gabion baskets and concrete wall in place of natural bank slopes. Conduct a hydrological assessment to correct serious flooding and bank instability; much of the creek's geometry has been altered. Conduct biotechnical streambank stabilization in most severe areas.
- Rock Creek Watershed: Restore the riparian buffer.
- Mill Run Watershed: Restore the riparian buffer. Enforce regulations.
- Abington Country Club to Township Line Road: Re-establish riparian buffer, possibly a 20-ft "no-mow" zone.
- Township Line Road near Foxcroft Road to Main Stem (unnamed tributary): Restore and stabilize some of the undercut and eroded banks.
- Abington Friends School to Township Line Road: Consider restoration of natural riparian buffer and channel along residential areas. Repair eroded areas using naturalized approaches such as native plantings.

- Township Line Road to Tookany Creek Parkway: Replant riparian areas and restore riparian buffer. Enforce regulations. Conduct biotechnical streambank stabilization.
- Cheltenham Avenue to Adams Avenue: Restore creek banks where there is severe undercutting.
- Crescentville and Adams Avenues to Rising Sun Avenue: Restore creek banks where there are exposed roots.
- Rising Sun Avenue to Roosevelt Boulevard: Repair undercut streambanks.
- Roosevelt Boulevard to Whitaker Avenue: Restore creek banks where there is severe erosion.
- Whitaker Avenue to Wyoming Avenue: Restore creek banks and repair restoration site.
- Wyoming Avenue to Castor Avenue: Repair undercut and exposed streambank. Repair manmade restoration project.
- Aramingo Avenue between Wheatsheaf Lane and Church Street: Restore creek banks.
- Holy Sepulchre Cemetery to Ralph Morgan Park: Remove fencing crossing stream; it appears to impede normal flow.

8.2.2 Target B Options: Channel Stability and Aquatic Habitat Restoration

Bed Stabilization and Habitat Restoration (BM1)

Related Goals: TK
Related Indicators: TK

What	Who	Where	When
Text to be inserted	Placeholder box	Text to be inserted	Placeholder box

Bank Stabilization and Habitat Restoration (BM2)

Related Goals: TK
Related Indicators: TK

What	Who	Where	When
Text to be inserted	Placeholder box	Text to be inserted	Placeholder box

Channel Realignment and Relocation (BM3)

Related Goals: TK
Related Indicators: TK

What	Who	Where	When
Text to be inserted	Placeholder box	Text to be inserted	Placeholder box

Plunge Pool Removal (BM4)

Related Goals: 5, 7
Related Indicators: 3, 15, 19, 20

What	Who	Where	When
Remove plunge pools below stormwater and CSO outfalls.	PWD, and municipalities bordering streams recommended for restoration.	Outfalls shown in Figure 8.3.	Begin within 5 years; monthly maintenance schedule to be determined.

When stormwater and combined sewer outfalls discharge directly to the stream channel, they may create deep, poorly mixed pools. Both types of outfalls discharge along the length of the Tookany/Tacony-Frankford and its tributaries (Figure 8.3). Because these pools are typically near the bank and not in the main flow, they can become poorly mixed during low flow. These pools often have increased odors and reduce the aesthetic quality of the stream. Biological activity in the sediment and water column can reduce dissolved oxygen to low levels, and this low-DO water can be flushed out and affect downstream areas during wet weather. The depression of DO is a function of both pollutant loads from the outfalls and in stream baseflow, and the physical condition of the channel. When DO is in an acceptable range in the well-mixed portion of the channel but not in nearby plunge pools, elimination of the plunge pools can eliminate a water quality condition that might affect the aquatic ecosystem.

When possible, outfalls can discharge further up the bank into a wetland or biofiltration area; these areas provide detention, evaporation, cooling, and treatment of pollutant loads in addition to protecting the integrity of the stream channel. Opportunities for creation of these areas (Options BM6 and BM8, respectively) will be discussed later in this section. Where the only place for an outfall to discharge is directly into the stream channel, the area may be protected using appropriate bed and bank stabilization features (Options BM1 and BM2), as discussed above.

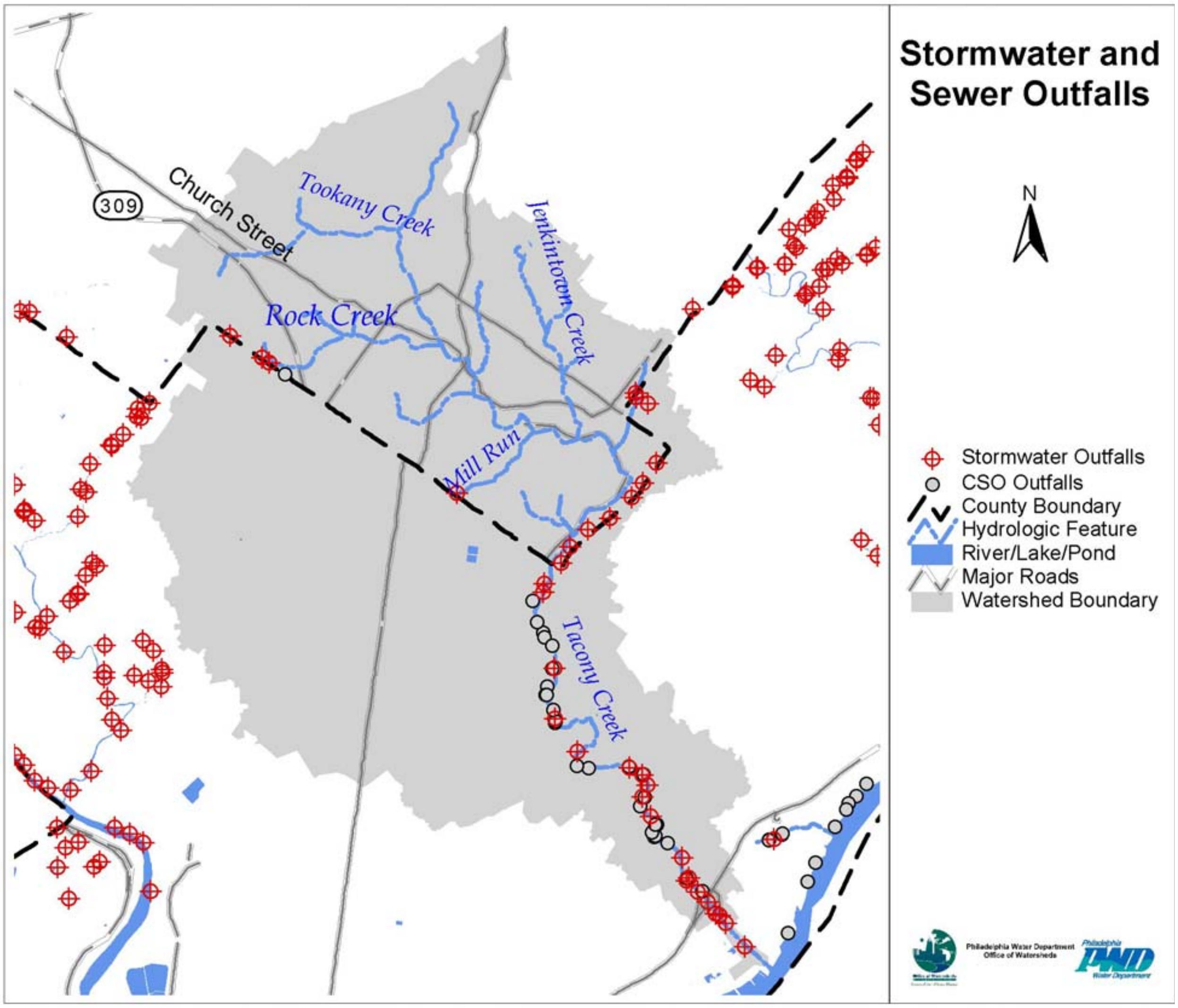


Figure 8.3 Stormwater and CSO Outfalls in the Philadelphia Portion of the Tookany/Tacony-Frankford Watershed

Improvement of Fish Passage (BM5) Related Goals: 1, 6, 7 Related Indicators: 3, 5, 6, 16, 19, 20, 21			
What	Who	Where	When
Assess potential to improve fish migration through dam modification or installation of fish ladders.	PWD; Fairmount Park Commission.	To be determined by future study.	Long-term; after pollutant sources in lower Tacony are addressed.

For the Tookany/Tacony-Frankford Creek, the State-designated aquatic life uses for the non-tidal portion of the creek are Warm Water Fishes (WWF) and Migratory Fishes (MF). The designated recreational water uses also include boating, when surface water flow or impoundment conditions allow; fishing, for recreation and/or consumption; water contact sports; and aesthetics.

Investigation and restoration of fish migration is recommended as a long-term goal. However, areas of low dissolved oxygen (DO) have been identified south of Castor Avenue. Further investigation and remediation of this problem is recommended as a short-term goal; efforts to remove barriers to fish migration will not succeed in restoring populations until water quality conditions are sufficient to support fish.

The River Conservation Plans (RCPs) noted the following:

- Township Line Road to Tookany Creek Parkway: Work with landowner to remove wooden plank to allow fish to pass through.

8.2.3 Target B Options: Lowland and Upland Restoration and Enhancement

Wetland Creation and Enhancement (BM6)

Related Goals: 1, 2, 3, 4, 5, 7
Related Indicators: 1, 2, 3, 4, 7, 8, 9, 15, 19

What	Who	Where	When
Wetland creation and enhancement for flood flow alteration, groundwater recharge, increased habitat, increased plant and animal diversity, and improved water quality.	PWD; Fairmount Park Commission. Municipalities bordering streams recommended for restoration.	Recommended locations for floodplain wetland creation; areas for pocket wetland creation need to be field determined, based on where they are adjacent to lands proposed for stream realignment and bank restoration (see Figure 8.5).	Prototype design and evaluation phase, followed by upstream creation/enhancement in years 1-5; downstream implementation over two 10-year phases.

One high-priority riparian corridor improvement action, from both an ecological and water quality improvement perspective, is creation and enhancement of wetlands along the Tookany/Tacony-Frankford Creek. The Fairmount Park Commission has proposed four vegetation restoration sites along the creek, two of which are wetland sites. The Tookany/Tacony-Frankford Creek subwatersheds were field surveyed in 2002/2003 to assess wetland improvement opportunities for existing wetlands, and wetland creation opportunities for new locations. Existing wetlands were evaluated for their ability to perform important wetland functions (e.g., flood flow alteration, water quality improvement, and habitat), where degraded actions were evaluated to improve compromised functions. Existing wetlands were then assessed to determine if they might be effectively expanded. Finally, locations where new wetlands could be created were identified. New wetland creation opportunities were classified into two groups:

- Wetlands immediately adjacent to the waterway and which would receive flood flows frequently during the year (< one year storm); and
- Pocket wetlands that can be created using checkdams that are higher in the landscape and that would receive stormwater flows from adjacent subwatershed areas, but would receive flood flows only from major storm events.

Wetlands Enhancement

The wetland field investigations for the TTF Watershed rated the opportunity to improve and expand existing wetlands, by evaluating opportunities to reconnect the wetland to the waterway, to receive additional overland flows, to remove sources of encroachment, and to expand the size of the wetlands. Nearly all the 24 existing wetlands exhibited potential for functional improvement through hydrologic improvements, re-vegetation, or reducing historic disturbance. The field analysis indicates significant opportunity for wetland improvement, as shown in Table 8.12 and Figure 8.4.

Table 8.12 Wetland Improvement Potential

Wetland Improvement Potential	
Improvement Rating	*Wetland Areas*
High	15
Moderate	8
Low	1

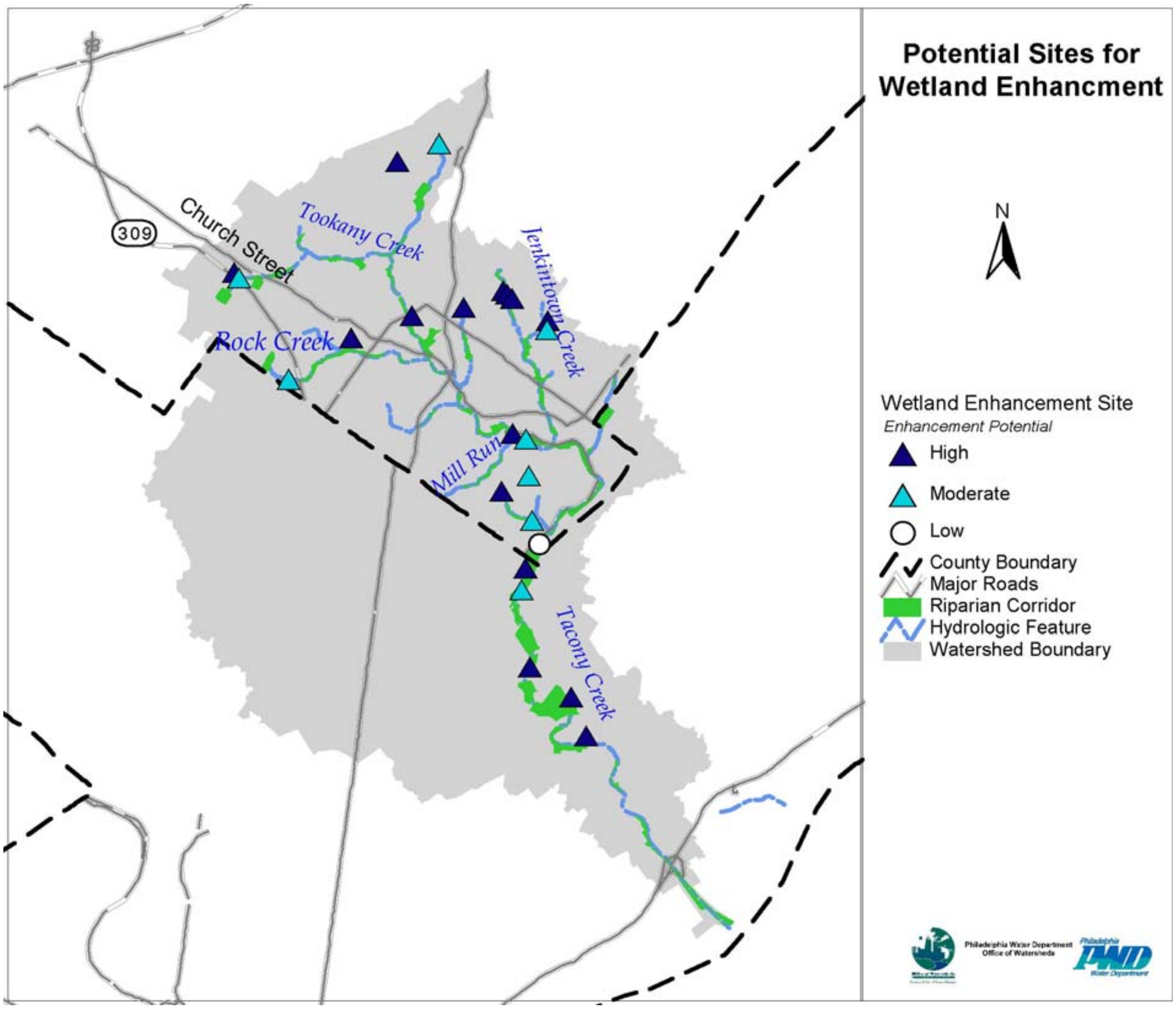


Figure 8.4 Potential Sites for Wetland Improvement

While there are many opportunities for wetland improvement, there is only limited opportunity for wetland expansion. The total potential estimated increase in wetland area for the moderate and high potential wetland sites was limited to less than 3 acres, increasing the existing inventory from about 15 acres to 18 acres. Greater opportunity for increasing wetland acreage is available from wetland creation/re-creation activities.

Wetlands Creation

The wetland field analysis also included an evaluation of potential opportunities for wetland creation along the riparian corridor. The evaluation of wetland creation potential was focused on the physical potential (undeveloped land area present, proximity to waterway, position in landscape) and did not address institutional or ownership factors.

Because stream relocation and realignment typically involve extensive grading and replanting, new runoff patterns and hydrology can be created that are more similar to original riparian conditions, whereby riparian corridor wetlands could receive storm runoff sheet flow from the adjacent landscape. In addition, wetland habitats can be created that allow more diverse habitat. Wetlands are rich habitats that rely on saturated soils and vegetation adapted to these conditions. They could be recreated concurrently with channel realignment, bank restoration, and planting of more diverse native vegetation, including hydrophytic species adapted to saturated soil conditions.

Wetlands must have an adequate input of water, either by flooding or runoff, to maintain the soil and vegetation characteristics that are unique to wetlands. Field investigation of wetlands revealed, however, that several factors constrain the creation of extensive areas of new wetland. These include:

- Extensive urban and suburban encroachment into the riparian corridor;
- Competing active recreational uses along the waterway; and
- Steep slopes adjacent to the waterway limiting potential for floodplain hydrology.

Field estimates indicate that over 24 acres of wetland might be created in 26 separate creation locations. This would result in a more than 150% increase in wetland acreage along the riparian corridor. If wetland expansion potential were also included, the wetland acreage along the riparian corridor could be increased by 175% to about 42 acres. These estimates represent a highly optimistic wetland expansion scenario, but indicate the significant potential to at least double the area of wetland along the riparian corridor. These wetland creation locations are identified in Figure 8.5 below.

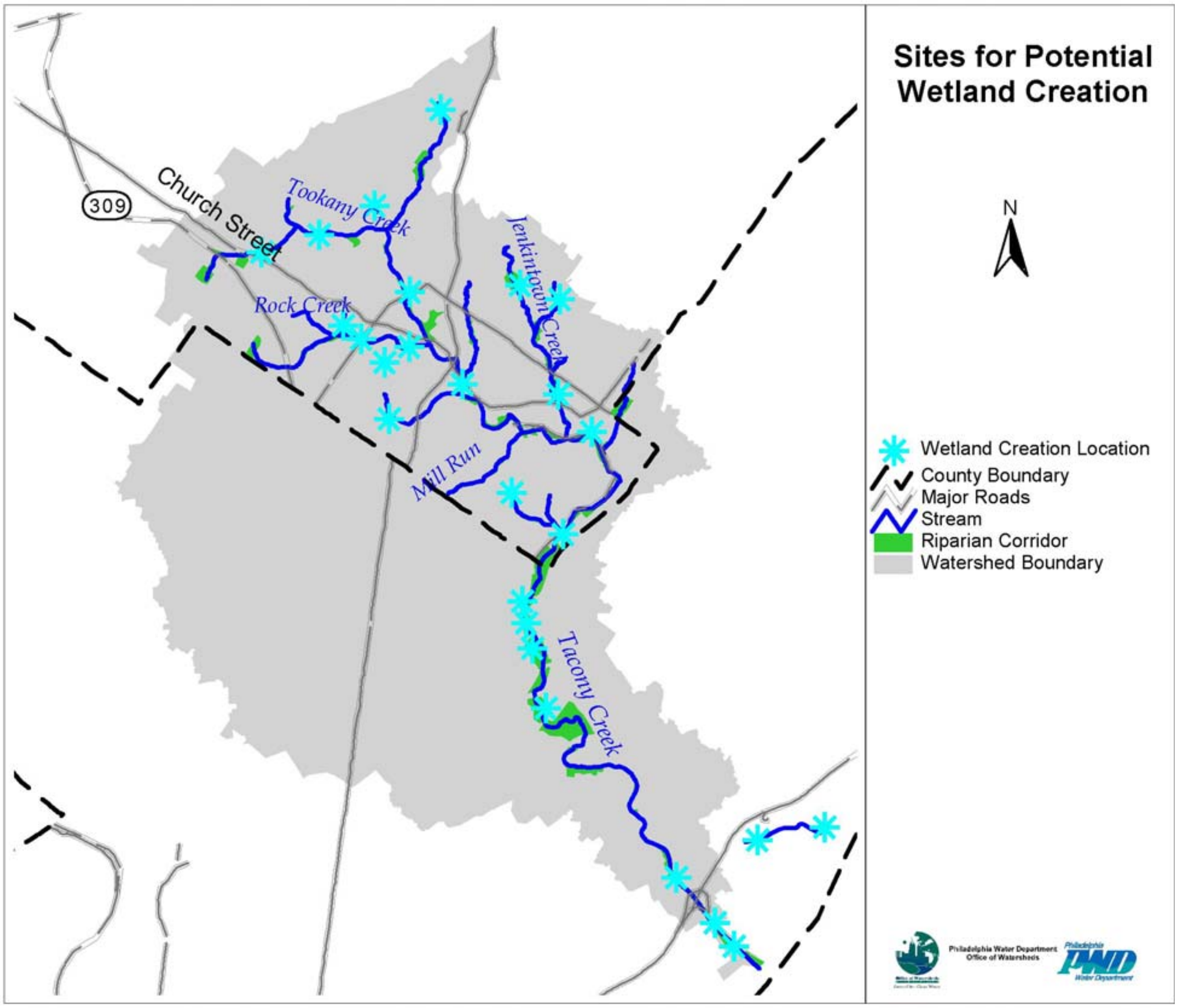


Figure 8.5 Potential Sites for Wetland Creation

In general, priority will be given to wetland creation and improvement over reforestation of uplands because of the greater water quality benefits provided by wetlands.

As noted above, two types of wetland creation are recommended: floodplain wetlands and pocket wetlands. There are numerous opportunities for creation of pocket wetlands throughout the watershed; as stormwater runoff from the adjacent subwatershed is redirected over the riparian landscape, checkdams and piping may be used to spread the runoff over the vegetated riparian land surface. More specific locations for creating pocket wetlands will need to be evaluated in the future as the riparian corridor restoration design is developed during the facilities planning stage. This is because opportunities for creation of pocket wetlands arise from bank restoration, revegetation, and biofiltration actions that will be implemented as part of the integrated riparian corridor improvement strategy for the TTF Watershed.

Both floodplain wetlands and pocket wetlands offer significant opportunity for water quality and ecological improvement along the Tookany/Tacony-Frankford Creek riparian corridor, and both will play a central role as the design of the riparian corridor improvements is developed.

Assuring long term success for wetland creation projects will involve future monitoring to measure integration of the wetland into the riparian landscape and to correct defective conditions, where possible. However, proper design of the wetland to assure adequate input of water (via flooding or runoff), protection from erosion, and maintenance of the diverse planted vegetation is essential to long-term success. Wetland creation projects typically involve monitoring and maintaining the created wetland's hydrology, vegetation (including invasive species, discussed below), and erosion characteristics for a period of three years following creation.

Further investigation of all potential wetland enhancement and creation opportunities should include the following: identification of landowners, rainfall data collection and evaluation, runoff calculations, soils investigation, water budget, native species investigation, and groundwater/soil saturation monitoring.

Invasive Species Management (BM7)

Related Goals: 4
Related Indicators: 12, 13, 14, 19

What	Who	Where	When
Implement an Invasive Species Management Plan (already in effect in Fairmount Park).	PWD; Fairmount Park Commission.	Lowland and upland habitat restoration sites.	Within 5 years.

A plan to control invasive plant species is necessary when restoring or enhancing wetlands and riparian forests. Invasive species provide little value to native animals that depend on native species for habitat and food. Japanese knotweed (*Polygonum cuspidatum*) is one prevalent invasive species that was observed during the field reconnaissance. In many areas, knotweed, due to its aggressive nature, has already out-competed native vegetation. Maintaining a healthy riparian plant community along Tookany/Tacony-Frankford Creek will retain biodiversity and support a healthy stream ecosystem.

The Fairmount Park Commission has implemented an invasive species control program in the Fairmount Park portion of the stream corridor. It is recommended that invasive species control be expanded to the remaining natural areas of the corridor. Implementation of an invasive species management plan would assist natural succession within the riparian buffer and decrease further impacts of invasive species.

Planting plans for all restoration efforts should complement the invasive species management plan by recommending appropriate native planting to supplement areas where invasives have been eliminated. Although invasive species management priority areas are considered those that contain 80% or greater invasive species, the most practical approach is to recommend invasive species management be implemented for all riparian restoration sites. An invasive species management plan will require, at a minimum, a three-year commitment to ensure success.

The River Conservation Plans (RCPs) highly recommend removing invasives and replant native vegetation. The most common invasive was Japanese knotweed. Specific sites noted include:

- Holy Sepulchre Cemetery to Ralph Morgan Park**:** Control invasive plants and replant with natives.
- Ralph Morgan Park to Greenwood Avenue: Remove Japanese Knotweed and replant with natives. Remove invasive vines from trees.
- Greenwood Avenue to Wyncote Post Office: Remove invasive plants from banks and replant with natives.
- Washington Lane Underpass to Church Road: Remove invasive vines from trees and knotweed. Replant native shrubs and groundcover.

- Church Road at Chelten Hills Drive to Church Road near Ogontz Field: Remove knotweed and other invasives. Replant a native buffer zone.
- High School Park to Ashbourne Road along the Tookany Creek Parkway: Eradicate invasive plants and replant with natives.
- Unnamed Tributary in Glenside: Clear knotweed.
- Baeder Creek Watershed: Eradicate invasives and replant natives.
- Rock Creek Watershed: Plant creek banks with natives to prevent invasives from dominating.
- Mill Creek Watershed: Eradicate invasives plants and replant with natives.
- Cheltenham Avenue to Adams Avenue: Remove invasives and replant with natives.
- Crescentville and Adams Avenues to Rising Sun Avenue: Remove invasives and replant with native plants.
- Rising Sun Avenue to Roosevelt Boulevard: Remove invasives and replant with native plants.
- Roosevelt Boulevard to Whitaker Avenue: Remove invasives and replant with native plants.
- Whitaker Avenue to Wyoming Avenue: Remove invasives and replant with native plants.
- Wyoming Avenue to Castor Avenue: Remove invasives and replant with native plants.
- Castor Avenue to Erie Avenue: Remove Japanese knotweed.
- Aramingo Avenue between Wheatsheaf Lane and Church Street: Remove Japanese knotweed.
- Rohm & Haas, 5000 Richmond Street: Remove invasives.

Biofiltration (BM8)

Related Goals: 1, 2, 3, 5, 7
Related Indicators: 1, 2, 3, 4, 15, 19, 20

What	Who	Where	When
Biofiltration involves creating sheet flow over the vegetated landscape to slow the rate of runoff, facilitate groundwater recharge, and remove sediment, nutrients, and toxicants from the runoff.	PWD; Fairmount Park Commission.	Throughout Tookany/Tacony-Frankford riparian corridors; focus on vegetated landscape.	Two 10-year implementation phases (high and medium priority).

The goal of the Tookany/Tacony-Frankford Creek riparian corridor improvement strategy is to identify all opportunities along the riparian corridor for natural landscape designs that achieve water quality improvement. For higher landscape positions at the outer edges of the riparian corridor there are extensive opportunities to implement biofiltration to improve runoff. Biofiltration involves creating sheet flow over the vegetated landscape to slow the rate of runoff, facilitate groundwater recharge, and remove sediment, nutrients, and toxicants from the runoff. Typical biofiltration approaches include installation of stormwater swales and checkdams along natural drainage-ways that spread runoff, creation of bioretention plantings and hydrology, and creation of hydrologic features that allow sheet flow to spread over grassed and shrub/scrub fields to achieve water quality improvement. The advantage of biofiltration is that it is compatible with recreational use of the riparian corridor, because flows are very shallow and are usually present only during rainfall events.

Analysis of the existing stormwater management in the Tookany/Tacony-Frankford Watershed shows that most stormwater outfalls discharge directly to the waterway. However, if the stormwater was redirected over the vegetated landscape higher in the stream valley, it would follow the natural slope and land contour as it traveled down to the stream. There are over 685 acres of undeveloped land along the Tookany/Tacony-Frankford Creek riparian corridor, but almost none of that land carries runoff sheet flow because the stormwater piping system conveys all flows, from storms large and small, directly to the stream. In order to achieve water quality improvement goals, it is important to optimize the ability of this vegetated riparian land to receive overland runoff, rather than piping the runoff directly into the stream.

Biofiltration has an effectiveness range of about 25-60% in removing suspended solids from runoff, and the concept of directing runoff to sheet flow over the vegetated riparian landscape matches fully with the way that such lands function naturally in an undeveloped watershed. Thus, the goal of biofiltration is to restore sheet flow of runoff over the landscape, by using piping and hydraulic controls to spread runoff from smaller storms over the vegetated surface. To avoid erosion, it is essential that the design for biofiltration provide for high velocity flows from major storms to be bypassed.

Reforestation (BM9)

Related Goals: 1, 2, 4, 5, 6, 7
Related Indicators: 1, 2, 4, 12, 13, 16, 18, 19

What	Who	Where	When
Reforestation adjacent to the channel to provide wetland habitat and other associated benefits.	PWD; Fairmount Park Commission. Municipalities bordering streams recommended for restoration.	Priority reforestation sites: lands adjacent to the creek that are not developed and are currently unforested. Potential reforestation sites are existing ball fields, golf courses, hospital grounds, seminaries, and cemeteries located adjacent to the channel. These should also be evaluated.	Begin within 5 years; monthly maintenance schedule to be determined.

The riparian corridor restoration and enhancement plan being proposed in this section covers the width of the stream corridor from developed edge to developed edge, including both lowland and upland forest. Reforestation that occurs adjacent to the channel will provide wetland habitat and other associated benefits. Although priority reforestation areas consist of floodplains, steep slopes, and wetlands, smaller areas such as public rights-of-way, parks, schools, and neighborhoods also provide reforestation opportunities. Benefits of reforestation are numerous: cooler temperatures, rainfall interception, reduced runoff, reduced sediment load, reduced discharge velocities, increased groundwater recharge, increased species diversity and habitat, and improved air quality and aesthetics.

At this time, only the recommendations from the River Conservation Plans (RCPs) are available. These include:

- Washington Lane Underpass to Church Road: Have SEPTA plant low growing shrubs in the areas of the bird sanctuary to develop wildlife habitat.
- Unnamed Tributary in Glenside: Partner with SEPTA to plant native vegetation that is in keeping with their track maintenance requirements in order to reduce NPS pollution and stabilize soil to prevent erosion and downstream sedimentation.

8.2.4 Target B Options: Monitoring and Reporting

Monitoring, Reporting, and Further Study (BMR)

Related Goals: 1, 2, 3, 4, 5, 6, 7
Related Indicators: all indicators relevant to Target B

What	Who	Where	When
Monitoring of implementation and benefits for all Target B options. Creation of a Tookany/Tacony-Frankford Stream Corridor Restoration Master Plan.	PWD; Fairmount Park Commission; municipalities bordering streams.	All implementation sites.	Monitoring and reporting to begin immediately and continue throughout the life of the plan. Master Plan creation within 5 years.

The preceding sections are a first step in identifying proposed projects that can lead to comprehensive stream corridor restoration. However, additional planning is needed to ensure that individual projects do not interfere with one another. For example, realignment of a stream section might eliminate a proposed wetland or reforestation site; or removal of a dam might increase stream velocity and erode restored streambanks or eliminate flow of water to a riparian wetland. Creation of a more detailed Restoration Master Plan for the stream corridor is necessary before individual projects can proceed. This plan will be primarily graphical and will identify boundaries and key elevations for existing features and proposed projects. Detailed designs on individual projects will be required to be consistent with the Master Plan. The plan will show the following on a single map:

- Proposed stream bank stabilization and bed stabilization;
- Proposed stream realignment and relocation;
- Proposed dam modification or fish ladder sites;
- Stream obstructions proposed for further study or removal;
- Existing wetlands; proposed wetland creation and enhancement;
- Existing habitat not to be disturbed, including threatened or endangered species;
- Proposed reforestation and habitat creation areas;
- Existing and proposed upland BMPs (biofiltration); and
- Key recreation and access facilities (trails, parking lots).

Before habitat restoration is recommended, however, water quality problems that might now be the cause of poor fish species diversity must be better investigated, and eventually solved.

8.3 Target C: Wet Weather Water Quality and Quantity

Target C must be approached somewhat differently from the first two targets. Full achievement of this target means meeting all water quality standards during wet weather, as well as eliminating all flooding. Clearly, that will be difficult, particularly with regard to wet weather water quality. It would certainly be extremely expensive, and would require a long-term effort. The only rational approach to full achievement of Target C goals is through stepped implementation with interim targets for reducing wet weather pollutant loads and stormwater flows. During implementation, monitoring must continuously assess the effectiveness of the program. Based on the extensive modeling analysis carried out for Tookany/Tacony-Frankford Creek to date, an initial goal of a 20-25% reduction in stormwater flows and stormwater/CSO related pollutant loads has been identified as a challenging but achievable goal. The stakeholders have identified Mill Creek (also called Mill Run) as a priority area for stormwater control.

It is expected that changes to the approach required to meet Target C, and even to the desired results, will occur as measures are implemented and results are monitored. With most discharge permits of five-year duration, discharge targets and reduction targets must be set and implementation designed in the first five years. Implementation for meeting Target C will begin over the next five years with Targets A and B, while monitoring for effectiveness in order to utilize an adaptive management approach for subsequent years to achieve full implementation of Target C. During the final five-year period, PWD should also work with the regulatory agencies to review water quality standards and determine whether any adjustments to them may be appropriate based on the results of monitoring.

Below are the Target C options that were "recommended" (either fully or conditionally) in Section 7. Most of these options are described in detail in the pages that follow.

Section 8.3.1 **<u>Regulatory Approaches</u>**
CR2 Requiring Better Site Design in Redevelopment
CR3 Stormwater and Floodplain Management
CR4 Industrial Stormwater Pollution Prevention
CR5 Construction Stormwater Pollution Prevention
CR6 Post-Construction Stormwater Runoff Management
CR8 Use Review and Attainability Analysis
CR9 Watershed-Based Permitting

Section 8.3.2 **<u>Public Education and Volunteer Programs</u>**
CP1 Public Education and Volunteer Programs

Section 8.3.3 **<u>Municipal Measures</u>**
CM1 Sanitary Sewer Overflow Detection
CM2 Sanitary Sewer Overflow Elimination: Structural Measures
CM3 Reduction of Stormwater Inflow and Infiltration to Sanitary Sewers
CM4 Combined Sewer Overflow (CSO) Control Program
  - Nine Minimum Controls
  - Long Term CSO Control Plan
  - Watershed-Based Planning

CM5 Catch Basin and Storm Inlet Maintenance
CM6 Street Sweeping

CM7 Responsible Landscaping Practices on Public Lands
CM9 Responsible Bridge and Roadway Maintenance

Section 8.3.4 Stormwater Management

Source Control Measures

CS1 Reducing Effective Impervious Cover Through Better Site Design
CS2 Porous Pavement and Subsurface Storage
CS3 Green Rooftops
CS4 Capturing Roof Runoff in Rain Barrels or Cisterns
CS5 Increasing Urban Tree Canopy

Onsite and Regional Stormwater Control Facilities

CS6 Maintaining/Retrofitting Existing Stormwater Structures
CS8 Retrofitting Existing Sewer Inlets with Dry Wells
CS9 Residential Dry Wells, Seepage Trenches, and Rain Gardens
CS12 Bioretention Basins and Porous Media Filtration
CS13 Treatment Wetlands: Onsite and Regional

Section 8.3.5 Monitoring and Reporting

CMR Monitoring, Reporting, and Further Study

Table 8.13 Maximum Feasible Reductions for BMPs with Quantifiable Benefits

Target C	Maximum Feasible Implementation	Volume Reduction		Pollutant Reduction
		CSO	Stormwater	
Municipal Measures				
CM4 Combined Sewer Overflow (CSO) Control Program				
Real Time Control	2 sites	5.9%	N/A	6.1%
Stormwater Management				
Source Control Measures				
CS1 Reducing Impervious Cover Through Better Site Design	1% reduction in DCIA	0.5%	0.5%	1.0%
CS2 Porous Pavement and Subsurface Storage	50% of parking lots	8.0%	3.3%	11.6%
CS3 Green Rooftops	5% of rooftops	1.8%	0.9%	2.7%
CS4 Capturing Roof Runoff in Rain Barrels or Cisterns	10% of homes	1.4%	0.1%	1.8%
CS5 Increasing Urban Tree Canopy	5% of watershed area	0.3%	0.3%	0.5%
Onsite and Regional Stormwater Control Facilities				
CS8 Retrofitting Existing Sewer Inlets with Dry Wells	100% of inlets	6.9%	0.3%	7.5%
CS9 Residential Dry Wells, Seepage Trenches, Rain Gardens	school grounds; 25% of homes	5.7%	0.8%	10.4%
CS12 Bioretention Basins and Porous Media Filtration	50% of parking lots	6.3%	2.1%	11.6%
CS13 Treatment Wetlands: Onsite and Regional	100% of identified potential	1.4%	0.4%	2.5%

8.3.1 Target C Options: Regulatory Approaches

Requiring Better Site Design in Redevelopment (CR2)

Related Goals: 1, 2, 4, 7
Related Indicators: 1, 12, 13, 16, 19, 20

What	Who	Where	When
Adopt or improve ordinances to encourage developers to use low impact methods for new ("greenfield") development and redevelopment of urban areas.	See Table 8.14 (may not identify all municipalities with ordinances).	Entire watershed.	Within 5 years; update as needed.

Environmentally friendly site design, also called low impact development (LID) and conservation site design, encompasses a range of site design elements for developers, and design requirements from municipalities. Some examples of LID design concepts include maintaining stream buffers, designing for open space, reduced street and sidewalk footprints where appropriate, and parking lot designs that reduce runoff and encourage infiltration. Stormwater source controls, infiltration BMPs, and treatment BMPs can be integrated with LID designs. Recommendations for incorporating these features in the Tookany/Tacony-Frankford Watershed are found throughout Target C.

LID is intended to reduce the impact of development on natural resources and water resources. Municipal design requirements are intended to preserve or increase open space, protect sensitive natural resources, and limit impervious cover. The environmental goals of land development and stormwater ordinances are closely related, although the ordinances themselves and mechanisms for enforcing them may be separate.

It appears that some of the municipalities in the Tookany/Tacony-Frankford Watershed encourage several standard low impact development practices through their existing land use ordinances. However, these guidelines tend to focus on clustering housing by allowing higher-density multi-family residential developments with common open spaces. Separate language focusing specifically on the protection of natural resources is recommended. While some municipalities in the watershed have already adopted a steep slope ordinance, Abington and Cheltenham Townships are currently the only municipalities within the watershed with cluster development ordinances and non-binding wetlands protection ordinances in place. Table 8.14 demonstrates that all municipalities located in the watershed have adopted some aspects of low impact development.

Table 8.14 Better Site Design in Existing Ordinances

Municipality	Better Site Design Ordinance (at least one component)	Comments
Abington Township	X	Cluster development for residential zoning districts; max. impervious cover by zoning type; wetlands conservation; steep slope conservation overlay district.
Cheltenham Township	X	Planned cluster development; open space requirements; designated wetlands; steep slope conservation district.
Jenkintown Borough	X	Minimum street, sidewalk widths; maximum grades; non-binding guidelines for density and open space.
Philadelphia County	X	Max. impervious cover requirements; minimum street, driveway widths.
Rockledge Borough	X	Max. impervious cover requirements by zoning type.

Source: www.ordinance.com, *Delaware Valley Regional Planning Commission*

The Delaware Valley Regional Planning Commission (DVRPC) has recently completed the task of reviewing the municipal zoning ordinances of the Delaware Valley's 353 municipalities. Based upon this analysis, DVRPC has created a list of "outstanding sample natural resource and open space protection ordinances." These model ordinances as well as additional information on DVRPC's program are available at these sites:

- DVRPC Natural Resource Protection Information:
  http://www.dvrpc.org/planning/community/ProtectionTools.htm
- Model Ordinances:
  http://www.dvrpc.org/planning/community/ProtectionTools/ordinances.htm

Guidelines for LID in an Urban Setting

Table 8.15 (see below) identifies various zoning ordinances that could be adopted by the municipalities in the Tookany/Tacony-Frankford Watershed. While some municipalities already incorporate elements of these zoning measures within their existing code, it is recommended that ordinances specific to low impact development be adopted to better facilitate future growth and redevelopment. Model ordinances for each of these examples are available on the DVRPC website at the address listed above.

Table 8.15 Selected Components of Low Impact Development Ordinances

Municipal Zoning Ordinance	Description
"Net-Out" of Resources / Site Capacity Calculations	Protect wetlands, floodplains, and riparian buffers by removing them from the area considered for new development and redevelopment. In calculating the developable area, environmentally sensitive areas should be excluded. Some local governments allow increased densities in the remaining developable land area to provide an incentive for protecting sensitive environments. Existing trees should be protected if possible; if not, the land owner may contribute to a mitigation fund for each tree cut down.
Wetlands Management Ordinance	Protects environmentally sensitive wetlands areas. This ordinance usually requires wetlands delineation within the municipality and prohibits any type of development in a delineated wetland area.
Cluster Development Ordinance	Allows developers to build at higher densities on one portion of a site in exchange for preserving another portion as open space. Land preservation percentages and densities vary, but the preferred percentage is for at least 50% of the tract to remain as open space. Achieving a landowner's financial objectives may be a function both of partial development and donation of a conservation easement (and its inherent deductibility under the federal tax code).
Planned Residential Development (PRD)	Facilitates residential development in areas designated by the municipality. Provisions are made for higher housing densities, thereby creating larger contiguous common open spaces, and providing for pedestrian access between residential areas.
Steep Slope Ordinance	Regulates development on areas designated as steep slopes. The minimum gradient classified as steep varies by municipality, but, according to DVRPC, 8% is typical.
Transfer of Development Rights (TDR)	Designates areas of a municipality as "sending" and "receiving" areas. Allows community to preserve open space and natural features while still permitting growth. Development is moved from large tracts of rural land (sending area) to areas designated for higher densities (receiving area).

While the measures above were originally intended for new development, they may be adapted for larger redevelopment projects in urban areas. Older areas often have large areas of vacant and abandoned properties that may be demolished all at once, creating significant open space. Cluster development, for example, could be applied on these larger sites.

In addition to the specific ordinances above, municipalities should require, or provide strong incentives for, innovative site design when urbanized areas are redeveloped. Effective conservation design techniques to consider include the following:

- Review municipal codes for any minimum size requirements for impervious surfaces, such as road and sidewalk widths. Review any stipulation of a minimum size lot that development and stormwater ordinances apply to. In the City of Philadelphia, the ordinance requiring all downspouts to be connected directly to the sewer system is not appropriate in all cases; wherever feasible, infiltration (e.g., using dry wells) should be encouraged over disposal of stormwater to combined or separate storm sewers.

- Depending on the zoning classification, specify a maximum effective impervious cover allowed after construction. Many publications recommend that impervious cover connected directly to the drainage system be limited (see Section 8.3.4, Option CS1, "Reducing Effective Impervious Cover through Better Site Design," for specific recommendations). Developers are then free to choose a combination of methods to meet the requirement: an absolute reduction in impervious cover, directing runoff onto depressed landscaped areas, tree credits, and structural BMPs. Consider incentives in the stormwater control calculations to reduce directly connected impervious surfaces.

- For areas experiencing redevelopment, structural stormwater controls may be tied to the impervious area calculations discussed above. Developers have an incentive to reduce impervious area because it may be more cost effective than installing structural stormwater BMPs. Specific recommendations for stormwater ordinances are discussed below, under Option CR3, "Stormwater and Floodplain Management."

- Promote discussions early in the development review process at the sketch plan/conceptual plan level (before developers have spent large sums of money on design and engineering). A number of municipalities around the U.S. have concluded that sketch/conceptual plans are more important in the planning process than preliminary plans because early intervention and change allows greater opportunity to include innovative low impact development designs. Some municipalities have opted to eliminate the final plan and accept the preliminary plan as the final plan as an incentive to developers to participate.

- After the final plan is submitted, require a pre-construction meeting and a site visit to discuss construction issues and pollution prevention.

- Consider incentives in addition to regulations; for small sites, incentives alone may be sufficient. For example, award density or stormwater control bonuses for reducing impervious cover. Streamline project reviews and waive permit fees when conservation design objectives are met. Tie stormwater fees and/or property taxes to impervious cover and stormwater management practices.

The River Conservation Plans (RCPs) noted the following:

- Church Road at Chelten Hills Drive to Church Road near Ogontz Field: For areas that are redeveloped, landscape architects should design a more natural buffer zone.

Stormwater and Floodplain Management (CR3)

Related Goals: 1, 2, 3, 4, 5, 7
Related Indicators: 1, 2, 12, 13, 15, 19, 20

What	Who	Where	When
Participate in finalization of the watershed-wide Act 167 plan and model ordinance being developed in the watershed. Adopt and enforce the model ordinance.	Counties to adopt plan and ordinance first, followed by all municipalities (see Table 8.16).	Entire watershed.	Begin within 5 years; update as needed.

Table 8.16 identifies the municipalities in the Tookany/Tacony-Frankford Watershed that currently have a floodplain protection or stormwater ordinance in place.

Table 8.16 Floodplain and Stormwater Ordinances in the TTF Watershed

Municipality	Floodplain Ordinance	Stormwater Ordinance	Erosion and Sedimentation Control	Comments
Abington Township	X	X	X	Stormwater design requirements; floodplain conservation district; erosion and sedimentation control plan.
Cheltenham Township	X	X	X	Storm drainage requirements; floodplain conservation district; soil erosion and sediment control (DEP Manual compliance).
Jenkintown Borough	X	X	X	Storm drainage design requirements; floodplain conservation district; erosion and sedimentation control measures required (no description).
Philadelphia County	X	X	X	Stormwater management controls; erosion and sedimentation control measures – engineer required.
Rockledge Borough				No stormwater/floodplain ordinances; all development served by public sewer and public water.

Source: www.ordinance.com, *Delaware Valley Regional Planning Commission*

The majority of municipalities in the watershed have adopted ordinances limiting development in the floodplain or designating a floodplain conservation district. The protection offered varies by municipality, but an effective ordinance should place controls on land development within the 100-year floodplain as well as limit development within riparian corridors. EPA posts a model floodplain preservation ordinance at: www.epa.gov/owow/nps/ordinance/osm1.htm

Philadelphia and Montgomery Counties are cooperating to develop an official Act 167 Stormwater Management Plan and model ordinance. The model ordinance will specify measures that must be undertaken to promote infiltration, improve water quality, reduce streambank erosion rates, and protect against flooding. These requirements will apply to both new (also called "greenfield") development and redevelopment (including brownfields or former industrial sites), and to both separate-sewered and combined-sewered areas. The plan and model ordinance shall be completed with county and municipal input by late 2007.

Adoption and implementation of the model ordinance is a critical step that will allow municipalities to begin implementing many of the wet weather management measures mentioned later under Target C. For example, the ordinance may require a specific storage volume to be created on a developed site and may indicate that it must be a BMP capable of water quality treatment. The developer will then consult a state or local stormwater manual designated by the municipality to determine an appropriate BMP and appropriate design criteria.

While many of the state manuals provide excellent guidance for new development, PWD plans to develop a manual with guidance for redevelopment projects given local conditions. Some preliminary ideas for this BMP manual are listed below.

Commercial/Industrial Land Uses

1. Encourage better site design techniques, impervious cover disconnection, and tree credits to decrease impervious cover directly connected to the drainage system.
2. Directly-Connected Parking Lots:
   - Encourage a bioretention system if sufficient space is available to meet parking needs.
   - In highly urban areas where adding landscaping is not possible, encourage porous pavement (or other drainage mechanism) and subsurface storage if feasible.
3. Directly-Connected Rooftops:
   - If parking lot storage is installed, recommend routing rooftop drainage to the storage.
   - If parking lot storage is not feasible, route rooftop drainage to dry wells. If dry wells are not feasible, route rooftop drainage to rain barrels or tanks.
   - Other approaches may be proposed and considered on a case-by-case basis.

Residential Land Uses

1. Encourage better site design techniques, impervious cover disconnection, and tree credits to decrease impervious cover directly connected to the drainage system.
2. Route roof runoff to dry wells if feasible. If dry wells are not feasible, route rooftop drainage to rain barrels or tanks.
3. Other approaches may be proposed and considered on a case-by-case basis.

The River Conservation Plans (RCPs) recommend the following:

- Holy Sepulchre Cemetery to Ralph Morgan Park: Purchase properties in floodplain to convert land to open space.
- Mill Creek Watershed: Relocate or purchase then demolish structures in the floodplain.
- Church Road at Chelten Hills Drive to Church Road near Ogontz Field**:** Assess upstream issues to see why Shoemaker Road area floods more.

Industrial Stormwater Pollution Prevention (CR4)

Related Goals: 1, 2, 3, 7
Related Indicators: 1, 2, 3, 4, 7, 8, 9, 10, 19, 20

What	Who	Where	When
Enforcement of NPDES requirements for Industrial Stormwater Management. Dissemination of information on spill prevention and pollution prevention plans.	PA DEP is the Designated Authority responsible for issuing, administering, and enforcing NPDES permits. Municipalities are responsible for information dissemination.	All sites contributing stormwater discharges associated with industrial activity within the watershed.	Within 5 years.

Industrial stormwater pollution prevention measures can contribute significantly to achieving the watershed plan's wet weather implementation targets. These measures include monitoring and enforcing existing industrial stormwater permit requirements under Phase I of the NPDES program, as well as Official Industrial Pollution Prevention Plans and Spill Response Actions required by the state. Full implementation of these measures should be monitored and enforced throughout the watershed.

NPDES Industrial Stormwater Permits

All sites contributing stormwater discharges associated with industrial activity, defined in federal regulations (40 CFR §§ 122.26(b)(14)(i)-(xi)), are required to be covered under Phase I of the NPDES stormwater program. This includes discharges from any conveyance that is used for collecting and conveying stormwater and that is directly related to manufacturing, processing, or raw materials storage areas at an industrial plant. This includes, but is not limited to, stormwater discharges from industrial plant yards; immediate access roads and rail lines used or traveled by carriers of raw materials, manufactured products, waste material, or by-products used or created by the facility; material handling sites; refuse sites; sites used for the application or disposal of process waste waters; sites used for the storage and maintenance of material handling equipment; sites used for residual treatment, storage, or disposal; shipping and receiving areas; manufacturing buildings; storage areas (including tank farms) for raw materials, and intermediate and final products; and areas where industrial activity has taken place in the past and significant materials remain and are exposed to stormwater. The term "material handling activities" includes storage, loading and unloading, transportation, or conveyance of any raw material, intermediate product, final product, by-product, or waste product.

The PA DEP is the Designated NPDES Authority responsible for issuing, administering, and enforcing NPDES stormwater permits under the EPA's regulatory provisions set forth in 40 CFR.

Stormwater discharges from most industrial facilities are covered under General Permits when they discharge into municipal separate sanitary sewers. General NPDES permits have a fixed term not to exceed five years. An operator of a stormwater discharge associated with industrial activity which discharges through a large or medium municipal separate storm sewer system shall submit, to the operator of the municipal separate storm sewer system receiving the discharge, the following information: the name of the facility; a contact person and phone number; the location of the discharge; a description, including Standard Industrial Classification, which best reflects the principal products or services provided by each facility; and any existing NPDES permit number.

In addition, the operator of a stormwater discharge associated with industrial activity covered under a general, group, or individual permit, shall provide the following minimum information (40 CFR § 122.26 (c)(i)):

- A site map showing topography, drainage features, buildings, and areas where materials or activities may contribute pollutants to stormwater.
- An estimate of the area of impervious surfaces (including paved areas and building roofs) and the total area drained by each outfall (within a mile radius of the facility) and a narrative description of materials handled or stored as well as measures taken to control pollutants in the runoff.
- A certification that all outfalls that should contain stormwater discharges associated with industrial activity have been tested or evaluated for the presence of non-stormwater discharges which are not covered by a NPDES permit. Tests for such non-stormwater discharges may include smoke tests, fluorometric dye tests, analysis of accurate schematics, as well as other appropriate tests. The certification shall include a description of the method used, the date of any testing, and the onsite drainage points that were directly observed during a test.
- Existing information regarding significant leaks or spills of toxic or hazardous pollutants at the facility that have taken place within the three years prior to the submittal of this application.

Quantitative data based on samples collected during storm events from all outfalls containing a stormwater discharge associated with industrial activity for a number of water quality parameters.

Industrial Pretreatment Requirements

Industrial pretreatment requirements are another area where enforcement can result in lower pollutant concentrations in stormwater. Under PA Code Title 25 § 94.15, the operator of the sewerage facilities in cases where pollutants contributed by industrial users result in interference or pass through, and the violation is likely to recur, must develop and implement specific local limits for industrial users and other users, as appropriate, that together with appropriate sewerage facility or operational changes, are necessary to ensure renewed or continued compliance with the plant’s NPDES permit or sludge use or disposal practices.

Additional Measures

Information on existing pollution prevention plans and spill response requirements should be provided to relevant industries in the watershed as part of the Phase II public education measures.

Industrial Pollution Prevention Plans are one means to prevent spills and accidental releases. Under PA Code Title 25 § 91.34 (Activities Utilizing Pollutants):

- Persons engaged in an activity which includes the impoundment, production, processing, transportation, storage, use, application, or disposal of pollutants shall take necessary measures to prevent the substances from directly or indirectly reaching waters of this Commonwealth, through accident, carelessness, maliciousness, hazards of weather, or from another cause.

- PA DEP may require a person to submit a report or plan setting forth the nature of the activity and the nature of the preventative measures taken. The Department will encourage consideration of the following pollution prevention measures, in descending order of preference, for environmental management of wastes: reuse, recycling, treatment, and disposal.

Spill response is another area that can improve wet weather water quality in Tookany/Tacony-Frankford Creek. Spill response requirements are promulgated under PA Code Title 25 and issued under section 5 of The Clean Streams Law (35 P. S. § 691.5).

Under PA Code Title 25 § 91.33 (Incidents Causing or Threatening Pollution):

- If, because of an accident or other activity or incident, a toxic substance or another substance which would endanger downstream users is discharged, it is the responsibility of the person at the time in charge of the substance to immediately notify PA DEP by telephone of the location and nature of the danger and, if reasonably possible to do so, to notify known downstream users of the waters.

- In addition to the notices, the person shall immediately take steps necessary to prevent injury to property and downstream users, and within 15 days from the incident, remove from the ground the residual substances to prevent further pollution.

The River Conservation Plans (RCPs) noted the following:

- <u>Rising Sun Avenue to Roosevelt Boulevard</u>: Examine car-recycling shop for runoff and determine if it's a legal operation.

Construction Stormwater Pollution Prevention (CR5)

Related Goals: 1, 2, 3, 7
Related Indicators: 1, 2, 3, 4, 7, 8, 9, 10, 19, 20

What	Who	Where	When
Construction Site Stormwater Program in conformance with Phase II Stormwater Permits: • Enact an ordinance. • Review and approve Erosion and Sediment Control Plans. • Distribute educational materials.	All municipalities required to do Phase II permit (see Table 8.7).	N/A	5-year program associated with stormwater permit (see Table 8.17).

In accordance with the TTF Integrated Watershed Management Plan's stated purpose of integrating various existing programs, and to avoid duplication of effort, the recommended implementation plan follows the PA DEP Stormwater Management Program Protocol to meet the six minimum control measures required of municipal permittees under the Phase II NPDES Stormwater Regulations (listed in Section 1.4.1 of this report, and found at 40 CFR §§ 122.26 – 123.35). One of the six minimum controls is a Construction Site Stormwater (CSS) Program.

In Pennsylvania, two programs currently exist that address stormwater runoff from construction activities: 1) the Erosion and Sediment Control Program under 25 Pa. Code Chapter 102, and 2) the NPDES Stormwater Construction Permit Program.

The Erosion and Sediment Control Plan submitted by the developer must contain BMPs appropriate to the site and the surrounding area that might be impacted by the construction activities, as well as for post-construction runoff. Construction activity-related BMPs are available to developers and others through the Erosion and Sediment Pollution Control Program Manual (PA DEP ID: 363-2134-008) at www.dep.state.pa.us (directLINK "stormwater"), as well as at the County Conservation District (CCD).

The CSS program can be summarized as consisting of the following steps:

- Enact, implement, and enforce a stormwater control ordinance using PA DEP model language;

- Coordinate the review and approval of Erosion and Sediment Control Plans with the County Conservation District(s) (CCD) or PA DEP for any earth disturbance of one acre or more causing runoff, or for any earth disturbance of five acres or more. Make approval of the Erosion and Sediment Control Plan a prerequisite for the formal approval of land development and redevelopment plans or the issuance of building permits; and

- Distribute educational materials to land developers with the applications for building permits and other land development/redevelopment.

Municipalities must have an agreement with their local CCD that addresses these reviews and permitting requirements. This agreement ensures the close coordination between the municipality and the CCD on these important issues affecting water quality. Note that a NPDES Stormwater Construction Permit is required for earth disturbance activities where the construction disturbs five acres or more, or where there is a discharge from a site to the MS4 where earth disturbance is one acre or more.

In most cases, the County Conservation District implements these two programs, and PA DEP is responsible for implementing and enforcing these programs in cases where the County does not have this responsibility. By requiring review and approval of Erosion and Sediment Control Plans by the CCD or PA DEP (and proof of NPDES Stormwater Construction Permits where required), and by coordinating building permit and other land development permits or approvals with the CCD (or PA DEP in some cases), municipalities will meet MS4 permit requirements for this component of the Construction Stormwater Runoff Management Minimum Control Measure. Utilizing this existing statewide program, the municipality avoids the need to do a duplicative, independent review of every Erosion and Sediment Control Plan.

All municipalities in the watershed are required to fulfill this aspect of the stormwater regulations. Table 8.17 shows the schedule for implementation.

Table 8.17 Implementation Schedule for Construction Stormwater Pollution Prevention

PERMIT YEAR	***IMPLEMENTATION SCHEDULE***	
	Construction Site Stormwater Program	**Developer Education**
Year 1	**Ordinance:** Enact an ordinance requiring: • the review and approval of Erosion and Sediment Control Plans by the local County Conservation District or PA DEP; • for any earth disturbance one acre or more with runoff to the MS4, or five acres or more regardless of the planned runoff; and • as a prerequisite for the formal approval of land development plans or the issuance of building permit. **Process:** Establish an agreement with the local CCD for the review and approval of Erosion and Sediment Control Plans for all earth disturbance activities equal to or greater than one acre with runoff to the MS4 (or five acres or more regardless of the planned runoff). **Standard:** Require that the Erosion and Sediment Control Plans be developed in accordance with the requirements of Chapters 102 (erosion and sedimentation) of the PA DEP regulations.	Meet permit requirements and measurable goals for Year 1 under Public Education and Outreach MCM.
Years 2-5	Implement the ordinance and agreement for review of Erosion and Sediment Control Plans.	Meet permit requirements and measurable goals for Year 2 under Public Education and Outreach MCM.

Post-Construction Stormwater Runoff Management (CR6)

Related Goals: 1, 2, 3, 7
Related Indicators: 1, 2, 3, 4, 7, 8, 9, 10, 19, 20

What	Who	Where	When
Post-Construction Stormwater Runoff Management in conformance with Phase II Stormwater Permits: • Enact ordinance. • Coordinate review and approval of Plans. Ensure BMP maintenance.	All Municipalities required to do Phase II permit (see Table 8.7).	N/A	5-year program associated with stormwater permit (see Table 8.18).

In accordance with the TTFIWMP's stated purpose of integrating various existing programs, and to avoid duplication of effort, the recommended implementation plan follows the PA DEP Stormwater Management Program Protocol to meets the six minimum control measures required of municipal permittees under the Phase II NPDES Stormwater Regulations (listed in Section 1.4.1 of this report, and found at 40 CFR §§ 122.26 – 123.35). One of the six minimum controls is a Post-Construction Stormwater Runoff Management Program. The program can be summarized as consisting of the following steps:

- Enact, implement, and enforce a stormwater control ordinance using PA DEP model language;
- Coordinate the review and approval of post-construction BMPs simultaneously with the review and approval for construction Erosion and Sediment Control Plans as described in the Construction Minimum Control Measure; and
- Ensure long-term operation and maintenance of the BMPs.

PA DEP links management of post-construction runoff with the Construction Minimum Control Measure component discussed above (see Option CR5). Approvals for construction activities will be dependent on how post-construction issues are addressed. For example, if an applicant's plan for a land development or redevelopment project adequately addresses stormwater issues during construction but does not do so for post-construction impacts, then it must not be approved until the post-construction issues are addressed.

Ordinance

Municipalities must enact, implement, and enforce a stormwater control ordinance using PA DEP model language. The ordinance must address the proper standard for BMPs and operations and maintenance requirements for the BMPs. The ordinance will apply a statewide post-construction requirement until the water quality-based Act 167 Plan is adopted by the County and implemented by the municipality, at which time the municipality will need to amend it to include those requirements.

The ordinance should require that all development and redevelopment activities with earth disturbance one acre or more with runoff to the MS4 (or five acres or more regardless of the planned runoff) be conducted in accordance with the ordinance. No formal approval of land development plans or issuance of building permits should occur without municipal approval of post-construction stormwater controls. A model ordinance is available from PA DEP.

Implement Program

The municipalities must commit resources or establish an agreement with the local County Conservation District (CCD) or other service provider (e.g., municipality's consulting engineer) for coordination of post-construction BMP approvals. There must be a process to review the post-construction controls in conjunction with the review process for construction approval.

Municipalities must ensure that the post-construction controls will meet state water quality requirements. Those requirements depend upon the status of the Act 167 Stormwater Management planning in the watershed. Where a water-quality-based Act 167 plan has been completed (or updated), those local watershed requirements apply. Otherwise, statewide requirements must be implemented.

While it is the municipalities' responsibility to ensure that the BMPs meet the water quality requirements, PA DEP will be reviewing post-construction plans for individual permits, and some County Conservation Districts have the expertise to conduct the reviews under an agreement with the municipality similar to that for the Construction Minimum Control Measure.

Operation and Maintenance of Post-Construction BMPs

It is the municipalities' responsibility to ensure that the post-construction BMPs required and approved pursuant to the program are constructed, operated, and maintained. Many BMPs may be "non-structural," and will require no operation or maintenance. Examples are use of open space and vegetated buffers in development design, minimization of soil disturbance and compaction during construction, and minimization of directly connected impervious areas. Other BMPs – "structural BMPs" – will require proper operation and maintenance. Examples include wet ponds, grassed swales, infiltration basins, and bioretention areas.

Municipalities will need to have a monitoring program that ensures that the post-construction BMPs are constructed, operated, and maintained, within the first permit term of five years. The program must have two elements:

- Implementation: Ensure installation of the BMPs as designed. Coordinate the monitoring with the CCD, especially where a permit has been issued.
- Operation and Maintenance: Some of the structural BMPs will require maintenance over time to be effective. Municipalities must have a system to monitor these BMPs. If any BMPs

are not operated or maintained and are ineffective, municipalities must develop a plan to address them. The PA DEP Model Ordinance provides legal tools to accomplish this.

All municipalities within the Tookany/Tacony-Frankford Watershed must carry out this program (see Table 8.7). The schedule for full implementation is provided, in accordance with the new Phase II rules, in the table below.

Table 8.18 Post-Construction Stormwater Runoff Management: Implementation Schedule

PERMIT YEAR	*IMPLEMENTATION SCHEDULE*	
	Stormwater Management Program	Long Term Operation and Maintenance
Year 1	**Ordinance:** Enact an ordinance requiring: • No formal approval of land development plans or issuance of building permits without municipal approval of post-construction stormwater controls. • Development and redevelopment activities with earth disturbance of one acre or more with runoff to the MS4, or five acres or more regardless of the planned runoff, must be conducted in accordance with the ordinance. **Process:** Rely on PA DEP review of permits where applicable; where no PA DEP review of post-construction controls is conducted, use municipal resources, or establish an agreement with the local CCD or other service provider (e.g., municipal engineer) for coordination of post-construction BMP approvals. **Standard:** Require post-construction structural and non-structural BMPs be designed, constructed, and maintained to meet (1) the requirements of the approved Act 167 plan and the municipal ordinance, or (2) the PA DEP statewide water quality requirements, until such Act 167 Plan is in place.	Ensure that stormwater BMPs are built, operated, and maintained as designed.
Years 2-5	• Implement the ordinance and post-construction BMP approval process.	Ensure that stormwater BMPs are built, operated, and maintained as designed.

Use Review and Attainability Analysis (CR8) Related Goals: 1, 2, 3, 4 Related Indicators: 7, 8, 9, 10, 11			
What	Who	Where	When
Coordinate water quality standards review and revision with PWD's CSO LTCP	EPA and PADEP in partnership with PWD and other permitted dischargers	The Tookany/Tacony-Frankford creek and tributaries	Within 5 years (1 NPDES CSO permit cycle)

The CSO Policy calls for the development of a long-term control plan (LTCP) which includes measures that provide for compliance with the Clean Water Act, including attainment of water quality standards. The CSO Policy provides that "development of the long term plan should be coordinated with the review and appropriate revision of water quality standards (WQS) and implementation procedures on CSO-impacted receiving waters to ensure that the long-term controls will be sufficient to meet water quality standards" (59 FR 18694).

As part of a renewed focus on this commitment, EPA has issued a guidance document, Coordinating CSO Long-Term Planning with Water Quality Standards Reviews (EPA-833-R-01-002). This document lays a strong foundation for integrating water quality standards reviews, implementation of high-priority CSO controls, and development of well-designed and operated LTCPs that support attainment of water quality standards without causing substantial and widespread economic and social impacts. In addition to CSO impacts, many of the processes, procedures and ideas presented can be used to address wet weather issues such as stormwater and other point and nonpoint sources on a watershed basis. An iterative, phased implementation of CSO controls fits well with the watershed approach.

Depending on the impacts, possible water quality standards revisions could include:

1. Re-evaluating recreational uses and applying criteria for bacteria at the point of contact rather than at the end-of-pipe,
2. Segmenting the water body to preserve recreation in areas where it actually occurs, and
3. Revising the use by creating subclasses to recognize intermittent exceedances of bacteriological criteria.

Watershed-Based Permitting (CR9) Related Goals: 2, 3, 4, 5, 7 Related Indicators: 1, 2, 3, 7, 10, 11, 15, 16, 19			
What	Who	Where	When
Explore approaches to developing NPDES permits for multiple point sources located within the watershed	PADEP	Watershed-wide	Long term

Source: Watershed-Based National Pollutant Discharge Elimination System (NPDES) Permitting Implementation Guidance, December 2003 (EPA 833-B-03-004)

Watershed-Based NPDES Permitting
Watershed-based NPDES permitting is an approach to developing NPDES permits for multiple point sources located within a defined geographic area (watershed boundaries) to meet water quality standards. This approach, aimed at achieving new efficiencies and environmental results, provides a process for considering all stressors within a hydrologically defined drainage basin or other geographic area, rather than addressing individual pollutant sources on a discharge-by-discharge basis. This plan provides the first steps in this process. In the long term, a watershed-based permit in the Tookany/Tacony-Frankford system can provide the regulatory framework for implementation of this integrated watershed management plan.

A truly comprehensive watershed management approach should bring together key programs under the Clean Water Act, such as the NPDES Program, the TMDL Program, the Section 319 Nonpoint Source Program, and Section 404 Wetlands Permitting, as well as the Source Water Assessment Program under the Safe Drinking Water Act. Watershed-based NPDES permitting can be another tool to facilitate comprehensive programmatic integration at a watershed level and ensure that permitting activities tie into existing watershed management efforts.

Developing and Implementing a Watershed-Based NPDES Permitting Approach EPA’s suggested process for developing and implementing a watershed-based NPDES permitting approach consists of the following six steps. This integrated watershed management plan fulfills most requirements of the first three steps.

Step One - Select a Watershed and Determine the Boundaries

Step Two - Identify Stakeholders and Facilitate Their Participation

Step Three - Collect and Analyze Data for Permit Development

Step Four - Develop Watershed-Based Permit Conditions and Documentation

Step Five - Issue Watershed-Based NPDES Permit

Step Six - Measure and Report Progress

8.3.2 Target C Options: Public Education and Volunteer Programs

Public Education and Volunteer Programs (CP1) Related Goals: 4, 6, 7 Related Indicators: 16, 17, 18, 19, 20, 21			
What	Who	Where	When
See Public Education and Volunteer Programs under Target A options (Section 8.1.2).	All municipalities.	All municipalities.	Short-term: first 5 years coinciding with the stormwater permit (see Table 8.8).

8.3.3 Target C Options: Municipal Measures

Sanitary Sewer Overflow Detection (CM1)

Related Goals: 3, 7
Related Indicators: 10, 11, 19, 20

What	Who	Where	When
SSO Detection Program.	Municipalities with separate sewer systems in TTF Watershed (see Table 8.7).	See Figure 8.3 (map of separate sewers and responsible authorities).	Permanent ongoing program should be part of each agency's program.

Discharges from sanitary sewers to Tookany/Tacony-Frankford Creek during wet weather are suspected in some areas. Some of the techniques used for inspection of sewer lines can also be used for identifying potential locations of SSOs. Some of the most effective techniques for identifying the location of SSOs are listed below. (Source: Protocols for Identifying Sanitary Sewer Overflows, American Society of Civil Engineers EPA Cooperative Agreement #CX 826097-01-0, June 2000.)

Sewer System Mapping

GIS maps of the sewer system should be developed in all municipalities. These maps serve as the basis for hydraulic modeling, and are key to many of the techniques described below.

Customer and/or Public Complaint

When a basement backup occurs or an SSO occurs in an area exposed to view, it is almost certain that someone will call the sewerage agency and report the incident. The agency should have a plan in place to investigate the reported SSO, find its cause, and take remedial measures to avoid recurrence of the SSO.

Visual Inspections after Overflows

Visual inspections can be used to confirm the occurrence of SSOs at suspected locations. The agency should develop a list of such locations and update it periodically. Immediately following a major storm, an inspection team should be sent to investigate these locations. A visual inspection program can be enhanced by encouraging participation of the public through providing opportunities for the public to become part of the solution.

Scheduled Maintenance Inspection

Municipal sewerage agencies should be performing routine maintenance inspections of their system. While the maintenance crew is performing the inspection, it can also look for signs of SSOs. These are most likely to occur at pumping stations, manholes, stream crossings, and cleanouts.

GIS-Based Analysis of Past SSOs

GIS analysis can answer questions related to location, condition, trends, patterns, and modeling. Listed below are some typical questions that GIS can answer:

- What exists at a given location?
- Where is the location of an object or outcome with a number of specific characteristics?
- What has changed over a given period?
- What is the spatial distribution of areas with a certain attribute?

Sanitary Sewer Management Systems

A Sanitary Sewer Management System (SSMS) can be used to store, organize, and analyze large quantities of data associated with sewer system operation, maintenance, inspection, modeling, and rehabilitation. The SSMS may include the following modules:

- Inventory Module
- Flow Module
- Modeling Module
- Inspection Module
- Maintenance Module
- Rehabilitation (CIP) Module
- Mapping Module

Analysis of the data in the SSMS can reveal many problem areas, trends, and patterns. For example, the database can be searched to develop a list of lines with flat slopes or areas where frequent maintenance is needed. Another application of the SSMS is analysis of historical data.

Flow Monitoring

Flow monitoring at strategic locations may be used to identify potential locations of SSOs. Flow monitors can be installed in open channels and pumping stations to obtain the data necessary for proper system evaluation. In conjunction with flow monitoring, rain gauges should also be installed. Many open channel temporary flowmeters have both velocity and depth measuring sensors. Municipalities should use the existing rain gauge network in the TTF Watershed.

Flow data can be used to determine the average daily flow, the infiltration rate, and the inflow rate. The rain gauge data can be used to determine the recurrence interval or severity of the storm event (for example, 5-year) that caused the inflow. The flow data will also indicate whether a surcharge occurred during the flow monitoring period.

Monitoring of Receiving Stream for Sewage Indicators

This technique may be used for identifying the locations of dry weather SSOs. Samples from a nearby stream are taken at regular intervals along the stream and tested for fecal coliforms. Significant presence of these bacteria could be an indication of sewage leaking from the sewer line into the stream.

Closed Circuit Television (CCTV) Inspection

CCTV inspection has been widely used for inspection of sewer line interiors. The final product of a CCTV inspection is videotape and a field log prepared and narrated by an operator. The videotape provides a visual and audio record of problem areas in the sewer line. Evaluation of the CCTV records help identify structural problems; locate leaking joints and non-structural cracks, blockages, and dropped joints; and identify areas of root intrusion.

Sewer Scanner and Evaluation Technology Surveys (SSET)

The SSET is a new pipeline inspection technology developed in Japan. The equipment consists of a scanner, a CCTV, and a three-axis mechanical gyroscope. The mechanics of placing the SSET in the sewer line are similar to those of CCTV inspection. The images produced by SSET are of higher quality than CCTV images. Interpretation of the results is done in the office by an engineer rather than in the field by a technician. This increases the speed of field operations and reduces the cost.

Surcharge Level Alarms/Remote Monitoring

These devices can be placed at strategic locations in the manholes and pumping stations. Once the flow reaches a certain elevation, the alarm goes off and sends a signal to a control center via a telephone line or SCADA system. The sewerage agency should have a plan in place to respond immediately to such alarms. In addition, the responding agency should also record the event in a database.

Dye Tracing

Dyed water testing consists of dye tracing or flooding, and is done to locate possible sources of inflow such as area drains or catch basins suspected of being connected to the sewer line, or sources of rainfall-induced infiltration/inflow which indirectly contribute to the flow in the sewer line through the soil and pipe cracks. Dye testing is normally used to complement smoke testing of suspect areas. The downstream manhole is monitored to see if the dye water injected into an outside source such as a downspout has found its way into the sewer system. Color CCTV may also be used for locating problem areas after the dye enters the pipeline through the surrounding soil.

Smoke Testing

The purpose of smoke testing is to locate rainfall-dependent I/I (Inflow and Infiltration)sources which could lead to SSOs during a storm events. Public notification is an important and critical element of any smoke testing program. Specific I/I sources detected by smoke testing includes roof, yard, and area drain connections; catch basins; and broken service lines. The testing procedure consists of pumping non-toxic smoke through a manhole into the sewer pipe for distances up to 600 ft. The smoke will surface through open breaks in the pipe connections. All such sources are photographed and documented.

Aerial Monitoring

Aerial monitoring by helicopter may be used to gain a general understanding of conditions along a sewer line which may lead to an SSO. For example, washout may expose a section of pipe, which would then be at risk of damage and subsequent SSO. Examples of features which may be observed during such monitoring include manholes with broken or missing covers and sewer lines exposed by erosion.

Monitoring of Grease Buildup

A significant cause of SSOs during dry weather is sewer stoppages resulting from grease buildup. Such stoppages occur most frequently in downtown areas where restaurants are major sources of flow in the sewer system. A list of locations of grease buildup should be developed and these locations should be regularly inspected. Grease buildup can be prevented by enforcing grease ordinances, by effective pretreatment programs, and by promoting public education. The grease accumulations can be removed using the many available cleaning techniques, such as bucket machines with brushes, power rodders, and high velocity jet cleaners. Bioaugmentation, which involves the addition of bacteria cultures to sewers to speed up the breakdown of grease deposits, can also be effective.

Pump Station Inspection

Pump station failures can lead to significant SSO problems. Such failures can be avoided by regular inspections. The frequency of inspections may vary from once a day to once a month, depending on the size and criticality of the station, and reliance on monitoring by means such as the SCADA system.

Manhole Inspection

Manhole interiors are inspected for physical soundness for evidence surcharging such as high water marks on manhole walls. The observed defects should be compiled into a database that will be used to estimate the I/I attributable to each manhole and to establish manhole maintenance and rehabilitation program.

Line Lamping

Line lamping is done in conjunction with manhole inspection by inspecting the interior of the sewer lines connected to the manhole using an artificial light and a mirror. Lamping helps identify pipe defects and provides a basis for selecting sewers for television inspection.

Building Inspection

Building inspections are conducted to investigate extraneous flow from connections to sump pumps, foundation drains, downspouts, or leaking laterals. Building inspections should include investigation of the causes of basement backups.

Ground Penetrating Radar

Ground penetrating radar uses the transmission and reflection properties of an electromagnetic wave passing through the soil to determine soil properties and the depth and extent of subsurface objects. The speed and amplitude of the electromagnetic wave are dependent on the moisture content of the soil. This principle can be used to detect leaking joints in the line and voids around the pipe, which may be caused by soils being washed out. In such locations, the signal will be delayed because the speed of the wave will be reduced, and the amplitude of the wave will be attenuated.

Soil Moisture and Temperature Monitoring

When the ground is relatively dry, a larger portion of the rainfall will penetrate the soil, which will result in a decrease of groundwater to sanitary sewers. However, as the soil moisture increases, the amount of infiltration to sewers increases. For this reason, the impact of subsequent storm will be more severe: while the system did not overflow during the first storm, it will do so during the second storm, although the second storm of smaller intensity than the first. By monitoring the soil moisture and temperature, it may be possible to develop a measure for assessing the occurrence of SSOs.

Inspections of Stream Crossings and Parallel Lines

Pipes running alongside or crossing streams are often vulnerable to SSOs. If the sewer is buried under the stream bed, the scouring action of the stream bed will eventually expose it, causing the pipe to lose its soil support. The pipe segments may move under the water pressure and joints may open, or the pipe may become exposed as a result of bank erosion. Any such openings admit significant amounts of flow, which may exceed the capacity of the sewer pipe. Stream crossings that include inverted siphons often become clogged with accumulations of silt and debris, which may cause an overflow upstream. The foundations of aerial stream crossing piers are also subject to scouring and may lead to foundation failure of the sewer line.

Sewer pipes that cross or parallel streams should be inspected to ensure that they are not broken or cracked. The manholes on each side of the stream should be checked for excess flow, which would indicate a leaking sewer under the stream. Since these sewers are usually in remote areas, they are vulnerable to vandalism and can overflow undetected for long periods.

All municipalities in the Tookany/Tacony-Frankford Watershed should have a routine and effective SSO detection program. Once SSOs are found and the cause determined, proper measures to eliminate the SSO should be taken.

All municipalities with separate sanitary sewers are responsible for developing an effective SSO detection program.

The River Conservation Plans (RCPs) recommend the following:

- Greenwood Avenue to Wyncote Post Office: Inspect and repair manhole covers as needed.
- Wyncote Post Office to Washington Lane Underpass: Inspect and repair all manhole covers and cement encasements.

Sanitary Sewer Overflow (SSO) Elimination: Structural Measures (CM2)

Related Goals: 3, 7
Related Indicators: 10, 11, 19, 20

What	Who	Where	When
Implement a CMOM program (see Option AM1). Update and implement official Act 537 Sewage Facilities Plans.	Municipalities with separate sewer systems in Tookany/Tacony-Frankford Creek (see Table 8.7).	See Figure 8.3 (map of separate sewers and responsible authorities).	Short-term (within 5 years of SSO detection).

Discharges to U.S. waters from municipal sanitary sewer collection systems are prohibited, unless authorized by an NPDES permit. Permits authorizing discharges from such systems must contain technology-based effluent limitations, based upon secondary treatment and applicable water quality standards. NPDES permits for municipal wastewater treatment plants should require record-keeping and reporting of overflows that result in a discharge. Permits should also contain requirements for operation and maintenance of the sanitary sewer collection system.

The EPA and PA DEP are continuing to address SSO problems with compliance assistance and enforcement in accordance with the Compliance and Enforcement Strategy Addressing Combined Sewer Overflows and Sanitary Sewer Overflows, issued April 27, 2000. In addition to the national policy, Act 537, enacted by the Pennsylvania Legislature in 1966, requires that every municipality in the state develops and maintains an up-to-date sewage facilities plan. The main purpose of a municipality's sewage facilities plan is to ensure that the sewage collection and treatment systems have adequate capacity to convey present and future to sewage flows to a wastewater treatment facility. Official plans contain comprehensive information, including:

- The location of treatment plants, main intercepting lines, pumping stations and force mains, including their size, capacity, point of discharge and drainage basin served (preferably in a GIS format);
- Descriptions of problems with existing sewerage facilities and operation and maintenance requirements; and
- Planning objectives and needs:
  - Physical description of planning area
  - Evaluation of existing wastewater treatment and conveyance systems
  - Evaluation of wastewater conveyance and treatment needs

EPA has developed a comprehensive management framework called Capacity, Management, Operations, and Maintenance (CMOM) to assist municipalities in developing more comprehensive sanitary sewer system management programs. A CMOM program (described in Section 8.1.3, Option AM1) helps to prevent SSOs. Once a recurring SSO is detected using the methods recommended under Option CM1, measures must be taken to eliminate the discharge.

Reduction of Stormwater Inflow and Infiltration (RDII) to Sanitary Sewers (CM3)

Related Goals: 3, 7
Related Indicators: 10, 11, 19, 20

What	Who	Where	When
RDII Reduction Program.	Municipalities with separate sewer systems in TTF Watershed (see Table 8.7).	See Figure 8.3 (map of separate sewers and responsible authorities).	Short-term.

Where significant RDII is detected, measures can be taken to seal the sanitary sewer system to reduce inflow of stormwater and groundwater. These measures are discussed in detail under Option AM3, "Sanitary Sewer Rehabilitation" (in Section 8.1.3).

Combined Sewer Overflow (CSO) Control Program (CM4)

Related Goals: 3, 7
Related Indicators: 7, 8, 9, 10, 11, 19, 20

What	Who	Where	When
Nine Minimum Controls (NMCs). Long Term Control Plan (LTCP) Capital Projects, including real time control (RTC). Watershed Plan development.	PWD	Philadelphia combined sewer system.	NMCs complete and ongoing. RTC short-term (within 5 years).

The fundamental goal of the Philadelphia Water Department's (PWD) combined sewer overflow (CSO) program is to improve and preserve the water environment in the Philadelphia area and to fulfill PWD's obligations under the Clean Water Act and the Pennsylvania Clean Streams Law by implementing technically viable, cost-effective improvements and operational changes.

The PWD's strategy to attain these goals has three primary phases: aggressive implementation of a comprehensive program for Nine Minimum Controls; planning, design, and construction of capital projects that further enhance system performance and reduce CSO volume and frequency; and comprehensive watershed-based planning and analyses that will identify additional, priority actions to further improve water quality in Philadelphia area water bodies.

The implementation of each of these control measures is discussed briefly below.

Nine Minimum Controls

In the first phase of PWD's CSO strategy, and in compliance with its NPDES permits, PWD submitted CSO Documentation: Implementation of Nine Minimum Controls to the PA DEP on September 27, 1995. The nine minimum controls are low-cost actions or measures that can reduce CSO discharges and their effect on receiving waters, do not require significant engineering studies or major construction, and can be implemented in a relatively short time frame. To provide information needed for the development of the Nine Minimum Controls (NMC) program, PWD instituted a $6.5 million project to upgrade its comprehensive system flow monitoring network. This program provides information necessary to identify and eliminate dry weather overflows, monitor system performance and operation, and configure and calibrate computer hydraulic models needed to develop the NMCs and long-term CSO control plans. This information provided the basis for the System Hydraulic Characterization Report that was submitted to the PA DEP in June 1995 and provided the technical basis for the development of the NMC plan.

Extensive data from the PWD's Geographic Information System (GIS), flow monitoring system, the U.S. Army Corps of Engineer's Storage, Treatment, Overflow, Runoff Model (STORM), and the EXTRAN and RUNOFF blocks of the EPA Stormwater Management Model (SWMM) were used to support each phase of the CSO program. These tools were developed to support concept engineering through implementation and post-construction monitoring. The monitoring system, models, and GIS will serve as the basis for planning improvements and enhancing operation of the sewerage system over the long-term.

Using the above tools, the PWD's NMC program includes comprehensive, aggressive measures to maximize water quality improvements through the following nine measures:

1. Review and improvement of ongoing operation and maintenance programs.

CSO Regulator Inspection & Maintenance Program

PWD has committed to demonstrating an improved follow-up response to sites experiencing a dry weather overflow. PWD has instituted a policy of next day follow-up inspection at sites that experience an overflow. PWD will conduct an evaluation of the effectiveness of twice-weekly inspections.

A database has been developed to document the maintenance performed on each CSO site. This system will ensure that proper regulator settings are maintained and system changes are documented. This database can also store scanned plan view and profile view drawings of CSO regulator and hydraulic control point chambers for inclusion in the filed inspection report forms.

Additional components of the O&M program include:

- Pumping Station Maintenance
- Sewer Cleaning Contracts
- Inflow Prevention Program
- Tide Gate Inspection and Maintenance Program
- Emergency Overflow Weir Modification

2. Measures to maximize the use of the collection system for storage.

Use of the collection system for storage has long been recognized as a potentially cost-effective means to mitigate the occurrence and impacts of CSOs. PWD has been implementing in-system storage in Philadelphia's combined sewer system for nearly 20 years, using a variety of technologies:

- Reducing tidal inflows at regulators can reduce CSO overflows to Tookany/Tacony-Frankford Creek by increasing available treatment capacity at the POTW.
- A program to install tide gates or other backflow prevention structures at Tookany/Tacony-Frankford Creek regulators to protect these regulators from potential inundation.
- Another approach that can be implemented to gain additional in-system storage is to raise the overflow elevation by physically modifying the overflow structure (e.g., raising an overflow weir). However, this approach must be implemented cautiously, since raising the overflow elevation also raises the hydraulic grade line in the combined trunk sewer during storm flows, and therefore increases the risk of basement and other structural flooding within the upstream sewer system due to backup or surcharge problems.

3. Review and modification of PWD's industrial pretreatment program.

(Also see Section 8.3.1, Option CR4, "Industrial Stormwater Pollution Prevention.")

- Over the years, PWD has implemented a rigorous industrial pretreatment program. The effectiveness of this program has allowed the City to develop one of the largest and most successful biosolids beneficial reuse programs in the nation. As part of the nine minimum controls effort, PWD is committed to taking actions to encourage industries to better manage their process water discharges to the sewer collection system during wet weather periods.

4. Measures to maximize flow to the wastewater treatment facilities.

As a minimum control, maximizing flow to the publicly owned treatment works (POTW) means making simple modifications to the sewer system and treatment plant to enable as much wet weather flow as possible to reach the treatment plant and receive treatment. The secondary capacity of the treatment plant should be maximized, and all flows exceeding the capacity of secondary treatment should receive a minimum of primary treatment (and disinfection, when necessary). The most effective way to determine the ability of the POTW to operate acceptably at incremental increases in wet weather flow, and to estimate the effect of the POTW's compliance with its permit requirement, is to perform stress testing to determine optimum flows, loads, and operations of the plant's unit processes.

5. Measures to detect and eliminate dry weather overflows.

Relevant measures are discussed in Section 8.1.3, which details various recommended Target A Municipal Measures.

6. Control of the discharge of solid and floatable materials.

Solids are waterborne waste material and debris consisting of sand, gravel, silts, clay, and organic matter. Significant concentrations of solids are not only a visual nuisance, but can affect turbidity and dissolved oxygen, and carry pathogens in the receiving water. In addition, excessive amounts of solids can affect the combined sewer system by decreasing hydraulic capacity, thus increasing the frequency of overflows. Solids can enter the system through domestic and industrial wastewater, and debris washed from streets.

Floatables are waterborne waste material and debris (e.g., plastics, polystyrene, and paper) that float at or below the water surface. Floatables seen in significant quantities are aesthetically undesirable and can cause beach closings, interfere with navigation by fouling propellers and water intake systems, and impact wildlife through entanglement and ingestion.

Floatables and solids control measures consist of non-structural and structural technologies.

Non-structural technologies include combined sewer system maintenance procedures such as sewer flushing, street sweeping, and catch basin cleaning. Public education, land use planning and zoning, and ordinances are also considered non-structural technologies implemented to reduce solids and floatables entering the combined sewer system. (These technologies are discussed elsewhere in Section 8, under various relevant options.)

Structural controls typically consist of abatement devices that would be constructed near the point of discharge. Technologies used for removing solids and floatables from CSOs include: Baffles, Booms, Catch Basin Modifications, Netting Systems, Swirl Concentrators, Screens, and Trash Racks. (Modification of storm and combined sewer inlets for solids control, as well as catch basin and storm inlet maintenance are also discussed elsewhere under Section 8 options.)

Solids and floatables discharged from CSOs may represent a potentially significant impact to Tookany/Tacony-Frankford Creek. PWD currently expends considerable effort to minimize the potential discharge of solids and floatables.

- PWD performs over 50,000 inlet cleanings each year preventing many tons of street surface-related materials from discharging to waterways through CSOs. The significant pipe cleaning and grit removal activities conducted by PWD also remove a great deal of material that otherwise might discharge through CSO outlets during wet weather.
- The continued practice of regularly cleaning and maintaining grit pockets at critical locations in the trunk and interceptor system is an important part of the CSO control strategy. Grit buildup reduces the hydraulic capacity of the interceptor both by constricting its cross sectional area, and by increasing its frictional resistance. For example, quarterly cleaning of the 100-foot deep siphon grit pocket located at the Central Schuylkill wastewater pumping station is a major undertaking requiring specialized equipment and the commitment of significant labor resources. This practice has been shown to reduce the hydraulic grade surface at the siphon, increasing the wet weather flow capacity to the SWWPCP. Prior to the institution of this cleaning practice, the grit pit at this location had not been cleaned regularly in over 40 years.
- Operation condition inspections of regulator chamber and backflow prevention devices are conducted for each structure approximately weekly, resulting in more than 10,000 inspections conducted each year. Additionally, comprehensive structural and preventative maintenance inspections are performed annually.
- A pilot, in-line, floatables netting chamber was constructed as part of a sewer reconstruction project at CSO T-4 Rising Sun Ave. east of Tacony Creek. The construction of the chamber was completed in March 1997 and the netting system continues to operate. The quantity of material collected is weighed with each net change. On an area weighted basis, the inlet cleaning program data suggests that street surface litter dominates the volume of material that can enter the sewer system. The pilot in-line netting system installed at T-4 has been shown to capture debris on the same order as the WPCP influent screens indicating that effective floatables control needs to target street surface litter in order to effectively reduce the quantity of debris likely to cause aesthetic concerns in receiving streams.
- Debris grills are maintained regularly at sites where the tide introduces large floating debris into the outfall conduit. This debris can then become lodged in a tide gate thus causing inflow to occur. Additionally, these debris grills provide entry restriction, and some degree of floatables control. Repair, rehabilitation, and/or expansion of debris grills were performed at outfall F05 during calendar year 2002.

7. Implementation of programs to prevent generation and discharge of pollutants at the source.

Most of the city ordinances related to this minimum control are housekeeping practices that help prohibit litter and debris from being deposited on the streets and within the watershed. These measures include litter ordinances and illegal dumping policies and enforcement (see Section 8.1.1, Option AR2). If such pollutants eventually accumulate within the watershed, practices such as street sweeping and regular maintenance of catch basins can help to reduce the amount of pollutants entering the combined system and ultimately, the receiving water.

8. Measures to inform the public about the occurrence, location, and impacts of CSOs.

PWD has developed and will continue to develop a series of informational brochures and other materials about its CSO discharges and the potential affect on the receiving waters, in addition to information regarding dry weather flows from its stormwater outfalls. The brochures provide phone contacts for additional information. Also, the opportunity to recruit citizen volunteers to check or adopt CSO outfalls in their watersheds (e.g.,, notifying PWD of dry weather overflows, etc.) will be explored through the watershed partnership framework. Brochures and other educational materials discuss the detrimental affects of these overflows and request that the public report these incidences to the department. In addition, the Water Department has enlisted watershed organizations to assist it with this endeavor. PWD continued with this focus in 2002 to raise the level of awareness in its citizens about the function of combined and stormwater outfalls through a variety of educational mediums. The watershed partnerships are important for this kind of public/private effort to protect stream water quality. Lastly, the Department's Waterways Restoration Unit will investigate the feasibility of installing signs that can withstand nature and vandals at PWD outfalls.

9. Comprehensive inspection and monitoring programs to characterize and report overflows and other conditions in the combined sewer system.

Monitoring and characterization of CSO impacts from a combined wastewater collection and treatment system are necessary to document existing conditions and to identify water quality benefits achievable by CSO mitigation measures. Tables are compiled annually to represent average annual CSO overflow statistics as required in the NPDES Permit.

Long Term Control Plan Capital Projects

The second phase of PWD’s CSO strategy is focused on technology-based capital improvements to the City’s sewerage system that will further increase its ability to store and treat combined sewer flow, reduce inflow to the system, eliminate flooding due to system surcharging, decrease CSO volumes, and improve receiving water quality. The recommended capital improvement program is the result of a detailed analysis of a broad range of technology-based control alternatives.

A Real Time Control (RTC) center is being established at PWD’s Fox Street facility. The ultimate goal for this center is to house a centralized RTC system that will allow telemetered commands to be sent to site-specific, automated controls located throughout the collection and treatment facilities. These signals may be transmitted based upon an optimized response to rainfall patterns and are intended to further enhance capture of CSO volume. Establishing a RTC center will enable PWD to provide 24-hour monitoring and, eventually, control of key collection system facilities including automated CSO regulators, pump stations, and inter-district diversions.

Two RTC projects are currently being designed for regulators that discharge to Tacony Creek. The trunk sewer discharging to regulator structure T-14 near Juniata Park and Tacony Creek Park contains excess storage capacity that can be utilized by increasing the overflow elevation during smaller rain events. A dynamic gate is ideal because the original overflow capacity is still needed to provide adequate drainage during very large storms. The project will reduce discharge volume associated pollutants such as bacteria, organic matter, solids, and litter from both untreated stormwater and wastewater.

The trunk sewer discharging to regulator structure T-08, near Nedro Avenue and Hammond Street in Tacony Creek Park, also has excess storage capacity during smaller storms. A similar dynamic gate is being proposed for this location to take advantage of this capacity and increase capture of combined sewage during wet weather. These projects are cost-effective because they modify existing infrastructure rather than requiring construction of new infrastructure. Both areas are in or near parkland used by the public for recreation.

Watershed-Based Planning and Management

The third component of the City's CSO strategy involves a substantial commitment by the City to watershed planning to identify long term improvements throughout the watershed, including possibly additional CSO controls, which will result in further improvements in water quality and, ultimately, the attainment of water quality standards. The need for this watershed initiative is rooted in the fact that, prior to development of the Integrated Watershed Management Plan, insufficient physical, chemical, and biological information existed on the nature and causes of water quality impairments, sources of pollution, and appropriate remedial measures. Because of this deficiency, it was impossible to determine what needed to be done for additional CSO control or control of other wet weather sources throughout the watershed. This deficiency, especially with respect to the effects of wet weather discharges and receiving water dynamics, is increasingly recognized nationwide and has led to a broader recognition of the need for watershed-based planning and management to properly define water quality standards and goals. PWD believes that the National CSO Policy, state and federal permitting and water quality management authorities, cities, environmental groups, and industry, now recognize that effective long-term water quality management can be accomplished only through watershed-based planning. Completion of the Tookany/Tacony-Frankford Integrated Watershed Management Plan represents the realization of this commitment to watershed-based planning.

Catch Basin and Storm Inlet Maintenance (CM5)

Related Goals: 3, 5, 6, 7
Related Indicators: 11, 15, 16, 19, 20

What	Who	Where	When
Regularly inspect catch basins (in combined areas) and storm inlets (in separate areas). Remove sediment as needed.	Sewer owners (PWD and municipalities).	All inlets throughout watershed.	Continue existing programs.

Catch basins and storm inlets that are part of the stormwater collection and conveyance system should be cleaned on a regular basis. Sediment, leaves, grass clippings, pet wastes, litter, and other materials commonly accumulate in catch basins. These materials can contain significant concentrations of nutrients, organics, bacteria, metals, hydrocarbons, and other pollutants. When a storm occurs, runoff entering the basin may dislodge and suspend some of this material. This debris can be conveyed along the storm sewer system and released to a surface water body. Catch basin clean out should be scheduled for the fall and early spring in order to remove leaves and road salt and sand before the spring rains. In general, this is done with vacuum trucks, with disposal of the debris handled as solid waste.

In separate sewered areas of the Tookany/Tacony-Frankford Watershed, each municipality is responsible for an effective storm sewer cleaning program. In Philadelphia, PWD has this responsibility.

Street Sweeping (CM6) Related Goals: 3, 5, 6, 7 Related Indicators: 11, 15, 16, 19, 20			
What	Who	Where	When
Evaluate existing Street Sweeping programs and implement enhanced practices.	All municipalities.	Streets and parking lots in commercial and dense residential areas.	Within next 5 years.

Street and parking lot cleaning performed on a regular basis in urban and dense residential areas can be an effective measure for minimizing stormwater pollutant, sediment, and floatables loading to receiving waters.

Street sweeping programs had largely fallen out of favor as a pollutant removal practice following the 1983 NURP report. Recent improvements in street sweeper technology, however, have enhanced the ability of the machines to pick up the fine grained sediment particles that carry a substantial portion of the stormwater pollutant load, and have led to a recent reevaluation of their effectiveness. New studies show that conventional mechanical broom and vacuum-assisted wet sweepers reduce non-point pollution by 5 to 30 percent and nutrient content by 0 to 15 percent. However, newer dry vacuum sweepers can reduce non-point pollution by 35 to 80 percent and nutrients by 15 to 40 percent for those areas that can be swept (Runoff Report, 1998). A benefit of high-efficiency street sweeping is that by capturing pollutants before they are made soluble by rainwater, the need for structural stormwater control measures might be reduced. Structural controls often require costly added measures, such as adding filters to remove some of these pollutants and requiring regular maintenance to change filters. Street sweepers that can show a significant level of sediment removal efficiency may prove to be more cost-effective than certain structural controls, especially in more urbanized areas with greater areas of pavement.

Computer modeling of pollutant removal in the Pacific Northwest suggests that the optimum sweeping frequency appears to be once every week or two (CWP, 1999). More frequent sweeping operations yielded only a small increment in additional removal (Bannerman, 1999; Claytor, 1999).

The following measures should be implemented toward achieving non-point source reductions in wet weather pollutant loads:

- Evaluate existing street and parking lot sweeping practices by municipalities with urban and dense residential areas contributing stormwater runoff to the watershed.
- Implement enhanced street and parking lot sweeping programs in urban and dense residential areas, prioritizing those not served by existing stormwater BMPs designed to reduce stormwater pollutant, sediment, or floatables loading to the receiving waters.

Responsible Landscaping Practices on Public Lands (CM7)

Related Goals: 1, 2, 3, 4, 6, 7
Related Indicators: 1, 10, 11, 12, 13, 16, 19

What	Who	Where	When
Incorporate integrated pest management (IPM) to reduce chemical use on public lands. Prevent clippings and cuttings from being transported by stormwater, and dispose of them through composting if possible.	Fairmount Park Commission, municipalities. PennDOT for vegetation along state roads.	Parks, golf courses, school and institutional grounds, roadside vegetation.	Short-term (within 5 years).

Common pesticides such as diazinon and chlorpyrifos can be harmful to aquatic life even at very low levels (CWP, 1999; Schueler, 1995). Proper use of these chemicals can be encouraged through public relations campaigns and demonstrated on public lands. Clippings and cuttings carried into the stormwater system and receiving streams can degrade water quality in a variety ways. A related problem exists with the illegal dumping of clippings and cuttings in or near drainage facilities. Recommended controls include:

- Consider an integrated pest management (IPM) program that encourages the use of alternatives to chemical pesticides. An IPM program incorporates preventative practices in combination with non-chemical and chemical pest controls to minimize the use of pesticides and promote natural control of pest species. In those instances when pesticides are required, programs encourage the use of less toxic products such as insecticidal soaps. The development of higher tolerance levels for certain weed species is a central concept of IPM programs for reducing herbicide use. This approach should be balanced with the invasive species control methods discussed in Section 8.2.3, Option BM7.

- Collect clippings and cuttings on slopes and the bottom of stormwater control facilities and near stormwater inlets. Avoid mowing when significant rain events are predicted. Dispose of material through composting when possible.

The River Conservation Plans (RCPs) recommend the following:

- High School Park to Ashbourne Road along the Tookany Creek Parkway: Educate Cheltenham Township Public Works in ecological maintenance practices. Encourage the two golf courses to evaluate fertilizing, mowing regime. Consider Audubon Golf Certification Program.
- Baeder Creek Watershed: Work with Abington Jr. High School to restore riparian buffer. Establish “no-mow” zone 30 feet from creek and plant native plants.

- Rock Creek Watershed: The mowed township-owned park would benefit from a change to a wooded area for both habitat enhancement and increased infiltration.
- Abington Country Club to Township Line Road: The Club greens should be maintained in a way to protect water quality.
- Abington Friends School to Township Line Road: Alter land management practices in the park to the restored pond shoreline including BMPs for the chip and putt course.
- Wyoming Avenue to Castor Avenue: Meet with Juniata golf course to discuss creating a “no mow” zone.

Responsible Bridge and Roadway Maintenance (CM9) Related Goals: 1, 2, 4, 7 Related Indicators: 1, 19			
What	Who	Where	When
Incorporate BMPs into regular repairs and maintenance: Road and bridge resurfacing practices, Deicing chemicals and practices, and Existing bridge drains.	Bridge and roadway owners (municipalities and PennDOT).	Roadways and bridges (Figure 8.6).	Short-term (within 5 years).

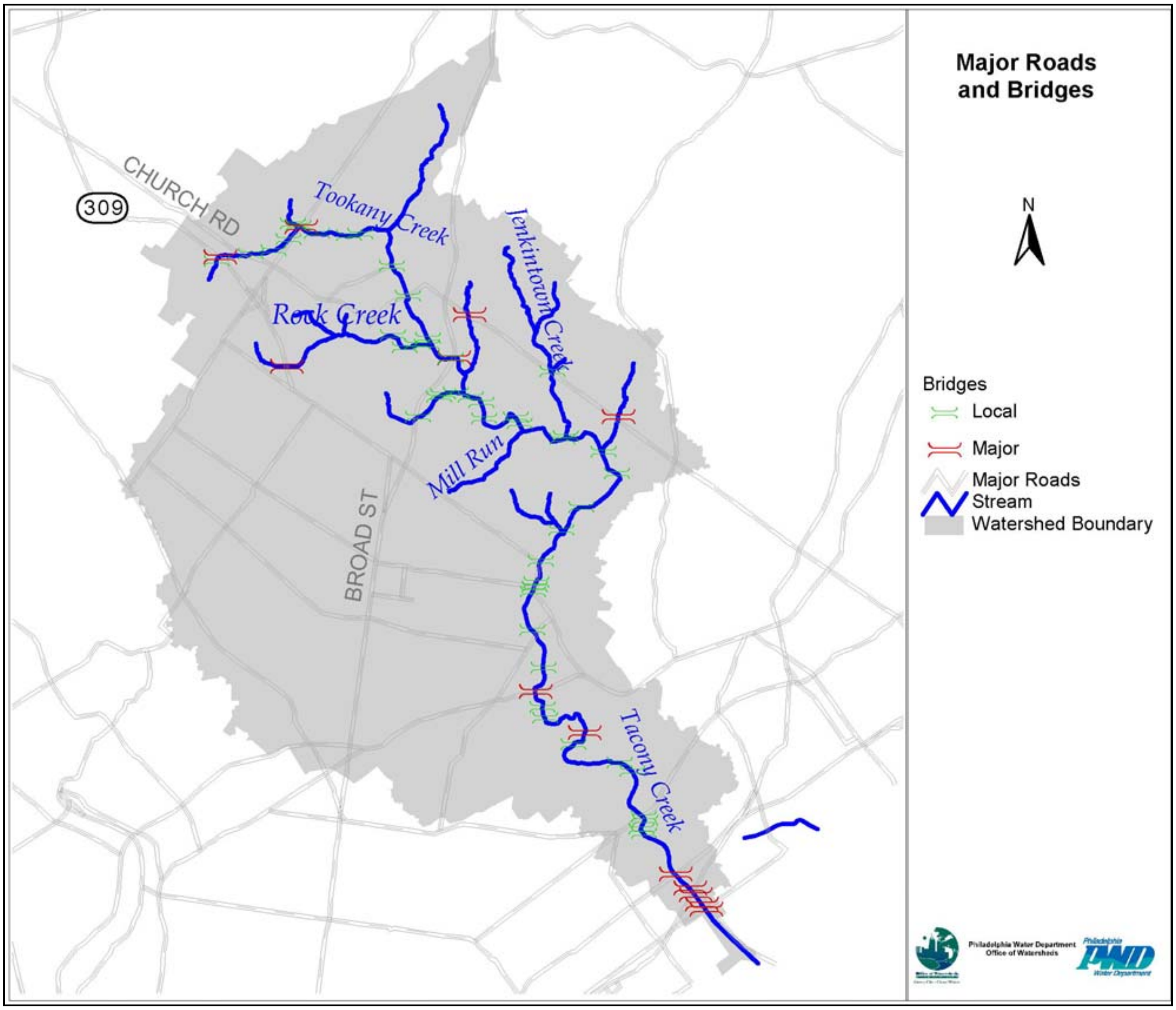


Figure 8.6 Major Roads and Bridges

Sediment and pollutants are generated during daily roadway and bridge use and scheduled repair operations, and these pollutants can impact local water quality by contributing heavy metals, hydrocarbons, sediment, and debris to stormwater runoff. The use of road salt is a public safety and a water quality issue. Aside from contaminating surface and groundwater, high levels of sodium chloride from road salt can kill roadside vegetation, impair aquatic ecosystems, and corrode infrastructure such as bridges, roads, and stormwater management devices.

Recommended techniques are as follows:

- Consider alterations to road and bridge resurfacing practices near the creeks (Figure 8.6). Perform paving operations only under dry conditions. Cover storm drain inlets and manholes during paving operations, use erosion and sediment control measures, and use pollution prevention materials such as drip pans and absorbent material for all paving machines to limit leaks and spills of paving materials and fluids. Finally, consider using porous asphalt for shoulder areas to reduce runoff.

- Consider adjusting the use and application of deicing materials as summarized below.

Table 8.19 Watershed Protection Techniques for Snow and Snowmelt Conditions

Use of De-Icing Compounds:
- Consider alternative de-icing compounds such as $CaCl_2$ and calcium magnesium acetate (CMA).
- Designate salt-free areas on roads adjacent to key streams, wetlands, and resource areas.
- Reduce use of de-icing compounds through better driver training, equipment calibration, and careful application.
- Sweep accumulated salt and grit from roads as soon as practical after surface clears.

Storage of De-Icing Compounds:
- Store compounds on sheltered, impervious pads.
- Locate at least 100 feet away from streams and floodplains.
- Direct internal flow to collection system and route external flow around shelters.

Dump Snow in Pervious Areas Where It Can Infiltrate:
- Stockpile snow in flat areas at least 100 feet from stream or floodplain.
- Plant stockpile areas with salt-tolerant ground cover species.
- Remove sediments and debris from dump areas each spring.
- Choose areas with some soil-filtering capacity.

Blow or Shovel Snow from Curbside to Pervious Areas.
Operate Stormwater Ponds on a Seasonal Mode.
Use Level Spreaders and Berms to Spread Meltwater Over Vegetated Areas.
Intensive Street Cleaning in Early Spring Can Help Remove Particulates on Roads.

- Consider alterations to existing bridge drains. Scupper drains can cause direct discharges to surface waters and have been found to carry relatively high concentrations of pollutants (CDM, 1993). At a minimum, routinely clean existing drains to avoid sediment and debris buildup, and consider retrofitting with catch basins or redirecting runoff to vegetated areas to provide treatment.

Runoff from bridges and roadways can become a serious hazard to water quality when the toxic pollutants from vehicles are taken into consideration.

The River Conservation Plans (RCPs) recommend the following:

- <u>Ralph Morgan Park to Greenwood Avenue</u>: Communicate with SEPTA regarding their maintenance practices of the parking lot.
- <u>Cheltenham Avenue to Adams Avenue</u>: Check railroad area for possible chemical runoff.

8.3.4 Target C Options: Stormwater Management

Source Control Measures

Reducing Effective Impervious Cover through Better Site Design (CS1)

Related Goals: 3, 5, 7
Related Indicators: 1, 15, 16, 19

What	Who	Where	When
Reduce effective impervious cover by approximately 1% through: Downspout disconnection. Pervious landscaping. Sidewalk and driveway width reduction. Vacant lands management.	All municipalities require and/or encourage these measures using regulatory and/or public education options discussed elsewhere in this section.	All areas.	Long term: 15+ years.

Small changes in site design can lead to a gradual reduction in effective impervious cover that becomes significant over time. When applied consistently, the measures above can result in a 5-10% reduction in areas that are redeveloped. Assuming 10% of the watershed might be redeveloped over the planning horizon, a reduction in effective impervious area of 1% is a reasonable goal. Programs to require or encourage these practices are discussed under the regulatory approaches and public education options (Sections 8.3.1 and 8.3.2, respectively).

Downspout disconnection: In highly urbanized areas of the watershed, it is not always possible to direct runoff to pervious areas, and an informal inspection of lower density areas indicates that many properties are already disconnected. However, a further reduction in directly connected roof leaders from just 10% of residences will result in an effective impervious cover reduction of about 5%.

Pervious Landscaping: When repaving parking lots and loading areas, conversion of 10% of the area in half of parking lots to pervious landscaping (a measure required by some municipalities, including Portland, OR) will decrease watershed effective impervious cover by approximately 0.5%.

Sidewalk and Driveway Width Reduction: Reducing sidewalk and driveway widths by one foot will result in a watershed effective impervious cover reduction of approximately 1%.

Vacant Lands Management: Vacant and abandoned lands in Philadelphia are gradually being acquired and demolished by the City. Proper grading of these sites to encourage infiltration, or addition of small, inexpensive BMPs if needed, can eliminate runoff from these sites during all but the largest storms. Similar techniques can be followed for vacant and abandoned lands in the other municipalities.

Porous Pavement and Subsurface Storage (CS2)

Related Goals: 1, 2, 3, 4, 6, 7
Related Indicators: 1, 10, 11, 16, 19, 20

What	Who	Where	When
Install porous pavement and subsurface storage in 10-50% of parking lots; coverage to be chosen by municipality to meet a share of watershed-wide reduction targets. Route runoff from nearby impervious cover to storage when possible.	Public and private parking lot owners.	See Figure 8.7.	Long-term: 15+ years

As discussed in Section 7.2.3, subsurface storage under parking lots is one of the most feasible and effective ways to create storage and promote infiltration in a highly urbanized environment. Porous pavement is an effective way of directing parking lot runoff to storage, but more conventional inlets or grates are also possibilities. The depth of storage is important. Whenever possible, runoff from nearby impervious areas should be routed into the storage under nearby parking lots. When this is not possible, only a few inches of gravel are needed to store a chosen design storm. Storage designs always include an overflow mechanism for very large storms.

The total parking lot area in the TTF Watershed is estimated at 1039 acres in the combined-sewered portion and 623 acres in the separate-sewered portion. Philadelphia has approximately 75% of parking lot area in the watershed. Other municipalities with large parking lot areas are Cheltenham Township (16%), Abington Township (7%), and Jenkintown Borough (2%). Other municipalities have smaller percentages as listed in Figure 8.8.

Because this BMP is believed to be the most important, an ambitious target is proposed. Begin with demonstration projects on public land. Over the long term, convert 10%-50% of parking lots watershed-wide to porous pavement with subsurface gravel storage.

There are a variety of approaches for implementing porous pavement and other structural BMPs. Regulatory and incentive-based approaches were discussed under low-impact redevelopment (see Option CR2, in Section 8.3.1). Distribution of structural BMPs may also be incorporated in a pollution trading program.

- Install demonstration projects in public parking lots.
- Consider requiring all parking lots to be retrofitted with porous pavement (or other drainage mechanisms) and subsurface storage when they are redone. Private land owners cannot be expected to bear the entire cost of this approach; municipalities should consider funding the additional cost of these changes either directly or through tax incentives.

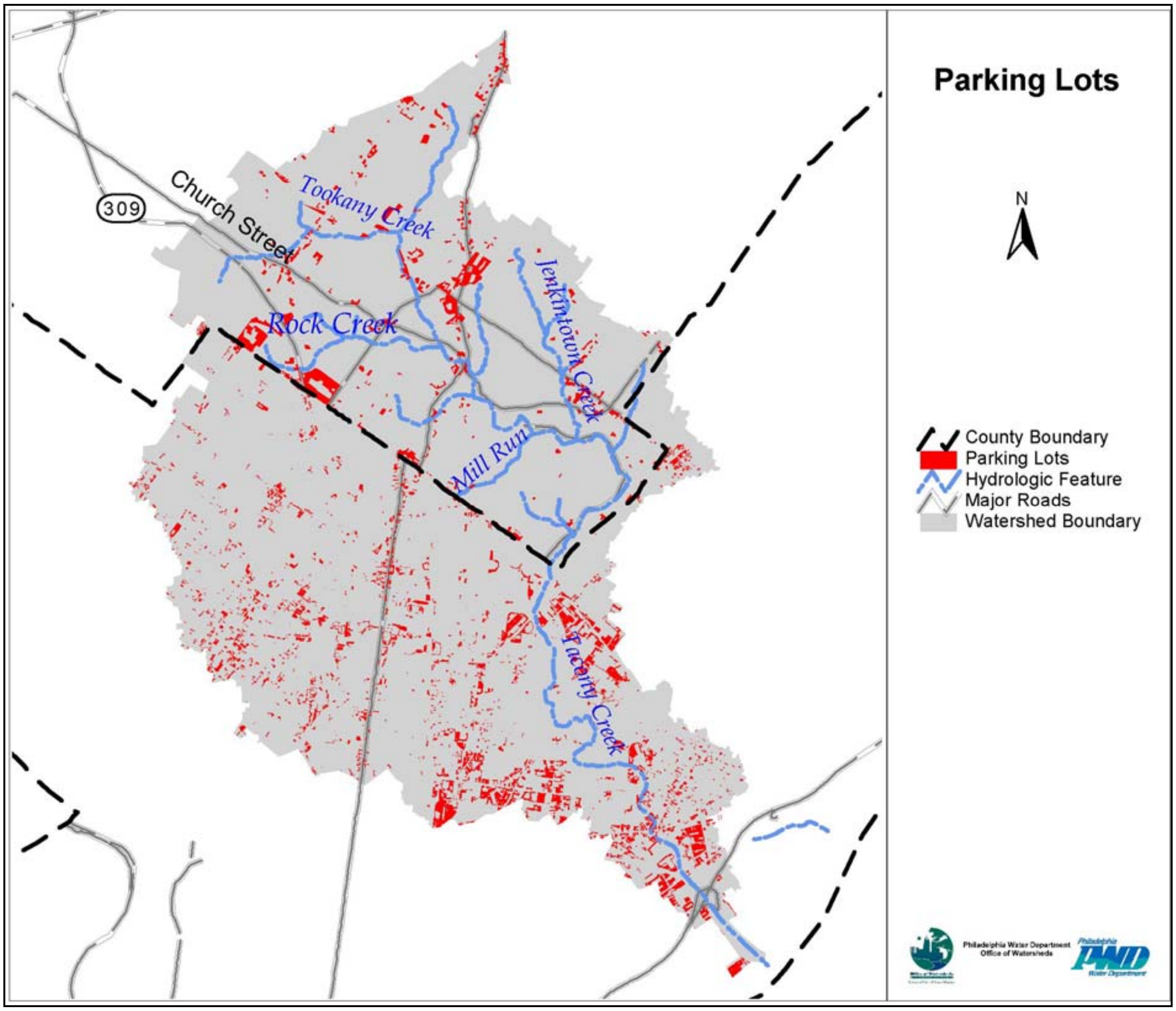


Figure 8.7 Parking Areas in Tookany/Tacony-Frankford Creek Watershed

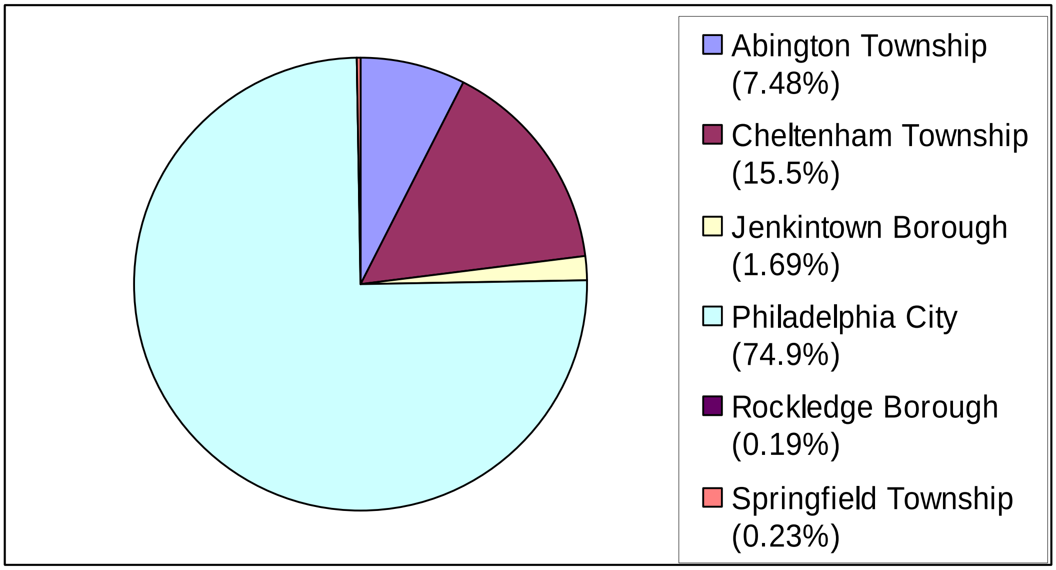


Figure 8.8 Percent of Total Parking Area by Municipality

The River Conservation Plans (RCPs) recommend the following:

- Greenwood Avenue to Wyncote Post Office: If parking lots are renovated, use pervious material to reduce pollutants from washing into creek.

Green Rooftops (CS3)

Related Goals: 1, 2, 4, 6, 7
Related Indicators: 1, 16, 18, 19, 20

What	Who	Where	When
Green rooftop demonstrations. Targeted public information campaign on advantages of green roofs. Feasibility study and green roof implementation plan.	PWD	Appropriate public buildings chosen by PWD.	Medium term: 5-15 years.

The analyses in Section 7.2.3 indicate that green rooftops, while highly effective at detaining and evaporating stormwater, are not currently a cost-effective option for the Tookany/Tacony-Frankford Watershed. However, there is the potential for them to become more cost-effective in the future. As more successful demonstration projects are implemented in the United States, the materials and construction techniques will become more common and the economies of scale will improve. To facilitate this long-term change locally, this plan recommends that Philadelphia take the lead and implement one or more projects on public buildings in the City. Along with this project, we recommend a feasibility study of the potential for a larger-scale green roof program throughout the watershed. The feasibility study will form the basis for future recommendations when this plan is revised. In addition, we recommend a public relations campaign to change the perceptions of citizens, public officials, and contractors.

Capturing Roof Runoff in Rain Barrels or Cisterns (CS4) Related Goals: 1, 2, 4, 6, 7 Related Indicators: 1, 16, 18, 19			
What	Who	Where	When
Install rain barrels on 5 - 25% of homes; coverage to be chosen by municipality to meet a share of watershed-wide reduction targets.	Homeowners through municipal incentive and education programs.	Homes where dry wells are not feasible.	Medium term: 5-15 years.

The Tookany/Tacony-Frankford Watershed Partnership initiated a rain barrel project in 2002, which placed 215 rain barrels at homes throughout the watershed. Rain barrels can be an effective stormwater management tool if they are properly designed and maintained. For detention of residential roof runoff, dry wells are the preferred technique because they have a larger capacity, require no maintenance, and allow more infiltration. Rain barrels are recommended as a secondary technique in areas where dry wells are infeasible. Proper design, including an appropriate slow release, is the responsibility of the municipality or non-profit group leading the rain barrel program. Proper maintenance is accomplished through an intensive public education campaign and series of workshops. An ambitious target is to install rain barrels on 5-25% of homes within a small subshed of "sewershed" area within the watershed in the medium term.

Increasing Urban Tree Canopy (CS5)

Related Goals: 1, 2, 4, 6, 7
Related Indicators: 1, 4, 13, 16, 17, 18, 19, 20

What	Who	Where	When
Increase tree canopy in the watershed from 27% to 32%.	Municipalities (through ordinances, education, and incentive programs affecting land owners).	Private property, parking lots, streets. Parks (riparian corridors under Target B, Section 8.2).	Medium-term (5-15 years).

Tree planting and urban reforestation programs provide hydrologic benefits in addition to quality of life improvements. Leaf surfaces intercept some rainfall that might otherwise fall on impervious surfaces. The rainfall then either evaporates or is conveyed more slowly to the ground along plant stems and trunks. American Forests has assessed tree canopy in the TTF Watershed at 27% (report "Urban Ecosystem Analysis, Delaware Valley Region" available at www.americanforests.org). American Forests recommends the following levels of tree canopy coverage for urban watersheds:

- 40% overall
- 50% in suburban residential zones
- 25% in urban residential zones
- 15% in central business districts

A goal of increasing tree canopy by 5% of the watershed over the medium term was selected as a feasible implementation level. Several regulatory and incentive-based strategies to achieve these goals are listed below. (Also see Option CR2 in Section 8.3.1 on Regulatory Approaches.)

- Requirements to protect existing trees on private property, or creation of "tree banks" to offset loss.
- Tree credits for redevelopers as part of impervious cover requirements or incentives. The City of Portland, Oregon has given developers an impervious cover credit equal to 25% of tree canopy over impervious area.
- Parking lot landscaping or shade requirements.
- Reforestation in parks and along the stream corridor.
- Increases in the number of trees along public streets and on vacant lots. The City of Philadelphia is taking this approach as part of its Green City Strategy.

Tree canopy over an additional 5% of impervious cover will result in an effective impervious cover reduction of approximately 2% over the watershed.

Municipalities with tree related ordinances are shown in Table 8.20.

Table 8.20 Landscape and Tree Related Ordinances

Municipality	Landscaping	Shade Tree/ Street Trees	Wooded Lots*	Tree Advisory Commission	Comments
Abington Township	X	X	X		Buffer areas; tree-planting requirements (streets/parking lots); open space standards/preservation.
Cheltenham Township		X	X	X	Buffer areas; green areas; Tree Commission regulations; Preservation Overlay District.
Jenkintown Borough		X		X	Shade tree-planting desirable along streets; Tree Commission regulations.
Philadelphia County	X	X		X	Fairmount Park Commission regulations; required tree/landscaping ratios in certain residential districts.
Rockledge Borough	X	X			Residential landscaping/buffer area requirements; parking buffer areas for Institutional District; common open space preservation.

Source*:** www.ordinance.com, ***Delaware Valley Regional Planning Commission

* Note: "Wooded Lots" refers to any ordinance directly involving the preservation of open space/undisturbed natural areas. Most of the municipality ordinances included the intention of open space preservation under general goals.

Forming a tree commission is one way of implementing an urban forestry program in Pennsylvania. The powers and responsibilities of a tree commission are based on state statute and are assumed by local government. By forming and empowering a tree commission, a community can empower and motivate volunteers to run an effective urban forestry program. Tree commissions are either advisory or administrative and may have various responsibilities, including the following:

- Advise community leaders and staff on administering the community forest.
- Stimulate and organize tree planting and maintenance.
- Develop and implement urban forest inventories, management plans, and ordinances.
- Lessen liability by arranging to remove hazardous trees and repair damage caused by trees.

In Pennsylvania, a tree commission created by municipal ordinance as a decision-making body has exclusive control over a community's shade trees. No tree can be planted or removed within the public right-of-way except under the auspices of the tree commission. This includes public trees that may be planted or removed in conjunction with subdivisions or approved development plans. Tree commissions can be given additional power within a municipality by a council, including:

- Control over all public trees such as trees within community parks.
- Review and approval of landscaping proposed in development plans.

The formation and empowerment of a tree commission can be a crucial element in developing broad-based support for community trees and ensuring long-term success and continuance of a community forestry program. (For more information, contact the Extension Urban Forestry Program, School of Forest Resources, The Pennsylvania State University, 108 Ferguson, University Park, PA 16802, or call 814-863-7941.)

Onsite and Regional Stormwater Control Facilities

Maintaining/Retrofitting Existing Stormwater Structures (CS6)

Related Goals: 1, 2, 3, 4, 5, 7
Related Indicators: 4, 11, 15, 19

What	Who	Where	When
Inventory structures. Assess potential for increased infiltration.	Municipalities.	Entire watershed.	Short term (within 5 years).

PWD performed an inventory of existing privately owned stormwater control basins in 2000. The results of this study indicate seven confirmed structures within the Philadelphia portion of the watershed. Other municipalities are asked to inventory and inspect existing stormwater control structures. Although this is not an explicit requirement of the Act 167 program, it is a reasonable task to include within the Act 167 framework. Older dry and wet detention basins may have been designed to reduce flood peaks but not to facilitate infiltration; this approach helps prevent property damage but may actually increase stream erosion. In some cases, it may be possible to retrofit these older basins to allow infiltration. Specific guidance on retention times and design recommendations will be included in the Act 167 Plan.

Retrofitting Existing Sewer Inlets with Dry Wells (CS8)

Related Goals: 3, 5, 7
Related Indicators: 11, 15, 19

What	Who	Where	When
Retrofit 5 - 100% of existing stormwater catch basins in the combined sewered area to provide storage and allow infiltration.	PWD	5 - 10% of existing inlets in combined-sewered areas.	Long-term: 15+ years.

As discussed in Section 7 (especially Section 7.2.3), retrofitting existing sewer inlets with dry wells is an expensive but effective measure in combined-sewered areas. Each inlet provides small amounts of storage and detention; distributed over a significant area, these measures reduce the number and duration of overflows.

During the first permit cycle that this plan is in effect, inlets that are being repaired or replaced can be retrofitted at the same time. If, after the first five years, the program is not on track to affect the targeted number of inlets in 15 years, existing inlets in good condition may be retrofitted.

Residential Dry Wells, Seepage Trenches, and Rain Gardens (CS9)

Related Goals: 1, 2, 3, 4, 5, 6, 7
Related Indicators: 1, 11, 15, 16, 17, 19

What	Who	Where	When
Install dry wells in 5-10% of residential yards; coverage to be chosen by municipality to meet a share of watershed-wide reduction targets. Install water gardens on school grounds.	Municipalities. School boards.	Dry wells throughout watershed. Water gardens in school yards with enough space.	Long term: 15+ years.

Routing residential roof runoff to dry wells is recommended as a priority control for the Tookany/Tacony-Frankford Watershed. Dry wells are cost-effective, can potentially affect a large portion of impervious cover, and require virtually no maintenance. They are clearly applicable in the lower density residential areas but can also be installed in some higher density areas; only a small lawn area is necessary. A properly sited and designed dry well will not cause basement flooding. Where soil conditions are insufficient to infiltrate all roof runoff, excess flows can be routed to a combined or sanitary sewer. Because dry wells are a priority control, they are recommended for implementation in the yards of 5%-10% of all homes in the watershed.

Rain gardens are recommended for implementation on school grounds, where they can both promote infiltration and educate students about stormwater management.

The River Conservation Plans (RCPs) recommend the following:

- High School Park to Ashbourne Road along the Tookany Creek Parkway: Incorporate stormwater infiltration devices.
- Rock Creek Watershed: Incorporate stormwater infiltration devices especially in commercial areas.

Bioretention Basins and Porous Media Filtration (CS12)

Related Goals: 1, 2, 3, 4, 5, 7
Related Indicators: 1, 7, 8, 9, 15, 19, 20

What	Who	Where	When
Install bioretention and/or sand filters in 10-50% of parking lots; coverage to be chosen by municipality to meet a share of watershed-wide reduction targets.	Public and private parking lot owners.	Everywhere in watershed.	Long-term: 15+ years. Focus on redevelopment.

The screening and detailed evaluation analyses in Section 7 targeted parking lot runoff for widespread implementation of BMPs. The preferred approach for parking lots is to route runoff to subsurface gravel storage through porous pavement, inlets, or grates. However, there will be cases where that approach is not feasible. The second preferred alternative is to direct parking lot runoff to a bioretention basin and/or a porous media filter. These systems infiltrate smaller storms completely, detain larger storms, and provide effective water quality treatment in separate sewered areas. 10-50% of parking lots are targeted for retrofit with bioretention. Over the long term, it is the goal to retrofit as many parking lots as possible with either subsurface storage or bioretention. However, private land owners should not necessarily be expected to bear the entire cost of this approach; municipalities should consider funding the additional cost of these changes either directly or through tax incentives.

The River Conservation Plans (RCPs) recommend the following:

- <u>Holy Sepulchre Cemetery to Ralph Morgan Park</u>: Incorporate stormwater filtration devices.
- <u>Abington Country Club to Township Line Road</u>: The stormwater management facilities for the parking lots should be examined to see if BMPs are being used to help reduce runoff.

Treatment Wetlands: Onsite and Regional (CS13)

Related Goals: 1, 2, 3, 4, 7
Related Indicators: 1, 10, 11, 13, 19

What	Who	Where	When
Create or enhance wetlands to treat as much runoff as possible in Philadelphia and Montgomery County.	Municipalities.	See Figure 8.4 for proposed sites.	Medium term: 5-15 years.

Wetland creation and enhancement has benefits in terms of habitat, water quality, and water quantity. These benefits as well as proposed sites are discussed extensively under Option BM6, in Section 8.2.3.

8.3.5 Monitoring and Reporting

Monitoring, Reporting, and Further Study (CMR)

Related Goals: 7
Related Indicators: 16, 17, 19

What	Who	Where	When
Monitoring of implementation and benefits for all Target C options.	City of Philadelphia and Municipalities.	Watershed-wide.	Annually beginning after the first year of implementation is initiated

The preceding are a series of implementation options identified as initial measures geared toward meeting Target C. This Target will be more difficult to achieve than Targets A and B as it entails meeting all water quality standards during wet weather, as well as eliminating all flooding. Based on the extensive modeling analysis carried out for Tookany/Tacony-Frankford Creek to date, an initial goal of a 20-25% reduction in stormwater flows and stormwater/CSO related pollutant loads has been identified as a challenging but achievable goal.

The suggested approach to full achievement of Target C goals is through the use of adaptive management while utilizing stepped implementation with interim targets for reducing wet weather pollutant loads and stormwater flows. During implementation, monitoring must continuously assess the effectiveness of the program. Based on monitoring results of each option, recommendations will be made for future implementation. It is expected that changes to the approach, or potentially even to the desired results, will occur as measures are implemented monitored.

Section 9
Cost and Institutional Analysis

This section presents cost estimates for the various recommended "management options," and for the full set of Implementation Guidelines (from Section 8). Those cost estimates are then broken down by county and by municipality within the TTF Watershed. Finally, the section outlines the primary roles and responsibilities for the various levels of stakeholders in the implementation of the TTFIWMP.

9.1 Estimated Cost of Implementation

Planning-level costs have been developed for many of the recommended options. Because costs are highly dependent on site specific conditions as well as the extent to which implementation occurs, costs included in this section are only approximate. These costs are useful, however, in providing order of magnitude funding needs, and also as a comparison to potential costs associated with more traditional approaches to CSO control, such as large scale storage tanks designed to reach the 85% capture goal. Planning level costs are provided for each of the options discussed under the three Targets.

The combination of structural BMPs and implementation percentages in this section are suggested as a feasible plan that will equal or exceed the 20% discharge reduction target. The exact combination of BMPs implemented in each area of the watershed will be determined by local municipalities or by a government or institutional body to be chosen at a later time.

Order-of-magnitude, planning-level cost estimates are shown in Tables 9.1 through 9.4. For structural stormwater BMPs, cost estimates are based on an assumed "feasible implementation" percentage shown in Table 7.5 (in Section 7.2.3) and also Table 8.13 (Section 8.3).

Table 9.1 Planning-Level Cost Estimates for Target A Options

	Total		Philadelphia		Montgomery County	
	Annual Cost	**One-Time**	**Annual Cost**	**One-Time**	**Annual Cost**	**One-Time**
Regulatory Approaches						
AR1 On-Lot Disposal (Septic System) Management	$50,000				$50,000	
AR2 Pet Waste, Litter, and Dumping Ordinances[1]						
Public Education and Volunteer Programs (AP1-3)	$1,005,000		$814,044		$190,644	
Municipal Measures						
AM1-4 Sewer Evaluation, Cleaning, and Rehabilitation[2]	$909,000	$41,121,000	$455,000	$20,592,000	$454,000	$20,529,000
AM5 Illicit Discharge, Detection, and Elimination (IDD&E)		$6,022,000				$6,022,000
AM6 Stream Cleanup and Maintenance	$107,000	$96,000	$24,000	$21,000	$83,000	$75,000
AO1 Enhancing Stream Corridor Recreational and Cultural Resources[1]						
AMR Monitoring, Reporting, and Further Study[3]	$17,000		$17,000			
Total Cost for Target A Options	$2,088,000	$47,239,000	$1,310,044	$20,613,000	$777,644	$26,626,000
Cost per acre for Target A Options	$99	$2,246	$108	$1,693	$88	$3,008

1 - Already in place in most locations, or costs difficult to quantify.

2 - Includes CMOM, NMCs, inspection and cleaning, and rehabilitation of combined and sanitary sewers.

3 - Field monitoring cost.

Table 9.2 Planning-level Costs for Target B Options

	Total		Philadelphia		Montgomery County	
	Annual Cost	**One-Time**	**Annual Cost**	**One-Time**	**Other Counties**	**One-Time**
Channel Stability and Aquatic Habitat Restoration						
BM1 Bed Stabilization and Habitat Restoration[1]	$3,000	$8,131,000	$1,000	$4,066,000	$1,000	$4,066,000
BM2 Bank Stabilization and Habitat Restoration[1]	$3,000	$8,131,000	$1,000	$4,066,000	$1,000	$4,066,000
BM3 Channel Realignment and Relocation[1]	$3,000	$8,131,000	$1,000	$4,066,000	$1,000	$4,066,000
BM4 Plunge Pool Removal[2]						
BM5 Improvement of Fish Passage[3]						
Lowland and Upland Restoration and Enhancement						
BM6 Wetland Creation and Enhancement[2]						
BM7 Invasive Species Management[2]						
BM8 Biofiltration[2]						
BM9 Reforestation[4]						
BMR Monitoring, Reporting, and Further Study[5]	$17,000		$17,000			
Total Cost for Target B Options	$26,000	$24,393,000	$20,000	$12,198,000	$3,000	$12,198,000
Cost per acre for Target B Options	$1.2	$1,160	$1.6	$1,002	$0.3	$1,378

1 - Based on restoration of high-priority reaches at $700/ft. If actual cost is lower, medium priority reaches may also be restored.

2 - Cost considered under options BM1, BM2, and BM3.

3 - Not evaluated; recommended as a longer-term option.

4 - Cost included in Target V urban tree canopy cost.

5 - Field monitoring cost.

Table 9.3 Planning-level Costs for Target C Options

	Total		Philadelphia		Montgomery County	
	Annual Cost	**One-Time**	**Annual Cost**	**One-Time**	**Annual Cost**	**One-Time**
Regulatory Approaches						
CR2 Requiring Better Site Design in Redevelopment[1]		$300,000		$100,000		$200,000
CR3, CR6 Stormwater and Floodplain Management[1]		$300,000		$100,000		$200,000
CR4 Industrial Stormwater Pollution Prevention[2]						
CR5 Construction Stormwater Pollution Prevention[2]						
Municipal Measures						
CM1 Sanitary Sewer Overflow Detection[3]						
CM2 Sanitary Sewer Overflow Elimination: Structural Measures[3]						
CM3 Reduction of Stormwater Inflow and Infiltration to Sanitary Sewers[3]						
CM4 Combined Sewer Overflow (CSO) Control Program[4]		$2,400,000		$2,400,000		
CM5 Catch Basin and Storm Inlet Maintenance	$816,000		$545,000		$271,000	
CM6 Street Sweeping	$135,000		$45,000		$90,000	
CM7 Responsible Landscaping Practices on Public Lands[2]						
CM9 Responsible Bridge and Roadway Maintenance[2]						

1 - Estimated cost for ordinance development.

2 - Already in place in most locations, or costs difficult to quantify.

3 - Cost included in options AM1-5.

4 - Includes real time control cost only; other aspects of program included in options AM1-5.

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Table 9.3 Planning-level Costs for Target C Options (continued)

	Total		**Philadelphia**		**Montgomery County**	
	Annual Cost	**One-Time**	**Annual Cost**	**One-Time**	**Annual Cost**	**One-Time**
Stormwater Management						
Source Control Measures						
CS1 Reducing Effective Impervious Cover Through Better Site Design[5]						
CS2 Porous Pavement and Subsurface Storage[5]		$30,689,000		$10,985,000		$19,705,000
CS3 Green Rooftops[5]	$100,000	$1,000,000	$100,000	$1,000,000		
CS4 Rain Barrels and Cisterns[5]		$622,000		$424,000		$199,000
CS5 Increasing Urban Tree Canopy[5]	$2,000,000	$20,000,000	$1,000,000	$10,000,000	$1,000,000	$10,000,000
Onsite and Regional Stormwater Control Facilities						
CS6 Maintaining/Retrofitting Existing Stormwater Structures[5]	$140,000	$14,000	$70,000	$7,000	$70,000	$7,000
CS8 Retrofitting Existing Sewer Inlets with Dry Wells[5]		$454,000		$454,000		
CS9 Residential Dry Wells and Rain Gardens[5]		$8,476,000		$5,346,000		$3,130,000
CS12 Bioretention and Porous Media Filtration[5]		$7,910,000		$2,831,000		$5,079,000
CS13 Treatment Wetlands: Onsite and Regional[5]	$850,000	$4,562,000	$425,000	$2,281,000	$425,000	$2,281,000
Use Review and Attainability Analysis		$100,000		$100,000		
CMR Monitoring, Reporting, and Further Study	$17,000		$17,000			
Total Cost for Target C Options	$4,058,000	$76,827,000	$2,202,000	$36,028,000	$1,856,000	$40,801,000
Cost per acre for Target C Options	$193	$3,653	$181	$2,958	$210	$4,610

1 - Estimated cost for ordinance development.

2 - Already in place in most locations, or costs difficult to quantify.

3 - Cost included in options AM1-5.

4 - Includes real time control cost only; other aspects of program included in options AM1-5.

5 - Implementation levels taken from Section 8, Implementation Guidelines.

Table 9.4 Total Watershed Plan Cost

Total		Philadelphia		Montgomery County	
Annual Cost	One-Time	Annual Cost	One-Time	Annual Cost	One-Time
$6,172,000	$148,459,000	$3,532,000	$68,839,000	$2,637,000	$79,625,000
$290/ac	$7,060/ac	$290/ac	$5,650/ac	$300/ac	$9,000/ac

9.2 Distribution of Costs by Political Boundary

In addition to total estimated costs associated with the TTFIWMP, it is useful to express the costs on an annual basis and in the context of acreage and number of households affected. Presenting costs this way allows comparison to existing wastewater infrastructure-related costs supported by users and taxpayers. Those cost estimates are presented by county and by municipality, below.

9.2.1 Distribution of Costs by County

Table 9.5 compares projected costs on a per-acre basis and per-household basis in the City of Philadelphia and outside the City of Philadelphia. The table shows costs on an annual basis, using a 20-year period to pay off the capital costs. Philadelphia pays approximately 50% of the total annual cost (line 3), while representing approximately 60% of the watershed area. On a per-acre basis, costs within Philadelphia are approximately 70% of costs outside the City. This difference occurs because of the greater land area and length of stream outside Philadelphia. (An illustrative distribution of costs among municipalities in the watershed is shown in Section 9.2.2.)

Table 9.5 Affordability Impact by County

	Philadelphia	**Montgomery County**
(1) One-Time Cost (Annualized)	$3,338,000	$3,875,000
(2) Annual Cost	$2,598,733	$2,268,386
(3) Total Annual Cost Associated with WMP	$5,936,733	$6,143,386
(4) Cost per acre in watershed	$487	$694
(5) 2000 Median Household Income	$30,746	$59,621
(6) Estimated Annual Sewer User Charge*	$343	$250
(7) WMP cost per household in watershed (in entire municipalities)	$52.53 ($10.06)	$258.93 ($157.00)
(8) WMP cost as % of mean household income in watershed (in entire municipalities)	0.17% (0.03%)	0.43% (0.26%)
(9) Existing sewer cost + WMP cost in watershed (entire municipalities)	1.59% (1.15%)	0.62% (0.46%)

* *The sewer user charge in Philadelphia includes a stormwater collection and treatment fee. Stormwater-related charges outside Philadelphia were not investigated.*

In addition to showing costs per unit area, it is useful to express costs on a per-household basis. Line 7 in Table 9.5 expresses cost per household, assuming only households inside the watershed boundaries would be required to pay. This comparison is made because improvements occur, and citizens benefit, primarily within the watershed boundaries. Expressed in this manner, the cost is greater for households outside Philadelphia (line 7, outside parentheses); because of greater population density within the urban watershed, there are more households to distribute the cost among inside the City. Line 8 of Table 9.5 expresses the per-household cost inside the watershed boundary as a percentage of mean household income (line 8, outside parentheses).

While expressing costs in terms of households inside the watershed boundary allows direct comparison between communities, it is also useful to express costs on the basis of all households within the boundaries of municipalities that intersect the watershed. Currently, most funding and institutional mechanisms occur on a municipal basis. For example, a given township may use a percentage of all water and sewer bills paid to finance improvements related to the TTFIWMP, including bills paid by households outside the TTF watershed boundary.

The numbers in parentheses on lines 7 through 9 of Table 9.5 present the costs in terms of all residents of municipalities intersecting the watershed. These costs are lowest in Philadelphia because it has the greatest number of households; all households paying sewer bills will pay approximately 0.03% of household income to support the TTFIWMP, compared to 0.26% for the remaining communities. Compared to the other municipalities, Philadelphia has many more households to spread the cost of the TTFIWMP over, but will ultimately have additional watersheds that will require management activities. Over time and on a regional basis, watershed management costs are expected to approach 0.3% to 0.5% of mean household income within affected communities.

The costs associated with the TTFIWMP are generally incremental to existing maintenance and management activities associated with water-related infrastructure. Therefore, it is useful to add the TTFIWMP cost to current wastewater charges paid by households to obtain an approximate measure of the total annual cost of watershed and water-related infrastructure management. These costs, shown in the final line of Table 9.5, range from approximately 0.6% to 1.6% of mean household income regionally.

9.2.2 Distribution of Costs by Municipality

Tables 9.6 and 9.7, below, provide data to assist communities in placing projected TTFIWMP costs in a local context. Table 9.6 expresses estimated costs for communities per acre and per household inside the watershed boundaries; Table 9.7 presents costs within the boundaries of all municipalities that intersect the watershed. For the purposes of this illustrative example of cost distribution, general, watershed-related costs for communities outside of Philadelphia are apportioned according to the percentage of the watershed area within each municipality's jurisdiction.

These cost tables are but one illustration of a possible cost distribution, and are provided to aid municipalities in deciding what funding and institutional mechanisms may be most appropriate given local conditions.

Table 9.6 Affordability Impact by Municipality – Rate Payers in TTF Watershed

	Abington	Cheltenham	Jenkintown	Philadelphia	Rockledge
Municipality area in watershed (ac)	2,712	5,691	367	12,178	81
Area of municipality in watershed (% of municipality total)	27%	98%	99%	13%	37%
Households in municipality and watershed	7,147	14,218	2,013	113,022	348
Annual cost associated with TTFWMP	$807,899	$1,695,749	$109,277	$3,532,000	$24,075
Cost per acre (within watershed)	$297.95	$297.95	$297.95	$290.03	$297.95
Cost per household (within watershed)	$113.04	$119.27	$54.29	$31.25	$69.18
Median household income ($/year)	$59,921	$61,713	$47,743	$30,746	$47,958
Cost per household (% of MHI)	0.19%	0.19%	0.11%	0.10%	0.14%

Table 9.7 Affordability Impact by Municipality – All Rate Payers in Municipality

	Abington	Cheltenham	Jenkintown	Philadelphia	Rockledge
Municipality area (ac)	9,893	5,779	369	91,287	219
Watershed area in municipality (ac)	2,712	5,691	367	12,178	81
Watershed area in municipality (% of watershed total)	12.9%	27.1%	1.7%	57.9%	0.4%
Households in municipality	21,690	14,346	2,035	590,071	1,060
Annual cost associated with TTFIWMP	$807,899	$1,695,749	$109,277	$3,532,000	$24,075
Cost per acre (whole municipality)	$81.66	$293.42	$296.36	$38.69	$109.91
Cost per household (whole municipality)	$37.25	$118.20	$53.70	$5.99	$22.71
Median household income ($/year)	$59,921	$61,713	$47,743	$30,746	$47,958
Cost per household (% of MHI)	0.06%	0.19%	0.11%	0.02%	0.05%

9.3 Institutional Analysis

The primary purpose of Section 9 of this plan is to provide recommendations and guidance to stakeholders - primarily state, county, and other government agencies, municipalities, non-government organizations, land owners, and individuals - on ways to better manage the water resources of Tookany/Tacony-Frankford Creek. Everyone in the watershed communities can contribute in numerous ways to the protection of water resources.

Both government and non-government organizations will play a role in the successful implementation of the Tookany/Tacony-Frankford Integrated Watershed Management Plan. The primary roles are outlined below.

9.3.1 PA DEP Role

Two agencies of the Commonwealth of Pennsylvania are directly and indirectly involved in watershed planning in the TTF Watershed: the Department of Environmental Protection (PA DEP) and the Department of Conservation and Natural Resources (DCNR). Achievement of Watershed Plan goals through local implementation will require continued support through funding and integration of the various existing state level stormwater management and runoff related programs. Particular attention should be paid to the following programs:

- Act 167 Plans
- Phase II Stormwater permits
- Act 537 / CMOM Plans
- Construction Stormwater Pollution Prevention
- Industrial Stormwater Pollution Prevention
- Watershed monitoring and performance reporting
- Watershed permitting opportunities

A critical PA DEP role will be activities required under Section 303(d) of the Clean Water Act and the EPA's Water Quality Planning and Management Regulations (40 CFR Part 130). PA DEP will need to actively administer the water quality standards process for portions of the Tookany/Tacony-Frankford Creek in the near future. PA DEP should be active in encouraging municipalities to carry out the requirements of Phase II stormwater permits and Act 167 requirements. This plan provides the blueprint for effectively integrating both programs, and addressing water quantity and quality goals.

9.3.2 PWD Role

PWD, as the primary author of this plan, plays a central role in its implementation, as well as in continued monitoring to chart improvements to water quality. PWD will take a lead role in implementing a variety of the recommendations, including;

- Stream restoration
- Improvement of fish passage
- CSO Control

- Green rooftop demonstrations
- Stormwater BMP installation
- Organization of stakeholder participation
- Monitoring

9.3.3 Municipal Role

Municipalities can play a key role in the implementation of recommendations through the incorporation of water resource strategies into their land use planning and governance functions. Because of the authorities contained in the Pennsylvania Municipalities Planning Code (MPC), municipalities are one of the two main foci of implementation efforts (PWD being the other). Enabled by the MPC, municipalities are the focal point to address runoff from redeveloped and existing developed lands, to address problems associated with sanitary sewer collection systems, to enhance recreational opportunities, and to protect natural resources from the effects of land disturbance.

The most fundamental roles recommended for municipalities are to consider undertaking a comprehensive review of their existing land use regulations, policies, and requirements to identify where they may be unnecessarily causing impacts to water resources, and to undertake the necessary actions needed to eliminate SSOs and sanitary sewer leaks.

The primary actions recommended for municipalities include: encouraging disconnection of roof leaders from storm sewers, reduction of expansive paved (impervious) parking lot requirements and replacement of asphalt with porous paving surfaces or the installation of bioretention structures to handle parking lot stormwater runoff, repair and maintenance of leaking sanitary sewers, and the elimination of SSOs. Municipalities also might consider creating an Environmental Advisory Council (EAC), which is possible under Pennsylvania General Assembly enabling legislation - Act 148 of 1973. The EAC could then participate in the implementation of the plan, and help to coordinate the approach among all the municipalities within the watershed.

9.3.4 County Role

An important role of Montgomery County is to conduct the necessary comprehensive stormwater management studies to:

- Complete an Act 167 stormwater plan that is consistent with and furthers the achievement of the goals and objectives of the TTFIWMP.
- Work with municipalities to update Act 537 plans.

In addition, the Montgomery County Conservation District has several important responsibilities within the watershed, including:

- Chapter 102 Erosion Control: Administer the State's program to control sediment pollution from earth disturbance activities.
- National Pollution Discharge Elimination System (NPDES): Process applications and seek compliance towards stormwater discharge permits for Construction Activities.

- Chapter 105 Waterways and Wetlands General Permitting: Assist applicants with permit information. Process general permits for work within wetlands and streams.

These are important elements in coordinating Act 167 planning requirements with Phase II of the NPDES Stormwater Program.

9.3.5 Non-Government Organization Role

The Tookany/Tacony-Frankford Watershed Partnership will be critical to the successful implementation of the TTFIWMP. As noted in the introduction to Section 9, this newly incorporated watershed organization has formed with the purpose of implementing the recommendations of the TTFIWMP. With representatives of the two counties, several municipalities, and various non-profit organizations making up the Board of Directors of this organization, the vehicle for coordination and collaboration now exists.

Some of the primary functions of the newly formed organization could include:

- Creating a watershed-wide implementation plan and receiving approval from watershed municipalities. This approval includes obtaining signatures from municipalities followed by a letter of support from PA DEP.
- Overseeing the continued implementation of basic, essential services required of all municipalities by stormwater permits (e.g., sewer system maintenance).
- Overseeing continued monitoring, sampling, data analysis, and reporting on both the water quality and biology of the system using the established indicators.
- Providing public participation and public education opportunities (both workshops and other types of participatory programs).
- Exploring innovative solutions to long-term operation and maintenance of stormwater management facilities.
- Requiring that projects within the watershed area applying for state funding (Growing Greener, DCNR) must be reviewed and shown to be consistent with the TTFIWMP. The organization would review all submitted projects and apply a rating scale for consistency with the plan.
- Encouraging the idea of applying for federal funding for regional projects (e.g., stream restoration, regional wetlands); however, most smaller-scale projects would be funded locally. Public funding for major infrastructure projects on private land could be explored.

Another role for the new organization would be created if the State sets up a watershed-based permitting experiment in the watershed. The organization could then function as a Watershed Compliance Association (WCA). A WCA is a Commonwealth-created non-profit entity comprised of public and private entities that hold individual NPDES permits or General Permits to discharge to the creeks. A WCA is specifically created to implement watershed based permitting. The WCA would constitute a point of contact between PA DEP and its co-permittee members on issues related to the group permit for the parameter(s) of concern, once a TMDL is established in the watershed. If the WCA exceeds its parameter limit (load) for the year, the

Association would be out of compliance, and any co-permittee member that exceeds its individual load limit would also be out of compliance and subject to enforcement action. Through the group approach, however, pollution trading can be easily implemented.

9.3.6 Land Owners' Role

Voluntary watershed stewardship by all land owners can contribute significantly toward the protection and restoration of the Tookany/Tacony-Frankford Watershed while simultaneously minimizing the need for additional regulatory controls. Recommended roles for land owners include:

- Implementing "watershed stewardship" practices in their landscape and outdoor housekeeping practices.
- Disconnecting roof leaders and installing rain barrels or dry wells.
- Considering pervious solutions for driveways.
- Joining and supporting the activities of the TTF Watershed Partnership.

Appendix A: Glossary of Terms

Acute	Describing an effect or response, such as toxicity, that is measured or occurs over a relatively short amount of time; not chronic.
Adaptive management	Process of continually monitoring progress and adjusting the approach.
Algae	Any of a number of several groups of single-celled or multi-cellular organisms, all of which lack leaves, roots, flowers, and other organ structures that characterize higher plants.
Ammonia/ Ammonium	A Nitrogen-containing molecule that exists naturally in both gaseous (NH3) and ionized (NH_4+) forms. The gaseous form is corrosive and toxic, while the ionized form is a usable source of nitrogen for plant growth. Ammonia may be produced by decomposition of nitrogen-containing molecules such as proteins.
Anthropogenic	Man-made or human in origin; influenced by mankind.
Aquatic	Relating to water, particularly freshwater.
Aquifer	An underground geologic feature containing water.
Autotroph/ Autotrophic	Describing organisms that can produce their own food, such as plants, algae or certain specialized bacteria.
Bankfull discharge	The high flow stage of a fluvial system distinguished by the highest stage elevation a stream can reach before spilling over.
Baseflow	Flow in a stream that is not influenced by precipitation.
Basic	Alkaline; containing oxide or hydroxyl ions; not acidic.
Benthic	Used to describe aquatic organisms living at the bottom of a body of water.
Benthic macroinvertebrates	Aquatic insect larvae that live on stream bottom. Because of a short lifespan and relative immobility, they reflect the chemical and physical characteristics of a stream and chronic sources of pollution.
Bioassessment	An evaluation technique that uses measures of the structure, condition, or distribution of biological communities.
Bioindicator	An organism that exhibits sensitivity or tolerance of environmental conditions and may be used in assessing an environmental condition, such as water pollution.

Biotic	Living, relating to life or biology.
BMP	Best Management Practice – Also called a "management option," a BMP is a technique, measure, or structural control that addresses one or more objectives (e.g., a detention basin that gets built, an ordinance that gets passed, and an educational program that gets implemented).
BOD	Biological or biochemical oxygen demand, an empirical test procedure that measures the ability of a water sample to deplete oxygen.
Cadmium (Cd)	A toxic heavy metal element.
Calcium (Ca)	A metallic element found in limestone and numerous naturally occurring compounds.
$CaCO_3$	Calcium carbonate
CCD	County Conservation District
CCTV	Closed Circuit Television
Channelization	The process of modifying the natural course of a stream in order to make it flow into or along a restricted path.
Chlorophyll	Any of a group of green pigments necessary for photosynthesis, concentrations of which are used as a surrogate measurement of producer biomass.
Chl-*a*	Chlorophyll-α, a form of chlorophyll that is found universally in autotrophic organisms.
Chromium (Cr)	A heavy metal element, occurring naturally in trivalent [CrIII] and hexavalent [CrIV] forms. The latter form is highly toxic.
Chronic	Describing an effect or response, such as toxicity, that occurs or can be measured over a relatively long period of time; not acute.
Clay	Inorganic sediment particles smaller than 0.002 mm.
CO_3^{2-}	Carbonate ion
Cobble	A stream particle with diameter between 64 and 256 mm.
Coliform	Of or relating to the bacilli (bacteria) that inhabit the intestines of warm-blooded animals.
Conductance/ Conductivity	A measure of the ability of a water sample to conduct an electric current; a measure of dissolved ionic strength.

Copper	An essential metallic nutrient that can be toxic in relatively small concentrations.
Criterion	An established standard, such as concentration of a pollutant, that is limited or regulated by law.
CSO	Combined Sewer Overflow
CSS	Combined Sewer System
Culvert	A metal, concrete, or plastic pipe that allows water to flow under a road or any other obstruction.
CWA	Clean Water Act – Federal Amendment that authorizes EPA to implement pollution control programs and set water quality standards for all contaminants in surface waters. "The Act made it unlawful for any person to discharge any pollutant from a point source into navigable waters, unless a permit was obtained under its provisions. It also funded the construction of sewage treatment plants under the construction grants program and recognized the need for planning to address the critical problems posed by nonpoint source pollution." (EPA website)
CWA Section 104(b)(3) Program	Promotes the coordination and acceleration of research, investigations, experiments, training, demonstrations, surveys, and studies relating to the causes, effects, extent, prevention, reduction and elimination of pollution.
CWA Section 208 Wastewater Planning	Intended to encourage and facilitate the development and implementation of area-wide waste treatment management plans.
CWA Section 319(b) Non-point Source Management Program	Designed to address mine drainage, agricultural runoff, construction/urban runoff, hydrologic and habitat modifications, on-lot wastewater systems, and silviculture.
DCIA	Directly Connected Impervious Area
Decomposition	Decay; process through which a complex substance, such as dead organic matter, is broken down into smaller molecules.
Defective lateral	A plumbing problem in which a lateral pipe is damaged, potentially leading to sanitary waste in a storm sewer and the receiving water body.
Designation/ Designated Use	Describing the uses a waterbody is intended to support, such as stocking trout for recreational fishing.

Diatom	Single-celled algae of the class bacillariophyceae, having a cell wall composed of silica. Diatoms are primary producers in streams and lakes.
Diffusion	Spontaneous, random movement of molecules that tends to result in equalization of concentrations over time as net movement occurs from areas of greater concentration to areas of lower concentration.
Diluent/Dilutant	A thinning agent, such as water, which reduces the concentration of a solution. Pollution may be diluted by streamwater.
Dilute/Dilution	The process through which a solution is made less concentrated through the addition of a diluent/dilutant.
Discharge	Flow; a measure of the volume of water flowing through a defined area in a given time. Discharge is often abbreviated as Q, and measured in cubic feet per second (cfs).
Dissolve	Cause to pass into solution. In laboratory testing, substances may be considered dissolved if they pass through a 0.45 μm filter.
Diurnal	Relating to or occurring in a 24-hour period; daily.
DO	Dissolved Oxygen
Drainage area	The area of land that drains to a particular body of water or site on a waterbody.
DRBC	Delaware River Basin Commission
DVRPC	Delaware Valley Regional Planning Commission
DWO	Dry-Weather Outlet - connector pipe between a CSO regulator and interceptor sewer.
Dynamic	Relating to conditions that change or are in motion; not static.
E. coli	A common rod-shaped bacterium that is found in the intestinal tract of warm blooded animals. Used as an indicator of contamination by feces/sewage.
EACs	Environmental Advisory Councils
Ecoregion	A relatively large area of land characterized by a unique set of communities, physical, and climatological characteristics.
Ecosystem	A collection of living things and their environment.
Effluent	Outflow of liquid waste, such as discharge from a sewage treatment plant.

Empirical	Of or related to direct observation; not theoretical.
Encapsulated	Enclosed or covered, such a stream that has been built into a sewer.
Endogenous	Coming from or produced wholly from within, such as an enzyme produced by bacteria.
EPA	U.S. Environmental Protection Agency
Epifaunal	Of or relating to stream surfaces upon which attached algae and other living things may grow or find shelter.
Equilibrium	A steady state or condition in which opposing influences balance one another out.
Erosion	The process by which soil particles are removed or displaced, usually by wind or water.
Estuary	A body of water intermediate between an ocean and river, usually tidal and highly productive.
Eutrophic	Characterized by abundant or overabundant life, such as a stream or river that is nutrient enriched and has dense growth of algae or aquatic vegetation.
Eutrophication	The process through which a waterbody comes to have an overabundance of life, usually caused by nutrient enrichment.
FGM	Fluvial Geomorphology is the study of a stream's interactions with the local climate, geology, topography, vegetation, and land use; the study of how a river carves its channel within its landscape.
Fluvial	Of or relating to flowing waters, especially rivers.
Floatables	Waterborne waste material and debris (e.g., plastics, polystyrene, paper) that float at or below the water surface.
GIS	Geographic Information Systems
H_2CO_3	Carbonic acid
Hardness	A measure of the concentration of calcium and magnesium ions in water.
HCO_3-	Bicarbonate ion
Heterotrophic	Describes organisms that cannot synthesize their own food through photosynthesis or other chemical means.
Hilsenhoff Biotic	A biological index of stream health that employs a scale of sensitivity of

Index (HBI)	macroinvertebrates to organic pollution.
HNO_3	Nitric acid, a source of atmospheric nitrogen pollution and acid rain.
Hydraulic	Of or relating to forces exerted by a fluid, often water, under pressure.
Hydrograph	A graphical representation of the change in stage or discharge of a stream as a function of time.
Hydrolysis	A chemical reaction in which water reacts with another molecule, often resulting in new compounds. The breakdown of urea is a hydrolytic reaction.
IDD&E	Illicit Discharge, Detection, and Elimination – one of the six minimum control measures required of permittees under the Phase II NPDES Stormwater Regulations. Program steps include developing maps of municipal separate storm sewer system outfalls and receiving waterbodies; prohibiting illicit discharges via PA DEP-approved ordinance; implementing an IDD&E Program that includes a field screening program and procedures, and elimination of illicit discharges; conducting public awareness and reporting program. A similar program is being followed by PWD in the Long Term Control Plan (LTCP) for CSOs.
Illicit connection	An illegal sewer connection, particularly connection of a sanitary sewer, household or industrial waste pipe to a storm sewer. Illicit connections may result in sewage or other pollution inputs to receiving waterbodies.
Impairment	Weakening, damage, or instability, such as the effects caused by pollution.
Impervious	Incapable of being penetrated, such as a surface that does not absorb water.
Index/Indices	A number, ratio, or value on a scale of measurement that can reveal differences between observations or reveal changes over time. Numerous indices are used to assess the health of aquatic communities, such as the Hilsenhoff Biotic Index or HBI.
Infrastructure	The basic system of utilities and services needed to support a society. Structures such as culverts, pipes, bridges, dams, and flood control measures can cause instability of streams and affect aquatic habitats.
Insoluble	Unable to pass into solution.
Instantaneous	Immediate; occurring, such as a change, quickly. Some continuous water quality parameters are observed instantaneously.

Invertebrates	Animals, such as insects and crustaceans, that lack backbones (vertebrae).
IPM	Integrated Pest Management
Iron (Fe)	A common metallic element; an essential nutrient that may be toxic in relatively large concentrations. Iron can cause problems with taste and color of drinking water.
Kjeldahl nitrogen test	A laboratory procedure for determining the concentration of ammonia and organically-bound nitrogen in a water sample.
Larva/larvae	Immature life stage of an invertebrate, such as a beetle or fly. Many insects that have aquatic larval stages are used as bioindicators of water pollution.
LID	Low-Impact Development (similar to "better site design" and "conservation site design").
LTCP	Long-Term CSO Control Plan – part of the EPA's CSO Control Policy for regulation of CSOs under NPDES that guides municipalities, state, and federal permitting agencies in reaching full compliance with the CWA.
Macroinvertebrates	Macroinvertebrates are invertebrate animals that can be seen without the aid of a microscope.
Macronutrient	A nutrient, such as nitrogen or phosphorus, needed in relatively large amounts for biological growth.
Magnesium (Mg)	A common cation that contributes to hardness in water.
Mainstem	The main flow or central channel of a stream drainage network into which tributaries flow.
Manganese (Mn)	A relatively common metallic element; an essential nutrient that may be toxic in relatively large concentrations.
Mean/ Arithmetic mean	Average; a measure of the central tendency of a set of numbers equal to the sum of all members of a set divided by the number of members of the set.
Median	In descriptive statistics, the value in a set of numbers for which half the members of the set are greater and half are smaller. In some instances, the median value may be more informative than the arithmetic mean if a small number of extreme values tends to skew the mean.
Metabolism	All the biochemical processes exhibited by a living organism.

Model	A useful representation, such as a computer simulation, that can be used to simplify and study systems and processes.
MPC	Municipalities Planning Code
MS4	Municipal Separate Storm Sewer System
NH_3	Ammonia (gaseous, un-ionized)
NH_4+	Ammonium ion
Nitrate (NO_3)	An oxidized form of nitrogen; an essential plant nutrient. Elevated nitrate concentration may result in eutrophication of water bodies and in very great concentrations may be toxic (see methemoglobinemia).
Nitrification	The process of converting ammonia to nitrite and nitrate in the presence of oxygen, especially by the action of naturally occurring bacteria.
Nitrite (NO_2-)	An oxidized ion of nitrogen; an intermediate form in the reaction that converts ammonia to nitrate. Nitrite is usually not available for plant growth.
Nitrogen	A macronutrient needed for biological growth. Inert nitrogen gas makes up a large portion of the Earth's atmosphere.
NOAA	National Oceanic and Atmospheric Administration
Nonferrous	Not containing iron; especially metals and alloys that do not contain iron.
Nonparametric statistics	A collection of statistical analysis tools, used when the data to be analyzed do not meet the assumptions of parametric statistics, such as homogeneity of variances.
Non-point source pollution	Pollution that comes from a diffuse source such as atmospheric deposition, stormwater runoff from pasture and crop land, or individual on-lot domestic sewage systems discharging through shallow groundwater.
Non-structural BMPs	These BMPs will require no operation or maintenance. Examples are use of open space and vegetated buffers in development design, minimization of soil disturbance and compaction during construction, and minimization of directly-connected impervious areas.
NPDES	National Pollutant Discharge Elimination System
NPDES Phase I	The stormwater management component of the NPDES program instituted in 1990, which addressed the storm runoff sources most threatening to water quality. Under this phase, industrial activity, and construction sites within large communities (population 100,000 or more) are required to obtain permits for the stormwater leaving the site.

NPDES Phase II	Additional stormwater management regulations enacted in 1999, applying to smaller communities and construction sites.
NRCS	Natural Resource Conservation Service
NTU	Nephelometric turbidity units; a unit of measure describing the light scattering properties of a water sample.
Nutrient	An element or molecule needed for biological growth. When nutrients such as phosphorus are present in great concentrations, biological growth (algae in particular) can become overabundant, causing problems for aquatic ecosystems.
OLDS	On-Lot sewage Disposal Systems
O&M	Operations and Maintenance
OOW	PWD's Office of Watersheds
Orthophosphate (OPO_4)	A dissolved, inorganic form of phosphorus, available as a nutrient for plant growth; soluble reactive phosphorus.
Outfall	A pipe or other structure that discharges flow, such as treated sewage effluent or stormwater, to receiving waters.
Oxidation	Chemical process in which a molecule or atom reacts with oxygen or generally, a reaction in which an atom loses electrons and increases in valence state; the opposite of a reduction reaction.
Oxygen	An element, common in Earth's atmosphere and dissolved in water, necessary for most forms of complex animal and plant life.
PA Act 167	Stormwater Management Act
PA Act 537	Sewage Facilities Planning Act
PA DCNR	Pennsylvania Department of Conservation and Natural Resources
PA DEP	Pennsylvania Department of Environmental Protection
Parameter	A chemical constituent or physical characteristic of water quality (e.g., dissolved oxygen is a chemical constituent, temperature is a physical characteristic).
Parametric statistics	A collection of powerful statistical tools that assume certain qualities of the data being analyzed, such as homogeneity of variances.

Parasite	A functional feeding group of aquatic organisms characterized by feeding usually upon bodily fluids of other organisms, rather than direct predation and consumption. The organism that is fed upon need not die due to the effects of feeding
PEC	Pennsylvania Environmental Council
PFBC	Pennsylvania Fish and Boat Commission
Phosphate	An oxidized form of phosphorus, which may be organic or inorganic. Inorganic phosphates are generally more likely to be available as nutrients for biological growth.
Photosynthesis	A set of chemical reactions in which plants and other organisms, such as blue-green algae, can synthesize their own food using light and inorganic carbon. Photosynthetic activity in water increases dissolved oxygen concentration during daylight hours.
Physicochemical	Physical and chemical properties of water; a term used to group water quality parameters of interest.
Phytoplankton	Collectively, algae suspended in water; a group or growth form of algae defined by passive or active suspension in the water column.
PO_4	Phosphate
Point source	Pollution discharged from a single point, defined in the CWA as “any discernable, confined and discrete conveyance, including but not limited to any pipe, ditch, channel, tunnel, conduit, well, discrete fissure, container, rolling stock, concentrated animal feeding operation, vessel, or other floating craft from which pollutants are or may be discharged.”
Potassium (K)	An elemental macronutrient required for biological growth.
POTW	Publicly Owned Treatment Works
PRD	Planned Residential Development
Predator	A functional feeding group of aquatic organisms characterized by actively feeding upon captured prey.
Productivity	A measure of the amount of biological growth that occurs in an ecosystem.
PWD	Philadelphia Water Department
QA/QC	Quality Assurance/Quality Control

RBP	(Rapid Bioassessment Protocol) A standard method developed by the EPA to assess aquatic health through fish and macroinvertebrate diversity (EPA website).
RBPIII	(Rapid Bioassessment Protocol III) EPA approved technique for evaluating macroinvertebrate communities of a river or stream.
RBPV	(Rapid Bioassessment Protocol V) EPA approved technique for evaluating the fish communities of a river or stream.
RCP	PA DCNR's Rivers Conservation Planning Program.
Reach	A segment of a stream as defined by the study being undertaken.
Reference	A condition or value used for comparison. Many types of biological assessment techniques require comparison to references.
Regulator	In sewer infrastructure, a physical gate, valve, or other control structure that routes flow between two or more receiving pipes, usually one of which terminates in a CSO.
Respiration	Biological metabolic process in which a large molecule is broken into smaller pieces to yield usable energy. Aerobic respiration, the efficient respiration reaction favored by complex living things, requires oxygen.
Riffle	A reach of stream that is characterized by shallow, fast moving water broken by the presence of rocks and boulders.
Riparian	Related to, within, or near a river or its banks.
Riparian corridor	The area of land along the bank or shoreline of a body of water (EPA website).
Riparian woodlands	Woodlands that grow within the riparian corridor.
RTC	Real Time Control - a dynamic system of hydraulic controls to provide additional storage and reduce overflows from a combined sewer system.
Run	A reach of stream that is characterized by smooth flowing water.
Runoff	Generally, precipitation that is not absorbed by surfaces or evaporated, but allowed to flow over the surface to a receiving body of water.
Sediment	Particles, especially inorganic soil particles, that settle upon stream surfaces.
SEO	Sewage Enforcement Officers (designated by PA DEP).

Sinuosity	A measure of the degree to which a stream, viewed from above, deviates from a linear path, expressed as the ratio of stream length between two points divided by the valley length, or point-to-point distance between the same two points.
Significant	When describing the results of scientific or experimental study, describes a comparison or relationship that has been determined to be more likely real than related to randomness or chance to a stated degree of confidence.
Silt/Siltation	Inorganic sediment particles between 3.9 and 62.5 µm in diameter. also the process of being covered by or embedded in silt.
Soluble/Solubility	The quality or state of being able to pass into solution. In water chemistry analysis, a substance may be considered soluble or dissolved if it passes through a 0.45 µm filter.
Sonde	A continuous water quality monitoring instrument.
Species	The level of biological taxonomic classification at which living things are separated from one another by the ability to reproduce yielding fertile offspring.
SSA	Separate-Sewered Area stormwater runoff
SSO	Sanitary Sewer Overflow
STORET	U.S. EPA's water quality database (STOrage and RETrieval).
Stormwater Management Program Protocol ("Protocol")	PA DEP guidance for implementing the requirements of the NPDES Phase II stormwater regulations.
Structural BMPs	These BMPs will require proper operation and maintenance. Examples include wet ponds, grassed swales, infiltration basins and bioretention areas.
SWMM	Storm Water Management Model
TDR	Transfer of Development Rights
Temporal	Of or relating to time, such as a change observed over time.
TIGER	Topologically Integrated Geographic Encoding and Referencing (U.S. Census database).
TMDL program	Total Maximum Daily Load program - EPA/PA DEP program for limiting and allocating discharges of a pollutant within a watershed.

Toxic/toxicity	Describing a substance that is harmful, able to cause injury or death; also the concentration at which a substance may cause injury or death.
Transpiration	The process by which water vapor passes through the membrane or pores of plants to the atmosphere.
Trophic	Describing or relating to food, food type, or the process through which a living thing acquires food.
TSS	Total Suspended Solids
TTFIWMP	The Tookany/Tacony-Frankford Integrated Watershed Management Plan.
Turbidity	A measure of the light scattering properties of water.
UA	Urban Areas
UAA	Use Attainability Analysis
Unimpaired	Natural, unmolested; describing an unaltered or undisturbed state.
USDA	United States Department of Agriculture
USGS	United States Geological Survey
Velocity	A vector quantity that describes speed in a stated direction or along an axis.
Vertebrate	A complex living thing having a backbone (vertebrae).
Violation	An instance or time period during which a regulated water quality parameter was exceeded.
Watershed	The area of land draining to a stream, river, or other water body. Watershed boundaries are established where any precipitation falling within the boundary will drain to a single water body. Precipitation falling outside the boundary will drain to a different watershed. These boundaries are typically formed on high elevation ridges. The water bodies formed from the watershed drainage are usually at the lowest elevation in the watershed. Watersheds can also be called drainage basins.
WLA	Waste Load Allocation
WMP	Watershed Management Plan
WQS	Water Quality Standards
WRAS	PA DEP's Watershed Restoration Action Strategy

Public Survey

Tacony-Frankford River Conservation Plan

Philadelphia Residents: Do you live within the boundaries of the **Tacony-Frankford Watershed?** (see map below). If yes, please fill out and return this survey. Thank you!

A **watershed** is all the land that drains rain into a specific body of water, such as a creek.

Philadelphia Neighborhoods in the Tacony-Frankford Watershed:

Bridesburg
Cedarbrook
Crescentville
East Falls
East Mt. Airy
Fairhill
Feltonville
Fernrock
Fox Chase
Frankford
Germantown
Harrowgate
Hunting Park
Juniata Park
Lawndale
Logan
Nicetown
Oak Lane
Ogontz
Olney
Rhawnhurst
Richmond
Tioga
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Westside

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OPPORTUNITIES FOR YOUR INVOLVEMENT

16. Would you like to participate in any of the following activities? Check those that interest you.

___Monitor water quality in the creek.
___Volunteer in the parks to plant trees, pick up trash, or fix trails.
___Participate in planning meetings.
___Educate others about watershed issues.
___Take a guided walk along the creek.

17. If you checked any lines above, or if you would like to stay informed about future watershed-related events, please provide the following information.

Name: ____________________
Organization: ____________________
Address: ____________________
City/State/Zip: ____________________
Phone: ____________________
Email: ____________________

* * *

The Tacony-Frankford River Conservation Plan is a collaborative project of Philadelphia citizens, community groups, and public agencies. Key organizers of the plan include the Philadelphia Water Department, Frankford Group Ministry, Fairmount Park Commission, Heritage Conservancy, and the Pennsylvania Environmental Council, with funding provided by the Pennsylvania Department of Conservation & Natural Resources.

Upstream of the Tacony-Frankford Creek, Montgomery County citizens and officials are creating a conservation plan for the **Tookany Creek.**

Together, these river conservation plans will provide a community-based vision for improving the entire Tookany-Tacony-Frankford Watershed. To learn more about how you can participate in the **Tookany/Tacony-Frankford Watershed Partnership**, contact the Pennsylvania Environmental Council at 215-563-0250, or visit www.phillywater.org (Go to "Watershed Partnerships" link).

Mailing Instructions: Please fold along lines, tape closed, and mail by June 30, 2002. Postage is prepaid for your convenience, or use a stamp to help cut costs.

Tacony-Frankford Public Survey

BACKGROUND INFORMATION

Philadelphia Neighborhood: ____________________

Zip code:______________ Age:______

Type of dwelling:	Length of residency there:
A. Detached house	A. 0 to 1 year
B. Twin	B. 1 to 5 years
C. Rowhouse	C. 5 to 10 years
D. Apartment	D. 10 to 20 years
	E. > 20 years

YOUR WATERSHED AWARENESS

1. Before reading the cover of this brochure, did you know what a watershed was? (Circle one)
   A. Yes.
   B. No.
   C. I was aware of the term but not entirely sure what it meant.

2. Do you ever think of yourself as a resident of the Tacony-Frankford Watershed?
   A. No, I never thought of myself as a resident of any watershed.
   B. No, I knew that I live in a watershed, but I wasn't sure which one.
   C. Yes.

3. When it rains, where does most of the water drain to from your roof?
   A. Into my driveway/street and down a storm drain.
   B. Into my yard where it absorbs in the soil.
   C. Into the downspout and directly underground to the city sewer system.
   D. Other ____________________________
   E. I don't know.

4. In your neighborhood, when water goes into storm drains on the street, where does it go?
   A. Wastewater treatment plant. C. Into the ground.
   B. Directly to a stream. D. I don't know.

5. During a heavy rain storm, do you ever see flooding in these places? (Circle each place that floods.)
   A. My street. D. My basement.
   B. My driveway. E. Other ______________
   C. My yard. F. No flooding problems.

TACONY-FRANKFORD WATERSHED

6. How close do you live to Tacony-Frankford Creek?
   A. The creek flows next to my property.
   B. Less than 4 blocks away.
   C. More than 4 blocks away.
   D. I don't know.

7. Do you or anyone in your family spend time along Tacony-Frankford Creek? How often?
   A. At least 2-3 times per week.
   B. Once a week.
   C. Once a month.
   D. Several times a year.
   E. Rarely or never (Go to question #9)

8. What activities do you and/or your family do there? (Circle all that apply)
   A. Fishing. D. Picnic.
   B. Nature exploration. E. Walking.
   C. Outdoor sports. F. Other _______________

9. How clean do you think the water is in Tacony-Frankford Creek?
   A. High quality. I would wade or swim in the water.
   B. Moderate quality. I might wade occasionally.
   C. Poor quality. I would never wade or swim.

10. Of all the possible sources of pollution from the entire Tookany/Tacony-Frankford Watershed, which of these sources do you think are a problem? Circle one option for each. 1=major problem, 2=occasional problem, 3=not a problem, ?= don't know.

1 2 3 ? Pollution discharge from factories.
1 2 3 ? Sewage from homes or commercial buildings.
1 2 3 ? Trash and litter from careless people.
1 2 3 ? Stormwater runoff from streets/parking lots.
1 2 3 ? Animal waste from dogs, geese, etc.
1 2 3 ? Lawn fertilizers and herbicides.
1 2 3 ? Sediment from eroding creek banks.
1 2 3 ? Illegal dumping.
1 2 3 ? Other ___________________________

11. If money were used to enhance or improve Tacony-Frankford Creek and its surrounding communities, which of these changes would you recommend as important? Circle one number for each. 1= very important, 2=somewhat important, 3=not important.

1 2 3 Less litter.
1 2 3 Cleaner water.
1 2 3 Less flooding.
1 2 3 Better trails along the creek.
1 2 3 More recreational facilities (ballfields, play grounds, etc.)
1 2 3 More native trees and shrubs on stream banks.
1 2 3 Increased safety and security in parks.
1 2 3 More environmental education programs.
1 2 3 Preservation of historic buildings.
1 2 3 More public art near or about the creek.
1 2 3 More cultural events along the creek.
1 2 3 Other ______________________

ACTIONS IN YOUR NEIGHBORHOOD

12. All of the following actions can harm water quality in streams. Put a check next to actions you have observed in your neighborhood.

___Leaving dog waste on lawns/streets.
___Car-washing with detergents that go into streets.
___Leaky motor oil or antifreeze from cars.
___Dumping fluids or trash into storm drains.
___Over-use of lawn fertilizers or herbicides.
___Riding ATVs in the parks, tearing up soil/plants.
___Dumping tires or other trash into vacant lots/parks.
___Dumping leaves or grass clippings in the creek.
___Other ______________________

13. Do you think *most* people in your neighborhood know these actions pollute streams? YES NO

14. Do you know where to report illegal dumping? YES NO

(You can report to the Philadelphia Police Environmental Response Unit, 215-685-3097, *or* the PA Department of Environmental Protection, 610-832-6014.)

15. Have you ever helped with any watershed protection activities? If so, what? (for example, picking up trash, planting trees, putting "no dumping" signs on storm drains, etc.)

____
____
____

CONTINUE →

Appendix C

TOOKANY/TACONY-FRANKFORD WATERSHED PARTNERSHIP CORPORATE BYLAWS

ARTICLE 1
NAME; PRINCIPAL OFFICE

1.1. **Name**. The name of the nonprofit corporation is Tookany/Tacony-Frankford Watershed Partnership ("Corporation").

1.2. **Principal Office**. The principal office of the Corporation shall be c/o the Pennsylvania Environmental Council (PEC) at 123 Chestnut Street, Suite 401, Philadelphia, PA 19106. The Corporation may also have offices at other places as the Directors may from time to time see fit or the activities of the Corporation may require.

ARTICLE 2
PURPOSES

2.1. **General Purposes.** The Corporation is established in compliance with the Nonprofit Corporation Law of 1988 (the "Act"). The Corporation is established exclusively for charitable, educational and scientific purposes as set forth in the Articles of Incorporation. In pursuing such purposes, the Corporation shall not act so as to impair its eligibility for exemption under Section 501(c) (3) of the Internal Revenue Code of 1986, as amended.

2.2. **Specific Purposes.** The primary purposes of the Corporation are to carry out all activities allowable under Section 501(c)(3) of the Internal Revenue Code (or the corresponding section of any future Internal Revenue Law of the United States), including but not limited to: implement the Integrated Watershed Management Plan for the Tookany/Tacony-Frankford Watershed ("TTF Watershed"); improve stream habitat and integrity of aquatic life; reduce the impact of urbanized flow on living resources; improve dry and wet weather stream quality to reduce the effects on public health and aquatic life; protect and restore stream corridors, buffers, floodplains, and natural habitats including wetlands; identify flood prone areas and decrease flooding; enhance community environmental quality of life; foster community stewardship; and improve inter-municipal, inter-county, state-local and stakeholder cooperation and coordination on a watershed wide basis through dedicated public education and outreach.

ARTICLE 3
MEMBERS

3.1. **Membership Corporation.** The Corporation shall have no members.

3.2. **Honorary Titles.** The Directors may create such classes of membership, such as contributing members or honorary members, as the Directors see fit, but such persons shall not have the rights of members under the Act.

ARTICLE 4
DIRECTORS

4.1. **Powers.** The activities, property, and affairs of the Corporation shall be managed by the Board of Directors ("Board"). Each Director shall possess all powers and undertake duties required for the conduct and management of the business and affairs of the Corporation except as otherwise required by law, these Bylaws, or a resolution duly adopted by the Board. The Board may adopt such rules and regulations as may be required by regulatory authorities.

4.2. **Categories of Board Membership.**

(a) The Board of Directors shall consist of not less than eleven (11) and not more than twenty-four (24) persons. Board members shall represent a specific Board category as defined herein.

(b) *Appointed Board Members:*

Each of the following entities ("Eligible Appointing Entities") shall be entitled to appoint one member of the Board of Directors: Montgomery County Board of Commissioners, Abington Township, Cheltenham Township, Jenkintown Borough, Rockledge Borough, Philadelphia Water Department, Fairmount Park Commission, Philadelphia City Planning Commission, the Mayor's Office of the City of Philadelphia, and the Office of the President of City Council (Philadelphia).

(c) *Elected Board Members*:

The *Elected Directors* shall be elected by the Board in accordance with procedures established in these Bylaws. The *Elected Directors* shall, whenever possible, represent the following constituencies: non-profit organizations, large businesses, small businesses, universities, civic organizations, and individuals who are stakeholders of TTF Watershed.

4.3. **Term of Office.**

(a) The members of the initial Board of Directors shall include both *Appointed Directors* and *Elected Directors*. *Appointed Directors* shall be appointed by their respective Eligible Appointing Entities; *Elected Directors* shall be appointed by the Incorporator at the First Organizational Meeting of the Board. The initial Directors shall be assigned an initial Board term of one (1) year, two (2) years, or three (3) years.

(b) Thereafter, as the initial terms of the initial Board Directors conclude, Directors shall be appointed or elected to the Board at the Corporation's Annual Meeting. Directors shall be appointed or elected to fill specific categories of Board membership in accordance with these Bylaws.

(c) Upon the conclusion of the initial terms as described in Section 4.3(a), all Directors shall serve a three-year term. The terms of the Directors shall be fixed so that the term of one-third of such Directors shall expire at each Annual Meeting of the Corporation.

(d) No Director may serve more than six consecutive years (not including the initial term).

4.4. **Appointment of the *Appointed Directors*.**

(a) Not less than thirty (30) days before the First Organizational Meeting, the Eligible Appointing Entities shall submit to the Incorporator their respective appointments for Directors ("*Appointed Directors*"). Eligible Appointing Entities shall only appoint professionals or staff of the Eligible Appointing Entities, or those who provide professional services to the jurisdiction of the Eligible Appointing Entities. During the First Organizational Meeting, the Incorporator shall announce and seat the *Appointed Directors*.

(b) Thereafter, not less than thirty (30) days before each Annual Meeting, the Eligible Appointing Entities shall appoint the number of nominees equal to the number of directorships that are vacant or will become vacant at the time of the Annual Meeting. These Eligible Appointing Entities shall submit to the Secretary of the Board their appointments for *Appointed Directors*. The Secretary shall immediately inform the Board of Directors of these appointments. During the Annual Meeting, the Board of Directors shall announce and seat the *Appointed Directors*.

4.5. **Nomination and Election of the *Elected Directors*.**

(a) During the First Organizational Meeting, the Incorporator shall announce and seat the first *Elected Directors*.

(b) Thereafter, not less than sixty (60) days prior to each Annual Meeting, the President shall send written notice to the members of the Board announcing the number of Directors to be elected, declaring that the nominations of candidates for election as Director are open, and calling for nominations. Nominations will be directed though a Nominations Committee appointed by the Board President.

Not less than thirty (30) days before the Annual Meeting, the Nominations Committee shall submit to the Secretary of the Board its nominations. After nominations have been made, the President shall declare the nominations closed, and thereafter no further nominations may be made.

(c) During the Annual Meeting, the voting procedure followed shall be such that a separate vote is taken for each directorship to be filled. Each directorship shall be filled by majority vote of the Directors voting (a quorum must be present).

d) Upon demand of any three Directors in attendance, elections shall be conducted by written ballot; otherwise all ballots will be cast by voice vote only.

4.6. **Removal.**

(a) The Board, by a majority vote, may make a recommendation for removal of an *Appointed Director*. After a lawfully conducted vote to recommend removal is affirmed, the President shall contact the Eligible Appointing Entity that appointed this Director and discuss matters concerning removal of this Director and appointment of a new Director by the Eligible Appointing Entity. The Eligible Appointing Entity shall make the final decision concerning the removal of this *Appointed Director*.

(b) Any *Elected Director* may be removed from office, without the assignment of any cause, by a majority vote of the Board, whenever in the judgment of the Board the best interest of the Corporation will be served.

(c) Votes in accordance with the above Section 4.6 (a) and (b) shall be conducted at a duly convened meeting of the Board. The written notice of the intention to consider removal of such Director shall be included in the notice of the meeting. No Director shall be removed without having the opportunity to be heard at such meeting, but no formal hearing procedure need be followed.

4.7 **Vacancies.**

(a) When a directorship of an *Appointed Director* becomes vacant during the period between Annual Meetings of the Corporation, the President shall inform the affected Eligible Appointing Entity to appoint a new Director to fill such vacancy until the next Annual Meeting.

(b) When any directorship of an *Elected Director* becomes vacant during the period between Annual Meetings of the Corporation, the Board may elect a new Director to fill such vacancy until the next Annual Meeting. The vacancy shall be filled with a Director from the same type of organization, business, civic interest, or individual interests as set forth in Section 4.2 (c).

4.8. **Resignation**. Any Director may resign at any time by giving written notice to the Corporation. The resignation shall be effective upon receipt by the President (or in the case that the President elects to resign or is not available, receipt by the Board of Directors), or at such subsequent time as may be specified in the notice of resignation.

4.9. **Director Compensation.** Directors shall not be compensated for their service on the Board, although they may be reimbursed for reasonable and necessary expenses incurred for the benefit of the Corporation. Reimbursement shall require the submission of expense vouchers and receipts.

4.10. **Conflict of Interest.**

(a) No contract or transaction between the Corporation and its Directors or Officers or between the Corporation and any other corporation, partnership, association, organization, or governmental agency in which one or more of its Directors or Officers have a financial interest shall be void or voidable if:

(1) the material facts as to the relationship or interest and as to the contract or transaction are disclosed to the Board of Directors, and are authorized in good faith by the affirmative vote of a majority of disinterested Directors; and

(2) the contract or transaction is fair to the Corporation as of the time it is authorized by the Board of Directors.

(b) In making the above determination, the affected Director or Officer shall withdraw from the meeting in which this matter is discussed for as long as this matter remains under consideration. Should the matter be brought to a vote, the affected Director shall neither be present nor cast a vote.

ARTICLE 5

MEETINGS

5.1. **Annual Meetings.**

(a) The Annual Meeting of the Directors shall be held during the month of May of each year at the offices of one of the Directors or at such other location as agreed upon by the Directors at least two (2) weeks prior to the Annual Meeting. If all of the Directors agree, the Annual Meeting may be held during a month other than May as determined at least two (2) weeks prior to the Annual Meeting.

(b) At the Annual Meeting, the Board shall be organized for the succeeding year, including the official recognition of appointment of the *Appointed Directors* and the election of the *Elected Directors* by vote of the remaining Directors, to fill the positions of those whose terms expire at that time, as well as review and adoption of the annual budget, and consideration of such other matters as may properly come before the Board.

5.2. **Regular Meetings.** The Board of Directors shall meet according to a schedule it determines, provided that it meets at least four times a year, and without an interval of more than four months between any two meetings. Each Director shall receive timely advance notice of meetings, in accordance with these Bylaws.

5.3. **Special Meetings.** Special meetings may be called by the President or by any five Directors calling for the meeting by contacting the President.

5.4. **Telephone Communication.** Members of the Board of Directors may participate in any meeting of the Board through the use of conference telephone or similar communication equipment that enables all participants in the meeting to hear each other at the same time. Such participation shall constitute presence in person at the meeting.

5.5. **Quorum and Voting**.

(a) Two-thirds of the Directors seated shall constitute a quorum for amendment of the Articles of Incorporation or the Bylaws; issues relating to the sale, lease, or purchase of real estate; and removal or suspension of any Officer at any Board meeting, whether annual, regular, or special. For matters mentioned above, if a quorum is present, the act of two-thirds of Directors voting shall be an act of the Board of Directors.

(b) For all other matters, unless specifically stated by resolution of the Board, a majority of the Directors seated shall constitute a quorum. If a quorum is present, the act of a majority of Directors voting shall be an act of the Board of Directors, except as otherwise expressly provided in these Bylaws or required by law.

5.6. **Notice**. Notice shall be given in writing to each Director of each Annual, regular, or special meeting of the Directors. Such notice shall be delivered by hand, by mail, or by facsimile or electronic mail at least ten (10) days before the day named for the Annual, regular or special meeting. The notice shall state the date, time, place, and purpose of the meeting, including the agenda, if one has been established or required by these Bylaws.

5.7. **Waiver of Notice.** A written waiver signed by a Director, or attendance by a Director at any Annual, regular, or special meeting, shall be deemed equivalent to appropriate notice and shall be considered consent to the holding of the meeting.

5.8. **Proxy Votes**. A Director is allowed to vote by proxy, if necessary. Every proxy shall be executed in writing by the Director or by his or her duly authorized representative and filed with the Secretary of the Corporation. A proxy statement shall indicate the specific matters on which the proxy is authorized to vote. A Director’s proxy who is entitled to vote at the meeting shall vote only in the matters specified in the proxy statement executed by the Director and only for that specific meeting. A vote by proxy that exceeds the authority specified in the proxy statement is invalid. A proxy shall be revocable at will, notwithstanding any other agreement or any provision in the proxy to the contrary, but the revocation of a proxy shall not be effective until notice thereof has been given to the Secretary of the Corporation. A proxy shall not be revoked by the death or incapacity of the maker unless before the vote is counted or the authority is exercised, written notice of such death or incapacity is given to the Secretary of the Corporation.

ARTICLE 6
OFFICERS

6.1. **Officers.** The officers of the Corporation shall be a President, Vice-President, Treasurer, Secretary, and an Executive Director, and such other officers as the Board of Directors may from time to time elect. The duties of the officers of the Corporation shall be as provided in the Bylaws, except as modified from time to time by the Board.

6.2. **Election and Term.** Officers may be elected for more than one office and serve for consecutive terms. The Officers (except for Executive Director) shall be elected by a majority vote of the Board at the Annual Meeting of Directors and shall serve for a term of one (1) year and until their successors are elected and qualified, or until death, resignation, or removal.

6.3. **Qualification of Officers.** The President, Vice-President, Secretary, and Treasurer must be at least 18 years of age and shall be members of the Board of the Corporation.

6.4. **President.** The President shall preside at meetings of the Board, shall have general responsibility for dealing with questions of policy related to the Corporation's affairs, and shall be responsible for calling meetings of the Board and for assuring adequate communication between the operating staff of the Corporation and the Board on matters of policy and financial concerns.

6.5. **Vice-President.** The Vice-President shall perform such duties as may from time to time be assigned by the Board of Directors or designated by the President. In the case of the death, disability, or absence of the President, the Vice-President shall fulfill all the duties and be vested with all powers and responsibilities of the President.

6.6. **Secretary.** The Secretary shall keep a book of minutes of all meetings of the Board, shall direct the issue of all notices required by law or requested from time to time by the Board of Directors or by the President, and shall perform such other duties as are incident to the office of Secretary. The Secretary shall be the custodian of the seal of this Corporation and all books, records, and papers of this Corporation, except those documents in the charge of the Treasurer, or of some other person authorized to have custody and possession thereof by a resolution of the Board of Directors.

6.7. **Treasurer.** The Treasurer serves as the principal financial advisor to the Board of Directors in planning, directing, and appraising the effectiveness of the Corporation's fiscal operations. The Treasurer shall ensure full and accurate accountability and control of the receipts and disbursements of the Corporation's assets. The Treasurer shall perform such other duties as may be assigned by the Board of Directors or as are incidental to the office. The Treasurer shall agree to be bonded as deemed necessary by the Board of Directors.

6.8. **Executive Director.** The position of Executive Director is a paid position within the Corporation. The Executive Director shall be appointed or dismissed by the Board of Directors, on such terms and conditions as the Board of Directors deems appropriate. The Executive Director shall be an ex-officio member of the Board of Directors, shall direct all operations of the Corporation, shall supervise all personnel, and shall have control and management of its business and affairs, all subject to the direction of the Board of Directors. The Board shall evaluate the performance of the Executive Director annually, against a set of written, agreed upon goals and objectives.

ARTICLE 7
COMMITTEES

7.1. **Establishment.**

(a) The Board of Directors may, if set forth in these Bylaws or by resolution, establish one or more committees and give them such powers and authority as the Board shall deem appropriate.

(b) Committees shall have and shall exercise authority as prescribed by the Board of Directors. The creation of a committee shall not operate to relieve the Board of Directors, or any individual Director, of the responsibility imposed by law. No committee shall have the authority of the Board to conduct any of the following:

(1) The filling of vacancies of the Board;
(2) The adoption, amendment, or repeal of the Bylaws;
(3) The amendment or repeal of any resolution of the Board; and
(4) Action on matters committed by the Bylaws or by resolution of the Board to another committee of the Board, or to the full Board.

7.2. **Executive Committee**.

(a) The members of the Executive Committee shall be the Officers who are elected by the Board at the Annual Meeting. This shall include the President (who shall serve as chair of the Committee), Vice-President, Secretary, and Treasurer. In addition, the Executive Committee shall include one additional Director. Such additional member shall be elected to the Executive Committee at each Annual Meeting following the election of Directors and Officers, and shall serve for one year or until his/her successor is seated to this Committee.

(b) The Executive Committee shall have power and authority to take actions on behalf of the Board of Directors for emergencies and other urgent business matters that occur between meetings of the Board. The Executive Committee shall not be authorized to conduct the standard and usual business of the Board. All actions taken by the Executive Committee shall be reported at the next meeting of the Board and shall be binding on the Board only when approved by formal vote of the Board or when so authorized previously by the Board and delegated to the Executive Committee.

ARTICLE 8
DISSOLUTION

8.1. **Distribution of Assets.** Upon dissolution of the Corporation, the Board of Directors shall, after paying or making provision for the payment of all the liabilities of the Corporation, dispose of all of the assets of the Corporation exclusively for the purpose of the Corporation in such manner, or to such organization or organizations organized and operated exclusively for charitable, educational, or scientific purposes as shall at the time qualify as an exempt organization or organizations under Section 501(c)(3) of the Internal Revenue Code of 1986 (or the corresponding provision of any future United State Internal Revenue Law), as the Board of Directors shall determine. Any such assets not so disposed of shall be disposed of by a Court of competent jurisdiction of the County in which the principal office of the Corporation is then located, exclusively for such purposes or to such organization or organizations, as said Court shall determine, which are organized and operated exclusively for such purposes.

ARTICLE 9
AMENDMENTS

9.1. **Amendments.**

(a) The Directors may, by a two-thirds vote of those present in person at any duly called meeting at which a quorum is present as set forth in Article 5.5(a) of these Bylaws, alter, amend, or repeal the Articles of Incorporation or these Bylaws or any portion thereof. Provided, however, that no such alteration, amendment, or repeal should impair the Corporation's eligibility for exemption under Section 501(c) (3) of the Internal Revenue Code of 1986.

(b) Written notice as to the substance and effect of any proposed amendment to the Articles of Incorporation or these Bylaws shall be given or mailed to each Director not less than ten (10) days prior to the meeting of the Board at which such proposed amendment is submitted to a vote.

ARTICLE 10
OPERATIONS

10.1. **Execution of Documents.** Except as otherwise provided by law or resolution of the Board of Directors, checks, drafts, promissory notes, orders for payment of money, other evidences of indebtedness of this Corporation, contracts, leases, or other instruments executed in the name of and on behalf of the Corporation may be signed by any Officer or any Director. If the amount of indebtedness or obligation on any single document mentioned in this Article is two thousand dollars ($2,000) or above, such document shall be executed by two people who have authority to sign (Officer or Director) in order to be binding on the Corporation.

10.2. **Corporate Seal.** The Corporation may have a corporate seal containing the name of the Corporation, the year of incorporation, and such other details as may be approved by the Board of Directors.

10.3. **Books and Records.** The Corporation shall keep correct and complete books and records of account, and will also keep minutes of the proceedings of its Board of Directors and Committees. The Corporation will keep at its registered office the original or a copy of its Articles of Incorporation as filed with the Secretary of State of the Commonwealth of Pennsylvania, and the original or a copy of these Bylaws, including amendments, certified by the Secretary of the Corporation

10.4. **Fiscal Year.** The fiscal year of the Corporation shall begin on July 1 and end on June 30 of each year.

ARTICLE 11
LIABILITY AND INDEMNIFICATION

11.1. **Liability.** General Rule. A Director shall not be personally liable for monetary damages as a Director for any action taken, or any failure to take action, unless:

(a) the Director has breached or failed to perform the duties of Director in accordance with the standard of conduct contained in section 5712 of the Act, “Standard of care and justifiable reliance”; and

(b) The breach or failure to perform constitutes self-dealing, willful misconduct, or recklessness.

Provided, however, the foregoing provision shall not apply to (1) the responsibility or liability of a Director pursuant to any criminal statute or (2) the liability of a Director for the payments of taxes pursuant to local, state, or federal law.

11.2. **Insurance.** The Corporation may purchase and maintain insurance on behalf of any person who is or was a Director, Officer, or employee of the Corporation or is or was serving at the request of the Corporation as a representative of another domestic or foreign corporation for profit or not-for-profit, partnership, joint venture, trust, governmental agency, or other enterprise against any liability asserted against him or her and incurred by him or her in any such capacity, or arising out of his or her status as such, whether or not the Corporation would have the power to indemnify him or her against that liability under the Act.

11.3. **Indemnification.**

(a) The Corporation shall reimburse any Director, Officer, or other representative of the Corporation (each, a “Representative”) for any expenses that are actually and reasonably incurred by him or her in connection with any lawsuit or action in which the performance of his or her duties as a Representative is in question (“Reimbursable Costs”) if he or she is successful in defending himself or herself against the lawsuit or action as demonstrated by a judgment in his or her favor on the merits of the claim.

(b) Subject to paragraph (c) below, the Board has discretion to decide, by a unanimous vote, whether to reimburse a Representative for Reimbursable Costs in those instances where a judgment in his or her favor on the merits of the claim is not reached and, therefore, he or she is not entitled to mandatory indemnification pursuant to paragraph (a) above, but where the Representative acted in good faith and in a manner he or she reasonably believed to be in, or not opposed to, the best interests of the Corporation or, with respect to a criminal proceeding, had no reasonable cause to believe that his or her conduct was unlawful. The Corporation may only reimburse the Reimbursable Costs up to the limit amount that its insurance covers.

(c) Under no circumstances may the Corporation reimburse a Representative for Reimbursable Costs if a court determines that his or her behavior in connection with the lawsuit or action at issue constituted willful misconduct or recklessness.

ADOPTED BY THE BOARD OF DIRECTORS ON ____________________.

____ ____________________

President, Date
Board of Directors

____

Secretary,
Board of Directors
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Appendix D: Potential Sources of Funding

SOURCE OF ASSISTANCE	PROGRAM NAME	CONTACT NUMBER	BRIEF DESCRIPTION OF PROGRAM
DCED	Communities of Opportunity		Provides grants to municipalities, redevelopment authorities and housing authorities for community revitalization, economic development, and low-income housing development and rehabilitation.
DCED & Governor's Office	Community Revitalization Program		Very broad grant program. Officially intended to promote community stability, increase tax bases and improve quality of life. Applications may be made by municipalities, authorities, economic development organizations and non-profit corporations. Public/non-profit/profit partnerships are encouraged. Generally can be used for infrastructure, community revitalization, building rehabilitation, demolition of blighted structures, public safety, and crime prevention.
DCED in cooperation with PA DEP	Industrial Sites Reuse Program, PA ("Brownfields")		Provides grants of up to 75% and low interest loans for assessment of environmental contamination and remediation work at former industrial sites. Available to private companies, non-profit economic development agencies or authorities that own the land. Mainly targeted towards cities. Financing is not available to the company that caused the contamination.
DCED	Intermunicipal Projects Grants		Promotes cooperation between neighboring municipalities so as to foster increased efficiency and effectiveness in the delivery of municipal services at the local level.
DCED	Land Use Planning and Technical Assistance Program		Assists local governments and counties to prepare comprehensive plans, downtown plans, special community development studies and development regulations. Typically provides 50% of the eligible costs.
DCED	Shared Municipal Services		Provides modest-sized 50/50 matching grants to promote cooperation among municipalities, in order to increase the efficiency of public services. Two or more municipalities may apply, or a council of governments.
DCNR	Community Conservation Partnership Grant Program		Funds a wide variety of recreation, greenway, rivers conservation and open space preservation activities with 50% matching grants. Four main categories of grants are: Planning and Technical Assistance, Acquisition Projects, Development Projects, Federally Funded Projects

SOURCE OF ASSISTANCE	PROGRAM NAME	CONTACT NUMBER	BRIEF DESCRIPTION OF PROGRAM
DCNR	Conservation Corps, PA.		Provides funding for work crews for community projects, such as trail improvements.
DCNR	Keystone Rec., Park & Cons. Program - Land Trust Grants		Grants to well-established non-profit land trusts and conservancies to plan for and acquire critical natural areas. Land that is acquired must be open to the public.
DCNR	Keystone Rec., Park & Cons. Program - Community Grants		Provides 50% matching grants to municipalities to fund: overall planning for park and recreation, master plans for individual parks, acquisition of parkland and nature preserves, countywide natural area inventories, and rehabilitation and improvements to public recreation areas. Grants up to $20,000, without a local match, are available for material and design costs in small municipalities.
DCNR	Pennsylvania Forest Stewardship/Stream ReLeaf Program	717-787-2106	Cost-Share (75%) assistance for riparian zone protection or improvement projects: streambank restoration, fencing and crossings.
DCNR	Rivers Conservation Program	717-787-2316	Conserve and enhance river resources by offering planning grants, technical assistance, implementation grants, development grants, and acquisition grants.
DCNR	Urban Forestry Grants		Provides grants for tree planting projects. Is also a Federal "America the Beautiful" grant program for tree planting.
DEP	Coastal Zone Management Program	717-787-5259	Grants for planning and construction in the Lake Erie and the Delaware Estuary Coastal Zones.
DEP	Environmental Stewardship and Watershed Protection Grant Program	717-787-5259	Grants focus on nonpoint source pollution and watersheds: acid mine drainage abatement, mine cleanup efforts, well plugging, planning and implementing local watershed-based conservation efforts (formerly WRAP+WRPA).
DEP Bureau of Waterways Engineering	Flood Protection Program, PA		Offers design and construction of flood protection projects. The project must be deemed economically justifiable under the state capital budget process.
DEP	Nonpoint Source Management (EPA 319) Program	717-787-5259	Grants for planning and nonpoint source pollution control projects.
DEP	PA Environmental Education Grants Program	717-772-1828	Provides financial support for projects that design, demonstrate or disseminate environmental education practices, methods or techniques.

SOURCE OF ASSISTANCE	PROGRAM NAME	CONTACT NUMBER	BRIEF DESCRIPTION OF PROGRAM
DEP	Pennsylvania Wetland Replacement Project	717-787-6827	Grants for restoring wetlands, riparian corridors and other aquatic systems within the Commonwealth.
DEP	Sewage Facility Planning Grants		Grants to pay up to 50% of the costs to prepare a new sewage facilities plan or update an existing plan, under State Act 537 of 1966.
DEP	Stormwater Management Program	717-772-4048	Watershed planning for stormwater control (counties) and implementation of programs at local levels (municipalities).
DEP	Stream Bank Fencing Program	717-783-7577	To improve water quality and reduce soil erosion by constructing one or two strand fences to limit livestock access streams.
DEP	Stream Improvement Program (SIP)	717-787-3411	Assistance through the construction of small projects to prevent flooding, restore natural stream channels and to stabilize banks.
Federal Emergency Management Agency	Flood Hazard Mitigation Grant Program		Provides 75% funding to relieve imminent hazards from flooding, such as voluntary buy-outs and demolitions of highly flood-prone properties.
National Fish and Wildlife Foundation	Chesapeake Bay Small Watershed Grants Program	202-857-0166	This program supports communities undertaking small-scale watershed projects. Grants range from $1,000 to $35,000 to local governments and community groups for education and demonstration projects to protect watersheds.
National Park Service	Rivers, Trails and Conservation Assistance Program	215-597-1581	The National Park Service works with communities to conserve land and river resources and provides funding for various projects dealing with the conservation of these resources including the development of trails and greenways.
PACD	Nonpoint Source Pollution Education Mini Project Grant	717-238-7223	Small grants for Pennsylvania-based, grassroots educational projects that address nonpoint source watershed concepts.

SOURCE OF ASSISTANCE	**PROGRAM NAME**	**CONTACT NUMBER**	**BRIEF DESCRIPTION OF PROGRAM**
PA Infrastructure Investment Authority and PA DEP Bureau of Water Supply Management--Involves both U.S. EPA and State funds	PENNVEST		Offers low interest loans for construction and improvement of drinking water and wastewater systems. Outright grants may be available for highly distressed communities. Mainly intended for public systems, but some private systems may be approved. Water projects are funded through the Drinking Water Revolving Loan Fund. Sewage projects are funded through the Clean Water Revolving Fund. In addition, PennVest is authorized to provide loans for projects to control existing stormwater problems, such as separating stormwater from sanitary sewage. The "Advance Funding Program" provides low-interest loans for feasibility studies and engineering of systems if the utility cannot fund such work itself.
Pennsylvania Department of Community and Economic Development		888-223-6837	Financial assistance may include: preparing environmental protection or physical development strategies or special studies that will support comprehensive land use planning. The application of advanced technology such as Geographic Information Systems (GIS).
The William Penn Foundation Philadelphia, PA		215-988-1830	Grants to preserve natural areas, including environmental education and planning within the foundation's geographic area (primarily southeastern Pennsylvania).
U.S Department of the Interior U.S. Fish and Wildlife Service North America Waterfowl and Wetlands Office (NAWWO)		703-358-1784	The North American Wetlands Conservation Act of 1989 provides matching grants to carry out wetlands conservation projects in the United States, Canada, and Mexico. Both the Standard and Small Grants Programs help deliver funding to on-the-ground projects through protection, restoration, or enhancement of an array of wetland habitats.
U.S. Environmental Protection Agency Office of Wetlands, Oceans, and Watersheds		202-260-4538	EPA establishes a cooperative agreement with one or more nonprofit organization(s) or other eligible entities to support watershed partnership organizational development and long-term effectiveness. Funding supports organizational development and capacity building for watershed partnerships with diverse membership.

SOURCE OF ASSISTANCE	PROGRAM NAME	CONTACT NUMBER	BRIEF DESCRIPTION OF PROGRAM
U.S. Environmental Protection Agency Office of Wetlands, Oceans, and Watersheds		202-260-8076	This Five-Star Program seeks to support restoration projects in 500 watersheds by 2005, a key action of the Clean Water Action Plan. Competitive projects will have a strong on-the-ground habitat restoration component that provides long-term ecological, educational, and/or socioeconomic benefits to the people and their community.
U.S. EPA	Brownfields Program		Grants for a very limited number of pilot demonstration projects for cleanup of contaminated underused industrial sites.
U.S. EPA	Sustainable Development Challenge Grants (SDCG)	206-553-2634	Grants to support communities in establishing partnerships to encourage environmentally and economically sustainable practices.

Tookany/Tacony-Frankford Integrated Watershed Management Plan (TTFIWMP)

5-Year Implementation Plan 2006 – 2011

PWD commitment $18,000,000

This Implementation Plan (IP) builds upon an already significant body of work developed by the Philadelphia Water Department in cooperation with the Tookany/Tacony-Frankford Watershed Partnership. The Tookany/Tacony-Frankford Integrated Watershed Management Plan (TTFIWMP) was completed in the winter of 2005. This planning effort incorporated both regulatory and non-regulatory programs including the Phase I and Phase II stormwater regulations, the PA Act 537 sewage facilities planning program, the PA Act 167 stormwater management program, EPA's Combined Sewer Overflow (CSO) Control Policy and PA DCNR's River Conservation Planning program while also combining the ideas and concerns of watershed stakeholders in order to create a comprehensive vision for restoring this region.

The TTFIWMP included guidelines for implementing the management options identified by our watershed partners for areas outside the City of Philadelphia over the upcoming 20 year planning horizon. Implementation projects and initiatives within the guidelines have undergone intensive screening to determine that they are both cost-effective and feasible under the specific conditions found in the Tookany/Tacony-Frankford Creek watershed.

This implementation plan is designed to provide a more detailed blueprint for implementation of projects within the City of Philadelphia during the initial five-year period (2006-2011), though many projects have already been initiated. This plan represents the first steps in the simultaneous implementation of projects related to Targets A, B, and C. These environmental targets were established to guide the overall implementation strategies while always keeping our eyes on the long-term goals of the program.

Note that each project being implemented will require a feasibility study, followed by conceptual, preliminary, and final design reports that will provide successively more detail.

Planning, Outreach & Reporting

PWD Commitment: $1,000,000

It is imperative that the existing Tookany/Tacony-Frankford Watershed Partnership not only continue to function as a driving force within the watershed, but that it also evolve into an implementation oriented entity to take on the responsibility of executing many of the projects identified during the integrated planning process. These projects have been identified for implementation over a 20 year period, broken into five-year increments. Progress must be tracked and reported in order to illustrate progression as implementation moves forward.

P-1. Maintain Watershed Partnership

In the summer of 2005, the Tookany/Tacony-Frankford Watershed Partnership filed incorporation papers with the federal government in order to evolve its organizational structure from that of a loose alliance of stakeholders into a formal, 501(c)3 non-profit organization. The Partnership has a mission focused on implementation of the plan, and is now structurally aligned to do so. PWD will take part in the new organization, as well as move forward with its own implementation plan. PWD will support the newly formed organization in developing and carrying out future implementation efforts.

Priority Tasks	**Projected Timeline:**
1. Establish Permanent 501c3 Watershed Organization:	End of 2005
2. Develop and secure funding for project implementation: PWD will assist the TTF Partnership in the pursuit of funding for individual project implementation	Begin in 2006
3. Identify and incorporate high-priority/"Marketing" messages from the TTFIWMP Produce a document containing a short list of high-priority messages (e.g., litter and dumping, good housekeeping practices for homes and businesses, etc.) to be included in all community relations work to help support the goals of the plan. (Should include a plan for distribution of the messages, including targeted groups and means of distribution)	2006
4. Incorporate high-priority/"Marketing" messages in all outreach activities: Work interdepartmentally with PWD to incorporate messages in outreach materials. Additionally work with TTF Partnership to achieve the goals for distribution	2006 - 2011

P-2. Track WMP programs and progress

Develop and maintain a performance tracking system for plan progress. This system would track projects and monitored improvements using the indicators from the TTFIWMP.

Priority Tasks	Projected Timeline:
1. Inventory all TTF projects and initiatives related to TTFIWMP implementation, create database of information:	Begin in 2006
2. Utilize database as the clearinghouse for implementation project related information (budget, lead contact, status etc.):	2006-2011
3. Utilize for annual reporting purposes:	Begin in 2007

P-3. Annual report

CDM and OOW staff will collaborate to produce an annual report at the end of each fiscal year.

Priority Tasks	Projected Timeline:
1. Update status of each task proposed in this implementation plan:	Annually, begin 2007
(a) Write recommendations for moving each task forward in the following year:	Annually, begin 2007
2. Initiate Watershed Indicator Status Update:	Biannually, begin 2008
(a) Evaluate all 21 Watershed Indicators, document any changes:	Biannually, begin 2008
(b) Write memo documenting status changes for sharing with watershed partners:	Biannually, begin 2008
3. Update the list of projects proposed, in progress, or completed in the given year:	Annually, begin 2007
4. Monitor status and results for any projects that have been completed within the given year:	Annually, begin 2007

P-4. Update WMP and supporting technical documentation

The TTFIWMP will be updated at the end of the permit cycle. Information in the annual reports will be consolidated, progress will be assessed, and a new 5-year implementation plan will be produced.

Priority Tasks	Projected Timeline:
1. Evaluate Biological Monitoring Data collected in 2010: PWD Biological monitoring program is scheduled to be updated every five years. (Last program update was 2005)	2011
2. Evaluate accomplishments and recommendations of each Annual Report:	2010 - 2011
3. Evaluate Watershed Indicators, update with new information:	Biannually, begin 2008
4. Update TTFIWMP with new information:	2011

Target A

PWD Commitment: $9,100,000

This target is designed to help achieve water quality standards in the stream during dry weather periods. The focus is on the elimination of sources of sewage discharge during dry weather, as well as trash removal and litter prevention.

A-1. Sewer Rehabilitation and Maintenance

Sewers must be assessed to identify segments in need of rehabilitation, particularly where leakage is directly flowing into the stream. In separate sewered areas, a detection program for potential cross-connections is needed in order to eliminate dry weather flows.

Maintenance of sewers includes activities required to keep the system functioning as it was originally designed and constructed. Any reinvestment in the system, including routine maintenance, capital improvements for repair or rehabilitation, inspection activities, and monitoring activities are generally classified as maintenance.

Priority Tasks	**Projected Timeline:**
1. Continue PWD Sewer Inspection and Cleaning Program: a. Identify Sewers in need of Rehabilitation: b. Initiate Sewer repairs: c. Create a memorandum with map showing all problem areas identified: d. Provide information from the stream assessment regarding exposed and/or leaking sewers to sewer maintenance: e. Track and document sewer repairs:	2006 – 2011

A-2. Source Controls

Runoff pollution has severely impacted the stream. Ordinances must be evaluated, updated and enforced in order to ensure the reduction of pollutant sources such as pet waste and dumping. Street sweeping, inlet maintenance and additional NPDES related measures must be enforced.

Priority Tasks	Projected Timeline:
1. Implement 6 Minimum Control Measures for NPDES Stormwater Phase II:	2006 - 2011
2. Continue PWD Inlet Cleaning & Maintenance Program:	2006 - 2011
(a) Work with Inlet Maintenance team to develop an ongoing schedule of maintenance for this watershed area:	
3. Continue City of Philadelphia Street Sweeping Program:	2006 - 2011
(a) Meet with Philadelphia Streets Department to gather information regarding current street sweeping programs and scheduling:	
(b) Work with the Philadelphia Streets Department to develop a city-wide schedule of sweeping:	
4. Review Enforcement of City of Philadelphia Pet Waste Disposal and Litter/Dumping Related Ordinances:	Mid-2006
(a) Develop recommendations for improvement:	2007
(b) Discuss changes with implementing agencies:	Mid-2007
(c) Identify access points with the Fairmount Park Commission:	2007
(d) Monitor progress:	2008 - 2011
5. Continue and expand upon outreach and assistance programs to other municipalities:	2006 – 2011
(a) Outreach to municipalities regarding status of plan implementation:	
(b) Workshops and programs to share information about Stormwater BMPs:	
6. Continue the efforts of the Philadelphia Inter-Governmental Scrap and Tire Yard Task Force:	2006 – 2011
Program response to complaints about operation of scrap metal and auto salvage businesses operating in violation of regulations	

A-3. Stream Clean-up

Target A is also associated with improving the esthetic quality of the stream so that it can be viewed and treasured as a resource. Stream clean-ups are a way to achieve this while also involving residents and volunteers in the process.

The Waterways Restoration Unit was created in order to assist with the removal of litter and heavy debris from streams, maintain habitat improvements (fish ladders, FGM, elimination of plunge pools).

Priority Tasks	**Projected Timeline:**
1. Continue the efforts of the Waterways Restoration Unit: (a) Inspect and assess the condition of sewerage infrastructure along streams: (b) Identify, prioritize, & maintain a list of obstructions, aesthetic nuisances, and debris removal needs: (c) Develop and maintain a corrective action plan: (d) Investigate ROW complaints and update action plan:	2006 - 2011

Target B

PWD Commitment: $2,300,000

This target is focused on improving the in-stream conditions of the Tookany/Tacony-Frankford Creek. Implementation projects are aimed at habitat improvements as well as measures to provide the opportunity for organisms to avoid high velocities during storms. Improvements to the number, health, and diversity of the benthic invertebrate and fish species are anticipated as a result of these measures.

B-1. Stream Restoration

A high priority is placed on the creation of a restoration master plan for the Tookany/Tacony-Frankford Watershed. The plan will include recommendations from the wetland assessment program, information from the stream assessments, WRU activities, and input from the Fairmount Park Commission. The resulting document could be as simple as a large map showing outlines and key elevations for all the projects together – which would then become a check list for the creation of a detailed design for a given reach. A schedule should be outlined for high priority locations in stream restoration.

Priority Tasks	Projected Timeline:
1. Develop an FGM-based stream restoration master plan:	Mid-2006 through 2007
(a) Demonstration Project #1 – Mill Run at 7th and Cheltenham: Include bank revetment and channel modifications to the stormwater outfall. The goal is to clear the concrete pad at the outfall and re-grade 90 linear feet of the natural channel bottom and stabilize the stream banks.	2006
(b) Demonstration Project #2 – Awbury Arboretum: This multi-phased project includes; riparian buffer restoration , wetland restoration, meadow enhancement, stream daylighting, and stormwater diversion	2005-2007
(c) Demonstration Project #3 – Whitaker Ave: Include stream bank stabilization using soil bioengineering, and natural channel design measures that protect infrastructure and the environment	2006-2008
(d) Develop specific projects for large-scale restoration: Conceptual design of large scale stream restoration should be developed based on recommendations of FGM study	2008 - 2011

B-2. Wetlands Restoration and Construction

There are currently several large projects taking place (Riverfront development along the Delaware River, and the Airport expansion) that will require significant mitigation of wetlands and open water. Stream restoration provides an ideal opportunity to provide projects that serve as mitigation for the planned development projects, and that fit within the overall goals of the watershed plan.

Priority Tasks	**Projected Timeline:**
1. Complete Wetland Master Plan – including prioritization of restoration opportunities: (a) Initiate Demonstration Project #1: i. Design Demonstration Project #1: ii. Construct Demonstration Project #1:	2006 - 2011

B-3. Protect & Enhance Riparian Corridors

It is imperative that PWD and the TTF Watershed Partnership continue to work closely with the Fairmount Park Commission in order to meet the mutual goal of protecting and enhancing the riparian corridor along the Tookany/Tacony-Frankford Creek.

Priority Tasks	**Projected Timeline:**
1. Assist Fairmount Park Commission with Restoration Projects: PWD can offer assistance through project prioritization with the FGM and wetlands assessment data, project design and pursuit of funding	2006 - 2011
2. Invasive species controls: The FPC ES&ED has implemented invasive species control program in Fairmount Park portion of the stream corridor; recommended that initiative be expanded to the remaining natural areas of the corridor.	2006 - 2011
3. Assist Fairmount Park Commission with volunteer clean-up programs: Work with TTF Partnership to support clean-up efforts	2006 - 2011

Target C

PWD Commitment: $5,600,000

This target is designed to improve water quality standards in the stream during wet weather periods. These projects are designed to reduce and improve the quality of storm water discharges and to reduce CSOs.

C-1. CSO Controls

The use of Real Time Control is designed to utilize the maximum in-system storage capacity of the sewer system by using a computer controlled CSO outfall/regulator gate that uses level monitors to control the position of the dry-weather outlet (DWO) gate and tide gate at each location. This allows the capture and delivery to the treatment works of flow at the maximum rate at which it can be treated.

Priority Tasks	Projected Timeline:
1. Real Time Control Implementation	2006 - 2011

C-2. Stormwater Management Regulations

Act 167 Stormwater Management Planning is currently underway within this watershed area. The resulting model ordinance will allow for watershed-wide management of stormwater runoff. The city of Philadelphia must implement and enforce regulations city-wide to reflect the ordinance adopted by their Montgomery County counterparts in the watershed.

Priority Tasks	Projected Timeline:
1. Work with Montgomery County on completion of Act 167 Stormwater Management Planning and creation of model ordinance for the TTF Watershed:	2006 - 2008
2. Enforce new city-wide stormwater regulations:	2006 - 2011
3. Establish review procedures and staff for implementation of Urban Stormwater BMP manual:	2006
4. Complete SW Rate Structure Review and make Recommendations: (Cost of stormwater management should be fully reflected in rates charged to homeowners, businesses, and land owners in the form of stormwater fees.)	2006 - 2010
5. Begin implementing city-wide SW Rate Structure Improvements:	2010

C-3. Stormwater BMP Projects

"Model" Stormwater BMP demonstration projects will be designed and constructed illustrating the various types of on-site stormwater management techniques that can be applied in urban areas. The goal is to provide local examples of BMPs recommended under the new stormwater regulations that reduce the volume of runoff entering the sewer system as well as reduce the pollutant loads within the runoff whenever possible.

Initial load reduction targets for parameters such as stormwater flow, metals, total suspended solids, and bacteria have been set at 20%, with the goal of continuous reassessment of the load reduction target as projects are implemented.

Priority Tasks	**Projected Timeline:**
1. Complete BMP implementation plan, site list & prioritization of projects:	2006 - 2008
2. Demonstration Projects:	
(a) Martin Luther King Jr. High School: Will result in detaining and/or infiltrating first 1.5 inches of runoff from parking lots, thus diverting nearly 2.5 million gallons of runoff from combined sewer system each year	2006 - 2011
(b) Bureau of Laboratory Services Low Impact Development (LID) Retrofit Project: This retrofit could include the implementation of multiple BMPs, including an infiltration trench, cisterns, a green roof, and a bioretention system.	2006 - 2011
(c) Implement Demonstration Project #3: Demonstration projects will include the implementation of BMPs such as median infiltration, porous pavement or green roof technology.	2006 - 2011
(d) Implement Demonstration Project #4:	2006 - 2011
(e) Implement Demonstration Project #5:	2006 - 2011
(f) Implement inlet & roof leader disconnect project (Located at Awbury Arboretum):	2006 - 2011
(g) Initiate a Targeted Rain Barrel Program PWD and the TTF Partnership have already conducted a Rain Barrel Pilot Project. Based upon successes and lessons learned, a second program would be targeted to an individual sewershed and monitored for the reduction of stormwater contribution.	2006 - 2011

Priority Tasks	**Projected Timeline:**
(h) Initiate and/or invigorate TreeVitalize program in the TTF Watershed	2006 - 2007
i. Set 5 year goals for tree planting	2007 - 2008
ii. Plant trees	2008 - 2011
3. Initiate incentive grant programs for stormwater BMP implementation city-wide	2007 - 2010

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Philadelphia Combined Sewer Overflow Long Term Control Plan Update

Supplemental Documentation
Volume 14

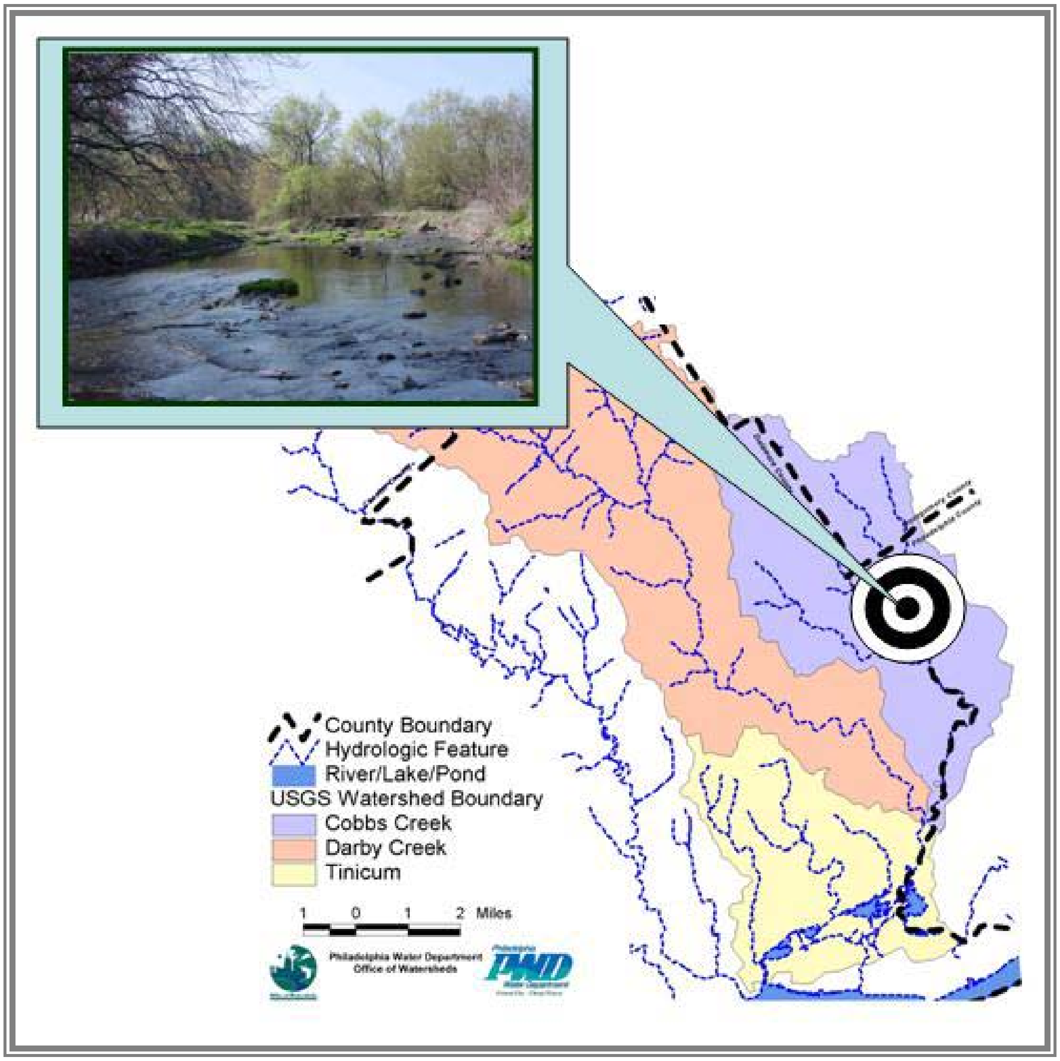
Darby-Cobbs Watershed Comprehensive Characterization Report

Updated: September 1, 2009

Darby-Cobbs Watershed Comprehensive Characterization

Technical Companion to the Cobbs Creek Integrated Watershed Management Plan

Updated June 2004 (includes data collected through December 2002)



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Section 1 Introduction

To meet the regulatory requirements and long-term goals of its CSO, stormwater, and drinking water source protection programs, The Philadelphia Water Department (PWD) has embraced a comprehensive watershed characterization, planning, and management program. Watershed management fosters the coordinated implementation of programs to control sources of pollution, reduce polluted runoff, and foster managed growth in the city and surrounding areas, while protecting the region's drinking water supplies, fishing and other recreational activities, and preserving sensitive natural resources such as parks and streams. PWD has helped form watershed partnerships including surrounding urban and suburban communities to explore regional cooperation based on an understanding of the impact of land use and human activities on water quality.

Coordination of these different programs has been greatly facilitated by PWD's recent creation of the Office of Watersheds (OOW). This newly formed organization is composed of staff from the PWD's planning and research, CSO, collector systems, laboratory services, and other key functional groups, allowing the newly established organization to combine resources to realize the common goal of watershed protection. OOW is responsible for characterization and analysis of existing conditions in local watersheds to provide a basis for long-term watershed planning and management.

OOW is developing a series of watershed management programs on each of its watersheds. Cobbs Creek is the first watershed to complete a management plan. This report contains a series of technical documents that form the technical basis for the Cobbs Creek Integrated Watershed Management Plan (CCIWMP), released in 2004. The report characterizes the land use, geology, soils, topography, demographics, meteorology, hydrology, water quality, ecology, fluvial geomorphology, and pollutant loads found in the Darby-Cobbs Creek watershed. It presents and discusses data collected through the end of 2002. The report is not intended as a single, comprehensive document, but rather a compilation of background documents that can be periodically updated as additional field work or data analysis is completed. The sections of the report were written at different times by a variety of groups, and no attempt at consistency in style or formatting has been made. Some sections of the report, including wetlands and fluvial geomorphology, are incorporated by reference to other reports.

Section 2 Characterization of the Study Area

2.1 Watershed Description and Demographics

The Darby-Cobbs watershed is defined as the land area that drains to the mouth of Darby Creek at the Delaware Estuary, encompassing approximately 80 square miles in southeastern Pennsylvania. This area includes portions of Chester, Delaware, Montgomery, and Philadelphia Counties. The watershed may be subdivided into the Cobbs Creek, Darby Creek, and Tinicum subwatersheds. Figures 2-1 and 2-2 include the watershed boundaries, hydrologic features, and political boundaries. Much of the information is based on the U.S. Census Bureau's TIGER (Topologically Integrated Geographic Encoding and Referencing) database.

Cobbs Creek drains approximately 14,500 acres or 27% of the total watershed area. The upper portions and headwaters of Cobbs Creek, including East and West Branch Indian Creek, include portions of Philadelphia, Montgomery, and Delaware Counties. The lower portion of Cobbs Creek watershed, including the lower mainstem and Naylors Run, drains parts of Philadelphia and Delaware Counties. Cobbs Creek discharges to Darby Creek.

The Darby Creek watershed drains approximately 29,000 acres or 55% of the total study area. The watershed is located primarily in Delaware County. The northwest corner of the watershed, including the headwaters of the mainstem, is located in Chester County. Darby Creek has a number of small tributaries, including Little Darby Creek, Ithan Creek, and Foxes Run.

The Darby-Cobbs watershed discharges to the Delaware River through the wetlands of the Tinicum Refuge. The Tinicum watershed includes portions of Philadelphia and Delaware Counties and totals 9800 acres or 18% of the total. Much of the area consists of low-lying wetlands, including the John Heinz National Wildlife Refuge. Named streams in the subwatershed include Hermesprota, Muckinipattis, and Stony Creeks.

In a relatively undisturbed watershed, watershed boundaries follow topographic high points or contours. The U.S. Geological Survey (USGS) has further subdivided the Darby-Cobbs watershed based on topography, as shown in Figure 2-3. These USGS subwatersheds are determined from the land area draining to a particular point of interest, such as a stream confluence or gauging site. These boundaries allow initial determinations of drainage areas and modeling elements. However, it is important in the urban environment to include the effects of man-made changes to natural drainage patterns.

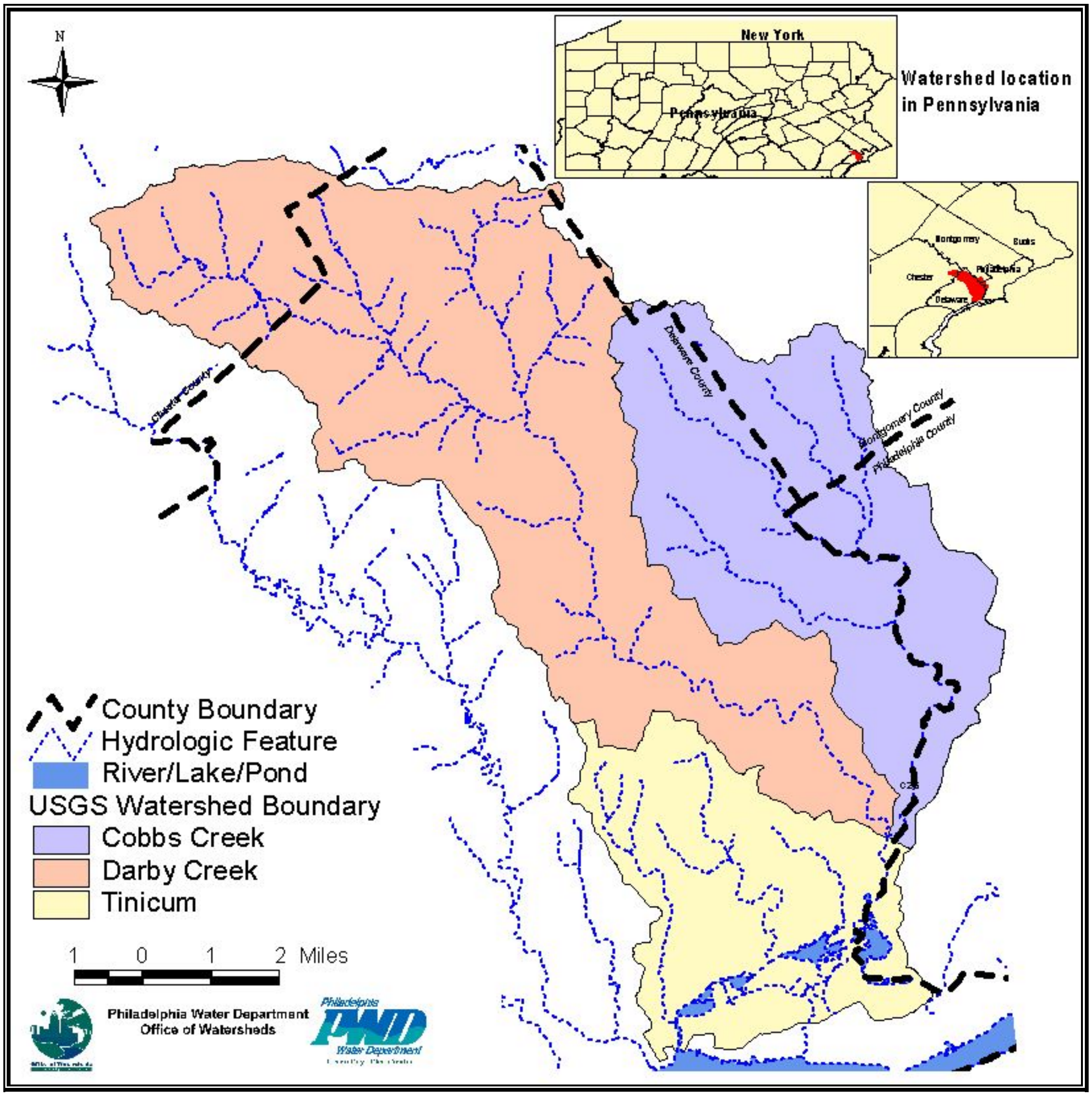


Figure 2-1 Darby-Cobbs Study Watershed

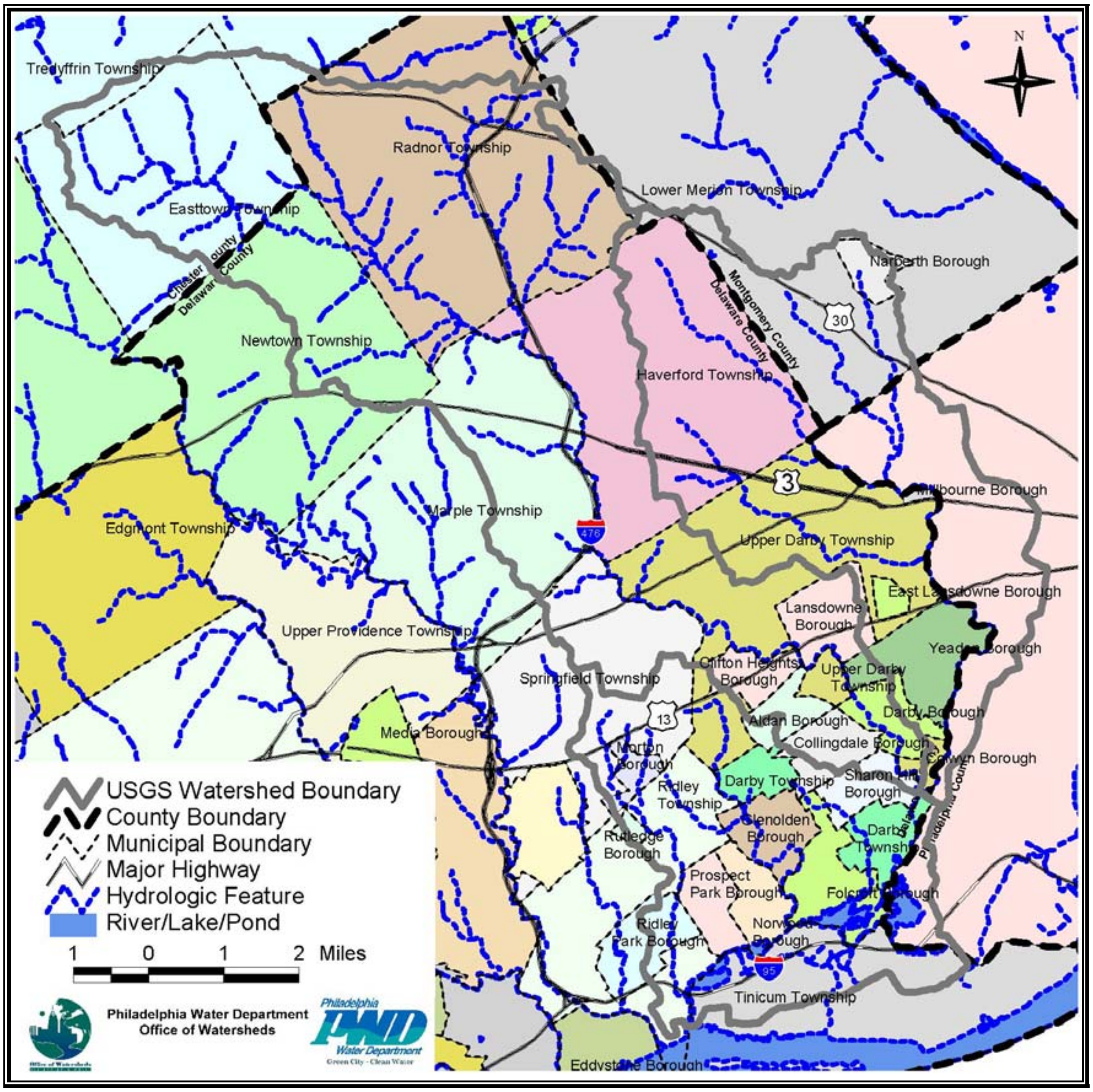


Figure 2-2 Darby-Cobbs Study Area

Geology and Soils

Geology and soils play a role in the hydrology, water quality, and ecology of a watershed. The Darby-Cobbs watershed falls within the Coastal Plain and Piedmont physiographic provinces. Geologic formations on the surface in the area include gneiss, schist, and serpentine formations in most of the watershed (Piedmont) and layers of sediment in the downstream reaches (Coastal Plain) as shown in Figure 2-4. Soils in the upper portions of the Darby Creek subwatershed include loams and silty loams, as shown in Figure 2-5. Soil in much of the rest of the watershed is classified as urban or made land and is not representative of the original undisturbed soil. Wetland soils are present in the Tinicum area.

Demographic Information

Population density and other demographic information in the watershed are available from the results of the 2000 census. Approximately 500,000 people live within the drainage area of the Darby and Cobbs Creeks. Figure 2-6 shows the population density in the watershed at the census block level. Spatial trends in population correspond closely to land use, with multi-family row homes displaying the greatest population density of 20 people per acre or more, single-family homes displaying a lower density, and other land use types displaying the lowest density. In addition to population data, the U.S. Census Bureau provides a range of socioeconomic data that are often useful in watershed planning and general planning studies. Median household income and mean home value (Figures 2-7 and 2-8) are two of the many sample datasets provided.

Figure 2-3 USGS Topographic Subwatersheds

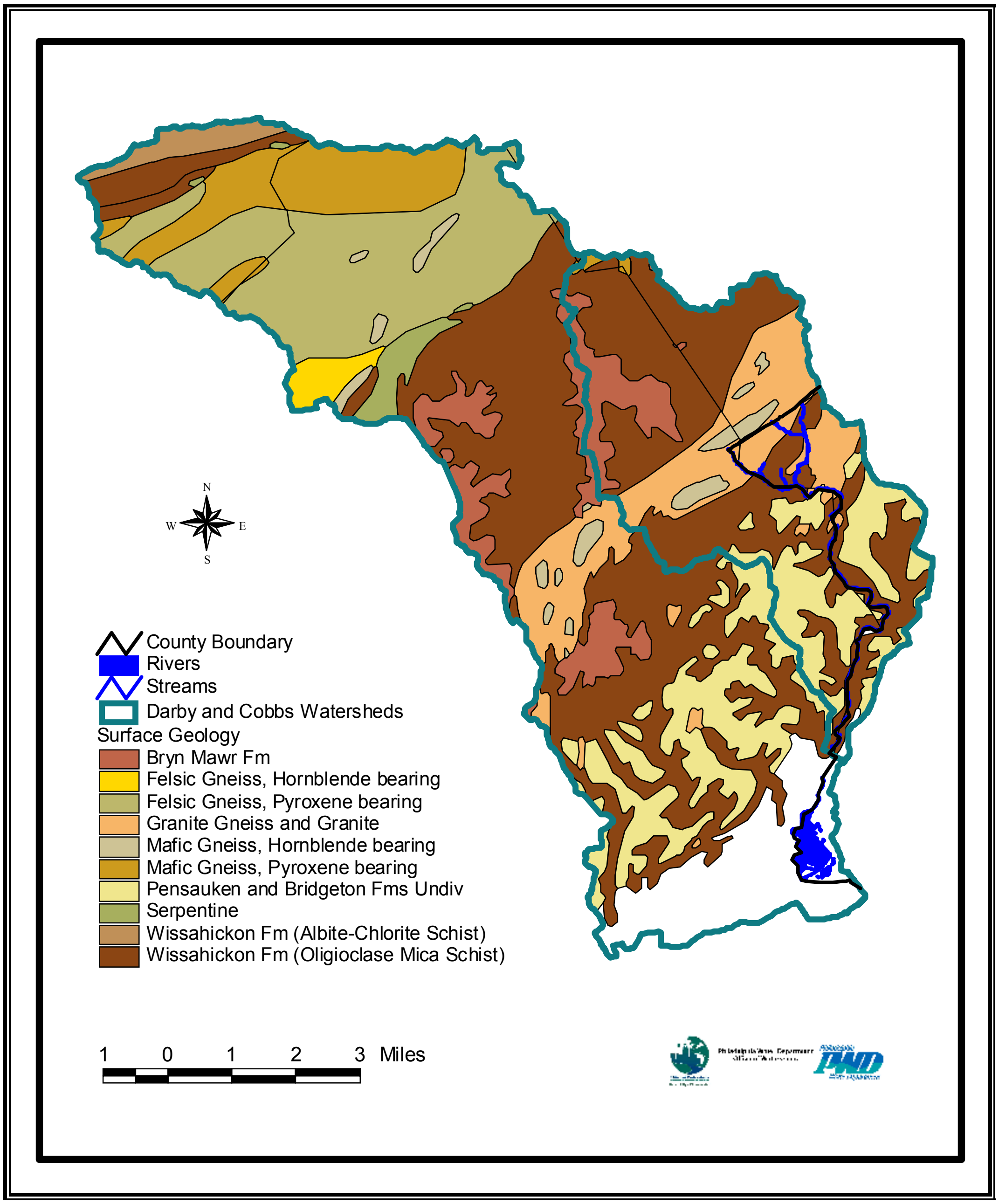


Figure 2-4 Surface Geologic Formations

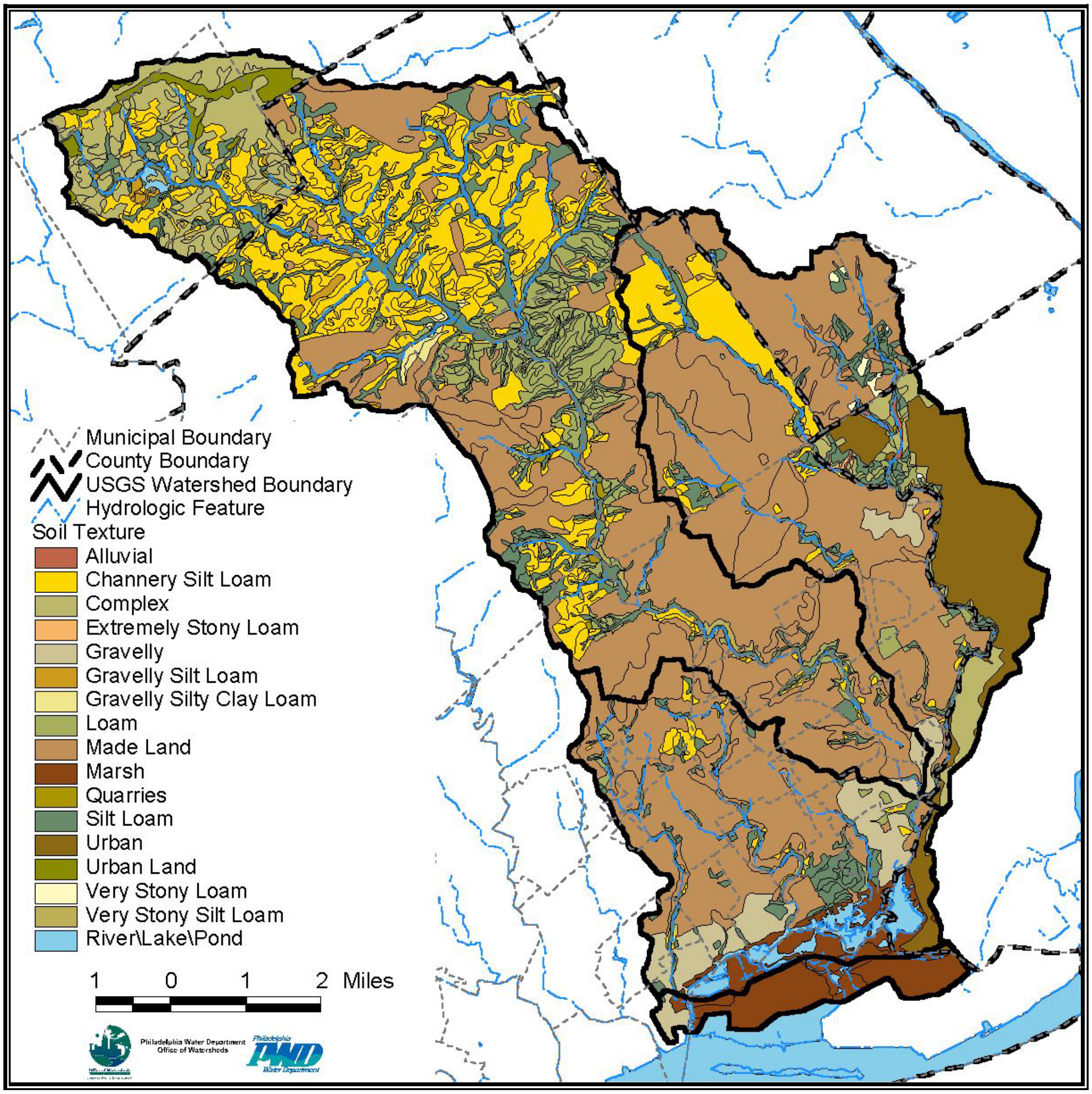


Figure 2-5 Soil Types in the Darby-Cobbs Watershed

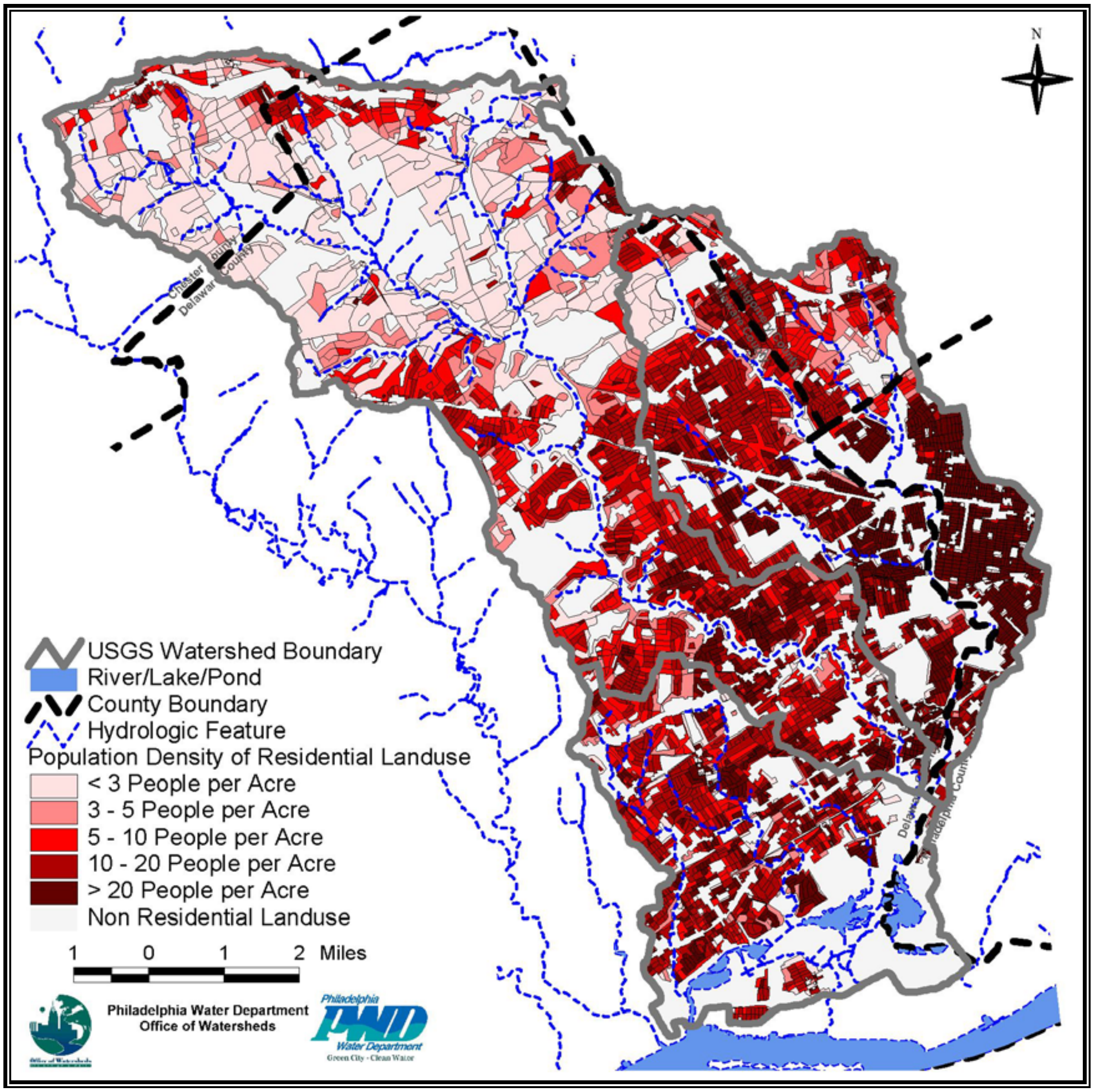


Figure 2-6 Population Density Based on 2000 Census Data

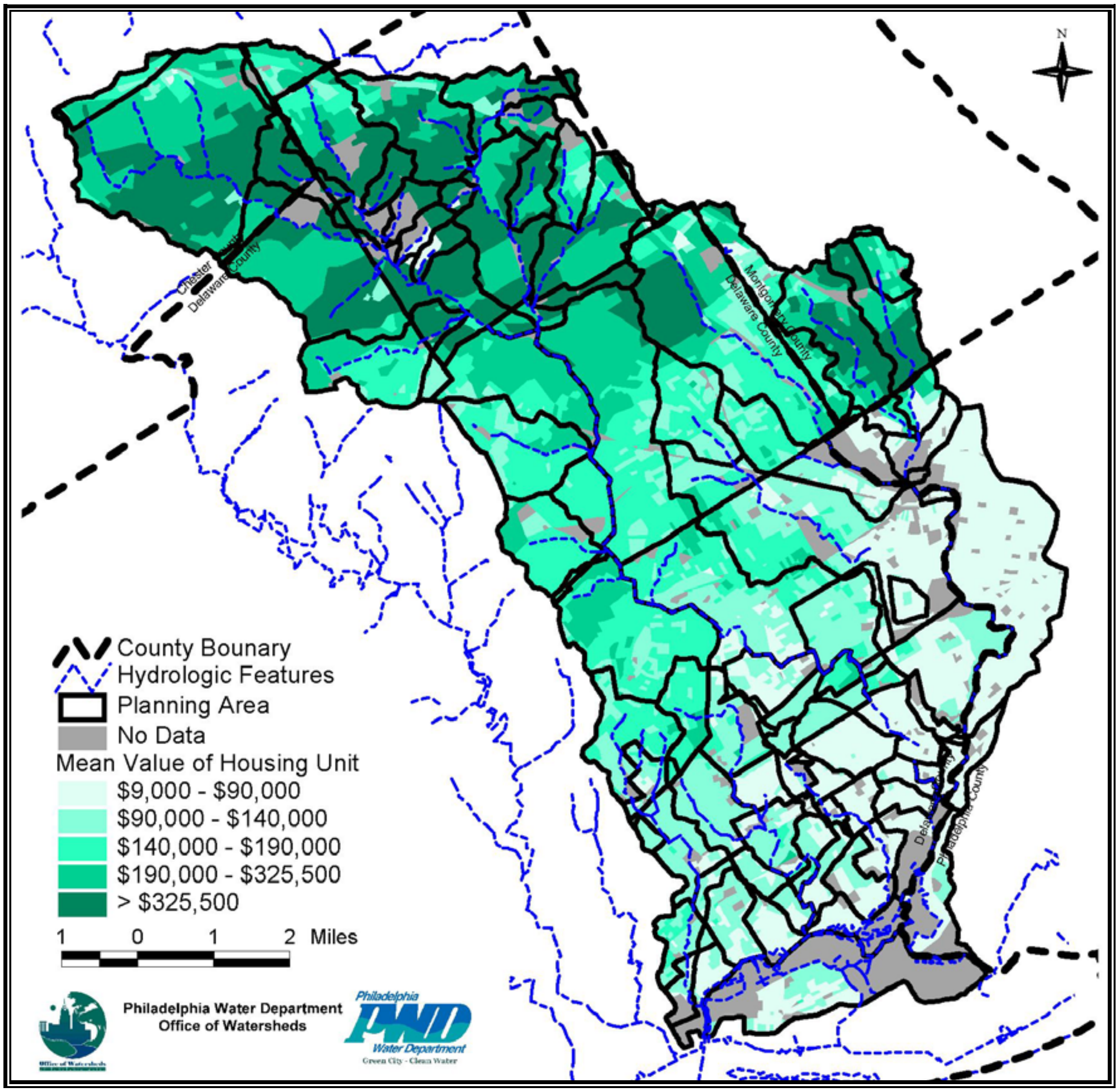


Figure 2-7 Mean Home Value

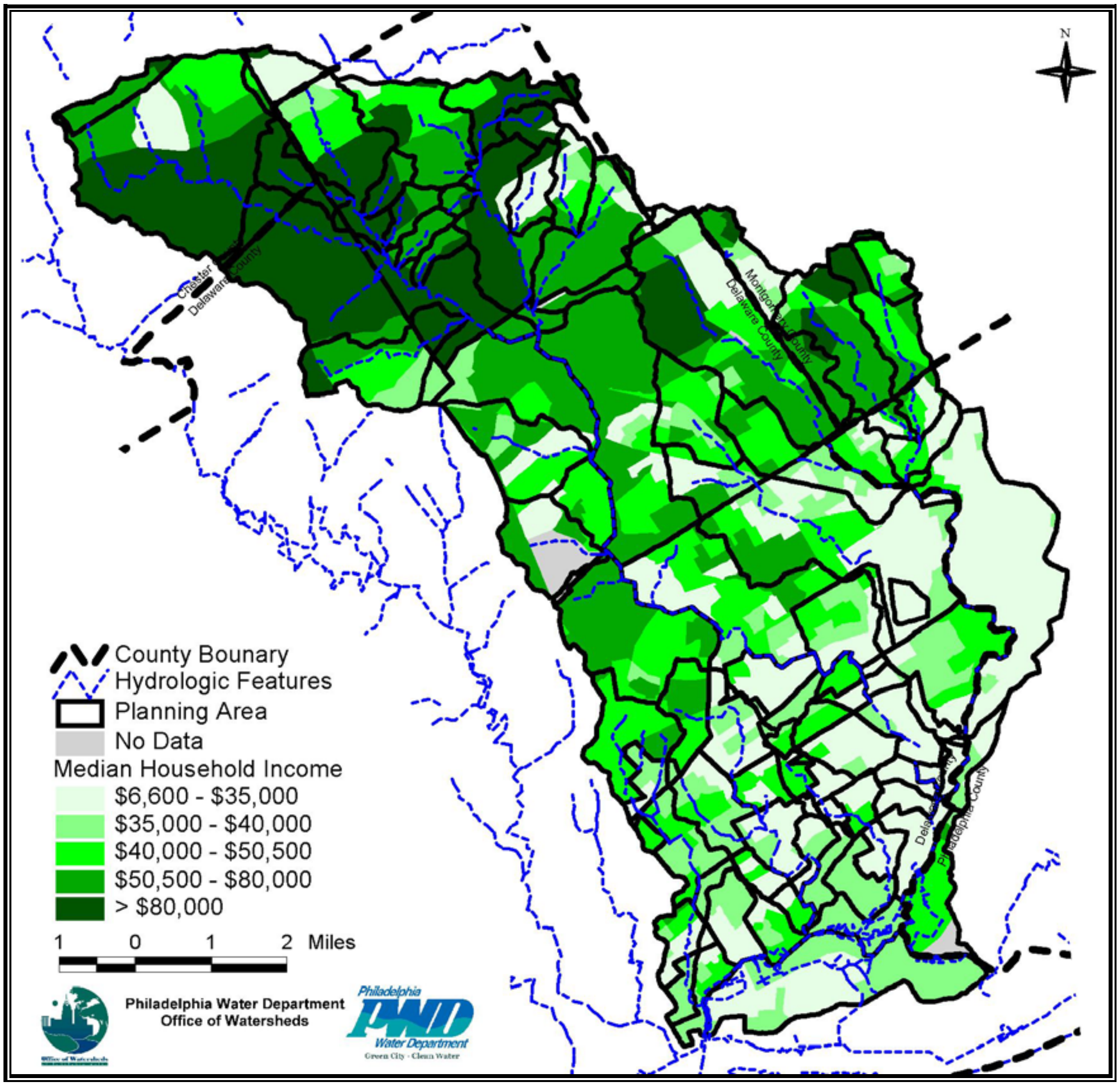


Figure 2-8 Mean Household Income

2.2 Land Use

Land use information for the Darby and Cobbs Creeks Watershed was obtained from the Delaware Valley Regional Planning Commission (DVRPC). Figure 2-9 is the current land use map for the study area. The upper reaches and headwaters of the Cobbs Creek watershed are characterized primarily by a mix of multiple-family and detached single-family residential areas. The lower portions of the Cobbs Creek watershed are primarily high-density residential areas in the City of Philadelphia and a mix of high- and low-density residential areas in the Delaware County portion, with commercial areas along highway corridors. Riparian lands within the City consist mainly of relatively undisturbed parkland.

Land uses in the Darby Creek watershed consist primarily of single- and multiple-family residential areas in the lower portions and a combination of single-family residential, commercial, park land, and golf course uses in the upper reaches. A large commercial area is located along the northern edge of the watershed in Chester and Delaware Counties. The Tinicum watershed consists of residential and commercial development to the northwest and undeveloped wetlands and marshes to the southeast.

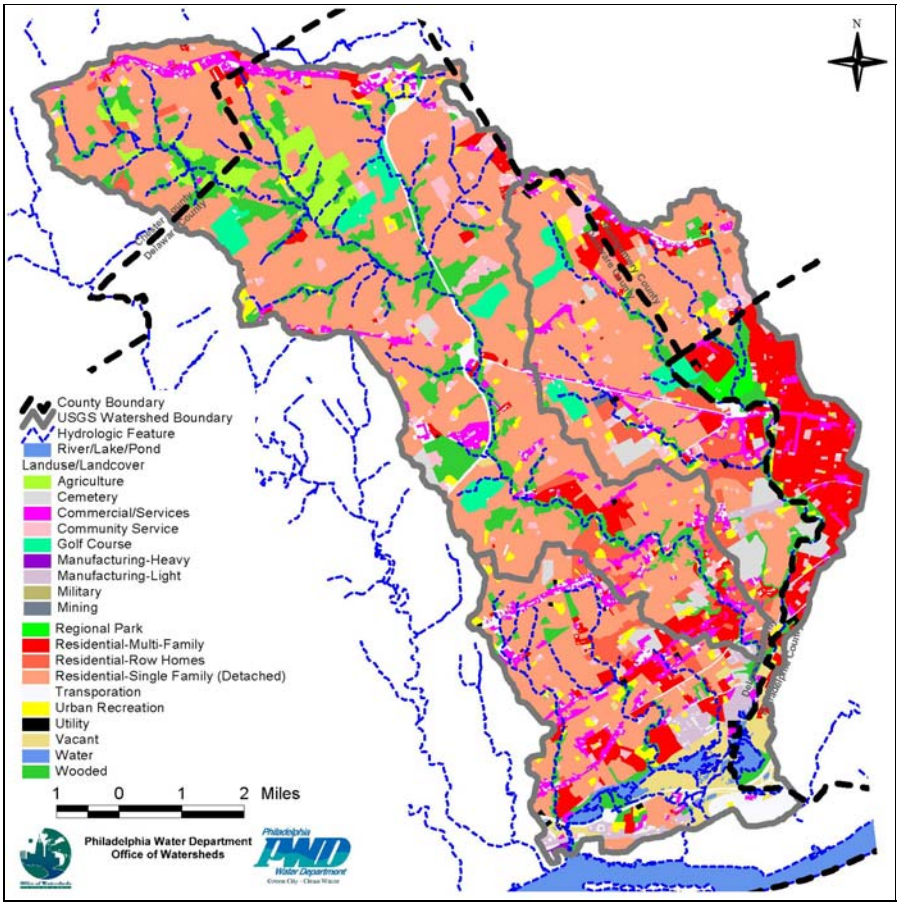


Figure 2-9 Land Use

One of the primary indicators of watershed "health" is the percent of impervious cover in the watershed. Based on numerous research efforts, studies and observations, a general categorization of watersheds has been widely applied to watershed management based on percent impervious cover (Schueler 1995). These are summarized in Table 2-1. Table 2-2 shows that the entire watershed is above 25% impervious cover, placing it in the "Non-Supporting" category of stream health.

Table 2-1 Impervious Cover as an Indicator of Stream Health (Schueler 1995)

Characteristic	Sensitive	Degrading	Non-Supporting
Percent Impervious Cover	0% to 10%	11% to 25%	26% to 100%
Channel Stability	Stable	Unstable	Highly Unstable
Water Quality	Good to Excellent	Fair to Good	Fair to Poor
Stream Biodiversity	Good to Excellent	Fair to Good	Poor
Pollutants of Concern	Sediment and temperature only	Also nutrients and metals	Also bacteria

Table 2-2 Estimated Total Impervious Cover

Watershed	County	Area (ac)	% Impervious
Cobbs	Delaware	8,041	46.7%
Cobbs	Montgomery	2,644	40.6%
Cobbs	Philadelphia	3,562	60.2%
Darby	Chester	4,217	25.7%
Darby	Delaware	24,503	38.7%
Darby	Montgomery	70	44.2%
Darby	Philadelphia	558	66.7%
Tinicum	Delaware	5,811	49.4%

Table 2-3 summarizes several of the impacts of traditional development on streams and watersheds, most of which are created by the addition of impervious cover across the portions of the land surface. Figures 2-10 and 2-11 illustrate the changes to the volume and duration of runoff as well as the physical stream channel before and after development. Figure 2-10 also illustrates the benefits of using various BMP's and low impervious techniques to manage stormwater. As Figure 2-11 depicts, traditional development within a watershed may raise the elevation of the floodplain limit and reduce summer low flows when compared to predevelopment conditions.

Table 2-3 Impacts of Traditional Development on Watershed Resources (Schueler 1995)

Changes in Stream Hydrology	Changes in Stream Morphology
▪ Increased magnitude/frequency of severe floods ▪ Increased frequency of erosive bankfull and sub-bankfull floods ▪ Reduced ground water recharge ▪ Higher flow velocities during storm events	▪ Channel widening and downcutting ▪ Streambank erosion ▪ Channel scour ▪ Shifting bars of coarse sediments ▪ Imbedding of stream substrate ▪ Loss of pool/riffle structure ▪ Stream enclosure or channelization

Changes in Stream Water Quality	Changes in Stream Ecology
▪ Instream pulse of sediment during construction ▪ Nutrient loads promote stream and lake algae growth ▪ Bacteria contamination during dry and wet weather ▪ Higher loads of organic matter ▪ Higher concentrations of metals, hydrocarbons, and priority pollutants ▪ Stream warming ▪ Trash and debris jams	▪ Reduced or eliminated riparian buffer ▪ Shift in external production to internal production ▪ Reduced diversity of aquatic insects ▪ Reduced diversity of fish ▪ Creation of barriers to fish migration ▪ Degradation of wetlands, riparian zones and springs ▪ Decline in amphibian populations

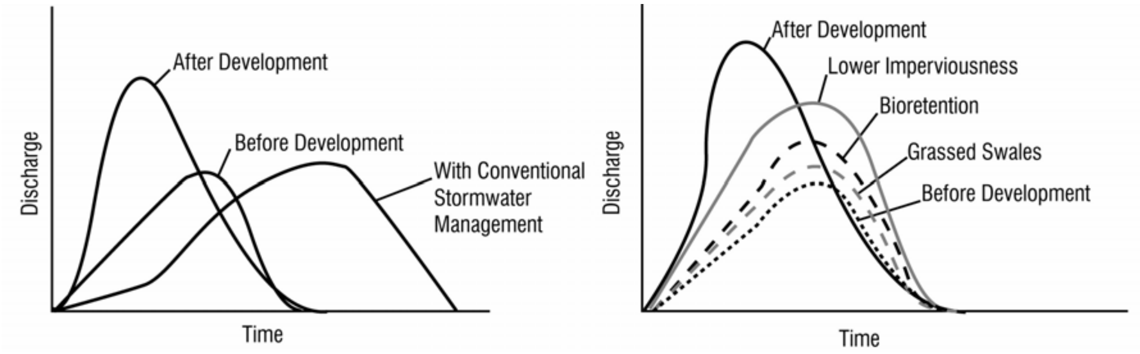


Figure 2-10: Comparison of volume and duration of stormwater runoff before and after land development, and reductions in runoff from BMP’s. (Prince George’s County Department of Environmental Resources et. al., undated)

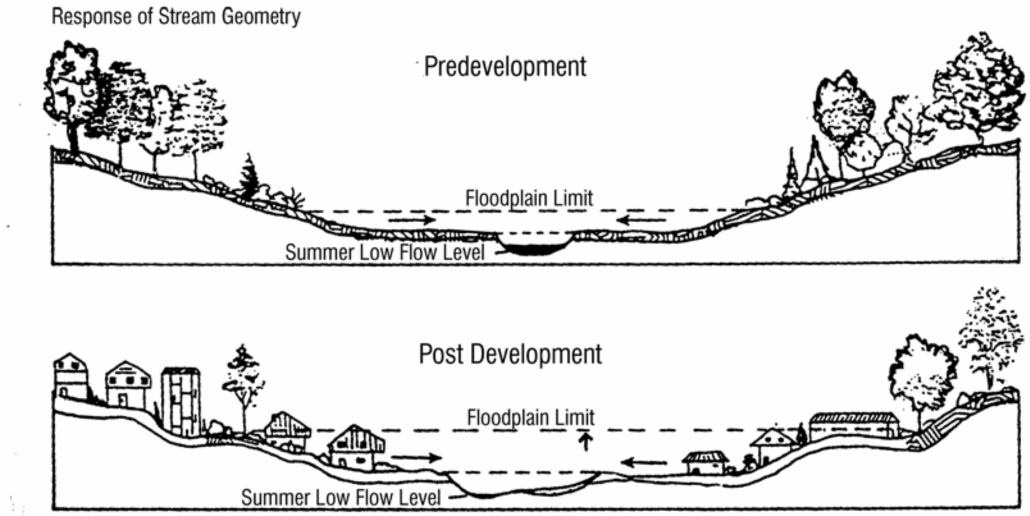


Figure 2-11: Potential impacts of development on stream flow and flooding. (Schueler 1995(a), and Schueler 1987)

Section 3 Sampling and Monitoring Program

Background

PWD's Office of Watersheds (OOW) has carried out an extensive sampling and monitoring program to characterize conditions in the Darby and Cobbs Creeks watershed. The program is designed to document the condition of aquatic resources and to provide information for the planning process needed to meet regulatory requirements imposed by EPA and PADEP. The program includes hydrologic, water quality, biological, habitat, and fluvial geomorphological aspects. OOW is well suited to carry out the program because it merges the goals of the city's stormwater, combined sewer overflow, and source water protection programs into a single unit dedicated to watershed-wide characterization and planning.

Under the provisions of the Clean Water Act, the National Pollutant Discharge Elimination System (NPDES) program requires permits for point sources that discharge to waters of the United States. In the Darby and Cobbs Creeks watershed, stormwater outfalls, wet weather sewer overflow points, and wastewater treatment plant discharges to surface waters are classified as point sources and are regulated by NPDES.

EPA's Combined Sewer Overflow Control Policy, published in 1994, provides the national framework for regulation of CSOs under NPDES. The Policy guides municipalities and state and Federal permitting agencies in meeting the pollution control goals of the CWA in as flexible and cost-effective a manner as possible. As part of the program, communities serviced by combined sewer systems are required to develop long-term CSO control plans (LTCPs) that will result in full compliance with the CWA in the long term, including attainment of water quality standards. PWD completed its LTCP in 1997 and is currently implementing its provisions. The strong focus of the National CSO Policy on meeting water quality standards is a main driver behind PWD's water quality sampling and monitoring program.

Regulation of stormwater outfalls under the NPDES program requires operators of medium and large municipal stormwater systems or MS4s, such as the separate-sewered portions of the Darby and Cobbs Creeks watershed, to obtain a permit for discharges and to develop a stormwater management plan to minimize pollution loads in runoff over the long term. Partially in administration of this program, PADEP assigns designated uses to water bodies in the state and performs ongoing assessment of the condition of the water bodies to determine whether the uses are met and to document any improvement or degradation. These assessments are performed primarily with biological assessments based on the EPA's Rapid Biomonitoring Protocols (RBPs) for benthic invertebrates and fish. Water bodies that do not meet their designated uses are classified as unattained and are included on the state listing of impaired waters under section 303(d) of the CWA.

Cobbs Creek and its tributaries are designated warm water fisheries. Darby Creek is designated a cold water fishery above PA Route 3 and a trout stocking fishery below Route 3. Muckinipattis and Stony Creeks in the Tinicum subwatershed are designated warm water fisheries. All of the Cobbs watershed and the lower portions of the Darby watershed are classified as unattained by PADEP. For this reason, the stormwater permit for the City of Philadelphia specifies that the state of the aquatic resource must be evaluated periodically. Because PADEP has endorsed biomonitoring as a means of determining attainment of uses, PWD periodically performs RBPs in the Cobbs watershed and has assisted PADEP on assessments in the Darby watershed.

OOW is responsible for characterization and analysis of existing conditions in local watersheds to provide a basis for long-term watershed planning and management. The extensive sampling and monitoring program described in this section is designed to provide the data needed for the long-term planning process.

Summary of Sampling and Monitoring

PWD’s Office of Watersheds (OOW) and Bureau of Laboratory Services (BLS) have planned and carried out an extensive sampling and monitoring program to characterize conditions in the Darby and Cobbs Creeks watershed. The program includes hydrologic, water quality, biological, habitat, and fluvial geomorphological aspects. OOW is well suited to administer the program because it merges the goals of the city’s stormwater, combined sewer overflow, and source water protection in a single unit dedicated to watershed-wide characterization and planning.

Sampling and monitoring follow the Quality Assurance Project Plan (QAPP) and Standard Operating Protocols (SOPs) prepared by BLS. These documents cover the elements of quality assurance, including field and laboratory procedures, chain of custody, holding times, collection of blanks and duplicates, and health and safety. They are intended to help the program achieve a level of quality assurance and control that is acceptable to regulatory agencies.

Tables 3-1 and 3-2 summarize the types, amounts, and dates of recent sampling and monitoring performed by PWD, PADEP, and USGS. A river mile-based naming convention is followed for sampling and monitoring sites located along waterways in the watershed. The naming convention includes three letters and three or more numbers which denote the watershed, stream, and distance from the mouth of the stream. For example, site DCC-110 is located as follows:

- “DC” stands for the Darby-Cobbs watershed.
- “C” stands for Cobbs Creek.
- “110” places the site 1.10 miles upstream of the mouth of Cobbs Creek, where it flows into Darby Creek.

Table 3-1 Summary of Physical and Biological Sampling and Monitoring

Site Name	USGS Gauge	Physical			Biology			
		PWD Geomorph.	USGS Daily Flow	USGS Annual Peak Flow	PWD			PADEP
					RBP III	RBP V	Habitat	
DCC-110	01475550	Assessments were performed at cross-sections located throughout the system.	1964-1990	1964-1990	December 1999		December 1999	
DCC-175						April 2000		
DCC-455					December 1999		December 1999	
DCC-505						April 2000		
	01475540		1964-1973	1965-1971				
DCC-770	01475530		1964-1981	1964-1980			December 1999	
DCC-820						April 2000		
DCC-865					December 1999		December 1999	
DCD-765	01475510		1964-1990	1964-1990				
	01475545		1972-1978	1972-1978				
DCD-1170								
DCD-1570								
DCD-1660								
	01475300		1972-1997*	1972-1996				
STA01 - STA12								1995-1996
DCI-010								
DCI-135					December 1999		December 1999	
DCIW-010					December 1999		December 1999	
DCIW-100						April 2000		
DCIW-185					December 1999		December 1999	
DCM-300								
DCN-010								
DCN-185					December 1999		December 1999	
DCN-215						April 2000		
DCS-170								

* Provisional data are available up to the present.

Table 3-2 Summary of Water Quality Sampling and Monitoring

		Chemical		
	USGS	PWD		
Site Name	Gauge	Discrete	Continuous	Wet Weather
DCC-110	01475550	14 samples 5/11/99-6/29/00	3379 hrs	3 periods 5/23/00-7/28/00
DCC-115			951 hrs	
DCC-175				
DCC-455		10 samples 5/11/99-7/20/99	3176 hrs	
DCC-505				
	01475540			
DCC-770	01475530	10 samples 5/11/99-7/20/99	2486 hrs	
DCC-820				
DCC-865				
DCD-765	01475510	12 samples 5/11/99-6/12/00	1854 hrs	3 periods 5/23/00-7/28/00
	01475545			
DCD-1170		10 samples 5/11/99-7/20/99		
DCD-1570		10 samples 5/11/99-7/20/99		
DCD-1660		4 samples 6/1/00-7/13/00	2645 hrs	1 period 7/27/00-7/28/00
	01475300			
STA01 - STA12				
DCI-010		10 samples 5/11/99-7/20/99		
DCI-135				
DCIW-010				
DCIW-100				
DCIW-185				
DCM-300		10 samples 5/11/99-7/20/99		
DCN-010		10 samples 5/11/99-7/20/99	167 hrs	
DCN-185				
DCN-215				
DCS-170		10 samples 5/11/99-7/20/99		

Hydrologic and Outfall Monitoring

Hydrologic monitoring includes a system of precipitation gauges and measurement of flows at outfall points. Characterization of hydrologic and hydraulic data is presented in Section 4.

Precipitation data are available from the National Oceanography and Atmospheric Administration (NOAA) and from local gauges operated by PWD and other organizations. NOAA's gauge at the Philadelphia International Airport, located in southeastern Philadelphia, has over 100 years of hourly precipitation data; the period of record runs from January 3, 1902 through the present. Additional precipitation data can be obtained from PWD's network of 23 rain gauges throughout the city; these data are available in 15-minute increments from the early 1990's to the present. Five of the City gauges are located in or near the Darby and Cobbs Creeks watershed, as shown in Figure 3-1.

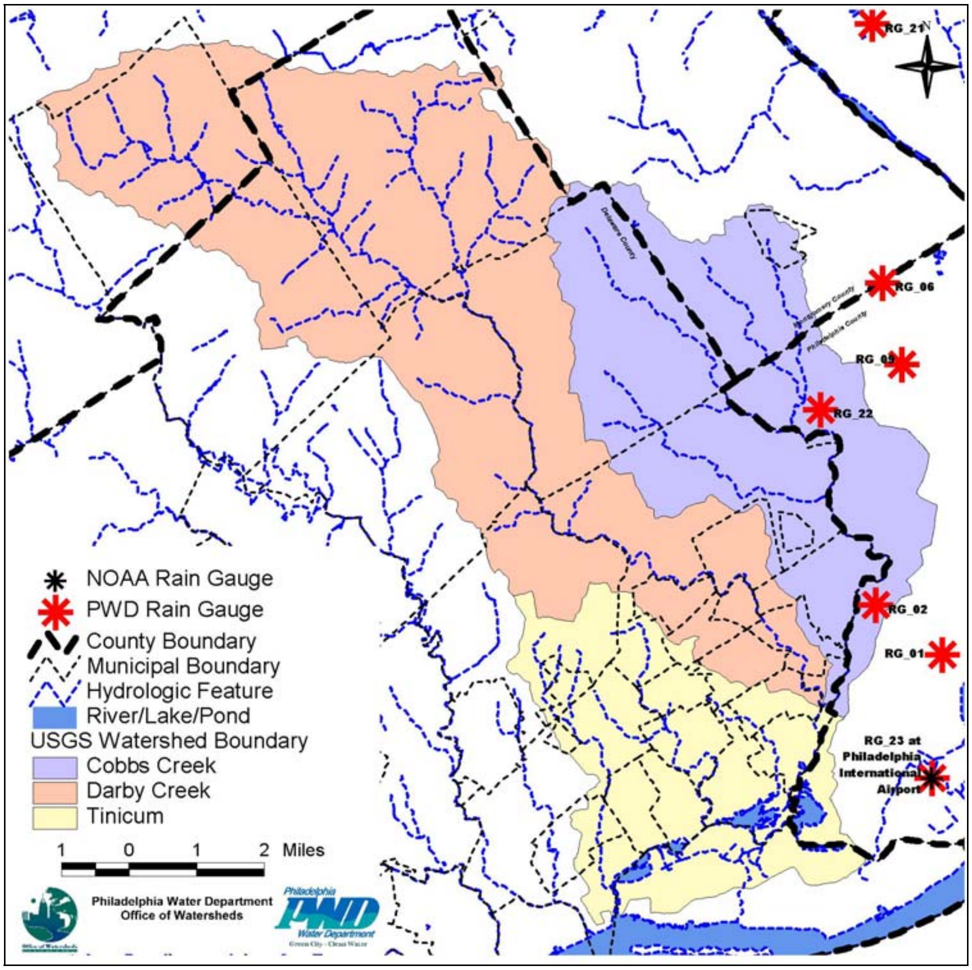


Figure 3-1 City Rain Gauges In or Near the Watershed

PWD maintains real-time sewer monitors in the Cobbs Creek system. At these points, monitors are typically present in the trunk sewer just above the regulator and in the outfall pipe itself. The magnitude and quality of discharges from the city's CSO outfalls are determined by a combination of this monitored data and calibrated computer models.

Water Quality Sampling and Monitoring

A range of water quality samples were collected between 1999 and 2001 at eleven sites in the watershed. The sites are listed in Table 3-3 and are shown on Figure 3-2. Three different types of sampling were performed as discussed below. Parameters were chosen because state water quality criteria apply to them or because they are known or suspected to be important in urban watersheds. The parameters sampled during each type of sampling are listed in Table 3-4. Water quality in each reach and section of the watershed is characterized in Section 5.

The sampling and analysis program meets AMSA (2002) et al. recommendations for the minimum criteria that should form the basis for impairment listings:

- Data collected during the previous five years may be considered to represent current conditions.
- At least ten temporally independent samples should be collected and analyzed for a given parameter.
- "A two-year minimum data set is recommended to account for inter-year variation, and the sample set should be distributed over a minimum of two seasons to account for inter-seasonal variation."
- "No more than two-thirds of the samples should be collected in any one year."
- "Samples collected fewer than four days apart at the same riverine location should be considered one sample event."
- "Samples collected within 200 meters [about 0.1 miles] of each other will be considered the same station or location." This convention was followed except where two sampling sites were chosen to represent conditions upstream and downstream of a modification such as a dam.

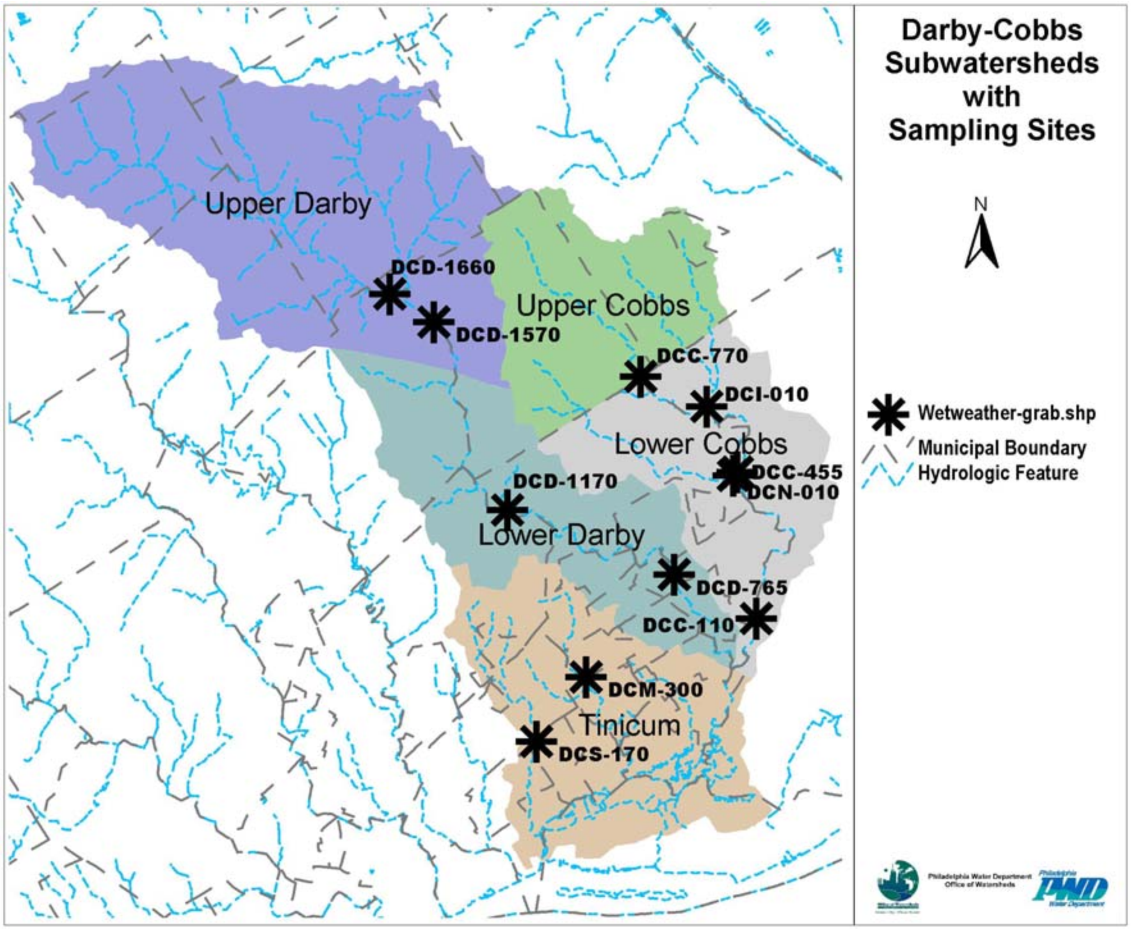


Figure 3-2 Water Quality Sampling Sites

Table 3-3 Water Quality Sampling Sites

Cobbs Creek	Darby Creek	Tinicum
Mainstem DCC110 DCC455 DCC770	Mainstem DCD765 DCD1570 DCD1660	Muckinpates Creek DCM300
Naylors DCN010		Stony Creek DCS170
Indian Creek DCI010		

Table 3-4 Water Quality Parameters Sampled

Parameter	**Units**	**Discrete**	**Wet Weather**	**Continuous**
PHYSICAL PARAMETERS				
Temperature	deg. C	X	X	X
pH	none	X	X	X
Specific Conductance	uS/cm	X	X	X
Alkalinity	mg/L as CaCO3	X	X	
Turbidity	NTU	X	X	X
TSS	mg/L	X	X	
TDS	mg/L	X	X	
OXYGEN AND OXYGEN DEMAND				
DO	mg/L	X	X	X
BOD5	mg/L	X	X	
BOD30	mg/L	X	X	
CBOD5	mg/L	X		
NUTRIENTS				
Total Ammonia	mg/L as N	X	X	X*
Nitrate	mg/L as N	X	X	X*
Nitrite	mg/L as N	X	X	X*
TKN	mg/L as N	X	X	
Phosphate	mg/L as P	X	X	
Total Phosphorus	mg/L	X	X	
METALS				
Aluminum	mg/L	X	X	
Calcium	mg/L	X	X	
Cadmium	mg/L	X	X	
Chromium	mg/L	X	X	
Copper	mg/L	X	X	
Fluoride	mg/L	X	X	
Iron	mg/L	X	X	
Dissolved Iron	mg/L	X		
Magnesium	mg/L	X	X	
Manganese	mg/L	X	X	
Lead	mg/L	X	X	
Zinc	mg/L	X	X	
BIOLOGICAL				
Chlorophyll A	ug/L	X	X	
Total Chlorophyll	ug/L	X	X	
Fecal Coliform	/100 mL	X	X	
E. coli	/100 mL	X	X	
Osmotic Pressure	mosm	X	X	
MISCELLANEOUS				
Phenolics	mg/L	X	X	

* Results did not pass quality assurance but may have some value as a relative measure.

Discrete Sampling. Discrete samples were collected at 11 sites in both wet and dry weather at an interval of two weeks to one month. During discrete sampling, each sampling site along a stream is sampled once during the course of a few hours. The purpose of discrete sampling is initial characterization of water quality under both dry and wet conditions and identification of parameters of possible concern. Discrete sampling follows the Standard Operating Protocol "Field Procedures for Grab Sampling".

Wet Weather Event Sampling. At three sites, a series of samples was collected over the course of several wet weather events. During wet weather sampling, several discrete samples are collected just before and during the course of a wet weather event. The data allow characterization of water quality responses to stormwater runoff and wet weather sewer overflows.

Continuous Measurement. Continuous data were collected at six sites for a total of over 12,900 hours. During continuous sampling, data for selected parameters are collected at 15-minute increments by a submerged instrument (YSI Sonde 6600) over approximately two weeks. The instrument measures parameters using voltage and diffusion-based probes rather than physically collecting samples. Parameters measured include stage, dissolved oxygen, temperature, pH, turbidity. To the author's knowledge, this type of equipment has not been employed extensively in urban streams in the past. This method produces 96 measurements per parameter every 24 hours, but cost and quality control are more challenging compared to discrete sampling. The SOP for continuous sampling describes the extensive quality control and assurance procedures applied to the data.

Biological and Habitat Monitoring

Benthic invertebrate, fish, and habitat assessments were carried out by PWD in the Cobbs Creek watershed between December 1999 and April 2000. Bioassessment procedures are summarized below. The results of the bioassessments are presented in Section 6.

Fish Sampling. Five sampling stations were chosen on Cobbs Creek; three on the main stem and two sites on the smaller tributaries, West Branch Indian Creek and Naylor's Run. Prior to the main stem analysis, the Academy of Natural Sciences (ANS) completed their assessment on the three tributaries and were interested in completing a watershed analysis on Cobbs Creek. Data from these sites were provided to the Philadelphia Water Department and the Pennsylvania Department Of Environmental Protection (PADEP). Using EPA protocols for rapid bioassessment, a reach was measured using a graduated tape and both upstream and downstream portions were blocked off using standard seining nets. Two Coffelt backpack electro-shockers were operated at 50-75 watts direct current (DC). Fish were collected using D-frame dip nets, identified to species and total length of each individual was obtained.

Benthic Invertebrate Sampling. On December 6th-7th, 1999, the Pennsylvania Department of Environmental Protection (PADEP), Office of Watersheds and the Bureau of Laboratory Services conducted Rapid Bioassessment Protocols (RBP III) on seven sites (Figure 3.2) in the Cobbs Creek watershed. Using EPA guidelines, macroinvertebrates were collected by placing a standard D-frame dipnet at the downstream portion of a riffle. The substrate was then kicked and scraped manually one meter from the net aperture to remove all benthic species. This procedure was repeated at another riffle location with less flow. Specimens were then preserved in 95% ETOH (ethyl alcohol) and returned to the laboratory in polyethylene containers. In the laboratory, samples were placed in a 11″ x 14″ gridded (numbered) pan and random "plugs" were examined until 100 individuals were collected. Macroinvertebrates were identified to genus and population estimates were calculated.

Habitat Assessment. Prior to the benthic procedures, habitat assessments at the seven sites were completed based on the Stream Classification Guidelines for Wisconsin (Ball, 1982) and Methods of Evaluating Stream, Riparian, and Biotic Conditions (Platts et al., 1983). Reference conditions were used to normalize the assessment to the "best attainable" situation. Habitat parameters are separated into primary, secondary, and tertiary parameters. Primary parameters are those that characterize the stream "microscale" habitat and have the greatest direct influence on the structure of the indigenous communities. Secondary parameters measure the "macroscale" habitat such as channel morphology characteristics. Tertiary parameters evaluate riparian and bank structure and comprise three categories: (1) bank vegetative protection, (2) grazing or other disruptive pressure, and (3) and riparian vegetative zone width. Additional habitat assessment was also carried out by the fluvial geomorphological study team using customized parameters from the Rapid Steam Assessment Technique (RSAT, Washington Metropolitan council of Governments) and the Qualitative Habitat Evaluation Index (Ohio).

Fluvial Geomorphological Monitoring

Assessment of fluvial geomorphological conditions in the watershed was performed to support future stream channel, streambank, and habitat restoration initiatives. The results of the assessments are presented in Section 8.

Approximately eleven miles of stream cross sections and banks were assessed within the study area. A team of three environmental scientists walked the length of Cobbs Creek and Indian Creek and characterized channel morphology, disturbance, stability, and habitat parameters. The team surveyed cross sections of Cobbs Creek and Indian Creek to characterize the morphological features of the channel, provide a template for hydrologic and hydraulic modeling, and serve as a baseline for assessing channel bank and bed changes (erosion and sediment accretion). Features surveyed included breaks in slope, bankfull stage, water surface and thalweg. A permanent bench mark was established on one side of the cross section to mark the location and relative elevation.

The assessment team installed bank pins and scour chains, providing PWD the opportunity to measure and quantify stream bank erosion and streambed degradation/aggradation. As the bank begins to erode, the pins protrude further and further into the steam. After a storm event, technicians can locate the pins and measure the distance they protrude and compare that to the previous distance. This 'depth' of erosion can then by multiplied by the length and height of the eroded bank to quantify the cubic yards of sediment being deposited into the channel. Over time these measurements can be correlated to different storm events to estimate the rate and quantity of sediment being deposited into the system. Similarly, scour chains are placed into the bed of the stream and allow one to measure the amount of bed scour or sediment accretion occurring during each storm event. Both the bank erosion pins and the bed scour chains are easy to maintain and measure and provide solid data that can be used to estimate degradation and prioritize capital improvement projects.

Section 4 Characterization of Hydrology

This section examines the components of the hydrologic cycle for the Darby-Cobbs watershed. The hydrologic cycle includes precipitation, evaporation, infiltration into soil, stormwater runoff over the land surface and in the sewer system, surface water flow in streams, and groundwater. The different types of sewer systems that serve the area are discussed in this section because they are an important part of the hydrologic cycle in the urban environment.

4.1 Components of the Urban Hydrologic Cycle

One way to develop an understanding of the hydrologic cycle is to develop a water balance. The balance tries to characterize the flow of water into and out of the "system" by assigning estimated rates of flow for all of the components of the cycle. It is also important to understand that the natural water cycle components of precipitation, evapotranspiration (ET), infiltration, stream baseflow, and stormwater runoff must be supplemented by the many artificial interventions related to urban water, wastewater, and stormwater systems.

The first step in developing a water balance for the urban hydrologic cycle is to identify the system boundaries and the pathways that allow water to cross those boundaries. For the Darby and Cobbs Creeks watershed, the system includes the land surface within the watershed boundaries, structures and vegetation on the surface, and the subsurface beneath the watershed. Inputs to the system are precipitation and outside sources of potable water. Outflows from the system include streamflow through the system outlet, evaporation and transpiration losses to the atmosphere, and flows of wastewater to the system outlet. In addition, it is possible for subsurface exchanges to occur across the boundary.

Precipitation that falls on the land surface may evaporate, be taken up by plants and lost through transpiration, flow directly to a water body over land or through a storm sewer system, or enter a combined sewer system. In combined sewer systems, a portion of flow is captured by the sanitary sewer system and a portion reaches surface water. Flow in streams consists of stormwater runoff, combined sewer overflow, delayed wet weather inputs through shallow groundwater, and a baseflow component due to the discharge of groundwater to the creek during dry weather. A portion of potable water pumped in from outside the watershed enters the sanitary sewer system and is sent to outside treatment plants, and a portion is lost to consumptive uses.

The system inflows and outflows can be split into a number of components. These are shown below as a simple, input equals output water balance with the many natural and anthropogenic components of a typical urban water cycle.

Inflows: P + OPW + WW/IND Rech + EDR + WW Disch

Outflows: RO + SWW+ GWW + EDW + BF + OWD + ET where:

P is the average precipitation at the Philadelphia gage

OPW is the outside potable water brought in

WW/IND Rech is the wastewater and industrial discharge back to groundwater

EDR is the estimated domestic recharge from private septic systems

WW Disch is the discharge of water to creeks from larger wastewater plants or industrial facilities

RO is the surface water runoff component of precipitation

SWW is the withdrawal of water from creek, primarily for public water supply and industrial use

GWW is the groundwater withdrawal from public water supply or industrial wells

EDW is the estimated domestic withdrawal of groundwater from private wells

BF is the median baseflow of streams

OWD is the discharge of wastewater to outside plant

ET is the evaporation and transpiration of water (including error)

4.1.1 Precipitation

P + OPW + WW/IND Rech + EDR + WW Disch = RO + SWW+ GWW + EDW + BF + OWD + ET

Precipitation is the primary, natural inflow to the hydrologic system. Precipitation data used to estimate this component are available from the National Oceanography and Atmospheric Administration (NOAA) and from local gauges operated by PWD and other organizations. NOAA's gauge at the Philadelphia International Airport, located in southeastern Philadelphia, has over 100 years of hourly precipitation data covering a period of record from January 3, 1902 through the present. The average annual rainfall in the Philadelphia area based upon the airport gauge is 41 inches. Most months have average precipitation totals of 3-4 inches. The driest season is late fall, and the wettest is late summer when thunderstorms are common (Table 4-1). Average temperatures during the winter months are above the freezing point during the day and below the freezing point at night. Snow and snowmelt events occur, but it is rare for a snow pack to accumulate and last through the season.

Additional precipitation data can be obtained from PWD's network of 23 rain gauges throughout the city; these data are available in 15-minute increments from the early 1990's to the present. Five of the City gauges are located in or near the Darby and Cobbs Creeks watershed, as shown in Figure 4-1. Data from these gauges provide precipitation at a higher level of spatial and temporal detail.

Table 4-1 Average Monthly Precipitation, Temperature, and Potential Evaporation

		Average Temperature		
Month	Average Precipitation (in)	High (°F)	Low (°F)	Potential Evaporation (in/month)
January	3.3	39.2	24.4	2.1*
February	2.9	42.1	26.1	2.1*
March	3.6	50.9	33.1	2.1
April	3.4	63	42.6	4.5
May	3.5	73.2	52.9	5.4
June	3.6	81.9	61.7	6.3
July	4.1	86.4	67.5	6.6
August	4.3	84.6	66.2	5.7
September	3.4	77.4	58.6	4.2
October	2.8	66.6	46.9	2.7
November	3.0	55	37.6	2.1
December	3.3	43.5	28.6	2.1*

* estimated

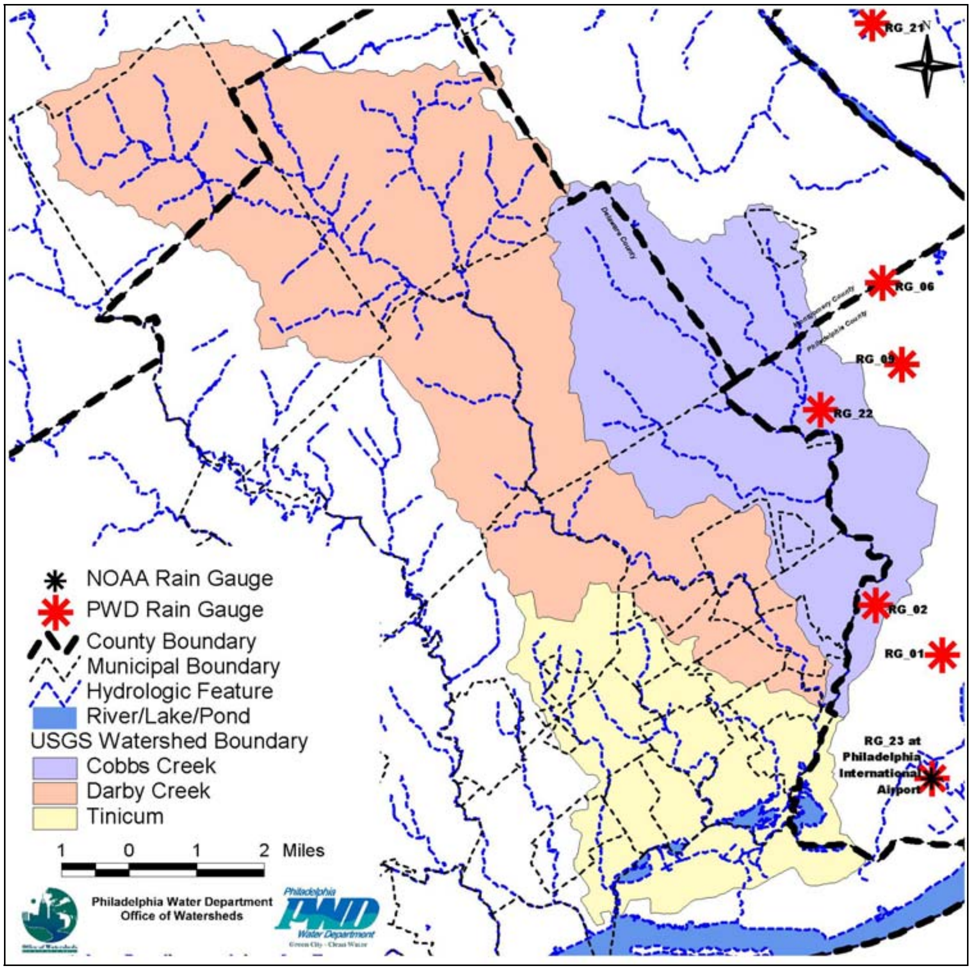


Figure 4-1 City Rain Gauges In or Near the Watershed

4.1.2 Outside Potable Water

P + OPW + WW/IND Rech + EDR + WW Disch = RO + SWW+ GWW + EDW + BF + OWD + ET

The watershed is generally supplied with drinking water from sources of water outside the watershed. For the Philadelphia portion of the watershed, water is "imported" into the watershed through the drinking water distribution system from raw water drawn from the Schuylkill and Delaware Rivers. For the outside communities, most of the water is supplied by Aqua America (formerly Philadelphia Suburban) and Pennsylvania American from Crum and Ridley Creeks.

For the Darby-Cobbs watershed, most of this water never leaves the urban infrastructure used to transmit drinking water to and convey wastewater from homes to wastewater treatment plants outside the watershed. In this sense, this component of the watershed water balance is not critical to the development of the watershed management plan.

4.1.3 Wastewater and Industrial Recharge to Groundwater

P + OPW + WW/IND Rech + EDR + WW Disch = RO + SWW+ GWW + EDW + BF + OWD + ET

This component represents water that has been used in homes or industry, has been treated, and is subsequently discharged back to the groundwater, thus making it an "inflow" component. Available data suggest that there are no such discharges within the watershed. For this reason, this component is not included in the table of estimated flows for components of the hydrologic cycle.

4.1.4 Estimated Domestic Recharge

P + OPW + WW/IND Rech + EDR + WW Disch = RO + SWW+ GWW + EDW + BF + OWD + ET

This component represents water that has been used in homes and is subsequently discharged to septic systems. In this way, it represents an inflow component to the groundwater portion of the hydrologic cycle. Although there are some septic system areas in the watershed, most of the population is served by sanitary sewers, making this a very small component of the water cycle. Counts of septic systems are based on 1990 U.S. census data and are highly uncertain. Based on this information and an estimate of 50 gallons of sewage per person per day discharged to septic systems, this component represents 56,000 gallons per day in the Cobbs watershed and 205,000 gallons per day in the Darby watershed upstream of the confluence. These flows may also be expressed as 0.05 inches per year for the Cobbs and 0.11 inches per year for the Darby.

4.1.5 Wastewater Discharges to the Stream

P + OPW + WW/IND Rech + EDR + WW Disch = RO + SWW+ GWW + EDW + BF + OWD + ET

This component represents water that has been used in homes or industry, has been treated, and is subsequently discharged back into the stream, thus making it an "inflow" component. Available data suggest that there are no discharges to Cobbs Creek, and only a few, very small permitted discharges on the Darby Creek. For this reason, this component can be considered insignificantly small in comparison to the main inflow components and is not included in the table of estimated flows for components of the hydrologic cycle.

4.1.6 Runoff

P + OPW + WW/IND Rech + EDR + WW Disch = RO + SWW+ GWW + EDW + BF + OWD + ET

Precipitation is the primary natural inflow component of the water cycle. This inflow component generally results in three, natural outflow components: evapotranspiration (ET), runoff, and infiltration into the groundwater. Thus runoff is one of the major, natural outflow components to be estimated.

The amount of stormwater runoff depends on a variety of factors, including rainfall intensity, surface ponding of rain, ground slope, and, most importantly, the imperviousness of the ground surface. The amount of impervious cover follows patterns of land use and population density because manmade structures and pavement are the cause of impervious surface. Estimates of imperviousness can be further refined by examining the relative proportion of impervious surfaces on the USGS quadrangles and in aerial photos. Because of the urbanized nature of the watershed, runoff is almost always collected into a sewer system. Depending on the location within the watershed, it can either be discharged through storm sewers or through combined sewers. Therefore, this component is further discussed under the Runoff/Outside Wastewater Discharge component below.

4.1.7 Surface Water Withdrawals

P + OPW + WW/IND Rech + EDR + WW Disch = RO + SWW+ GWW + EDW + BF + OWD + ET

This outflow component represents intakes for water withdrawal for drinking water or industrial use. For the Darby-Cobbs watershed, no permitted withdrawals exist on either river, and this component can be left out of the water balance table.

4.1.8 Groundwater Withdrawals

P + OPW + WW/IND Rech + EDR + WW Disch = RO + SWW+ GWW + EDW + BF + OWD + ET

This outflow component represents groundwater pumping for industrial use or public water supply. There are no public supply or industrial wells of significance in the watershed, and this component can be left out of the water balance table.

4.1.9 Estimated Domestic Withdrawals

P + OPW + WW/IND Rech + EDR + WW Disch = RO + SWW+ GWW + EDW + BF + OWD + ET

The entire watershed is served by a public water supply distribution system. There are no areas where domestic wells form a significant source of supply, and groundwater pumping can be ignored as a significant component of the water balance.

4.1.10 Baseflow

P + OPW + WW/IND Rech + EDR + WW Disch = RO + SWW+ GWW + EDW + BF + OWD + ET

Precipitation results in three, natural outflow components: evapotranspiration (ET), runoff, and infiltration into the groundwater. In most shallow groundwater systems, the surface watershed generally corresponds to the recharge and discharge area of the groundwater system. This means that infiltration enters the groundwater aquifer, and flows underground to the stream for eventual discharge as stream baseflow. This allows us to equate infiltration with stream baseflow, making it possible to estimate infiltration through baseflow separation techniques at stream gauges.

In pervious areas, the amount of water that infiltrates the soil, and thus reappears as stream baseflow, depends on soil properties. At the beginning of a storm, when soil pores are usually not saturated, the moisture content of the soil determines the amount of infiltration that can occur. Capillary suction forces caused by surface tension in the pores also affect the infiltration rate. The size, shape, and distribution of soil pores determine the rate at which a soil can transmit flow in both the unsaturated and saturated states. The infiltration rate decreases as soil pores become filled with water during the course of the storm. When the pores become completely saturated, the water transmission rate reaches an equilibrium and is referred to as the saturated hydraulic conductivity or soil permeability. Sandy soils allow the highest infiltration rates, while soils with high clay content allow very slow infiltration; loams and mixtures of different soil types fall between the two extremes. Table 4-2 lists typical values for saturated hydraulic conductivity, capillary suction, and initial moisture deficit for a range of NRCS soil textures (Handbook of Hydrology, D.R. Maidment, Editor in Chief, McGraw-Hill, Inc., 1993, pp 5.1-5.39.) Soil textures found in the watershed were discussed in Section 1. It is important to remember that in urbanized areas, the original soils have often been disturbed, compacted, or replaced by fill material that may have different hydraulic characteristics from the undisturbed state.

Table 4-2 Typical Hydraulic Properties of Different NRCS Soil Textures

	Saturated Hydraulic Conductivity (in/hr)	Capillary Suction (in)	Initial Moisture Deficit (fraction)
Sand	9.3	2.0	0.35
Loamy Sand	2.4	2.4	0.31
Sandy Loam	0.86	4.3	0.25
Loam	0.52	3.5	0.19
Silt Loam	0.27	6.6	0.17
Sandy Clay Loam	0.12	8.6	0.14
Clay Loam	0.08	8.2	0.15
Silty Clay Loam	0.08	10.8	0.11
Sandy Clay	0.05	9.4	0.091
Silty Clay	0.04	11.5	0.092
Clay	0.02	12.5	0.079

The simplest way to compute infiltration, which is generally difficult to measure and/or model, is to perform baseflow separation on streamflow. In this way, if baseflow is assumed to equal infiltration, then the infiltration component can be directly balanced by the baseflow component. For the Darby-Cobbs watershed, this approach results in an annual infiltration/baseflow component of 8.1 inches per year in Cobbs Creek and 14.4 inches per year Darby. This difference is a good indication of the more impervious nature of the Cobbs Creek watershed when compared to the Darby Creek watershed.

Table 4-3 Summary of Hydrograph Separation Results Over the Period of Record

Gauge	Mean Total Flow (in/yr)	Mean Baseflow (in/yr)	Mean Runoff (in/yr)	Baseflow (% of Total Flow)	Runoff (% of Rainfall)
French Creek 01475127	20.3	12.9	7.4	64	18
Cobbs Creek 01475550	18.8	8.1	10.7	43	26
Darby Creek D/S 01475510	23.3	14.5	8.9	62	21
Darby Creek U/S 01475300	23.7	15.6	8.1	66	20

4.1.11 Runoff and Outside Wastewater Discharges

P + OPW + WW/IND Rech + EDR + WW Disch = RO + SWW+ GWW + EDW + BF + OWD + ET

Almost the entire watershed is served by sewers. Depending on the area of the watershed, stormwater may either enter surface water directly, enter a combined sewer, or enter a separate storm sewer system. Unsewered areas, where runoff flows overland to the stream system, make up approximately 5-10% of the Darby and Cobbs Creeks watershed. These areas serve mainly natural areas located along the stream corridor, such as Cobbs Creek Park, where storm sewers are not necessary. Some areas in western Delaware County are also unsewered.

Sewered areas within the watershed are served by two types of sewer systems. In areas served by combined sanitary and storm sewers, the sewer system conveys flows to an interceptor sewer and later to a wastewater treatment plant under dry weather conditions. During larger wet weather events, a combined flow regulator structure diverts a portion of the flow to a receiving stream. Portions of Philadelphia County, including 20% of the Cobbs Creek subwatershed, are serviced by combined sewers. The City of Philadelphia has 38 regulator structures within the watershed, as shown in Figure 4-2. 25 of these structures are instrumented with continuous flow monitors.

Except for park lands (about 5% of the Cobbs watershed), the rest of the watershed area is serviced by separate sanitary and storm sewer systems. In these areas, the storm sewer system conveys most surface runoff directly to a receiving stream. A portion of stormwater, known as infiltration and inflow, enters the sanitary sewer system during wet weather. The occurrence of CSO and the categorization of sampling periods as wet or dry are discussed later in the section.

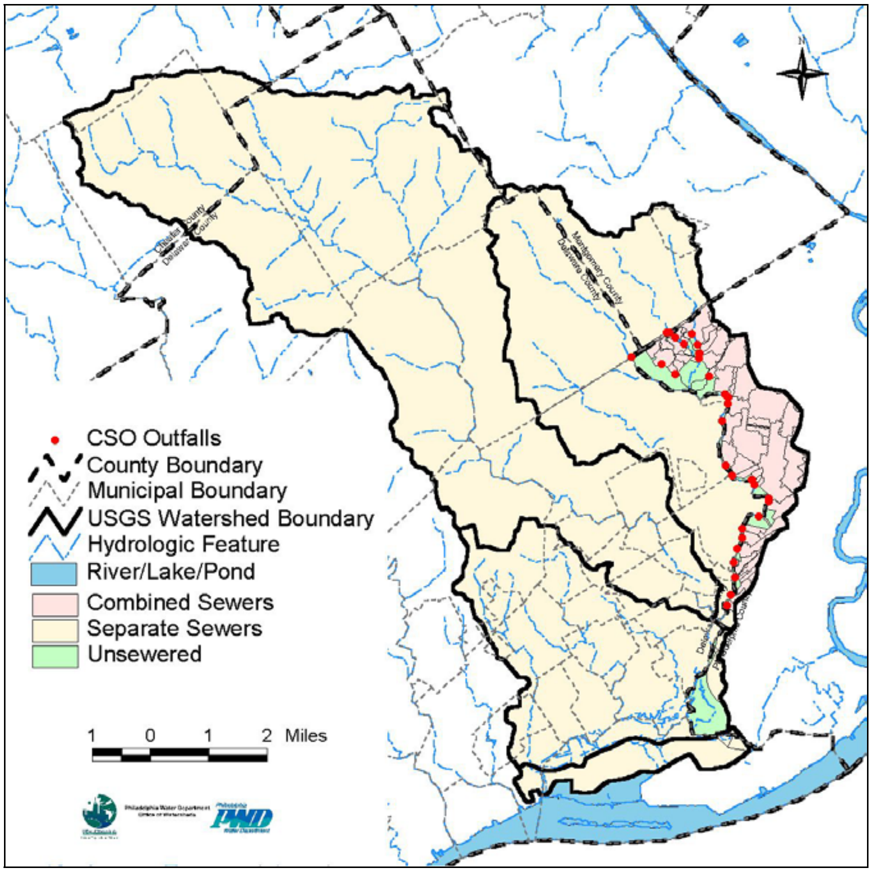


Figure 4-2 Types of Sewer Service and Locations of Regulator Structures

Hydrologic and Hydraulic Modeling

Estimates of the volume, frequency, and duration of combined sewer overflows are based on results from calibrated hydrologic and hydraulic models. Model calibration depends on data from PWD's extensive rainfall gauge network and sewer monitoring program.

The hydraulic and hydrologic model development process focused the greatest detail on the interceptor sewer system, using the USEPA Storm Water Management Model (SWMM) Extended Transport (EXTRAN) module. The EXTRAN module of SWMM was chosen as the most appropriate tool for the interceptor model. This model is the most widely used and accepted model for interceptor and CSO modeling (Roesner et al., 1988). It accurately simulates complex hydraulic conditions that occur in combined sewer interceptors, including unsteady flow, surcharging, branched and looped pipe networks, pumps, orifices, and weirs.

To estimate the treatment rates of the combined sewer regulator structures, or the maximum flow that can pass through the regulator's connector pipe to the interceptor in wet weather, the initial sewershed hydrologic representation is in the form of ramp-function hydrographs loaded directly to EXTRAN. Later in the process, the combined sewersheds are modeled in the United States Army Corps of Engineers (USACOE)

Storage, Treatment, Overflow, Runoff Model (STORM), providing a more detailed characterization of the hydrologic response of the system with an algorithm for the computation of rainfall excess. STORM thereby provides a wet weather characterization that is useful for assessment of impacts and for planning-level alternatives screening used to establish the direction for detailed facility planning and design.

STORM is run in continuous simulation mode using a long-term rainfall record. There is general agreement in the modeling community that single event or design storm simulations are not sufficient for the generation of long-term CSO statistics, including average annual frequency and volume (EPA, 1993). Continuous simulation more thoroughly accounts for antecedent conditions and inter-event conditions within the system.

Discharge Monitoring Report and Annual Report Generation

The EXTRAN model is used for the hydraulic characterization of interceptors and regulators to a fine level of detail. The model supports estimates of sewer system overflow characteristics using STORM. This characterization of the combined sewersheds and trunk sewer system is at the correct level of detail for the hydrologic and hydraulic characterization requirements of NPDES permits for CSO and sanitary sewer facilities and for the alternatives analyses required for long term CSO control planning.

Quarterly discharge monitoring reports (DMR's) are required under the NPDES permit system. In addition, the results of the SWMM/NetSTORM model are used to prepare the CSO Annual Report required under Philadelphia's LTCP and Chapter 94 of the Pennsylvania Code. This report details progress on the three phases of the LTCP: implementation of the Nine Minimum Controls, construction of capital projects, and watershed-based planning. The report also summarizes CSO volume, frequency, and capture statistics for the year.

Annual CSO Frequency and Volume Stats

Table 4-4 lists estimated capture percentages for regulator structures in the Cobbs Creek watershed, based on the modeling results listed in the CSO Annual Reports. A capture percentage is defined as the percentage of combined sewage (mixed sanitary sewage and stormwater) that is "captured" and sent to a treatment plant during rainfall events over the course of a year. 85% capture is considered to be an ultimate goal for many communities as they implement CSO long term control plans. Based on Table 4-4, capture percentages are generally in the range 50-60% for the Cobbs Creek High Level sewer system (32 regulator structures draining 2180 acres) and 70-80% for the Cobbs Creek Low Level sewer system (12 regulator structures draining 390 acres). It is important to note that percent capture for a given year is strongly dependent on the frequency and magnitude of rainfall events during that year. The seven years of data listed in Table 4-4 are not sufficient to determine whether an increasing or decreasing trend has taken place. However, as the amount of data increases throughout implementation of the Long Term Control Plan, it will ultimately be possible to evaluate the effectiveness of the control measures.

Table 4-4 Estimated Annual Combined Sewage Capture Percentages

Year	Precipitation (in)	Capture (%) – Lowest and Highest Structure	
		Cobbs Creek High Level	Cobbs Creek Low Level
2001	31.1	61 – 62	84 – 85
2000	43.2	51 – 52	74 – 75
1999	48.6	49 – 50	73 – 74
1998	30.7	65 - 67	87 - 88
1997	32.0	59 – 63	88 – 92
1996	53.2	30 – 31	63 – 65
1995	31.6	74 – 75	76 – 78

4.1.12 Evapo-Transpiration

P + OPW + WW/IND Rech + EDR + WW Disch = RO + SWW+ GWW + EDW + BF + OWD + ET

Once precipitation reaches the earth's surface, it may take a variety of paths. Typically, a portion enters soil pores through infiltration, a portion returns to the atmosphere through evaporation, and a portion runs off over the land surface (or often into a sewer in urbanized areas). A portion may also be stored temporarily in puddles, in plant parts, through freezing, or in manmade structures designed to detain stormwater; this portion then infiltrates, evaporates, or runs off at a later time.

One of the largest "outflows" of water from the system is evaporation and transpiration. Evapotranspiration includes evaporation, or loss of water to the atmosphere as water vapor, and transpiration, or loss of water to the atmosphere through plants. Evapotranspiration rates depend on temperature, wind speed, solar radiation, type of surface, type and abundance of plant species, and the growing season. Because of these factors, estimated evapotranspiration rates for the Philadelphia region vary seasonally. Neither the Philadelphia Airport nor the Wilmington Airport records evaporation data. One site in New Castle County, Delaware was located which has recorded daily evaporation data from 1956 through 1994. Average daily evaporation rates from this site were developed and are listed in Table 4-1 (City of Philadelphia Combined Sewer Overflow Program: System Hydraulic Characterization).

4.2 Cobbs Creek Water Cycle Component Tables

The relevant components of the urban water cycle have been estimated for the Darby-Cobbs watershed. Outside Potable Water is assumed to balance Outside Wastewater Discharges, with stormwater and CSO's considered as part of the Runoff component of the water cylde. Tables 4-5 and 4-6 show the results of the analysis, first in inches per year, then in million of gallons per day. The inches per year figure simply takes all the flows over an average year, and divides by the area of the watershed. The million gallons per day table takes all the flows over an average year, and divides by 365 days to get an "average" day value.

Table 4-5 Water Budget Components (in/yr)

	Period of Record	Inflow		Outflow		
		P	EDR	RO	BF	ET+Error
Cobbs Creek	1964 - 1990	42.1	0.05	10.6	8.1	23.4
Darby Creek	1964 - 1990	42.1	0.11	8.9	14.4	18.9

Table 4-6 Water Budget Components (MGD)

	Period of Record	Inflow		Outflow		
		P	EDR	RO	BF	ET+Error
Cobbs Creek	1964 - 1990	44.4	0.06	11.2	8.6	24.7
Darby Creek	1964 - 1990	79.6	0.2	16.8	27.3	35.7

4.3 Surface Water Characteristics

The above component tables contain values for runoff, ET, and baseflow. These values, however, are complicated by the fact that much of the water is collected in both separate and combined sewers. This section describes, in more detail, the surface water portion of the cycle.

Stormwater runoff ultimately reaches Darby and Cobbs Creeks and their tributaries through surface runoff, a combined or separate storm sewer, or a treated water discharge. An understanding of the range and frequency of flows, the stage-velocity-discharge relationship, and trends over time is important to a more complete watershed characterization. This information is useful in water quality management, habitat restoration and management, and potable water and flood control applications.

During the USGS/PWD cooperative program in the 1970's, the USGS established streamflow gauging stations at six locations in the Darby and Cobbs Creeks Watershed. These locations are presented in Figure 4-3. Table 4-7 contains summary information at each of the gauging stations for their respective periods of record. Historical rating curves are available for four of the stations and are shown in Figure 4-4.

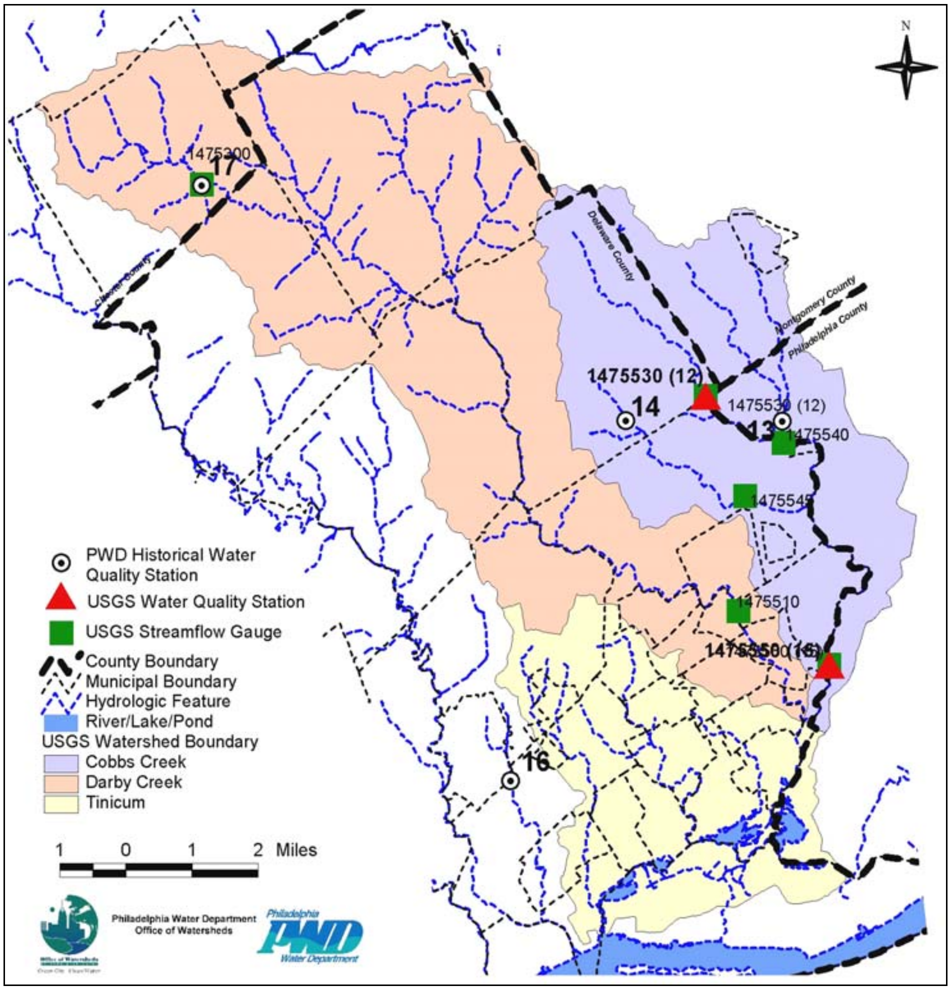


Figure 4-3 USGS Streamflow and Water Quality Gauges

Table 4-7 USGS Gauges and Periods of Record

Station ID	Location	Quality Data (Period)	Streamflow Data (Period)
01475300	Darby Creek At Waterloo Mills Near Devon, Pa.		4/28/1972-9/30/1994 6/28/1996-9/30/1997
01475530	Cobbs Creek At U.S. Highway No. 1 At Phila., Pa.	1/1/1965-3/3/1980	10/1/1964-9/30/1981
01475510	Darby Creek Near Darby, Pa.		2/1/1964-10/3/1990
01475550	Cobbs Creek At Darby, Pa.	11/9/70-3/3/80	1/1/1964-10/3/1990
01475545	Naylor Creek At West Chester Pike Near Phila., Pa.		6/1/1972-10/20/1978
01475540	Cobbs Creek Below Indian Creek Near Upper Darby, Pa.	10/10/1967-2/7/1973	10/1/1964-6/30/1973

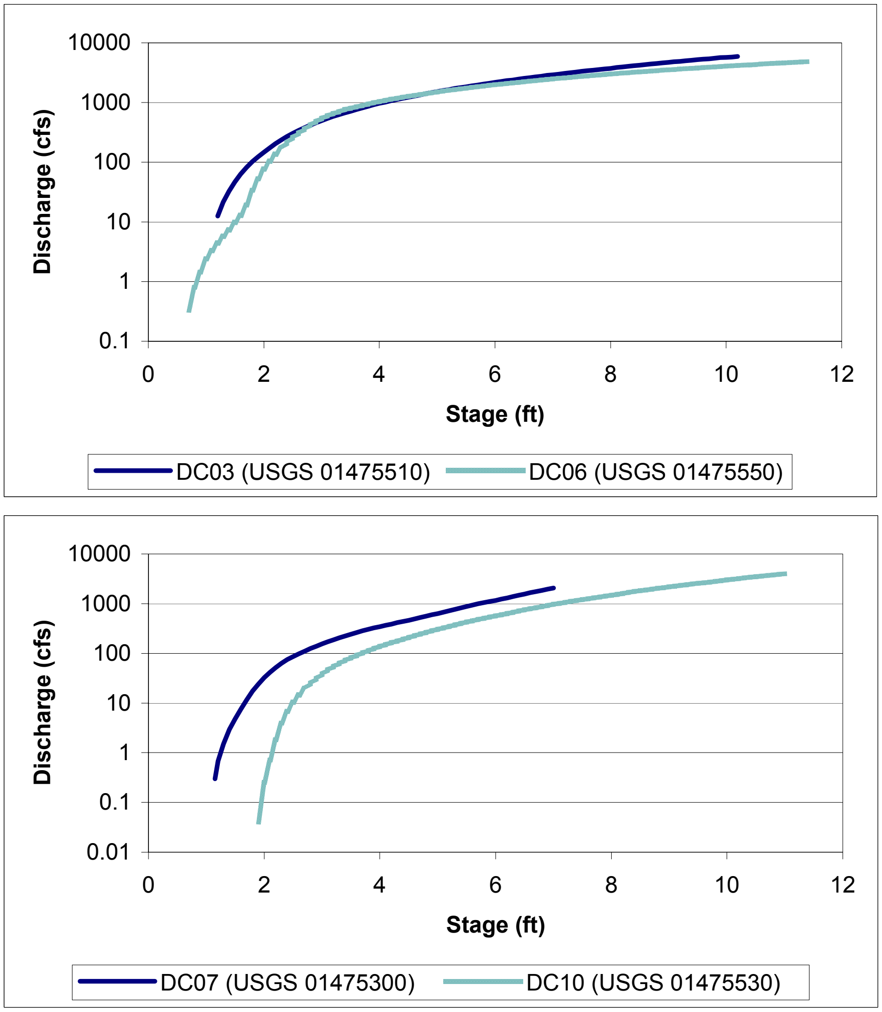


Figure 4-4 Historical Rating Curves for Four USGS Stations

4.3.1 Evaluation of Total Flow for Trends

Magnitude and Frequency of Flow

Cumulative distribution plots for each of the six gauges listed in Table 4-7 are presented in Figure 4-17. A cumulative distribution plot is a plot of discharge versus the percentage of time that a particular flow is not exceeded. These curves are not strictly probability curves because discharge is correlated to successive time intervals and is dependent upon season of the year. However, cumulative distribution plots provide a compact graphical summary of streamflow variability at the different gauging stations.

Trends in Total Flow

Modified Tukey box plots were used to identify seasonal discharge characteristics for both the upstream and downstream monitoring stations on Cobbs Creek. Tukey plots display statistical information including median, mean, minimum/maximum values, and selected percentile values as shown in Figure 4-5. Seasonal discharge characteristics are observed for an annual flow cycle using this approach. The discharge plots, discussed above, were used to delineate wet and dry flow regimes. A high flow season earlier in the year and a low flow season occurring later in the year are identified by the peak and trough locations on the plot. Discharges were plotted by weekly time segments, Figures 4-6 and 4-7, and monthly time segments, Figures 8-7 and 4-9.

Figures 4-10 and 4-11 present an analysis of the streamflow gauge data from USGS Gauge 01475300, Darby Creek at Waterloo Mills. This gauge is the only USGS gauge that remained operational through both the PWD/USGS Cooperative Program and the 1990s. Figure 4-10 shows an annual modified Tukey box plot of daily flow observations. This plot indicates that although average daily flow varies from year to year, generally, the flow regime has remained constant throughout the decades of the 1970s, 1980s, and 1990s. This observation holds even though some years the flows were statistically different from other years. Figure 4-11 shows the decade modified Tukey box plots. This plot indicated that although daily flows in the 1980s and 1990s are somewhat lower than flows in the 1970s, the differences are statistically insignificant.

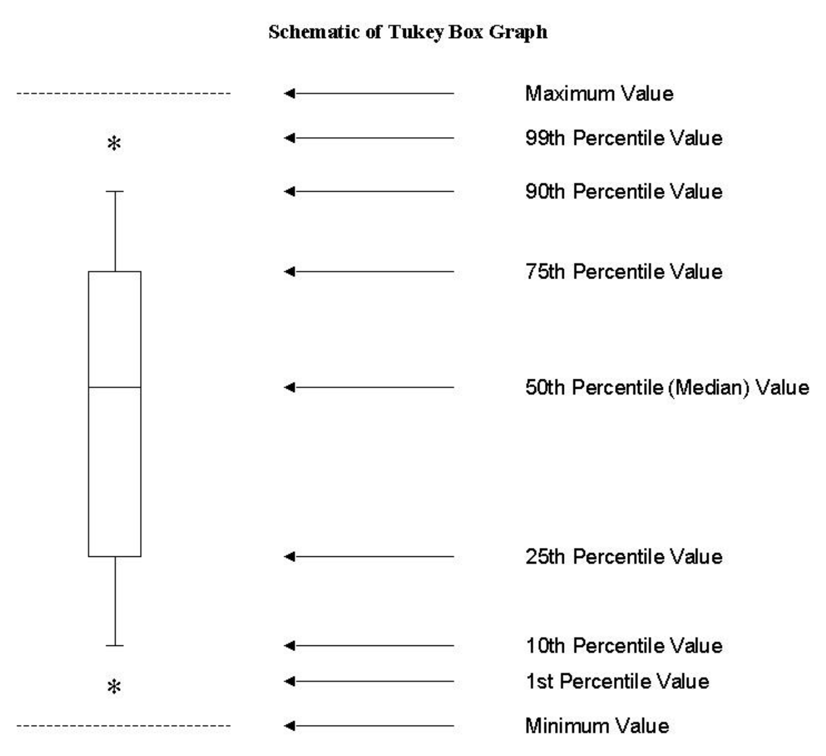


Figure 4-5 Explanation of Modified Tukey Box Plots

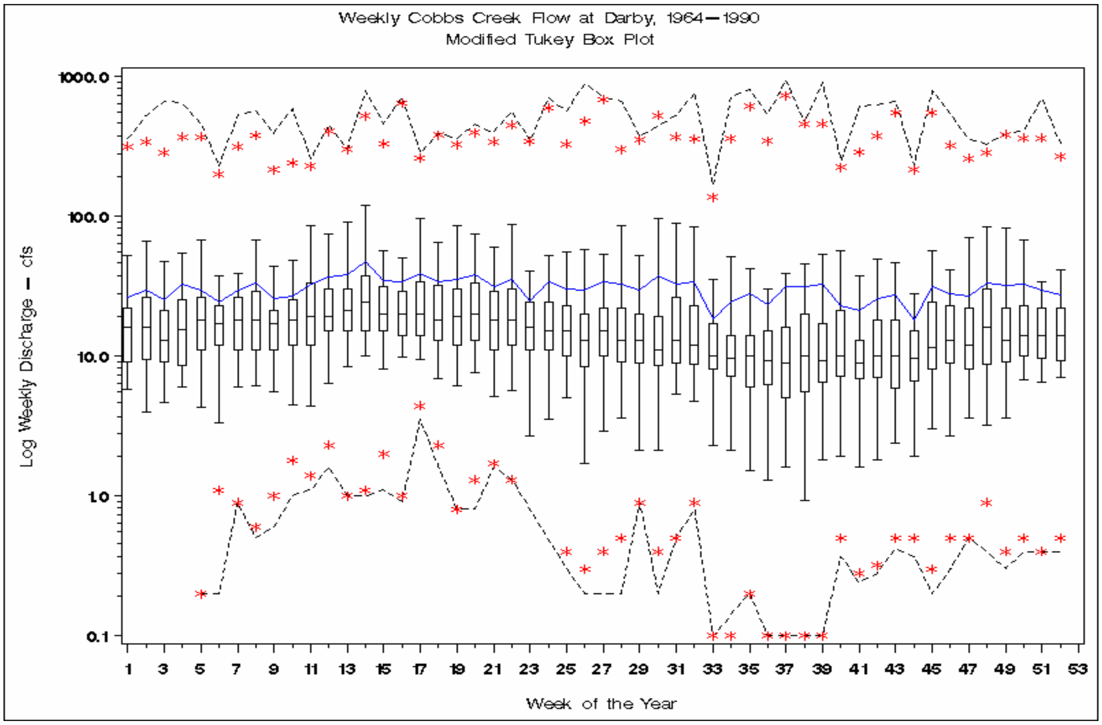


Figure 4-6

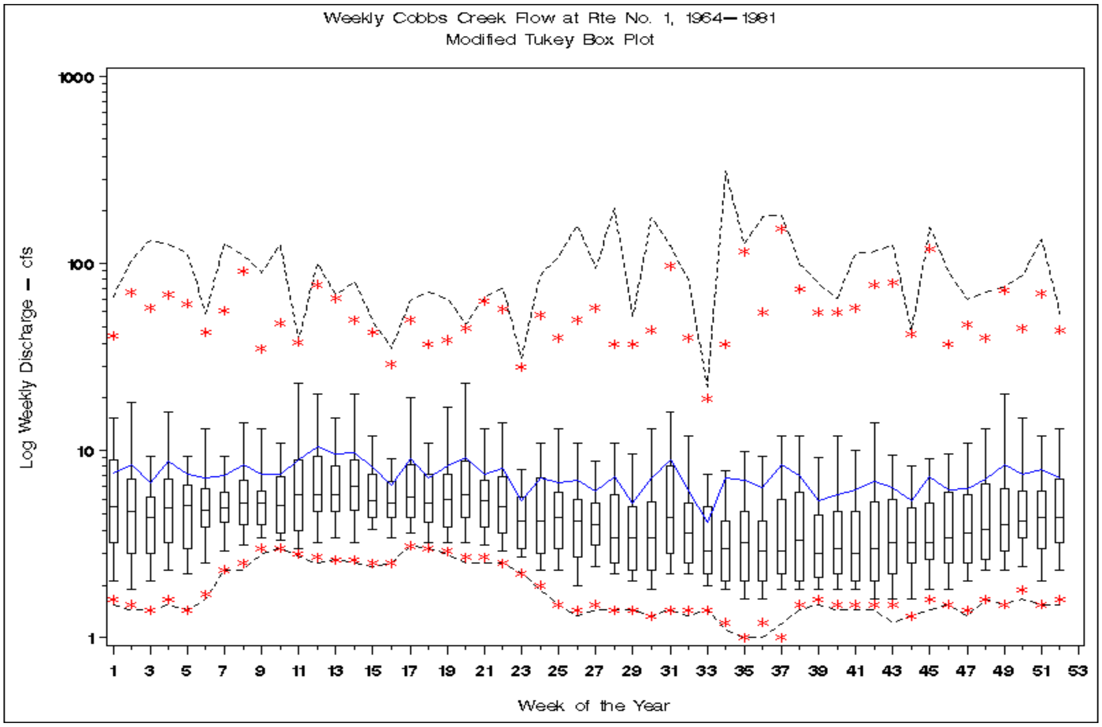


Figure 4-7

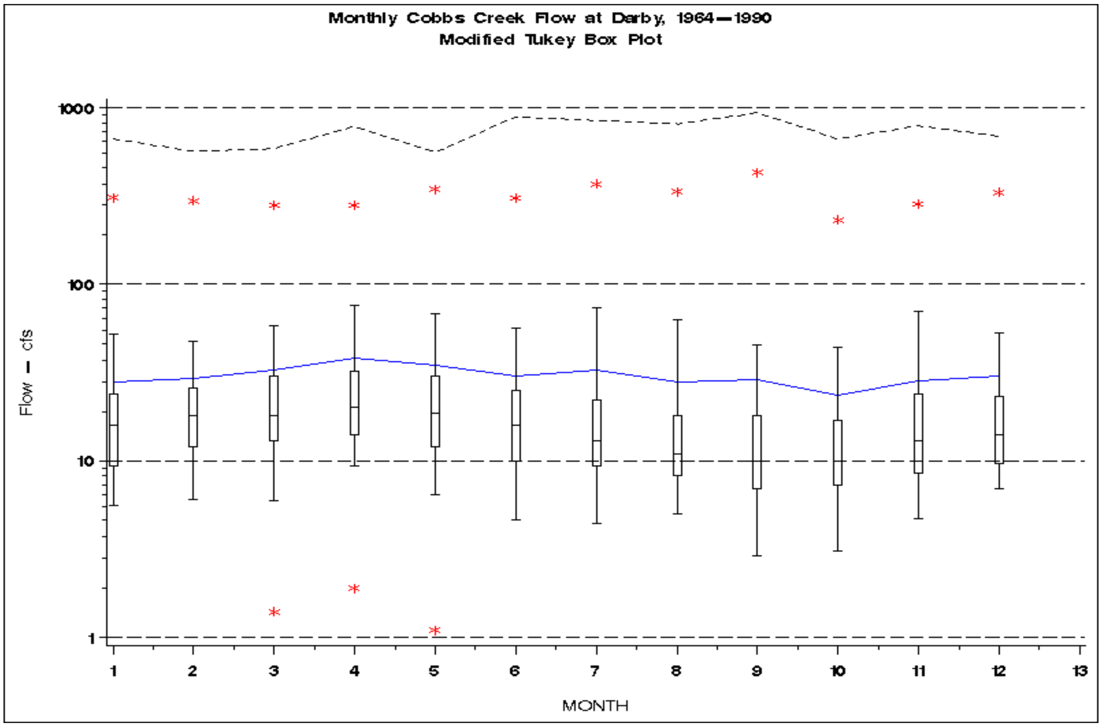


Figure 4-8

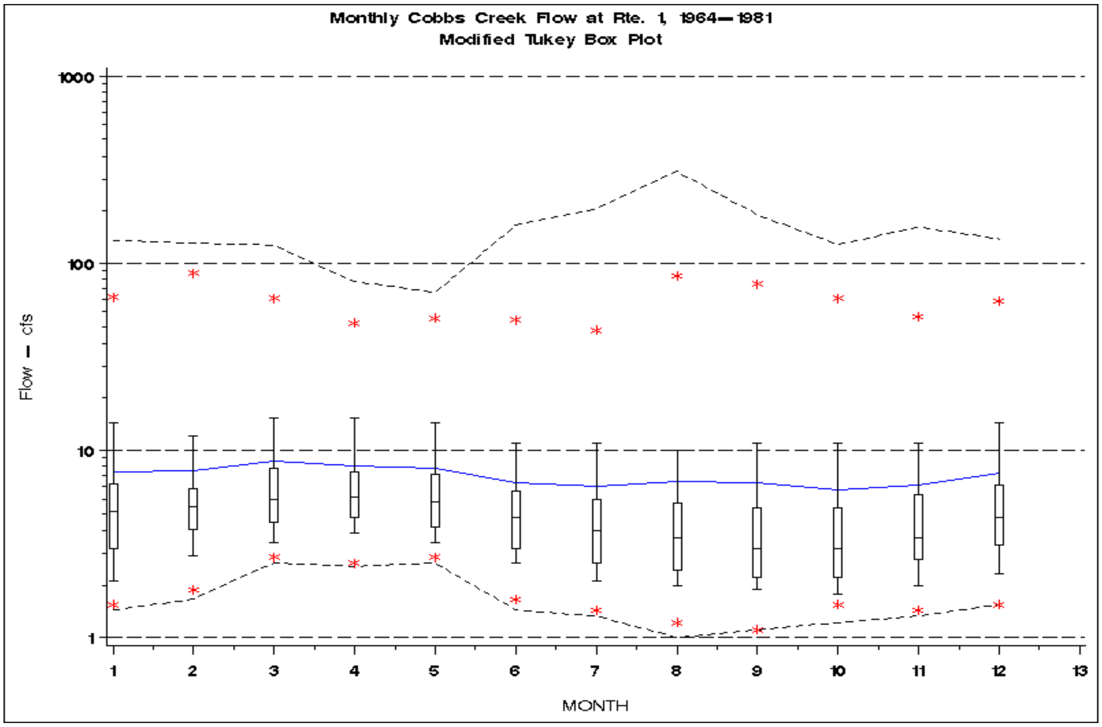


Figure 4-9

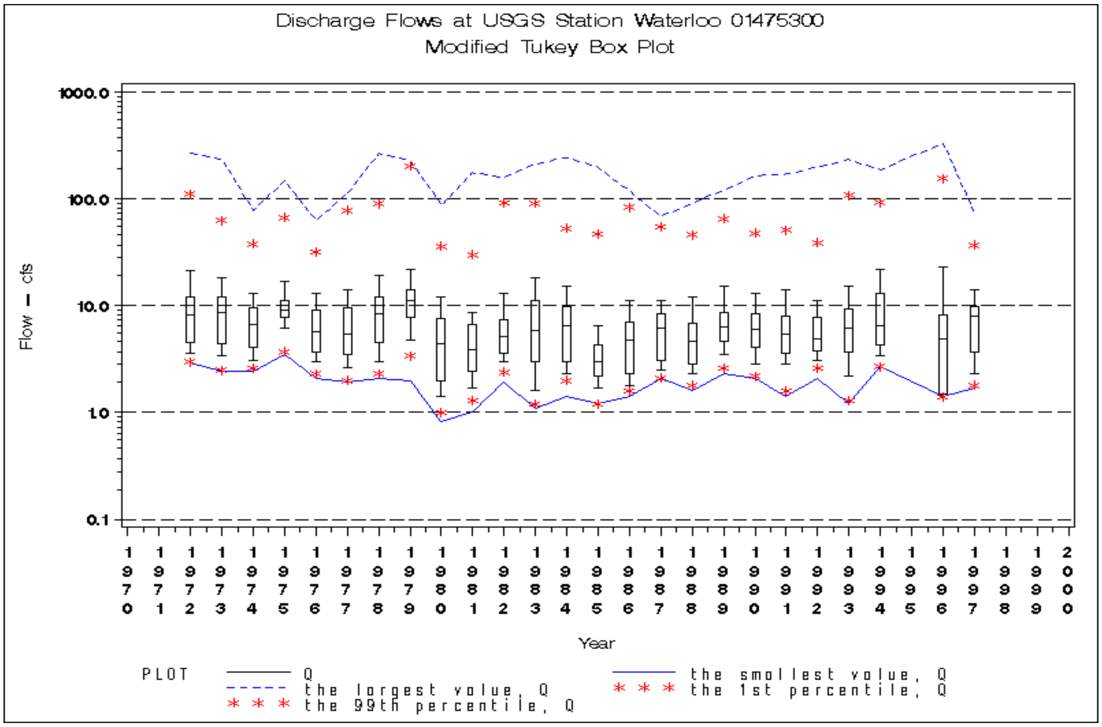


Figure 4-10

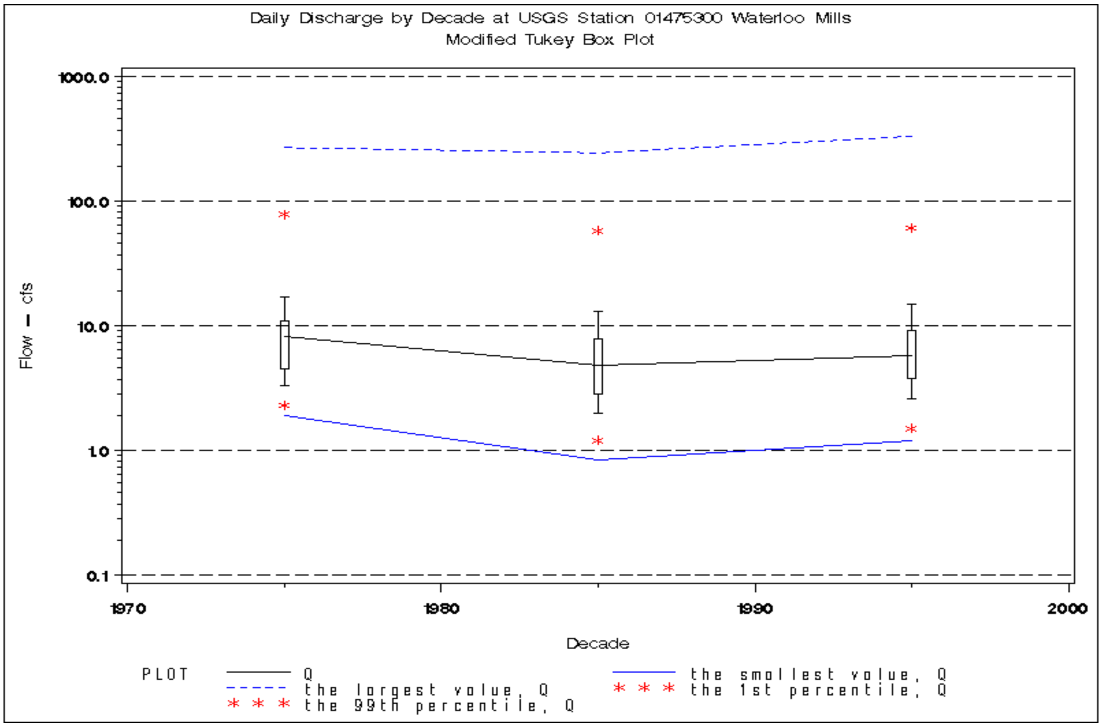


Figure 4-11

4.3.2 Hydrograph Decomposition Analysis

Areas and Gauges Studied

As discussed in Section 2, the Cobbs Creek watershed and the lower portions of the Darby Creek watershed are highly urbanized and contain a large proportion of impervious cover. The hydrologic impact of urbanization can be observed through analysis of streamflow data taken from USGS gauges on Darby and Cobbs Creeks. In addition, data from French Creek in Chester County provide a picture of a nearby, less-developed watershed. Table 4-8 lists four gauges with available data, including their locations, periods of record, and drainage areas.

Table 4-8 Data Used for Baseflow Separation

Gauge	Name	Period of Record (yrs)	Drainage Area (sq.mi.)	N (days)	2N* (days)
01472157	French Creek near Phoenixville Pa.	33.0	59.1	2.26	5
01475550	Cobbs Creek at Darby Pa.	26.7	22.0	1.86	3
01475510	Darby Creek near Darby Pa.	26.7	37.4	2.06	5
01475300	Darby Creek at Waterloo Mills Pa.	25.4	5.15	1.39	3

The interval 2N* used for hydrograph separations is the odd integer between 3 and 11 nearest to 2N. N is calculated based on watershed area.

Baseflow Separation

Baseflow due to groundwater inflow is the main component of most streams in dry weather. Baseflow slowly increases and decreases with the elevation of the shallow aquifer water table. In wet weather, a stormwater runoff component is added to the baseflow. Estimation and comparison of these two components can provide insights into the relationship between land use and hydrology in urbanized and more natural systems.

Baseflow separation was carried out following procedures similar to those found in the USGS "HYSEP" program. The following text is taken from "HYSEP: A COMPUTER PROGRAM FOR STREAMFLOW HYDROGRAPH SEPARATION AND ANALYSIS U.S. GEOLOGICAL SURVEY Water-Resources Investigations Report 96-4040":

"Hydrograph analysis is a useful technique in a variety of water-resource investigations. Separation of streamflow hydrographs into base-flow and surface-runoff components is used to estimate the ground-water contribution to streamflow. Hydrograph-separation techniques also have been used to quantify the ground-water component of hydrologic budgets and to aid in the estimation of recharge rates. In addition, base-flow characteristics determined by hydrograph separation of hydrographs from streams draining different geologic terrains have been used to show the effect of geology on base flow (Sloto and others, 1991, p. 29-33).

“The HYSEP program uses three methods to separate the base-flow and surface-runoff components of a streamflow hydrograph—fixed interval, sliding interval, and local minimum. These methods can be described conceptually as three different algorithms to systematically draw connecting lines between the low points of the streamflow hydrograph. The sequence of these connecting lines defines the base-flow hydrograph. The techniques were developed by Pettyjohn and Henning (1979). Hydrograph separations were performed for the streamflow-measurement station French Creek near Phoenixville, Pa., using three methods. Each method is described below.

The duration of surface runoff is calculated from the empirical relation:

$N=A^{0.2}$

where N is the number of days after which surface runoff ceases, and A is the drainage area in square miles (Linsley and others, 1982, p. 210).

“The interval 2N* used for hydrograph separations is the odd integer between 3 and 11 nearest to 2N (Pettyjohn and Henning, 1979, p. 31). For example, the drainage area at the streamflow-measurement station French Creek near Phoenixville, Pa. (USGS station number 01472157), is 59.1 mi2. The interval 2N* is equal to 5, which is the nearest odd integer to 2N, where N is equal to 2.26. The N and 2N* values used for the four gauges in this analysis were listed in Table 4-8.

“The hydrograph separation begins one interval (2N* days) prior to the start of the date selected for the start of the separation and ends one interval (2N* days) after the end of the selected date to improve accuracy at the beginning and end of the separation. If the selected beginning and (or) ending date coincides with the start and (or) end of the period of record, then the start of the separation coincides with the start of the period of record, and (or) the end of the separation coincides with the end of the period of record.

“The sliding-interval method finds the lowest discharge in one half the interval minus 1 day [0.5(2N*-1) days] before and after the day being considered and assigns it to that day. The method can be visualized as moving a bar 2N* wide upward until it intersects the hydrograph. The discharge at that point is assigned to the median day in the interval. The bar then slides over to the next day, and the process is repeated.”

Summary Statistics

The results of the hydrograph decomposition exercise support the relationships between land use and hydrology discussed above. For convenience, the flows in Tables 4-9 and 4-10 are expressed as a mean depth (flow per unit area) over a one-year time period. Based on the French Creek gauge and the two Darby Creek gauges, the hydrologic behavior of these two systems is similar. Effective impervious cover allows sufficient groundwater recharge to give streamflow relatively natural characteristics; a mean of approximately 20% of annual rainfall contributes to the stormwater component of streamflow, and baseflow represents approximately 65% of total annual streamflow. This is fairly typical of streams in the Piedmont Province. Cobbs Creek exhibits behavior typical of a highly urbanized stream, with over 25% of rainfall contributing to stormwater runoff in a mean year and with mean baseflow comprising only 43% of mean annual streamflow.

Table 4-9 Summary of Hydrograph Separation Results Over the Period of Record

Gauge	Mean Total Flow (in/yr)	Mean Baseflow (in/yr)	Mean Runoff (in/yr)	Baseflow (% of Total Flow)	Runoff (% of Rainfall)
French Creek 01475127	20.3	12.9	7.4	64	18
Cobbs Creek 01475550	18.8	8.1	10.7	43	26
Darby Creek D/S 01475510	23.3	14.5	8.9	62	21
Darby Creek U/S 01475300	23.7	15.6	8.1	66	20

Table 4-10 Annual Summary Statistics for Baseflow and Stormwater Runoff

	Baseflow (in/yr)				Runoff (in/yr)			
	Mean	Max	Min	St.Dev.	Mean	Max	Min	St.Dev.
French Creek 01475127	12.9	20.8	5.8	3.8	7.4	15.4	2.9	3.1
Cobbs Creek 01475550	8.1	16.1	1.8	3.6	10.7	15.6	5.2	2.7
Darby Creek D/S 01475510	14.5	21.4	7.6	4.0	8.9	15.6	3.6	2.9
Darby Creek U/S 01475300	15.6	26.0	8.0	4.3	8.1	16.7	3.8	2.9

	Baseflow (% of Annual Rainfall)				Runoff (% of Annual Rainfall)			
	Mean	Max	Min	St.Dev.	Mean	Max	Min	St.Dev.
French Creek 01475127	31%	44%	15%	7%	17%	30%	7%	5%
Cobbs Creek 01475550	19%	31%	5%	7%	25%	33%	18%	3%
Darby Creek D/S 01475510	34%	44%	20%	8%	21%	31%	12%	4%
Darby Creek U/S 01475300	37%	51%	18%	9%	19%	32%	10%	5%

	Baseflow (% of Annual Total Flow)				Runoff (% of Annual Total Flow)			
	Mean	Max	Min	St.Dev.	Mean	Max	Min	St.Dev.
French Creek 01475127	64%	75%	53%	5%	36%	47%	25%	5%
Cobbs Creek 01475550	42%	54%	16%	10%	58%	84%	46%	10%
Darby Creek D/S 01475510	62%	75%	54%	6%	38%	46%	25%	6%
Darby Creek U/S 01475300	66%	78%	50%	6%	34%	50%	22%	6%

As expected, the quantity of stormwater runoff on a unit-area basis follows patterns of impervious cover in the drainage area. The French Creek watershed, the least developed, has the smallest amount of stormwater runoff both as an annual mean quantity (7.4 in) and as an annual mean percent of rainfall (17%). As expected, the highly-developed Cobbs Creek watershed has the most runoff both as an annual mean quantity (10.7 in) and as an annual mean percent of rainfall (25%). Further highlighting the effects of development, mean runoff from the Cobbs basin is almost 50% greater than mean runoff in the French Creek basin. The two Darby Creek gauges have an intermediate quantity of stormwater runoff; the downstream gauge, representing most of the Darby basin, has slightly more runoff (8.9 in) on a unit-area basis than the gauge representing the less-developed headwaters (8.1 in).

The summary statistics for stormwater runoff in Table 4-10 present some interesting results. The standard deviation of annual stormwater flows for Cobbs Creek, both in inches (2.7 in) and as a percentage of rainfall (3%), is the lowest of the four gauges studied, indicating that these flows are less variable from year to year. A possible explanation for this pattern is that the capture of some stormwater as part of combined sewage reduces the variability of runoff reaching streams.

Another interesting statistic is that the maximum annual amount of stormwater runoff as a percent of annual rainfall is between 30% and 33% for all four gauges. This result suggests that the maximum amount of runoff that can occur is dependent on the way the rainfall is distributed during the year. In a very wet year characterized by a significant number of larger (greater than 1 inch) storm events, saturated pervious cover responds more like impervious cover during the larger storms. If much of the total annual rainfall occurs in these larger storms (an unusual event), the annual runoff as a percent of total rainfall becomes similar for urbanized and less developed watersheds.

Expressing runoff as a percent of annual rainfall as in Table 4-10 provides an estimate of the upper bound of directly connected impervious area (DCIA), that portion of impervious surfaces that are hydraulically connected to the drainage system. In other words, percent DCIA may be less than this number but is no greater. Runoff from impervious surfaces that are not directly connected may ultimately infiltrate or evaporate rather than contributing to stormwater runoff. It is interesting to note that compared to the land use-derived estimates of total impervious cover presented in Section 4, estimated DCIA is no more than 55% of total impervious area in the Darby watershed and 51% in the Cobbs watershed. These estimates are calculated as the long-term mean runoff, as a percentage of rainfall, divided by the impervious cover estimate listed in Section 4. For example, runoff in the Cobbs watershed is 25% of rainfall on an annual mean basis, and impervious cover is estimated at 49% on an area-weighted basis. Therefore 25/49 = 51% is one estimate of DCIA.

The magnitude of groundwater-derived stream baseflow also depends on impervious cover because pervious areas are necessary for groundwater to recharge. As expected, the unit-area Cobbs Creek baseflows (8.1 inches) shown in Table 4-10 are smaller than those in either Darby Creek (15.6 inches upstream, 14.5 inches downstream) or French Creek (12.9 inches). Baseflow is between 62% and 66% of mean annual streamflow in Darby and French Creeks and only 43% of mean baseflow in Cobbs Creek. Although the Darby Creek watershed contains more impervious cover than the French Creek watershed, it has higher mean baseflows on a unit-area basis. The most likely explanation for this behavior is a difference in the groundwater yield of the geologic formations underlying each basin.

Example Time Series Graphs

Figures 4-12 through 4-14 provide some idea of trends in unit-area flow, baseflow, and runoff from year to year. Although there is considerable variability between years, flows at the four gauges generally follow the same patterns. For example, the Cobbs Creek gauge has the lowest unit-area baseflow and the highest stormwater runoff almost every year of the period of record. This agreement between gauges suggests that the conclusions drawn from long-term mean flows in the previous section are valid for most individual years.

The annual baseflow time series also demonstrates the effects of an extended drought period on stream baseflow in urbanized watersheds. During the drought years 1964-1965, rainfall was less than 30 inches compared to the annual mean of 41.5 inches. Baseflow was below average at the Darby and French Creek gauges, but it was extremely low at the Cobbs Creek gauge. When rainfall recovered to more typical levels in the ensuing years, baseflow at the Cobbs Creek gauge recovered more slowly than baseflow in the less urbanized basins. The data support the assertion that impervious cover increases a watershed's sensitivity to both extreme flood and extreme drought events.

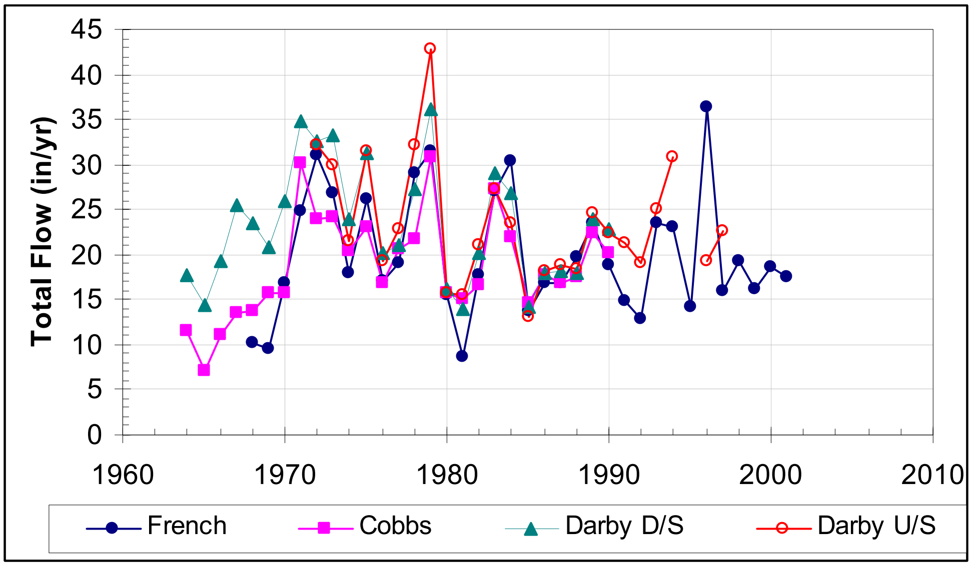


Figure 4-12

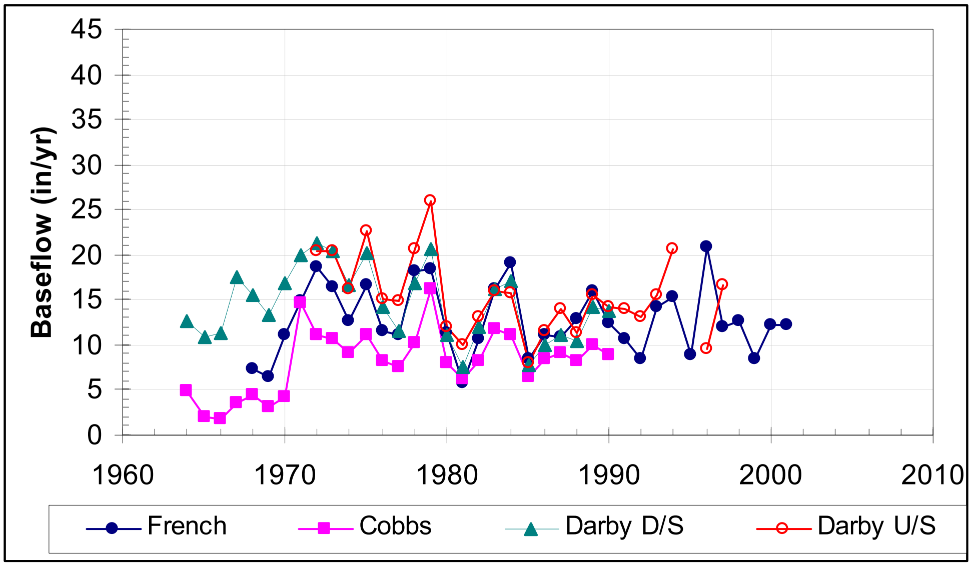


Figure 4-13

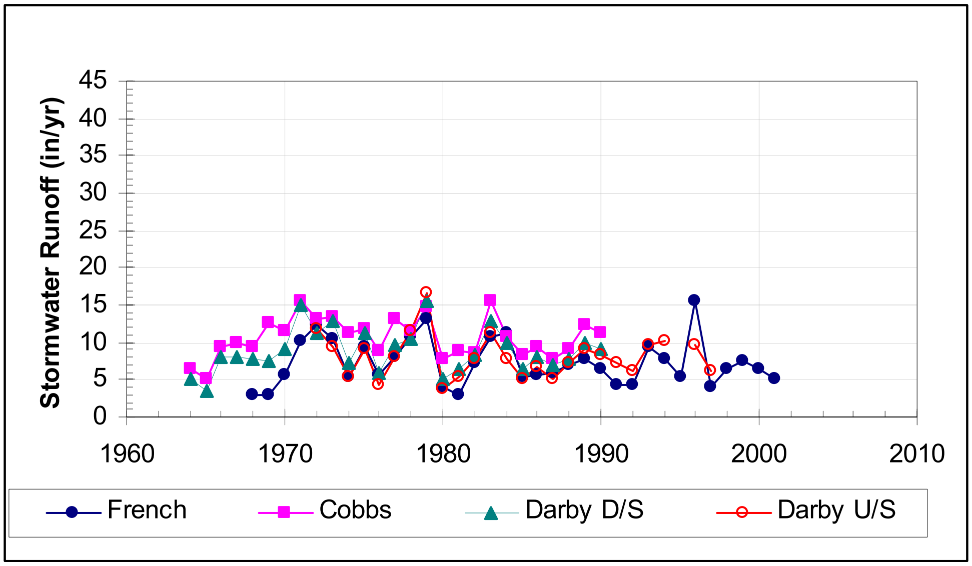


Figure 4-14

Cumulative Distribution

The cumulative distribution of average daily flow at the Cobbs and Darby gauges provides more evidence that the Cobbs gauge experiences greater extremes of flow. The graph shows the percent of daily flow observations (horizontal axis) that are equal to or less than a given value (on the vertical axis). For example, Figure 4-15 indicates that average daily flow at the Darby Creek gauge was less than 0.1 inches on about 90% of days observed. Cobbs Creek experiences greater extremes of flow than Darby Creek. On approximately 92% of days, flow in Cobbs Creek is less than flow in Darby Creek on a unit-area basis. On the driest 20% of days, flow in Cobbs Creek drops toward zero at a greater rate than flow in Darby Creek. On the wettest 8% of days, flow in Cobbs Creek is greater than flow in Darby Creek on a unit-area basis. These observations strengthen the evidence that Cobbs Creek is more prone to flash flooding than Darby Creek.

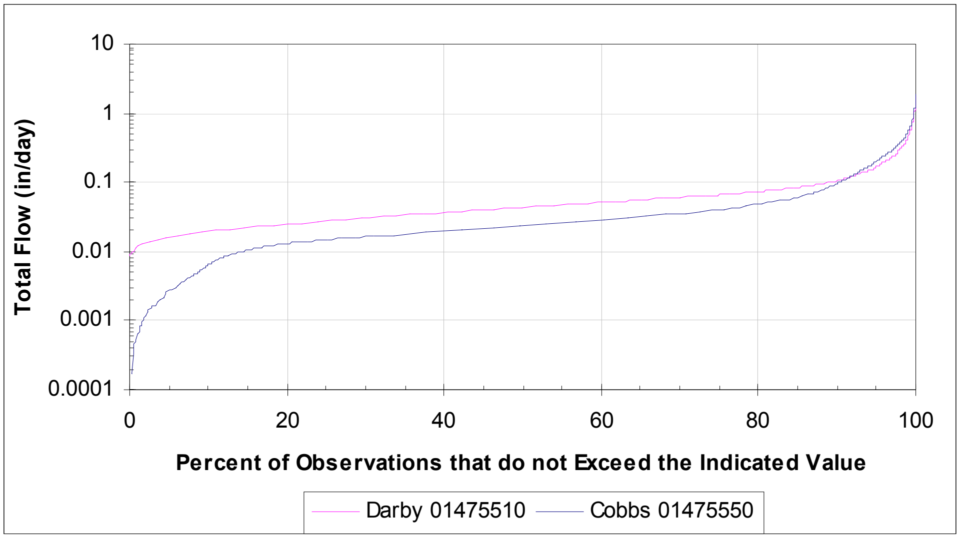


Figure 4-15 Cumulative Distribution of Total Flow

Another possible indicator of the degree of urbanization that was explored was a series of linear least-squares regressions of baseflow and runoff vs. seasonal rainfall. If the regression results were consistently strong ($r^2 >= 0.90$), then differences in slope and intersect between gauges might provide meaningful insights. However, regression results for baseflow vs. rainfall were poor, with r^2 values ranging from 0.11 to 0.40. Regression results for stormwater were better (Table 4-11) but still do not indicate a relationship strong enough to provide meaningful comparisons of different gauges over short periods of time. It is interesting to note that runoff and rainfall appear to be more closely correlated in more impervious basins.

Table 4-11 Correlation Coefficient of Stormwater Runoff and Rainfall

	Cobbs	Darby
Fall	0.73	0.66
Winter	0.76	0.67
Spring	0.90	0.82
Summer	0.63	0.54

A final indicator that was explored compared runoff as a percent of rainfall in one system to runoff as a percent of rainfall in a reference system. If this relationship were relatively constant from year to year, then it might provide a way to track changes in watershed conditions over a relatively short period of time. However, Figure 4-16 demonstrates that while runoff as a percent of rainfall is almost always greater in the Cobbs Creek watershed than in the French Creek watershed, the ratio between the two systems varies substantially from year to year. For this reason, this ratio is not likely to be a good indicator of hydrologic trends over time.

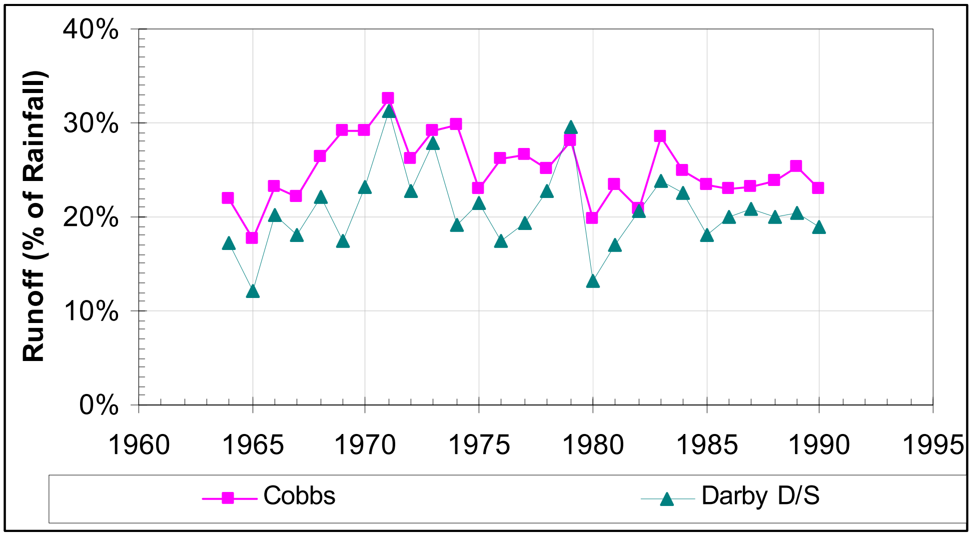


Figure 4-16 Runoff as a Percent of Rainfall in Two Systems

Characterization of Wet and Dry Weather Sampling Periods

The evaluation of water quality data begins with the segregation of water quality observations into wet and dry weather periods. This classification is based upon a combination of the following three factors: streamflow data when available, rainfall, and CSO occurrence data. To characterize the streamflow, cumulative distribution plots based on average daily USGS streamflow are plotted. Figure 4-17 shows the cumulative distribution for the six historical gauges on an annual basis. Because approximately 100 days per year are impacted by wet weather in the Philadelphia region, the 75th percentile flow for a particular stream is taken as a rough estimation of baseflow on a seasonal basis. This forms one basis for classification of wet and dry sampling periods. However, the lack of streamflow data and the fact that precipitation is spatially variable shifts focus towards the CSO occurrence data. Hence the evidence of CSO occurrence anywhere in the system becomes the main basis for characterizing the sampling periods as wet or dry.

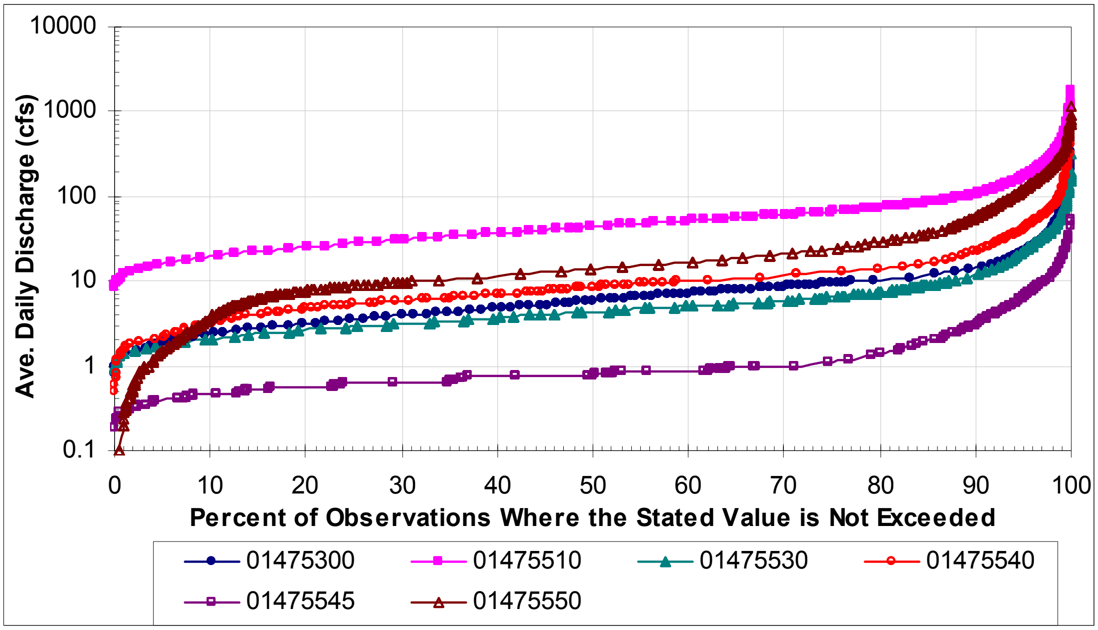


Figure 4-17 Cumulative Distribution of Historical USGS Gauge Data

Table 4-12 Wet Weather/Dry Weather Flow Estimates for Historical USGS Gauge Data

Gauge Name	Gauge Number	Season	Q3 (75%) (cfs)
Darby Creek at Waterloo Mills Near Devon	01475300	Annual	9.6
Darby Creek at Waterloo Mills Near Devon	01475300	Winter	11
Darby Creek at Waterloo Mills Near Devon	01475300	Spring	11
Darby Creek at Waterloo Mills Near Devon	01475300	Summer	5.4
Darby Creek at Waterloo Mills Near Devon	01475300	Fall	6.3
Darby Creek Near Darby	01475510	Annual	67
Darby Creek Near Darby	01475510	Winter	75
Darby Creek Near Darby	01475510	Spring	78
Darby Creek Near Darby	01475510	Summer	48
Darby Creek Near Darby	01475510	Fall	47
Cobbs Creek at US Hwy 1 At Philadelphia	01475530	Annual	6.5
Cobbs Creek at US Hwy 1 At Philadelphia	01475530	Winter	6.9
Cobbs Creek at US Hwy 1 At Philadelphia	01475530	Spring	7.3
Cobbs Creek at US Hwy 1 At Philadelphia	01475530	Summer	5.2
Cobbs Creek at US Hwy 1 At Philadelphia	01475530	Fall	5.5
Cobbs Creek Below Indian Creek Near Upper Darby	01475540	Annual	13
Cobbs Creek Below Indian Creek Near Upper Darby	01475540	Winter	15
Cobbs Creek Below Indian Creek Near Upper Darby	01475540	Spring	13
Cobbs Creek Below Indian Creek Near Upper Darby	01475540	Summer	10
Cobbs Creek Below Indian Creek Near Upper Darby	01475540	Fall	11
Naylor Creek at West Chester Near Philadelphia	01475545	Annual	1.2
Naylor Creek at West Chester Near Philadelphia	01475545	Winter	1.3
Naylor Creek at West Chester Near Philadelphia	01475545	Spring	1.3
Naylor Creek at West Chester Near Philadelphia	01475545	Summer	1.0
Naylor Creek at West Chester Near Philadelphia	01475545	Fall	1.0
Cobbs Creek at Darby	01475550	Annual	24
Cobbs Creek at Darby	01475550	Winter	25
Cobbs Creek at Darby	01475550	Spring	29
Cobbs Creek at Darby	01475550	Summer	19
Cobbs Creek at Darby	01475550	Fall	20

An example of trends in rainfall and corresponding CSOs can be observed in Figures 4-18 and 4-19. Figure 4-17 shows rainfall and CSO data for three CSO outfalls for the period May 23 to 27, 1999. A total of 2.75 inches of rain occurs during the period and CSOs are active. Because CSOs are observed at multiple points in the system, it can be inferred that sampling sites throughout the system are impacted by CSO and stormwater. The discrete sampling done on May 25, 1999 was thus called a wet day. Figure 4-19 shows rainfall and CSO data for the period May 31 to June 4, 1999. This period is classified as dry because neither rainfall nor CSO occurs. Table 4-13 shows the wet or dry categorization of sampling periods when discrete samples were collected. Table 4-14 lists the wet dates in the continuous monitoring or Sonde deployment periods.

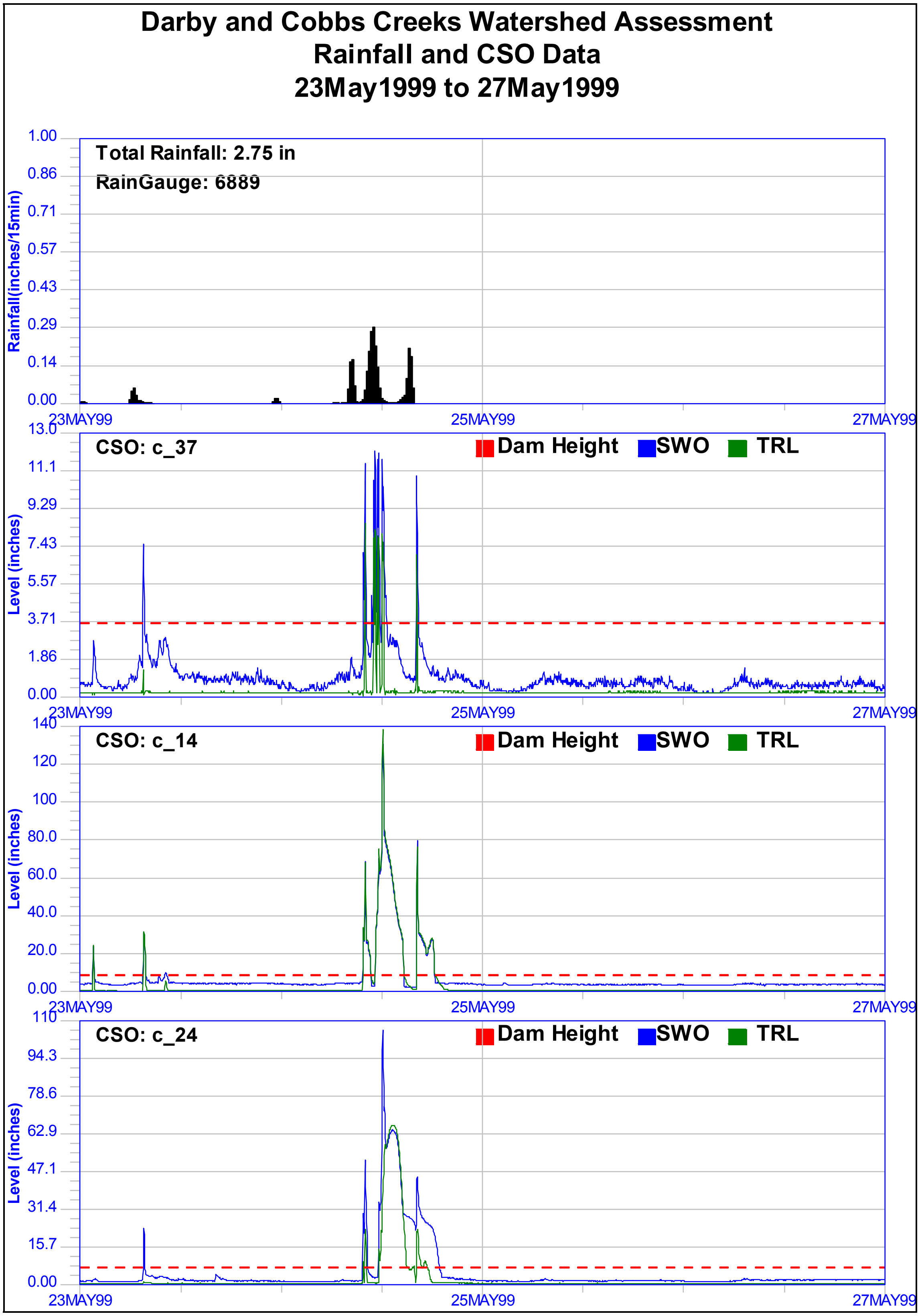


Figure 4-18 Rainfall and CSO plot for a wet period

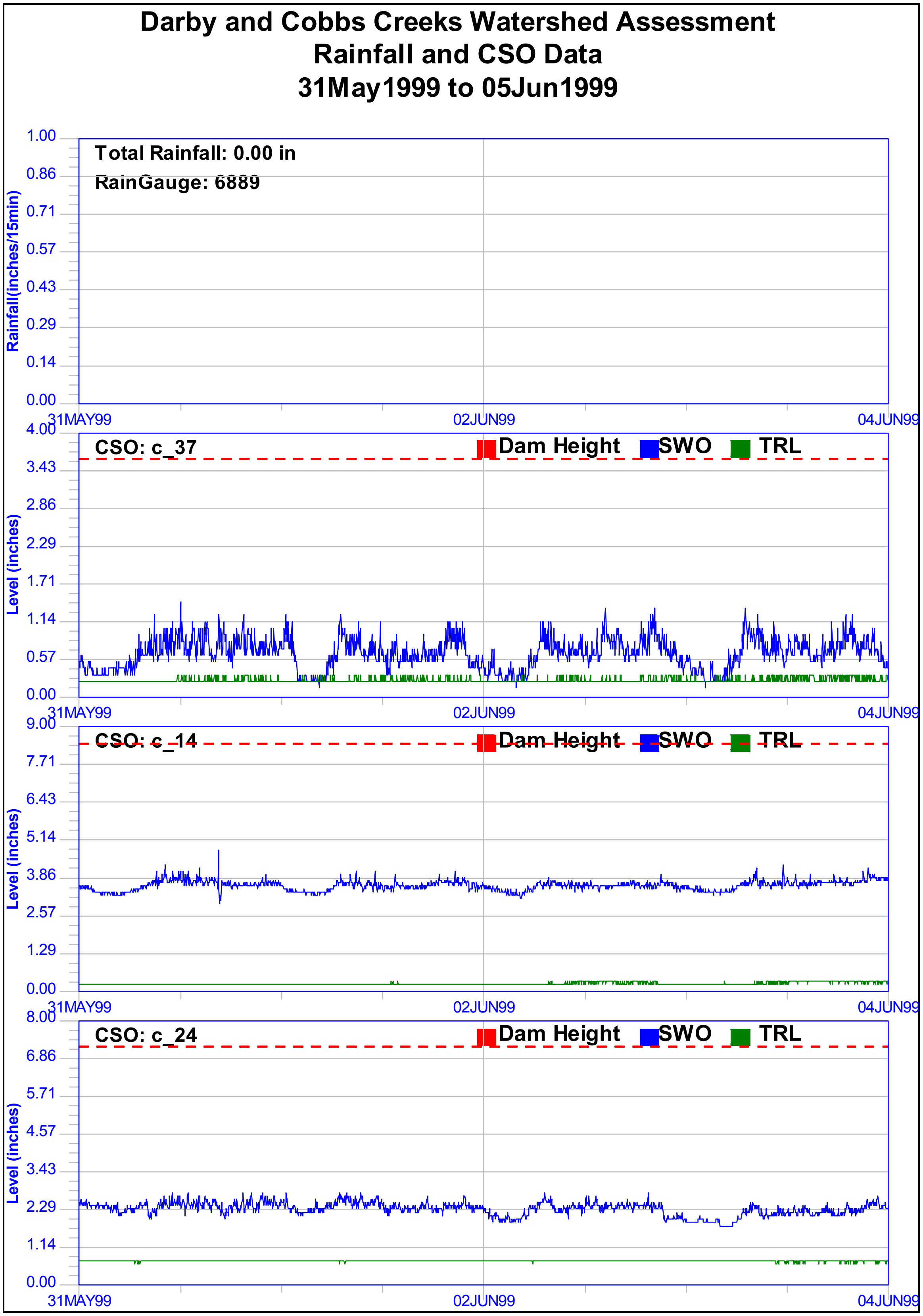


Figure 4-19 Rainfall and CSO plot for a Dry period

Table 4-13 Wet and Dry Period Characterization

Date/Period	Weather Status	Sampling Type
5/11/1999	DRY	Discrete
5/18/1999	DRY	Discrete
5/25/1999	WET	Discrete
6/2/1999	DRY	Discrete
6/8/1999	DRY	Discrete
6/15/1999	WET	Discrete
6/22/1999	WET	Discrete
6/29/1999	WET	Discrete
7/13/1999	DRY	Discrete
7/20/1999	WET	Discrete
6/1/2000	DRY	Discrete
6/12/2000	WET	Discrete
6/15/2000	WET	Discrete
6/29/2000	WET	Discrete
7/13/2000	DRY	Discrete
5/23-26/2000	WET	WETW
6/6-8/2000	WET	WETW
7/24-28/2000	WET	WETW

WETW = Series of samples taken during a wet weather hydrograph, but the first sample is taken in dry weather before the forecast storm.

Table 4-14 Wet Weather Days of Continuous Sampling Periods

Date/Period	Wet Weather Dates
07/09/99 To 07/13/99	--
07/14/99 To 07/22/99	07/20
08/14/99 To 08/20/99	08/14, 08/15, 08/16
08/26/99 To 09/03/99	08/26, 08/27
09/09/99 To 09/17/99	09/10, 09/16
09/15/99 To 09/21/99	09/16
02/11/00 To 02/27/00	02/13, 02/19
02/25/00 To 03/10/00	02/27
03/03/00 To 03/19/00	03/11, 03/17
04/28/00 To 05/06/00	--
05/18/00 To 06/03/00	05/19, 05/20, 05/24
06/02/00 To 06/16/00	06/06, 06/12, 06/14
06/16/00 To 06/30/00	06/18, 06/22, 06/29
07/14/00 To 08/05/00	07/14, 07/16, 07/19, 0727, 07/31, 08/03
08/09/00 To 08/25/00	08/11, 08/14
08/24/00 To 09/09/00	08/27, 08/31, 09/01, 09/03
09/01/00 To 09/09/00	09/01, 09/03
09/12/00 To 09/24/00	09/13, 09/15, 09/19
09/27/00 To 10/07/00	10/05
10/13/00 To 10/27/00	10/18
11/06/00 To 11/18/00	11/10, 11/14
05/11/01 To 05/25/01	05/21, 05/22, 05/23
07/26/01 To 08/11/01	07/26, 07/29, 08/03, 8/10
09/07/01 To 09/21/01	09/14
11/14/01 To 11/28/01	11/25
12/05/01 To 12/19/01	12/08
01/15/02 To 02/02/02	01/24

4.4 Flooding

Introduction

A stormwater management plan has been prepared for the watershed by Delaware County under Pennsylvania's Act 167, the Storm Water Management Act of 1968. The Act 167 report contains a more detailed listing of flooding "trouble spots" and floodplain obstructions.

The Darby Creek Watershed River Conservation Plan discusses the role of floodplains and riparian areas in flood control: "Floodplains and the riparian areas buffering streams, rivers, lakes, and other water bodies are especially sensitive watershed zones. In their naturally vegetated and undisturbed state, floodplains and riparian areas provide critical stormwater management and flood control functions, both in terms of water quantity and water quality. For example, floodplains intercept and reduce unmanaged sheet flow runoff and absorb/contain out-of-bank flows as storms increase in intensity. Flood flows are stored, detained, and infiltrated into the vegetated floodplain zone."

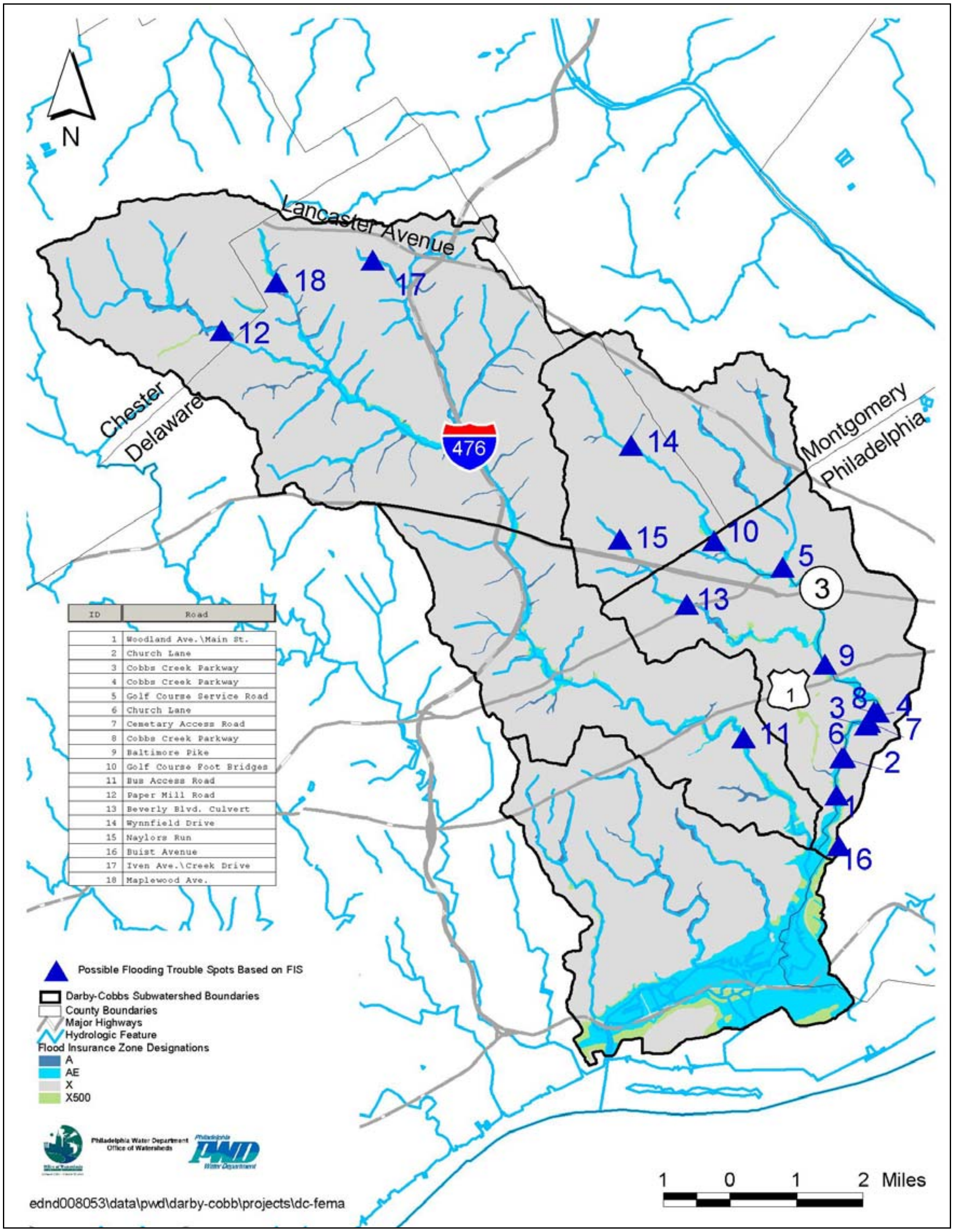
Frequent damaging flooding does not appear to be a major concern within the study area. However, frequent smaller events of flooding occur in some locations, and damaging flooding has occurred during very large storms.

FEMA Floodplains and Flood Insurance Rate Maps

Information on floodplain extents, historical flooding events, and flood insurance rates is available from FEMA and provides an idea of flood hazards in the study area. The flood insurance rate map (Figure 4-20) provides a quick idea of the areas in the watershed that may experience flooding. As summarized in Table 4-15, Zones A and AE are areas where flooding is likely (1% or greater annual chance of occurrence) and zones X and X500 are areas where flooding is unlikely (less than an annual 1% chance due to elevation or flood protection structures). Conditions within the individual subwatersheds (i.e. Cobbs Creek, Darby Creek, and Tinicum) are discussed below.

Table 4-15 National Flood Insurance Program Zone Designations

Zone	Description
A	Zone A is the flood insurance rate zone that corresponds to the 100-year floodplains that are determined in the FIS by approximate methods. Because detailed hydraulic analyses are not performed for such areas, no base flood elevations or depths are shown within this zone. Flood insurance is generally mandatory in these zones.
AE	Zone AE is the flood insurance rate zone that corresponds to the 100-year floodplains that are determined in the FIS by detailed methods. In most instances, whole-foot base flood elevations derived from detailed hydraulic analyses are shown at selected intervals within this zone. Flood insurance is generally mandatory in these zones.
X and X500	Zone X is the flood insurance rate zone that corresponds to areas outside the 500-year floodplain, areas within the 500-year floodplain but not the 100-year floodplain (X500), and to areas of 100-year flooding where average depths are less than 1 foot, areas of 100-year flooding where the contributing drainage area is less than 1 square mile, and areas protected from the 100-year flood by levees. No base flood elevations or depths are shown within this zone. Flood insurance is generally not mandatory in these zones.



ID	Road
1	Woodland Ave.\Main St.
2	Church Lane
3	Cobbs Creek Parkway
4	Cobbs Creek Parkway
5	Golf Course Service Road
6	Church Lane
7	Cemetary Access Road
8	Cobbs Creek Parkway
9	Baltimore Pike
10	Golf Course Foot Bridges
11	Bus Access Road
12	Paper Mill Road
13	Beverly Blvd. Culvert
14	Wynnfield Drive
15	Naylors Run
16	Buist Avenue
17	Iven Ave.\Creek Drive
18	Maplewood Ave.

Figure 4-20 FEMA Flood Insurance Rates and Possible Flooding Areas

Table 4-16 Potential Flooding Locations Identified by County FEMA Studies

County	Sheet	Creek	River Mile (ft)	Road Crown/Bridge Deck Below 50-Yr Flood Elevation
Philadelphia	07P	Cobbs	5,750	Woodland Ave./Main Street (just above 10-yr)
Philadelphia	07P	Cobbs	9,000	Church Lane
Philadelphia	08P	Cobbs	13,150	Cobbs Creek Parkway (below 10-yr)
Philadelphia	09P	Cobbs	14,500	Cobbs Creek Parkway
Philadelphia	17P	Indian	400	golf course service road
Delaware	29P	Cobbs	8,850	Church Lane
Delaware	30P	Cobbs	13,550	cemetery access road (below 10-yr)
Delaware	30P	Cobbs	14,350	Cobbs Creek Parkway (below 10-yr)
Delaware	31P	Cobbs	21,550	Baltimore Pike (just below 50-yr)
Delaware	35P	Cobbs	40,000	golf course foot bridges
Delaware	58P	Darby	40,700	bus access road, MacDade Blvd.
Delaware	64P	Darby	110,800	Paper Mill Road
Delaware	100P	Naylors	6,864	Beverly Blvd. culvert inlet / Beverly Blvd.

Floodplains and Flooding in the Cobbs Creek Subwatershed

Indian Creek and the upper and middle reaches of Cobbs Creek flow through Morris Park and Cobbs Creek Park, moderately sloped parkland where floodplain development is limited. This extensive undisturbed riparian area provides a hydrologic, aesthetic, and recreational benefit to the surrounding neighborhoods. The floodplain along the lower reaches of Cobbs Creek is relatively flat, and the original floodplain has been covered with fill material.

FEMA's Flood Insurance Study for Philadelphia (FEMA, 1996) indicates that low-lying portions of the greater Philadelphia area have experienced damaging flooding in the past during major tropical events, including Hurricanes Connie and Dianne in August 1955 and Hurricane Agnes in June 1972.

The FIS mentions that in 1974, Haverford Township experienced flooding problems along Cobbs Creek due to flow restrictions caused by a box culvert under Wynnfield Drive. This culvert may flood to a depth of four feet or more during intense rain events. Flooding is also known to occur along Naylors Run in Haverford Township.

The extreme southern reaches of Cobbs Creek, including portions of the Eastwick neighborhood, have experienced flooding during these events. On August 19, 1955, the Philadelphia Evening Bulletin noted "flooding of a portion of Eastwick near Buist Avenue to depth of ten feet over Cobbs Creek's banks and 400 evacuated by boat." Portions of the Eastwick neighborhood were also flooded in September 1999 as the remnants of Hurricane Floyd passed over the east coast. This area has existing flood protection measures, and future enhancement of these measures is under consideration by the Philadelphia Redevelopment Authority.

Flood profiles based on HEC-1/HEC-2 modeling from FEMA's Flood Insurance Study identify a few points where the crowns of roads may lie within the 50-year floodplain. Along Cobbs Creek, these include Cobbs Creek Parkway, Woodland Ave., and Church Lane. The crown of Beverly Boulevard is below the 50-year flood level where it crosses Naylors Run.

Floodplains and Flooding in the Darby Creek Subwatershed

The following text is taken from the Darby Creek Watershed River Conservation Plan:

"Over the years, development has encroached substantially into floodplains of the Darby Creek Watershed. In many places, this development has resulted in total stream enclosure/burial with virtual elimination of any semblance of the floodplain. Elsewhere, streams have been substantially channelized with structures that are built into and on the floodplain. Fill has been placed within floodplain areas to accommodate parking, roads, and other development elements, resulting in a broad array of impacts on natural floodplain functions. Even the relatively inoffensive clearing of floodplain areas with replacement as lawn and other landscaped areas takes its toll on the important water quality and water quantity functions of the natural floodplain.

"A major problem, as the data indicate, is that so much of the Darby Creek Watershed has been developed before the emergence of any floodplain regulations, the most notable of which are the Federal Emergency Management Agency (FEMA) set of minimum floodplain standards, which were modified and made more rigorous in the mid-1990's. At this time, virtually all of the 31 municipalities of the Darby Creek Watershed participate in the FEMA floodplain program; East Lansdowne is the one municipality in Delaware County which is not required to participate in the FEMA program. Most municipalities have incorporated minimum FEMA standards into their respective codes and ordinances, although some municipalities in Delaware County may not be in strict compliance with the FEMA program, especially given the FEMA program changes which occurred in the mid 1990's. (According to William Gothier at the Delaware County Conservation District, several municipalities may be in violation of FEMA program requirements; in cases of non-compliance with elements of the National Flood Insurance Program, municipalities could be suspended from the FEMA program and held responsible if flooding damages were to occur; in these cases, homeowners would be deprived of flood protection as part of the NFIP). In any case, a cursory review of the municipal ordinances requested from and made available by the municipalities for this RCP indicates that most municipalities have not gone beyond FEMA minimum requirements, although they are constitutionally enabled to enact more rigorous floodplain and riparian zone controls."

The FEMA Flood Insurance Study for Delaware County (1993) compiled flooding information from a number of anecdotal sources. It describes widespread flooding during Tropical Storms Diana in 1955, Hurricane Donna in 1960, a stationary front in September 1971, and Hurricane Agnes in 1972. In addition, it describes periodic flooding along Darby and Little Darby Creeks in Radnor Township due to undersized culverts; flooding occurs along Little Darby Creek behind Maplewood Avenue at the Mill Dam Club approximately once a year according to residents. Also in Radnor, flooding occurs along Ithan Creek due to undersized culverts in the vicinity of Iven Avenue and Creek Drive near the Township Building. The FEMA study mentions a flood control dam in Naylors Run Park and a detention basin on Naylors Run between Garrett Road and Sherbrook Boulevard, but states that the effectiveness of these measures has not been thoroughly tested. There are four dams in Upper Darby Township and one in Clifton Heights Borough, but these are not thought to perform significant flood control functions.

Low-lying points on roads identified from FEMA flood profiles are shown on Figure 4-20. These are defined as having a crown elevation below the 50-year flood elevation at the point of stream crossing, and include points on Church Lane, Cobbs Creek Parkway, and Baltimore Pike.

Floodplains and Flooding in the Tinicum Subwatershed

Darby Creek discharges to the Delaware River through the wetlands of the Tinicum Wildlife Refuge. In addition, developed areas within Tinicum Township drain directly to the wetlands. Virtually all of the watershed within the Tinicum area lies within the 100-year floodplain and is flood-prone, although flood protection and tidal control structures are in place along portions of Darby Creek, Long Hook Creek, and along many roads. Interstate 95 is built on fill material and forms a barrier to flood waters south of the highway. Development is prohibited within the Tinicum Wildlife Preserve itself (FEMA, 1996).

Section 5 Characterization of Water Quality

The purpose of this section is to characterize existing water quality in the surface waters of the Darby and Cobbs Creeks watershed. The watershed is divided into five sections: upper and lower Cobbs Creek, upper and lower Darby Creek, and the Tinicum area. Each section is represented by two to three sampling sites. Detailed information on the sampling sites is available in Section 3.

5.1 Historical Water Quality

5.1.1 PWD/USGS Cooperative Program (Water Quality and Flow Data)

In the early 1970's, the Philadelphia Water Department began a study in cooperation with the U.S. Geological Survey titled, "Urbanization of the Philadelphia Area Streams." The purpose of this study was to quantify the pollutant loads in some of Philadelphia's streams and possibly relate the degradation in water quality to urbanization. Two of the stations sampled for the study were in the Darby and Cobbs Creeks Watershed: Station 12, Cobbs Creek at U.S. Route 1, and Station 15, Cobbs Creek at Darby. Monthly "snapshot" water quality samples were collected at each site and analyzed for conductivity, BOD_5, total phosphate, ammonia, nitrite, nitrate, and fecal coliform. The program collected about 10 years of monthly samples. The water quality data collected for the Cobbs Creek stations showed a significant increase in BOD_5, ammonia, total phosphate, and fecal coliform between the upstream (12) and downstream (15) stations. These increases were attributed to malfunctioning regulators and higher pollutant loading rates during storm events. The loading rates were compared with estimates based on sampling data collected during the Phase I Reconnaissance Survey. The comparison is in Section 9 of the Comprehensive Characterization Report. Figure 5.1 shows the locations of the two monitoring stations from the PWD/USGS Cooperative Program. Also indicated on Figure 5.1 are the two locations where water quality samples were obtained during the 10 year study.

Partially through the cooperative program, the USGS also established streamflow gauging stations at six locations in the Darby and Cobbs Creeks Watershed. These locations are shown on Figure 5.1 and listed in Table 5.1. Table 5.2 contains summary information at each of the gauging stations for their respective periods of record. Historical rating curves are available for four of the stations and are shown in Figure 5.2.

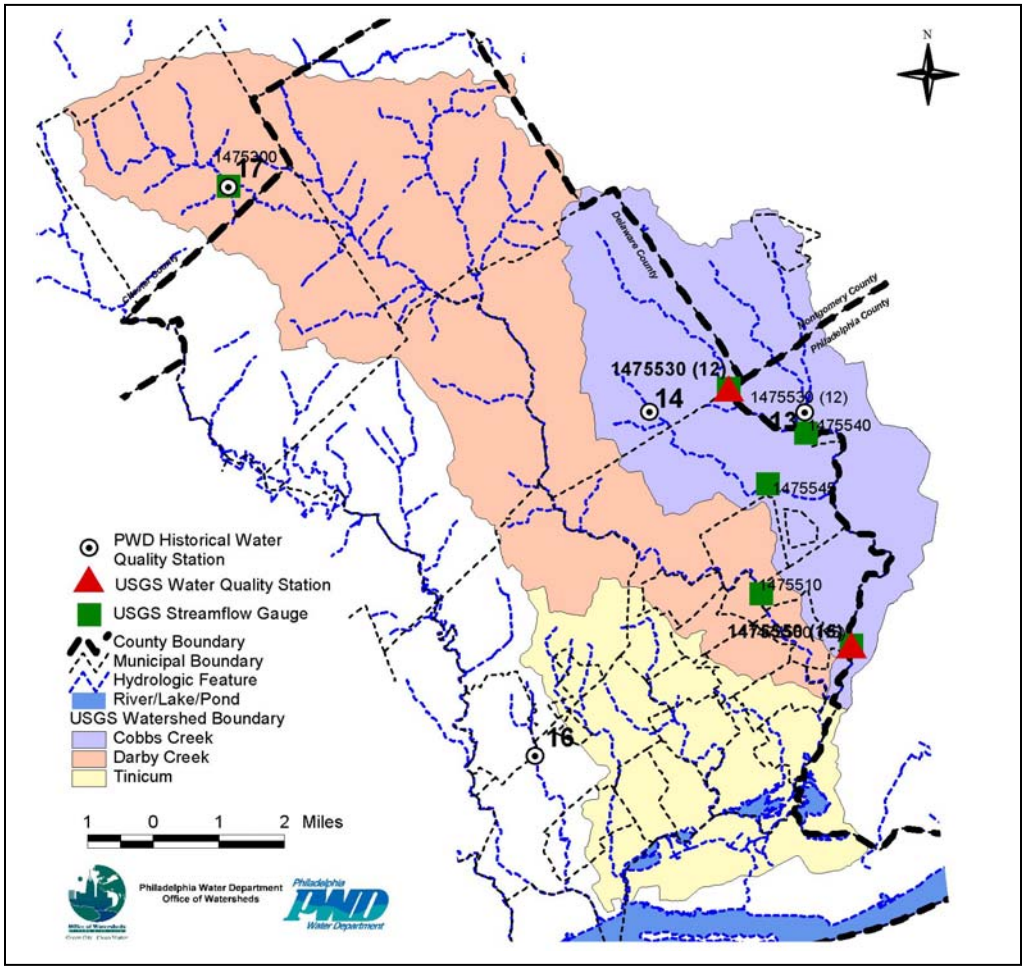


Figure 5.1 PWD/USGS Cooperative Program Water Quality Stations

Table 5.1 Periods of Record for Flow and Quality Data

Station ID	Location	Quality Data (Period)	Streamflow Data (Period)
01475300	Darby Creek At Waterloo Mills Near Devon, Pa.		4/28/1972-9/30/1994 6/28/1996-9/30/1997
01475530	Cobbs Creek At U.S. Highway No. 1 At Phila., Pa.	1/1/1965-3/3/1980	10/1/1964-9/30/1981
01475510	Darby Creek Near Darby, Pa.		2/1/1964-10/3/1990
01475550	Cobbs Creek At Darby, Pa.	11/9/70-3/3/80	1/1/1964-10/3/1990
01475545	Naylor Creek At West Chester Pike Near Phila., Pa.		6/1/1972-10/20/1978
01475540	Cobbs Creek Below Indian Creek Near Upper Darby, Pa.	10/10/1967-2/7/1973	10/1/1964-6/30/1973

Table 5.2 Summary Statistics for Six Gauge Stations

Station ID	Average Daily Flow Statistics (cfs)		
	Minimum	Mean	Maximum
01475300	0.83	9.0	330
01475530	0.90	7.3	310
01475510	8.6	64	1770
01475550	0	30	1150
01475545	0.18	1.7	54
01475540	0.50	14	480

5.1.2 STORET

The majority of the data available from STORET, USEPA's water quality database, for the Darby and Cobbs Creeks Watershed were from the PWD/USGS Cooperative Program, "Urbanization of the Philadelphia Area Streams." The STORET inventory of water quality data within the Darby and Cobbs Creeks Watershed is attached as Appendix B.

5.1.3 Evaluation of Water Quality Data

Analysis of the Philadelphia Water Department's water quality data from the "Urbanization of Philadelphia Stream Sites" report (1970-1980) was performed to assess the impact of the City (including its CSOs) on Cobbs Creek using two of the program's monitoring sites, as well as to provide a baseline for this watershed study. The upstream site is Cobbs at U.S. Highway No.1 (Station 12) and the downstream site is Cobbs at Darby (Station 15). The City's contribution to the pollution in Cobbs Creek is the difference in mass flux between the two stations. The water quality samples were collected monthly at each site by the U.S. Geological Survey and analyzed for conductivity, BOD_5, total phosphate, ammonia, nitrite, nitrate, and fecal coliform at the Water Department's laboratories. For the first three years, samples of metals also were collected and analyzed.

5.1.4 Baseline Water Quality

Tukey plots also were used to characterize water quality parameters by comparing total nitrogen, total phosphate, and fecal coliform load changes as Cobbs Creek passes through the city. Using the wet/dry flow splits determined during the lognormal probability analysis, paired box plots were compared over the 10-year period of water quality data collected. The total phosphate and fecal coliform plots, Figures 5.2 and 5.3, display an increased concentration from the upstream location at U.S. No. 1 to the downstream location at Darby. Malfunctioning regulators and higher loading rates during storm events are the most likely cause according to the study's report. However, other sources of fecal coliforms not previously considered include urban runoff, broken or leaking sewers, failing septic systems, and unanticipated pump station discharges from non-gravity separate sewer systems. In addition, total nitrogen concentrations, Figure 5.4, are higher within the upstream site and decrease after passing through the city. Some level of nitrification within the downstream portion of the stream may result in reduced levels of ammonia and nitrite.

Time series plots were developed for both monitoring sites from 1970-1980 for conventional water quality parameters and metals data and are available on the Partnership web site. These plots allow for visual identification and correlation to recorded storm events. Peak water quality measurements were identified with some recorded large storm events (i.e., hurricanes). Table 5.3 presents a quantitative summary of the water quality data from the PWD/USGS Cooperative Program. Table 5.4 qualitatively summarizes the data from the PWD/USGS Cooperative Program.

Table 5.3 Site Specific Statistics from Water Quality Samples

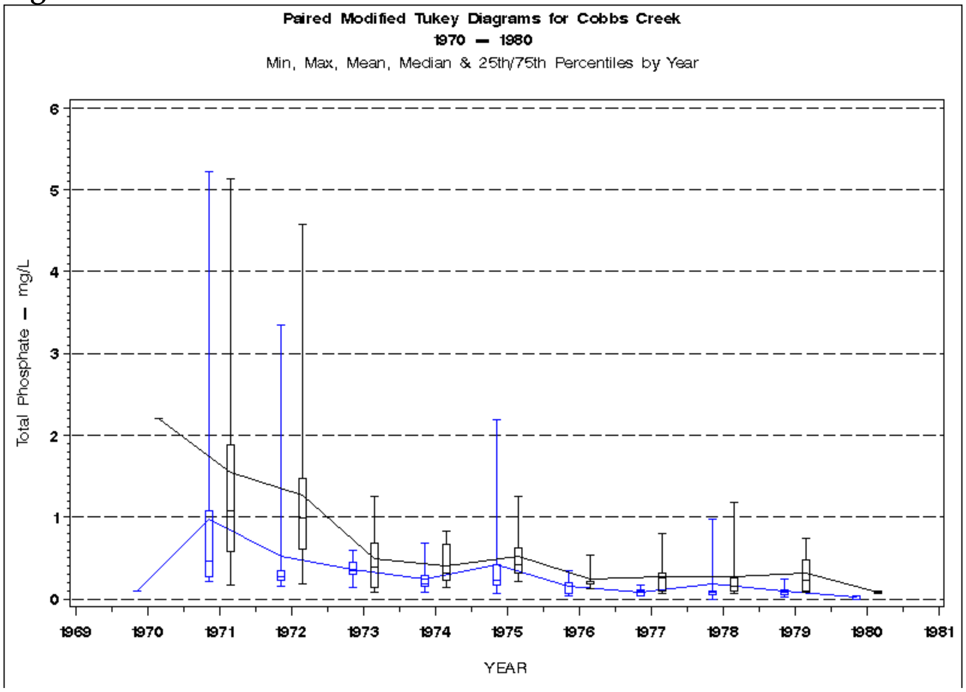
METALS 11/9/70 - 10/3/73

Site	Statistic	Zn (mg/L)	Ca (mg/L)	Mg (mg/L)	Fe (mg/L)	Ni (mg/L)	Cd (mg/L)	Cu (mg/L)	Cr (mg/L)	Co (mg/L)	Mn (mg/L)	Pb (mg/L)	Be (mg/L)	Al (mg/L)	Ag (mg/L)
12	N	27	11	11	27	10	27	27	27	12	27	27	4	10	4
	MIN	0.01	16	8	0.03	0.01	0.001	0.01	0.01	0.01	0.01	0.001	0.01	0.03	0.001
	MAX	0.18	32	13	1.64	0.04	0.004	0.06	1.66	0.01	0.48	0.51	0.01	0.44	0.001
	MEAN	0.0578	24	9.8182	0.2796	0.013	0.0011	0.0152	0.0722	0.01	0.07	0.0267	0.01	0.136	0.001
	STD	0.0393	4.5387	1.4013	0.3316	0.0095	0.0006	0.0122	0.3174	0	0.0965	0.0972	0	0.1525	0
15	N	27	12	12	27	11	27	27	27	13	27	27	5	11	5
	MIN	0.02	16	5	0.06	0.01	0.001	0.01	0.01	0.01	0.01	0.001	0.01	0.02	0.001
	MAX	0.15	38	13	1.41	0.05	0.006	0.02	0.48	0.01	0.27	0.11	0.01	0.63	0.001
	MEAN	0.07	29.6667	9.5833	0.6093	0.0136	0.0012	0.0119	0.0644	0.01	0.1359	0.019	0.01	0.1373	0.001
	STD	0.0344	7.9468	2.7122	0.3034	0.0121	0.001	0.004	0.1191	0	0.0686	0.0231	0	0.1714	0

CHEMICAL/Physical/Fecal
11/9/70 - 3/3/80

Site	Statistic	Discharge (cfs)	Temp deg C	DO (mg/L)	BOD (mg/L)	COD (mg/L)	TOC (mg/L)	COND. (umhos/cm)	TDS (mg/L)	TSS (mg/L)	pH stnd. units	TP (mg/L)	Org. N (mg/L)	NH3 (mg/L)	NO3 (mg/L)	NO2 (mg/L)	Fecal Col. (/100mL)
12	N	127	125	129	109	36	30	127	68	35	31	128	3	125	129	129	124
	MIN	0.3	0	0	0.1	0	3	118	2	1	6.5	0.01	0.18	0.02	0	0	50
	MAX	1150	26	15	14.3	47.2	12	920	736	29	9.1	14.3	0.3	4.93	0.7	6.11	170000
	MEAN	34.76	12.063	9.216	3.751	10.417	5.1333	350.29	241.82	7.314	7.4258	1.07	0.25333	0.573	0.071	2.595	15127.68
	STD	113.14	7.453	2.845	2.764	9.322	2.193	139.04	113.45	6.927	0.5228	1.843	0.06429	0.798	0.095	1.165	26415.6
15	N	107	108	109	93	36	31	109	64	35	30	109	3	107	110	110	94
	MIN	0.2	0	0	0	0	0	106	88	1	6.6	0.05	0.19	0.01	0	0.15	500
	MAX	463	29	16.3	26	60.4	13	1740	512	121	8.4	9.9	0.46	9.8	0.61	6.74	660000
	MEAN	29.641	12.163	8.515	5.1387	13.5056	5.8387	367.22	254.047	16.8	7.4067	1.447	0.32333	0.897	0.08	2.312	68218.04
	STD	59.561	7.727	3.049	4.8551	10.6941	3.3075	200.3	86.234	24.741	0.4842	1.915	0.13503	1.15	0.096	1.201	124606.99

Figure 5.2



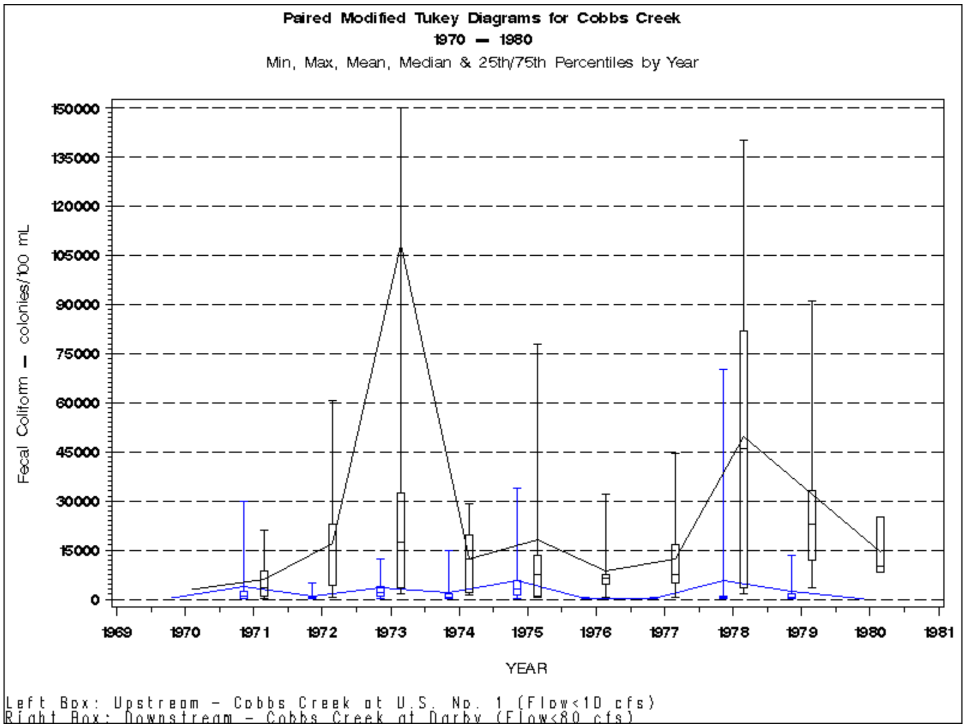


Figure 5.3

Figure 5.4

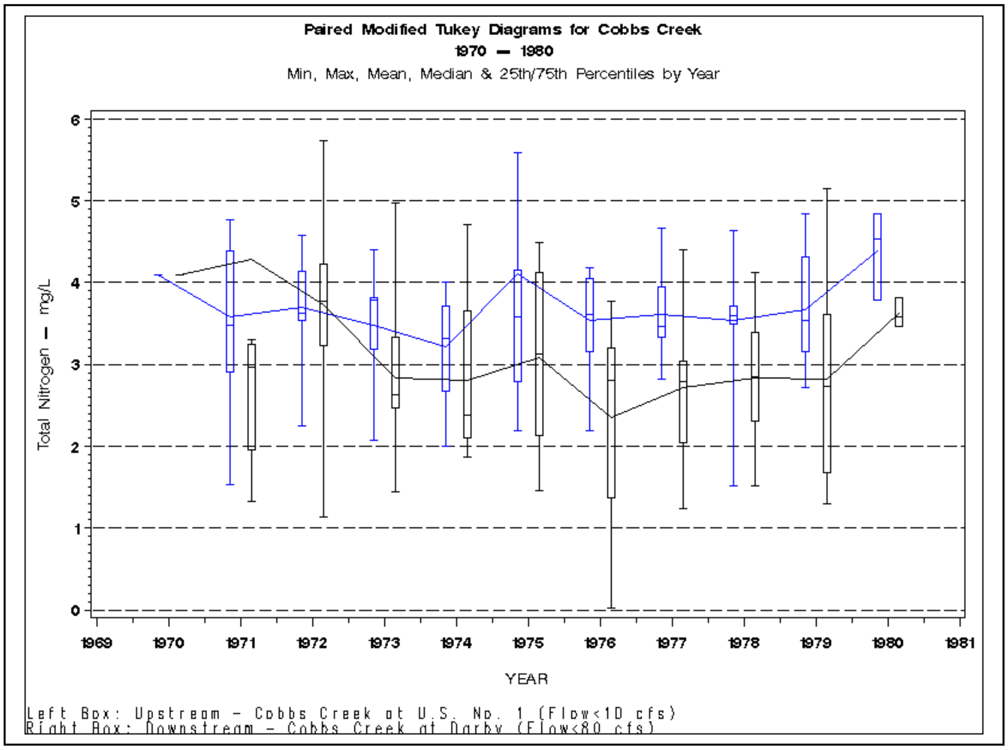


Table 5.4 Qualitative Summary of Water Quality Data Collected 1970-1980

Parameter	**Period of Observation**	**Comments**
Discharge	1970-1980	Discharge at the upstream and downstream sites follow the same pattern, with discharge increasing downstream.
Temperature	1970-1980	Water temperature goes through a seasonal cycle and differs very little between cross-sections.
pH	1970-1973	pH is lower at the downstream location for most of the samples. All the pH values fall between 6.5 and 8.5.
Specific Conductance	1970-1980	For most measurements, specific conductance was greatest at the downstream cross-section.
Dissolved Oxygen	1970-1980	DO concentrations at the upstream range seasonally from about 8 mg/L to 14 mg/L. DO concentrations at the downstream location are almost always lower and drop as low as 0 mg/L during some summers.
BOD	1970-1980	Upstream BOD loads are mostly less than 5 mg/L. Downstream BOD is higher but is usually still under 10 mg/L except for some peaks in mid-1971.
COD	1970-1973	COD concentrations range from about 0 to 30 mg/L at the downstream site and from about 5 to 45 mg/L at the upstream site. COD concentrations are greatest at the downstream site with the exception of three upstream peaks.
TOC	1970-1973	TOC concentrations range from about 0 to 10 mg/L at the upstream site and from about 0 to 25 mg/L at the downstream site. TOC concentrations are greatest at the downstream site with the exception of three upstream peaks.
Suspended Solids	1970-1973	Suspended solids are greatest in the downstream location, ranging as high as 60 mg/L, except for two peaks in the upstream concentration. Other than the peaks, upstream suspended solids are less than 10 mg/L.
Total Dissolved Solids	1970 – 1980	TDS was greatest at the downstream site for most samplings.

Table 5-4, continued

Organic Nitrogen	1972	The small number of data points for organic nitrogen concentrations show relatively constant values at the upstream site and values ranging between 0 and 2.25 mg/L at the downstream site.
Ammonia as Nitrogen	1970-1980	Other than downstream peaks as high as 20 mg/L in late 1971, most ammonia measurements are less than 2 mg/L. Downstream values are greater than upstream values for almost all measurements.
Nitrite an Nitrogen	1970-1980	Except for a few peaks, nitrite concentrations were less than 0.05 mg/L at the upstream location. Concentrations at the upstream location were higher and reached a maximum of 0.7 mg/L.
Nitrate as Nitrogen	1970-1980	Nitrate concentrations were greatest at the upstream location with very few exceptions.
Total Phosphate	1970-1980	The total phosphate concentration was greater at the downstream location for most measurements, reaching a maximum of 11 mg/L in late 1972.
Fecal Coliform	1970-1980	Fecal coliform counts appear to increase by a factor of approximately ten from the upstream to downstream locations.
Aluminum	1970-1973	The upstream and downstream concentrations follow the same shape. The downstream concentration is greater for two of the peaks, while the upstream concentration is greater for two other peaks.
Beryllium	1970-1973	All of the beryllium concentrations measured were less than 0.01 mg/L. These values were not graphed.
Cadmium	1970-1973	Most cadmium concentrations at the upstream and downstream locations are less than 0.001 mg/L. In 1971, the upstream peaks were earlier and greater than the downstream peaks. In 1972 and 1973, the downstream peaks are greater than the upstream peaks. The largest downstream peak is not reflected at the upstream location.
Calcium	1970-1973	The upstream and downstream concentrations follow the same shape. The downstream concentration is greater except for two times in late 1971 and mid-1972.
Chromium	1970-1973	Upstream concentrations are all less than 0.1 mg/L with the exception of one peak of about 1.7 mg/L in April 1972. Downstream concentrations range between 0 and 0.5 mg/L.
Cobalt	1970-1973	All upstream cobalt concentrations are less than 0.001 mg/L. All downstream concentrations are less than 0.001 mg/L except for one peak of 0.01 mg/L.
Copper	1970-1973	Many of the copper concentrations are less than 0.01 mg/L and plotted as zero. The downstream concentration reached five peaks of about 0.02 mg/L, and the upstream concentration reached three peaks of 0.03 to 0.06 mg/L.
Iron	1970-1973	The downstream iron concentration is greater than the upstream concentration except for one downstream peak in May 1973.
Lead	1970-1973	All the measured lead concentrations except for two are less than 0.05 mg/L. The downstream concentrations are greater than the upstream concentrations.
Magnesium	1970-1972	The upstream concentration varies between approximately 8 mg/L and 10 mg/L. The downstream concentration pattern follows a similar shape but has more extreme maximum and minimum values.
Manganese	1970-1973	The downstream concentration of manganese is greater than the upstream concentration except for three upstream peaks and the final reading.
Nickel	1970-1972	Measured nickel concentrations are less than 0.01 mg/L (plotted as zero) during the study period except for one peak that occurs both upstream and downstream. The downstream peak is larger in concentration and occurs about two months later than the upstream peak.
Silver	1970-1973	All of the silver concentrations measured were less than 0.001 mg/L. These values were not graphed.
Zinc	1970-1973	Other than four peaks in the upstream concentration, downstream concentrations of zinc are greater.

5.2 Summary of Water Quality Data Collected 1999-2002

PWD carried out a comprehensive sampling and monitoring program in the Darby-Cobbs watershed between 1999 and 2002 (see Section 3 of the Comprehensive Characterization Report). The first step in water quality analysis is to identify constituents of possible concern. Tables 5.5 and 5.6 list constituents monitored, applicable state water quality standards, number of samples, and number of samples that exceed the standards.

For dissolved oxygen, discrete sampling is not sufficient to characterize the condition of the stream. The magnitude of the diurnal pattern exhibited by DO is an indicator of the amount of algal activity in the steram, and the minimum DO occurs in darkness when sampling is impractical. For this reason, PWD has monitored dissolved oxygen on a continuous basis at several sites in the Cobbs Creek system (Figure 5.5). At sites DCC110 and DCC455, concentrations are occasionally (less than 5% of observations) below the average daily limit of 5 mg/L. The only site where concentrations are often below the average standard (20% of observations) and the instantaneous standard (5% of observations) is site DCC115. This site is just above the low dam at Woodland Ave.

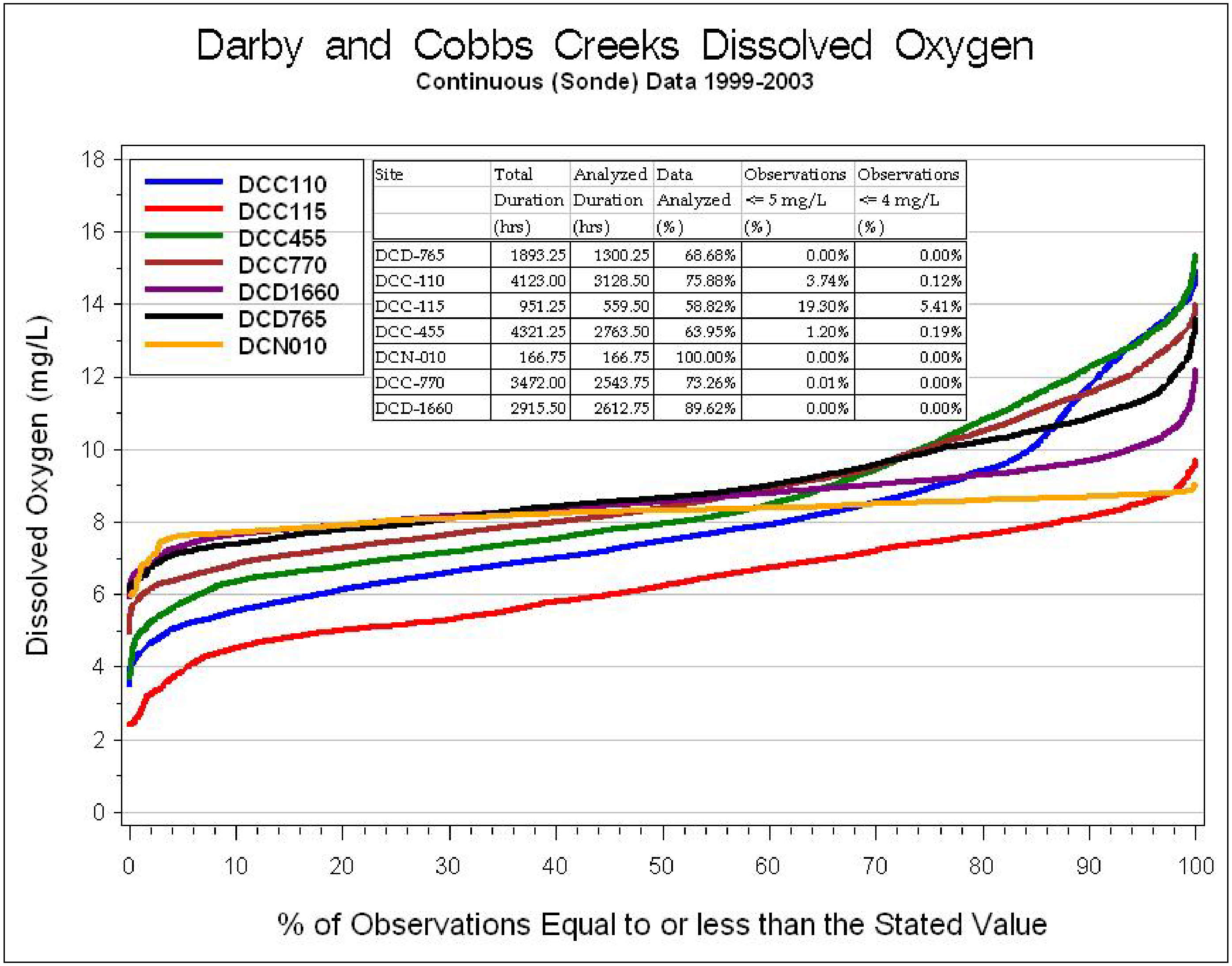
Following the determination of parameters of possible concern, sites were identified where exceedance of these parameters has occurred. Table 5.7 lists the parameters of possible concern and sites where they have been identified. Locations of sampling sites are shown in Figure 5.6.

Table 5.5 Dry Weather Water Quality Summary – Parameters with Standards

				Percentiles						
Parameter	Standard	Units	No. Observations	0	25	50	75	100	No. Exceeding	% Exceeding
Alkalinity	Minimum	mg/L	59	58.0	66.0	74.0	79.0	98.0	0	0.0
Cadmium	Aquatic Life Acute Maximum	mg/L	59	ND	ND	ND	ND	ND	0	0.0
Cadmium	Aquatic Life Chronic Maximum	mg/L	59	ND	ND	ND	ND	ND	0	0.0
Cadmium	Human Health Maximum	mg/L	60	ND	ND	ND	ND	ND	0	0.0
Chromium	Aquatic Life Acute Maximum	mg/L	59	ND	ND	ND	ND	0.00247	0	0.0
Chromium	Aquatic Life Chronic Maximum	mg/L	59	ND	ND	ND	ND	0.00247	0	0.0
Copper	Aquatic Life Acute Maximum	mg/L	59	0.00107	0.00236	0.00330	0.00409	0.0101	0	0.0
Copper	Aquatic Life Chronic Maximum	mg/L	59	0.00107	0.00236	0.00330	0.00409	0.0101	0	0.0
Copper	Human Health Maximum	mg/L	59	0.00107	0.00236	0.00330	0.00409	0.0101	0	0.0
Dissolved Iron	Maximum	mg/L	59	0.0545	0.136	0.173	0.209	0.436	4	6.8
DO	Average Daily Minimum	mg/L	58	4.88	6.98	7.96	8.80	10.7	1	1.7
DO	Instantaneous Minimum	mg/L	58	4.88	6.98	7.96	8.80	10.7	0	0.0
Fluoride	Maximum	mg/L	59	ND	ND	ND	0.108	0.142	0	0.0
Iron	Maximum	mg/L	59	0.152	0.231	0.286	0.399	0.918	0	0.0
Fecal	Maximum	/100mL	60	90	290	410	620	23000	51	85.0
Manganese	Maximum	mg/L	59	0.0137	0.0251	0.0330	0.0460	0.0972	0	0.0
NH3T	Maximum	mg/L	58	ND	ND	ND	ND	0.186	0	0.0
NO23	Maximum	mg/L	60	2.90	2.90	2.90	2.90	2.90	0	0.0
Osmotic Pressure	Maximum	mOsm/kg	20	3.00	4.00	5.00	6.00	6.00	0	0.0
pH	Maximum	dimensionless	58	7.09	7.39	7.57	7.73	8.18	0	0.0
Lead	Aquatic Life Acute Maximum	mg/L	59	ND	ND	ND	0.00102	0.00433	0	0.0
Lead	Aquatic Life Chronic Maximum	mg/L	59	ND	ND	ND	0.00102	0.00433	0	0.0
Lead	Human Health Maximum	mg/L	59	ND	ND	ND	0.00102	0.00433	0	0.0
Phenolics	Maximum	mg/L	56	ND	ND	ND	ND	0.17	3	5.4
TDS	Maximum	mg/L	59	148	210	234	289	420	0	0.0
Temperature	Instantaneous Maximum	degree C	58	13.7	15.7	18.9	20.3	24.1	7	12.1
Zinc	Aquatic Life Acute Maximum	mg/L	59	ND	0.00640	0.00947	0.0138	0.0582	0	0.0
Zinc	Aquatic Life Chronic Maximum	mg/L	59	ND	0.00640	0.00947	0.0138	0.0582	0	0.0
Zinc	Human Health Maximum	mg/L	59	ND	0.00640	0.00947	0.0138	0.0582	0	0.0

Table 5.6 Wet Weather Water Quality Summary – Parameters with Standards

Parameter	Standard	Units	No. Observations	Percentiles					No. Exceeding	% Exceeding
				0	25	50	75	100		
Alkalinity	Minimum	mg/L	96	24.0	42.0	58.5	68.0	85.0	0	0.0
Cadmium	Aquatic Life Acute Maximum	mg/L	93	ND	ND	ND	ND	ND	0	0.0
Cadmium	Aquatic Life Chronic Maximum	mg/L	93	ND	ND	ND	ND	ND	0	0.0
Cadmium	Human Health Maximum	mg/L	93	ND	ND	ND	ND	ND	0	0.0
Chromium	Aquatic Life Acute Maximum	mg/L	93	ND	ND	0.00151	0.0036	0.014	0	0.0
Chromium	Aquatic Life Chronic Maximum	mg/L	93	ND	ND	0.00151	0.0036	0.014	6	6.5
Copper	Aquatic Life Acute Maximum	mg/L	93	0.00183	0.00428	0.00625	0.0096	0.034	11	11.8
Copper	Aquatic Life Chronic Maximum	mg/L	93	0.00183	0.00428	0.00625	0.0096	0.034	23	24.7
Copper	Human Health Maximum	mg/L	93	0.00183	0.00428	0.00625	0.0096	0.034	0	0.0
Dissolved Iron	Maximum	mg/L	93	0.0739	0.129	0.155	0.2143	0.3924	5	5.4
DO	Average Daily Minimum	mg/L	94	1.73	5.27	6.52	8.07	10.25	22	23.4
DO	Instantaneous Minimum	mg/L	94	1.73	5.27	6.52	8.07	10.25	9	9.6
Fluoride	Maximum	mg/L	96	ND	ND	0.101	0.1145	0.194	0	0.0
Iron	Maximum	mg/L	93	0.181	0.317	0.550	0.747	6.456	13	14.0
Fecal Coliform	Maximum	/100mL	95	100	2100	7900	31000	200000	94	98.9
Manganese	Maximum	mg/L	93	0.0170	0.0385	0.0553	0.07443	0.2118	0	0.0
NH3T	Maximum	mg/L	93	ND	ND	0.100	0.198	1.62	0	0.0
NO23	Maximum	mg/L	102	2.90	2.90	2.90	2.9	2.9	0	0.0
Osmotic Pressure	Maximum	mOsm/kg	10	2.00	2.00	3.00	3.00	4.00	0	0.0
pH	Maximum	dimensionless	94	6.82	7.21	7.33	7.54	7.83	0	0.0
Lead	Aquatic Life Acute Maximum	mg/L	93	ND	0.00144	0.00246	0.00577	0.0571	1	1.1
Lead	Aquatic Life Chronic Maximum	mg/L	93	ND	0.00144	0.00246	0.00577	0.0571	40	43.0
Lead	Human Health Maximum	mg/L	93	ND	0.00144	0.00246	0.00577	0.0571	1	1.1
Phenolics	Maximum	mg/L	94	ND	ND	ND	ND	0.116	5	5.3
TDS	Maximum	mg/L	96	20.0	128	185	235	391	0	0.0
Temperature	Instantaneous Maximum	degree C	94	14.2	16.5	19.8	21.5	25.3	9	9.6
Zinc	Aquatic Life Acute Maximum	mg/L	93	ND	0.0110	0.0180	0.0295	0.111	3	3.2
Zinc	Aquatic Life Chronic Maximum	mg/L	93	ND	0.0110	0.0180	0.0295	0.111	6	6.5
Zinc	Human Health Maximum	mg/L	93	ND	0.0110	0.0180	0.0295	0.111	0	0.0



Site	Total Duration (hrs)	Analyzed Duration (hrs)	Data Analyzed (%)	Observations <= 5 mg/L (%)	Observations <= 4 mg/L (%)
DCD-765	1893.25	1300.25	68.68%	0.00%	0.00%
DCC-110	4123.00	3128.50	75.88%	3.74%	0.12%
DCC-115	951.25	559.50	58.82%	19.30%	5.41%
DCC-455	4321.25	2763.50	63.95%	1.20%	0.19%
DCN-010	166.75	166.75	100.00%	0.00%	0.00%
DCC-770	3472.00	2543.75	73.26%	0.01%	0.00%
DCD-1660	2915.50	2612.75	89.62%	0.00%	0.00%

Figure 5.5 Continuous DO Monitoring Results

Table 5.7 Sites with at least one Observed Exceedance of Water Quality Criteria

	Dry											
Parameter	DCC110	DCC115	DCC455	DCC770	DCN010	DCI010	DCD765	DCD1170	DCD1570	DCD1660	DCM300	DCS170
Chromium												
Copper												
Dissolved Iron	X				X						X	X
DO		X										
Iron												
Fecal Coliform	X		X	X	X	X	X	X	X		X	X
Lead												
Phenolics					X						X	
Temperature							X		X	X		
Zinc												

	Wet											
Parameter	DCC110	DCC115	DCC455	DCC770	DCN010	DCI010	DCD765	DCD1170	DCD1570	DCD1660	DCM300	DCS170
Chromium	X					X	X		X			
Copper	X		X			X	X					X
Dissolved Iron	X						X					X
DO	X	X					X			X		
Iron	X											
Fecal Coliform	X		X	X	X	X	X	X	X	X	X	X
Lead	X		X	X		X	X			X		X
Phenolics			X	X			X			X	X	
Temperature							X	X	X	X		
Zinc	X						X					

Note: DCC115 was sampled for DO only on a continuous basis.

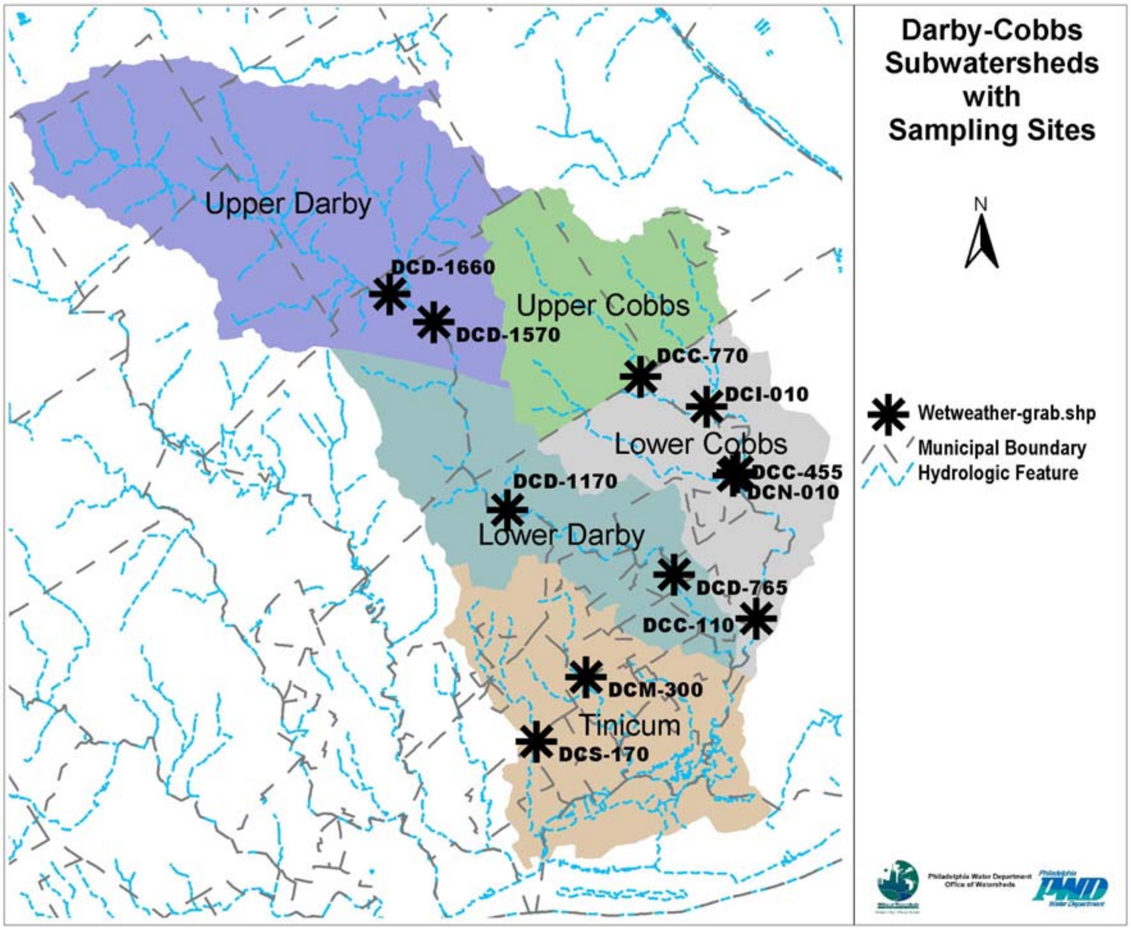


Figure 5.6 Subwatersheds and Sampling Sites

5.3 Detailed Discussion of Data Collected 1999-2000

5.3.1 Upper Cobbs Creek

Two sampling sites represent the headwaters and upper reaches of Cobbs Creek. Site DCC-770 is on the main stem of Cobbs Creek near the Philadelphia/ Montgomery County line, and DCI-010 is on Indian Creek just above the confluence with the main stem. These sites do not receive CSO inputs. Table 5.8 summarizes the mean concentrations of water quality constituents collected at the two sites.

Table 5.8 Summary of Upper Cobbs Mean Water Quality

		DCC-770		DCI-010	
Parameter	Units	Dry	Wet	Dry	Wet
Al	mg/L	0.066	0.216	0.018	0.102
Alk	mg/L	60.8	57.4	79.8	68.2
BOD30	mg/L	2.28	3.61	1.72	2.73
BOD5	mg/L	1.00	1.50	1.00	1.71
CBOD5	mg/L	1.00	1.43	1.00	1.69
Ca	mg/L	31.7	24.3	45.6	33.0
Cd	mg/L	5.00E-04	5.00E-04	5.00E-04	5.00E-04
Chla	ug/L				
Cr	mg/L	0.004	0.005	0.004	0.006
Cu	mg/L	0.004	0.007	0.004	0.007
DO	mg/L	7.72	7.30	8.13	7.18
DissCd	mg/L				
DissFe	mg/L	0.142	0.110	0.166	0.142
Ecoli	/100 mL	578	6800	350	9840
F	mg/L	0.050	0.070	0.060	0.082
Fe	mg/L	0.242	0.414	0.224	0.288
Fecal	/100 mL	440	1.64E+04	386	3.15E+04
Mg	mg/L	15.6	11.5	18.1	12.9
Mn	mg/L	0.028	0.032	0.018	0.028
NH3T	mg/L	0.050	0.110	0.050	0.114
NO2	mg/L	0.007	0.022	0.005	0.033
NO3	mg/L	2.29	1.86	1.66	1.39
OsPress	mosm	4.00	3.00	6.00	4.00
PO4	mg/L	0.020	0.028	0.020	0.032
Pb	mg/L	0.002	0.003	5.00E-04	0.002
Phen	mg/L	0.015	0.022	0.015	0.015
SpCond	uS/cm	349	294	447	354
TChl	ug/L				
TDS	mg/L	216	200	274	243
TKN	mg/L	0.614	1.09	0.536	1.09
TP	mg/L	0.036	0.074	0.056	0.098
TSS	mg/L	10.4	12.4	2.10	6.90

Table 5-8, cont'd

TempC	degrees C	17.4	19.0	17.4	19.3
Turb	NTU	3.24	11.3	3.03	2.98
Zn	mg/L	0.009	0.012	0.008	0.010
pH		7.38	7.32	7.70	7.50

Notes on tables in this section

- The individual data points used in calculation of these means are listed by site and date on the web site.
- For concentrations at or below the detection limit, half the detection limit is used in the calculation of the means listed above.
- For multiple observations during a wet weather event, a single value was chosen to represent the event as follows: for DO, the minimum; for pH, specific conductance, temperature, alkalinity, and turbidity, the mean; for all other parameters, the maximum. This single value was used in the calculation of means listed in the table above.

Upper Cobbs Physical Conditions: Temperature, pH, Solids, Conductivity, Turbidity

Figure 5.7 and 5.8 includes graphs of eutrophication related physical/chemical parameters and nutrients over the 1999 discrete sampling period at DCC-770. Other than the increase in temperature over the course of the summer, there are no obvious trends over time or between wet and dry dates.

Upper Cobbs Dissolved Oxygen

1335.5 hours of quality-assured continuous DO data are available for site DCC-770. Figure 5.9 includes graphs from four of these deployments. The data from July 9 to 12, 1999 (upper left) represent an uninterrupted dry weather period. Between July 26 and August 9, 2001 (upper right), several small wet weather events occurred. CSOs do not affect upper Cobbs sites, but they can be used to identified wet weather periods. Small quantities of CSO occur downstream on July 26 and 30. On Aug 10 and 12, larger CSOs occur throughout the system, including outfalls C_31, C_32 and C_33. Stormwater runoff and CSOs cause the noise or random variation in the measurements to increase slightly but have only a small effect on the overall magnitude or pattern of DO.

Similar effects are observed when a larger storm occurs on December 9-10, 2001 (lower left and lower right representing two instruments deployed concurrently). All data points are shown, but data that do not meet quality assurance criteria are shown with a thinner gray line. Quality assurance and control procedures developed to assess data from the urban environment are described in detail in the Appendix. Data points taken with a calibrated handheld instrument show that the lower right plot represents actual conditions more accurately except for a period during the runoff event. There does not appear to be a major difference in DO between dry and wet weather. In dry weather, the amplitude of the diurnal pattern is approximately 1.5-2.0 mg/L. The water column is often supersaturated in the afternoon.

The amplitude of the diurnal pattern at DCC-110 ranges from approximately 1.5 to 2.5 mg/L with an average of approximately 2.0 mg/L. The greatest amplitudes were observed during the autumn deployments and the least during summer deployments.

Figure 5.10 summarizes the range and cumulative distribution of DO in the Upper Cobbs and throughout the system. The plot shows the percentage of samples (on the horizontal axis) that are less than or equal to a range of DO concentrations (on the vertical axis). For example, DO at DCC-770 ranges from approximately 4 to 15 mg/L and is less than or equal to 6 mg/L for approximately 2% of quality-assured observations.

Upper Cobbs Nutrients

Mean inorganic nitrogen at DCC-770, including nitrate, nitrite, and ammonia, is 2.35 mg/L in dry weather and 2.00 mg/L in wet weather. Mean ammonia increases from approximately 2% of total nitrogen in dry weather to 4% in wet weather. Figure 5-8 shows the temporal trends at DCC-770 in nitrogen species, phosphorus species, and other parameters related to the trophic state of the site. DCC-770 generally has higher nitrate concentrations than those found further downstream.

Upper Cobbs Bacteria

Observed fecal coliform and *E. coli* concentrations at DCC-770 are on the order of 10^2/100 mL in dry weather and range higher than 10^4/100 mL in wet weather conditions. Similar trends are observed at DCI-010.

Upper Cobbs Metals

At both Upper Cobbs sites, mean concentrations of most metals are greater in wet weather. These metals include aluminum, chromium, copper, total iron, manganese, lead, and zinc. Cadmium samples are below the detection limit for all samples at both sites. For concentrations at or below the detection limit, half the detection limit is used in the calculation of mean and in temporal and spatial plots. Mean dissolved iron is lower in wet weather at both sites.

Upper Cobbs Fish Advisories

AMSA et al. (2002) recommend against using fish advisories alone as the basis for impairment listings, but they can provide a basis for further study and for establishment of water quality standards. Fish advisories are most often due to metals or organic chemicals. The April 2001 fish advisory for this watershed advises to limit consumption of White Perch, Striped Bass, and Carp to one meal a month, and to limit consumption of Channel Catfish to one meal every two months. American eel should not be eaten at all. This is all due to PCB pollution.

5.3.2 Lower Cobbs Creek

Three sampling sites represent lower Cobbs Creek. Site DCC-455 is on the main stem at Cobbs Creek Environmental Center, and DCN-010 is on Naylors Run just above the confluence with Cobbs Creek. Site DCC-110 is on the main stem about one mile above the confluence with Darby Creek. The two sites on the mainstem receive stormwater and CSO inputs, while the Naylors Run site receives only stormwater. Additional monitoring was conducted just upstream of the dam at DCC-110. Table 5.9 summarizes the mean concentrations of water quality constituents collected at the three sites.

Table 5.9 Summary of Lower Cobbs Mean Water Quality

		DCC-110		DCC-455		DCN-010	
Parameter	Units	Dry	Wet	Dry	Wet	Dry	Wet
Al	mg/L	0.058	0.623	0.026	0.152	0.044	0.058
Alk	mg/L	76.0	53.1	71.8	62.6	79.4	64.0
BOD30	mg/L	3.81	20.6	2.12	6.71	2.93	3.34
BOD5	mg/L	1.00	4.37	1.00	3.22	1.00	1.54
CBOD5	mg/L	1.00	3.39	1.00	2.72	1.00	1.48
Ca	mg/L	37.2	24.5	37.8	27.7	49.3	35.3
Cd	mg/L	5.00E-04	5.00E-04	5.00E-04	5.00E-04	5.00E-04	5.00E-04
Chla	ug/L	1.69	39.8				
Cr	mg/L	0.003	0.005	0.004	0.006	0.004	0.005
Cu	mg/L	0.004	0.009	0.003	0.006	0.003	0.006
DO	mg/L	6.57	4.15	7.40	5.64	8.34	8.06
DissCd	mg/L	5.00E-04	5.00E-04				
DissFe	mg/L	0.217	0.226	0.184	0.166	0.220	0.168
Ecoli	/100 mL	292	4.40E+04	850	4.37E+04	475	8980
F	mg/L	0.086	0.116	0.060	0.098	0.084	0.130
Fe	mg/L	0.456	0.954	0.310	0.414	0.272	0.252
Fecal	/100 mL	415	7.68E+04	972	4.68E+04	564	2.59E+04
Mg	mg/L	15.1	9.89	16.1	11.3	17.8	13.3
Mn	mg/L	0.054	0.110	0.026	0.060	0.034	0.036
NH3T	mg/L	0.089	0.463	0.050	0.270	0.050	0.120
NO2	mg/L	0.029	0.055	0.020	0.066	0.019	0.035
NO3	mg/L	1.56	1.21	1.89	1.49	2.45	2.13
OsPress	Mosm	5.00	2.00	5.00	3.00	6.00	4.00
PO4	mg/L	0.020	0.031	0.020	0.040	0.020	0.026
Pb	mg/L	0.002	0.008	5.00E-04	0.003	5.00E-04	5.00E-04
Phen	mg/L	0.015	0.015	0.015	0.020	0.018	0.042
SpCond	uS/cm	409	269	416	321	506	403
TChl	ug/L	2.75	47.2				
TDS	mg/L	244	195	247	224	304	280
TKN	mg/L	0.657	1.52	0.660	1.04	0.582	1.14
TP	mg/L	0.076	0.196	0.052	0.132	0.038	0.080
TSS	mg/L	2.25	23.0	1.70	8.00	3.60	3.30
TempC	degrees C	19.6	20.7	19.0	20.3	18.1	20.0
Turb	NTU	2.79	13.8	2.10	7.48	2.75	2.94
Zn	mg/L	0.016	0.026	0.008	0.012	0.010	0.014
PH		7.51	7.16	7.58	7.26	7.78	7.64

Lower Cobbs Physical Conditions: Temperature, pH, Solids, Conductivity, Turbidity

The continuous data collected by the Sonde instruments provides a picture of how various water quality constituents interact in the urban environment during dry and wet weather. In a highly impervious environment, the streamflow hydrograph responds to wet weather with a sudden, high peak flow followed by a rapid recession back to baseflow. In the warmer months, stormwater runoff from hot pavement can increase water temperature by several degrees during a runoff event. Suspended solids and turbidity in the water column both increase during the course of a storm because of stormwater inputs. In addition, high velocity flows may re-suspend bed sediments and cause bank erosion, further increasing solids in the water column. Conductivity, an indirect measure of dissolved solids, typically decreases during a storm as stormwater runoff dilutes the ambient water.

Figure 5.11 displays the results of one Sonde deployment at DCC-110 during November 2000. The effects of urban runoff and high velocity on depth, turbidity, and conductivity are all apparent. Although warm pavement may cause sudden increases in stream temperature during wet weather, the temperature trend observed during this deployment is most likely the result of a front passing through and affecting air temperature. The average daily water temperature mirrors air temperature, but its changes are less pronounced due to the higher specific heat of water (Figure 5.11.1). When the storm front raises air temperatures to a high of 19 ^{o}C on November 10, instream water temperature increases approximately 2.5^{o}C to just under 15 ^{o}C over a period of six hours. Both air and water temperature drop after the passage of the storm front.

Lower Cobbs Dissolved Oxygen

A total of 2597 and 1337.75 hours of quality-assured continuous DO data were collected at the two mainstem lower Cobbs sites: DCC-110 and DCC-455 respectively. Figure 5.12 includes time series plots of DO measured during four deployments at DCC-110. July 9 to 12, 1999 (upper left) is an example of dry weather conditions at the site. A total of 0.96 inches of rain was produced by wet weather events during the period from June 2 to 15, 2000 (upper right). The event, on June 6, 2000, depresses observed DO for a brief period; however, it is difficult to tell whether this effect is due to instrument error or actual conditions. The second event causes what appears to be a random fluctuation in the data.

The deployment from May 11 to 24, 2001 (lower left) includes a larger wet weather event that triggers multiple CSOs. The signal becomes extremely erratic during the event and does not recover. The data from May 21 to the end of the period do not meet quality assurance criteria and are not included in analyses. During the late summer deployment from July 26 to August 6, 2001 (upper right), the trough of the observed diurnal pattern at DCC-110 is between 4 and 5 mg/L. The gradually decreasing saturation DO indicates that air temperature increased during this period.

Figure 5.13 includes four time series plots of continuous DO measured at site DCC-455. After the DO probe readings stabilize, the September 27 to October 5, 2000 deployment (upper left) is a good example of dry weather conditions at this site. During the period from July 27 to August 10, 2001 (upper right), there is some noise or random fluctuation in the data, but this deployment provides another good example of dry weather conditions with one small wet weather event of 0.49 inches.

The December 5 to 17, 2001 deployment at DCC-455 (lower left) begins with a dry weather period with an observed diurnal amplitude of approximately 4 mg/L. Concentrations measured by the Sonde are verified by two readings taken with hand-held meters. A wet weather event of 0.72 inches occurs on December 8 and causes the instrument to cease functioning until maintenance is performed on December 10. Data taken after the wet weather event, while they do not match the hand-held data points exactly, provide more evidence that the diurnal amplitude was large during this period. The deployment period from January 15 to 31, 2002 displays similar conditions including low water temperatures, high DO, and a large difference between daily maxima and minima.

The observed dry weather diurnal DO amplitude at site DCC-110 is between 1.5 and 2.5 mg/L for quality-assured data. At site DCC-455, the diurnal amplitude of the DO signal ranged from approximately 1.5 to over 4 mg/L for quality-assured data. The average amplitude was approximately 2.5 mg/L. Thus, there is some evidence that the amplitude is greater at DCC-455. Pronounced differences between the amplitude in different seasons were not observed.

Figure 5.10 includes the cumulative distribution of DO at four sites in the lower Cobbs. At DCC-110, DO ranges from between 4 and 15 mg/L, with 95% of measurements greater than 5 mg/L. At DCC-455, DO ranges from just below 4 to greater than 15 mg/L. DO at DCC-455 is generally greater than DO at DCC-110, but the range in measurements is greater at DCC-455. The two main stem Darby Creek sites have the greatest range of all monitored sites in the Darby and Cobbs Creeks watershed.

Figure 5.10 also includes 560 hours of data at site DCC-115, just above the dam at DCC-110. This site has the lowest DO of any monitored site in the system, with nearly 20% of observations below 5 mg/L. The monitor is located just upstream of the dam in a deep pool of very low velocity, poorly mixed water.

Lower Cobbs BOD

Observed mean BOD at the lower Cobbs sites is greater in wet weather than in dry weather. Figure 5-14 shows multiple BOD_{30} observations during a single event at DCC-110 between June 1 and 8, 2000. The concentration is lowest during the dry weather sample before the storm, reaches a peak during the storm, and recedes to its dry weather level after the storm.

BOD measured under idealized laboratory conditions does not always represent the amount of oxygen demand exerted in the field. Figure 5-15 includes four graphs of laboratory 30-day BOD data sheets for wet weather samples taken at DCC-110. Very little oxygen demand is exerted during the first 2 to 3 days of the test. Because travel time in Cobbs Creek is thought to be on the order of 1-2 days, it is unlikely that BOD will have a significant effect on instream DO except in poorly mixed pools.

Lower Cobbs Nutrients

Figures 5.16 through 5.23 compare concentrations of nitrogen and phosphorus species along the length of Cobbs Creek and throughout the Darby and Cobbs Creeks system. The plots show the mean and range of measurements, river miles, and wet weather status. Figures 5.24 through 5.27 display temporal trends for a variety of eutrophication-related parameters at sites DCC-110 and DCC-455.

Compared to upstream sites, observed mean inorganic nitrogen in the water column (nitrate, nitrite, and ammonia) under dry conditions decreases from 2.35 mg/L at DCC-770 and 1.96 mg/L at DCC-455 to 1.68 mg/L at DCC-110. Under dry weather conditions, ammonia makes up approximately 2% of total nitrogen at sites DCC-770 and 4% at site DCC-110. Under wet conditions, ammonia makes up approximately 4% of total nitrogen at DCC-770, 10% at DCC-455, and 17% at DCC-110. The mean and range of ammonia concentrations at DCC-455 and DCC-110 are roughly equal but are double those seen at DCC-770.

Inorganic phosphorus under dry weather conditions is below the detection limit of 0.04 mg/L at all three sites. Maximum wet weather phosphate concentrations are similar at the three Cobbs sites, although dry weather concentrations appear to increase from upper to lower Cobbs. It is difficult to estimate ratios of nitrogen to phosphorus due to the detection limit samples. If the phosphate concentration is taken as half the detection limit, the ratio of inorganic nitrogen to inorganic phosphorus in dry weather decreases from 117:1 at DCC-770 to 98:1 at DCC-455 to 83:1 at DCC-110. However, any unknown trend in the phosphorus concentration could significantly change these ratios.

Lower Cobbs Bacteria

Bacteria are present at Lower Cobbs sites at high concentrations under both dry and wet conditions. Mean dry weather fecal coliform at DCC-110 is 2.3×10^4 /100 mL. Under wet weather conditions when CSOs are active, fecal coliform may peak at 10^5/100 mL or higher as shown in wet weather sampling results (Figure 5-28). Similar trends are seen in *E. coli* (Figure 5.29).

At DCC-455, fecal coliform observations range from 460/100 mL in dry weather to 2×10^5/100 mL in wet weather. At DCN-010, observations range from 8×10^2/100 mL in dry weather to 3×10^5/100 mL in wet weather.

Figures 5.30 and 5.31 compare fecal coliform and *E. Coli* along the length of Cobbs Creek and throughout the Darby and Cobbs Creeks system. The plots show the mean and range of measurements, river miles, and dry or wet weather status. Mean and maximum bacteria counts increase from upper Cobbs to Lower Cobbs.

Lower Cobbs Metals

In most cases, metals concentrations are greater in wet weather than in dry. At DCC-110, mean concentrations of all sampled metals except cadmium are greater in wet weather. At DCC-455, the following mean metals concentrations are greater in wet weather: aluminum, chromium, copper, manganese, lead, and zinc. At DCN-010, the following mean metals concentrations are greater in wet weather: aluminum, chromium, copper, manganese, and zinc. All lead samples were below the detection limit at this site. Observed concentrations of Cd are at or below the detection limit in both dry and wet weather for the three sites representing the lower Cobbs.

When multiple wet weather samples are collected during a storm, there is a greater chance that the peak concentration will be measured. During wet weather sampling at DCC-110 , the concentrations of metals follow a pattern similar to the runoff hydrograph (Figures 5.32 through 5.35).

Dissolved iron clearly increases from upstream to downstream along the length of the Cobbs. Concentrations of iron and dissolved iron do not always follow the trend of increasing in wet weather. Compared to the dry weather mean, mean total iron increases in wet weather in both of the main stem sites but decreases slightly at the Naylors Run site. At DCC-110, dissolved iron has a mean of 0.217 mg/L under dry conditions and 0.226 mg/L under wet conditions. Wet weather sampling at DCC-110 indicates that both species increase during a June 2000 runoff event of 0.3 inches (Figures 5.32 and 5.33). At DCC-455, dissolved iron has a mean of 0.184 mg/L under dry conditions and 0.166 mg/L under wet conditions. At DCN-010, the mean dry weather concentration is 0.220 mg/L and the mean wet weather concentration is 0.168.

Lower Cobbs Fish Advisories

AMSA et al. (2002) recommend against using fish advisories alone as bases for impairment listings, but they can provide a basis for further study and for establishment of water quality standards. Fish advisories are most often due to metals or organic chemicals. The April 2001 fish advisory for this watershed advises to limit consumption of White Perch, Striped Bass, and Carp to one meal a month, and to limit consumption of Channel Catfish to one meal every two months. American eel should not be eaten at all. This is all due to PCB pollution.

5.3.3 Upper Darby Creek

The headwaters of Darby Creek are represented by data taken from site DCD-1570 and by a limited amount of data from DCD-1660. These sites are not impacted by known CSOs. Table 5.10 lists the mean dry and wet weather concentrations of water quality constituents at the two sites.

Table 5.10 Summary of Upper Darby Mean Water Quality

		DCD-1570		DCD-1660	
Parameter	Units	Dry	Wet	Dry	Wet
Al	Mg/L	0.054	0.246	0.170	0.195
Alk	Mg/L	71.2	68.2	69.0	60.0
BOD30	Mg/L	1.81	6.81	3.66	2.71
BOD5	Mg/L	1.00	1.70	1.00	1.00
CBOD5	Mg/L	1.00	1.32		
Ca	Mg/L	31.2	25.0	24.4	26.1
Cd	Mg/L	5.00E-04	5.00E-04	5.00E-04	5.00E-04
Chla	ug/L			3.03	2.95
Cr	Mg/L	0.004	0.006	0.001	7.50E-04
Cu	Mg/L	0.002	0.003	0.002	0.003
DO	Mg/L	8.81	7.86	9.41	7.06
DissCd	Mg/L			5.00E-04	5.00E-04
DissFe	Mg/L	0.146	0.130	0.070	0.090
Ecoli	/100 mL	375	7700	175	6000
F	Mg/L	0.050	0.080	0.075	0.050
Fe	Mg/L	0.242	0.466	0.305	0.395
Fecal	/100 mL	404	6730	185	10000
Mg	Mg/L	15.6	12.2	12.1	13.0
Mn	Mg/L	0.024	0.030	0.025	0.040
NH3T	Mg/L	0.050	0.066	0.050	0.050
NO2	Mg/L	0.009	0.017		
NO3	Mg/L	1.67	1.33		
OsPress	mosm	3.50	2.00		5.00
PO4	Mg/L	0.020	0.026	0.030	0.323
Pb	Mg/L	5.00E-04	0.001	5.00E-04	5.00E-04
Phen	Mg/L	0.015	0.015	0.015	0.027
SpCond	uS/cm	338	271	237	197
TChl	ug/L			3.76	3.89
TDS	Mg/L	200	193	225	141
TKN	Mg/L	0.546	0.710		
TP	Mg/L	0.034	0.064	0.050	0.075
TSS	Mg/L	2.70	10.8	74.0	26.5
TempC	degrees C	17.2	19.3	17.5	19.0
Turb	NTU	4.19	8.88	2.66	23.6
Zn	Mg/L	0.009	0.009	0.010	0.015
pH		7.60	7.54	7.35	7.25

Upper Darby Physical Conditions: Temperature, pH, Solids, Conductivity, Turbidity

The continuous data collected by the Sonde instruments provides a picture of how various water quality constituents interact in the urban environment during dry and wet weather. Figure 5-36 includes graphs of multiple parameters for DCD-1660 between September 12 and September 24, 2000. Three wet weather events occurred during this period. The flood peaks are high, occur over short durations, and are followed by a rapid return to baseflow. Each flood peak is accompanied by a large increase in turbidity and a decrease in specific conductance. Temperature, DO, and pH all display characteristic diurnal patterns in dry weather.

Upper Darby Dissolved Oxygen

Continuous DO samples were collected during 8 periods at site DCD-1660. Data from the period October 13 to 27, 2000 (Figure 5.37 upper left) represent a dry weather pattern with the exception of one wet weather event of 0.41 inches on October 18. The period from June 2 to 15, 2000 (upper right) is similar to the previous period. Stormwater runoff appears to mute the diurnal pattern, but the pattern returns to its previous amplitude after less than 24 hours. Data reliability may have decreased after the second wet weather period, but the data still meet quality assurance criteria. Data from the periods June 2 to 15, 2000 (lower left) and July 14 to August 4, 2000 (lower right) display similar trends.

The amplitude of the diurnal variation at DCD-1660 is approximately 1 to 1.5 mg/L, the smallest of the sites studied. The amplitude is greatest during the summer deployments and smaller during the spring and fall.

Upper Darby BOD

At DCD-1570, mean BOD in the water column is greater in wet weather than in dry. At DCD-1660, there is not enough evidence to conclude that it is greater. Figure 5.38 shows the laboratory BOD measured over time for a sample taken at DCD-1660 on June 15, 2000, a wet weather day. The 30-day BOD is approximately 3 to 4 mg/L, but there is virtually no BOD exertion for the first 3 to 5 days.

Upper Darby Nutrients

Figures 5.16 through 5.23 display the means, ranges, and weather status of samples of nitrogen and phosphorus species taken along the length of Darby Creek and throughout the Darby and Cobbs Creeks system. Mean nitrate and ammonia concentrations increase slightly along the length of Darby Creek. Mean total phosphorus is greater at DCD-1660 than at DCD-1570.

Upper Darby Bacteria

Figures 5.30 and 5.31 display the means, ranges, and weather status of samples of fecal coliform and *E. coli* taken along the length of Darby Creek and throughout the Darby and Cobbs Creeks system. Mean and maximum counts both increase along the length of Darby Creek.

Upper Darby Metals

At the two Upper Darby sites, mean concentrations of aluminum, copper, iron, and manganese are greater in wet weather than in dry weather. Cadmium is at or below the detection limit for all samples. Dissolved iron is lower in wet weather than in dry at DCD-1570.

Upper Darby Fish Advisories

AMSA et al. (2002) recommend against using fish advisories alone as bases for impairment listings, but they can provide a basis for further study and for establishment of water quality standards. Fish advisories are most often due to metals or organic chemicals. The April 2001 fish advisory for this watershed advises to limit consumption of White Perch, Striped Bass, and Carp to one meal a month, and to limit consumption of Channel Catfish to one meal every two months. American eel should not be eaten at all. This is all due to PCB pollution.

5.3.4 Lower Darby Creek

Lower Darby Creek is represented by two sampling sites. DCD-1170 is in the northwest part of Upper Darby Township,and DCD-765 is upstream of the confluence with Cobbs Creek. These sites are impacted by stormwater but not by known CSOs. Table 5.11 lists the mean dry and wet weather concentrations of water quality constituents at the two sites.

Table 5.11 Summary of Lower Darby Mean Water Quality

		DCD-765		DCD-1170	
Parameter	Units	Dry	Wet	Dry	Wet
Al	Mg/L	0.033	0.635	0.034	0.178
Alk	Mg/L	68.4	57.4	70.2	67.6
BOD30	Mg/L	2.79	9.04	2.36	5.42
BOD5	Mg/L	4.00	2.32	1.00	1.82
CBOD5	Mg/L	1.00	1.75	1.00	1.45
Ca	Mg/L	29.4	22.9	31.2	25.7
Cd	Mg/L	5.00E-04	5.00E-04	5.00E-04	5.00E-04
Chla	Ug/L	1.85	12.0		
Cr	Mg/L	0.003	0.006	0.004	0.005
Cu	Mg/L	0.003	0.007	0.002	0.003
DO	Mg/L	9.24	7.30	8.38	7.65
DissCd	Mg/L	5.00E-04	5.00E-04		
DissFe	Mg/L	0.133	0.157	0.162	0.146
Ecoli	/100 mL	768	1.54E+04	400	3340
F	Mg/L	0.069	0.105	0.050	0.060
Fe	Mg/L	0.214	0.869	0.254	0.404
Fecal	/100 mL	964	3.30E+04	516	6940
Mg	Mg/L	14.5	11.0	15.3	12.3
Mn	Mg/L	0.018	0.060	0.046	0.048
NH3T	Mg/L	0.060	0.171	0.050	0.066
NO2	Mg/L	0.012	0.024	0.009	0.017
NO3	Mg/L	1.81	1.53	1.70	1.38
OsPress	mosm	5.00	3.00	4.00	3.00
PO4	Mg/L	0.020	0.033	0.020	0.024
Pb	Mg/L	5.00E-04	0.005	5.00E-04	0.001
Phen	Mg/L	0.015	0.031	0.015	0.015
SpCond	US/cm	334	254	373	297
TChl	Ug/L	2.18	14.1		
TDS	Mg/L	219	187	219	211
TKN	Mg/L	0.442	0.831	0.492	0.738
TP	Mg/L	0.059	0.118	0.032	0.068
TSS	Mg/L	1.69	32.4	2.30	8.40
TempC	degrees C	19.0	20.0	17.9	19.6
Turb	NTU	1.28	30.2	2.46	6.93
Zn	Mg/L	0.009	0.023	0.005	0.028
PH		7.92	7.57	7.58	7.54

Lower Darby Physical Conditions: Temperature, pH, Solids, Conductivity, Turbidity

The continuous data collected by the Sonde instruments provides a picture of how various water quality constituents interact in the urban environment during dry and wet weather. Figure 5.39 shows two dry weather periods separated by a wet weather event. During the initial dry weather period, temperature, pH, and DO all show a relatively constant diurnal pattern. The urban wet weather hydrograph is characterized by a high, short duration storm peak followed by a rapid return to baseflow in less than 24 hours. During the storm peak, a large increase in turbidity and a decrease in specific conductance are observed. The decrease in water temperature following the storm most likely corresponds to a decrease in air temperature. pH and DO data taken after the peak do not meet quality assurance criteria, as described in the Appendix.

Lower Darby Dissolved Oxygen

Continuous DO data were collected at DCD-765 during 8 periods between September 1999 and August 2001. The period from September 27 to October 5, 2000 (upper left, Figure 5-40), is an example of a dry weather DO pattern with an amplitude of approximately 1-2 mg/L. The period from October 13 to 26, 2000 (upper right) is an example of a mostly dry period with one small wet weather event. Runoff mutes the diurnal pattern, but it recovers within 24 hours of the storm passing. The muted effect can be explained by the diluting effect of stormwater runoff, although it is difficult to determine the role of instrument error in these readings. The amplitude of the signal in this case is approximately 2 to 2.5 mg/L. The period from July 26 to August 9, 2001 (lower left) is similar but includes several wet weather events. The deployment between September 1 and September 7, 2000 (lower right) begins with a dry weather period displaying an amplitude of 2 mg/L. Following the wet weather event, the data do not meet quality assurance criteria.

Overall, the amplitude of the diurnal DO variation at DCD-765 is approximately 2 mg/L. There are insufficient data to determine whether this amplitude varies between seasons.

Lower Darby BOD

Laboratory BOD tests conducted on wet weather samples at DCD-765 show that 5-day and 30-day BOD are greater in wet weather than in dry weather. When the samples are incubated in the laboratory for five days, the total oxygen demand generated is in the range of 2 mg/L. BOD exertion over 2-3 days, coupled with a high estimate of travel time in the stream, would mean that in-stream BOD is much less than 1 mg/L.

Lower Darby Nutrients

Inorganic nitrogen at DCD-765 has a mean concentration of 1.88 mg/L in dry weather and 1.73 mg/L in wet weather. Ammonia makes up approximately 3% of total nitrogen in dry weather and 7% in wet weather. Mean inorganic nitrogen at DCD-

1170 has a concentration of 2.20 mg/L in dry weather and 2.13 mg/L in wet weather. Ammonia makes up approximately 2% of total nitrogen in dry weather and 3% in wet weather.

At both DCD-765 and DCD-1170, phosphate is equal to or less than the detection limit for all samples except one wet weather sample on 7/20/99. At DCD-765, phosphate makes up approximately one-third of total phosphorus in both dry and wet weather. At DCD-1170, total phosphorus makes up approximately 62% of total phosphorus in dry weather and 35% in wet weather.

Figures 5.41 and 5.42 show the temporal relationships between discrete nitrogen and phosphorus species collected at DCD-765. Figures 5.16 through 5.23 display the means, ranges, and weather status of samples of nitrogen and phosphorus species taken along the length of Darby Creek and throughout the Darby and Cobbs Creeks system. Nitrate and ammonia concentrations increase along the length of Darby Creek. Total phosphorus is highest at the most upstream and most downstream sites.

Lower Darby Bacteria

Fecal coliform at the two Lower Darby sites ranges from a minimum of 190/100 mL in dry weather to greater than 10^5/100 mL in wet weather. *E. coli* ranges from a minimum of 100/100 mL in dry weather to a maximum of $2.6\text{x}10^4$ in wet weather. Figures 5.30 and 5.31 show how these concentrations compare to observations at other points in the system. Counts generally increase with distance downstream. At DCD-765, the mean and range of counts are similar to those in the combined-sewered areas of the Cobbs watershed.

Lower Darby Metals

Trends in metals between wet and dry weather are similar to those observed at other sites. Mean aluminum, chromium, copper, iron, manganese, lead, and zinc are all higher in wet weather for both sites. Cadmium is at or below the detection limit for all samples. Dissolved iron is greater in wet weather at DCD-765 but lower in wet weather upstream at DCD-1170. Figures 5.43 through 5.50 compare means, ranges, and weather status of metals concentrations observed along the length of Darby Creek and throughout the Darby and Cobbs Creeks system.

Lower Darby Fish Advisories

AMSA et al. (2002) recommend against using fish advisories alone as bases for impairment listings, but they can provide a basis for further study and for establishment of water quality standards. Fish advisories are most often due to metals or organic chemicals. The April 2001 fish advisory for this watershed advises to limit consumption of White Perch, Striped Bass, and Carp to one meal a month, and to limit consumption of Channel Catfish to one meal every two months. American eel should not be eaten at all. This is all due to PCB pollution.

5.3.5 Tinicum Area

Two sampling sites represent conditions in the Tinicum area. These include DCM-300 on Muckinipattis Creek and DCS-170 on Stony Creek.

Table 5.12 Summary of Tinicum Mean Water Quality

		DCM-300		DCS-170	
Parameter	Units	Dry	Wet	Dry	Wet
Al	Mg/L	0.013	0.054	0.044	0.142
Alk	Mg/L	72.4	62.6	76.2	60.2
BOD30	Mg/L	2.76	3.57	2.52	4.47
BOD5	Mg/L	1.57	1.84	1.53	2.23
CBOD5	Mg/L	1.00	1.45	1.00	2.05
Ca	Mg/L	28.9	20.5	39.7	25.2
Cd	Mg/L	5.00E-04	5.00E-04	5.00E-04	5.00E-04
Chla	ug/L				
Cr	Mg/L	0.004	0.004	0.004	0.005
Cu	Mg/L	0.003	0.006	0.007	0.009
DO	Mg/L	6.94	6.03	7.42	6.08
DissCd	Mg/L				
DissFe	Mg/L	0.258	0.184	0.248	0.246
Ecoli	/100 mL	1400	9840	600	8160
F	Mg/L	0.102	0.122	0.100	0.118
Fe	Mg/L	0.462	0.292	0.464	0.494
Fecal	/100 mL	1010	3.51E+04	970	3.43E+04
Mg	Mg/L	13.0	8.01	14.3	8.51
Mn	Mg/L	0.036	0.020	0.046	0.046
NH3T	Mg/L	0.050	0.064	0.062	0.086
NO2	Mg/L	0.008	0.006	0.007	0.020
NO3	Mg/L	0.834	0.836	1.42	1.17
OsPress	mosm	4.50	2.00	6.00	2.00
PO4	Mg/L	0.020	0.024	0.020	0.024
Pb	Mg/L	5.00E-04	8.00E-04	5.00E-04	0.002
Phen	Mg/L	0.046	0.015	0.015	0.015
SpCond	uS/cm	363	210	470	319
TChl	ug/L				
TDS	Mg/L	210	156	263	231
TKN	Mg/L	0.596	0.740	0.798	0.908
TP	Mg/L	0.030	0.066	0.036	0.088
TSS	Mg/L	2.10	1.90	4.80	6.10
TempC	degrees C	18.3	19.9	18.5	20.1
Turb	NTU	3.85	3.92	5.13	6.87
Zn	Mg/L	0.010	0.012	0.010	0.016
PH		7.28	7.22	7.36	7.16

Tinicum Dissolved Oxygen

Discrete samples of DO at DCS-170 range from 4.75 mg/L measured on 6/15/99 to 9.54 mg/L measured on 5/11/99. Observed DO at DCM-300 ranges from 4.36 mg/L measured on 6/29/99 to 9.90 mg/L measured on 5/11/99. Figures 5.51 and 5.53 display the temporal trend in dissolved oxygen and physical parameters for discrete samples collected in 1999.

Tinicum Nutrients

Mean total inorganic nitrogen (nitrate, nitrite, and ammonia) at site is 1.73 mg/L in dry weather and 1.41 mg/L in wet weather. Ammonia represents approximately 2% of total nitrogen in dry weather and 3% in wet weather. Figures 5.51 through 5.54 show the temporal trends in nitrogen and phosphorus species over the duration of the 1999 discrete sampling period. Nitrate concentrations are generally lower than those observed in other parts of the system, while ammonia concentrations are similar.

Tinicum Bacteria

Observed bacteria concentrations are similar at the two Tinicum sites, ranging from a minimum of 200/100 mL fecal coliform in dry weather to a maximum of 76,000/100 mL in wet weather. Figures 5.30 and 5.31 are visual representations of the range of concentrations found throughout the system in dry and wet weather. Mean and maximum counts are similar to those found at Upper Cobbs and Lower Darby sites.

Tinicum Metals

Mean concentrations of most metals increase from dry to wet weather at both sites, including aluminum, copper, lead, and zinc. Mean manganese concentrations are lower or unchanged in wet weather, and mean dissolved iron concentrations decrease at both sites in wet weather. Figures 5.43 through 5.50 compare means, ranges, and weather status of bacteria concentrations at the two Tinicum sites and throughout the Darby and Cobbs Creeks system.

Tinicum Fish Advisories

AMSA et al. (2002) recommend against using fish advisories alone as bases for impairment listings, but they can provide a basis for further study and for establishment of water quality standards. Fish advisories are most often due to metals or organic chemicals. The April 2001 fish advisory for this watershed advises to limit consumption of White Perch, Striped Bass, and Carp to one meal a month, and to limit consumption of Channel Catfish to one meal every two months. American eel should not be eaten at all. This is all due to PCB pollution.

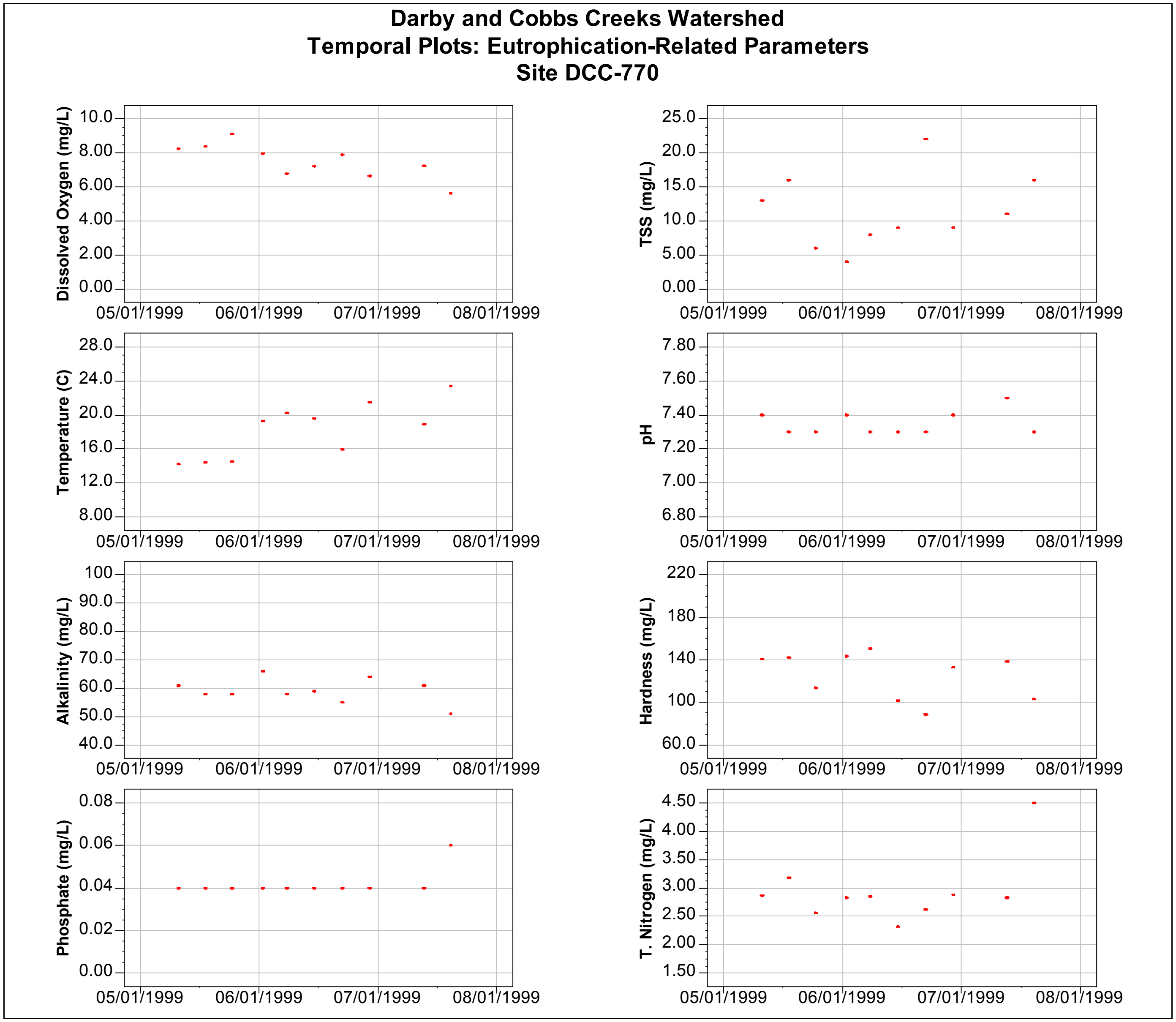


Figure 5.7 Eutrophication-Related Physical Parameters Temporal Plots at DCC-770

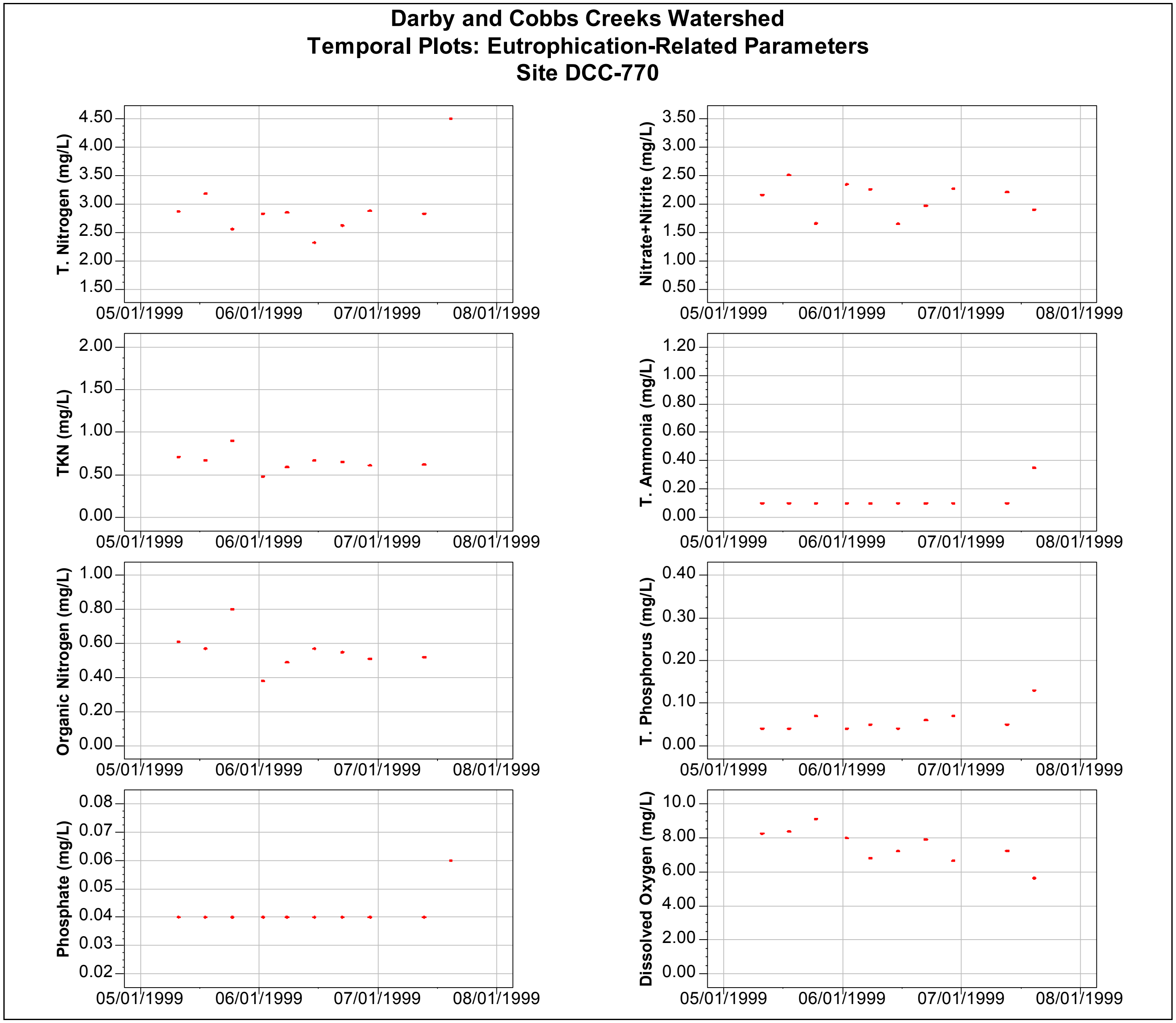


Figure 5.8 Eutrophication-Related Nutrient Parameters Temporal Plots at DCC-770

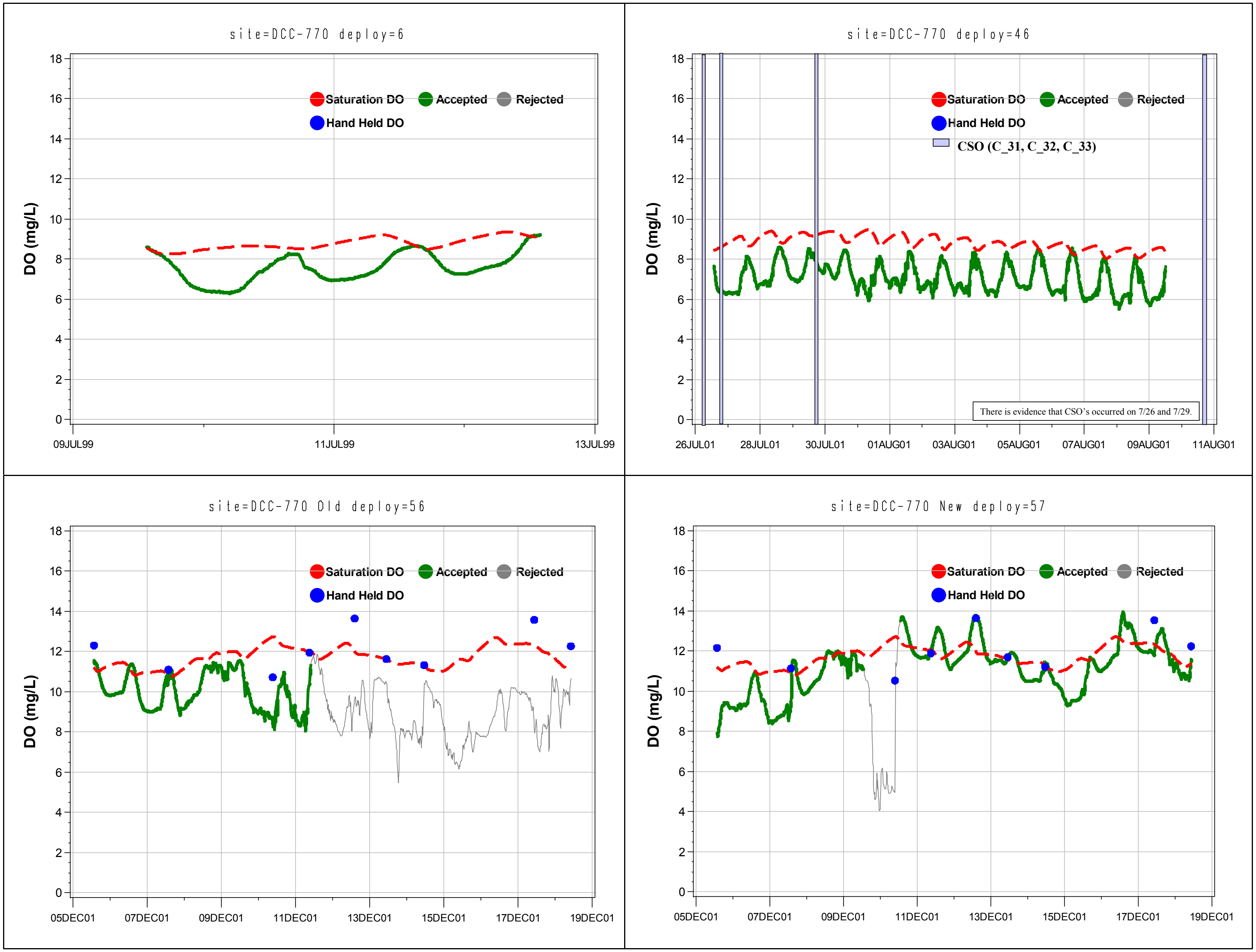
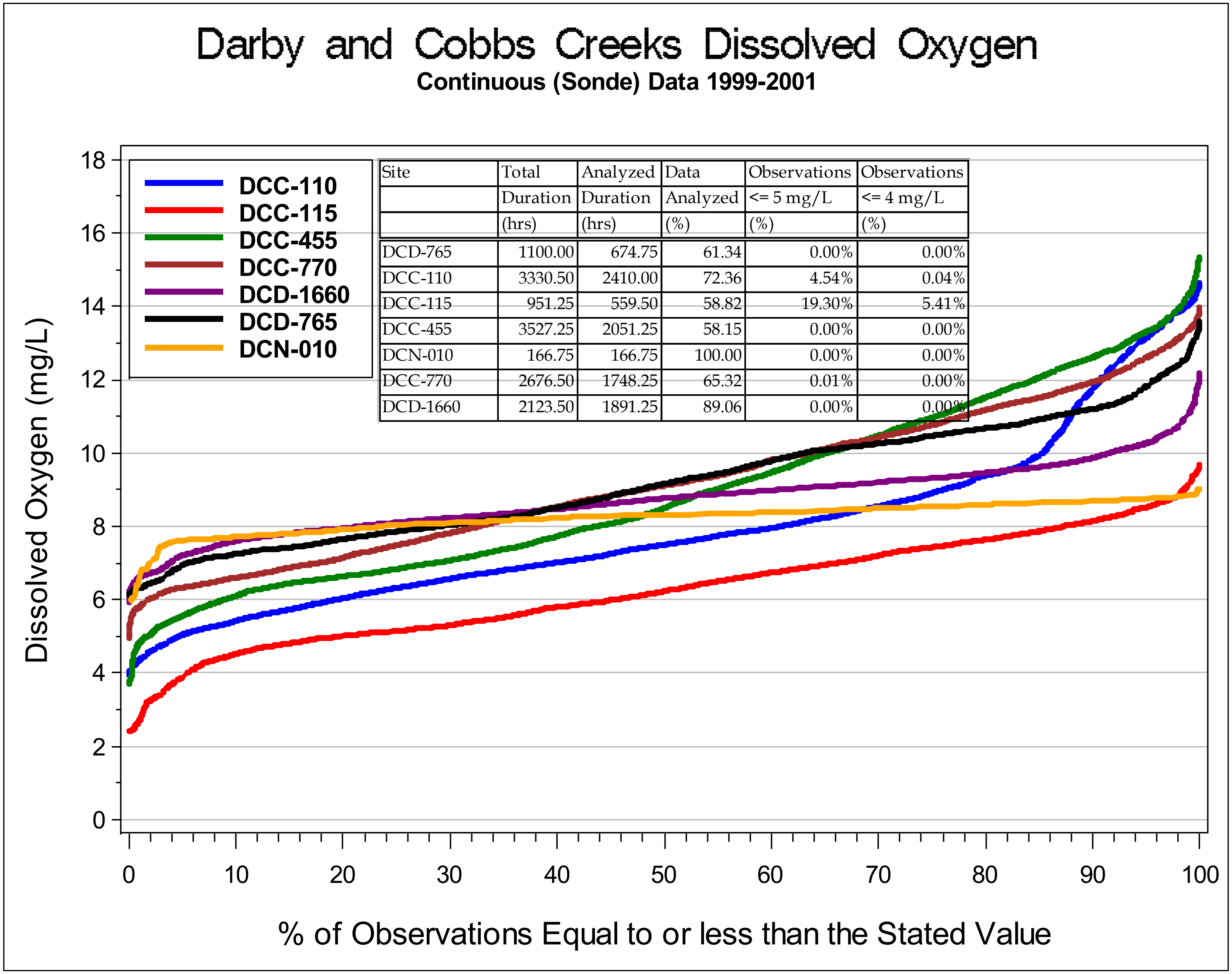


Figure 5.9 Sonde Continuous DO Temporal Plots at DCC-770



Darby and Cobbs Creeks Dissolved Oxygen

Continuous (Sonde) Data 1999-2001

Site	Total Duration (hrs)	Analyzed Duration (hrs)	Data Analyzed (%)	Observations <= 5 mg/L (%)	Observations <= 4 mg/L (%)
DCD-765	1100.00	674.75	61.34	0.00%	0.00%
DCC-110	3330.50	2410.00	72.36	4.54%	0.04%
DCC-115	951.25	559.50	58.82	19.30%	5.41%
DCC-455	3527.25	2051.25	58.15	0.00%	0.00%
DCN-010	166.75	166.75	100.00	0.00%	0.00%
DCC-770	2676.50	1748.25	65.32	0.01%	0.00%
DCD-1660	2123.50	1891.25	89.06	0.00%	0.00%

Figure 5.10 Sonde DO CDF plots of All Sites for 1999-2001

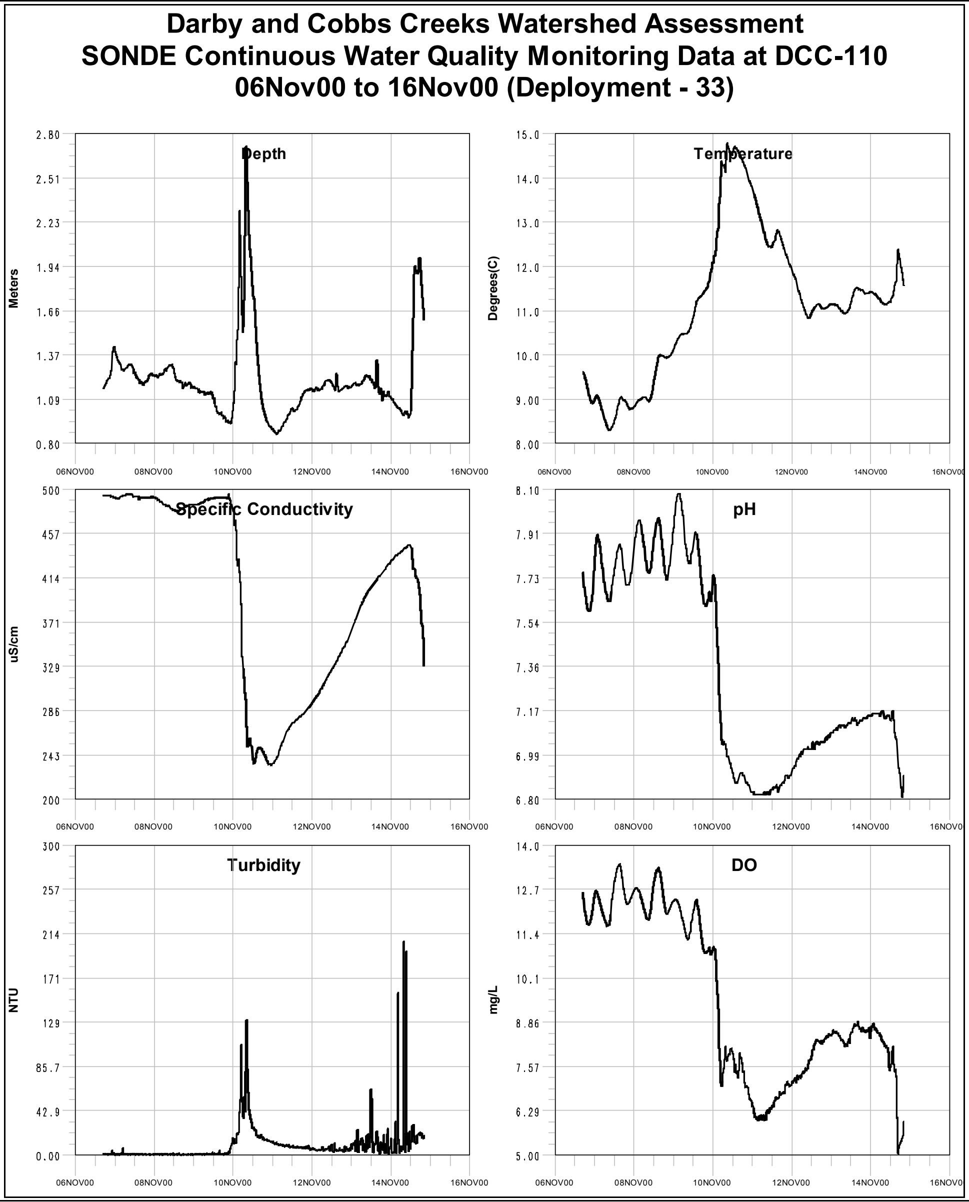


Figure 5.11 Sonde Continuous Multi Parameter Temporal Plots at DCC-110

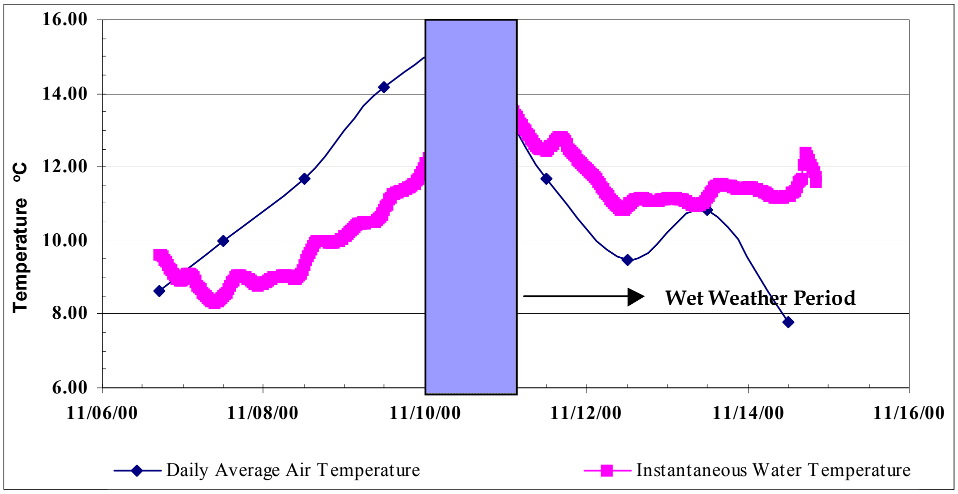
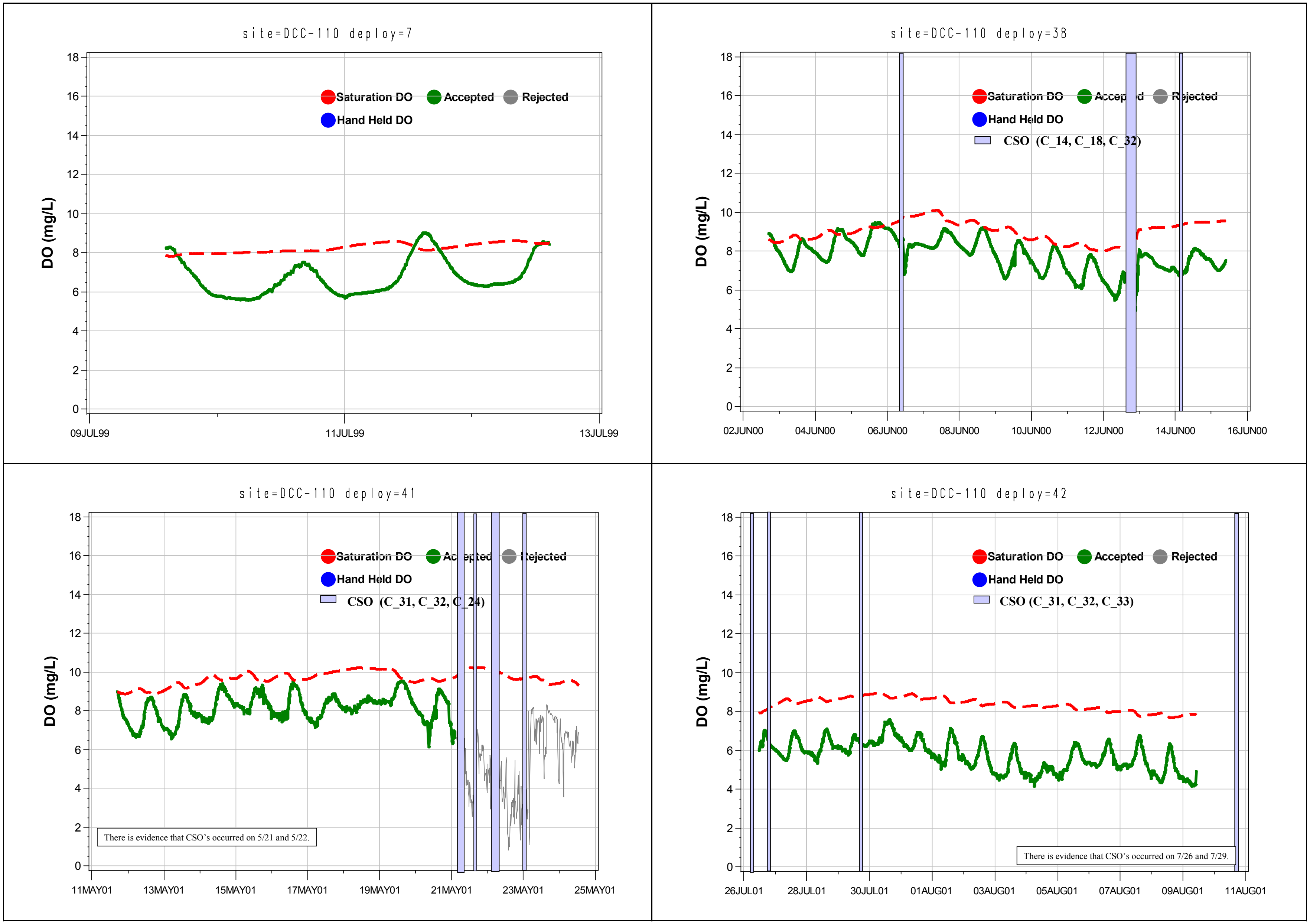


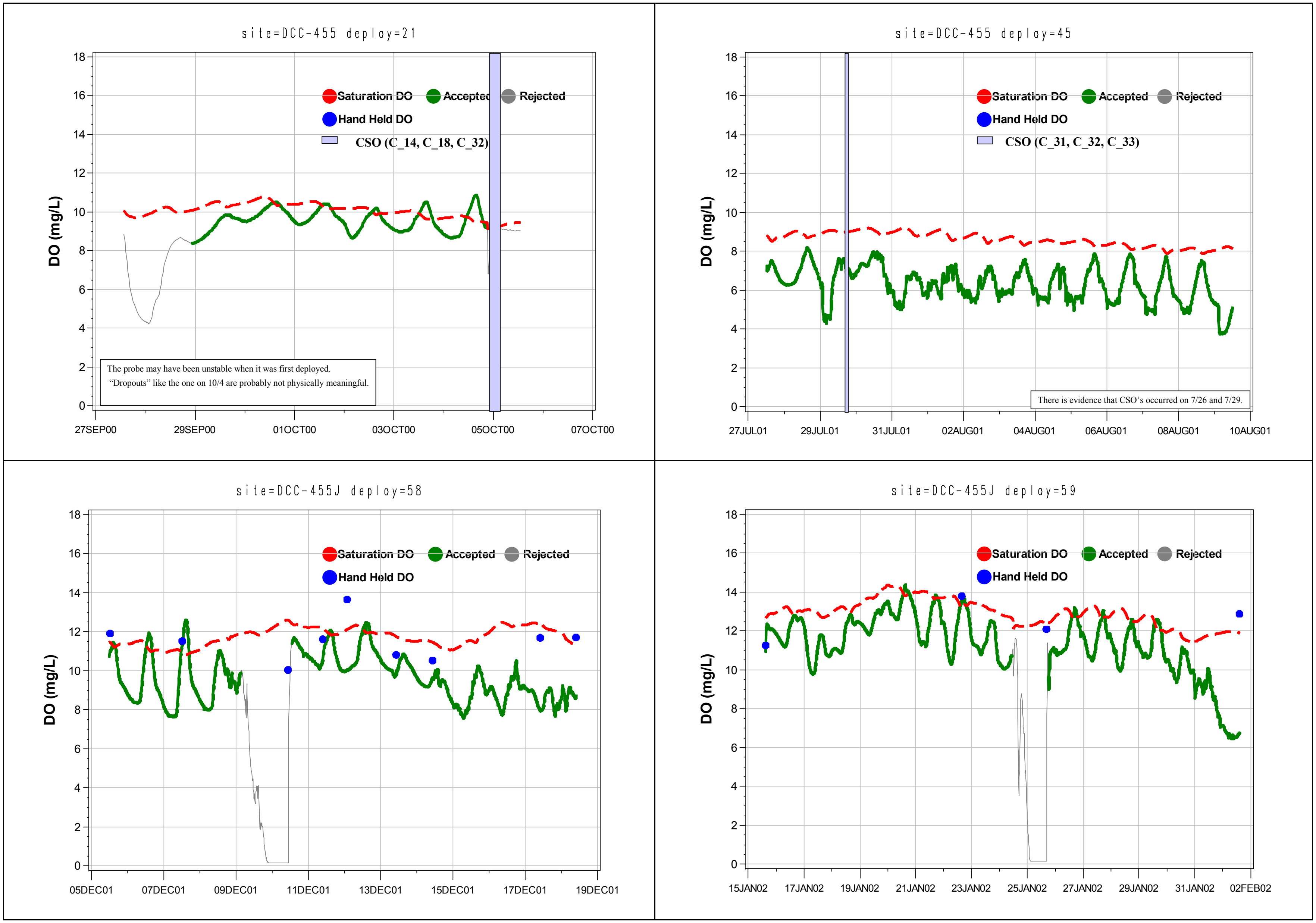
Figure 5.11.1 Comparison of Air and Water temperature Trend with a storm



There is evidence that CSO's occurred on 5/21 and 5/22.

There is evidence that CSO's occurred on 7/26 and 7/29.

Figure 5.12 Sonde Continuous DO Temporal Plots at DCC-110



The probe may have been unstable when it was first deployed. "Dropouts" like the one on 10/4 are probably not physically meaningful.

There is evidence that CSO's occurred on 7/26 and 7/29.

Figure 5.13 Sonde Continuous DO Temporal Plots at DCC-455

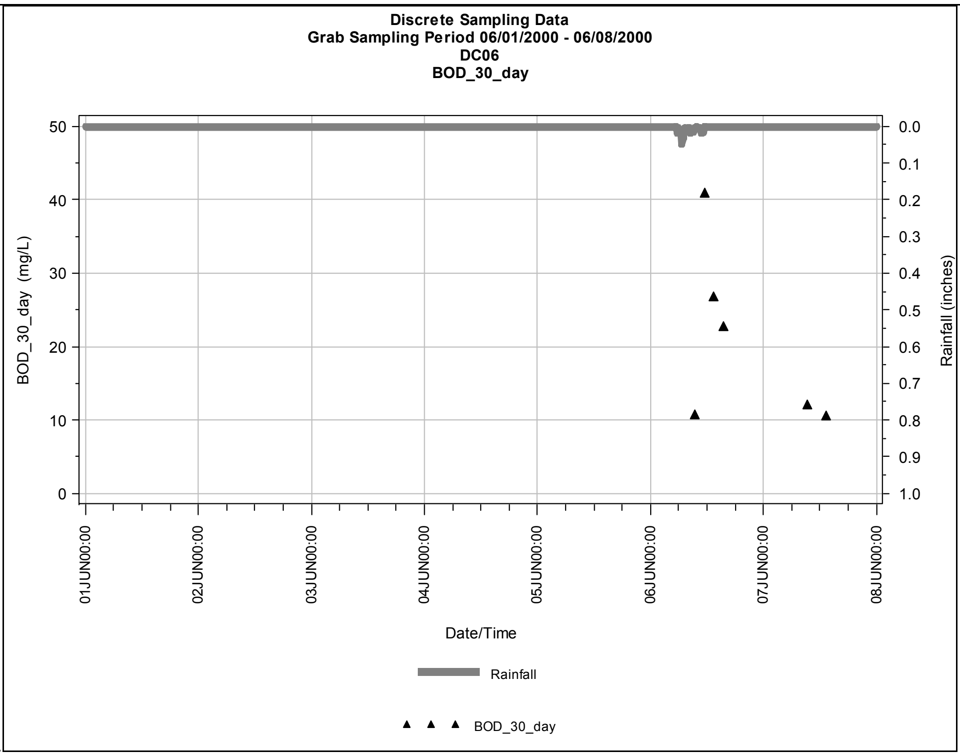


Figure 5.14 Wet Weather Plot for BOD30 at DCC-110

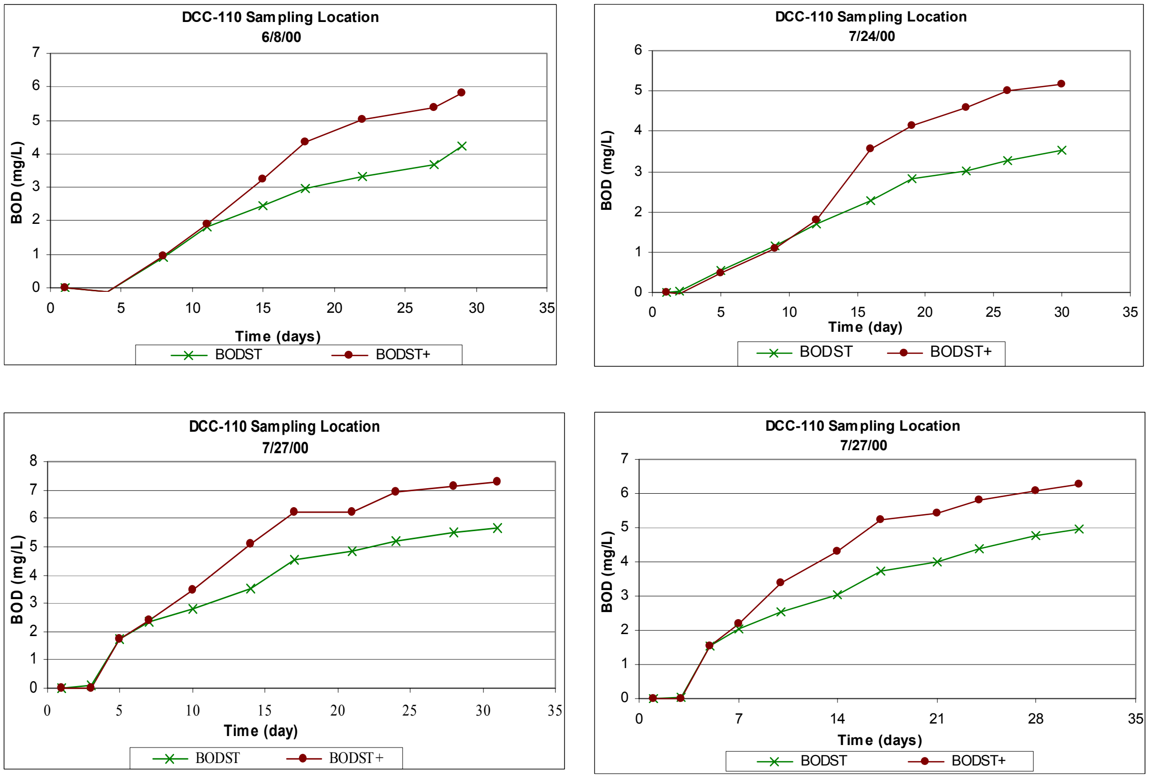


Figure 5.15 BOD Plots for DCC-110

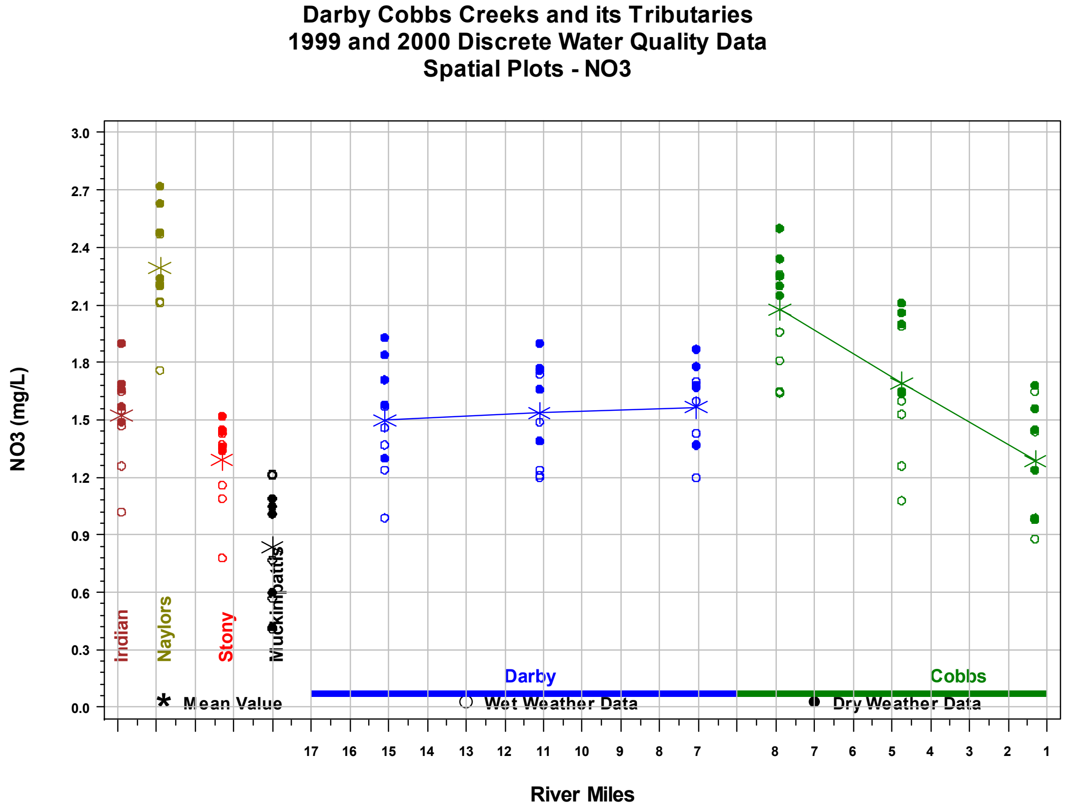


Figure 5.16 Spatial Plot for Nitrate

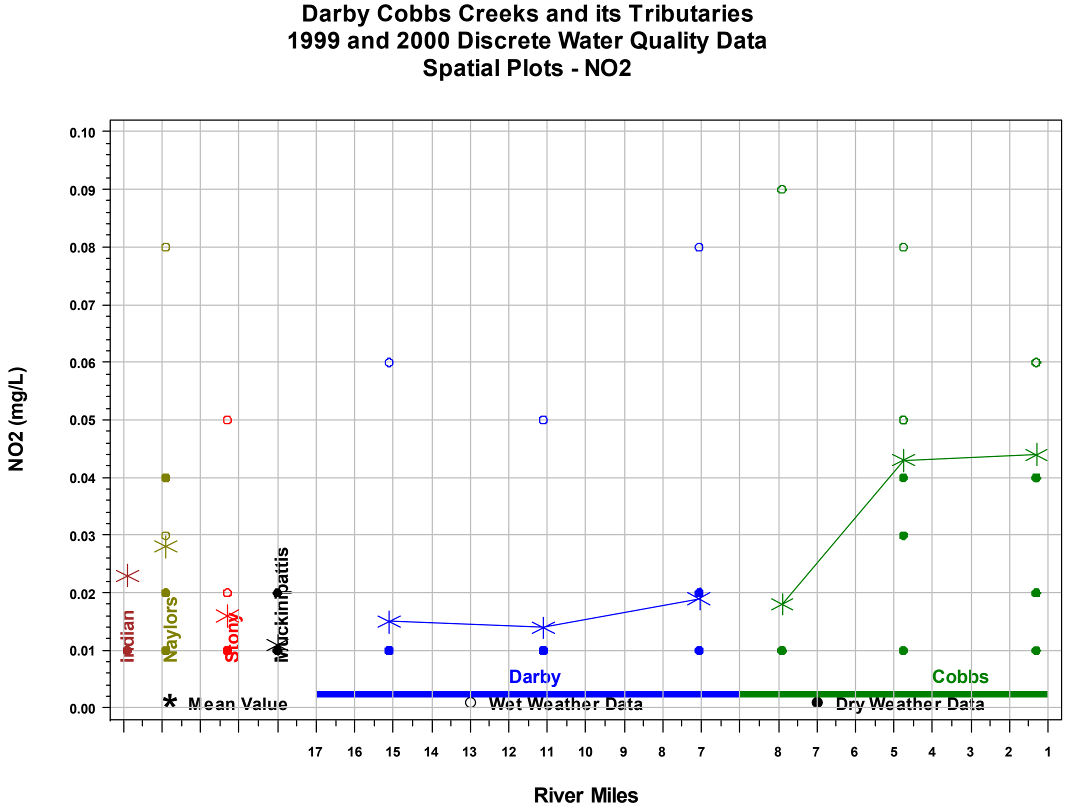


Figure 5.17 Spatial Plot for Nitrite

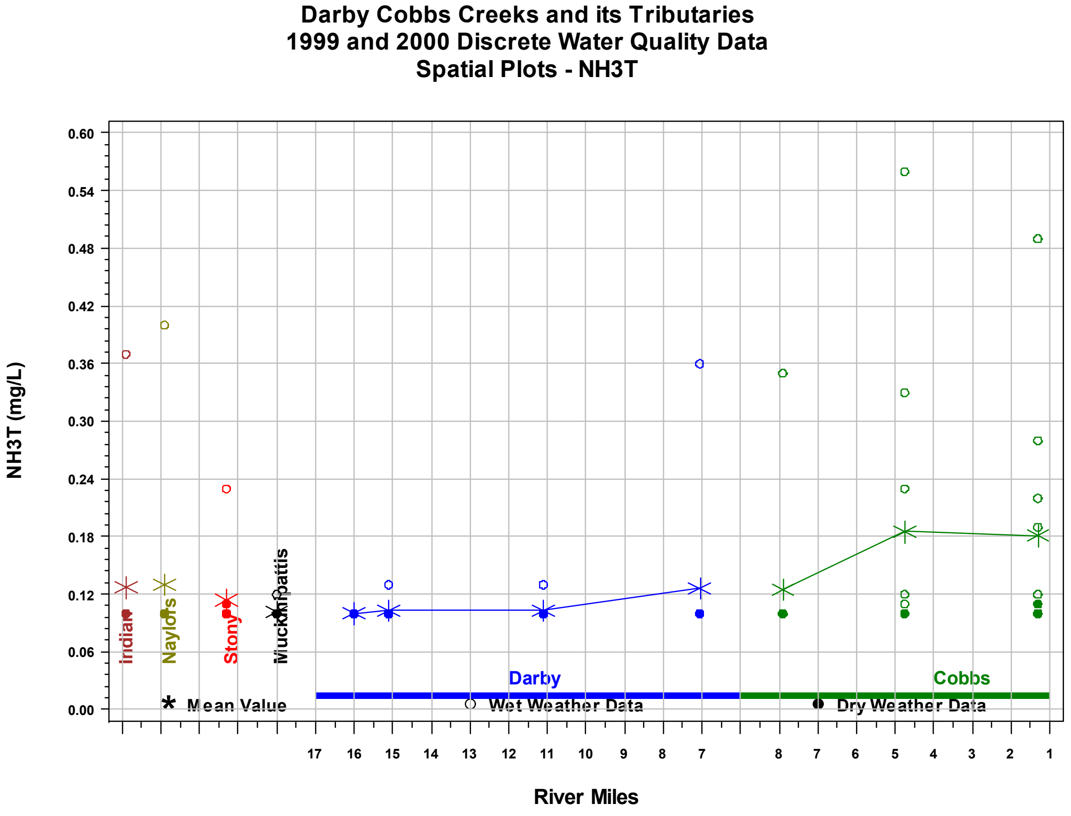


Figure 5.18 Spatial Plot for Total Ammonia

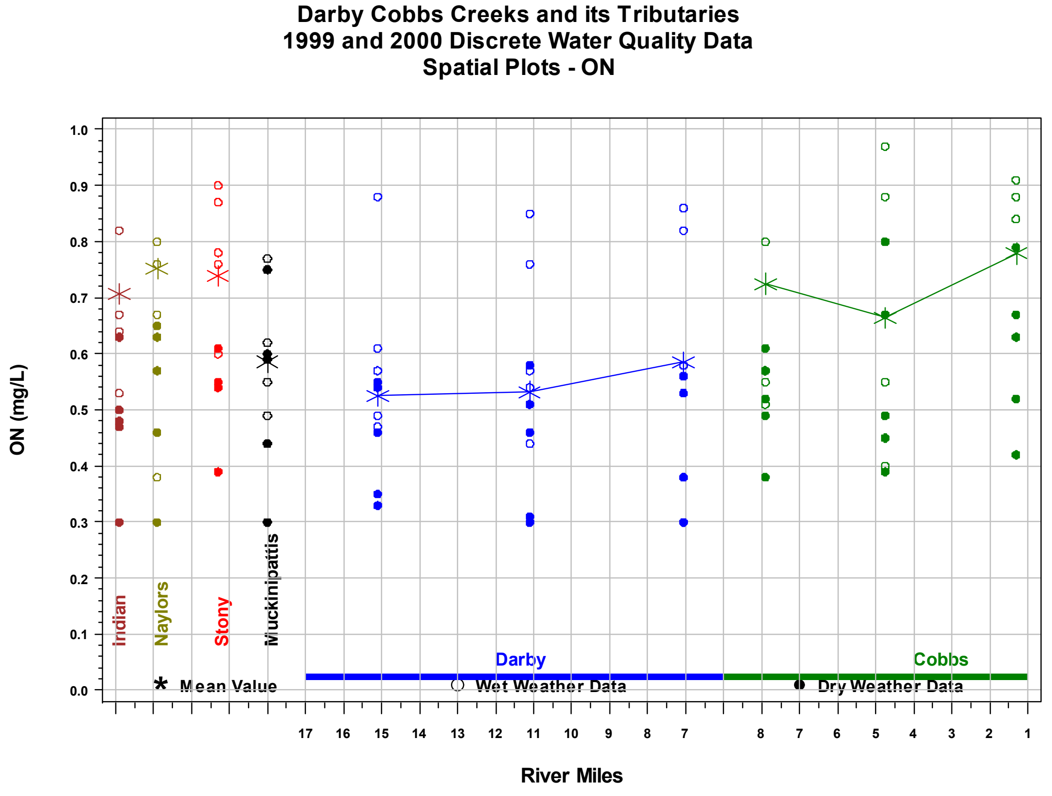


Figure 5.19 Spatial Plot for Organic Nitrogen

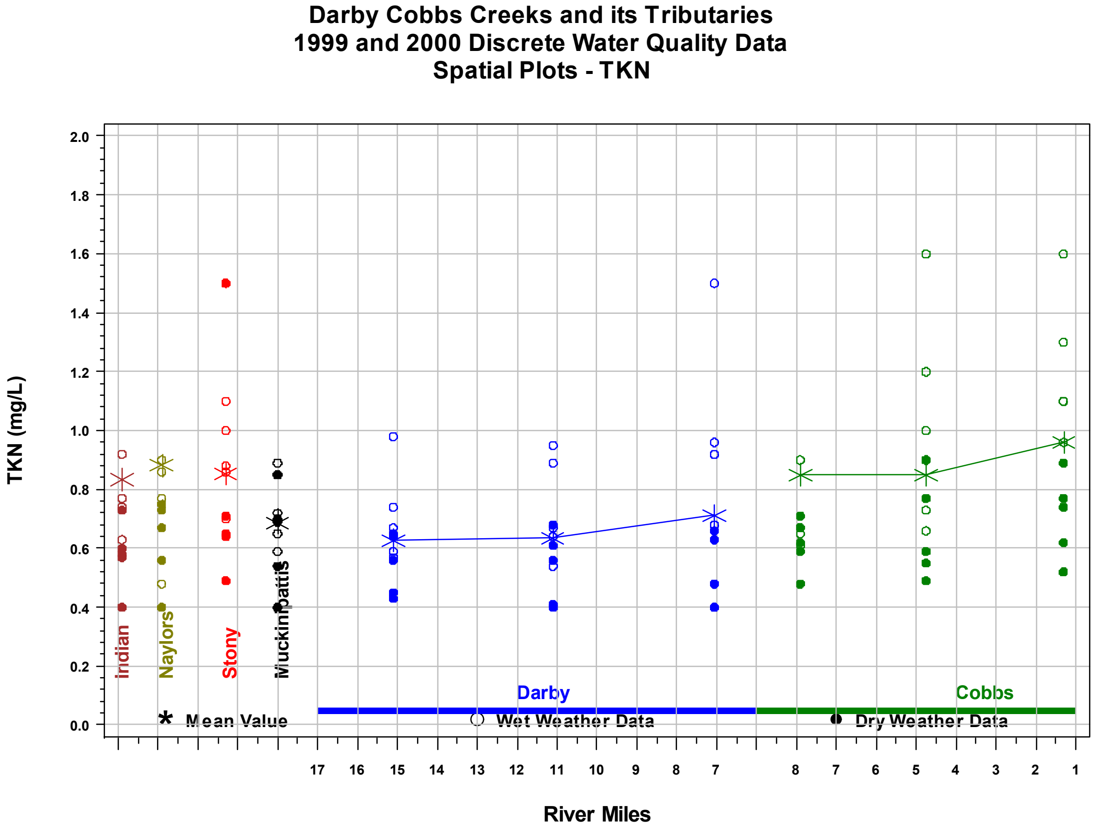


Figure 5.20 Spatial Plot for TKN

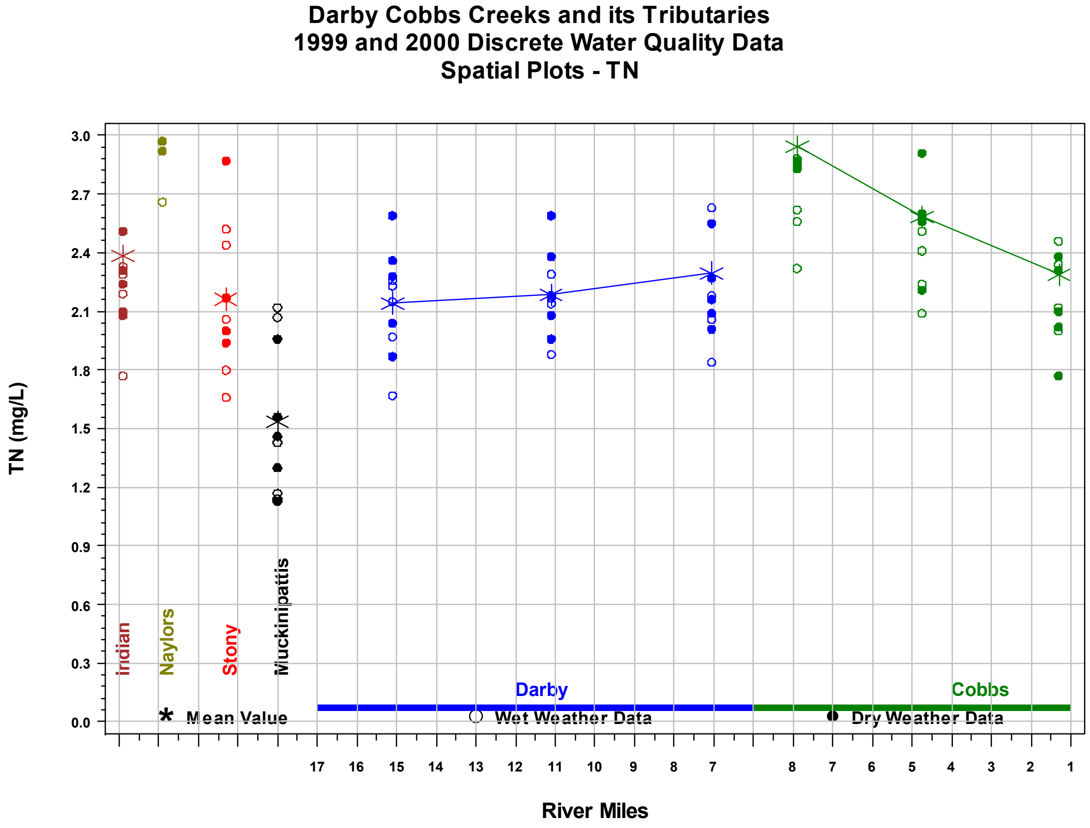


Figure 5.21 Spatial Plot for Total Nitrogen

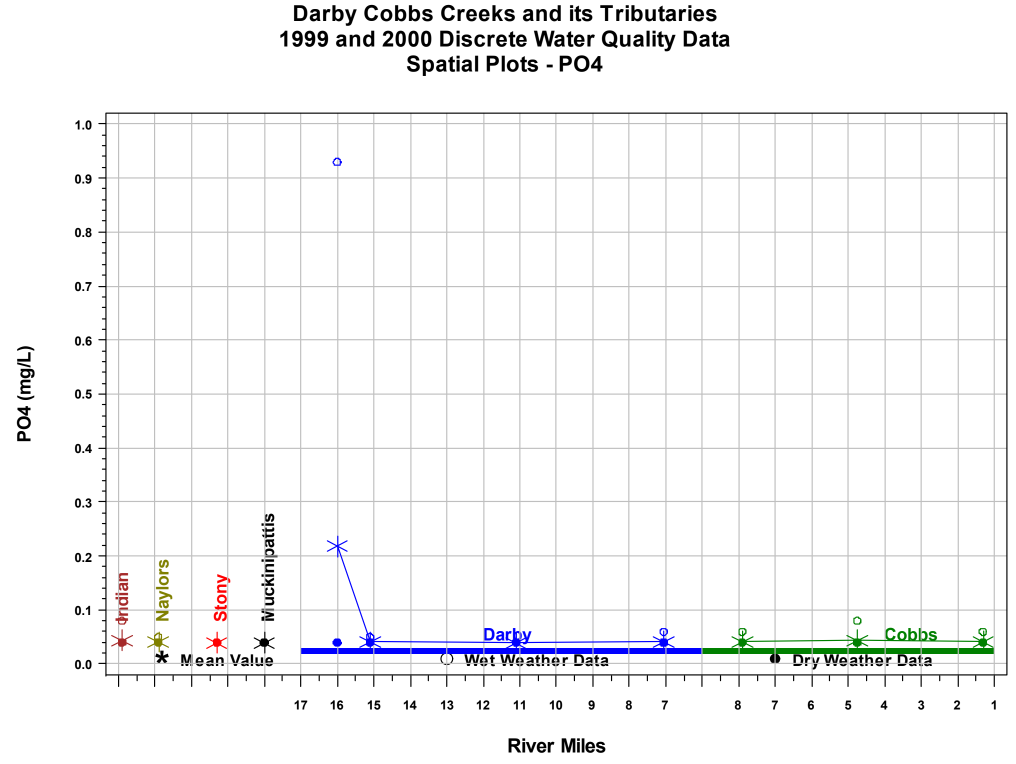


Figure 5.22 Spatial Plot for Ortho Phosphate

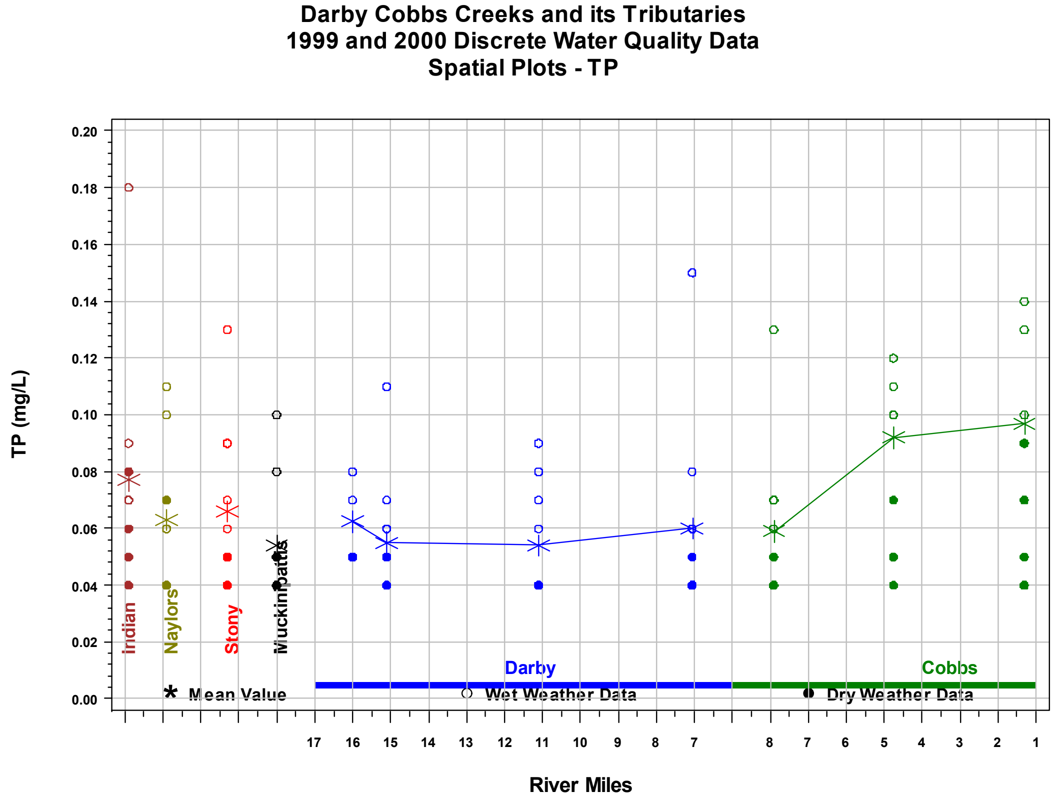


Figure 5.23 Spatial Plot for Total Phosphate

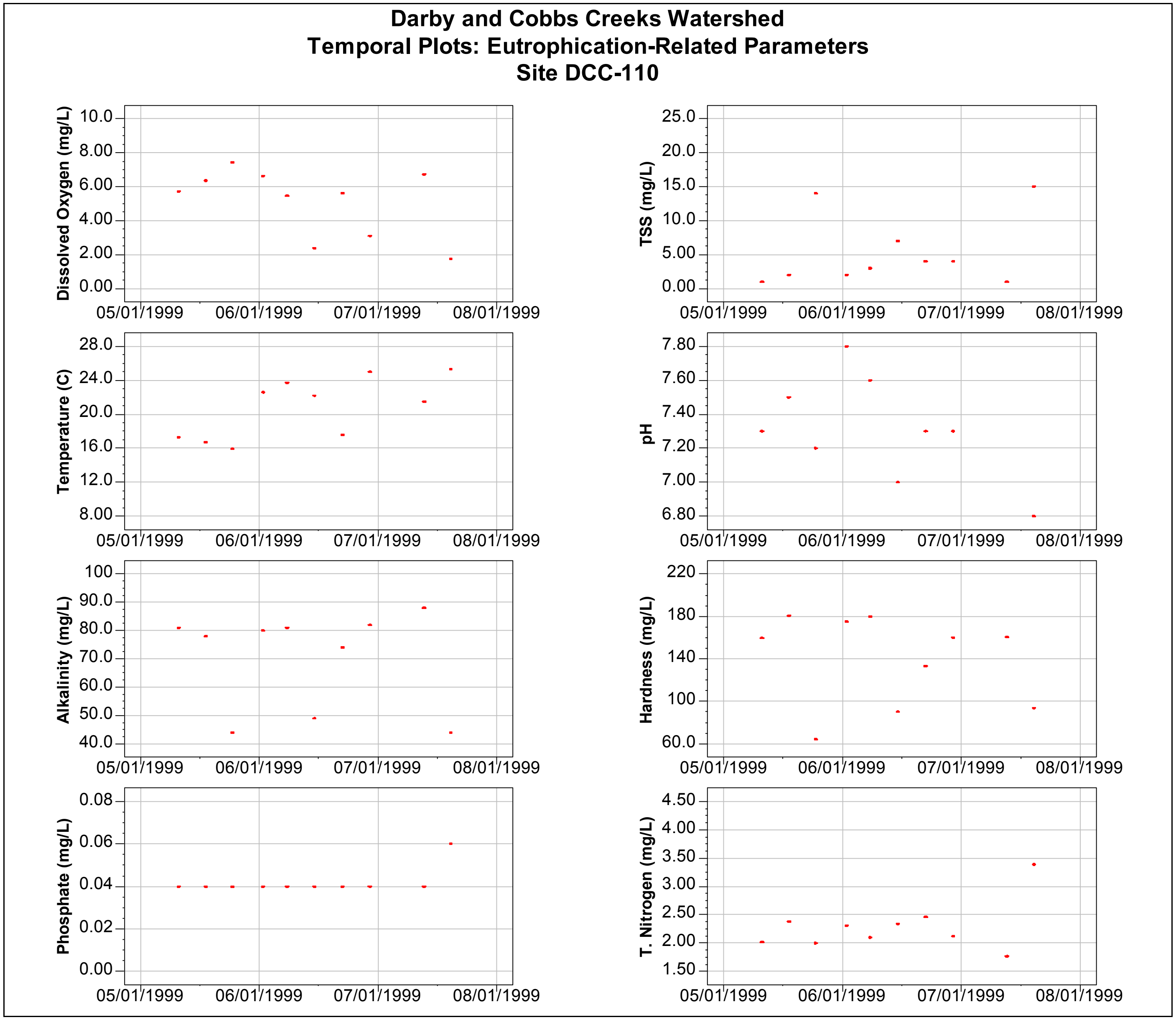


Figure 5.24 Eutrophication-Related Physical Parameters Temporal Plots at DCC-110

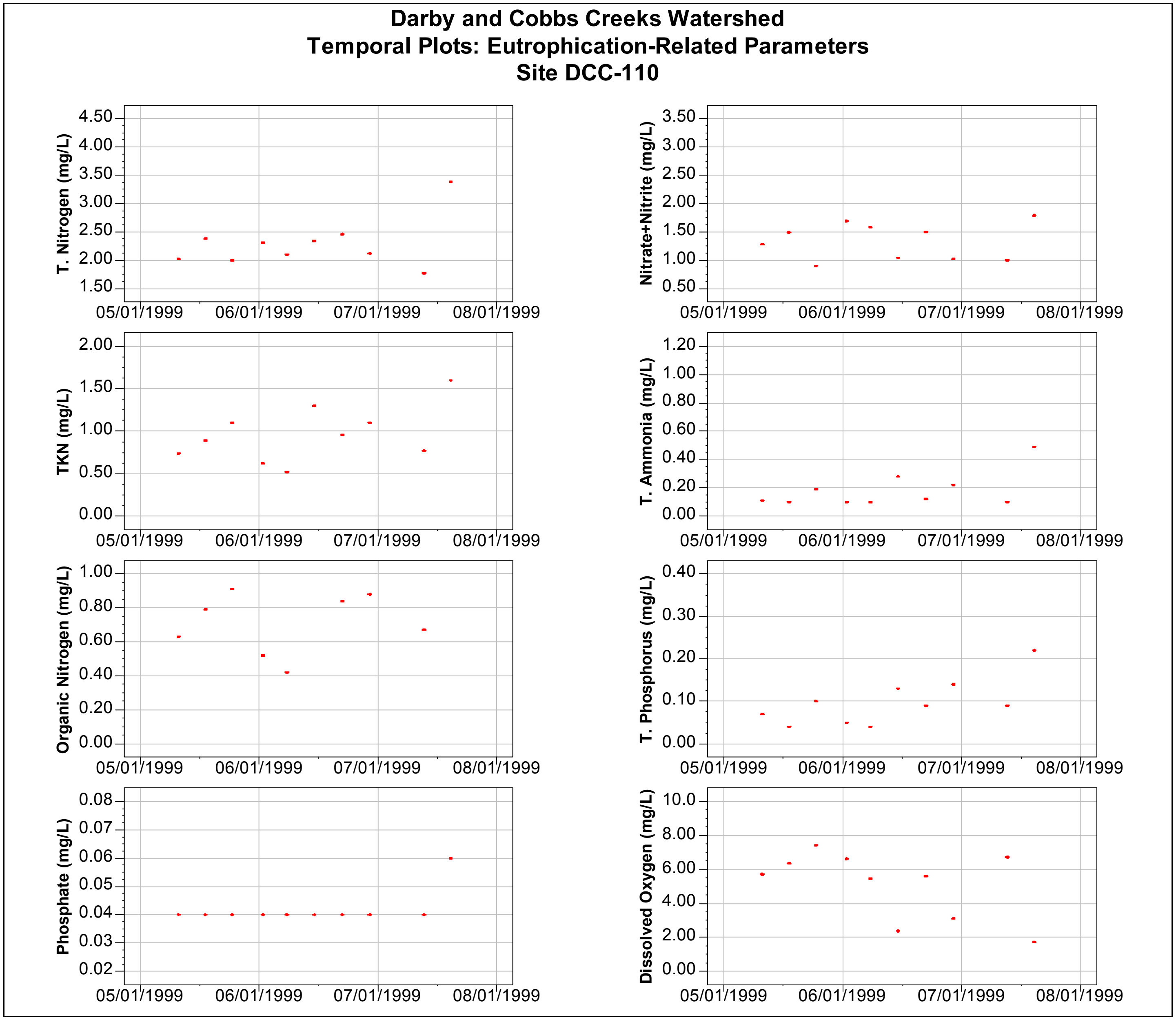


Figure 5.25 Eutrophication-Related Nutrient Parameters Temporal Plots at DCC-110

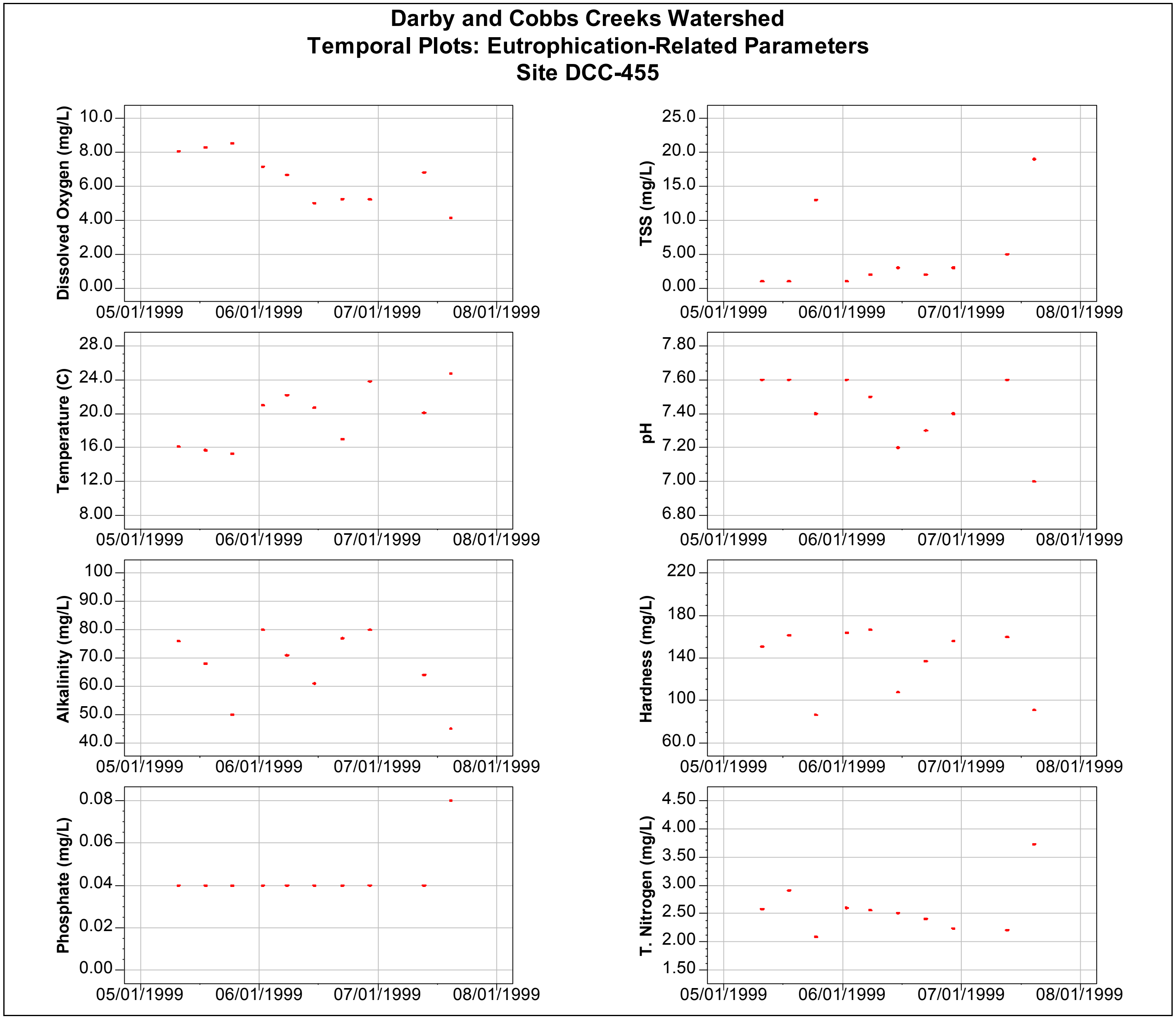


Figure 5.26 Eutrophication-Related Physical Parameters Temporal Plots at DCC-455

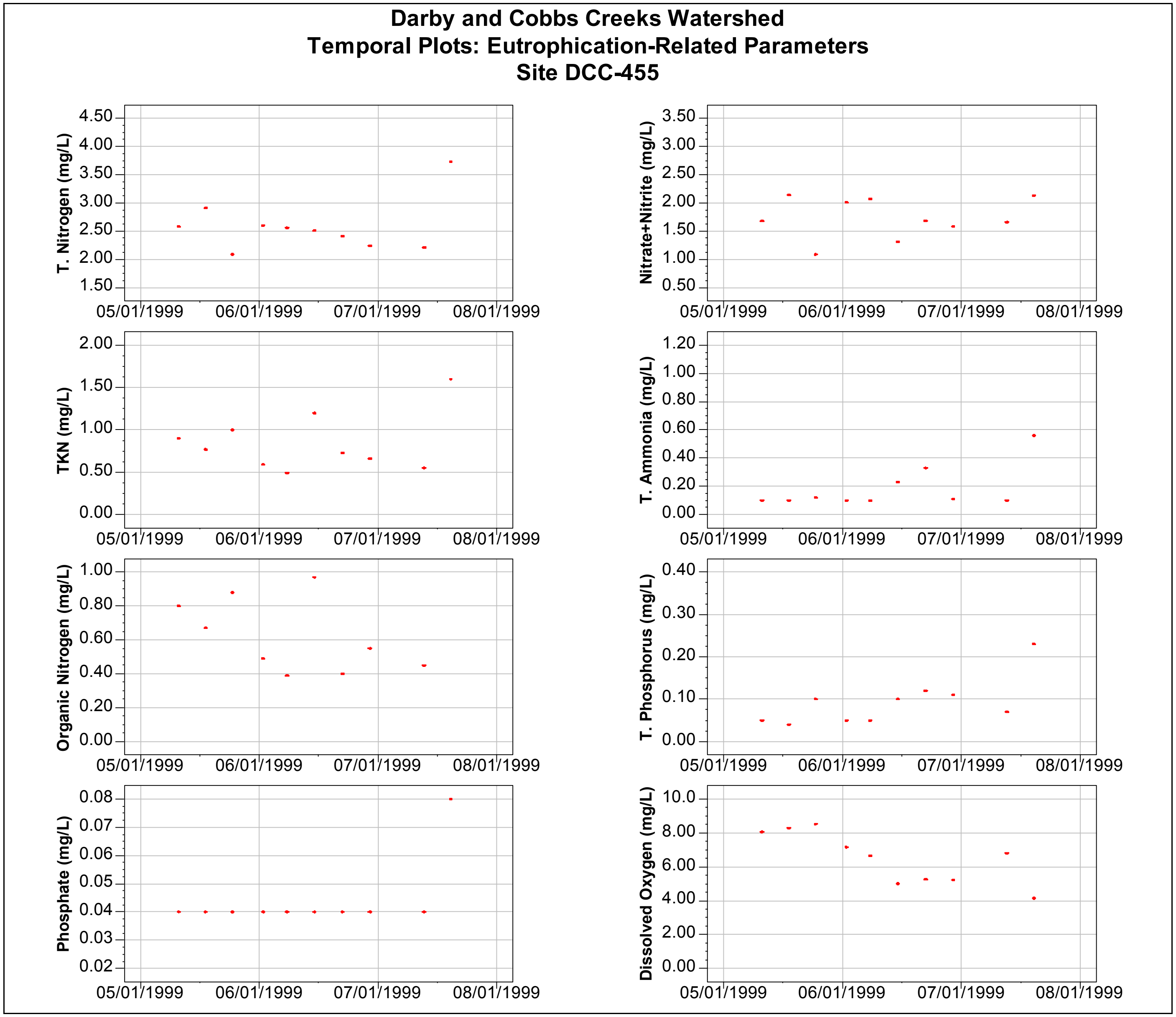

Darby and Cobbs Creeks Watershed
Temporal Plots: Eutrophication-Related Parameters
Site DCC-455

Figure 5.27 Eutrophication-Related Nutrient Parameters Temporal Plots at DCC-455

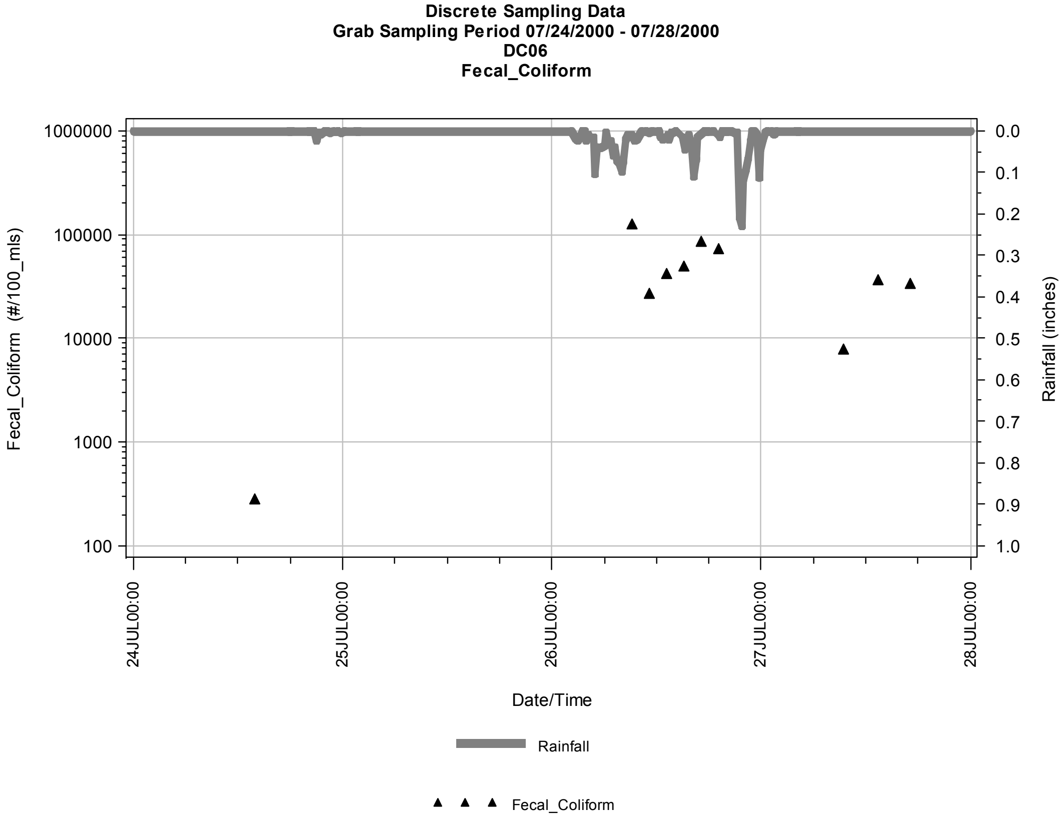


Figure 5.28 Wet Weather Plot for Fecal Coliform at DCC-110

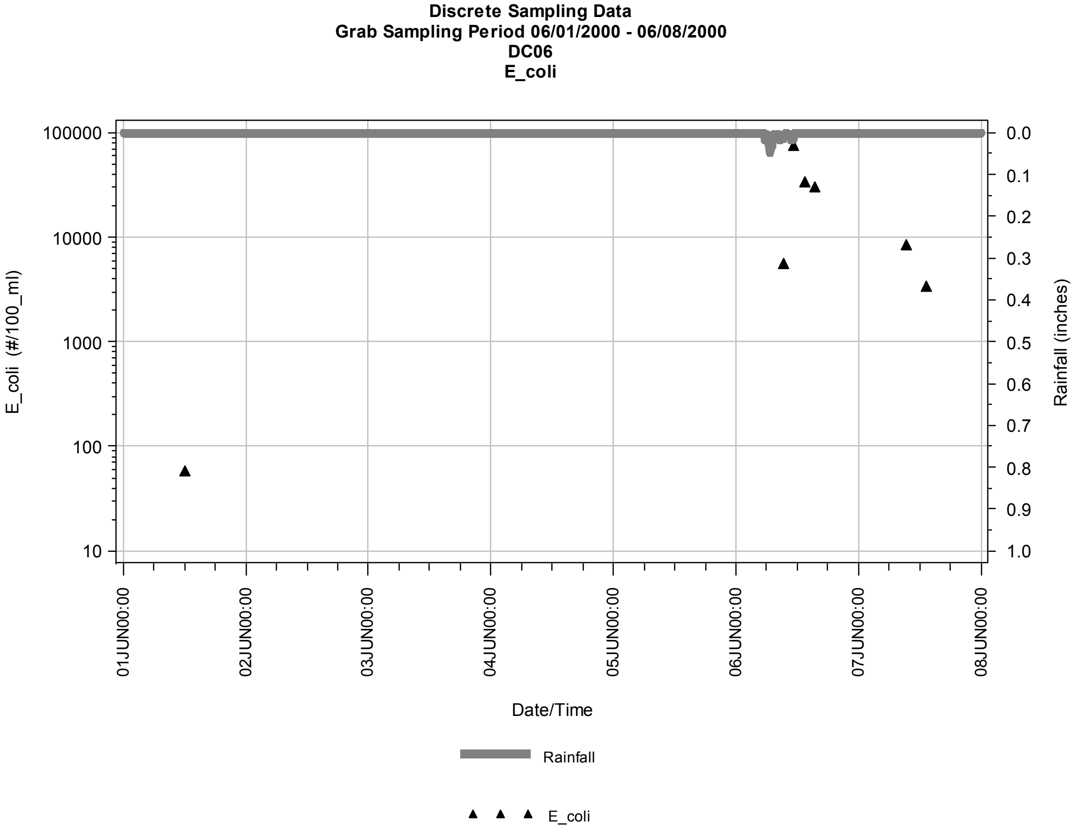


Figure 5.29 Wet Weather Plot for E. Coli at DCC-110

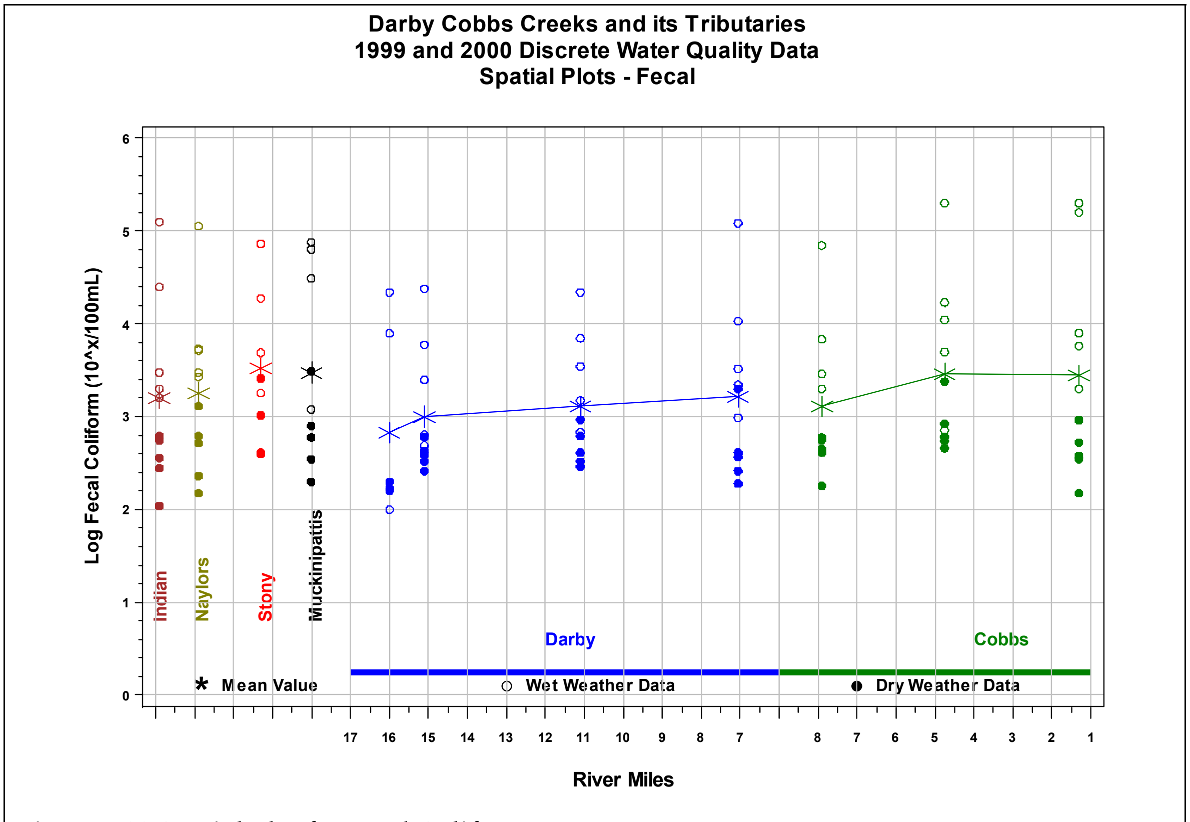


Figure 5.30 Spatial Plot for Fecal Coliform

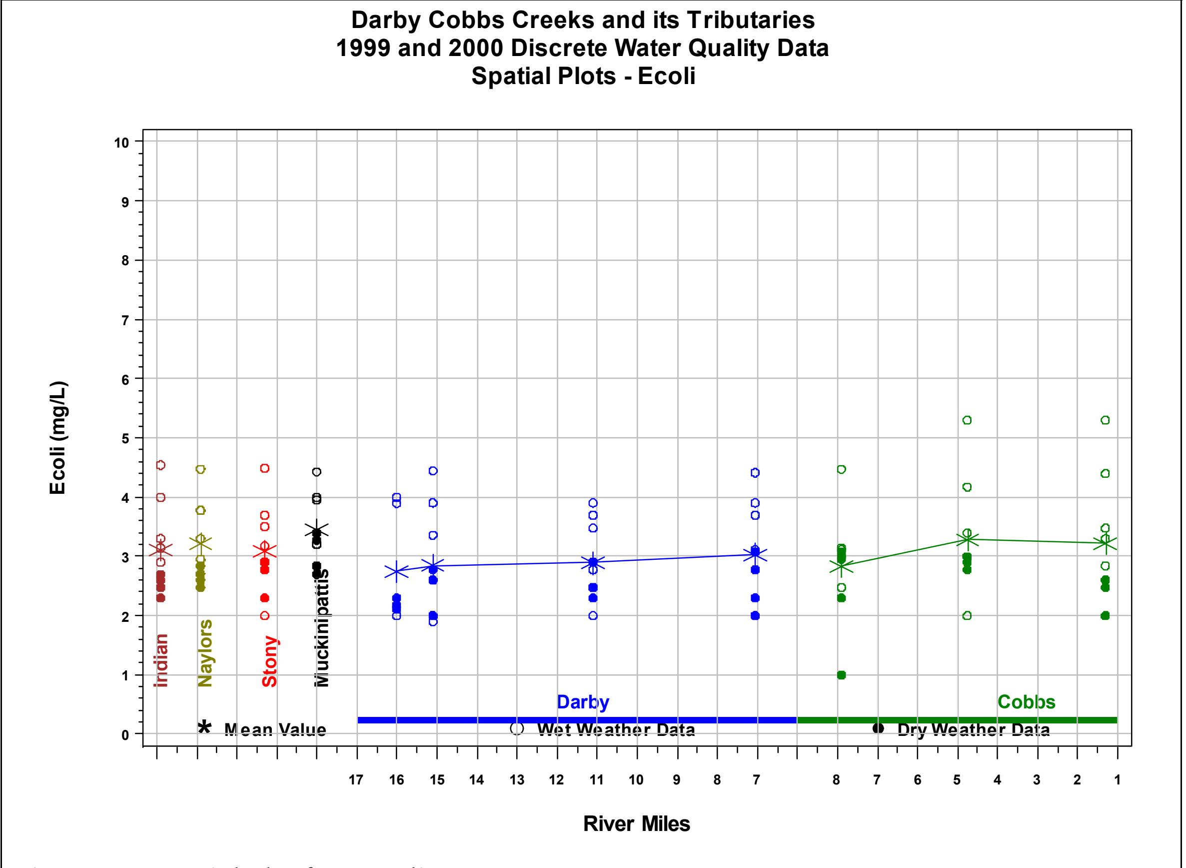


Figure 5.31 Spatial Plot for E. Coli

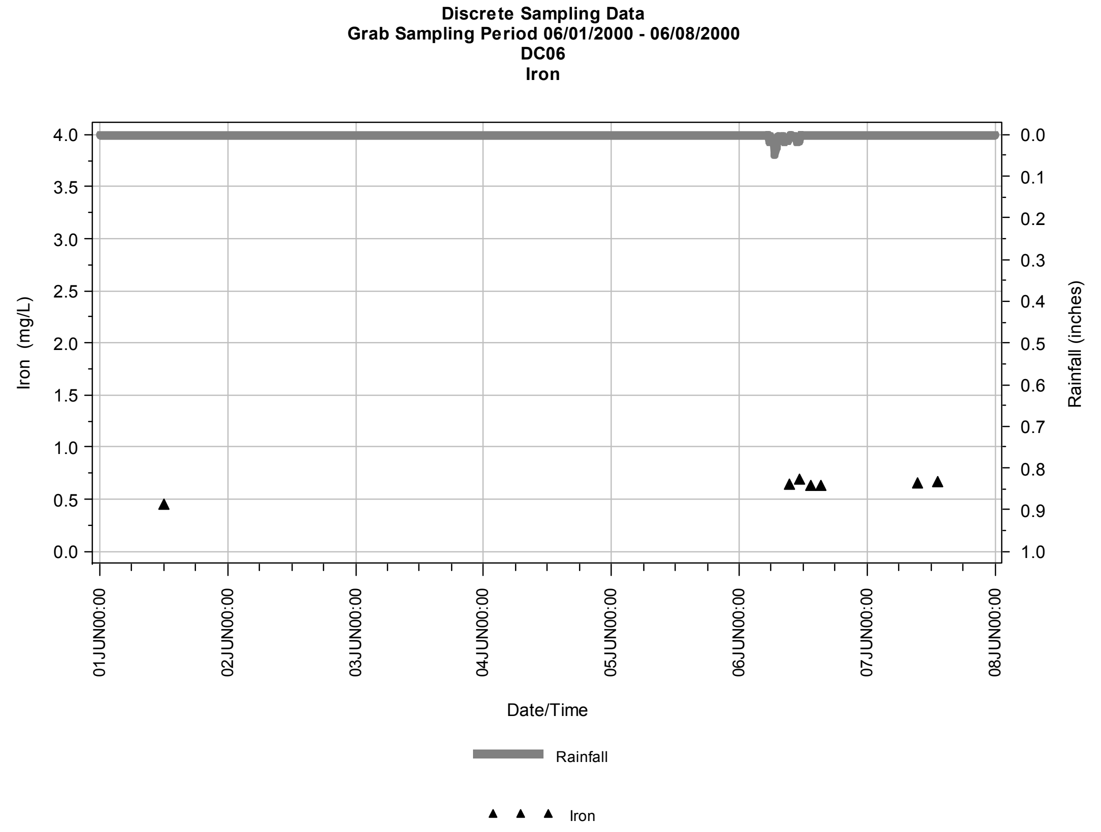


Figure 5.32 Wet Weather Plot for Iron at DCC-110

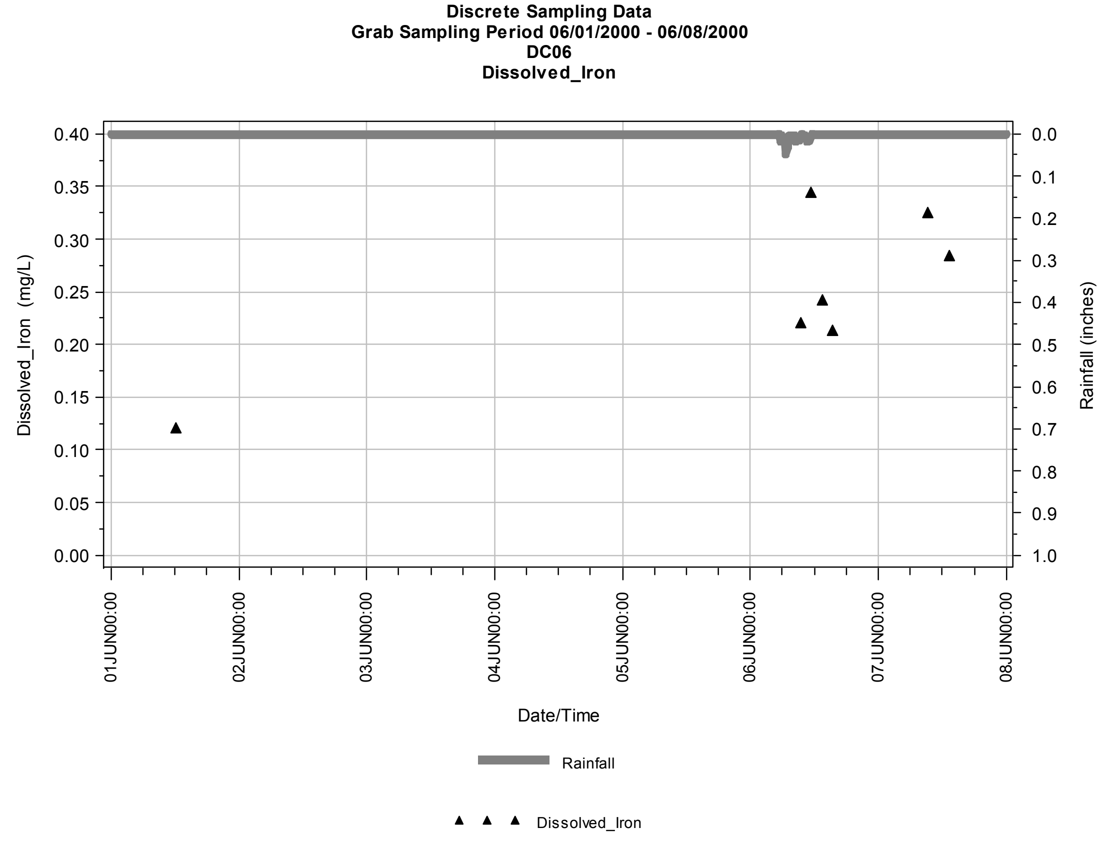


Figure 5.33 Wet Weather Plot for Dissolved Iron at DCC-110

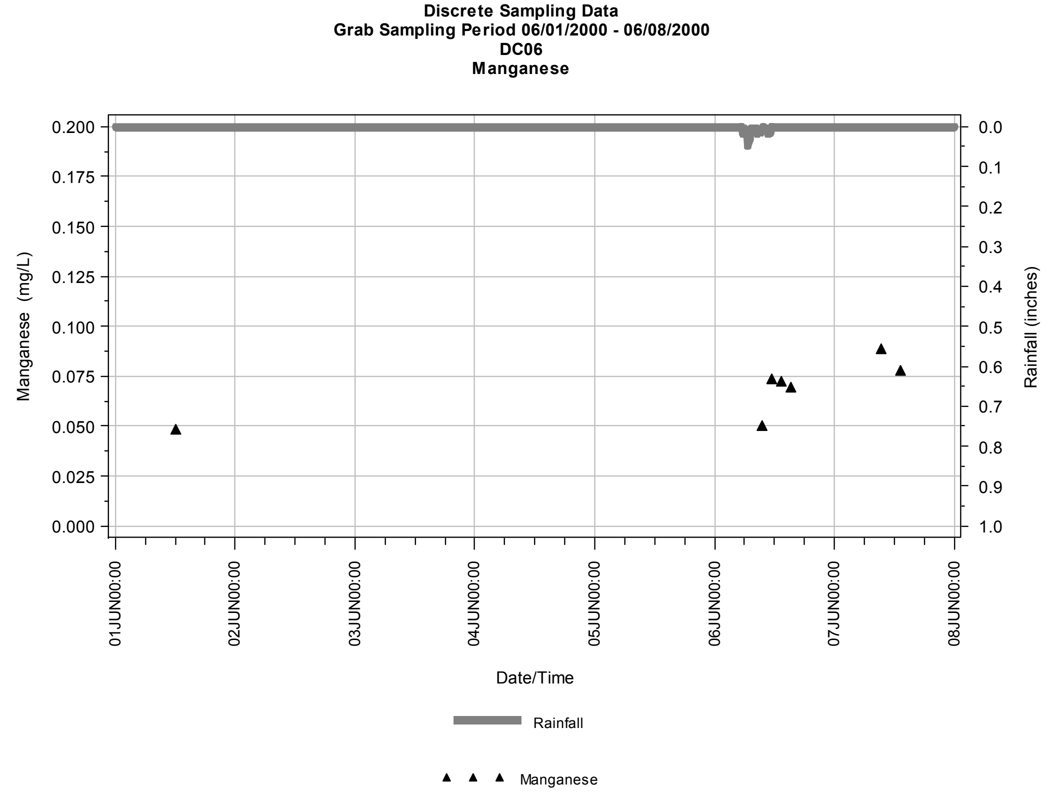


Figure 5.34 Wet Weather Plot for Manganese at DCC-110

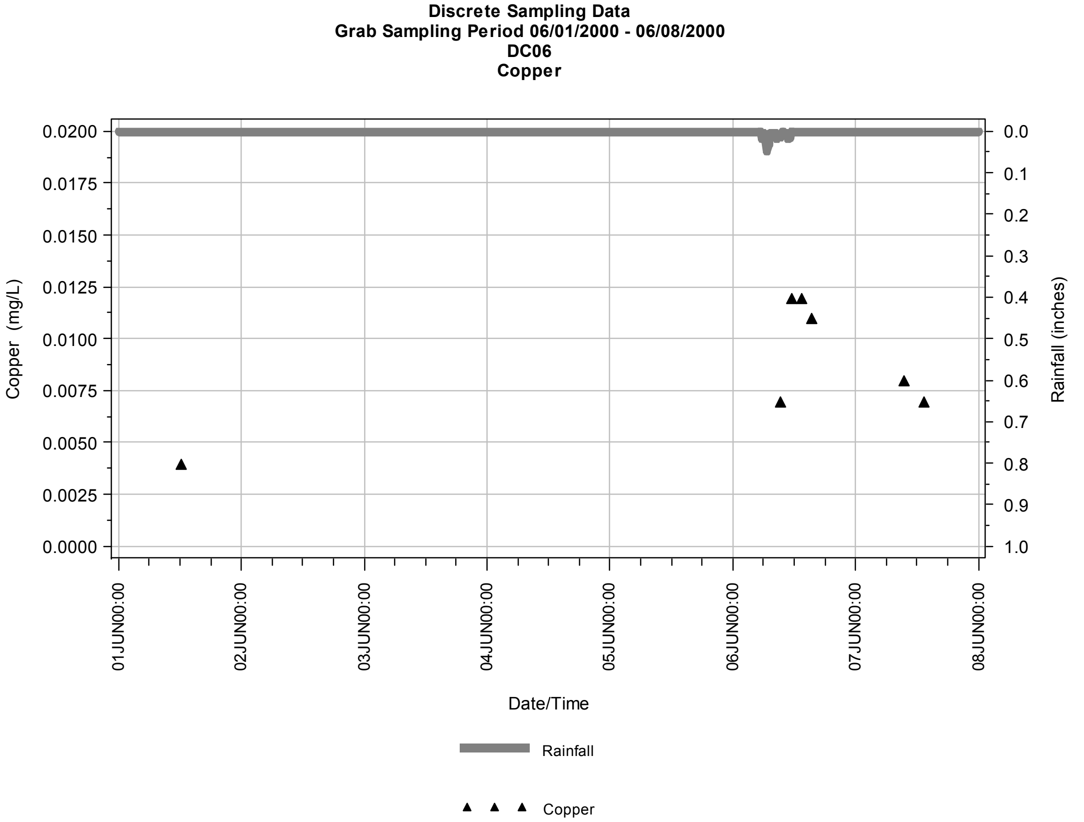


Figure 5.35 Wet Weather Plot for Copper at DCC-110

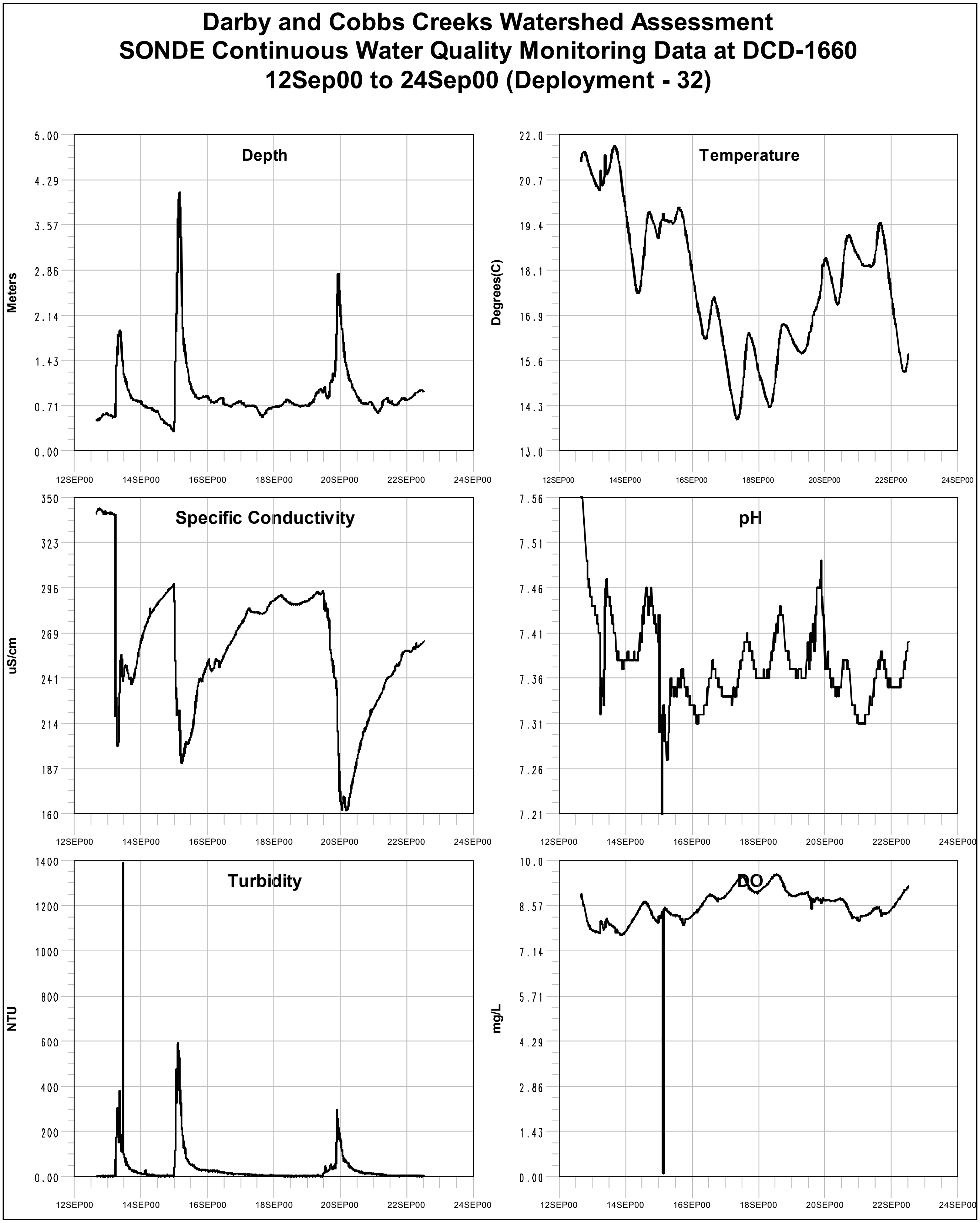


Figure 5.36 Sonde Continuous Multi Parameter Temporal Plots at DCD-1660

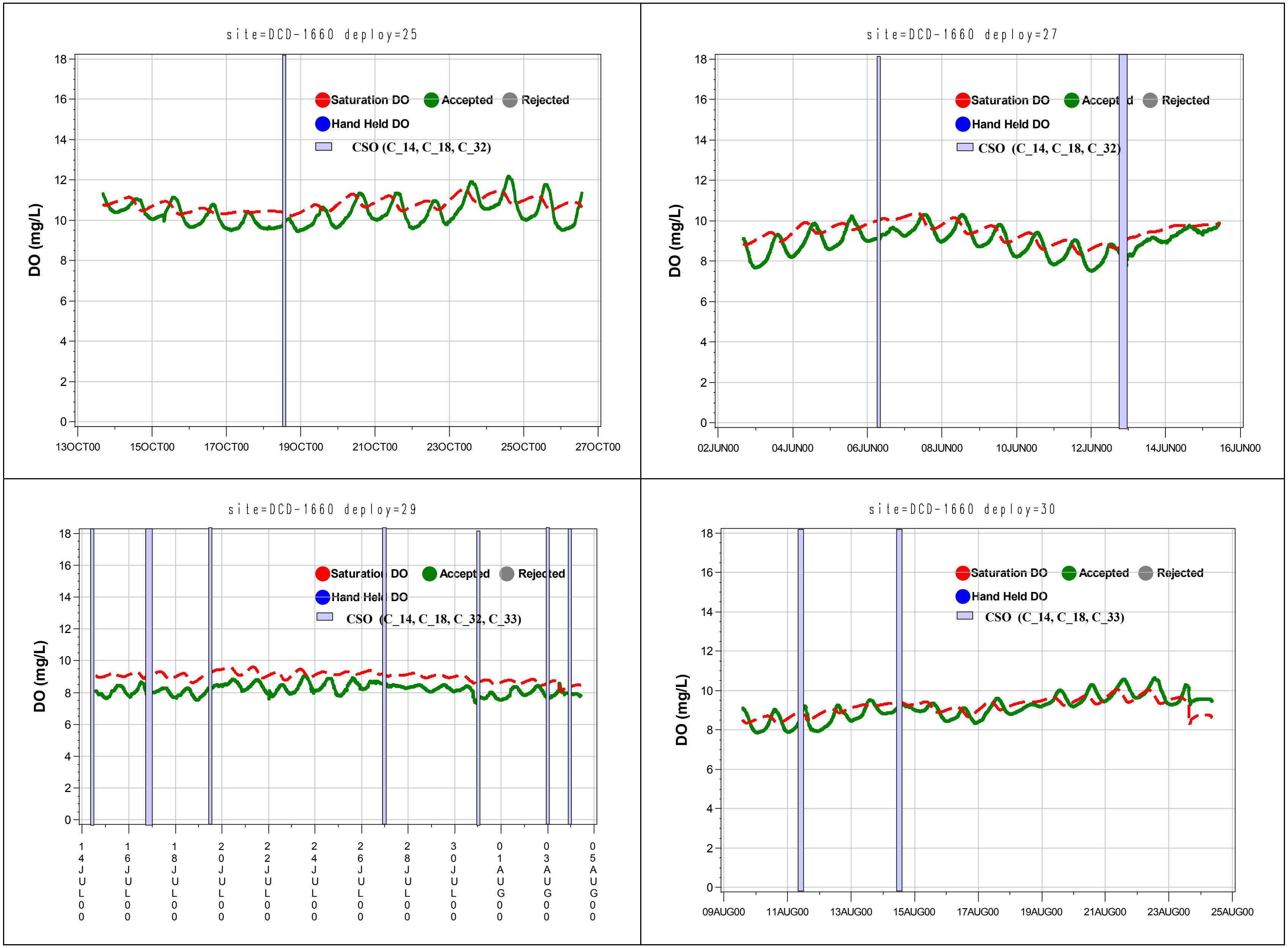


Figure 5.37 Sonde Continuous DO Temporal Plots at DCD-1660

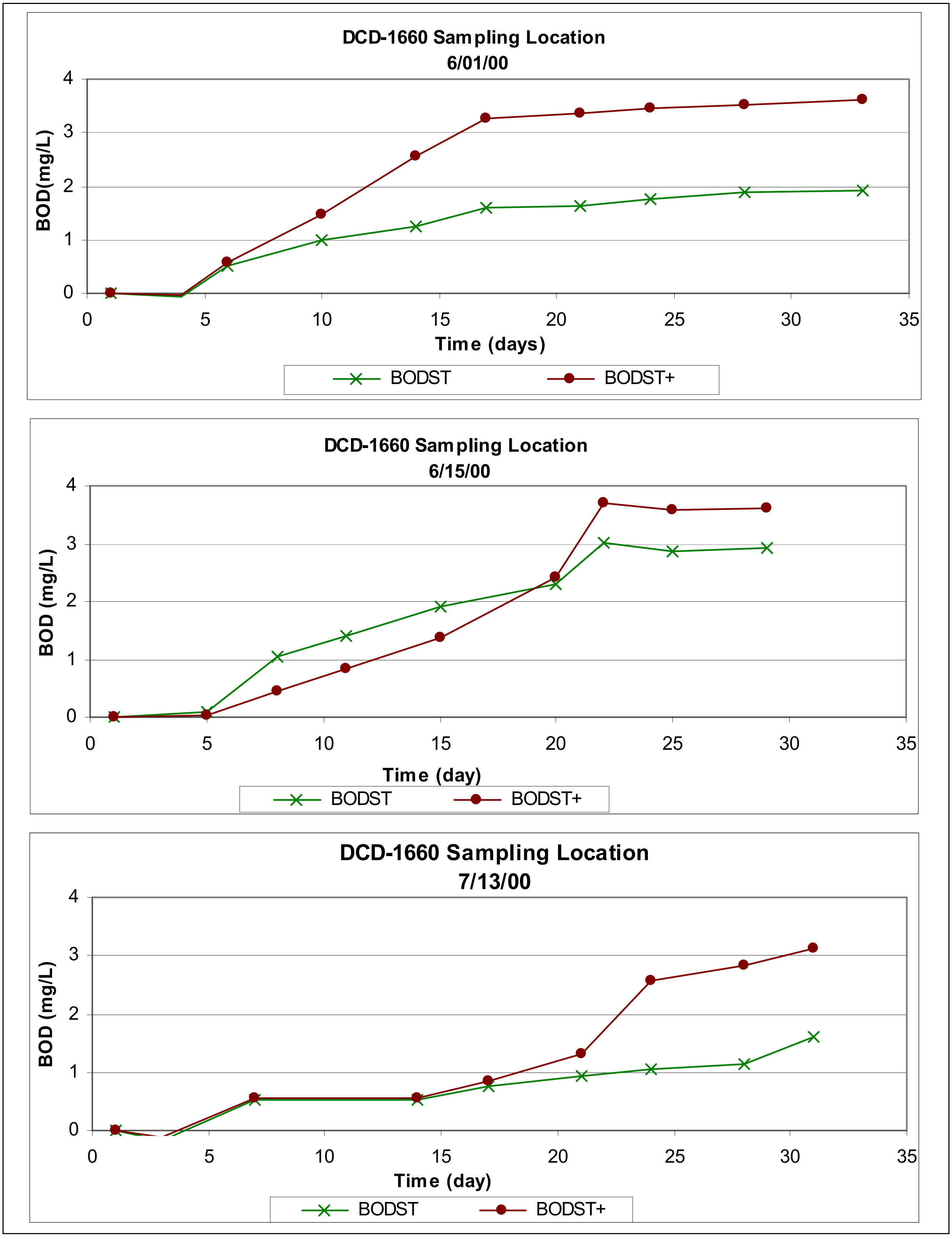
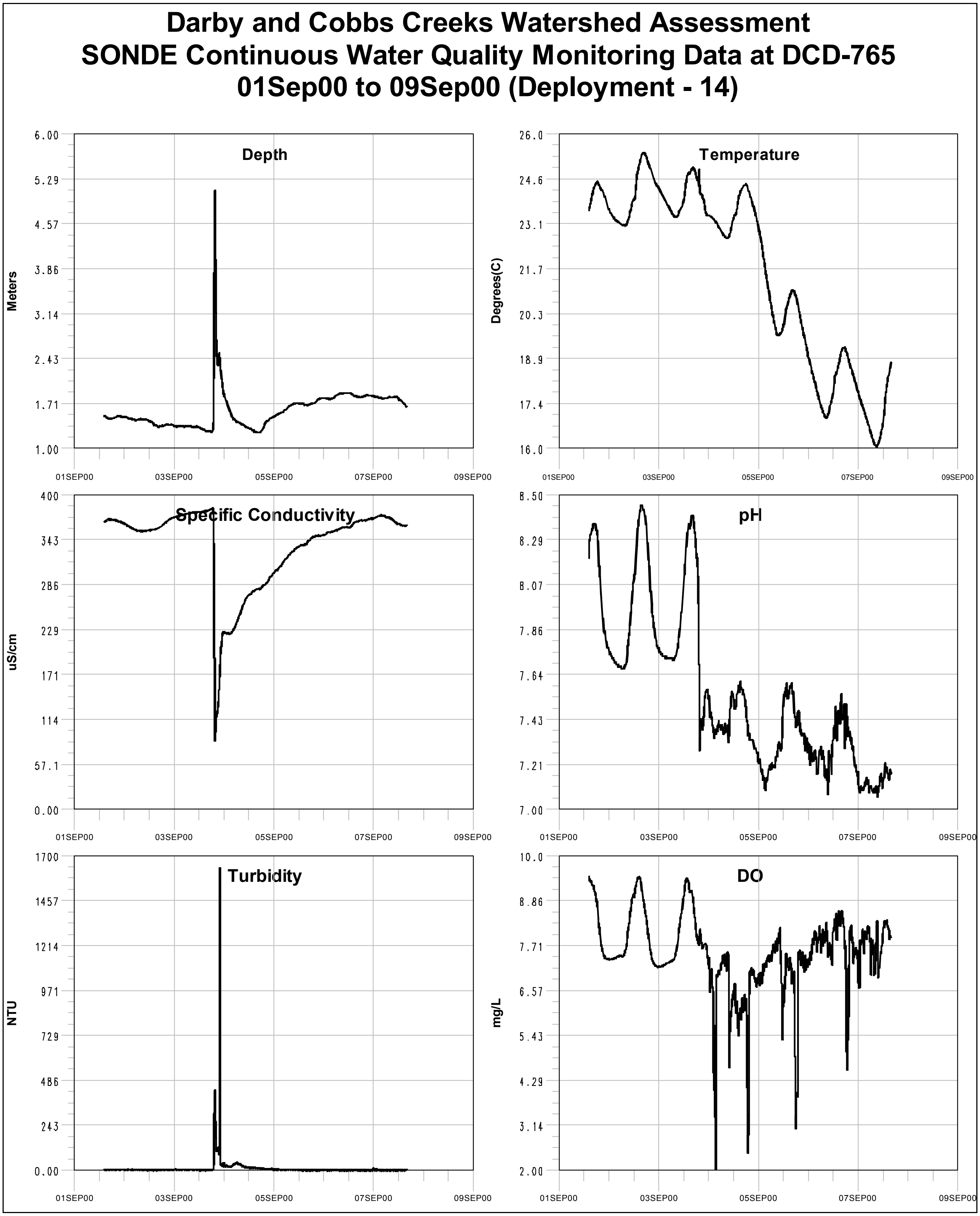
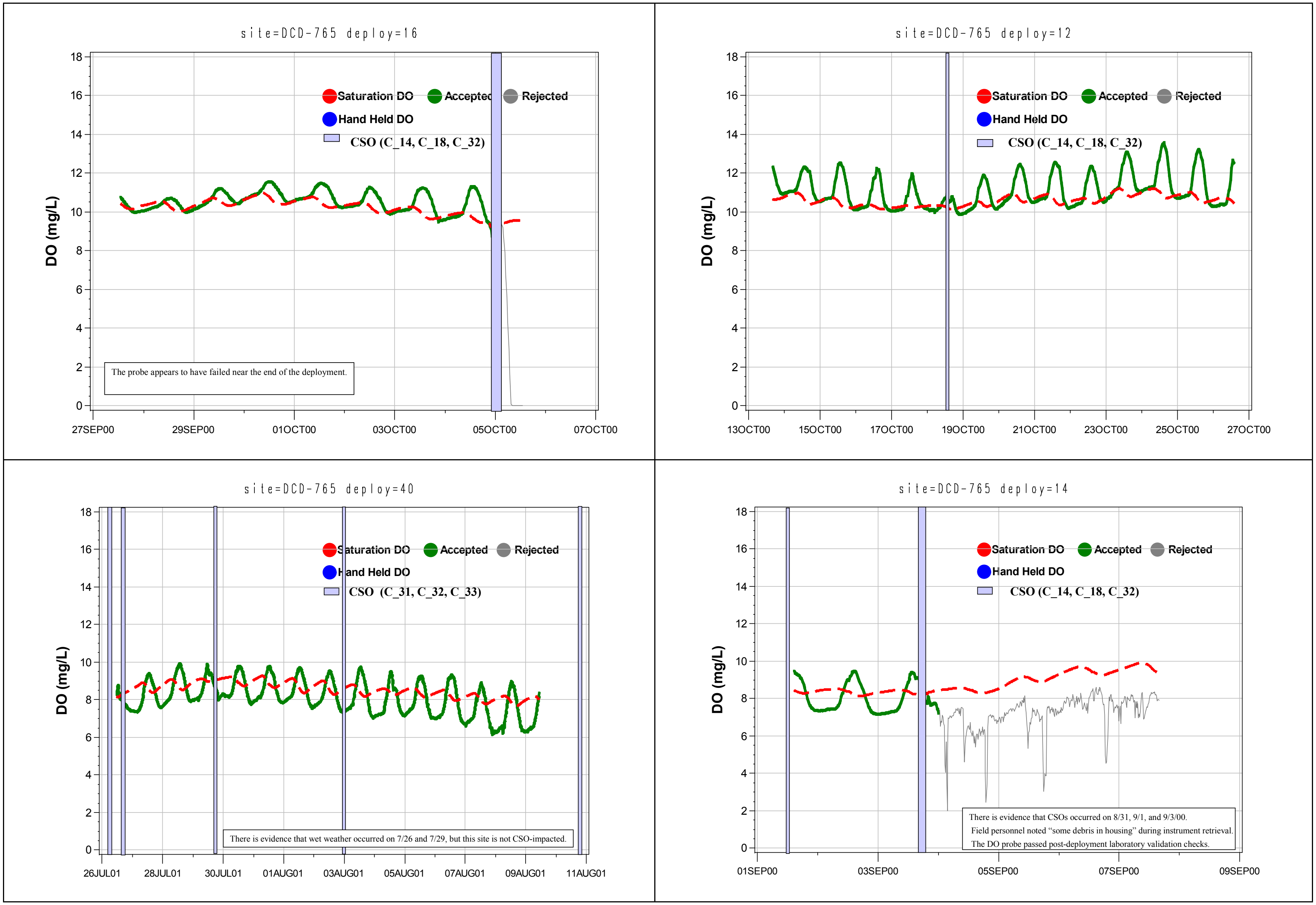


Figure 5.38 BOD Plots for DCD-1660



Darby and Cobbs Creeks Watershed Assessment
SONDE Continuous Water Quality Monitoring Data at DCD-765
01Sep00 to 09Sep00 (Deployment - 14)

Figure 5.39 Sonde Continuous Multi Parameter Temporal Plots at DCD-765



The probe appears to have failed near the end of the deployment.

There is evidence that wet weather occurred on 7/26 and 7/29, but this site is not CSO-impacted.

There is evidence that CSOs occurred on 8/31, 9/1, and 9/3/00.
Field personnel noted "some debris in housing" during instrument retrieval.
The DO probe passed post-deployment laboratory validation checks.

Figure 5.40 Sonde Continuous DO Temporal Plots at DCD-765

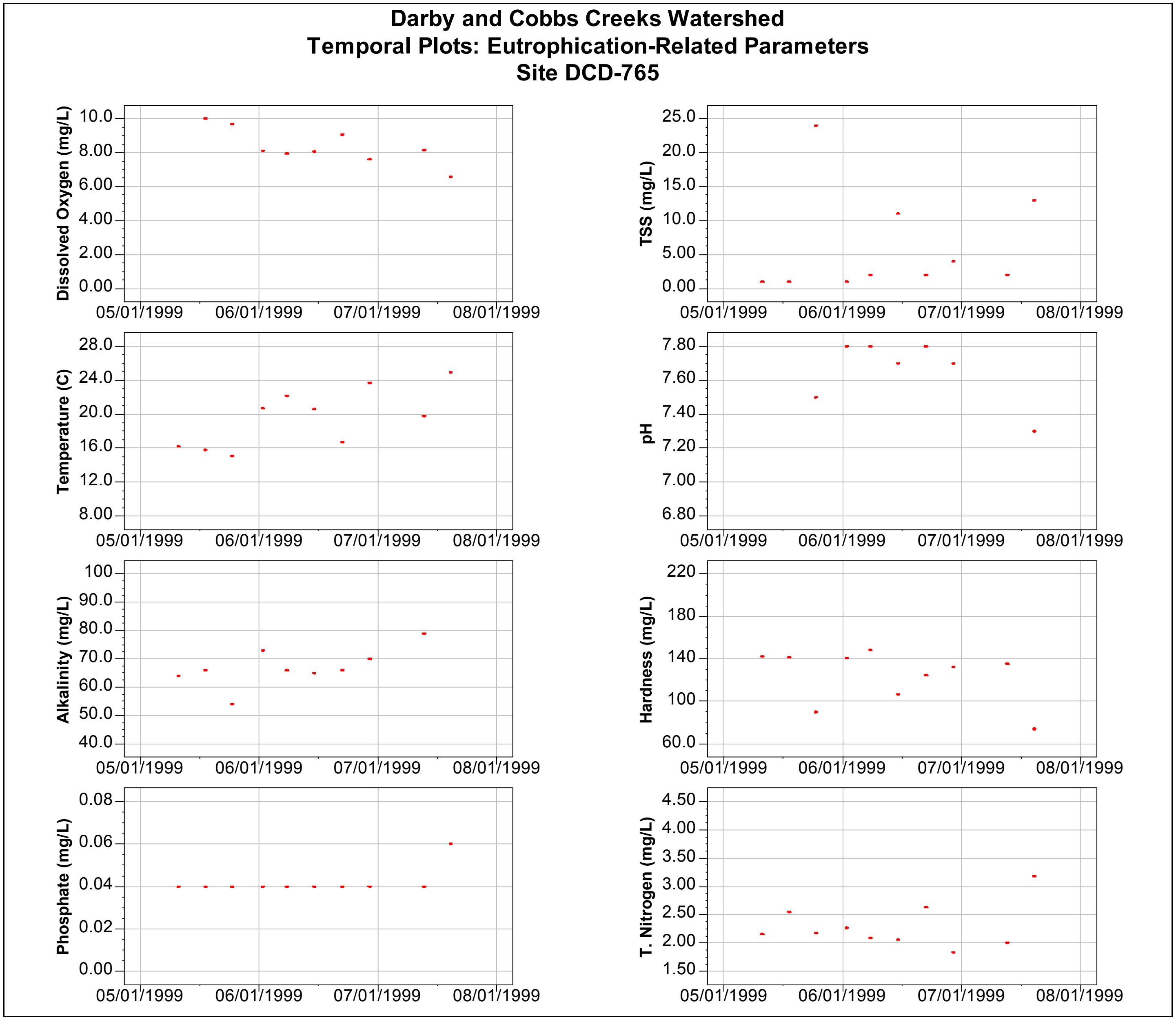


Figure 5.41 Eutrophication-Related Physical Parameters Temporal Plots at DCD-765

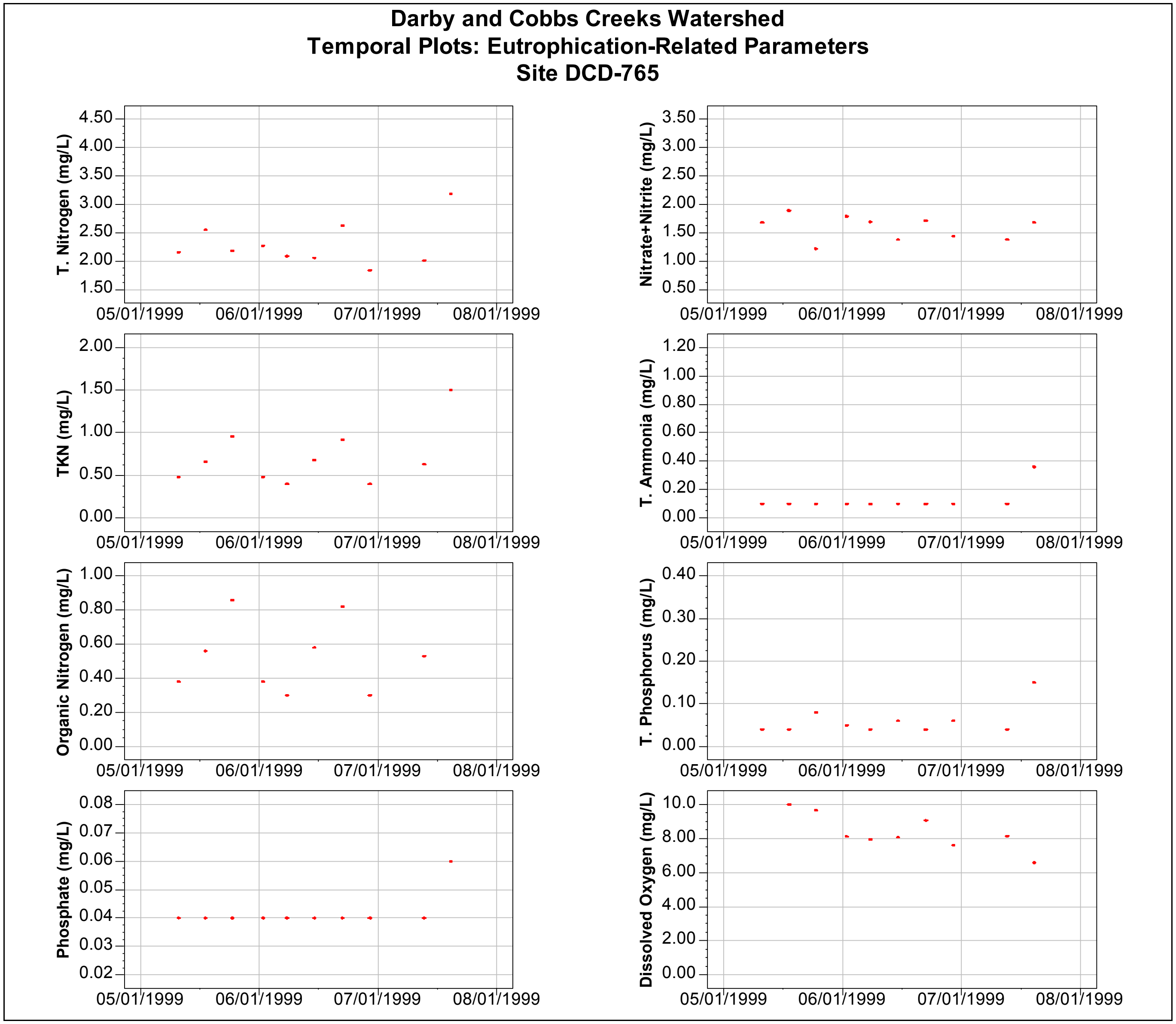


Figure 5.42 Eutrophication-Related Nutrient Parameters Temporal Plots at DCD-765

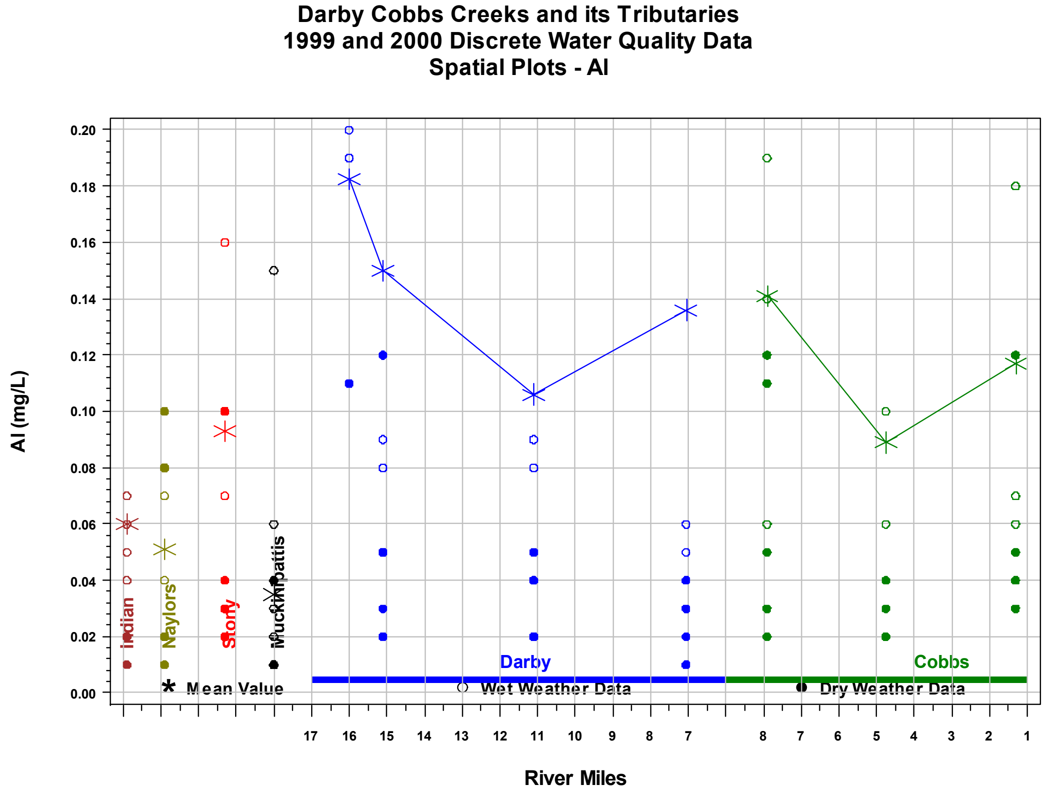


Figure 5.43 Spatial Plot for Aluminum

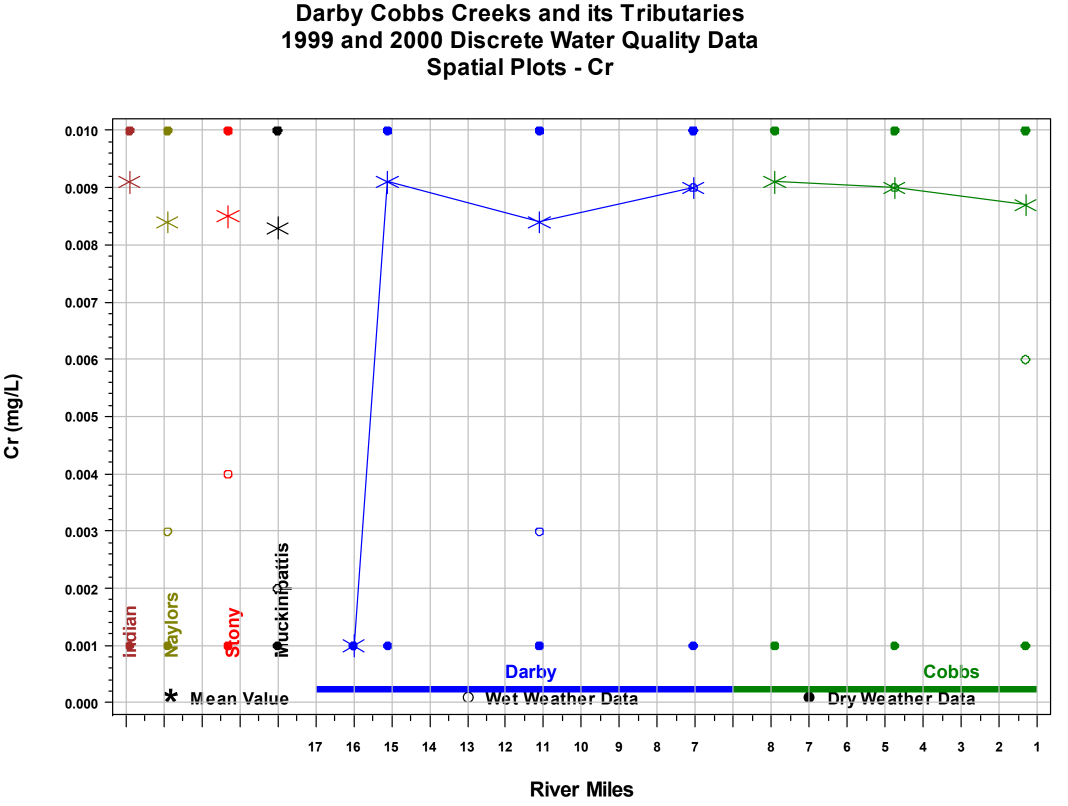


Figure 5.44 Spatial Plot for Chromium

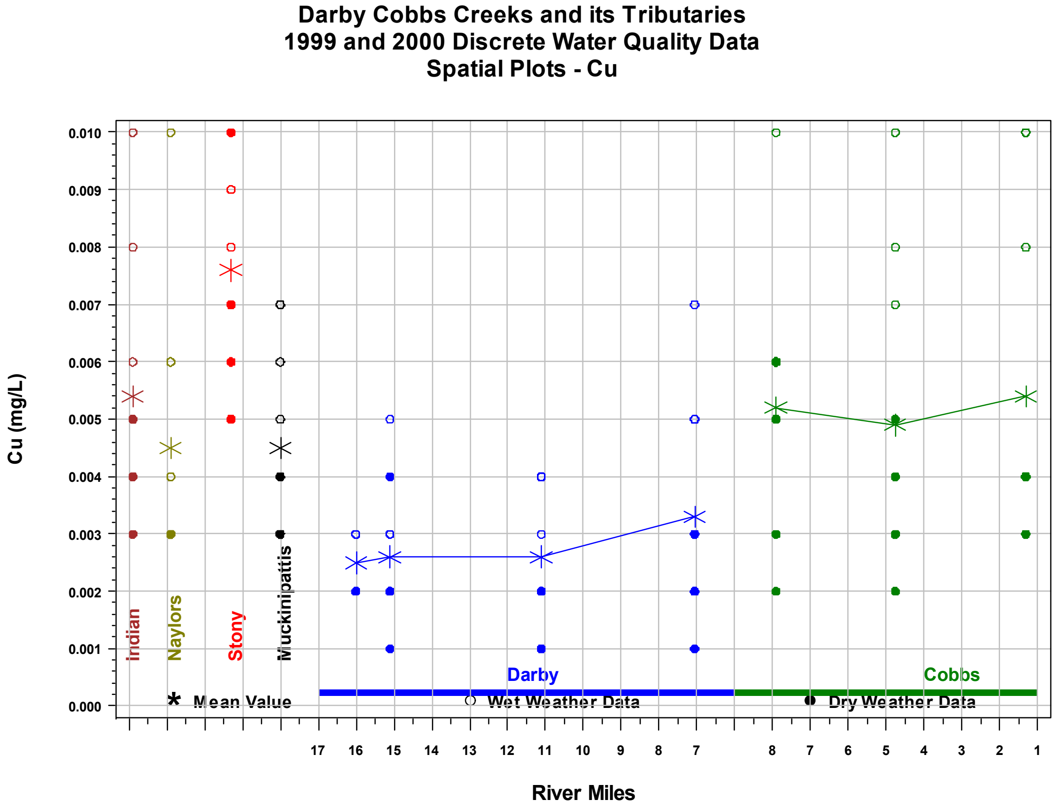


Figure 5.45 Spatial Plot for Copper

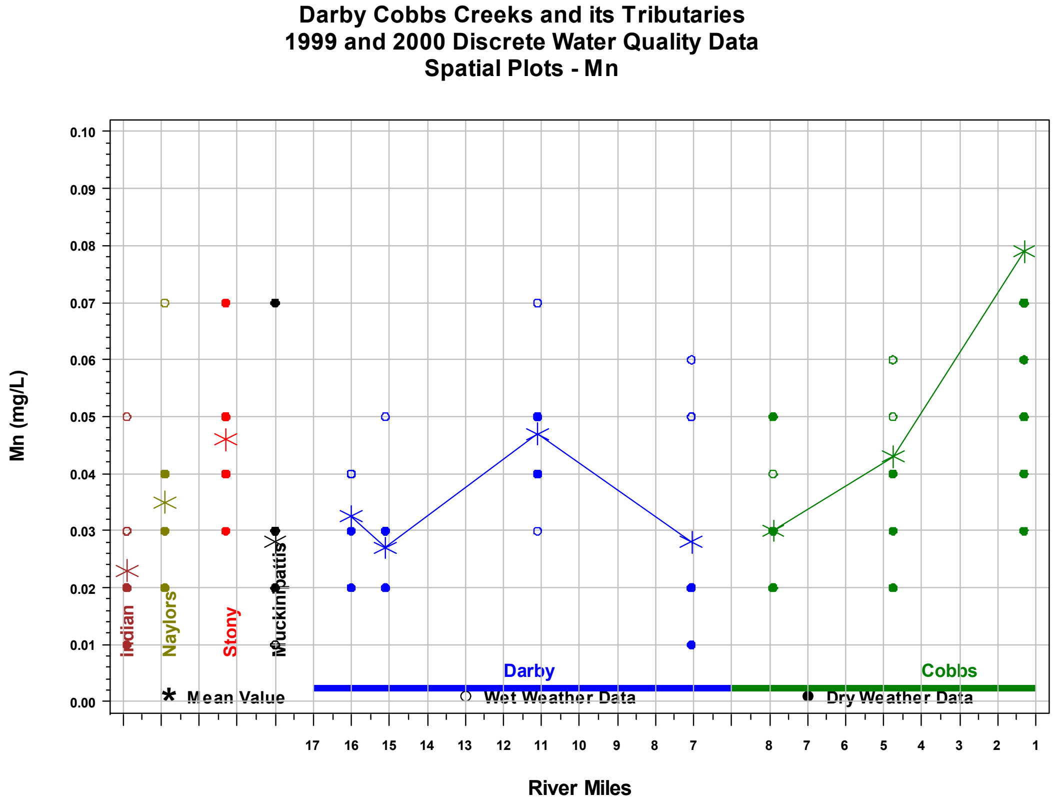


Figure 5.46 Spatial Plot for Manganese

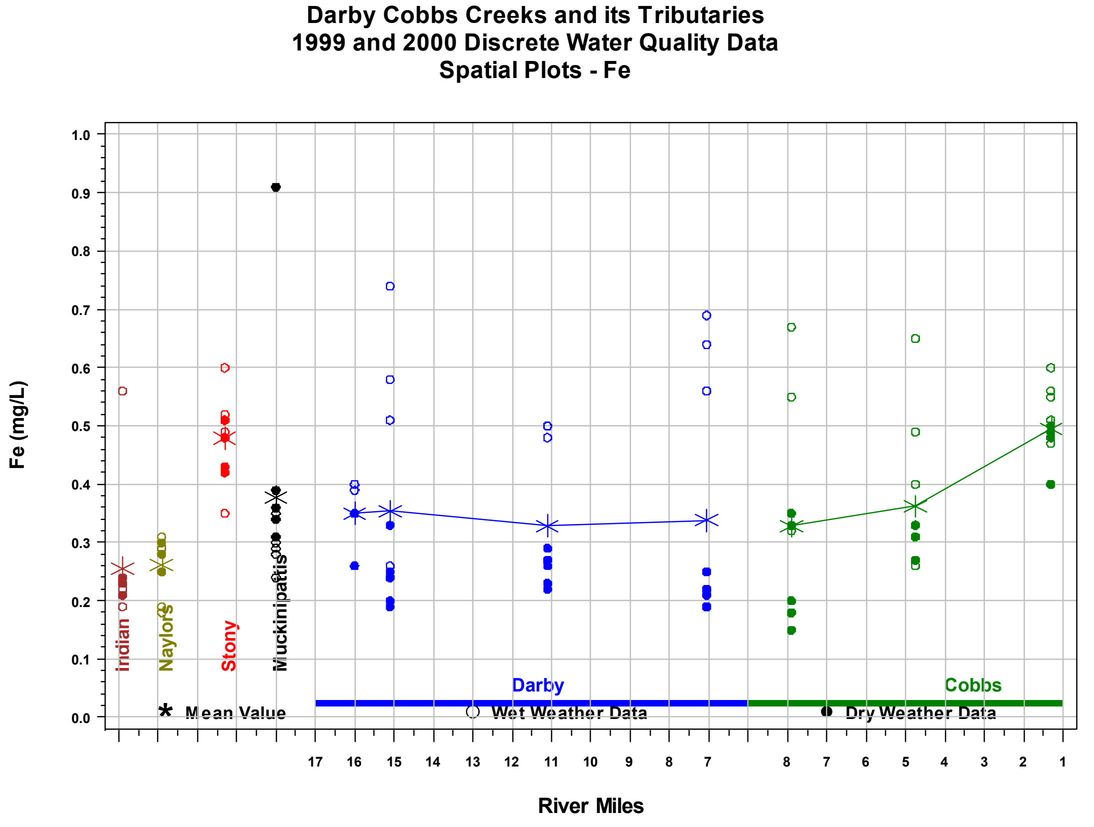


Figure 5.47 Spatial Plot for Iron

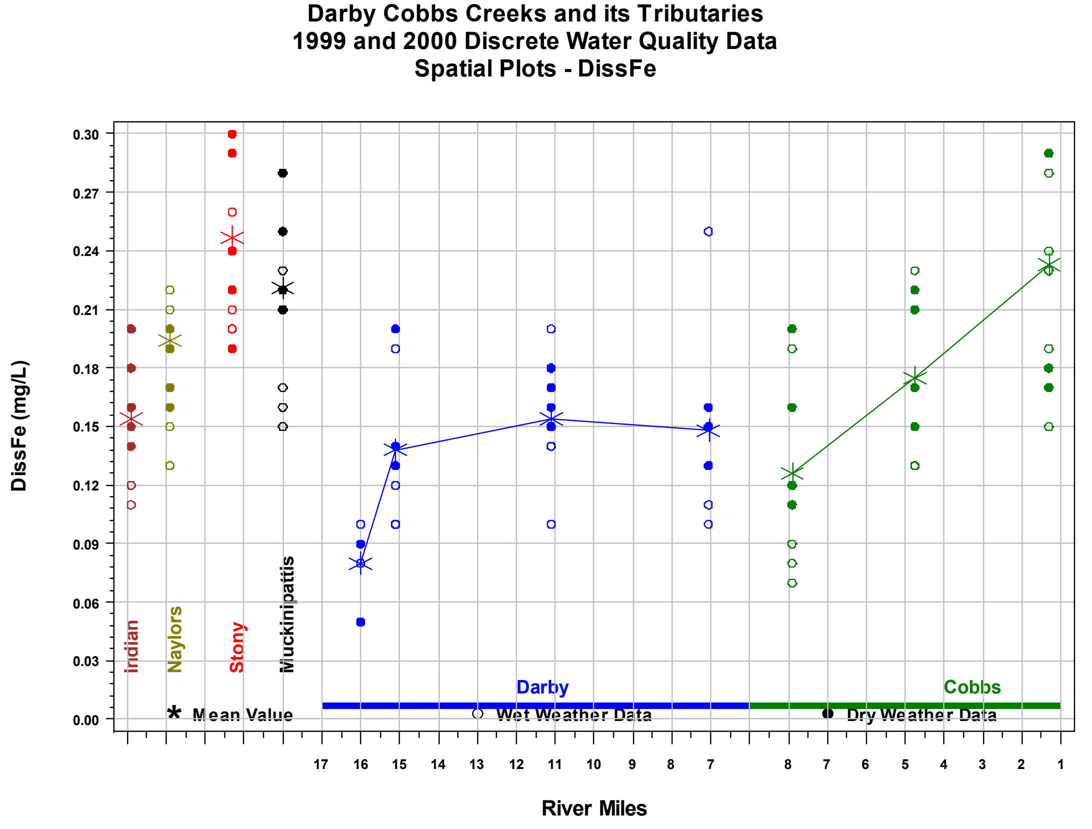


Figure 5.48 Spatial Plot for Dissolved Iron

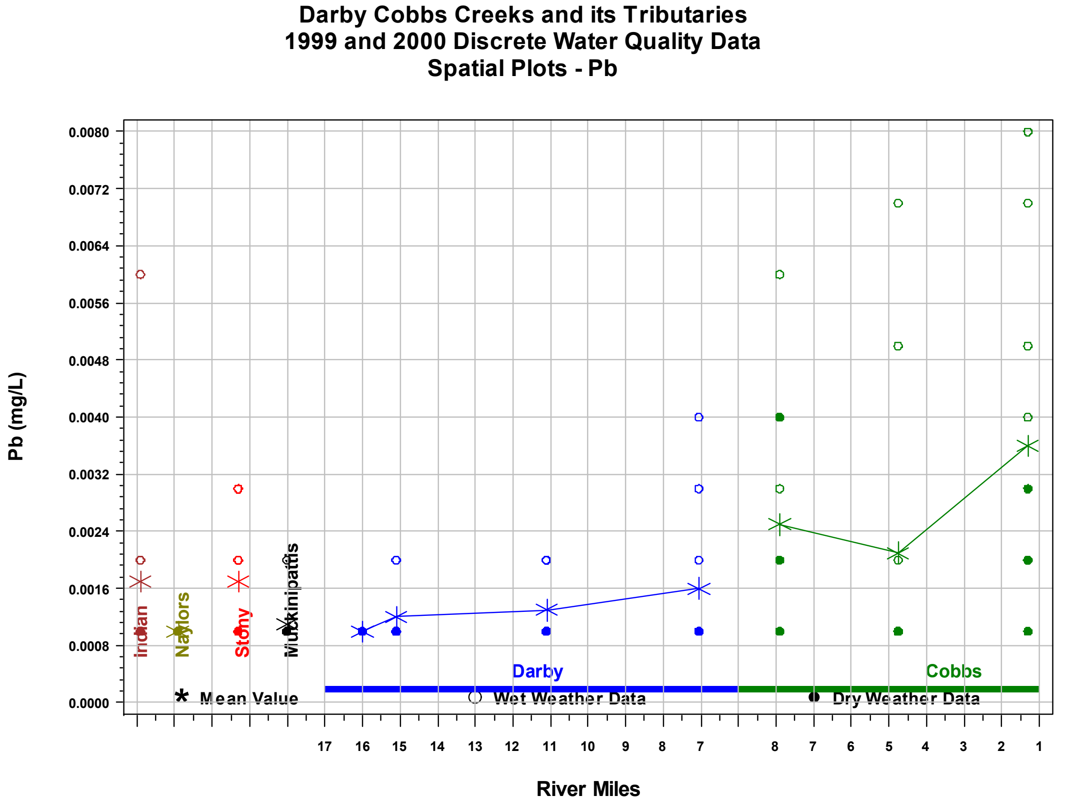


Figure 5.49 Spatial Plot for Lead

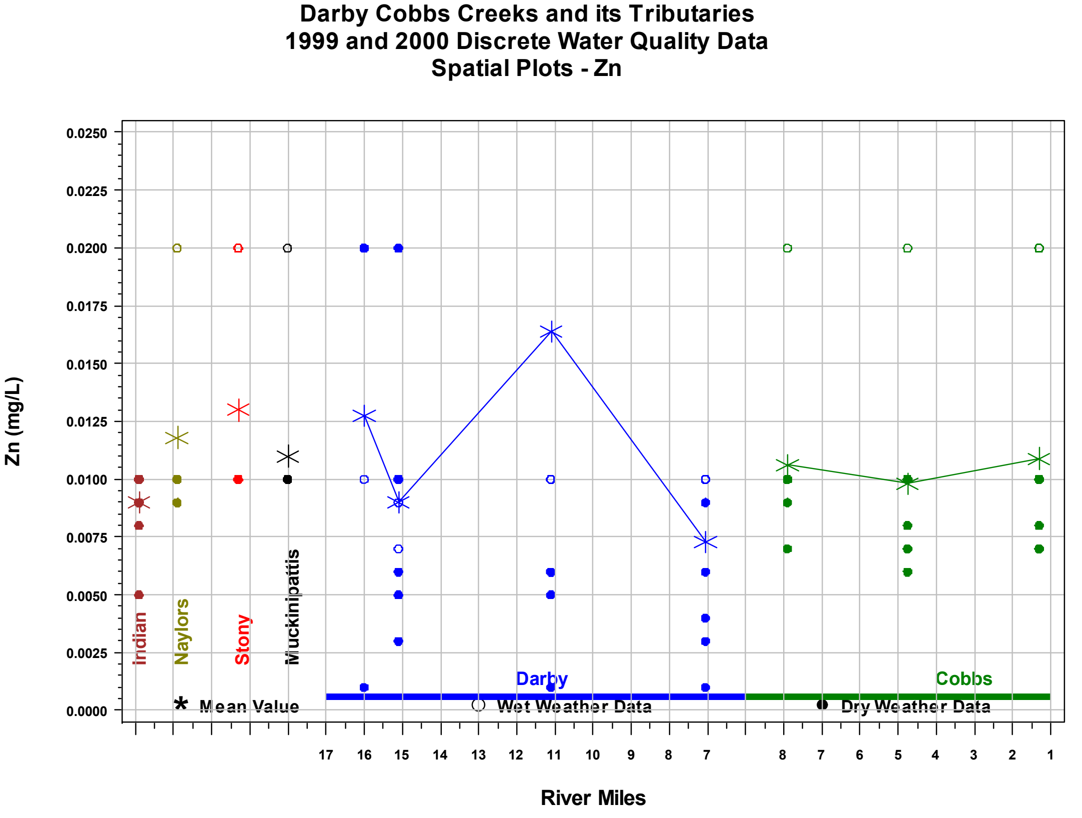


Figure 5.50 Spatial Plot for Zinc

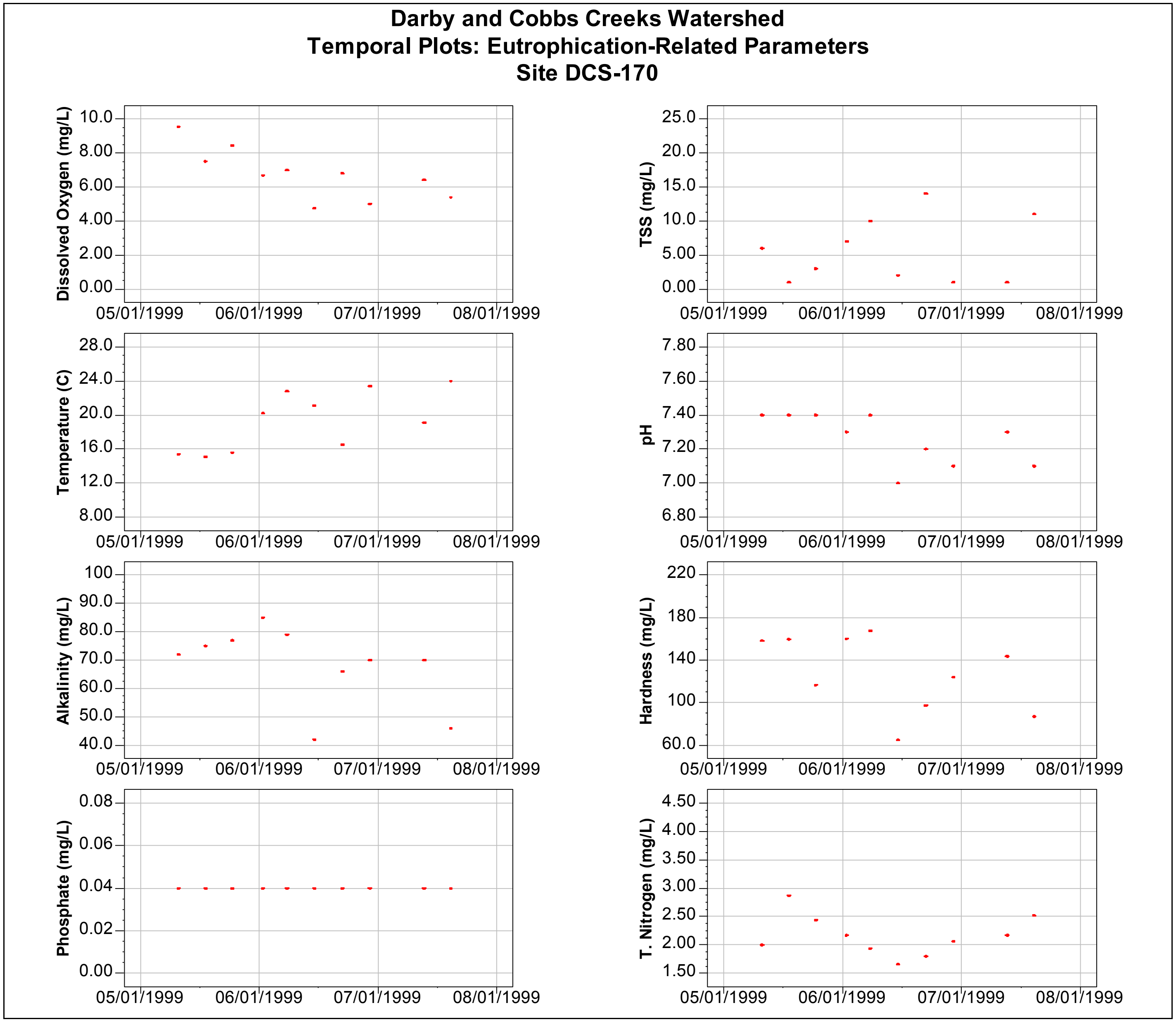


Figure 5.51 Eutrophication-Related Physical Parameters Temporal Plots at DCS-170

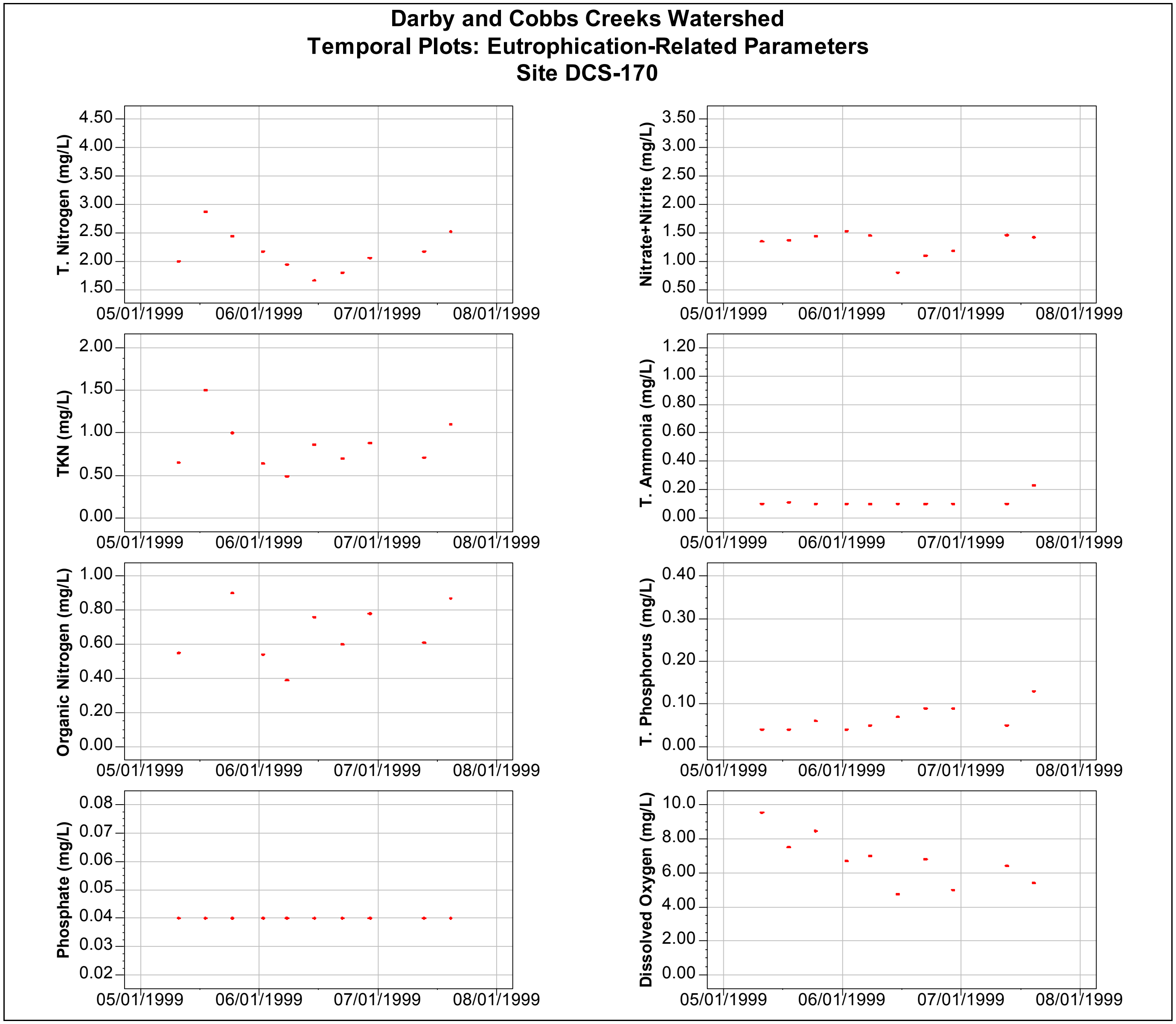


Figure 5.52 Eutrophication-Related Nutrient Parameters Temporal Plots at DCS-170

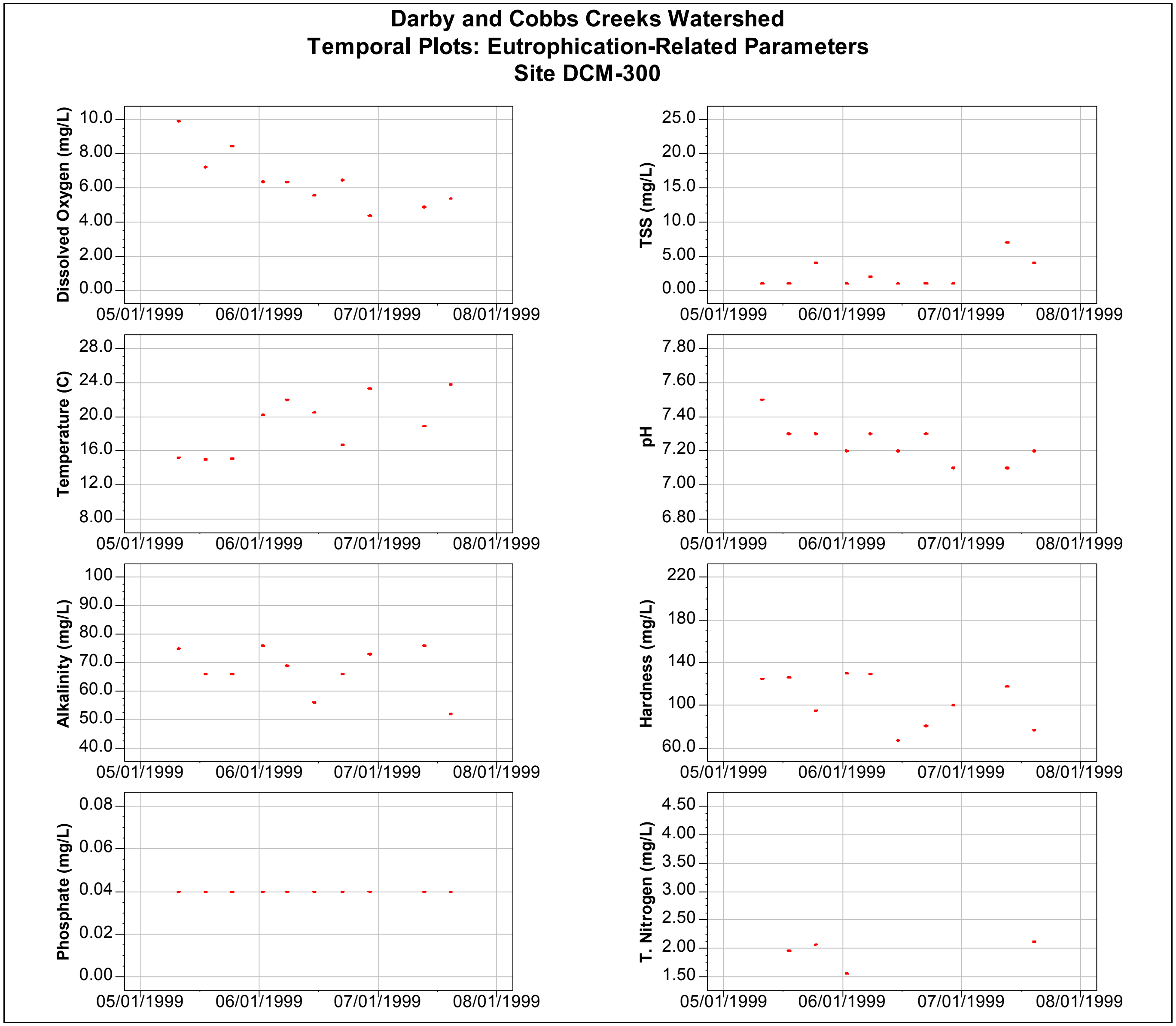


Figure 5.53 Eutrophication-Related Physical Parameters Temporal Plots at DCM-300

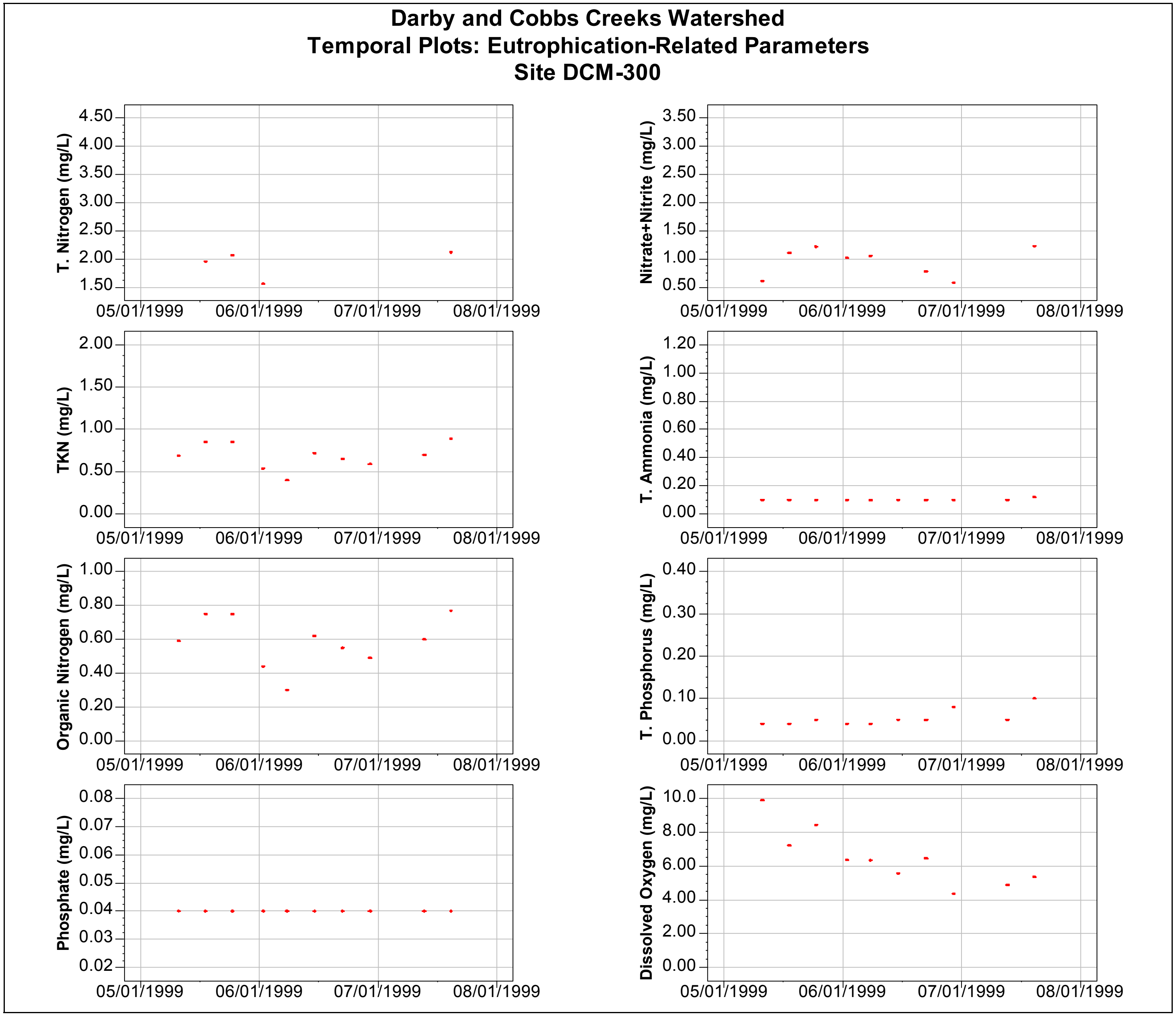

Darby and Cobbs Creeks Watershed
Temporal Plots: Eutrophication-Related Parameters
Site DCM-300

Figure 5.54 Eutrophication-Related Nutrient Parameters Temporal Plots at DCM-300

Section 6 Characterization of Biology and Habitat

6.1 Historical and Existing Information

ANS Geomorphology Study

The Philadelphia Academy of Natural Sciences collected stream morphology data for four streams in the Darby and Cobbs Creeks watershed in August 1998. The data were collected in Fairmount Park for Indian Run, Indian Creek, Bocce Tributary, and Cobbs Tributary 3. The geographic data showing the location of the stream morphology study was not available at time of publication. The data provide information about streambed slope, cross-sectional properties, and sediment grain size distribution.

The thalweg (channel bottom elevation) plot for Indian Run shows that the stream has a slope of approximately 2.6% in the area studied. The channel is approximately 15 m wide and 1 m deep at the cross-sections measured. Based on the grain size distribution, the sediment is poorly sorted, with most particle diameters ranging from 10 mm (medium gravel) to 200 mm (small boulders).

The thalweg of the Indian Creek channel varies more than the elevation of the other three creeks studied, with several deeper pools along the length of the channel. The average slope of the creek in the area studied is 1.6%. The five cross-sections measured all have widths of approximately 15 m and depths of approximately 1 m. The sediment is poorly sorted, with most particles ranging between 1 mm (coarse sand) and 100 mm (cobbles) in diameter.

The Bocce Tributary has a relatively constant bottom slope of approximately 2.5%. The channel is narrower than the others studied, with a width between 4 m and 8 m. The sediment grain size distribution is similar to the distribution for Indian Creek, with most particle diameters ranging from 1 to 100 mm.

Cobbs Tributary 3 has an average slope of 2.5% along the section studied. The channel has a width of approximately 6 to 8 m and a depth of approximately 1.5 m. Most of the sediment particles range in diameter from 1 to 200 mm.

PADEP Aquatic Biological Investigation

The Pennsylvania Department of Environmental Protection, with assistance from the Philadelphia Academy of Natural Sciences, conducted an aquatic biological investigation in the Darby Creek Watershed in June of 1995 and May of 1996. They investigated the general biological health of the watershed and assessed the damage from improper pesticide use in May of 1996. Figure 6-1 presents the locations where investigations were conducted. Only one of the stations, Station 12, was located on Cobbs Creek.

Table 6-1 summarizes the general assessment information available from the study, including information on shading, erosion, stream bed material, vegetation, land use, and biological quality.

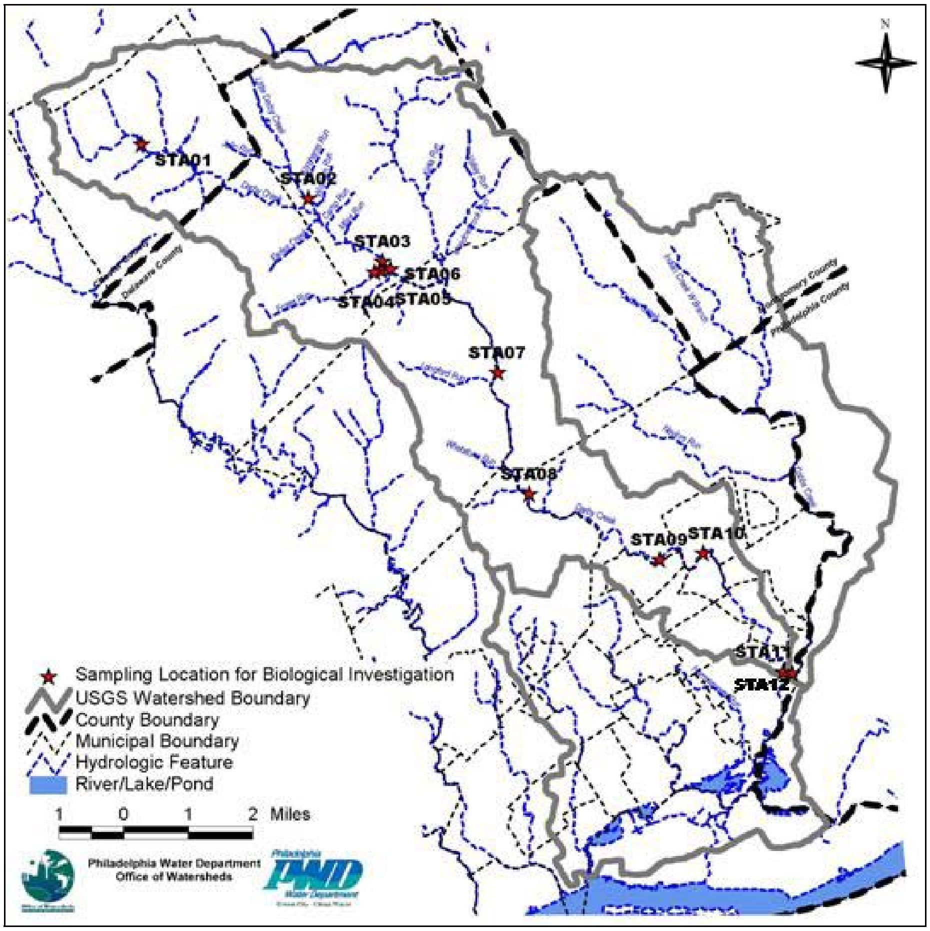


Figure 6-1 PaDEP/ANS Aquatic Biology Investigation 1995-1996

Water quality sampling indicated that the overall water quality in Darby Creek was good. The few parameters sampled above the detection limit but not threatening to fish were iron, aluminum, total suspended solids, and fecal coliform. Fecal coliform concentrations were only notable because they exceeded the Chapter 94 standards. In Cobbs Creek, low dissolved oxygen and elevated levels of ammonia, phosphorus, iron, lead and manganese were observed. The low dissolved oxygen and elevated nutrient levels led researchers to conclude that nutrient enrichment and associated plant growth were possibly affecting this part of Cobbs Creek adversely. Additional studies on Cobbs Creek were recommended to determine the level of impairment from nutrient enrichment and metals toxicity.

Benthic invertebrate data indicated fair conditions in the headwaters and Little Darby Creek and good conditions in some of the headwater tributaries. At other sampled stations, the benthic communities were considered poor. Fisheries data indicated fair conditions throughout the Darby Creek Watershed except for good conditions where the benthic community also was rated good. The fish habitat was thought to be better than indicated by the fisheries data.

Table 6-1 PaDEP/ANS Aquatic Biology Investigation

Station	Width (m)	Shading (%)	Erosion (%)	Silt (%)	Clay (%)	Sand (%)	Gravel (%)	Cobble (%)	Boulder (%)	Bedrock (%)	Veg-etation	Land Use	Biological Quality	
													Benthic	Fish
1	2	25	10	40	20			40			trees shrubs	residential	fair	not reported
2	5	85	20	25	25	10		10	30		trees shrubs	not reported	fair	not reported
3	6	90	60	10		40	20	30			trees lawn	residential woodlot	very good	good
4	2	80	60	10		30	20	30	10		shrubs lawn	residential	very good	good
5	2	80	60	5		10	20	60	5		trees shrubs lawn	residential	poor	fair
6	11	60	40	10		30	15	40	5		shrubs trees	residential woodlot	good	fair
7	6	50	70	15		40	30	30	5		trees shrubs lawn	residential	poor	fair
8	8	60	50	10		20	20	40	10		shrubs trees	woodlot residential	poor	fair
9	13	70	30	10		25	10	15	30	10	trees shrubs	not reported	poor	fair
10	15	40	50	40	10	30	10	5	5		trees shrubs	residential	not reported	not reported
11	10	30	70	40	30	30					trees shrubs	residential	not reported	not reported
12	10	40	80	20		60	20				shrubs	residential	not reported	not reported

Philadelphia Suburban Water Company

In May of 1997, Normandeau Associates conducted an ecological assessment of Cobbs Creek at the request of Philadelphia Suburban Water Company, eight months after observed fish mortality associated with a chlorinated drinking water main break. While the study concluded that the effects of the break were short term and that the recovery of the communities studied was complete, information from this biological assessment can be used for the Darby and Cobbs Creeks Watershed Study. The study area for the Normandeau Associates biological assessment runs from 500 feet above Manoa Road and extends 250 feet below City Line Avenue. All sampling occurred from within Cobbs Creek Park. Figure 6-2 shows the study area for the biological assessment.

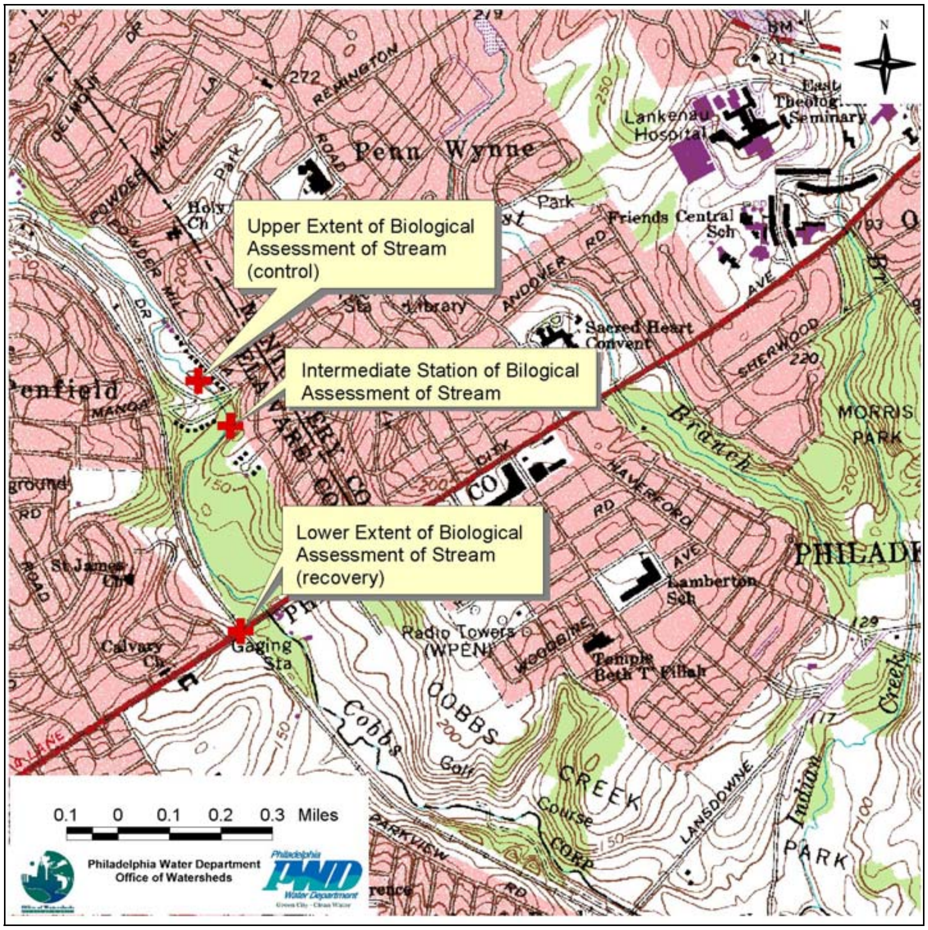


Figure 6-2 Biological Assessment for Philadelphia Suburban Water Company

During the biological assessment, the water temperature was unseasonably cool with temperatures in the range of 52 to 57 degrees F. Specific conductance ranged between 363 and 370 uS/cm.

Based upon USEPA's criteria for habitat assessment, the habitat in Cobbs Creek was rated as "good" to "excellent" in the study area. In the study area, habitat types of riffles, pools and backwater were present, but not throughout the study area. The invertebrate data, collected for the assessment, indicated poor taxonomy, domination by pollution tolerant species, and low diversity. The fisheries data indicated that although numerically dense, the fish community was species poor, containing a preponderance of blacknose dace and white suckers.

Pennsylvania Unassessed Waters Program

At the request of PWD, the Pennsylvania DEP (PaDEP) performed a biological assessment of the non-tidal portions of the Darby and Cobbs Creeks Watershed. For the assessment, 28 stations were chosen to represent the watershed based upon land use and stream order. Each station was evaluated using the Rapid Bio-assessment Protocol and EPA's habitat assessment methods. The assessments occurred between June and late October in 1998. The decisions to consider a station impaired or unimpaired were based upon the quality and quantity of habitat and macroinvertebrates.

The assessments indicated that 52 percent of the stations evaluated were impaired. Generally, impaired stations in the Darby and Cobbs Creeks Watershed were located below Route 3. Figure 6-3 presents the assessment locations and the State's delineation of impaired waters. The State listed the impaired stream segments below Route 3 in the Year 2000 303d list. Stormwater, CSOs, and habitat modification were surmised as the primary and secondary causes of impairment. As a result, TMDLs will need to be developed for pollutants causing stream impairment, once those pollutants are determined.

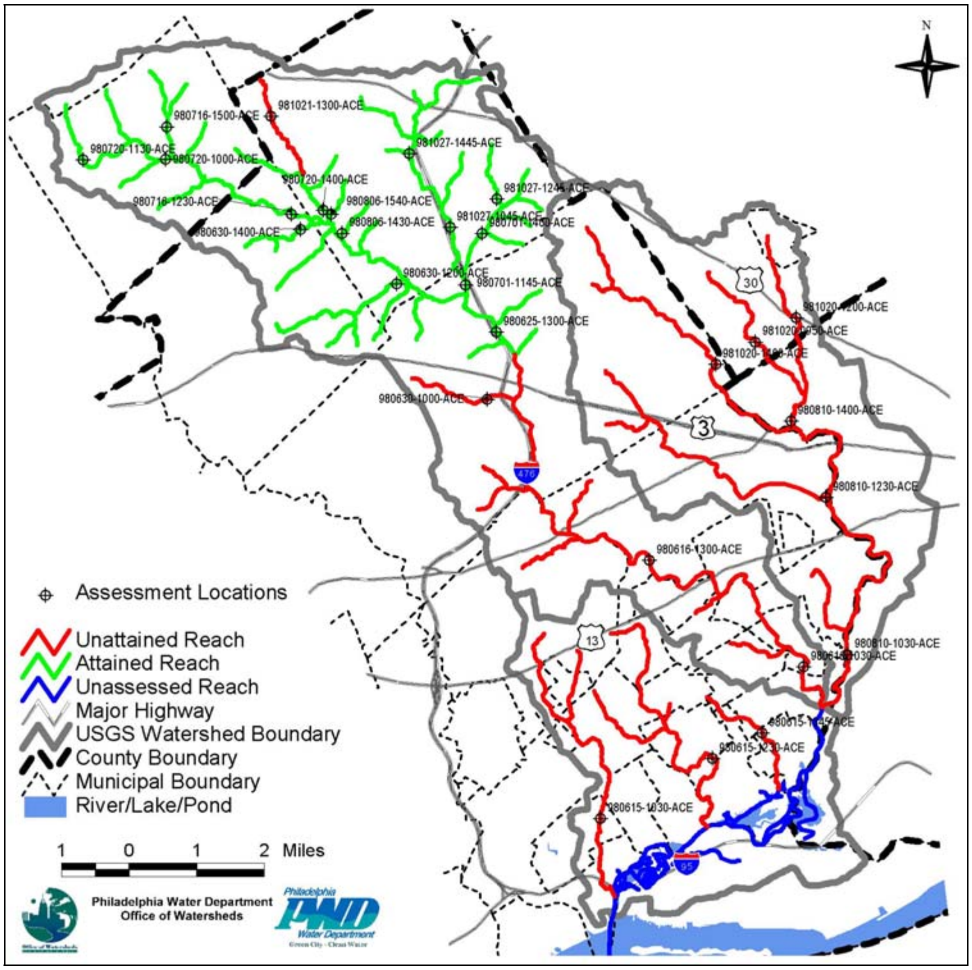


Figure 6-3 PaDEP Delineation of Impaired Reaches 1998

Darby Creek Valley Association

The Darby Creek Valley Association, a non-profit citizen's group, undertook a program to monitor aquatic ecosystem health at eleven sites in the Darby Creek watershed. These sites are shown on Figure 6-4. The program focused on monitoring of aquatic macroinvertebrate communities. The diversity of species and specific species present provide information about the degree of pollution in the stream. The data have not yet been published but will be made available on the internet at a future time.

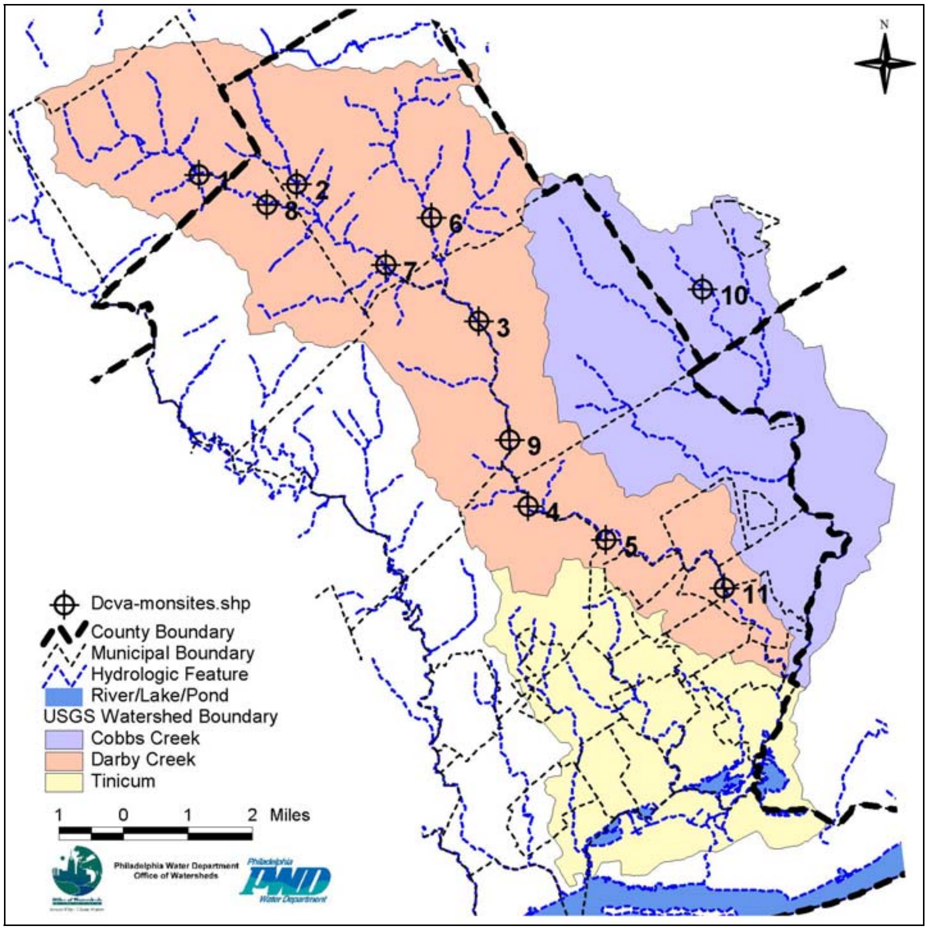


Figure 6-4 DCVA Stream Watch Macroinvertebrate Monitoring Sites

6.2 Preliminary Documentation on the Biological Assessment of the Cobbs Creek Watershed

6.2.1 Introduction

Biological monitoring is a useful means of detecting anthropogenic impacts to the aquatic community. Resident biota (e.g. benthic macroinvertebrates, fish, periphyton) in a water body are natural monitors of environmental quality and can reveal the effects of episodic and cumulative pollution and habitat alteration (Plafkin et. al. 1989, Barbour et al. 1995). Biological surveys and assessments are the primary approaches to biomonitoring.

The Philadelphia Water Department's Office of Watersheds and Bureau of Laboratory Services, along with the Academy of Natural Sciences and the Pennsylvania Department of Environmental Protection have been working together to develop a preliminary biological database to assess the aquatic integrity of the Darby-Cobbs watershed. Although each agency has different objectives for the data (e.g. rapid biological protocol assessments (RBPs), research and presentation, storm water permit compliance (NPDES), Phase II of Darby-Cobbs assessment), the main goal of this project was to avoid redundancy in data collection and to gather as much expertise in the field as possible. During this period, macroinvertebrate, ichthyfauna and habitat assessments were conducted at specified locations within Cobbs Creek watershed. Geographical Information Systems (GIS) databases and watershed maps were also constructed to provide accurate locations of the sampling sites. The Office of Watersheds and the Bureau of Laboratory Services then analyzed compiled data to provide both a quantitative and qualitative assessment of the biological integrity of Cobbs Creek and to provide insight on the current problems associated with this urban stream system. In addition, this report also addresses future assessments and potential solutions for the restoration of the Darby-Cobbs watershed.

6.2.2 Methodology

Fish Sampling

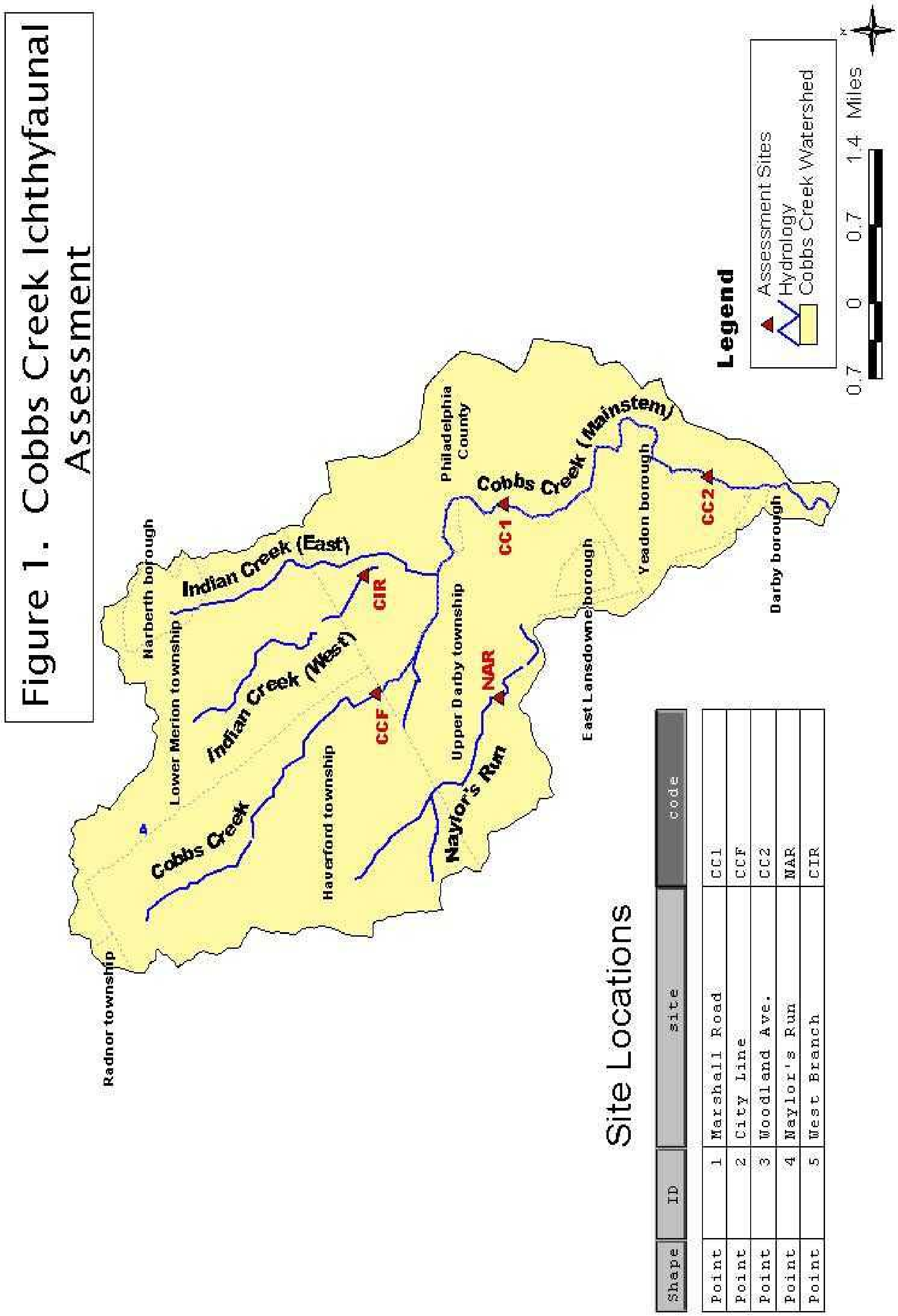
Five sampling stations were chosen on Cobbs Creek; three on the main stem and two sites on the smaller tributaries, West Branch Indian Creek and Naylor's Run. Prior to the main stem analysis, the Academy of Natural Sciences (ANS) completed their assessment on the three tributaries and were interested in completing a watershed analysis on Cobbs Creek. Data from these sites was provided to the Philadelphia Water Department and the Pennsylvania Department Of Environmental Protection (PADEP).

DCC-820: Main Stem (Cobbs Creek, Montgomery County): CCF

Sampling occurred on the main stem of the Cobbs Creek approximately 50 meters above City Line Avenue, Montgomery County (Latitude: 39°58′30.72″ Longitude: 75°16′51.60″, Figure 6-5). Using EPA protocols for rapid bioassessment, a 150 meter reach was measured using a graduated tape and both upstream and downstream portions were blocked off using standard seining nets. Two Coffelt backpack electro-shockers were operated at 50-75 watts direct current (DC). Fish were collected using D-frame dip nets, and identified to species and total length of each individual. Upon completion, an additional pass without replacement was completed.

The site name conventions in some graphics, including Figure 6-5 correspond to the current convention as follows:

Old Site Name Conventions	New Site Name Convention
CC1 / Site 1	DCC455
CCF / Site 2	DCC770
CC2 / Site 3	DCC110
NAR / Site 4	DCN215
CIR / Site 5	DCIW100



Shape	ID	site	code
Point	1	Marshall Road	CC1
Point	2	City Line	CCF
Point	3	Woodland Ave.	CC2
Point	4	Naylor's Run	NAR
Point	5	West Branch	CIR

Figure 6-5 Cobbs Creek Ichthyfaunal Assessment

DCC-175: Mainstem (Cobbs Creek, Philadelphia County): CC2

Sampling procedures occurred on the mainstem Cobbs Creek near Mt. Moriah Cemetery (Latitude: 39°56′4.92″ Longitude: 75°14′12.84″, Figure 6-5). Using EPA guidelines for ichthyfaunal assessment, a 200 meter reach was blocked off using standard seining nets. Fish collection, identification and health assessment at this location were similar to the DCC-820 collection. For more information on the methodology concerning fish assessment, refer to Barbour et. al. (1999).

DCN-215 and DCIW-100: (Tributaries To The Main Stem)

Prior to field sampling on Cobbs Creek main stem, the Academy of Natural Sciences conducted a field analysis on two tributaries, Naylor's Run (DCN-215) and West Branch Indian Creek (DCIW-100), and an additional site on the main stem of Cobbs Creek (DCC-505) (Figure 6-5).

3.3.2 Biological Assessment (Fish Biosurvey And Data Analysis)

Six metrics were used to assess the quality of the fish assemblages in Cobbs Creek (Table 6-2).

Table 6-2 Quantitative and Qualitative Analyses of Cobbs Creek Ichthyfaunal Community

1. **Species Richness**
2. **Species Diversity**
3. **Trophic Composition Relationships**
4. **Pollution Tolerance Levels**
5. **Disease and Parasite Abundance/Severity**
6. **Introduced (exotic) Species**
7. **Species descriptions***
   *Not used as a metric

Species Richness:

The first metric, species richness, addresses the total number of native fish species and generally signifies increased stream degradation as the number of species decreases. Number of native species, however, is strongly correlated to stream size at small stream sites and thus, it is important to develop species/waterbody size relationships for future assessments in the Darby-Cobbs watershed (Karr et al, 1986).

Species Diversity:

Species diversity, a characteristic unique to the community level of biological organization, is an expression of community structure (Brower et al., 1990). In general, high species diversity indicates a highly complex community. Thus, population interactions involving energy transfer (e.g. food webs), predation, competition and niche distribution are more complex and varied in a community of high species diversity. In addition, many ecologists support species diversity as a measure of community stability (i.e. the ability of community structure to be unaffected by perturbations). Using the Shannon-Weiner (H') index, the following formulas were used to calculate species diversity at each sampling location:

$$H' = -\sum (Pi)(\ln Pi), \qquad \text{(eq. 1)}$$

$$Pi = \frac{ni}{N}; \qquad \text{(eq. 2)}$$

where pi is the proportion of the total number of individuals n occurring in species I to the total number of species counted N.

Trophic Composition and Tolerance Designations:

Trophic composition metrics were used to assess the quality of the energy base and trophic dynamics of the fish assemblages (Plafkin et al., 1989). The trophic composition metrics offer a means to evaluate the shift toward more generalized foraging that typically occurs with increased degradation of the physiochemical habitat (Barbour et al., 1999). Pollution tolerance metrics were also used to distinguish low and moderate quality sites by assessing tolerance values of each species identified at the sampling locations. For a more detailed description of metrics used to evaluate the trophic and pollution designations of fish assemblages see Barbour et. al. (1999).

Disease and Parasite Abundance/Severity:

Two species, Rhinichthys atratulus and Catastomus commersoni, were used to assess the severity of parasite infestation on two fish populations. Using a sub-sample of individuals (n=15) located at Cobbs Creek at City Line (DCC-820) and Cobbs Creek near Woodland Avenue (DCC-175), the ranking of parasite infestation was based on the severity of trematode cysts, ranging from 0 (no infestation) to 3 (heavily infested). A one-way analysis of variance (ANOVA) was used to determine the significance of trematode cyst infestation on R. atratulus and C. commersoni between sites. While trematode cysts are generally not pathenogenic to fish species, the presence and severity of infestation represents a stressed and weakened community. Trematode cysts can cause damage to gill function (e.g. respiration) and skin defects (e.g. peeling and loss of proteins and fluids).

Proportion of Introduced/Exotic Species:

This metric was used as a qualitative approach to determine direct anthropogenic (e.g. human) effects on the stream ecosystem through introduction of non-native species. Generally, as environmental degradation increases, the percent of introduced species also increases. In addition, invasive species are also capable of shifting community dynamics by eliminating native species.

Species Descriptions:

Descriptions of habitat, functional feeding groups, reproduction and migratory processes of individual species were also created in this report to serve as an educational component for future work with community organizations, neighboring municipalities and educational systems within Philadelphia and surrounding school systems.

Benthic (Macroinvertebrate) Sampling

On December 6th-7th, 1999, the Pennsylvania Department of Environmental Protection (PADEP), Office of Watersheds and the Bureau of Laboratory Services conducted Rapid Bioassessment Protocols (RBP III) on seven sites (Figure6-6) in the Cobbs Creek watershed. Using EPA guidelines, macroinvertebrates were collected by placing a standard D-frame dipnet at the downstream portion of a riffle.

The substrate was then kicked and scraped manually one meter from the net aperture to remove all benthic species. This procedure was repeated at another riffle location with less flow. Specimens were then preserved in 95% ETOH (ethyl alcohol) and returned to the laboratory in polyethylene containers. In laboratory, samples were placed in a 11" x14" gridded (numbered) pan and random "plugs" were examined until 100 individuals were collected. Macroinvertebrates were identified to genus and population estimates were calculated. Using the following flowchart, the biological integrity and benthic community composition was determined (EPA guidelines for RBP III and PADEP Modified Rapid Biological Assessments) (Table 6-3):

Table 6-3: Biological Condition Scoring Criteria For RBP III

Metric	Biological Condition Scoring Criteria			
	6	4	2	0
Taxa Richness (a)	>80%	79-70%	69-60%	<60%
Hilsenhoff Biotic Index (Modified) (a)	<0.71	0.72-1.11	1.12-1.31	>1.31
Modified EPT Index (a)	>80%	79-60%	59-50%	<50%
%Contribution of Dominant Taxon (a)	<10	11-16	17-22	>22
%Modified Mayflies (a)	<12	13-20	21-40	>40
Ratio of Scrapers/Filter (b) Collectors	>50%	35-50%	20-35%	<20%
Community Loss Index (b)	<0.5%	0.5-1.5	1.5-4.0	>4.0
Ratio of Shredders/Total (b)	>50%	35-50%	20-35%	<20%

(a) Metrics used to quantify scoring criteria (PADEP)
Additional metrics used for qualitative descriptions of sampling locations (EPA)

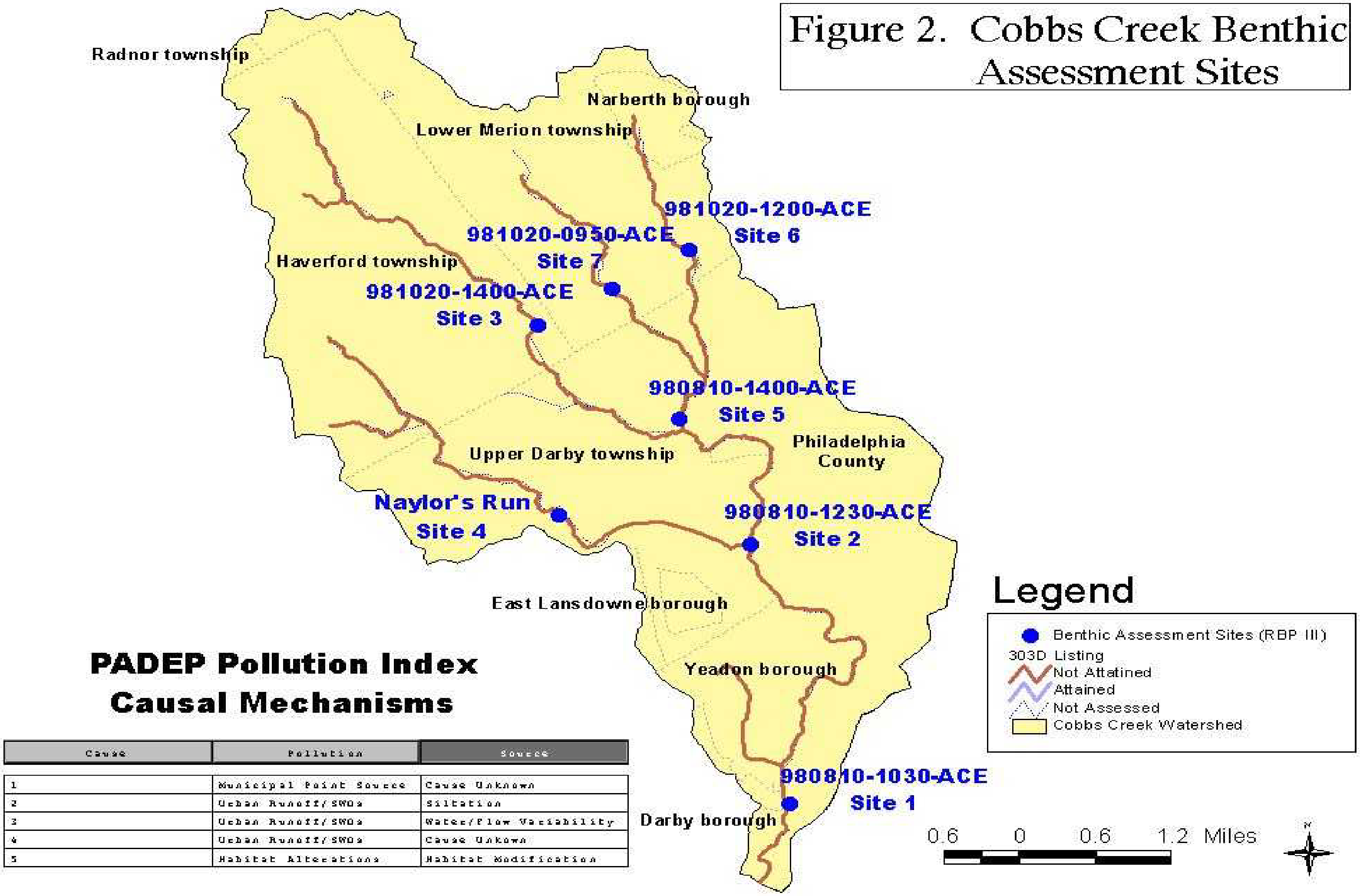


Figure 2. Cobbs Creek Benthic Assessment Sites

PADEP Pollution Index
Causal Mechanisms

Cause	Pollution	Source
1	Municipal Point Source	Cause Unknown
2	Urban Runoff/SWOs	Siltation
3	Urban Runoff/SWOs	Water/Flow Variability
4	Urban Runoff/SWOs	Cause Unkown
5	Habitat Alterations	Habitat Modification

Figure 6-6 Cobbs Creek Ichthyfaunal Assessment

Upon completion of the total biological scoring criteria, each site was compared to a reference site according to its drainage area and geomorphological attributes. The two reference sites chosen were Broad Run (located at the intersection of Chestnut Lane and Broad Run Road, West Bradford Township, Chester County) and French Creek (located at Coventry Road Bridge, South Coventry Township, Chester County). Using the following chart, a biological assessment of each site was established in attempt to create a baseline for monitoring trends in benthic community structure that might be attributable to improvement or worsening of conditions over time (Table 6-4):

Table 6-4 Bioassessment of Benthic Community Structure (RBPIII)

% Comparison to Reference Score [(a)]	Biological Condition Category	Attributes
>83%	Nonimpaired	Comparable to the best situation within an ecoregion. Balanced trophic structure. Optimum community structure for stream size and habitat quality.
54-79%	Slightly impaired	Community structure less than expected. Composition (species and dominance lower than expected due to loss of some intolerant forms. Percent contribution of tolerant forms increases.
21-50%	Moderately impaired	Fewer species due to loss of most intolerant forms. Reduction in EPT index.
<17%	Severely impaired	Few species present. If high densities of organisms, then dominated by one or two taxa.

(a)Percentage values obtained that are intermediate to the above ranges will require subjective judgment as to the correct placement. Use of the habitat assessment and physiochemical data may be necessary to aid in the decision process.

Habitat Assessment

Prior to the benthic procedures, habitat assessments at the seven sites were completed based on the Stream Classification Guidelines for Wisconsin (Ball, 1982) and Methods of Evaluating Stream, Riparian, and Biotic Conditions (Platts et al., 1983). Reference conditions were used to normalize the assessment to the "best attainable" situation. Habitat parameters are separated into three principal categories:

(1) primary, (2) secondary, and (3) tertiary parameters.

Primary parameters are those that characterize the stream "microscale" habitat and have the greatest direct influence on the structure of the indigenous communities.

Secondary parameters measure the "macroscale" habitat such as channel morphology characteristics. Tertiary parameters evaluate riparian and bank structure and comprise three categories: (1) bank vegetative protection, (2) grazing or other disruptive pressure, and (3) and riparian vegetative zone width. The following chart (Table 6-5) describes the analysis that was completed:

Table6-5: Habitat Assessment Criteria Used at Benthic Monitoring Stations*

Condition/Parameter	Condition			
	Optimal	**Suboptimal**	**Marginal**	**Poor**
Primary-Substrate And Instream Cover				
Instream Cover	**16-20**	**11-15**	**6-10**	**0-5**
Epifaunal Substrate	**16-20**	**11-15**	**6-10**	**0-5**
Velocity/Depth regimes	**16-20**	**11-15**	**6-10**	**0-5**
Secondary-Channel Morphology				
Channel alteration	**16-20**	**11-15**	**6-10**	**0-5**
Sediment Deposition	**16-20**	**11-15**	**6-10**	**0-5**
Frequency of Riffles	**16-20**	**11-15**	**6-10**	**0-5**
Channel Flow Status	**16-20**	**11-15**	**6-10**	**0-5**
Tertiary-Riparian and Bank Structure				
Bank Vegetative Protection	**16-20**	**11-15**	**6-10**	**0-5**
Grazing or Other Disruptive Pressure	**16-20**	**11-15**	**6-10**	**0-5**
Riparian Vegetative Zone Width	**16-20**	**11-15**	**6-10**	**0-5**

*Habitat assessment parameters used were in agreement with Pennsylvania Department Of Environmental Protection's Unassessed Waters Program.

6.2.3 Results

Fish Analysis:

Rapid Bioassessment Protocol V (RBP V) (Plafkin et al. 1989) is perhaps the most common method for assessing fish communities by using an established Index of Biotic Integrity (IBI) similar to that described by Karr et al. (1986). Due to temporal differences in fish collection on Cobbs Creek by the Academy of Natural Sciences and the Office of Watersheds, the data provided by this sampling effort were used to assess the general condition of the resident fish population as a function of abundance and diversity. Trophic relationships, tolerance values and percent infestation were also used as a means to quantify the overall health of the fish assemblage. The taxonomic list and common names of fish collected in Cobbs Creek watershed are displayed as an attached appendix (Table 6-6). In addition, an identification list of fish species comprising habitat preference, reproductive strategies and feeding behaviors is also included in the appendix (Figure 6-7).

Species Richness And Diversity

Fish abundance, richness and diversity varied greatly among the five sampling locations (Table6-6).

Table 6-6 Species abundance, richness and diversity (H′) at the five sampling locations on Cobb Creek.

Species	DCIW-100	DCC-820	DCN-215	DCC-505	DCC-175
American Eel	0	15	19	6	8
Brown Bullhead	0	0	0	0	2
White Sucker	10	190	0	19	20
Banded Killifish	0	0	0	0	74
Mummichog	0	0	17	16	171
Redbreast Sunfish	0	0	3	0	31
Pumpkinseed	0	14	6	1	2
Common Shiner	0	415	21	52	1
Spottail Shiner	0	0	0	3	1
Swallowtail Shiner	0	5	549	145	49
Fathead Minnow	0	0	0	0	48
Green Sunfish	0	0	1	0	0
Blacknose Dace	86	651	333	59	48
Creek Chub	7	48	0	0	1
Total Number	**103**	**1338**	**949**	**301**	**456**
Total Taxa	**3**	**7**	**8**	**8**	**13**
Shannon-Weiner Diversity Index (H')	**0.56**	**1.23**	**0.97**	**1.44**	**1.85**

Cobbs Creek at Indian Run (DCIW-100) displayed the lowest fish density and species richness (n=3) (Figure 6-7). The dominant taxon at this location was Blacknose Dace, *Rhinichthys atratulus*, (83.0%), a generalist/insectivore feeder with the ability to withstand high levels of pollution. The Shannon Diversity Index (H') value at this location was 0.56, also indicating low species richness as well as low relative diversity (evenness).

Cobbs Creek at City Line Avenue (DCC-820) possessed the highest number of individuals, dominated by white sucker (*Catastomus commersoni*) (14.2%), and two cyprinid species, common shiner (*Luxilus cornutus*) (31.0%) and blacknose dace (*Rhinichthys atratulus*) (48.7%). In addition, the catadromous species, *Anguilla rostrata*, was also present at this location although means of migration from into the Cobbs Creek watershed appear to be impeded due to dam structures (e.g. Woodland Avenue).

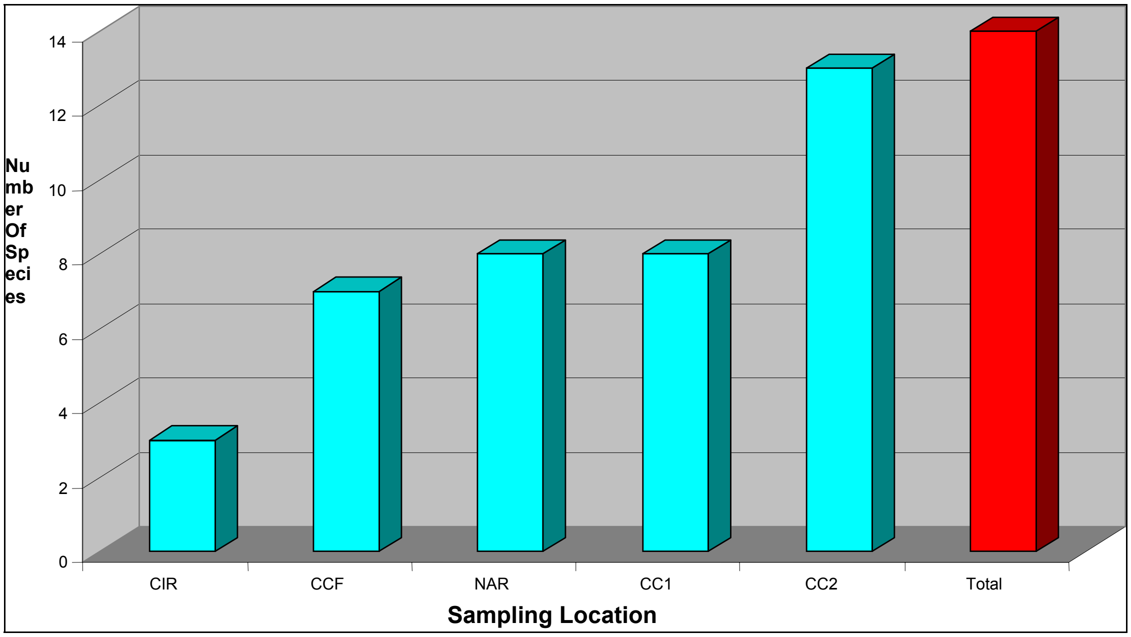


Figure 6-7 Number of species at each sampling location in Cobbs Creek.

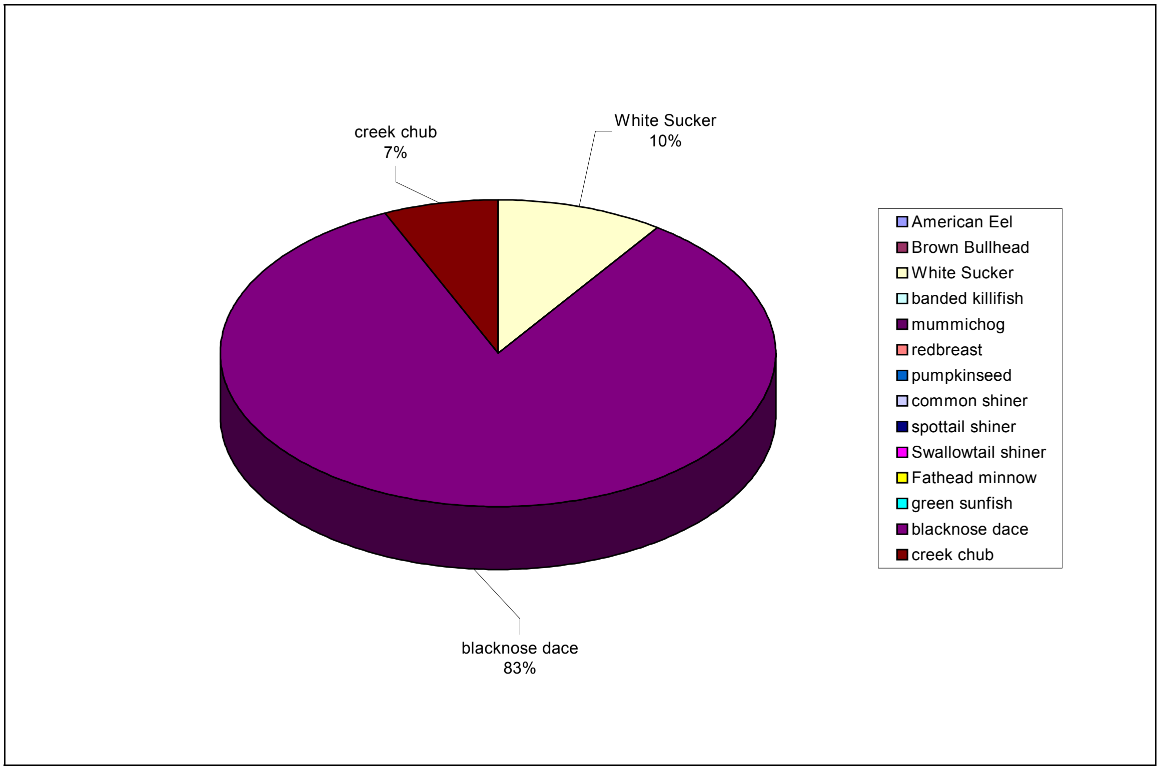


Figure 6-8 Species distribution (%) at West Branch Indian Run (DCIW-100)

Naylor's Run (DCN-215) and Cobbs Creek at Marshall Road (DCC-505) both contained a similar number of taxa (n=8) with dominant species being swallowtail shiner, *Notropis procne*, (57.9% and 48.2%, respectively) and blacknose dace, *R. atratulus* (35.1% and 19.6%, respectively). Common shiner, *Luxilus cornutus*, and mummichog, *Fundulus heteroclitus*, were also common species at these locations. Although Naylor's Run (DCN-215) station was higher in fish abundance (N=949) than Marshall Road (DCC-505) (N=301), the species diversity (H') value at DCC-505 was greater (1.44), indicating a more evenly distributed community.

Cobbs Creek at Woodland Avenue (DCC-175) displayed the highest species richness (n=13) and species diversity value (H'=1.855) of all the five monitoring locations. Dominant species at DCC-175 were *Fundulus diaphanus* (16.2%), *F. heteroclitus* (37.5%), *N. procne* (10.7%), *Pimephales promales* (10.5%) and *R. atratulus* (10.5%). While these metrics indicate a relatively diverse and evenly distributed community, four of the dominant species are classified as "pollution tolerant", capable of low oxygen concentrations and able to persist in physically and chemically degraded habitats.

Table 6-7 Species distribution (%) at all sites

SITES SPECIES	DCC-505	DCC-820	DCC-175	DCN-215	DCIW-100
American Eel	2.0	1.1	1.8	2.0	
Brown Bullhead			0.4		
White Sucker	6.3	14.2	4.4		
Banded Killish			16.2		10.0
Mummichog	5.3		37.5	1.8	
Redbreast			6.8	0.3	
Pumpkinseed	0.3	1.0	0.4	0.6	
Common shiner	17.3	31.0	0.2	2.2	
Swallowtail shinner	48.2	0.4	10.7	57.9	
Fathead minnow			10.5		
Green sunfish				0.1	
Blacknose dace	19.6	48.7	10.5	35.1	83.0
Creek chub		3.6	0.2		7.0
Spottail shinner	1.0				

Trophic Composition And Tolerance Designations

Functional feeding guilds for all five assessment sites are displayed in Table 6-8. Trophic designations (e.g. piscivore, invertivore, omnivore) of each taxon compiled in this report were obtained from literature by Barbour et al. (1999) and Halliwell et al. (1999). Results show that all sites are dominated by insectivores (80%-95%) with the exception of Cobbs Creek at Woodland Avenue (DCC-175) where the dominant functional feeding group is primarily generalist feeders (55.9%). In addition, the percent of piscivorous species at all locations is moderately low (1.1%-2.0%), with Indian Run (DCIW-100) containing no piscivorous species. This condition may be due to the lack of adequate habitat for large predatory species (e.g. deep pool systems).

Table 6-8 . Functional feeding guilds (%) at all sites

Functional Feeding Species	DCC-505	DCC-820	DCC-175	DCN-215	DCIW-100
Generalist Feeder	5.6	4.6	55.9	2.7	7
Insectivore	86.0	80.0	37.9	95.2	83.0
Omnivore	6.3	14.2	44.0	0.1	10.0
Piscivore	2.0	1.1	1.8	2.7	-

Tolerance values, expressed as the percentage of tolerant, intermediate and intolerant taxa, are shown in Figure 6-9. Fish assemblage at Indian Run (DCIW-100) showed the highest percentage (100%) of pollution tolerant species, consisting of three taxa (*Semotilus atromaculatus*, *Rhinichthys atratulus*, and *Catastomus commersoni*). Sites on Naylor's Run (DCN-215), Cobbs Creek at Marshall Avenue (DCC-505) and Cobbs Creek at Woodland Avenue (DCC-175) had similar percentages of moderately tolerant (58%-74%) and tolerant individuals (26%-42%). The percentage of pollution tolerant taxa at Cobbs Creek City Line (DCC-820) was substantially higher (66%) than the previously mentioned sites. More importantly, no sampling sites contained individuals classified as "pollution intolerant", indicating the probability of episodic periods of impaired water quality or habitat degradation.

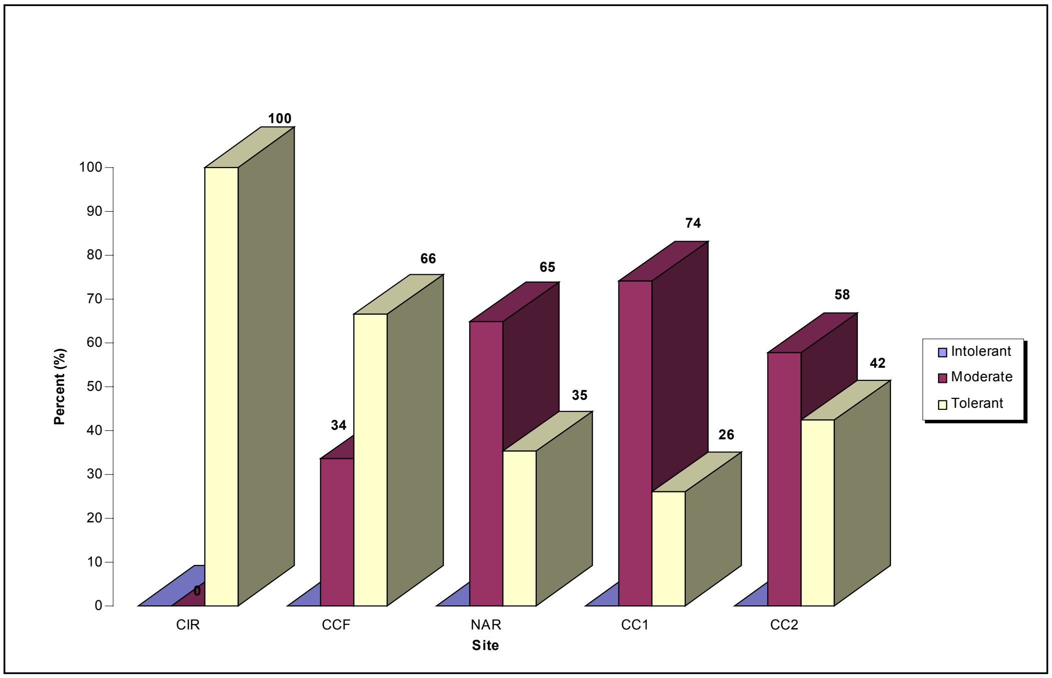


Figure 6-9 Fish tolerance levels at the five biomonitoring stations. Numbers indicate percentages in each tolerance category.

Disease and Parasite Abundance/Severity

Results from the study show significant differences in the amount of trematode infestation in both blacknose dace (R. atratulus) and white sucker (C. commersoni) between Cobbs Creek at City Line Avenue (DCC-820) and Cobbs Creek at Marshall Road (DCC-175) (p=0.0007 and p=0.0168, respectively) (Table6-9).

Table 6-9 ANOVA analysis of locational effects on trematode infestion in R. atratulus and C. commersoni shown as F statistics. Significance: *p<0.05, **p<0.01, and ***p<0.001.

Species	MS Effect	MS Error	F statistic
Blacknose Dace	8.533	0.581	14.688***
White Sucker	4.033	0.623	6.465*

Blacknose dace showed a higher abundance of trematode cysts at site DCC-175 (x=2.33 ± 0.72) when compared to site DCC-820 (x=1.27 ± 0.80) (Figure 3.15.). Similarly, severities of trematode cysts on white sucker at site DCC-175 were significantly higher than infestation rates at DCC-820 (x=1.87 ± 0.83 and x=1.13 ± 0.74, respectively).

Proportion of Introduced Species

Of the five sampling sites, Naylor's Run (DCN-215) and Cobbs Creek at Woodland Avenue (DCC-175) were the only sites that contained introduced/exotic species. These species were identified as green sunfish, *Lepomis cyanellus*, and fathead minnows, P*imephales promelas*. Although present, *L. cyanellus* and *P. promelas* at sites DCN-215 and DCC-175 were not dominant species within the community (0.001% and 0.105%, respectively).

Benthos

Scientific names and functional feeding groups of macroinvertebrates collected in Cobbs Creek watershed (11/10/99) are attached as an appendix. A master identification list of the macroinvertebrate community describing species specific attributes (e.g. life-history traits) and graphic representations of trophic designations are included in the appendix. Biological metrics calculated for the seven monitoring locations as well as the reference stations, French Creek and Broad Run, are also displayed in the Appendix .

DCC-110: (Cobbs Creek Mainstem, Philadelphia County):

The macroinvertebrate assemblage at DCC-110 received a total metric score of 6, representing 20.0% comparability to the reference conditions at French Creek and placing the benthos in the "moderately impaired" category (Tables 6-10 and 6-11). Samples collected in the 1999 survey were dominated by the filter-feeding caddisfly, Hydropsychidae. This dense filter-feeding assemblage appears to reflect the effects of moderate organic enrichment, and is indicative of an unbalanced community responding to an overabundance of a food resource---in this case Fine Particulate

Organic Matter (FPOM). The low abundance of scrapers relative to filtering collectors also corroborates that the FPOM has displaced periphyton as a food resource at DCC-110. Low taxa richness (56.3% comparability), an elevated Hilsenhoff metric (5.46) and the absence of modified EPT taxa (Hilsenhoff ≤ 3) indicate potentially episodic periods of poor water quality and/or habitat degradation.

DCC-110 received a total habitat assessment score of 109/240 and was the lowest habitat score received by a biomonitoring station during the 1999 survey. Total score reduction was mostly affected by low scores for epifaunal substrate, channel alteration, sediment deposition, frequency of riffles and riparian vegetative zone width. Stream reach characteristics included embedded riffle systems where 50%-75% of the gravel, cobble and boulder particles are surrounded by fine sediment. Well-defined pool systems were absent due to substantial sediment deposition throughout the stream reach.

Table 6-10 Metrics Used in Comparison of Cobbs Creek Stations to the Reference Sites.

Metric	DCC-110	DCC-455	DCC-865	DCN-185	DCIW-010	DCI-135	DCIW-185
Taxa Richness (%)(a)	56.3	100.0	93.8	72.2	72.2	88.9	55.6
Modified EPT Index (%) (a)	0	0	0	0	0	0	0
Modified Hilsenhoff (b)	2.93	3.78	4.02	3.64	3.04	3.44	3.42
Percent Dominant Taxa (b)	4.99	39.2	28.8	2.2	0.2	15.4	11.5
Percent Modified Mayflies ©	100	100	100	66.7	66.7	66.7	66.7

(a) Assessment Site/Reference Site.

(b) Assessment Site-Reference Site.

© Reference Site-Assessment Site.

Table 6-11 Biological Scoring and Condition Category of Each Assessment Site

Metric	DCC-110	DCC-455	DCC-865	DCN-185	DCIW-010	DCI-135	DCIW-185
Taxa Richness	**0**	**6**	**6**	**4**	**4**	**6**	**0**
Modified EPT Index	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Modified Hilsenhoff	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Percent Dominant Taxa	**6**	**0**	**0**	**6**	**6**	**4**	**4**
Percent Modified Mayflies	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Total	**6**	**6**	**6**	**10**	**10**	**10**	**4**
Percent Comparison	**20.0%**	**20.0%**	**20.0%**	**33.3%**	**33.3%**	**33.3%**	**13.3%**
Scoring Criteria	**Moderately Impaired**	**Moderately Impaired**	**Moderately Impaired**	**Moderately Impaired**	**Moderately Impaired**	**Moderately Impaired**	**Severely Impaired**

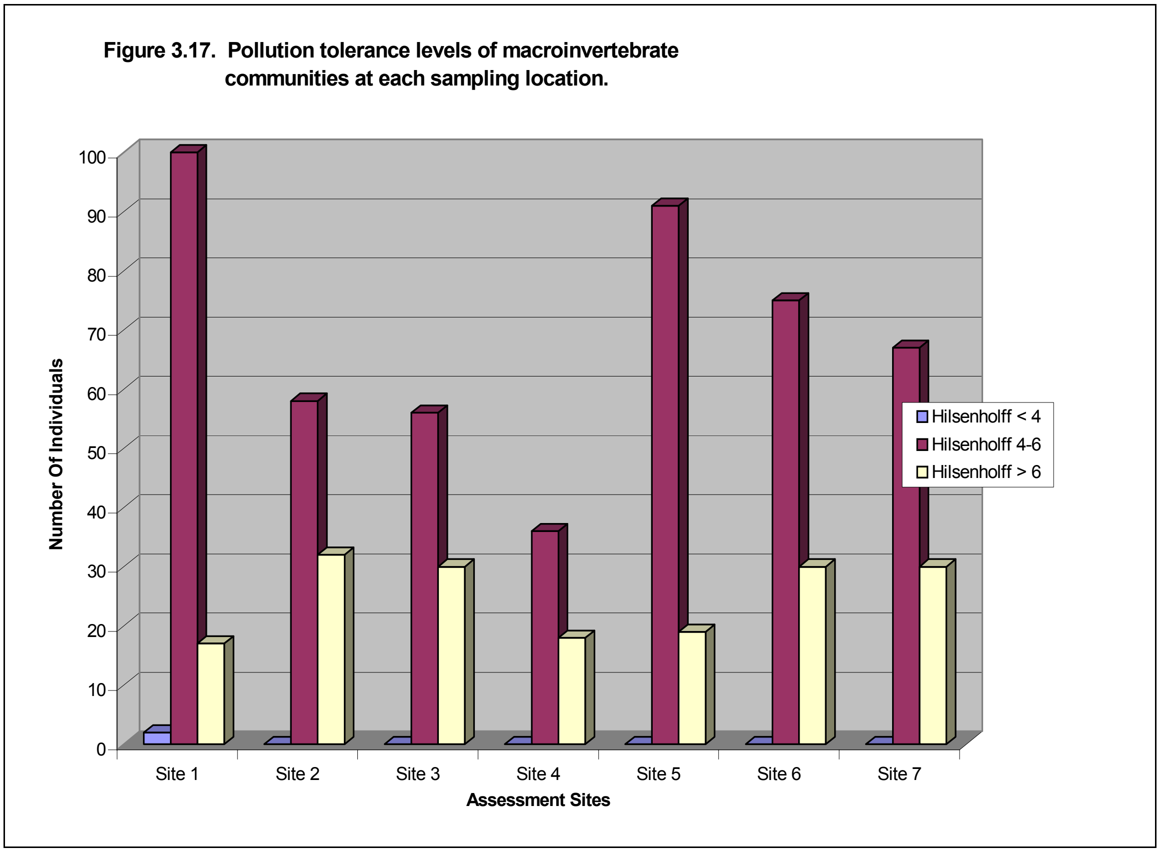


Figure 6.10 Pollution Tolerance Levels of Macroinvertebrate Communities

Table 6-12 Habitat Assessments of Each Biological Monitoring Station and Percent of Comparability to the Reference Sites.

Habitat Parameter	DCC-110	DCC-455	DCC-865	DCN-185	DCIW-010	DCI-135	DCIW-185
Instream Cover	10	11	15	11	12	14	11
Epifaunal Substrate	5	11	11	15	16	12	11
Embeddedness	8	9	12	5	10	11	9
Velocity/Depth	13	10	14	11	12	12	9
Channel Alteration	4	8	14	11	13	11	13
Sediment Deposition	5	16	15	11	7	15	13
Frequency Of Riffles	4	16	17	16	11	16	11
Channel Flow Status	14	6	12	10	15	6	14
Condition Of Banks	16	12	13	13	11	12	7
Bank Vegetation Protection	14	9	15	14	11	13	11
Grazing/Disruptive Pressure	12	6	16	8	10	6	7
Riparian Zone Width	4	2	12	5	5	2	2
Total	109	116	166	130	133	130	118
Percent Of Comparability (%)	60.22	64.09	91.71	74.71	76.44	74.71	67.82
Assessment Category	Partially Supporting	Partially Supporting	Comparable To Reference	Partially Supporting	Supporting	Partially Supporting	Partially Supporting

DCC-455: Cobbs Creek Mainstem and Naylor's Run Confluence (Philadelphia County):

DCC-455 received a biological scoring metric of 6 (20% comparability), placing the stream reach in the "moderately impaired" category, similar to that of DCC-110. Despite scoring high on the taxa richness metric (score: 6), all additional metrics received the lowest scores possible (score: 0). *Hydropsyche* sp. (n=20), *Cricotopus* sp. (n=14) and *Caecidotae* sp. (n=19) represented the three dominant taxa, all possessing Hilsenholff tolerance values ≥ 5. Similarly, the modified Hilsenholff score for DCC-455 was 6.31, indicating a tolerant macroinvertebrate assemblage. Functional feeding designations show a diverse trophic assemblage with filtering collectors and gathering collectors comprising a majority of the benthic community (34% and 31%, respectively). The absence of sensitive EPT taxa and modified mayflies also corresponds to the potential problems described at DCC-110.

The habitat assessment score at DCC-455 was 116/200, designating the site as "partially supporting" when compared to the reference station, French Creek (181/224). Reduction in habitat score at DCC-455 was due to low values for channel flow status, grazing or other disruptive pressure and riparian vegetative zone width. Riffle substrates were mostly exposed along with the decreased amount of water filling the stream channel. All additional scores, excluding sediment deposition (score: 16/20), ranged in the suboptimal to marginal categories.

DCC-865: Cobbs Creek Mainstem (Haverford Township, Delaware County):

The benthos assemblage at DCC-865 received a total metric score of 6, representing 20% comparability to "best attainable" conditions at French Creek. Dominant taxon at this sampling site was the net spinning caddisflies (*Hydropsyche* sp. and *Cheumatopsyche* sp.). The preponderance of hydropsychids (38% relative abundance) along with absence of a scraper population is similar to that of both DCC-110 and DCC-455, indicating the possibility of organic enrichment at this location. Also, the abundance of both filtering collectors (42%) and generalist feeders (16%) corroborates that FPOM is the dominant food resource in this area. DCC-865 received the highest Hilsenholff score (6.55) of all sites, indicating a moderately high pollution tolerant benthic community.

Despite being placed in the "moderately impaired" category for biological integrity, DCC-865 received the highest habitat assessment score (166/224) of all the seven sampling locations. High values were attributed to adequate instream cover, a well-defined channel with little evidence of accelerated sedimentation processes, ample vegetative cover along the banks and a substantial riparian buffer along the stream reach.

DCN-185: Naylor's Run (Upper Darby Township, Delaware County):

The macroinvertebrate assemblage at DCN-185 received a biological score of 10, representing 33.3% comparability to the reference station, Broad Run, and placing the benthic community in the "moderately impaired" category. Perhaps the most obvious problem associated with DCN-185 is the low abundance of macroinvertebrates collected and sorted at this location (n=54). The dominance of the hydropsychid caddisflies, categorized as filtering collectors (44%), high HBI score (6.28) and the lack of genera belonging to the Families Plecoptera, Trichoptera and Ephemeroptera are all indicators that Naylor's Run is biological impaired by physiochemical degradation along this reach.

In addition to benthic impairment, Naylor's Run received a total habitat score of 130/224, designating the site as "partially supporting" when compared to Broad Run. The reduction in habitat score is attributed to a heavily embedded substrate (score: 5/20) and the lack of riparian vegetation (score: 5/20). Despite having multiple riffle systems, all other metrics ranged in the suboptimal (11-15) and marginal (6-10) categories.

DCIW-010: Confluence of West Branch Indian Creek and East Branch Indian Creek (Philadelphia County):

DCIW-010 received a total biological score of 10 (33% comparability), placing the site in the "moderately impaired" category. The preponderance of Hydropsyche sp. and Cheumatopsyche sp. (48% relative abundance) at DCIW-010 is characteristic of a reach dominated by filtering collectors, indicating organic enrichment as a possible reason for the skewed community structure. Additional attributes of DCIW-010 are the absence of modified mayflies (Hilsenholff ≤ 3) and modified EPT taxa (Hilsenholff ≤ 3) and decreased ratio of shredder taxa to total taxa, all indicators of a biologically impaired stream reach.

The total habitat assessment score of DCIW-010 was 133/224, placing the stream reach in the "supporting" category. A decreased habitat score can be attributed to sediment deposition (score: 7) and riparian zone width (score: 5).

DCI-135: East Branch Indian Run (Lower Merion Township, Montgomery County):

DCI-135 benthos assemblage received a total metric score of 10, representing 33.3% comparability to "best attainable" conditions at Broad Run. In addition to the absence of modified mayflies and sensitive EPT taxa, the site is dominated by filtering collectors and gathering collectors (27% and 35%, respectively). A large proportion of shredder feeders (23%) represented by the genera *Cricotopus* sp. were present at the sampling site. Dominant taxa at the East Branch Indian Creek monitoring location were *Caecidotea* sp. (n=27), *Cricotopus* sp. (n=22) and Hydropsyche sp. (n=17).

East Branch of Indian Creek received a total habitat assessment score of 130/224, designating the site as "partially supporting" when compared to Broad Run. The decrease in overall habitat score can be attributed to channel flow status (score: 6) where a majority of flow composed approximately 50% of the channel, and the lack of a riparian zone (score: 2) where vegetation had been disturbed through anthropogenic influence (e.g. grass cutting, tree clearing).

DCIW-185: West Branch Indian Creek (Lower Merion Township, Montgomery County):

The total biological score at DCIW-185 was 4, representing 13.3% comparability to the reference site and designating the site as "severely impaired". All metrics scored poorly (score: 0) with the exception of percent dominant taxa (score: 4). Of the total amount of individuals collected (n=97), 66% belonged to the family *Hydropsychidae*, a pollution tolerant taxa indicative of possible organic enrichment. Similar to the other monitoring locations, West Branch of Indian Creek did not contain any modified mayflies, nor did the site include any modified EPT taxa. The ratio of scrapers to filtering collectors was also low, indicating an unbalanced community represented by pollution tolerant taxa (modified HBI=6.06).

When compared to the reference site, Broad Run, DCIW-185 received a total habitat score of 118/224 (67.82% comparability). Overall score reduction was attributed to the degraded condition of both banks and the lack of a riparian buffer. Habitat scores corroborated with the biological criteria, indicating an impaired stream reach due to anthropogenic stressors (e.g. bank erosion due to clear cutting).

6.2.3 Summary of Biology and Habitat by Reach

Upper Cobbs Creek

Seven sampling sites represent the headwaters and upper reaches of Cobbs Creek. Site DCI-135 is on Indian Creek main stem, 1.35 miles upstream of the confluence with Cobbs Creek. DCIW-185, DCIW-100, and DCIW-010 are located along Indian Creek West Branch. DCC-865, DCC-820, and DCC-770 are on the main stem of Cobbs Creek. These sites are all above the CSO-impacted area.

All of the Cobbs Creek subwatershed is considered unattained by PADEP, indicating that current conditions do not support designated uses. Additional RBP III benthic assessments at three sites score between 20% and 33% of the reference stream score and are classified as moderately impaired. The results of RBP V assessments indicate that fish species richness and diversity at DCIW-100 are the lowest of the sites studied in the Cobbs Creek subwatershed; however, it is important to consider the effect of stream size when evaluating these parameters. In addition, no piscivores were found at this site. Species richness and diversity at DCC-820 were similar to conditions found farther downstream on Cobbs Creek. All species found at DCIW-100 are considered pollution tolerant, while 66% of species found at DCC-820 are considered pollution tolerant and the remainder are considered moderately tolerant. Habitat scores ranged from 68% (DCIW-185, classified as partially supporting) to 92% (DCC-865, classified as comparable to the reference stream) of reference stream conditions.

Lower Cobbs Creek

Five sampling sites represent lower Cobbs Creek. DCN-215 is on Naylors Creek, 2.15 miles upstream of the confluence with Cobbs Creek. The remaining sites are on Cobbs Creek: DCC-505, DCC-455, DCC-175, and DCC-110. These sites receive both stormwater and CSO discharges.

All portions of the Cobbs Creek subwatershed are considered unattained by PADEP. Additional RBP III benthic assessments at two sites score only 20% of the reference stream score and are classified as moderately to severely impaired. The results of RBP V assessments indicate that fish species richness and diversity are greater in Lower Cobbs than higher in the watershed; however, the increase in stream size should be considered when comparing these numbers. A smaller percentage of highly pollution-tolerant species are found at lower Cobbs sites compared to sites located further upstream; however, no pollution-intolerant species are found. Habitat scores at the two lower Cobbs study sites are between 60% and 64% of the reference stream score and are classified as partially supporting.

Upper Darby Creek

The headwaters of Darby Creek are represented by data taken by PADEP and ANS at six sites upstream of PA Route 3 and numbered STA01 (farthest upstream) through STA06 (farthest downstream). These sites are not impacted by known CSOs.

Darby Creek and its tributaries north of Route 3 are classified as attained by PADEP. The health of the benthic ecosystem includes the full range from poor to very good depending on the site. Criteria based on fish range from fair to good. Some erosion was observed at all sites, and erosion generally increases with distance downstream.

Lower Darby Creek

PADEP/ANS sampling sites were STA07, just downstream of PA Route 3 in Delaware County, through STA10, near PWD sampling site DCD-765. These sites are classified as unattained by PADEP. The health of the benthic ecosystem is rated as poor at the three sites studied, and the health of the fishery is rated fair at the three sites studied. Observed erosion is generally greater at these sites than at the sites located in the upper portions of Darby Creek and its headwaters.

Tinicum Area

Data availability is limited in the Tinicum area. The non-tidal portions of this subwatershed are considered unattained by PADEP.

Section 7 Characterization of Wetlands

The locations and condition of existing wetlands have been extensively characterized in the Cobbs Creek watershed. Opportunities for enhancement of existing wetlands have been identified. Opportunities for creation of new wetlands, for both treatment and habitat, have been identified. The "Cobbs Creek Watershed Wetland Analysis", scheduled for release in 2004, documents the results of these studies.

Section 8 Characterization of Fluvial Geomorphology

The fluvial geomorphology (shape and condition of stream channels and banks) of Cobbs Creek has been extensively studied. The results of the study are documented in “Geomorphologic Survey – Level II: Guiding Principles for Fluvial Geomorphologic Restoration”, released in 2003.

Section 9 Active and Potential Sources of Water Quality Constituents

9.1 Model Description and Data Sources

Introduction

This subsection summarizes the results of a preliminary estimate of loading rates of various pollutants to Darby Creek, Cobbs Creek, and tributaries. The waters in the drainage area receive point source discharges including municipal wastewater, CSO and other urban and suburban stormwater, sanitary sewer overflows, and limited industrial storm, process, and cooling waters. Combined sewers service approximately 6% of the watershed. Nonpoint sources in the basin include atmospheric deposition, overland runoff from urban and suburban areas, and individual on-lot domestic sewage systems discharging through shallow groundwater. The results were obtained using the detailed Storm Water Management Model (SWMM) in the Cobbs Creek subwatershed and the simpler Watershed Management Model (WMM) in the Darby and Tinicum subwatersheds.

The Storm Water Management Model (SWMM)

The U.S. EPA's Storm Water Management Model (SWMM) was used to develop the watershed-scale model for Cobbs Creek. The major components of the SWMM model used in the development of the Cobbs Creek watershed model were the RUNOFF and EXTRAN modules.

The RUNOFF module was developed to simulate both the quantity and quality of runoff in a drainage basin and the routing of flows and contaminants to sewers or receiving body. The program can accept an arbitrary precipitation (rainfall or snowfall) hyetograph and performs a step by step accounting of snowmelt, infiltration losses in pervious areas, surface detention, overland flow, channel flow, and water quality constituents leading to the calculation of one or more hydrographs and/or pollutographs at a certain geographic point such as a sewer inlet. The driving force of the RUNOFF module is precipitation, which may be a continuous record, single measured event, or artificial design event.

The EXTRAN module was developed to simulate hydraulic flow routing for open channel and/or closed conduit systems. The EXTRAN module receives hydrograph inputs at specific nodal locations by interface file transfer from an upstream module (e.g. the RUNOFF module) and/or by direct user input. The module performs dynamic routing of stormwater flows through storm drainage systems and receiving streams.

The SWMM model development and calibration process is discussed in detail in the Cobbs Creek SWMM Model Report.

The Watershed Management Model (WMM)

The Watershed Management Model provides an overall framework for estimating pollutant loads within a watershed and can be used as a screening level model in the preliminary stages of total maximum daily load (TMDL) development. WMM was originally developed to assess watershed management plans but also works well as a screening level load estimator. WMM uses land use categories and associated event mean concentrations (EMCs) to determine the non-point source load contribution within individual watershed planning areas. The model also includes estimates for tabulated municipal and industrial process water discharges. WMM was used to develop screening-level loads for the Darby and Tinicum portions of the Darby-Cobbs watershed.

WMM uses land use type, imperviousness, and event mean concentrations to generate seasonal and annual runoff flows and pollutant loads. The model also includes annual loads for point sources, CSOs, baseflow, and septic systems. WMM was refined (version 4.3.1) through EPA's Rouge River Wet Weather Demonstration Project and by the City of Westminster, Colorado and includes a user-friendly graphical interface built on an EXCEL® data structure and macro program. Because EPA funded the development of WMM, the Rouge River version is available in the public domain. WMM 4.3.1 for EXCEL® was used for this application because of the greater flexibility in assigning geographically distributed baseflows and baseflow concentrations.

WMM's capabilities, appropriate to this phase of the Darby and Cobbs Creeks Watershed Study, include:

- Estimates stormwater runoff pollution loads for nutrients (total phosphorus; total kjeldahl nitrogen, including organic nitrogen and ammonia; and total nitrite and nitrate), metals (cadmium, copper, lead, and zinc), oxygen demand, and sediment based on EMCs, land use, percent imperviousness, and annual rainfall.
- Estimates pollutant loads from stream baseflow.
- Estimates pollution loads from failing septic system.
- Applies delivery ratio to account for reduction in runoff pollution load due to uptake or removal in stream courses.

Data Needs and Sources

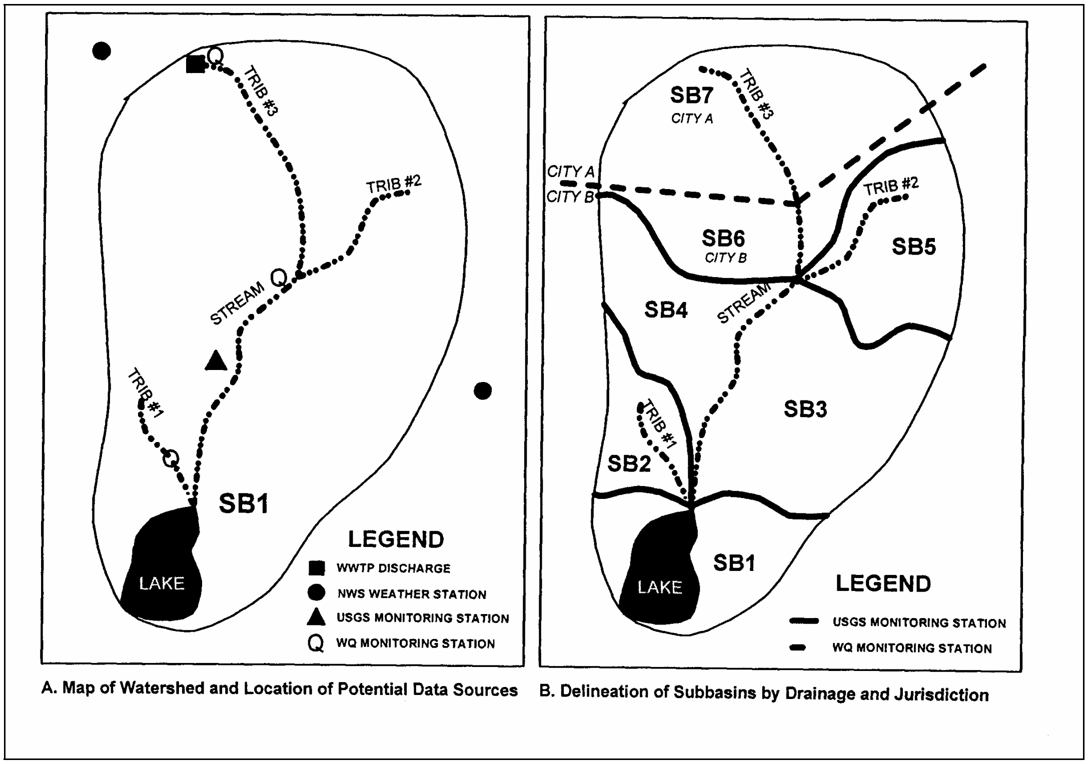
Table 9.1 presents the data requirements for screening-level applications of the Watershed Management Model and the sources of data used to develop the Darby and Cobbs Creeks Phase I load assessment model. A more detailed description of data used to build the SWMM model may be found in the associated report, "Watershed Scale Model Development".

Table 9.1 Data Requirements for WMM

Data Requirement	Use	Source for Darby-Cobbs
Subsheds	USGS topographic subwatersheds for Darby and Tinicum; topographic subwatersheds for separate-sewered areas in Cobbs; sewersheds for combined-sewered areas in Cobbs	Darby and Tinicum: USGS Cobbs separate-sewered areas: generated from elevation data Cobbs combined-sewered areas: PWD
Land Use	Used to define imperviousness and assign EMCs	Delaware Valley Regional Planning Commission
Imperviousness	Determines runoff volume in WMM; one factor affecting runoff volume in SWMM	Primarily Land Use. Population Density for Residential Land Uses (Manning, 1977 and Stankowski, 1974)
Event Mean Concentrations (EMCs)	Used to estimate pollutant loads from runoff	Literature values for stormwater concentrations; PWD treatment plant influent for sanitary concentrations
Baseflows	Used to estimate loads from background concentrations	USGS/PWD Cooperative Program
Other Loads	Point sources, CSOs, septic tanks	NPDES permits, CSO program, U.S. Census Bureau

Planning Areas/Units (Subsheds)

Delineation of subsheds in the SWMM model is discussed in detail in the associated report, "Watershed Scale Model Development". For WMM-based load estimates, the planning areas, or model units, for which WMM was compiled, are jurisdictional watersheds. Figure 9.1 presents WMM's conceptual framework for drainage area and sub-basin (model unit) delineation. USGS delineated sub-watersheds for streams tributary to Darby Creek were intersected with municipal jurisdictional boundaries to form the planning-level sub-areas. The USGS watersheds and the municipalities located wholly or partially within the watershed boundaries are shown in Figure 9.2.



A. Map of Watershed and Location of Potential Data Sources B. Delineation of Subbasins by Drainage and Jurisdiction

Figure 9.1 Conceptual Framework for Delineation of Model Units

The USGS delineated sub-basins and municipal boundaries were discussed in Section 2. The planning areas, also known as model units, are the intersection of the municipal boundaries and the watershed boundaries. These areas are identified by a sub-basin identifier, such as SB1, SB2, etc. The use of these planning units allows for loads to be summarized by sub-watershed and municipality and allows the city to determine its relative load contribution in comparison with other municipalities.

The planning areas or jurisdictional sub-watersheds range in size from less than 1 acre to greater than 3,000 acres. The mean size of the planning areas is about 430 acres with a median size of about 216 acres. The largest planning area is located in the Darby Creek Watershed on Darby Creek Branch D and Easttown Township, Chester County. The smallest basin is located in the southwestern most part of Sharon Hill Borough in Delaware County and drains a small portion of the Muckinipattis Creek A sub-basin. Eighty percent of the planning area is between 20 and 1000 acres.

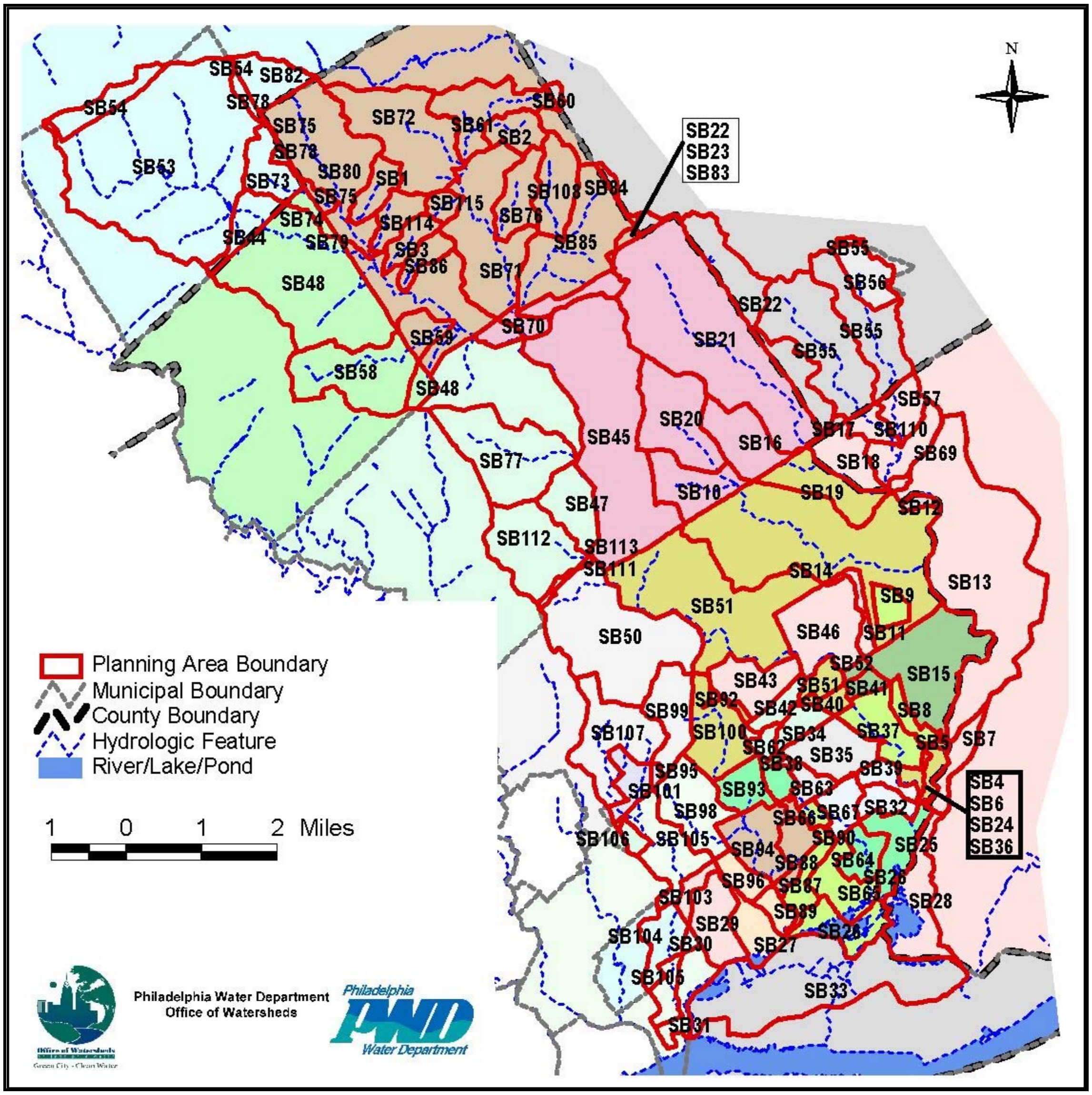


Figure 9.2 Planning Areas or Model Units

Land Use

Data used to define the land uses by planning area were compiled by the Delaware Valley Regional Planning Commission (DVRPC) and were discussed in detail in Section 2.

Land Surface Imperviousness and Runoff Volume

Estimated Imperviousness in the SWMM model is discussed in detail in the associated report, "Watershed Scale Model Development". For the WMM model, runoff coefficients used in the model were calculated from percent imperviousness values based on land use. Impervious area was determined for non-residential areas based on generally accepted percent imperviousness reported in the literature for various land use categories (Smullen, Hartigan, and Grizzard, 1978). For residential areas, percent imperviousness was based on population density. Generally, residential areas have much greater variability in percent imperviousness, which has been correlated with population density (Manning, 1987; Stankowski, 1974). Nine residential sub-categories were developed from the DVRPC land use data, based on a histogram of block group population density. The histogram of percent imperviousness based upon population density is shown in Figure 9.3. The categories were distributed so that each contained approximately the same number of census blocks. Table 9.2 presents the percent imperviousness associated with each land use category. Note that the 100 percent "impervious" assigned to water/wetlands simply means that all the water that falls on the waterbody, enters the water body, a slightly different definition than the imperviousness related to other land use.

Table 9.2 WMM Imperviousness by Land Use Category

Land Use	Imperviousness (%)
Agricultural/Pasture	5.0
Cemetery	5.0
Commercial	80.0
Golf Course	5.0
Transportation	30.0
Industrial	80.0
Regional Park	5.0
Residential 1	18.2
Residential 2	25.9
Residential 3	33.8
Residential 4	39.3
Residential 5	44.1
Residential 6	49.6
Residential 7	57.9
Residential 8	75.4
Residential 9	90.1
Urban Recreation	60.0
Vacant	5.0
Water/Wetlands	100.0
Wooded	5.0

WMM calculates annual runoff volumes for pervious and impervious areas in each land use category by multiplying the average annual rainfall volume by a runoff coefficient. Runoff coefficients can be adjusted to reflect local conditions and land uses. For impervious surfaces, a runoff coefficient of 0.95 is typically used (thus, 95 percent of the rainfall over an impervious surface is directly converted to runoff). The pervious area runoff coefficient typically used is 0.20. An important distinction about impervious areas is that not all runoff from impervious areas flows directly to a drainage system or river and is often routed to lawns or dry wells. Runoff that enters a drainage system or river is from "directly connected impervious areas (DCIA)". The DCIA percentage typically is 50% or more of the total impervious area percentage.

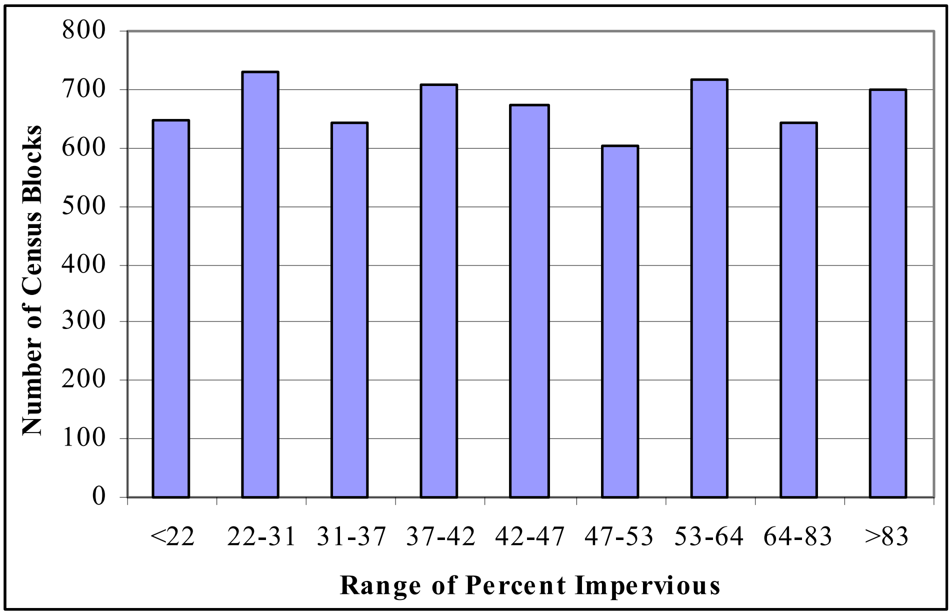


Figure 9.3 Distribution of Impervious Cover among Census Blocks

The total average annual surface runoff from land use, L, is calculated by weighting the impervious and pervious area runoff factors as follows:

$$R_L = [C_P + (C_I - C_P) * IMP_L] * I$$

where:

R_L = total average annual surface runoff from land use L (in/yr);
C_P = pervious area runoff coefficient;
C_I = impervious area runoff coefficient;
IMP_L = fractional imperviousness of land use L; and
I = long-term average annual precipitation (in/yr).

Total runoff from the watershed is the area-weighted sum of R_L for all land uses.

Event Mean Concentrations (EMCs)

Event Mean Concentrations (EMCs) are defined as the total mass load of a chemical parameter yielded from a site during a storm divided by the total runoff water volume discharged during the storm. The EMC is widely used as the primary statistic for evaluations of stormwater quality data and as the stormwater pollutant loading factor in analyses of pollutant loads to receiving waters.

Use of EMCs in Loading Analyses. Nonpoint source pollution loading analyses typically consist of applying land use- specific stormwater pollution loading factors to land use scenarios in the watershed under study. Loading rates of urban stormwater pollution (nutrients, metals, BOD, fecal coliform) are determined by the quantity of runoff from the land surface. Thus, they are closely related to the imperviousness of the land use type. Applying EMCs to calculated runoff volumes provides reasonable estimates of nonpoint source pollutant loadings, especially from urban areas.

Runoff volumes are computed for each land use category based on percent imperviousness of the land use and annual rainfall. These runoff volumes are multiplied by the land use specific EMC load factor (mg/L) to obtain nonpoint source pollutant loads by land use category. This analysis can be performed on a subarea or watershed-wide basis, and the results can be used to perform load allocation studies, to evaluate pollution control alternatives, or as input into a riverine water quality model.

The model calculates pollutant loads based upon nonpoint source pollution loading factors (expressed as lb/acre/year) that vary by land use and the percent imperviousness associated with each land use. The pollution loading factor M_L is computed for each land use L by the following equation:

$$M_L = EMC_L * R_L * K$$

where:

M_L = loading factor for land use L (lb/acre/year)

EMC_L = event mean concentration of runoff from land use L (mg/L); EMCs may vary by land use and pollutant

R_L = total average annual surface runoff from land use L (in/yr); and

K = 0.2266, a unit conversion constant.

By multiplying the pollutant loading factor by the acreage per land use and summing for all land uses, the total annual pollution load from a sub-basin can be computed. The EMC coverage is typically not changed for various land use scenarios within a given study watershed.

History and Sources of EMCs. Once point source discharges from treatment plants and industrial facilities were addressed in the 1970s and 1980s, more attention was focused on stormwater runoff from urban areas as a source of water quality degradation. As pollution from stormwater and urban drainage began to be investigated, studies focused on the types of pollution and methods to reduce the loads. However, these investigations did not consider the achievable level of improvement of receiving water bodies with the mitigation of stormwater pollution. In addition, many research studies concluded that additional and more comprehensive information was needed to make such assessments. This need led to the development of the Nationwide Urban Runoff Program, also known as NURP.

The goals of NURP were to develop and provide information to local decision makers, the States, EPA, and other parties for use in assessing the impacts of stormwater and urban runoff on water quality. The information collected also was intended to aid in the development of water quality management plans and provide a foundation for local, State and Federal policy decision making about water quality issues.

The NURP studies investigated 10 standard water quality constituents to characterize urban runoff. As a result of data collected through the NURP program, EMCs for these and other pollutants were developed from over 2,300 station-storms at more than 81 urban sites located in 28 different metropolitan areas. These studies greatly increased the knowledge of the characteristics of urban runoff, its effects upon the designated uses of receiving water bodies, and the performance efficiencies of various control measures. Pertinent conclusions from the NURP Program include:

- The variance of the EMCs, when data from sites are grouped by land use type or geographic region, is so great that differences in measures of central tendency among groups are not statistically significant.

- Statistically, the entire sample of EMCs and the medians of all EMCs among sites are log-normally distributed.

EMCs often are used in screening models such as WMM. The pollutant loads (L_i) are estimated as the product of the area of urban land (A_U), the rainfall-runoff depth as estimated by a modified rational formula approach (d_r), and a constant pollutant concentration (C_i), usually estimated from the EMCs reported by NURP (i.e., $L_i = C_i A_u d_r$).

Since the conclusion of the NURP Program in the 1980's, additional urban runoff quality monitoring data has been collected. One large effort conducted by the United States Geological Survey resulted in the collection of urban runoff data for over 1,100 station-storms at 97 urban sites in 21 metropolitan areas. Additionally, EPA required many major cities to collect urban runoff quality data as part of the application requirements for stormwater discharge permits under the National Pollutant Discharge Elimination System (NPDES). Data from 800 station-storms from 30 cities was gathered and incorporated into a database by CDM. CDM analyzed the data collected from NURP, USGS, and NPDES to assess if additional EMC observations (more degrees of freedom) would uncover statistically significant differences in EMCs among various land uses. While the resulting EMCs from the combined data sets did not indicate statistical differences in water quality among land uses, the pooled EMCs were significantly different than the NURP EMCs for several parameters (e.g., TSS, Cu, and Pb) and would produce different loading rates for urban areas. Table 9.3 indicates the EMCs used in the Darby and Cobbs Creeks Watershed Study and the source of each EMC value.

Table 9.3 Event Mean Concentrations

	Mean EMCs, mg/L											Source (Equivalent Category)
Land Use	BOD	COD	TSS	TP	DP	TKN	NO2+NO3	Pb	Cu	Zn	Fecal	
Agriculture	14.1	40.0	70.0	0.121	0.026	0.965	0.543	0.0300	0.0135	0.195	30000	EPA 1982 Chesapeake Bay Program
Commercial	14.1	52.8	78.4	0.315	0.129	1.73	0.658	0.0675	0.0135	0.162	30000	Smullen, J. T., et al. 1999
Industrial	14.1	52.8	78.4	0.315	0.129	1.73	0.658	0.0675	0.0135	0.162	30000	Smullen, J. T., et al. 1999
Transportation	24.0	103	141	0.430	0.129	1.82	0.830	0.5270	0.052	0.367	30000	FHA, 1990.
Water (Atmospheric Input)	1	1	1	0.064	0.02	1.022	0.571	0.00266	0.0022	0.0652	1	EPA 1982 Chesapeake Bay Program
Residential 1	14.1	52.8	78.4	0.315	0.129	1.73	0.658	0.0675	0.0135	0.162	30000	Smullen, J. T., et al. 1999
Residential 2	14.1	52.8	78.4	0.315	0.129	1.73	0.658	0.0675	0.0135	0.162	30000	Smullen, J. T., et al. 1999
Residential 3	14.1	52.8	78.4	0.315	0.129	1.73	0.658	0.0675	0.0135	0.162	30000	Smullen, J. T., et al. 1999
Residential 4	14.1	52.8	78.4	0.315	0.129	1.73	0.658	0.0675	0.0135	0.162	30000	Smullen, J. T., et al. 1999
Residential 5	14.1	52.8	78.4	0.315	0.129	1.73	0.658	0.0675	0.0135	0.162	30000	Smullen, J. T., et al. 1999
Residential 6	14.1	52.8	78.4	0.315	0.129	1.73	0.658	0.0675	0.0135	0.162	30000	Smullen, J. T., et al. 1999
Residential 7	14.1	52.8	78.4	0.315	0.129	1.73	0.658	0.0675	0.0135	0.162	30000	Smullen, J. T., et al. 1999
Residential 8	14.1	52.8	78.4	0.315	0.129	1.73	0.658	0.0675	0.0135	0.162	30000	Smullen, J. T., et al. 1999
Residential 9	14.1	52.8	78.4	0.315	0.129	1.73	0.658	0.0675	0.0135	0.162	30000	Smullen, J. T., et al. 1999
Wooded	14.1	52.8	40.5	0.145	0.129	0.505	0.245	0.0675	0.0135	0.162	30000	EPA 1982 Chesapeake Bay Program
Parks	14.1	52.8	78.4	0.145	0.129	3.19	1.0100	0.0675	0.0135	0.162	30000	EPA 1982 Chesapeake Bay Program
Cemetery	14.1	52.8	407	0.75	0.100	3.19	1.0100	0.0675	0.0135	0.162	30000	EPA 1982 Chesapeake Bay Program
Urban Recreation	2.00	52.8	60	0.188	0.100	3.19	1.0100	0.0675	0.0135	0.162	30000	EPA 1982 Chesapeake Bay Program
Vacant	2.00	52.8	60	0.188	0.100	3.19	1.0100	0.0675	0.0135	0.162	30000	EPA 1982 Chesapeake Bay Program
Golf Courses	14.1	52.8	407	0.75	0.100	3.19	1.0100	0.0675	0.0135	0.162	30000	EPA 1982 Chesapeake Bay Program

Note: All metals data are from Smullen (1999), except Highway. Atmospheric contributions are included in these values. The EMC for fecal coliform is based on NURP data as reported in NOAA (1987).

Baseflows

Most streams exhibit dry weather flow due to groundwater infiltration. As discussed in Section 4, baseflows for the individual planning areas were determined using USGS streamflow gauging data. To account for baseflow discharges as part of the average annual flow volume discharged from a watershed, an estimate of baseflow rate and quality is included in WMM. Concentrations of various constituents in baseflow are based on dry weather monitoring data.

Baseflow due to groundwater inflow is the main component of most streams in dry weather. Baseflow slowly increases and decreases with the elevation of the shallow aquifer water table. In wet weather, a stormwater runoff component is added to the baseflow. Estimation and comparison of these two components can provide insights into the relationship between land use and hydrology in urbanized and more natural systems. For a more detailed explanation of the baseflow separation techniques used see Section 4.3.

Constituent Source Types

For a watershed or TMDL study, an inventory of pollutant sources to the receiving water bodies must be compiled. The various types of sources usually considered are listed below. Note that urban stormwater runoff has some attributes of both point and nonpoint sources.

- Point (industrial and municipal dischargers, CSOs, SSOs);
- Nonpoint (stormwater, urban drainage, leaking septic systems);
- Background (instream, baseflow); and
- Atmospheric.

Municipal and Industrial Process Water Discharges. A file review of NPDES permits and Discharge Monitoring Reports (DMRs) for permitted dischargers within the Darby-Cobbs Creeks Watershed was performed at the Pennsylvania Department of Environment Protection in Conshohocken, PA. Information regarding site location, flow rates, and pollutant concentrations was gathered. Table 9.4 presents the list of dischargers and the information found for each point source.

Combined Sewer Overflows (CSOs). In many cities throughout the United States, stormwater runoff and sanitary wastewater are collected in the same sewer (a combined sewer). In dry-weather conditions, all flows are conveyed to and treated at a local or regional wastewater treatment plant. In wet-weather conditions, the capacity of the combined sewer system can be exceeded and discharges of mixed sanitary and stormwater then occur to receiving waters. The fraction of sanitary sewage in discharges varies from storm to storm, but is typically on the order of 10% over the long term, while the remaining 90% is untreated stormwater. For constituents where sanitary sewage and untreated stormwater concentrations are the same order of magnitude (e.g., TSS, nutrients), concentrations in CSO are similar or slightly higher compared to stormwater. For constituents where sanitary concentrations are typically lower (e.g., metals such as Pb, Cu, Zn), concentrations in CSO are slightly lower than in untreated stormwater. For bacteria and other pathogens, concentrations in CSO are an order of magnitude or higher than those found in stormwater.

Sanitary Sewer Overflows (SSOs). SSOs result in discharges of untreated wastewater that can affect stream quality and occasionally basements and city streets. The USEPA. has found that SSOs represent a significant health and environmental threat in areas where they occur frequently. Frequent SSOs may indicate that the capacity of the collection system is insufficient to convey the flows introduced or that the system is in need of maintenance or repair. Potential causes of excess flow include infiltration and inflow, illegal connections, population growth, and under-design. Problems requiring maintenance or repair may include broken or cracked pipes, tree roots, poor connections, and settling. Proper maintenance can help prevent problems or identify them before they become extremely costly to repair (USEPA, 2000).

Sanitary Sewer Overflows (SSOs) are a known source of bacterial and other pollution to the Darby and Cobbs Creeks watershed. Currently, no inventory of SSOs exists for the area within the four counties that contain the Darby and Cobbs Creeks Watershed. Since the data collection effort required to obtain SSO load information was beyond the scope of this screening-level study, SSO loads were not considered part of this study. An SSO assessment methodology will be implemented as part of the Phase II efforts.

Stormwater and Urban Drainage. Stormwater from areas with separate storm sewers contributes to water body impairment in highly urbanized, impervious catchments. Pollutants most frequently associated with stormwater include sediment, nutrients, bacteria, oxygen demanding substances, oil and grease, heavy metals, other toxic chemicals, and floatables. The primary sources of these pollutants include automobiles, roadways (pavement, bridges), housekeeping and landscaping practices, industrial activities, construction, non-storm connections to drainage systems, accidental spills and illegal dumping.

Septic Tanks. The number of septic tanks in Darby and Cobbs Creeks Watershed planning areas was estimated using 1990 Census data on population and housing. Comparison of water-only billed accounts with septic tank counts for the City of Philadelphia indicated a large discrepancy in the number of housing units with septic tanks. The 1990 census data estimated that 205 households were served by septic tanks in the Philadelphia portion of the watershed. However, a review of water-only accounts by the Water Department indicated that only 3 households within the City and the Cobbs watershed have septic tank or on-lot sewage disposal systems.

County agencies for Delaware, Montgomery, and Chester Counties were consulted about septic tank inventories/information in their areas. However, compilations of septic tank and on-lot sewer systems have not been completed to date. Detailed assessment of individual municipalities for septic tank and on-lot sewage disposal inventories and/or permits was beyond the scope of the current phase of this study.

Atmospheric Sources. Pollutants from atmospheric deposition on land surfaces are considered to be included in the calculations for the stormwater runoff. Direct deposition on water surfaces also is included in these calculations by the use of a water surface land use type. Specifically, precipitation falling on the water surface land use was assigned EMCs of nutrients and metals derived from rainfall data. For this study, the water surface EMCs were taken from the Chesapeake Bay Program literature (EPA, 1982).

Table 9.4 Active Point Sources Permitted Under NPDES

PA NPDES ID.	Site Name	Available Data
PA0056839	Sun Oil Company	Benzene, Total BTEX, Ethylbenzene, Toluene, Total Xylene, flow volume, and pH.
PA0011541	Sun Oil Company	Oil, Grease, Total Organic Carbon, flow volume, and pH.
PA0056685	SEPTA Victory Terminal	No water quality or flow data available.
PA0056642	Meenan Oil Company	Permitted discharge levels.
PA0052752	Mobil Oil Company	Benzene, Toluene, Xylene, and flow. Source removed in 1996.
PA0013323	Boeing Defense and Space Group	TDS, TSS, Oil and Grease, CN, Ag, Cd, Cr, Cu, Ni, Pb, Zn, and flow.
PA0028380	Tinicum Township Sewerage Authority	Settled solids, suspended solids, BOD, Chlorine residual, Fecal Coliform, pH and flow.
PA0057002	Township of Haverford Public Works	TSS, TDS, Mn, Mg, Color, Total Fe, Dissolved Fe, Barium, Specific Conductance, pH and flow.

9.2 Results: Estimated Annual Constituent Loads for the Cobbs Creek Subwatershed

Figures 9.4 through 9.12 show estimated loading rates for stormwater runoff and CSO. Table 9.5 breaks load estimates into two geographic regions, upper and lower Cobbs. The loads are estimates of the total input to the stream system. For example, the surface runoff listed for lower Cobbs (an area serviced partially by combined sewers) is relatively low because it does not include the volume that is captured, treated, and discharged outside the system. With some exceptions, higher pollutant loading rates are found in the lower Cobbs watershed, in and near the densely populated areas of Philadelphia. These results were obtained by using the SWMM model developed for Cobbs Creek. The specific components of the model that were utilized were the RUNOFF and EXTRAN modules.

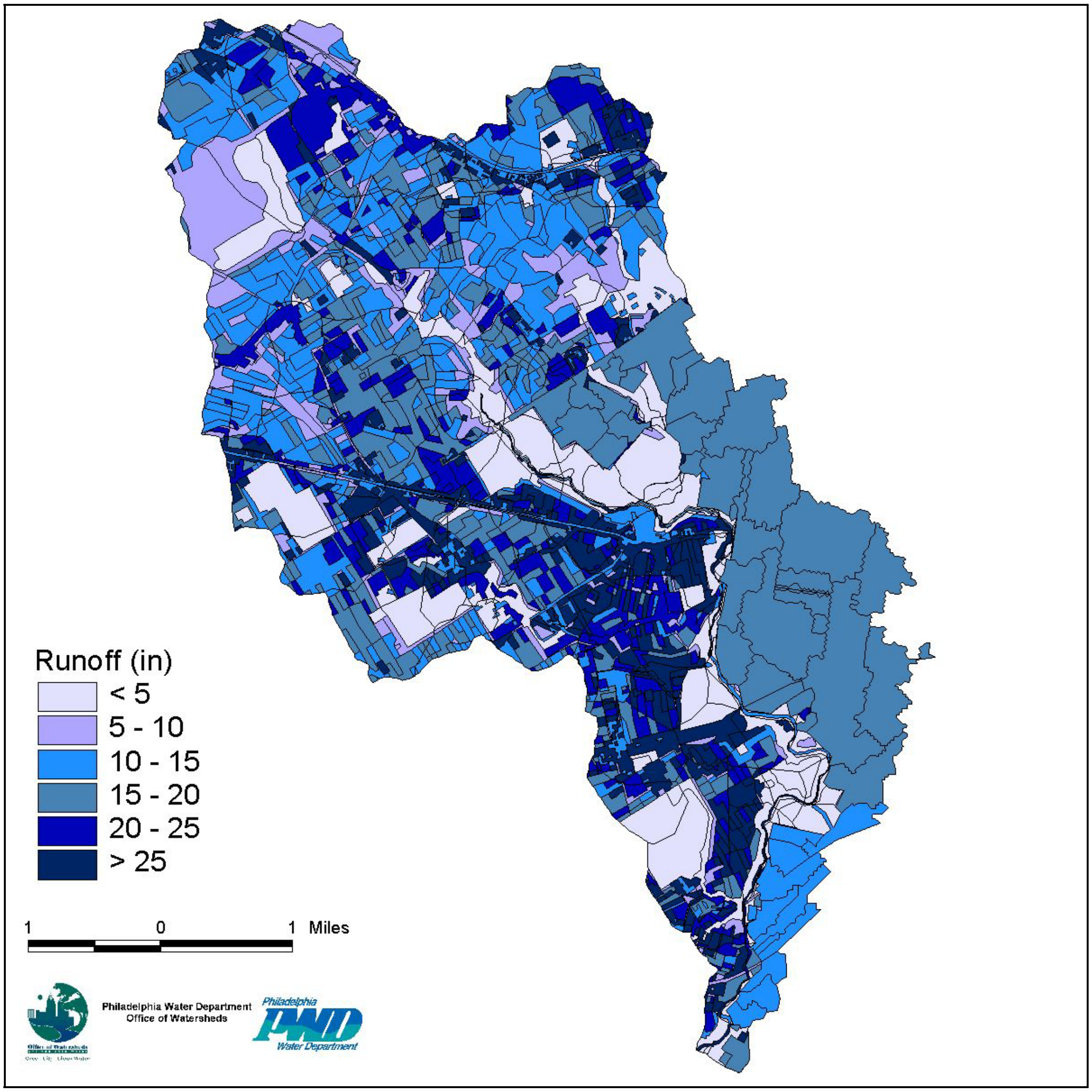


Figure 9.4 Estimated Annual Runoff for Cobbs Creek

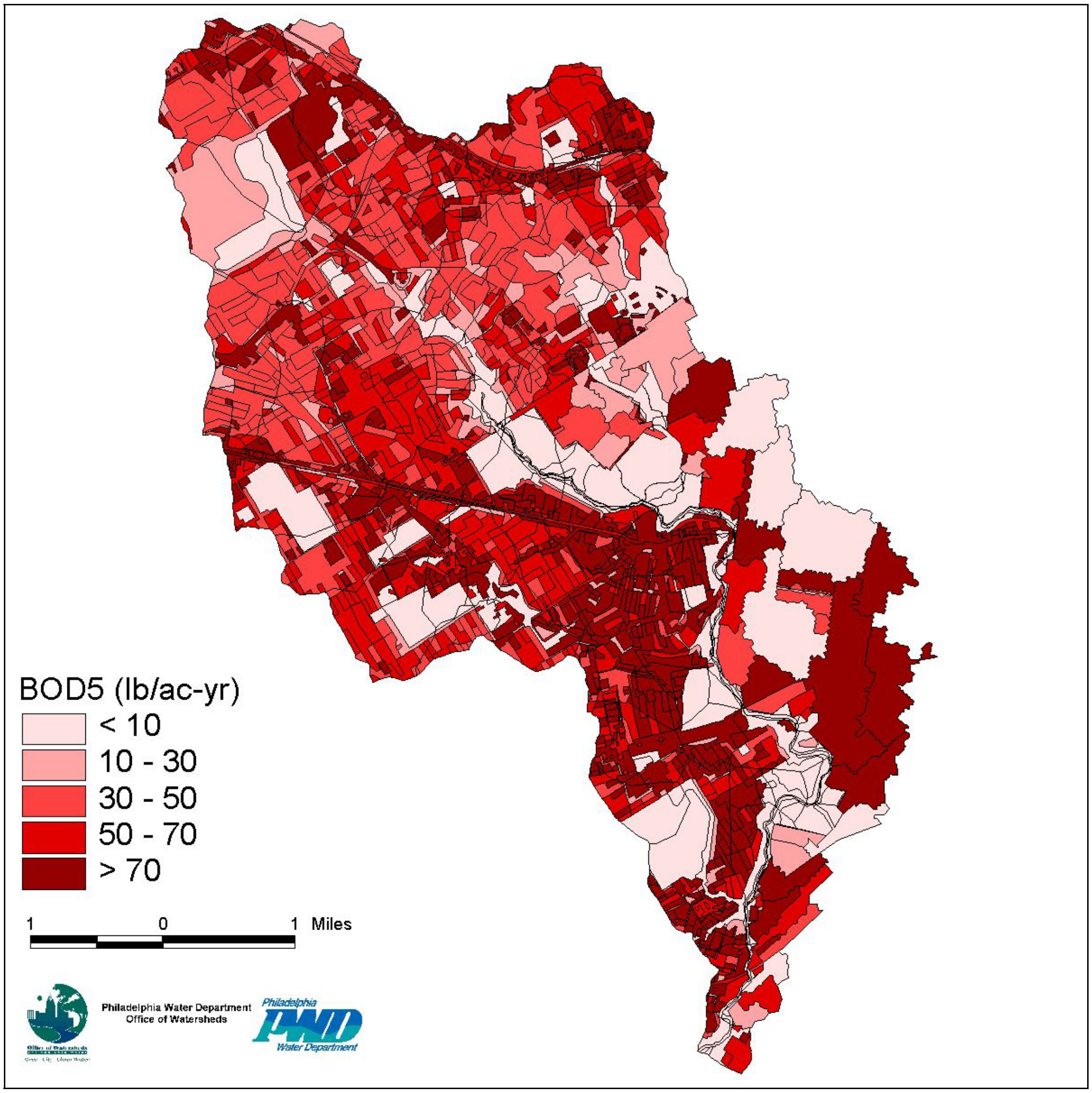


Figure 9.5 Estimated Annual Loading Rate for BOD for Cobbs Creek

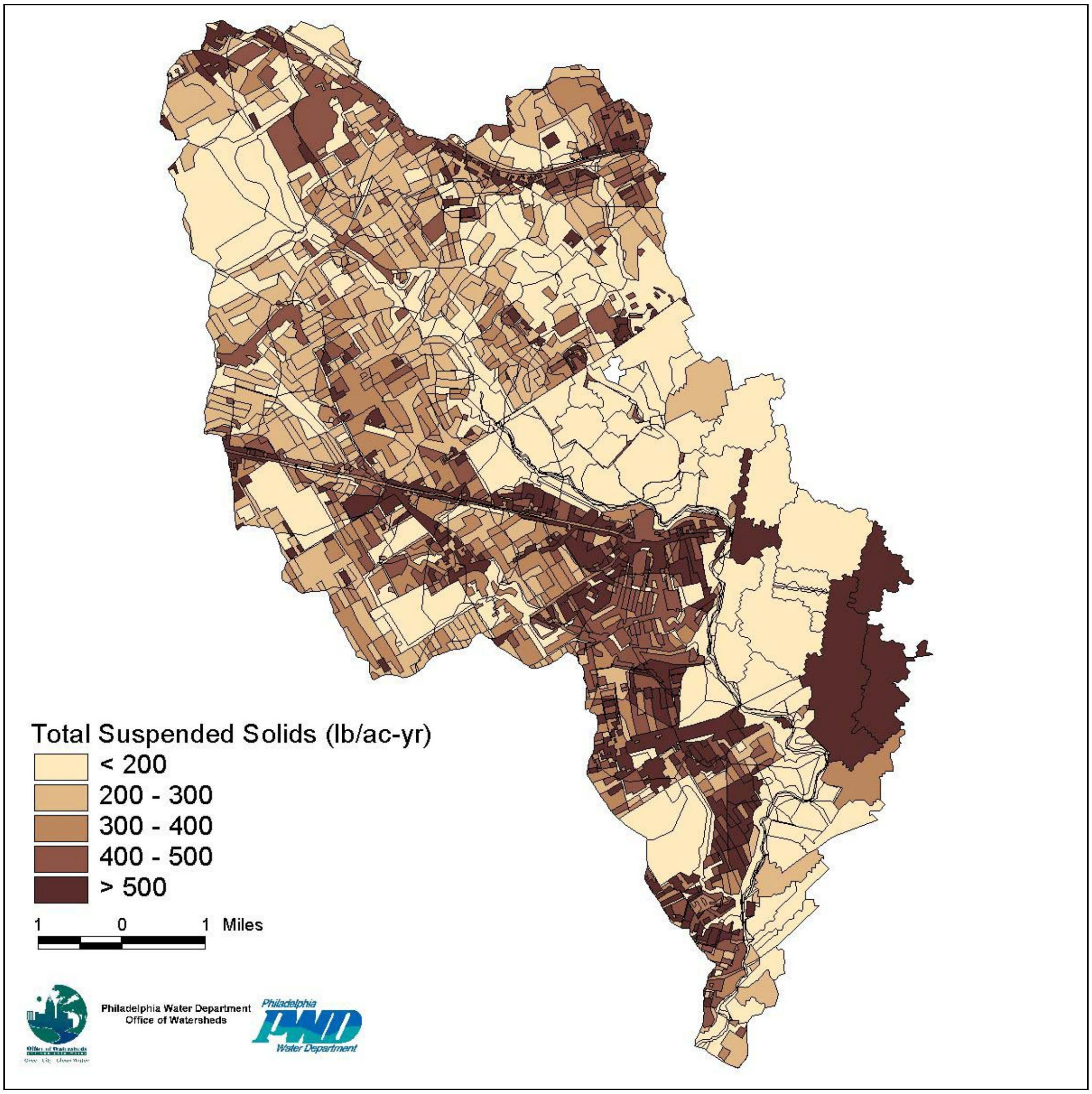


Figure 9.6 Estimated Annual Loading Rate for TSS for Cobbs Creek

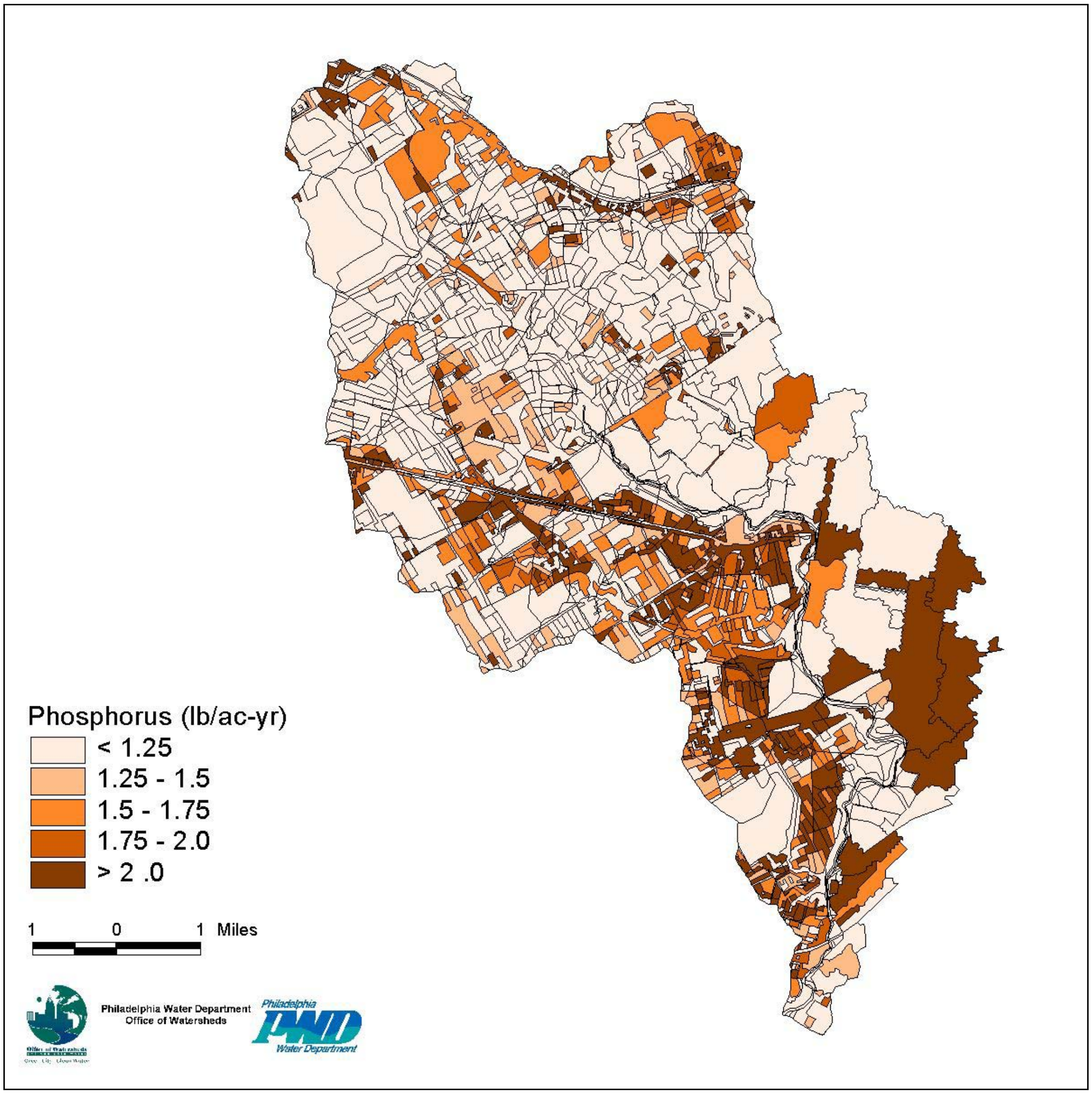


Figure 9.7 Estimated Annual Loading Rate for Total Phosphorous for Cobbs Creek

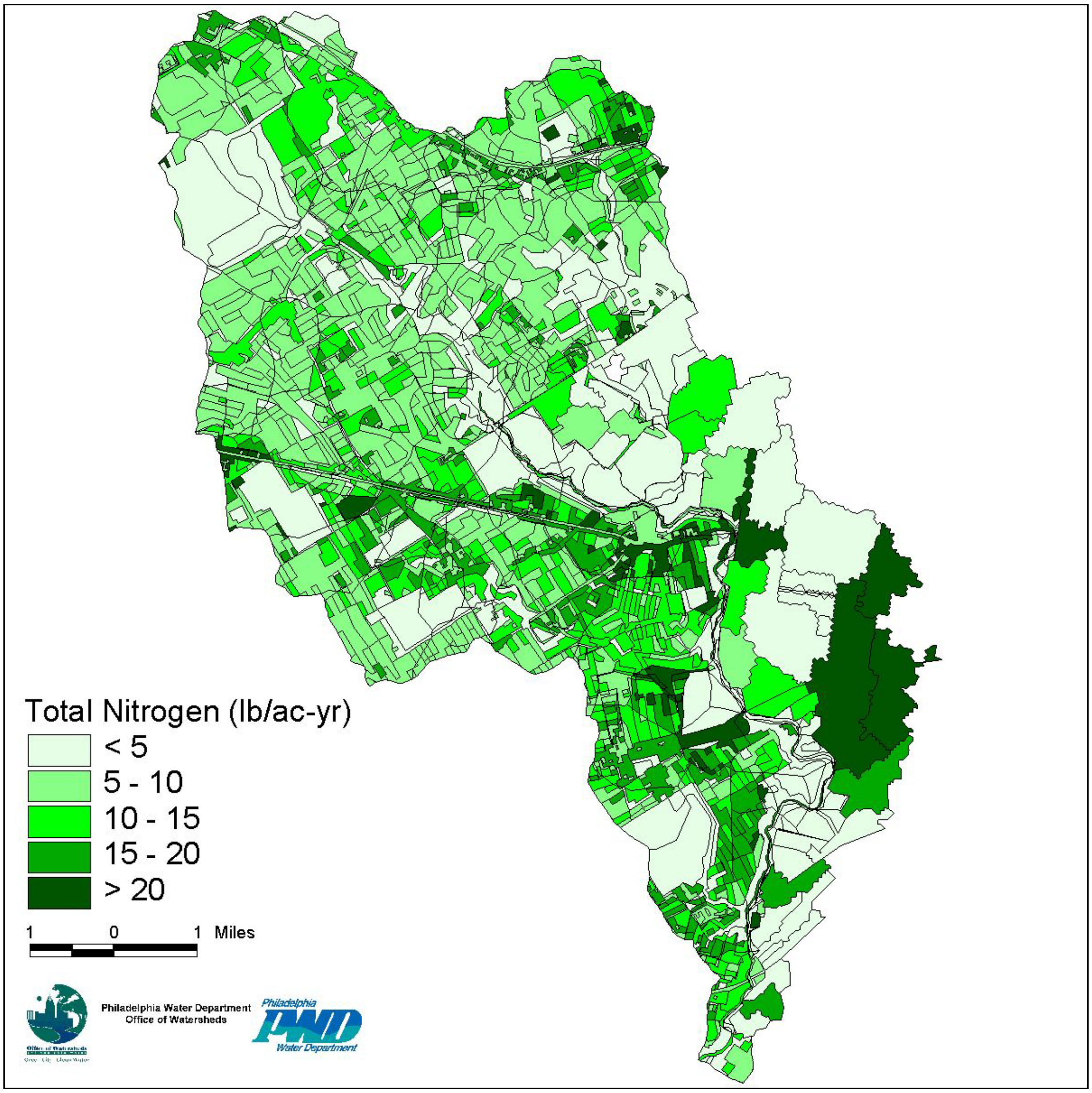


Figure 9.8 Estimated Annual Loading Rate for Total Nitrogen for Cobbs Creek

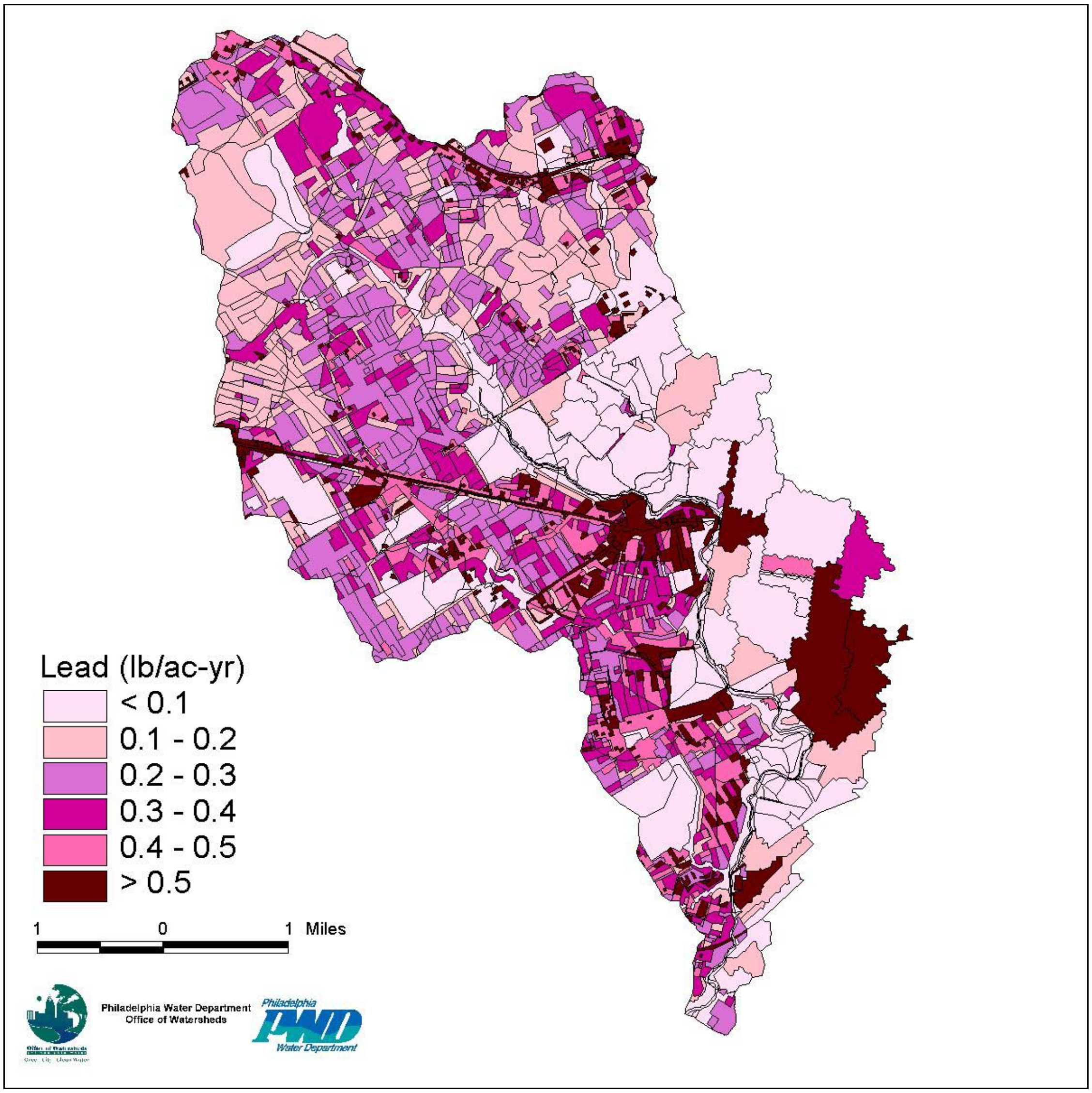


Figure 9.9 Estimated Annual Loading Rate for Lead for Cobbs Creek

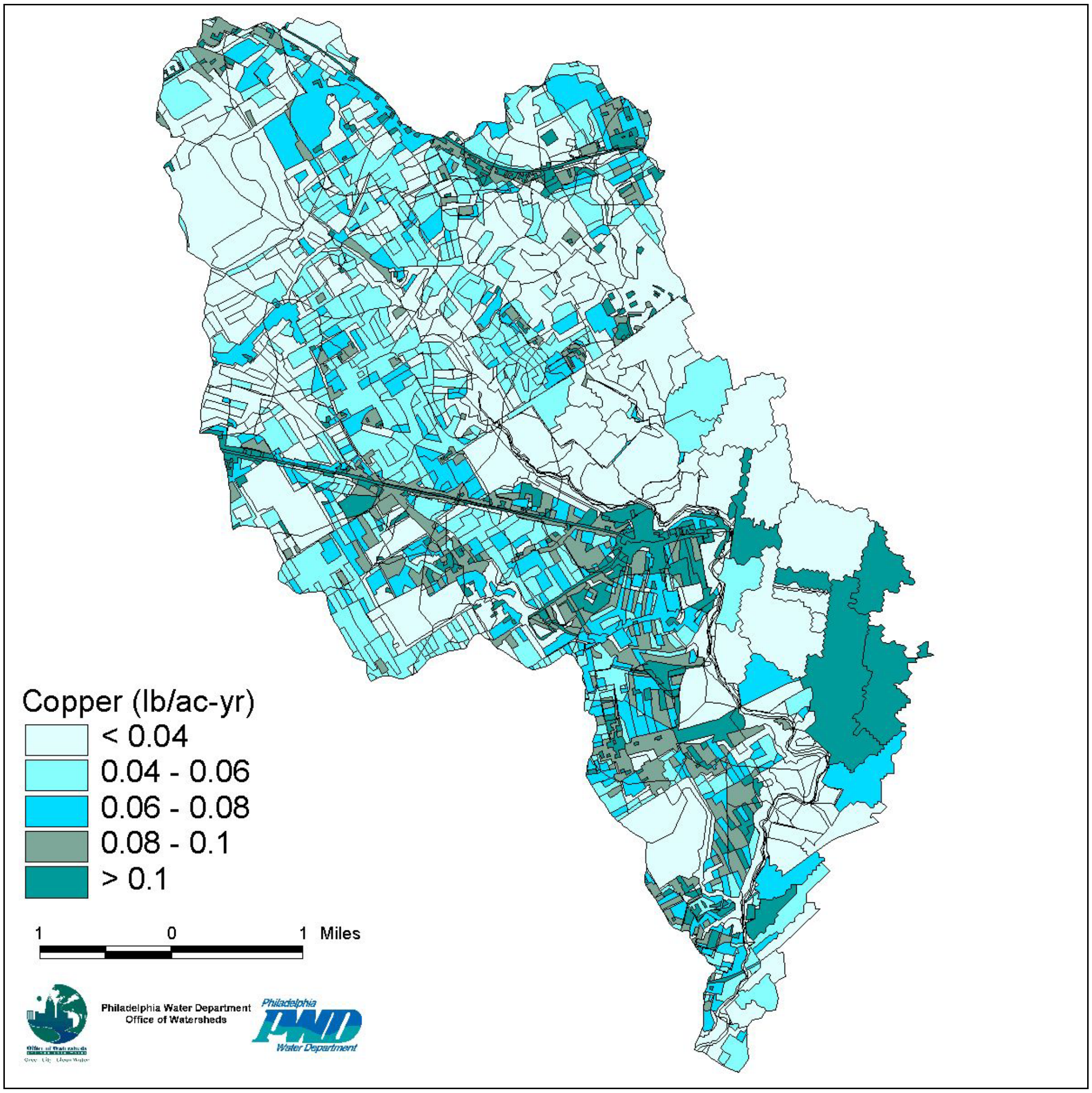


Figure 9.10 Estimated Annual Loading Rate for Copper for Cobbs Creek

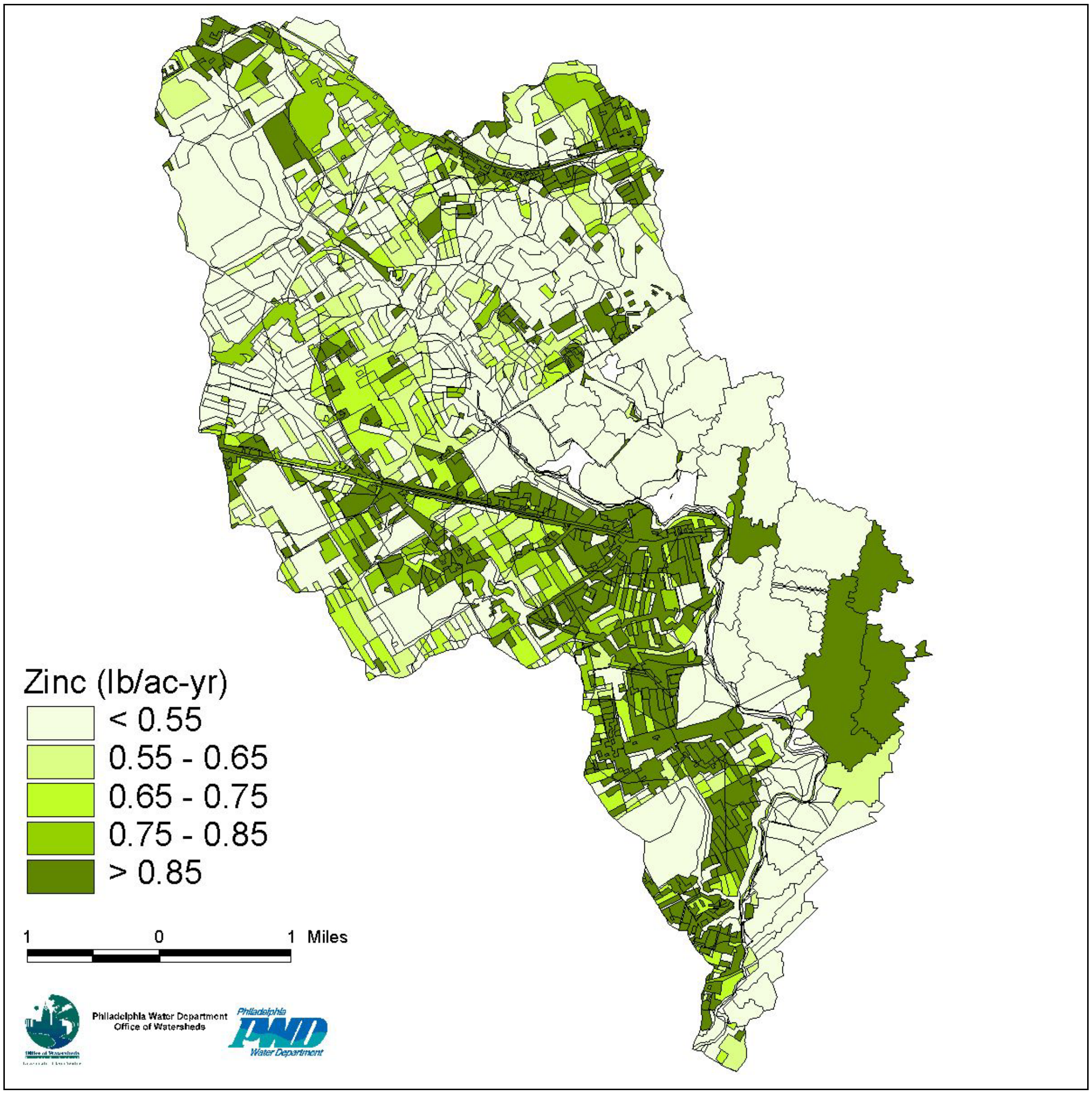


Figure 9.11 Estimated Annual Loading Rate for Zinc for Cobbs Creek

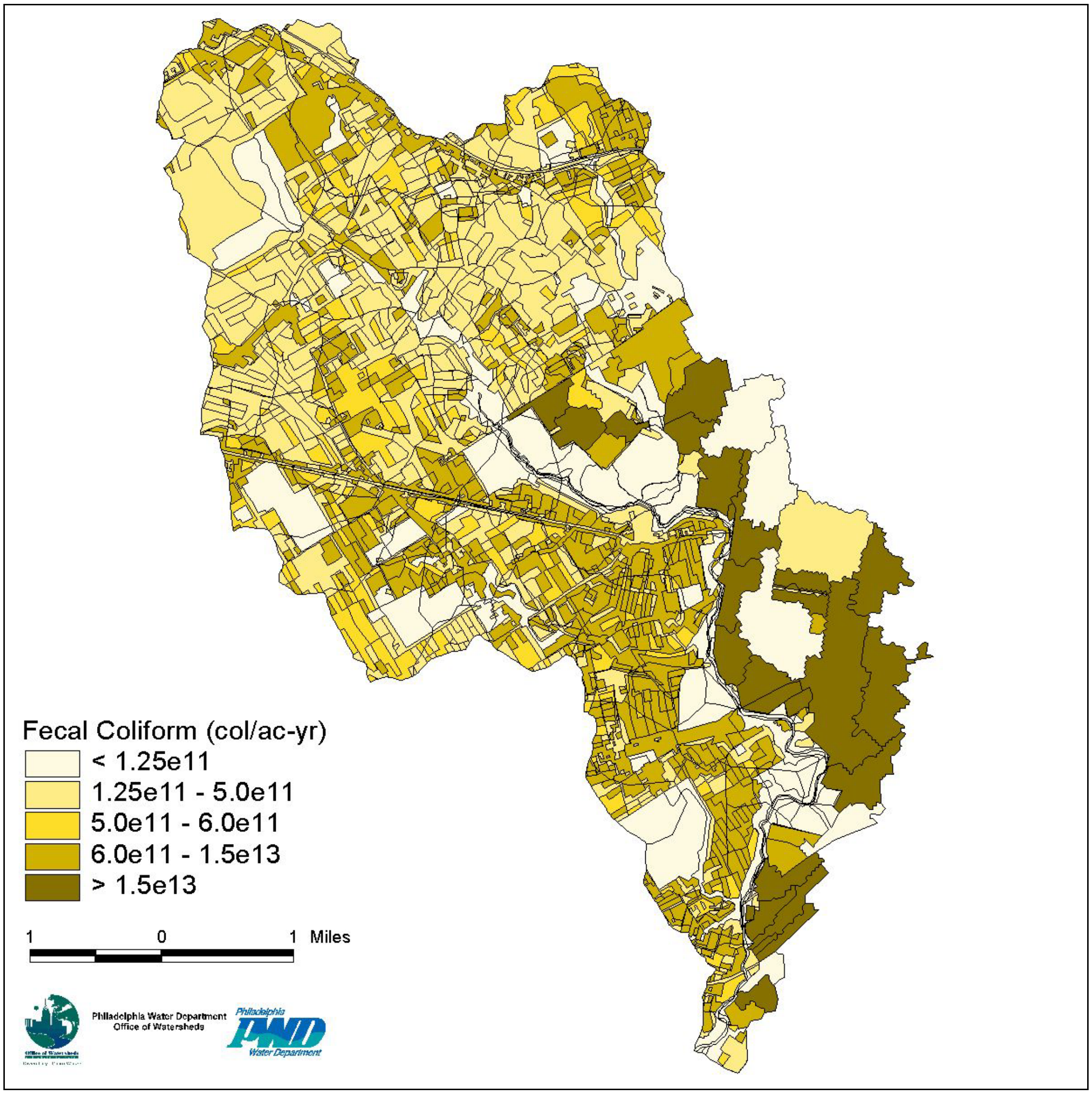


Figure 9.12 Annual Loading Rate for Fecal Coliform for Cobbs Creek

Table 9.5 Mean SWMM-Estimated Loads by Basins

Watershed	Area (ac)	Surface Runoff (in/yr)	Surface Runoff (MG)	BOD (ton/yr)	TSS (ton/yr)	Fecal (col/yr)	TN (ton/yr)	TP (ton/yr)	Cu (ton/yr)	Pb (ton/yr)	Zn (ton/yr)
Upper Cobbs	6,482	13.94	2046	145.5	813.2	2.76E+15	24.51	3.24	0.15	0.79	1.70
Lower Cobbs	4,202	17.93	2455	119.6	669.5	2.26E+15	20.30	2.67	0.12	0.68	1.41

9.2.2 Relative Contribution of Source Types

Figure 9.13 presents the approximate relative contribution each source (stormwater runoff from separate sanitary areas, baseflow, CSOs, industrial and municipal point sources, septic tanks, and atmospheric sources) contributes to the total potential load to the Delaware River from the Cobbs Creek watershed area. As expected in highly urbanized settings, runoff from separate sanitary areas is the dominant source of water pollution for most pollutant types except fecal coliform. Baseflow contributes a significant amount of total nitrogen. Separate sanitary overflows (SSOs) may be a significant source of pollutants, but information concerning these sources was insufficient to include in the current analysis. The results indicate that CSOs represent no more than 10% of the total load for any parameter except fecal coliform. The model indicates that over two-thirds of the fecal coliform introduced to the system is the result of CSOs; however, this portion may change when future work accounts for the contribution of SSOs. Industrial and municipal point sources are a relatively small source of pollutants. Septic tank loads are significant only for phosphorus and nitrogen. However, the reliability of the data available on septic tanks in the watershed is questionable. Atmospheric inputs, based on wetfall or concentrations within rainfall, are included in the EMCs for all land use types except for wetlands and open water. Atmospheric loads to wetlands and water were small (1% or less) but measurable.

Table 9.6 presents the average areal loads contributed by runoff from separate and combined sewer areas. Areal loads show the intensity of loading rather than total loads. The loads for all the parameters fall within the ranges shown on Figures 9.4 through 9.12. The areal loadings for most parameters are similar for the two sources, but the fecal coliform loads introduced by combined sewer areas are approximately 100 times greater per acre than those introduced by runoff from separate sewer areas. For comparison, the table includes loads for the other sources.

Sources of Uncertainty

Baseflow water quality information is based upon water quality sampling data obtained between 1999 and 2000. The data represents background conditions; if significant dry weather pollutant inputs are present, these will be reflected in the baseflow concentrations.

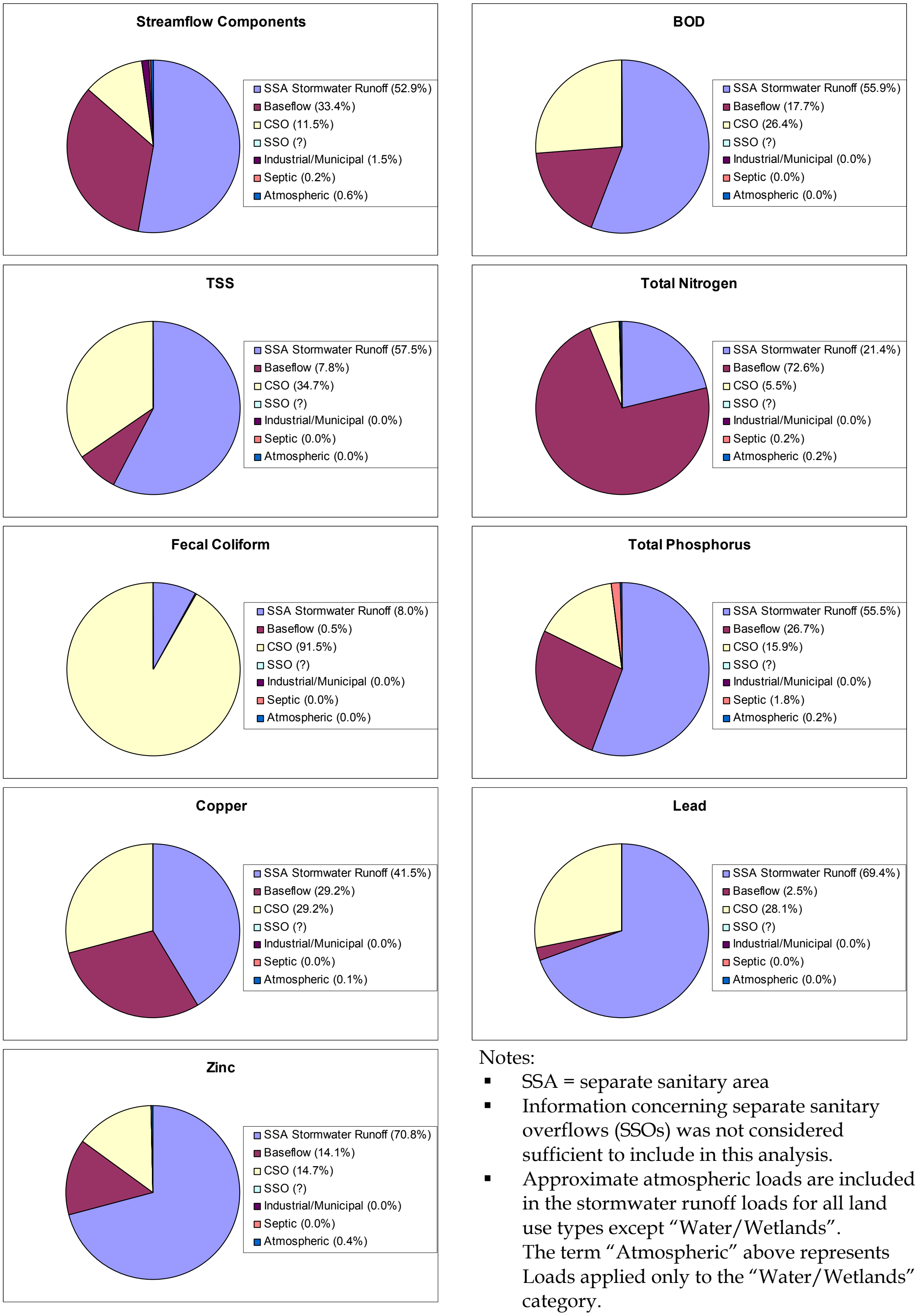
EMCs are based on literature values. The EMCs used for this study for urban land uses are from Smullen, Shallcross, and Cave (1999). These values represent a compilation of stormwater monitoring data from NURP, the USGS, and NPDES Phase I Municipal Stormwater Monitoring Requirements.

Sanitary sewer overflows (SSOs) are believed to be a significant potential source of bacterial and other pollution in the watershed. For the watershed study, estimates of SSO flows and pollutant loads were not calculated due to lack of readily available information on municipal sewer systems. Future studies may include a more thorough investigation of these sources.

Failures of septic tanks can contribute nutrient and bacterial loads to receiving waters. For this screening level study, the 1990 census data for on-lot septic systems was used to determine the number of septic systems in each drainage area. Although the census data indicated that over 200 septic systems were located within the Philadelphia portion of the Darby-Cobbs Creek watershed, water-only accounts indicated that three or fewer septic systems were located in this part of the watershed. Since extensive research into on-lot systems and Act 537 plans for Delaware and Chester Counties will be required, the 1990 census counts of septic systems were used for all portions of the Darby-Cobbs watershed study except Philadelphia.

Table 9.6 Cobbs Estimated Annual Areal Loads by Source (lb/ac except as noted)

Parameter	SSA Stormwater Runoff (lb/ac)	Baseflow	CSO	Industrial/ Municipal	Septic	Atmospheric
BOD	47.2	12.0	88	0	0	0
TSS	264	28.6	634	0	0	0
Fecal Coliform (col/ac)	4.47E+11	2.3E+10	2.04E+13	0	0	0
Total Nitrogen	8.00	21.7	8.22	0	0.072	0.062
Total Phosphorous	1.052	0.404	1.194	0	0.027	0.002
Copper	0.048	0.027	0.133	0	0	8.5E-05
Lead	0.262	0.007	0.421	0	0	1.0E-04
Zinc	0.555	0.088	0.456	0	0	2.5E-03



Notes:

- SSA = separate sanitary area
- Information concerning separate sanitary overflows (SSOs) was not considered sufficient to include in this analysis.
- Approximate atmospheric loads are included in the stormwater runoff loads for all land use types except “Water/Wetlands”. The term “Atmospheric” above represents Loads applied only to the “Water/Wetlands” category.

Figure 9.13 –Cobbs Estimated Annual Relative Contribution of Constituent Sources

9.2.3 Comparison of Load Estimates

Table 9.7 compares several loading rate estimates for Cobbs Creek. These estimates are based on historical water quality monitoring, 1999 water quality monitoring, and SWMM/WMM estimates. The loads from the monitoring data were calculated by applying wet weather and dry weather pollutant concentrations to USGS historical flow data. The resultant loads were averaged over the period of record to determine the average daily load.

Table 9.7 compares the loads of some conventional water quality parameters calculated from the results of the first 50 months of sampling of the PWD/USGS Cooperative Program “Effects of Non-Point Discharge on Urban Stream Quality,” reported by Radzuil, with loads calculated based on wet and dry flow regimes. Loads for metals and suspended solids were not reported. The calculated loads were developed by assigning wet and dry flow regimes and wet and dry concentrations, then accumulating the load over the discharge record. The estimated historical downstream load can be compared with Radzuil’s load for Cobbs Creek. The comparison suggests that the biochemical oxygen demand load increased for the duration of the cooperative program study. The phosphorus load may have been significantly reduced. Ammonia and nitrate loads were not calculated for the estimate. The loading rates estimated by SWMM/WMM are much larger than the instream mass load estimated from the current monitoring data. This difference is not a mistake but a result of the modeling philosophy:

- SWMM/WMM loads represent the total potential load to be delivered downstream and do not specifically account for the instream processes that reduce the total load.
- For the screening level study, the loads were used to estimate an overall delivery ratio for each pollutant, rather than estimate delivery ratios for various land uses by pollutant.
- The instream mass loads were based on limited, discrete, wet and dry weather monitoring data in addition to streamflow data from the 1970s.
- Loading is based on national EMCs which are measures of central tendency with significant variance. Local conditions may not be reflected by the national EMCs.

9.2.4 Delivery Ratios

The delivery ratio represents the fraction of the original pollutant load remaining after a particular pollutant travels downstream and is affected by instream processes. Data available in the literature indicate that the delivery ratio varies with drainage-area size. Some representative values calculated by the USDA for sediment are:

Drainage Area (sq. miles)	Delivery Ratio
0.5	0.33
10	0.18
100	0.10

However, the delivery ratios may vary substantially for any given size of drainage area. Other important factors affecting pollutant delivery include soil texture, relief (slope), types of erosion, sediment transport system, and deposition areas. For instance, a watershed with fine soil texture, high channel density, and high stream gradients would generally have a higher than average delivery ratio for watersheds of similar drainage area. Also, edge-of-field delivery ratios can approach 1.0 while delivery ratios for larger study areas can be less than 0.05. Instream processes also affect the delivery ratio. Such processes include deposition, sediment and water column diagenesis, remineralization, and volatilization. These processes are discussed in the next section.

Table 9.7 presents the calculated delivery ratios for two sites along Cobbs Creek (DC10 and DC06). Although delivery ratios might be expected to decrease with distance downstream, the Cobbs Creek data do not display such behavior. The delivery ratio for most pollutants increases from the upstream to the downstream cross-sections; the delivery ratios for total suspended solids, fecal coliform, and lead stay about the same. This trend may be largely explained by greater urbanization in the downstream reaches of Cobbs Creek; much of the loading occurs downstream where less time and distance are available for degradation processes to take place.

Table 9.7 Comparisons of Load Estimates for Cobbs Creek

	Historic Data		1999 Monitoring Data		1999 vs. Historical		Radzuil Loads	SWMM Estimate		Calculated Delivery Ratio	
	Upstr.	Downstr.	Upstr.	Downstr.	Upstr.	Downstr.	Downstream	Upstr.	Downstr.	Upstr.	Downstr.
Drainage Area (sq. mi)	4.5	22	4.5	22							
Arithmetic Mean Discharge (cfs)	7.3	30.4	7.3	30.4							
BOD_5 (lb/day)	412	1240	84.2	478	20%	39%	1280	797	1,717	11%	28%
TSS (lb/day)	8490	40,200	450	922	5%	2%		4,456	6,430	10%	14%
Total N (lb/day)			115	374				134	287.90	86%	130%
NH_3 (lb/day)	9.49	225	4.87	31.2	51%	14%	356				
NO_2 (lb/day)	7.71	136	0.73	8.15	9%	6%	16.1				
NO_3 (lb/day)	0.98	15.3	81.3	202	8290%	1320%	337				
Total P (lb/day)	295	1190	2.5	17.6	1%	2%	514	17.7	40.0	14%	44%
Fecal Coliform (col/day)	5.59E+08	1.55E+09	2.53E+11	4.83E+12	45300%	311000%		7.57E+12	4.55E+13	3%	11%
Cu (lb/day)	0.9	2.37	0.21	1.01	24%	43%		0.8	1.45	26%	69%
Cd (lb/day)	0.034	0.4	0.039	0.16	116%	41%					
Cr (lb/day)	29.3	30.3	0.36	1.48	1%	5%					
Fe (lb/day)	16	103	13.1	82.8	82%	80%					
Pb (lb/day)	4.22	4.74	0.098	0.63	2%	13%		4.4	5.7	2%	11%
Zn (lb/day)	2.35	12.1	0.49	2.34	21%	19%		9.3	13.6	5%	9%

Note: "Upstream" corresponds to station 12 for the historical and Radzuil data, station DC10 for the 1999 monitoring data and USGS station 01475530 (Cobbs Creek near Philadelphia). "Downstream" corresponds to station 15 for the Historical and Radzuil data, station DC06 for the 1999 monitoring data, and USGS station 01475550 (Cobbs Creek at Darby).

9.3 Results: Estimated Annual Constituent Loads for the Darby Creek and Tinicum Subwatersheds

Figures 9.14 through 9.22 show estimated loading rates for stormwater runoff and CSO. Table 9.8 presents the estimates summarized by watershed. The loads are estimates of the total input to the stream system. Higher pollutant loading rates are found in the lower Darby and Tinicum subwatersheds, in and near the densely populated areas of Philadelphia. Lower loading rates occur in the upper Darby watershed, where there is more open space and less densely populated residential areas. Pollutant loadings, population density, and runoff all follow the same general trends. WMM was used to develop screening-level loads for the Darby and Tinicum portions of the Darby-Cobbs watershed.

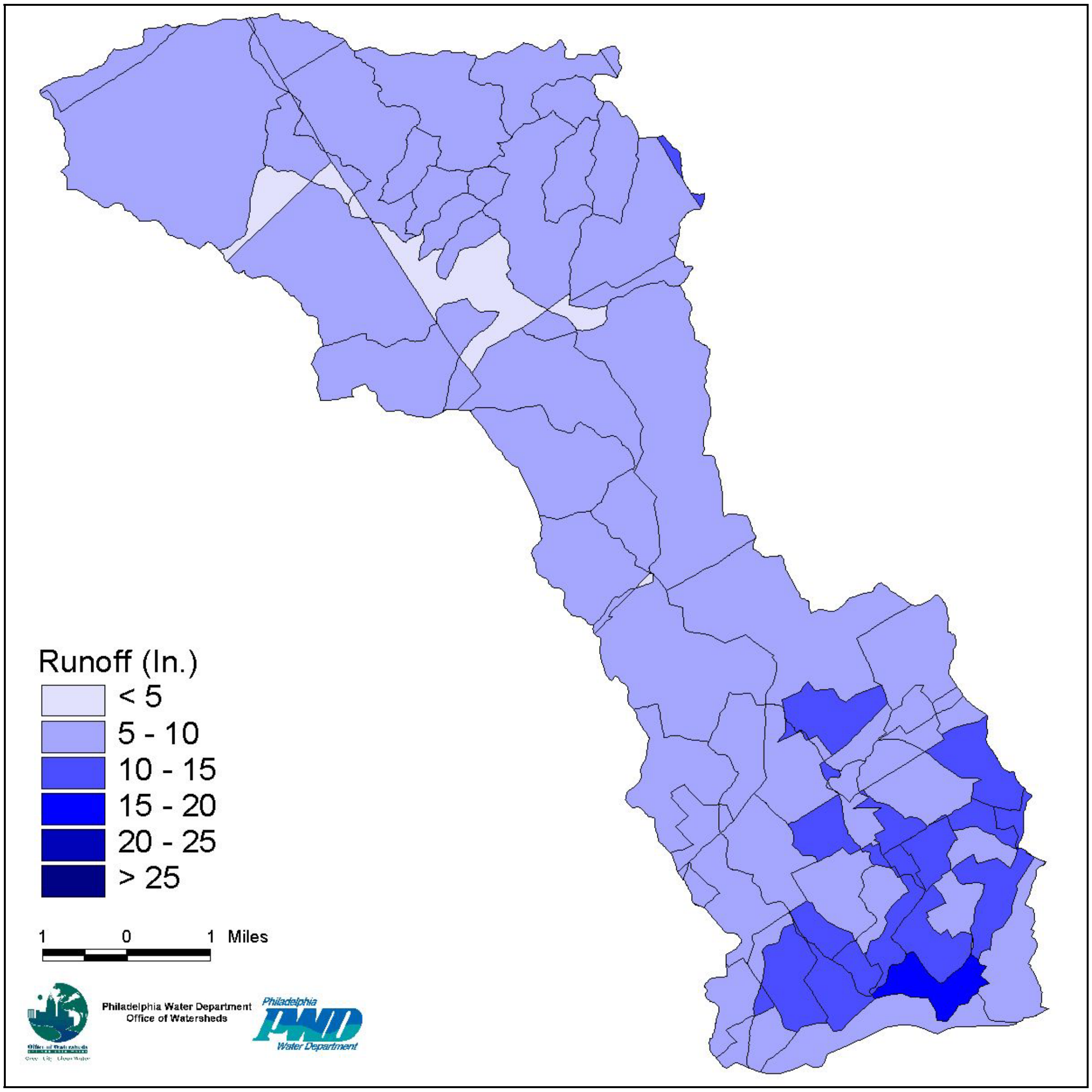


Figure 9.14 Estimated Annual Runoff Rate for Darby Creek and Tinicum

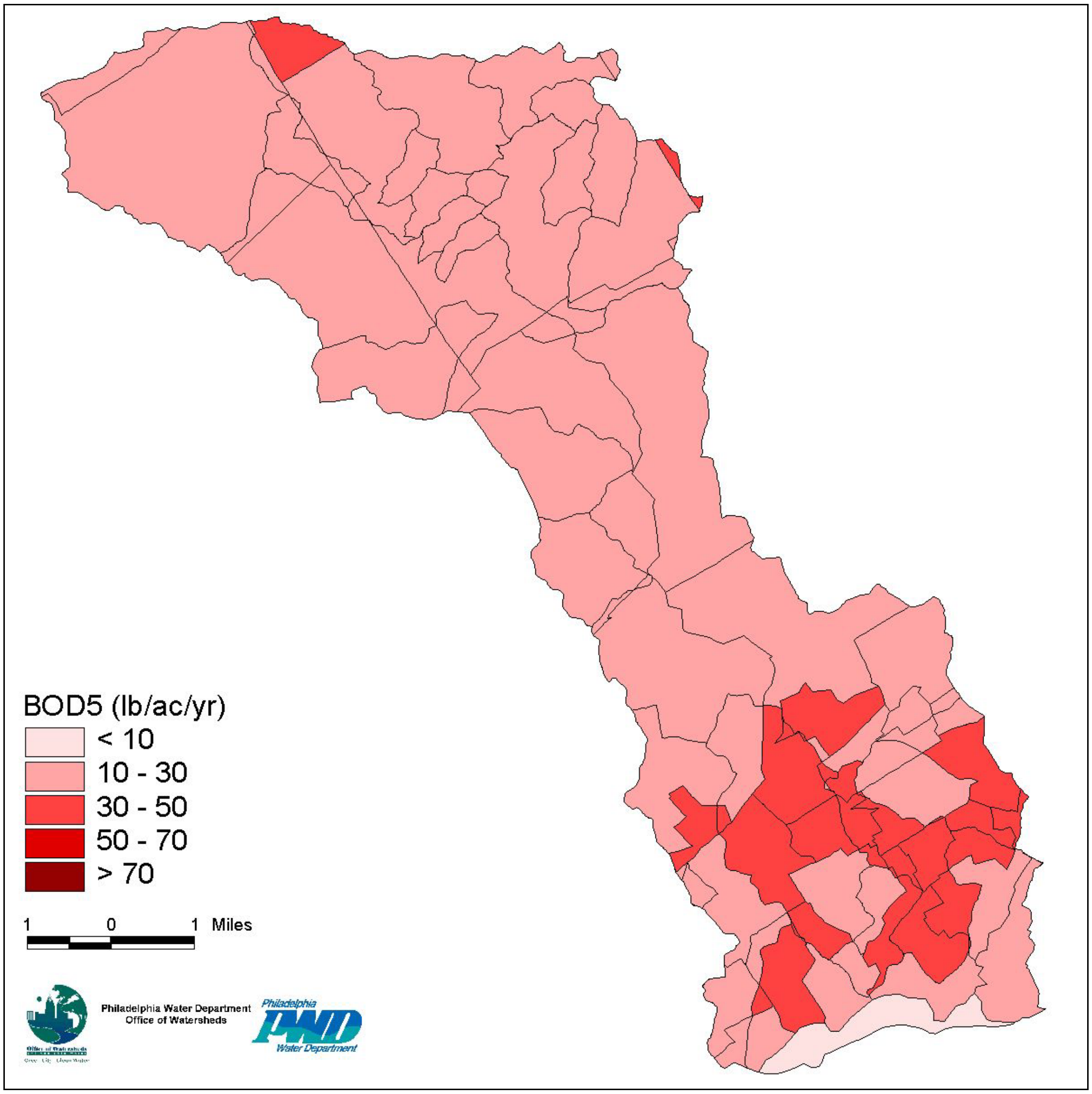


Figure 9.15 Estimated Annual Loading Rate for BOD for Darby Creek and Tinicum

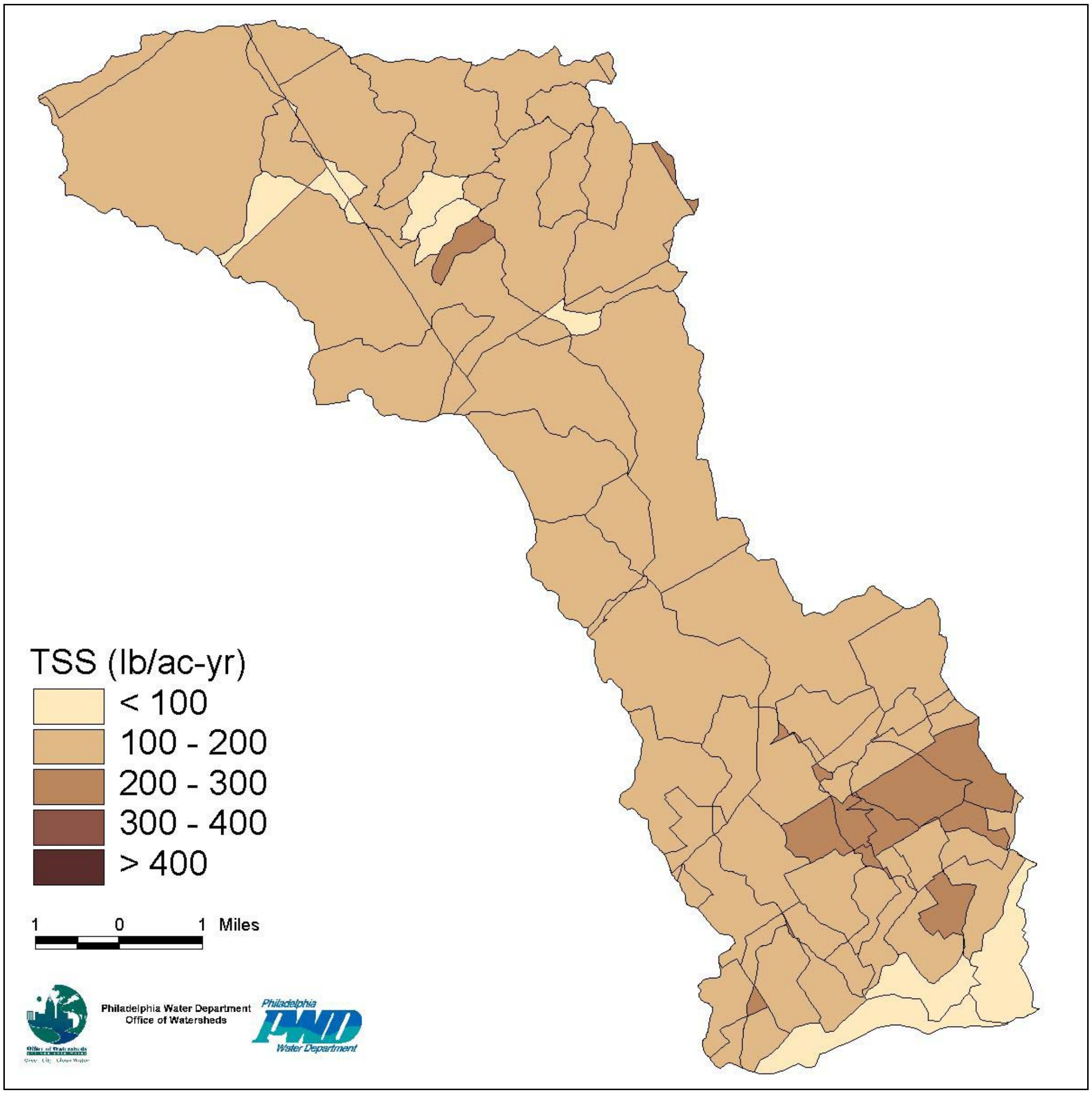


Figure 9.16 Estimated Annual Loading Rate for TSS for Darby Creek and Tinicum

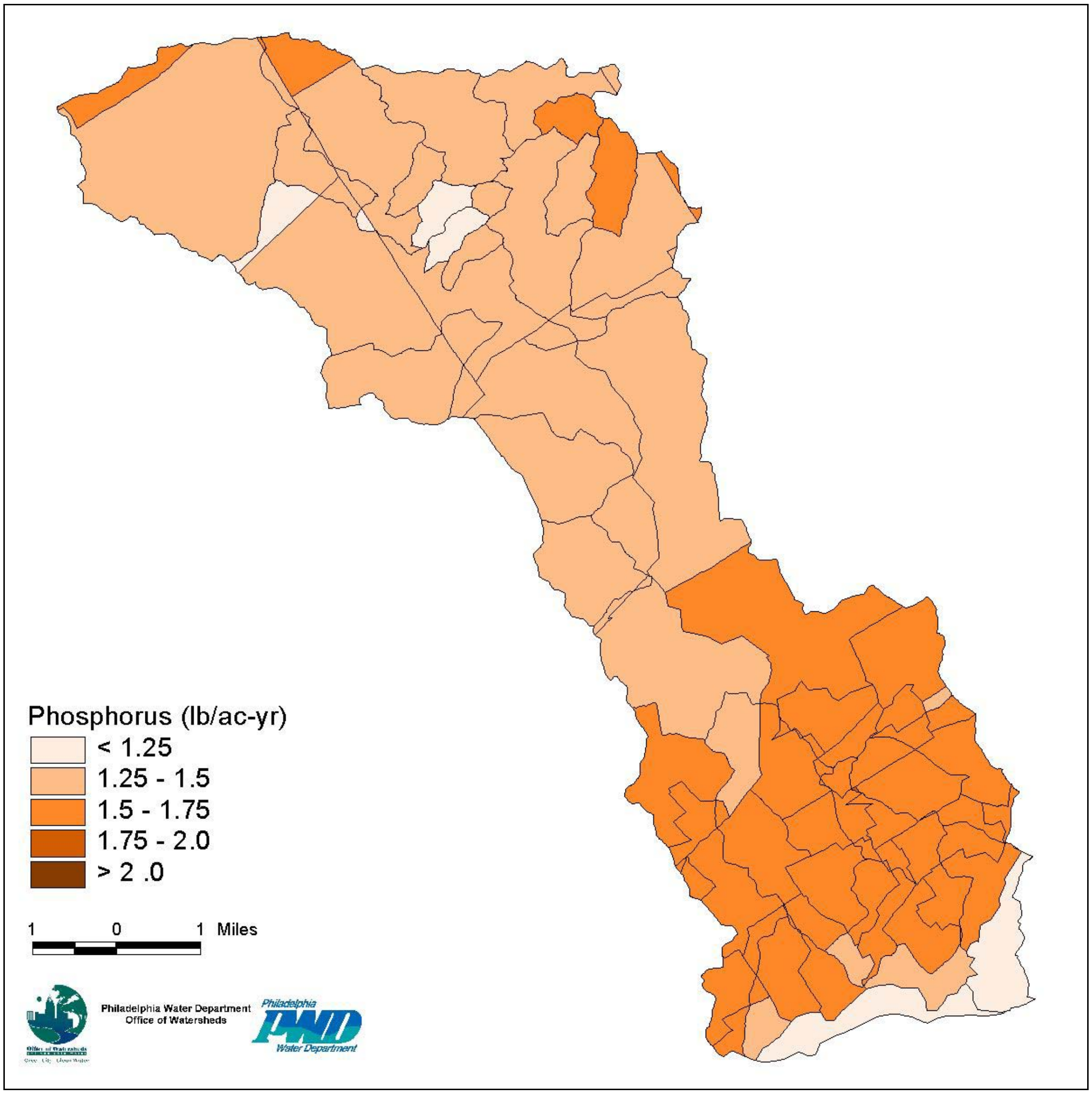


Figure 9.17 Estimated Annual Loading Rate for Total Phosphorous for Darby Creek and Tinicum

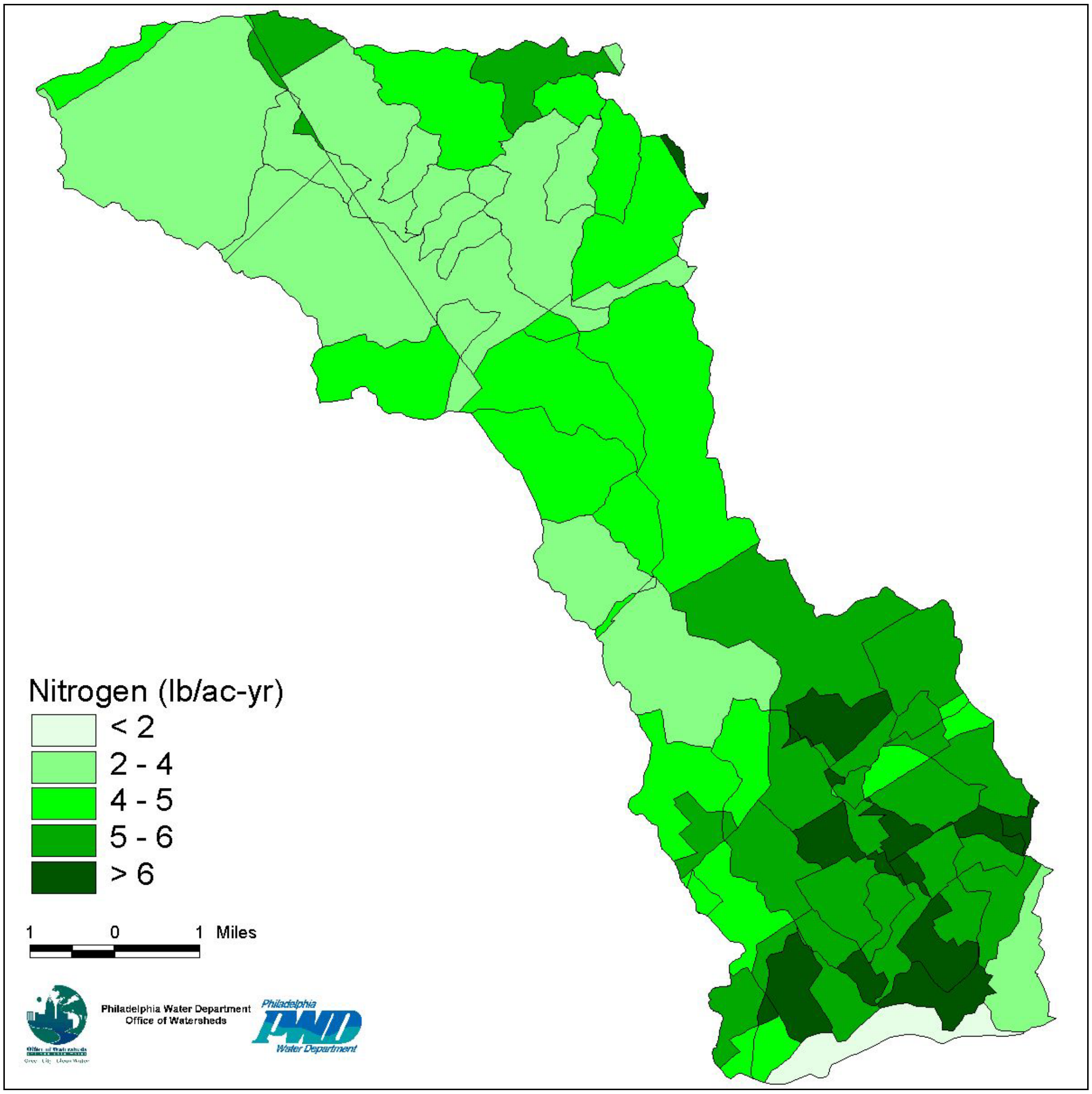


Figure 9.18 Estimated Annual Loading Rate for Total Nitrogen for Darby Creek and Tinicum

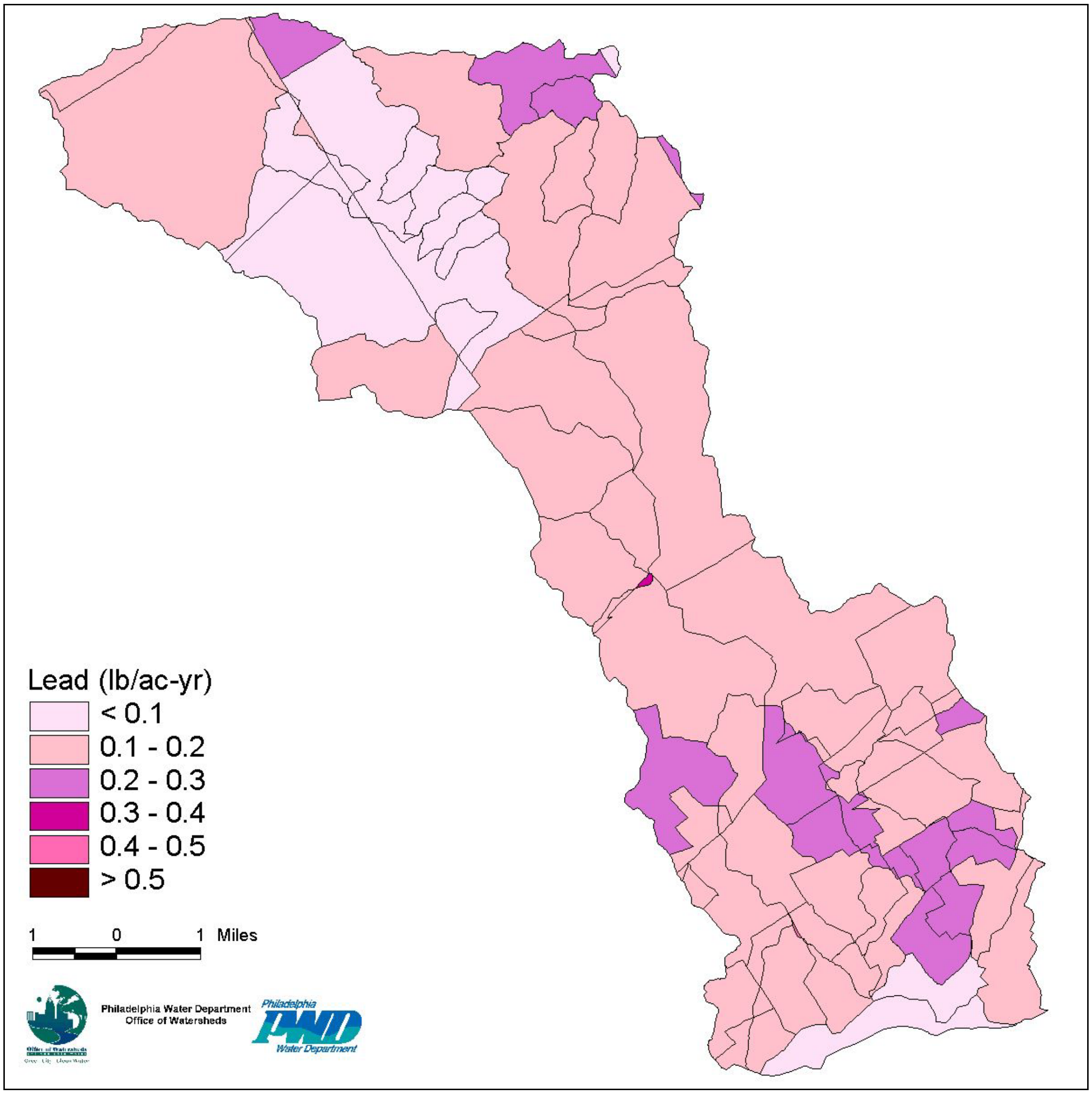


Figure 9.19 Estimated Annual Loading Rate for Lead for Darby Creek and Tinicum

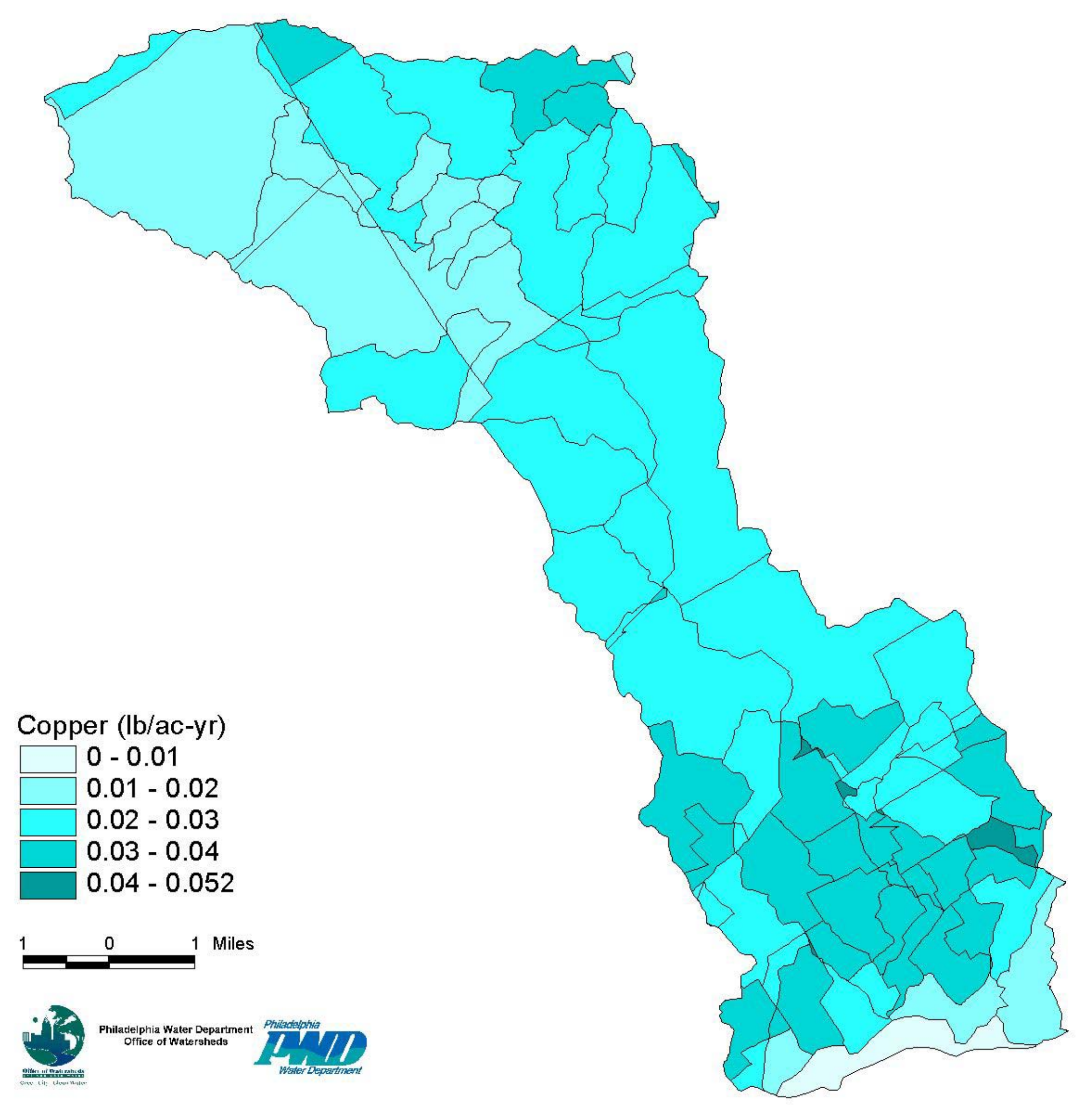


Figure 9.20 Estimated Annual Loading Rate for Copper for Darby Creek and Tinicum

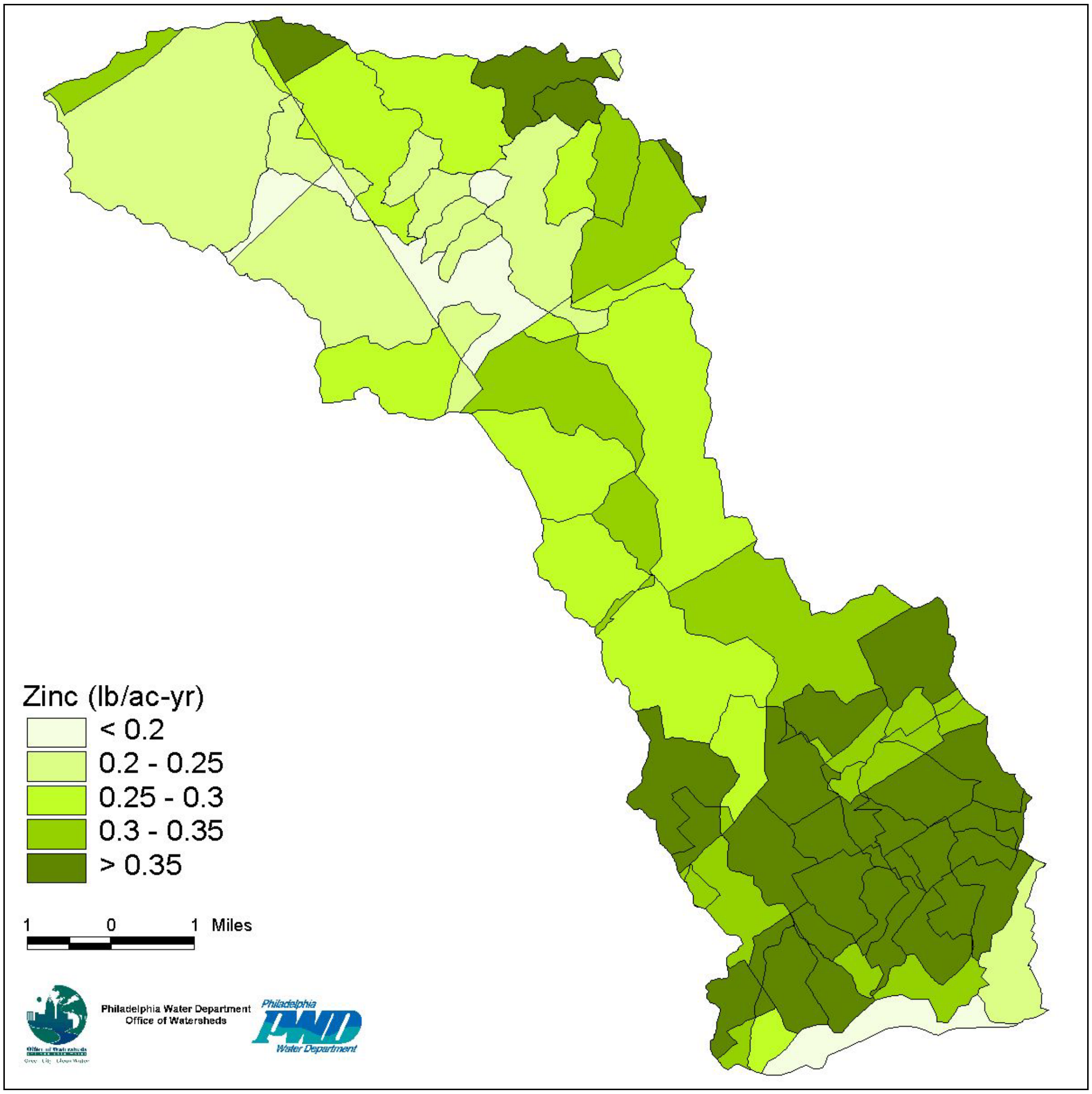


Figure 9.21 Estimated Annual Loading Rate for Zinc for Darby Creek and Tinicum

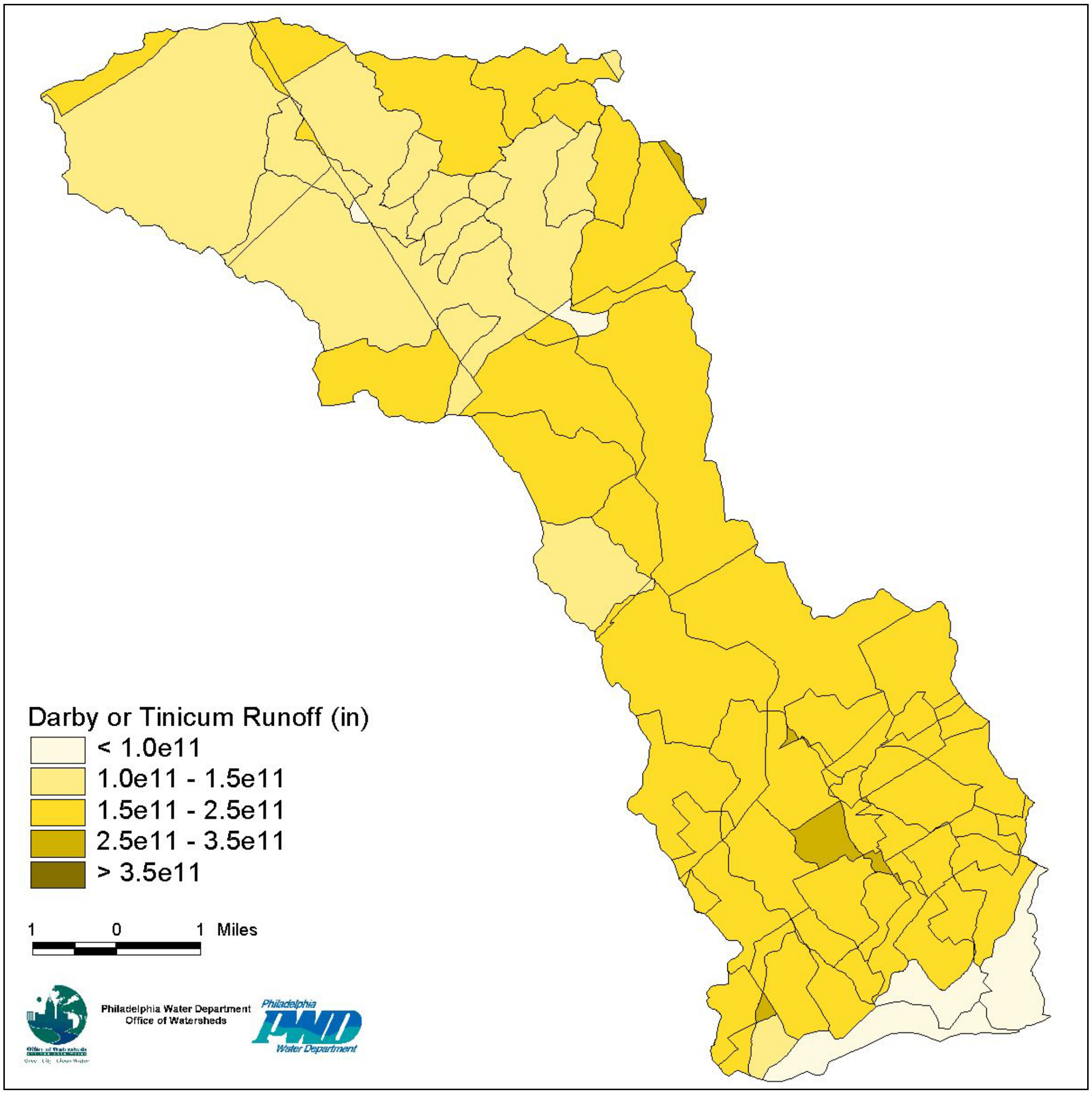


Figure 9.22 Annual Loading Rate for Fecal Coliform for Darby Creek and Tinicum

Table 9.8 Mean WMM-Estimated Loads by Basins

Watershed	Area (ac)	Surface Runoff (in)	Surface Runoff (MG)	BOD (ton/yr)	TSS (ton/yr)	Fecal (col/yr)	TN (ton/yr)	TP (ton/yr)	Cu (ton/yr)	Pb (ton/yr)	Zn (ton/yr)
Upper Darby	14,051	6.71	2,561	147.9	902	2.08E+15		3.28	0.15	0.82	1.81
Lower Darby	11,305	8.23	2,528	147	901	2.04E+15	26.1	3.38	0.15	0.85	1.76
Tinicum	5,811	9.76	1,540	86.4	512	1.21E+15	15.8	1.98	0.09	0.54	1.07

9.3.2 Relative Contribution of Source Types

Figures 9.23 and 9.24 present the approximate relative contribution each source (stormwater runoff from separate sanitary areas, baseflow, CSOs, industrial and municipal point sources, septic tanks, and atmospheric sources) contributes to the total potential load to the Delaware River from the Darby and Tinicum subwatershed areas. As expected in highly urbanized settings, runoff from separate sanitary areas is the dominant source of water pollution for most pollutant types. Baseflow contributes a significant amount of total nitrogen. Separate sanitary overflows (SSOs) may be a significant source of pollutants, but information concerning these sources was insufficient to include in the current analysis. There are no combined sewer systems in the Darby and Tinicum subwatersheds. Industrial and municipal point sources are a relatively small source of pollutants. Septic tank loads are significant only for phosphorus and nitrogen. However, the reliability of the data available on septic tanks in the watershed is questionable. Atmospheric loads were not considered in the Darby and Tinicum subwatersheds.

Tables 9.9 and 9.10 present the average areal loads contributed by runoff from separate sewer areas (there are no CSOs). Areal loads show the intensity of loading rather than total loads. The loads for all the parameters fall within the ranges shown on Figures 9.14 through 9.22. For comparison, the table includes loads for the other sources.

Sources of Uncertainty

Baseflow water quality information is based upon water quality sampling data obtained between 1999 and 2000. The data represent background conditions; if significant dry weather pollutant inputs are present, these will be reflected in the baseflow concentrations.

EMCs are based on literature values. The EMCs used for this study for urban land uses are from Smullen, Shallcross, and Cave (1999). These values represent a compilation of stormwater monitoring data from NURP, the USGS, and NPDES Phase I Municipal Stormwater Monitoring Requirements.

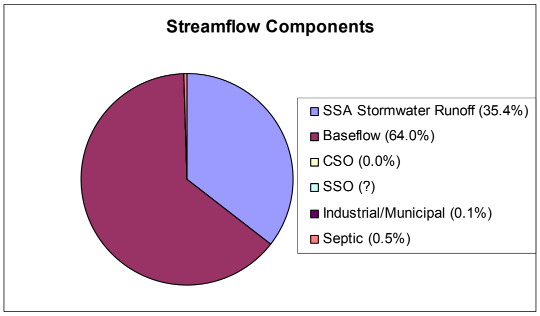
Separate Sanitary Overflows (SSOs) are believed to be a significant potential source of bacterial and other pollution in the watershed. For the watershed study, estimates of SSO flows and pollutant loads were not calculated due to lack of readily available information on municipal sewer systems. Future studies may include a more thorough investigation of these sources.

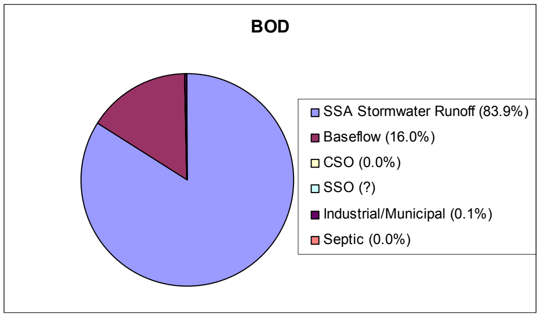
Failures of septic tanks can contribute nutrient and bacterial loads to receiving waters. For this screening level study, the 1990 census data for on-lot septic systems was used to determine the number of septic systems in each drainage area. Although the census data indicated that over 200 septic systems were located within the Philadelphia portion of the Darby-Cobbs Creek Watershed, water-only accounts indicated that three or fewer septic systems were located in this part of the watershed. Since extensive research into on-lot systems and Act 537 plans for Delaware and

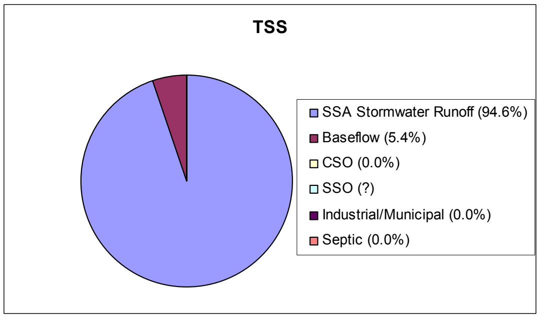
Chester Counties will be required, the 1990 census counts of septic systems were used for all portions of the Darby-Cobbs watershed study except Philadelphia.

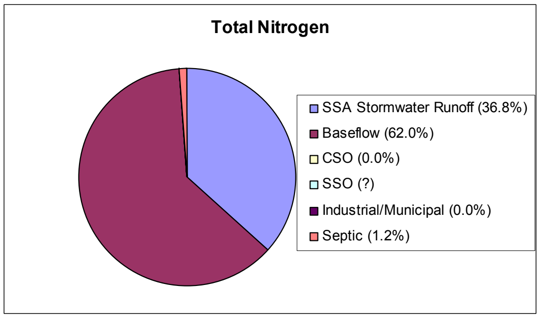
Table 9.9 Darby Estimated Annual Areal Loads by Source (lb/ac except as noted)

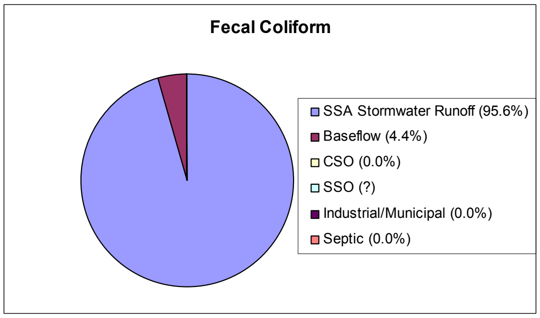
Parameter	SSA Stormwater Runoff (lb/ac)	Baseflow	CSO	Industrial/ Municipal	Septic
BOD	54.6	8.32	0	0.073	0
TSS	333	15.1	0	0.035	0
Fecal Coliform (col/ac)	3.8E+11	1.4E+10	0	0	0
Total Nitrogen	10.2	13.7	0	0.005	0.264
Total Phosphorous	1.25	0.251	0	0	0.099
Copper	0.058	0.014	0	0	0
Lead	0.319	0.004	0	0	0
Zinc	0.684	0.054	0	0.0002	0

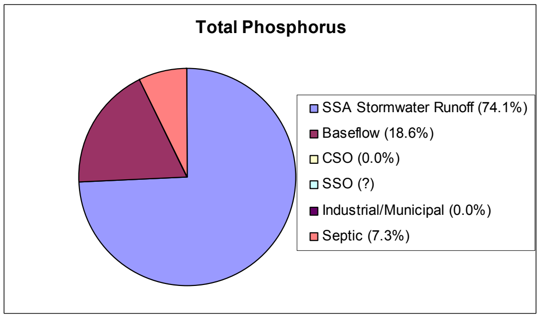


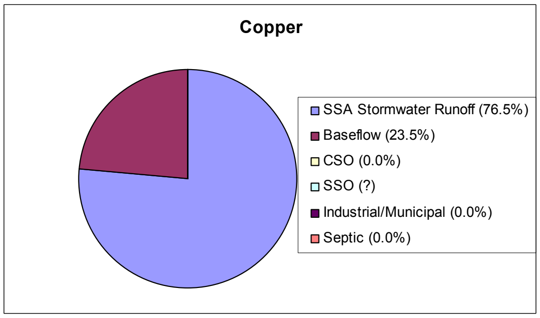


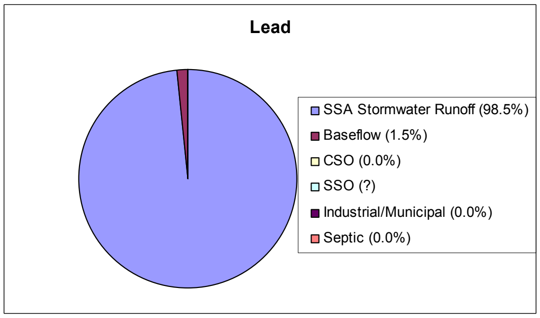


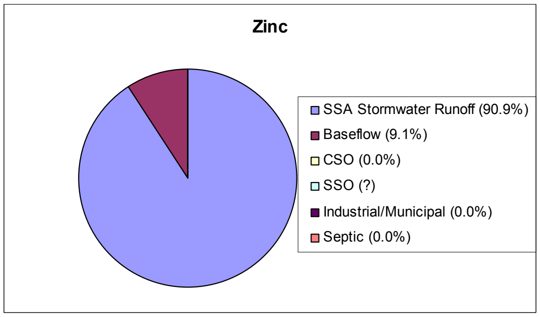












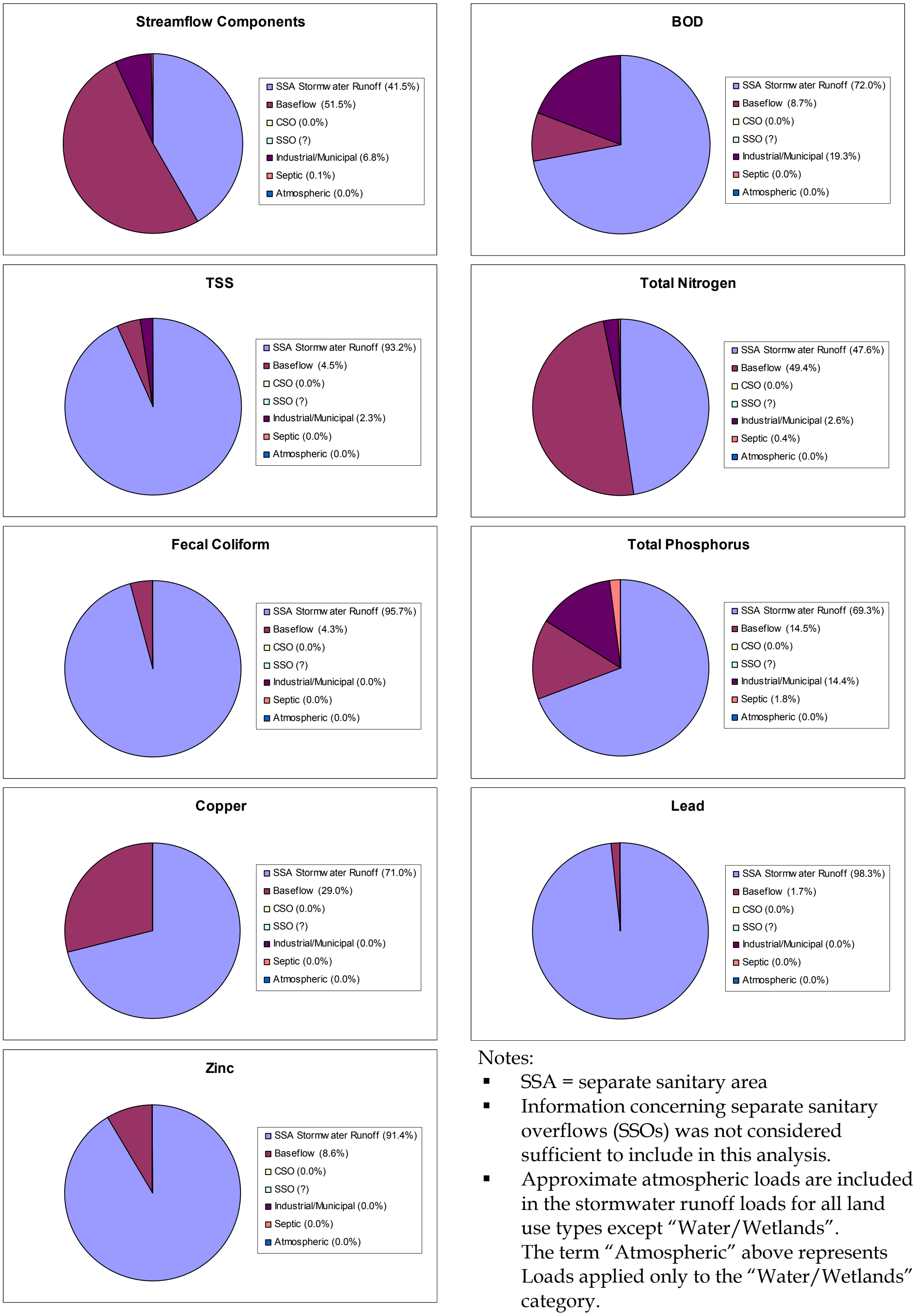
Notes:

- SSA = separate sanitary area
- Information concerning separate sanitary overflows (SSOs) was not considered sufficient to include in this analysis.
- Approximate atmospheric loads are included in the stormwater runoff loads for all land use types except “Water/Wetlands”. The term “Atmospheric” above represents Loads applied only to the “Water/Wetlands” category.

Figure 9.23 Darby Estimated Annual Relative Contribution of Constituent Sources

Table 9.10 Tinicum Estimated Annual Areal Loads by Source (lb/ac except as noted)

Parameter	SSA Stormwater Runoff (lb/ac)	Baseflow	CSO	Industrial/ Municipal	Septic
BOD	15.3	1.48	0	3.27	0
TSS	90.5	3.48	0	1.78	0
Fecal Coliform (col/ac)	1.1E+11	3.8E+09	0	9.6E+06	0
Total Nitrogen	2.79	2.32	0	0.123	0.02
Total Phosphorous	0.349	0.058	0	0.058	0.007
Copper	0.017	0.005	0	0	0
Lead	0.095	0.001	0	0	0
Zinc	0.189	0.014	0	0	0



Notes:

- SSA = separate sanitary area
- Information concerning separate sanitary overflows (SSOs) was not considered sufficient to include in this analysis.
- Approximate atmospheric loads are included in the stormwater runoff loads for all land use types except "Water/Wetlands". The term "Atmospheric" above represents Loads applied only to the "Water/Wetlands" category.

Figure 9.24 Tinicum Estimated Annual Relative Contribution of Constituent Sources

9.3.3 Comparison of Load Estimates

Separate loading rates were not estimated for upper Darby for two reasons. First, only one Cooperative Program site was located on Darby Creek, and its location (at Waterloo Mills, in the headwaters) does not represent a large enough portion of the watershed to compare to the 1999 monitoring and WMM-estimated loads. Second, the lack of USGS gauge data in the vicinity of DC05 causes difficulty producing a baseflow estimate.

Table 9.11 compares the loads of some conventional water quality parameters calculated from the results of the first 50 months of sampling of the PWD/USGS Cooperative Program "Effects of Non-Point Discharge on Urban Stream Quality," reported by Radzuil, with loads calculated based on wet and dry flow regimes. Loads for metals and suspended solids were not reported. The calculated loads were developed by assigning wet and dry flow regimes and wet and dry concentrations, then accumulating the load over the discharge record.

The loading rates estimated by WMM for some constituents are much larger than the instream mass load estimated from the current monitoring data. This difference is not a mistake but a result of the modeling philosophy:

- WMM loads represent the total potential load to be delivered downstream and do not specifically account for the instream processes that reduce the total load.
- For the screening level study, the loads were used to estimate an overall delivery ratio for each pollutant, rather than estimate delivery ratios for various land uses by pollutant.
- The instream mass loads were based on limited, discrete, wet and dry weather monitoring data in addition to streamflow data from the 1970s.
- Loading is based on national EMCs which are measures of central tendency with significant variance. Local conditions may not be reflected by the national EMCs.

9.3.4 Delivery Ratios

The delivery ratio represents the fraction of the original pollutant load remaining after a particular pollutant travels downstream and is affected by instream processes. Data available in the literature indicate that the delivery ratio varies with drainage-area size. Some representative values calculated by the USDA for sediment are:

Drainage Area (sq. miles)	Delivery Ratio
0.5	0.33
10	0.18
100	0.10

However, the delivery ratios may vary substantially for any given size of drainage area. Other important factors affecting pollutant delivery include soil texture, relief (slope), types of erosion, sediment transport system, and deposition areas. For instance, a watershed with fine soil texture, high channel density, and high stream gradients would generally have a higher than average delivery ratio for watersheds of similar drainage area. Also, edge-of-field delivery ratios can approach 1.0 while delivery ratios for larger study areas can be less than 0.05. Instream processes also affect the delivery ratio. Such processes include deposition, sediment and water column diagenesis, remineralization, and volatilization. These processes are discussed in the next section. Table 9.11 presents the calculated delivery ratios for one site near the outlet of Darby Creek (PWD sampling site DCD765).

Table 9.11 Comparisons of Load Estimates for Darby Creek

	1999 Monitoring Data	WMM Estimate	Delivery Ratio
Drainage Area (ac)	25,600	28,276	
Surface Runoff (in)	15.7	7.55	
BOD_5 (lb/day)	1,560	1,693	92%
TSS (lb/day)	1,940	10,332	19%
Total N (lb/day)	799	316	253%
Total P (lb/day)	22	38.83	57%
Fecal Coliform (col/day)	2.81E+12	1.17E+13	24%
Cu (lb/day)	1.13	1.81	63%
Pb (lb/day)	0.55	9.88	6%
Zn (lb/day)	2.66	21.22	13%

Note: Loading estimates based on monitoring data require a baseflow estimate. Unlike data for Cobbs Creek, USGS historical streamflow data for the Darby Creek watershed are insufficient to calculate separate loading rates for the upper portion of the watershed. Monitoring loads are based on data from DCD765 and USGS station 01475510, (Darby Creek near Darby).

Section 10 Discussion and Analysis

Sections 1 through 8 provide a wide range of information characterizing the geography, hydrology, water quality, biology, habitat, and fluvial geomorphology of the Darby and Cobbs Creeks watershed. The purpose of Section 10 is to examine the wide range of information presented in this report and to draw conclusions about the current state of the watershed. This analysis will provide a basis for future planning and management of the watershed.

10.1 Water Quality, Biology, and FGM Discussion

As part of the CCIWMP, the highest priority problems in the Cobbs Creek system were identified. With the exception of CSO-related issues, these same problems apply to some degree in the Darby and Tinicum subwatersheds. Given that the Cobbs Creek watershed is a highly urbanized watershed with both CSOs and significant stormwater flows, some of the highest priority problems include:

Dry Weather Water Quality and Aesthetics
- Water quality concerns including high fecal coliform during dry weather
- Dry weather sewage flows in separate sewered areas
- Trash-filled, unsightly streams that discourage residential use.
- Safety concerns along streams and stream corridors

Healthy Living Resources
- Degraded aquatic and riparian habitats
- Limited diversity of fish and benthic life
- Periodic, localized occurrences of low dissolved oxygen primarily associated with plunge pools and areas of stagnant water behind dams
- Utility infrastructure threatened by bank and streambed erosion
- Limited public awareness and sense of stewardship for Cobbs Creek

Wet Weather Water Quality and Quantity
- Water quality concerns including high fecal coliform during wet weather, and nutrients and metals during wet weather flows
- CSO impacts on water quality and stream channels
- Little volume control and treatment of stormwater flows in separate sewered areas

This section presents a brief summary of the analyses behind the watershed indicators presented in the CCIWMP. The data and analyses used to derive these results are documented in more detail in the Technical Memoranda and Comprehensive Characterization Report. The discussion covers each of five geographic areas as shown in Figure 10-1.

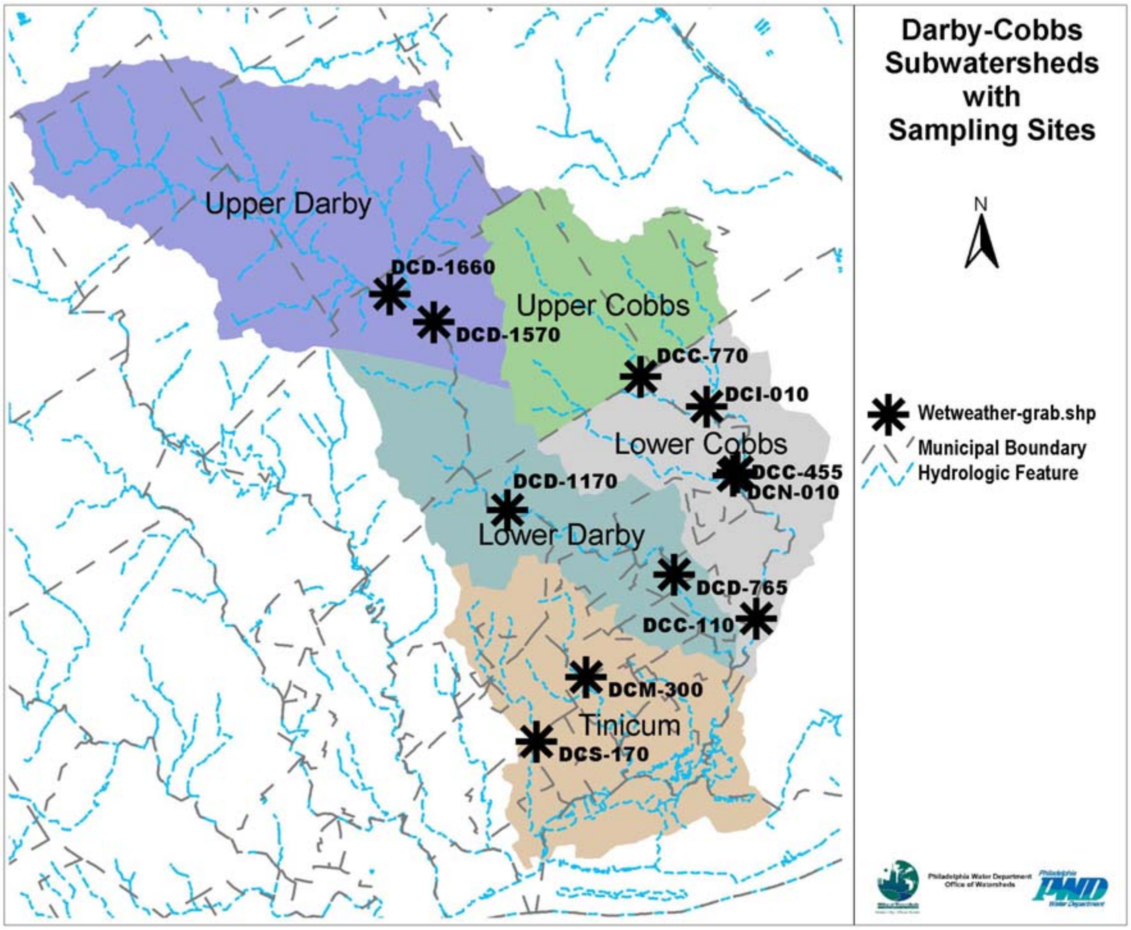


Figure 10-1 Subwatersheds and Sampling Sites

Upper Cobbs Creek

Two sampling sites represent the headwaters and upper reaches of Cobbs Creek. Site DCC-770 is on the main stem of Cobbs Creek near the Philadelphia/ Montgomery County line, and DCI-010 is on Indian Creek just above the confluence with the main stem. These sites do not receive CSO inputs.

Table 10-1 Status of parameters for Upper Cobbs

	Upper Cobbs Indicator Summary							
Site	1 Impervious Cover	2 Baseflow	3 Channel Type	5 Fish	6 Benthos	7 Bacteria	8 Metals	9 DO
DCC770	○	○	○	◐	○	○	●	●
DCI010	○	○	○		○	○	●	●
● Good ◐ Fair ○ Poor								

Land Use, Impervious Cover, and Stream Baseflow

The upper portion of Cobbs Creek consists of a mix of mainly residential land uses with disturbed urban soils, and significant natural park land along the stream corridor inside the City. Based on hydrograph separation analysis (documented in the Comprehensive Characterization Report), baseflow is approximately 43% of average annual rainfall for the Cobbs watershed as a whole. For French Creek, a reference stream with similar soils and geology, baseflow is 64% of average annual runoff. This difference is attributed to reduced groundwater recharge caused by urbanization.

Stream Channel Type and Trends

The headwaters of Cobbs Creek include East Indian Creek, West Indian Creek, and the upstream-most reaches of the main stem in Delaware County. Cross section surveys of East Indian Creek resulted in mostly B Rosgen channel types and a small number of F Rosgen channel types (Figure 10-2). A Rosgen channel type B is moderately entrenched, has a width/depth ratio greater than 12, and has moderate sinuosity. B channel types differ from F channel types since they generally have less steep, tall banks, and a deeper, more varied channel bed rather than being consistently flat. Sediment supply and bank erosion are usually high since they are actively changing through bed and bank erosion. Those East Indian Creek reaches classified as F channel types have completed downcutting and have undergone enough bank erosion to create a wide, flat bottom channel.

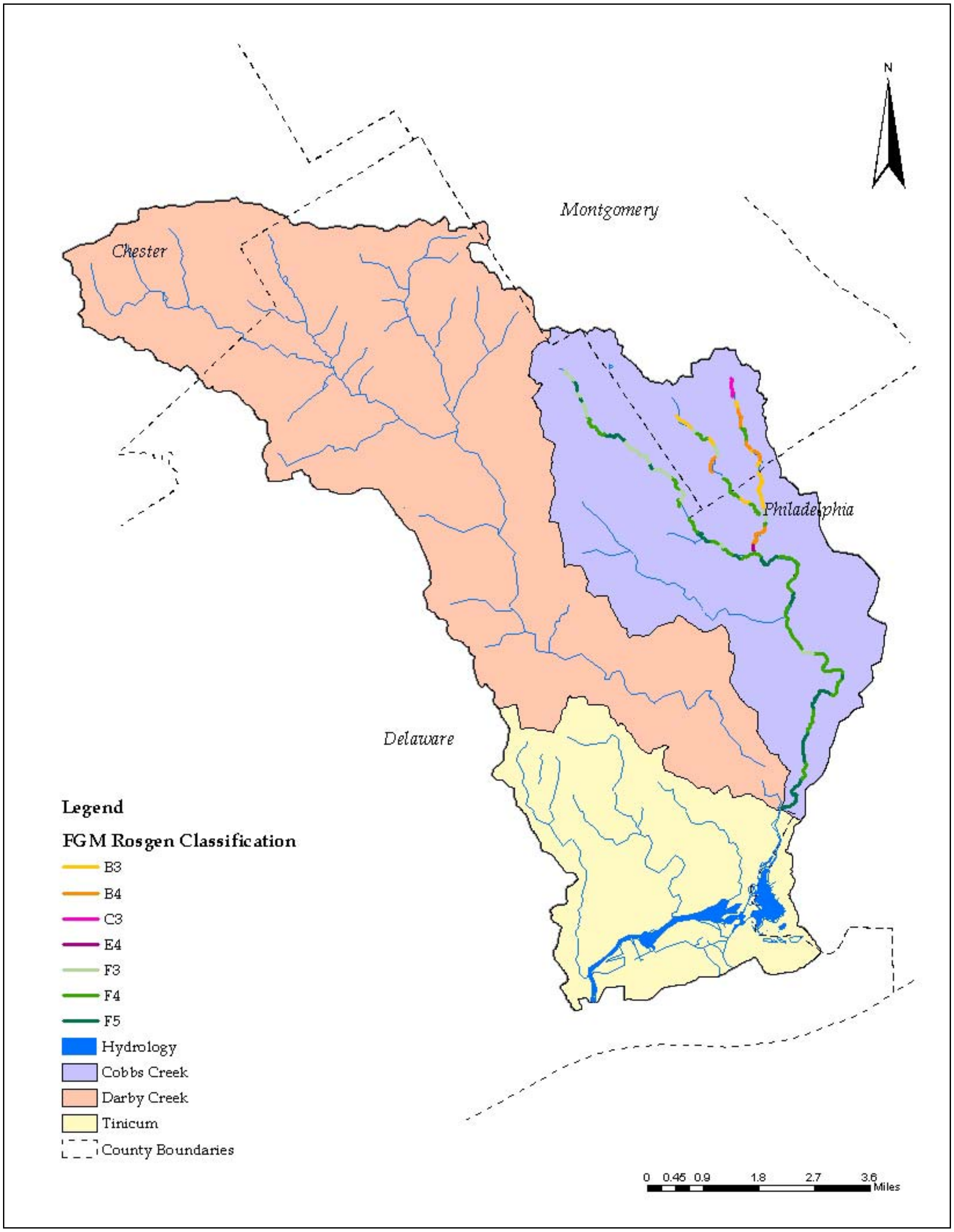


Figure 10-2 Fluvial Geomorphology Study - Rosgen Classification of Cobbs Reaches 2003

Bank conditions throughout East Indian Creek range from relatively stable in undisturbed areas to moderately eroded upstream of Lansdowne Avenue. Residential land use and regular mowing have limited the development of forested buffer, increased sediment supply, and facilitated bank erosion. Channel banks are the most degraded downstream of City Line Avenue where banks and adjacent slopes are the steepest within the subwatershed. These reaches are uncharacteristic of the remainder of the East Indian Creek subwatershed and are most similar to topography and valley types within the Cobbs Creek watershed.

Measured cross sections resulting in an F Rosgen channel type are located nearest the confluence with Cobbs Creek. These reaches have completed downcutting and possibly over-widening more quickly than the upstream reaches classified as B channel types. Existing channel geometry for the East Indian Creek suggests that the downstream end of East Indian Creek is further ahead in the channel migration process than the upstream portion. Over time, all reaches within East Indian Creek are expected to become F channel types and follow the same channel migration pattern over geologic time to transition to a stable C channel type.

West Indian Creek reaches are classified as B and F channel types. Overall, the upstream most portion of the channel is a B channel type and the downstream portion is an F channel type. The mid-section of West Indian Creek contains a transitional area where short overwidened F sections alternate with sections of entrenched, actively degrading B portions. West Indian Creek contains a greater percentage of F channel type than East Indian Creek, although both are still actively adjusting.

Most of West Indian Creek is surrounded by residential development where private homeowners have cleared forested buffers, reducing the buffer width to create additional lawn space or landscape their yards. Reaches downstream of City Line Avenue are the only ones within the subwatershed where a minimum of a 100-foot forested buffer remains. Additionally, 10 of the 15 reaches assessed are disturbed by in-stream structures, utilities, or road crossings.

Overall, bank erosion and sediment supply within the West Indian subwatershed were low and only a few isolated occurrences of more degraded banks were observed. None of the reaches assessed were determined to have high bank erosion or sediment supply ratings. Banks throughout this subwatershed are an average of 5 feet tall, although there are a few instances of banks that are higher than 6 feet tall. Additionally, existing conditions of West Indian Creek provide few indications of whether the channel is aggrading or degrading. Therefore, the reach bed stability was indeterminate throughout West Indian Creek.

The stream condition and stability of West Indian Creek are also influenced by a dam and pond located just downstream of Remington Road. West Indian Creek appears to have been redirected to the dam and away from the original channel located to the west of the pond. The original channel is approximately 5-8 feet wide, which is considerably smaller than the creek both upstream and downstream of the pond, and appears stable. Although the dam and associated structures appear to be in good condition, water in the pond was stagnant at the time of the field assessment. Because the dam and pond outfall downstream of Remington Road interrupt flow through the West Indian Creek, they are influencing the stability of the channel downstream.

West Indian Creek is also expected to follow the same channel migration pattern as Cobbs and East Indian Creek. West Indian Creek most likely was a stable B or C channel that began downcutting when development increased and has continued to adjust since that time. Since a greater percentage of West Indian Creek has migrated to an F channel type than in East Indian Creek, existing conditions suggest that West Indian Creek is further ahead in the channel migration process. Stream reaches within the West Indian Creek that are currently classified as B channel types are expected to over-widen and become F channel types over geologic time. Should no additional land use changes occur within the watershed, West Indian Creek will most likely begin forming depositional features and creating a more narrow, meandering channel within the old channel banks.

Channel cross section measurements and calculations show that the entire Cobbs Creek classifies as a Rosgen type F channel. A Rosgen type F channel is entrenched, has a width/depth ratio greater than 12, and has a low sinuosity. A low entrenchment ratio (less than 1.4 = a highly entrenched channel), allows for very high bank erosion, sediment supply and lateral over-widening in an effort to create a new floodplain within the channel. Lateral bars and moderated riffle/pool sequences are often present. F channel types generally have low slopes, ranging from less than 1 to 1%.

Bank conditions in Cobbs Creek vary throughout the watershed, and generally worsen as the Creek progresses downstream. Channel banks within the headwaters are no taller than 5 feet and are at least 60% vegetated. Bankfull width of the Creek in the headwaters is an average of 25 feet wide.

Currently, the majority of Cobbs has ceased downcutting and is continuing to over-widen. Evidence of over-widening is exhibited as undercutting and vertical banks. The majority of Cobbs Creek is expected to continue widening through bank erosion. The upstream-most portion is expected to begin downcutting and become more entrenched prior to beginning the over-widening stage that the remainder of the Creek is currently undergoing. The rate of channel over-widening will slow, or cease, when deposition is initiated in the channel.

Stream Biology

Indicators based on species abundance and diversity are poor in this portion of the system. Designated uses are considered unattained by PADEP, and both benthic and fish-based indicators indicate a moderately- to severely-impaired system. The sampling site on Indian Creek West Branch receives the lowest scores of any sampling site. However, habitat assessments are generally more positive. Site DCC-865, on Cobbs Creek main stem, scores the highest with respect to the reference stream of any sampling site in the system.

Pollutant Loads and Water Quality

Estimated loadings of water quality constituents, including nutrients, metals, and bacteria, are moderate compared to other portions of the watershed. However, mean nitrate concentrations measured at DCC-770 were some of the highest in the system. Observed DO concentrations meet state standards and are adequate to support aquatic life. The magnitude of the daily DO fluctuation is moderate at upper Cobbs sites, suggesting that excessive algal biomass is not present. Dry and wet weather bacteria counts are not as high as those found in the combined-sewered portion of the watershed, but they still rarely meet standards. With the exception of a small number of lead samples, concentrations of metals are low in dry and wet weather.

Lower Cobbs Creek

Three sampling sites represent lower Cobbs Creek. Site DCC-455 is on the main stem at Cobbs Creek Environmental Center, and DCN-010 is on Naylors Run just above the confluence with Cobbs Creek. Site DCC-110 is on the main stem about one mile above the confluence with Darby Creek. The two sites on the mainstem receive stormwater and CSO inputs, while the Naylors site receives only stormwater. Additional monitoring was conducted at DCC-115, just upstream of the dam at DCC-110.

Table 10-2 Status of parameters for Lower Cobbs

	Lower Cobbs Indicator Summary							
Site	1 Impervious Cover	2 Baseflow	3 Channel Type	5 Fish	6 Benthos	7 Bacteria	8 Metals	9 DO
DCC455	⭕	⭕	⭕	⭕	⭕	⭕	🟢	🟢
DCC110	⭕	⭕	⭕	⭕	⭕	⭕	◗	◗
DCN010/DCN208	⭕	⭕		⭕	⭕	⭕	🟢	🟢
🟢 Good ◗ Fair ⭕ Poor								

Land Use, Impervious Cover, and Stream Baseflow

The lower portion of the Cobbs Creek watershed is highly urbanized and highly impervious, with high-density residential areas in the City, a mix of high- and lower-density residential areas in Montgomery County, commercial land uses along highway corridors, and park land along riparian corridors. Combined sewers serve the Philadelphia portion of the watershed. Based on hydrograph separation analysis (documented in the Comprehensive Characterization Report), baseflow is approximately 43% of average annual rainfall for the Cobbs watershed as a whole. For French Creek, a reference stream, baseflow is 64% of average annual runoff.

Stream Channel Type and Trends

Bank conditions throughout Cobbs Creek vary throughout the watershed and generally worsen as the Creek progresses downstream. As the Creek progresses downstream, banks transition to greater than 6 feet tall and less than 50% vegetated. Bankfull width varies from 25 feet to approximately 60 feet wide.

Existing sediment supply and reach bed stability also worsen as the Creek continues downstream. Reaches in the headwaters are an average of 25 feet wide at bankfull and increase to an average width of 60 feet near the confluence with Darby Creek.

Generally, it is the goal of an F channel type to cease downcutting and begin depositing bed materials as alternating lateral bars. Deposition forming lateral bars in turn continues the over-widening process. Alternating lateral bars will slowly build over time through exchange of sediment during bankfull events to effectively decrease the width of the channel accessible by base flow. Limiting the width of the channel through the creation of alternating lateral bars will yield a greater sinuosity and a new, lower floodplain. Although an F channel type is not considered stable, it will generally migrate to a stable C channel type over geological time.

Currently, the majority of Cobbs has ceased downcutting and is continuing to over-widen. Evidence of over-widening is exhibited as undercutting and vertical banks. The majority of Cobbs Creek is expected to continue widening through bank erosion. The rate of channel over-widening will slow, or cease, when deposition is initiated in the channel.

Stream Biology

As has historically been the case in many urban stream ecosystems, the moderately impaired benthic community and pollution tolerant fish assemblages in Cobbs Creek are an apparent result of habitat deterioration and episodic water quality degradation throughout the watershed. All of the Cobbs watershed is classified as unattained by PADEP. Sampling sites are moderately to severely impaired based on benthic criteria. Habitat is classified as partially supporting aquatic life uses at approximately 60% of the reference stream condition.

Cobbs Creek watershed is a highly urbanized region where traditional methods of stream bank "reconstruction" and storm water management have significantly channelized the stream, creating a system which is not in dynamic equilibrium (i.e. the amount of erosion and sedimentation is not equal to the amount of sediment transport out of the system). Furthermore, this aquatic ecosystem has lost much of its link magnitude (e.g. small first order streams) and wetland systems due to development and increased impervious surfaces. By changing the "natural" state of the stream, development has altered the hydrologic profile, decreasing the time to peak flow and increasing the peak flow itself. In doing so, events reaching or exceeding bankfull stage are no longer managed by the stream channel and flood plain. Typical events scour stream banks, fill pool systems and cover riffle structures with sediment at an accelerated rate. As a result, a highly ephemeral (short-lived) system with increased sediment deposition, decreased habitat heterogeneity (e.g. pool-riffle-run systems) and unstable stream banks has been created. Biologically, these processes have had a deleterious effect on the benthic and ichthyfaunal communities inhabiting Cobbs Creek. Three of the most important attributes of streams for macroinvertebrate and fish persistence are oxygen, food, and habitat. Although the first two attributes are equally important, habitat modifications and loss of habitat appear to be the primary reasons for decreases in species diversity and fecundity, skewed population dynamics and increases in "pollution tolerant" species in Cobbs Creek.

Benthic invertebrates rely heavily on riffle systems as primary habitat to carry out most or all of their life cycles. Morphologically, many species have evolved and adapted to handle increased flow over riffle systems (e.g. dorsally flattened bodies, claws for clinging). However, increases in flow, sediment deposition and scouring in Cobbs Creek have impeded reproductive and feeding strategies of many species of macroinvertebrates. Those individuals not adapted to extreme hydrologic fluctuations have been extirpated from this area. Also, sediment deposition has created embedded riffle systems where eggs are either scoured downstream or covered by layers of fine and course sediment. By decreasing the species richness and evenness of the benthic community, functional feeding groups have also been modified. Many species responsible for conditioning course particulate organic matter (CPOM), are no longer present in this watershed (e.g. Order: *Plecoptera*). Organisms well adapted to hydrologic extremes and pollution, such as blackflies (Family: *Simuliidae*), *Hydropsychid* caddisflies (Family: *Hydropsychidae*) and midges (Family: *Chironomidae*) currently dominate the assessed areas. In addition to the community dynamics, the fluvial geomorphological profile in Cobbs Creek has created temporary riffles where spates may virtually change the "aqua-scape" in a period of days.

Like the benthic invertebrate community, fish communities rely heavily on various habitats within a stream reach. Many species (e.g., *Etheostoma olmstedi*) have adapted to shallow riffles systems for food acquisition. Other species (e.g. *Micropterus* sp.) rely on large pools for foraging and reproduction. Stream runs with vegetated areas are also important habitat components for many species of fish. Extremes in the hydrologic profile of Cobbs Creek have also contributed to decreased species diversity and offspring of fish within this area. Many species rely on vegetation or rocks to deposit their eggs, while other species build nests that are closely guarded by the parent or parents. Extreme flow conditions contribute to the deposition of sediment in pool systems and scouring regions where offspring have been deposited, thus increasing mortality rates in eggs and fry populations. In addition, pool systems in this area are highly dynamic (e.g., a moderately sized pool can be covered within a few days).

Pollutant Loads and Water Quality

Pollutant loading estimates generally correspond to degree of development, as represented by population density, in the separate-sewered areas, and are some of the highest in the system. BOD, TSS, and bacteria loading estimates are relatively high in the combined-sewered areas, while nutrient loading estimates are relatively low due to the proportion of captured flows. Estimates of metals loadings are mixed compared to other portions of the system.

Storm hydrographs at DCC-455 and DCC-110 in this portion of the system display the high intensity, low-duration behavior typical of highly urbanized, highly impervious systems; these high-velocity flows are erosive and can present a problem for aquatic life. Turbidity also increases sharply in wet weather and may indicate a combination of fine sediment in stormwater runoff, and streambed and bank erosion.

There is evidence to indicate that lower Cobbs sites, and DCC-455 in particular, may be eutrophic. Observed nitrate generally decreases along Cobbs Creek main stem; mean nitrate at DCC-455 is greater than mean nitrate at DCC-110, and observed nitrate concentrations at DCN-010 are among the highest in the system. The large daily range in DO and qualitative observations at DCC-455 suggest that this site is the most biologically active among the sites sampled. Continuous data suggest that DO at DCC-110 is below the level needed to support aquatic ecosystems approximately 5% of the time. DCC-115, located just above a low dam, experiences the lowest DO of any site due to poor mixing.

Bacteria counts in the lower Cobbs exceed standards in both dry and wet weather and in both combined- and separate-sewered areas. Copper, lead, and zinc exceed standards in wet weather at DCC-110. Stormwater outfalls and combined sewer overflows (CSOs) have also exacerbated the problems of sedimentation and erosion as well as contributed to episodic periods of reduced water quality.

Upper Darby Creek

The headwaters of Darby Creek are represented by data taken from site DCD-1570 and by a limited amount of data from DCD-1660. These sites are not impacted by known CSOs.

Table 10-3 Status of parameters for Upper Darby

	Upper Darby Indicator Summary							
Site	1 Impervious Cover	2 Baseflow	3 Channel Type	5 Fish	6 Benthos	7 Bacteria	8 Metals	9 DO
DCD1660	⭕	🟢			🟢	◗	🟢	◗
DCD1570	⭕	🟢			🟢	🟢	🟢	🟢
	🟢 Good	◗ Fair	⭕ Poor					

Land Use, Impervious Cover, and Stream Baseflow

The upper portion of the Darby Creek watershed is the least urbanized portion of the system and consists of mixed residential, commercial, park land, and golf course land uses. Estimates of pollutant loads are relatively low with the exception of commercial areas in the northern-most portion of the watershed. Hydrograph separation analysis of a USGS gauge in the headwaters (01475300) indicates that baseflow comprises approximately 66% of mean annual flow, similar to an undeveloped system.

Stream Biology

The upper portion of the Darby Creek watershed is listed by PADEP as attaining its designated uses. Benthic indicators range from poor to very good at different sites, and fish indicators range from fair to good. Habitat assessment data are limited. Although the area is less urbanized than other portions of the Darby and Cobbs Creeks watershed, continuous monitoring data of depth and turbidity still display the high flood peaks and short durations typical of urban flows. Qualitative assessments by ANS and PADEP indicate that some erosion has occurred, and the amount of erosion generally increases from upstream to downstream along the length of the Darby.

Pollutant Loads and Water Quality

Although many estimated pollutant loads are low in the area, estimated nitrogen and phosphorus loads are moderate, as expected from landscaped areas. DO is generally adequate to support aquatic life, although water temperatures occasionally exceed standards for designated cold water fisheries. DO fluctuations are smaller than those observed in other parts of the system, suggesting less algal activity and a less-enriched system. Bacteria counts are lower than those found downstream, but most samples still do not meet standards. Concentrations of metals increase in wet weather but do not exceed standards for protection of aquatic life.

Lower Darby Creek

Lower Darby Creek is represented by two sampling sites. DCD-1170 is on the main stem downstream of PA Route 3, and DCD-765 is upstream of the confluence with Cobbs Creek. These sites are impacted by stormwater but not by known CSOs.

Table 10-4 Status of parameters for Lower Darby

	Lower Darby Indicator Summary							
	1	2	3	5	6	7	8	9
Site	Impervious Cover	Baseflow	Channel Type	Fish	Benthos	Bacteria	Metals	DO
DCD1170	○	○			○	○	●	●
DCD765	○	○			○	○	●	●

● Good ◐ Fair ○ Poor

Land Use, Impervious Cover, and Stream Baseflow

The lower portion of the Darby Creek watershed consists primarily of a mix of single and multiple-family residential land uses. The estimated average annual runoff is 17.8 inches or 43% of average annual rainfall; this level of imperviousness is similar to upper Cobbs, less than lower Cobbs, and greater than upper Darby. As in other separate-sewered areas, estimated constituent loadings generally follow trends in imperviousness and population density. Continuous monitoring data indicate high-intensity, short-duration runoff events occur that are likely to cause erosion of streambeds and banks.

Stream Biology

PADEP lists lower Darby Creek, defined as the area below PA Route 3, as unattained for designated uses. ANS and PADEP list benthic quality as poor and fish quality as fair. Habitat data are limited, but observed erosion is generally greater than that observed further upstream. These conditions suggest that in addition to some instances of degraded water quality in wet weather, urban flow modifications are degrading habitat.

Pollutant Loads and Water Quality

There is some evidence that DCD-765 may be nutrient-enriched. Nitrate and ammonia concentrations increase slightly over the length of Darby Creek, although they are generally lower than those found in the Cobbs Creek system. DO is less than the state standard during some wet weather events.

Bacteria counts are lower in dry weather than those found in Cobbs Creek; however, wet weather bacteria counts are similar to those found in the combined-sewered areas of Cobbs Creek. Metals concentrations increase in wet weather as they do throughout the system and sometimes exceed state standards at DCD-765.

Tinicum

Two sampling sites represent conditions in the Tinicum area. These include DCM-300 on Muckinipattis Creek and DCS-170 on Stony Creek.

Table 10-5 Status of parameters for Tinicum

	Tinicum Indicator Summary							
	1	2	3	5	6	7	8	9
Site	Impervious Cover	Baseflow	Channel Type	Fish	Benthos	Bacteria	Metals	DO
DCM300	○				○	○	●	●
DCS170	○				○	○	●	●

● Good ◐ Fair ○ Poor

Land Use, Impervious Cover, and Stream Baseflow

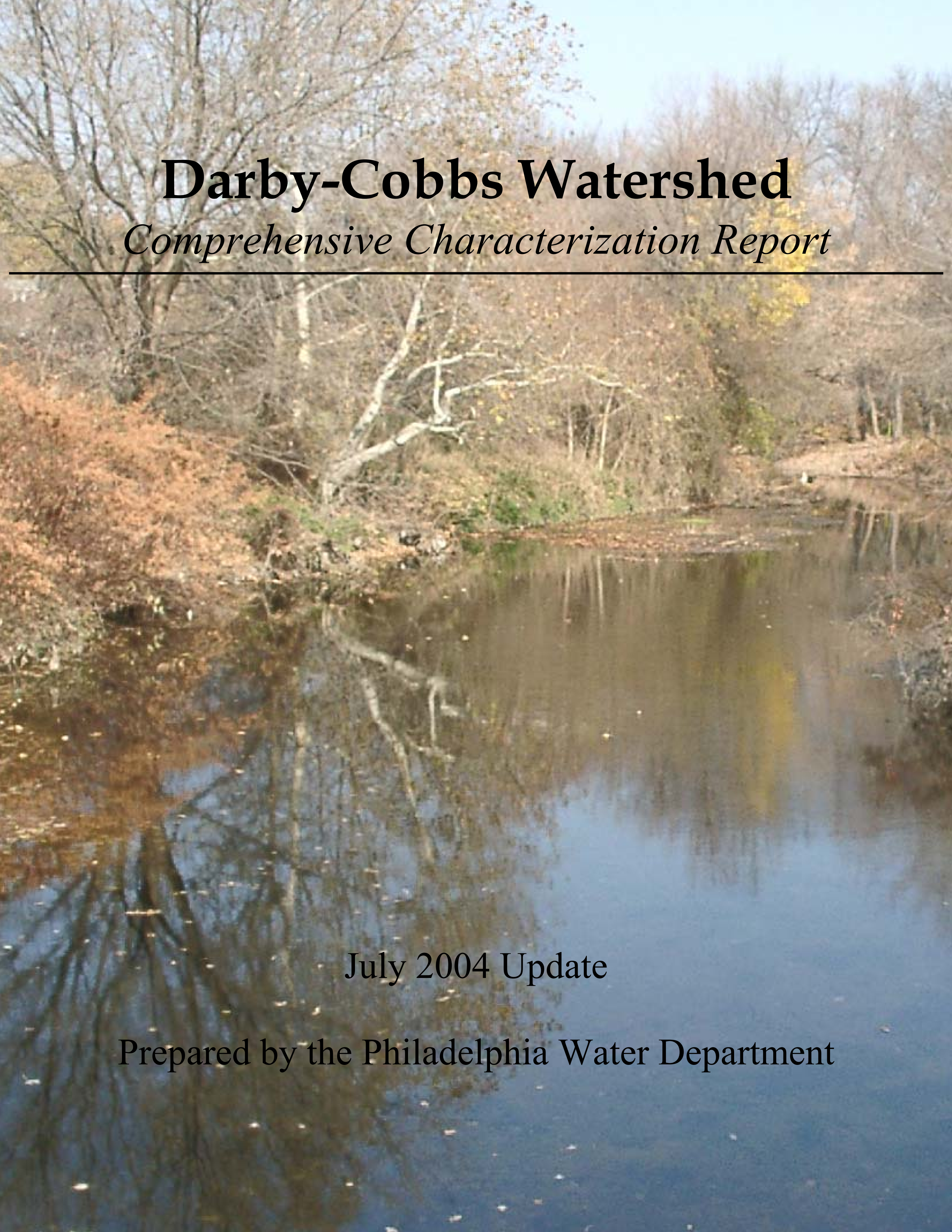
The Tinicum watershed consists of residential and commercial development to the northwest and undeveloped wetlands and marshes to the southeast. The more developed portion of the watershed results in moderate pollutant load estimates relative to other portions of the watershed.

Stream Biology

PADEP lists the area as unattained based on benthic macroinvertebrate species diversity.

Pollutant Loads and Water Quality

Discrete DO samples sometimes were less than state standards in dry and wet weather. Nitrate is generally lower in Tinicum than in other parts of the system, but ammonia is generally greater. Metals concentrations are elevated and sometimes exceed state standards in wet weather.



Darby-Cobbs Watershed

Comprehensive Characterization Report

July 2004 Update

Prepared by the Philadelphia Water Department

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ACKNOWLEDGEMENTS

Philadelphia Water Department (PWD) would like to thank those individuals who devoted their time and energy to assist water department personnel in completing the comprehensive assessment of Darby-Cobbs Watershed. In particular, Mike Boyer and Alan Everett of the Pennsylvania Department of Environmental Protection (Southeast Regional Office) were instrumental in field assistance and quality control/quality assurance oversight. Paula Conolly (D.S. Winokur), Virginia Ranly (D.S. Winokur) and Gary Martens (Camp, Dresser & McKee) provided support with field work, database management and Geographic Information Systems (GIS).

PWD would also like to thank Drexel University's Cooperative Program for providing highly qualified students to assist in various monitoring programs. More specifically, Kelly Anderson, Rick Howley and Jim Pagana contributed to the fieldwork effort and assisted in data organization.

In addition to the aforementioned individuals and agencies, scientists from the Office of Watersheds (OOW) and Bureau of Laboratory Services (BLS) would like to extend their gratitude to individuals within the Water Department for their involvement in the assessment. Maureen Jaroszewski, Marla Johnson, Steve Ostrowski, Joe Roman, Cindy Rettig and staff, and the staff of the Central Receiving Unit were actively involved with fieldwork activities and/or laboratory analyses.

SECTION 1: INTRODUCTION

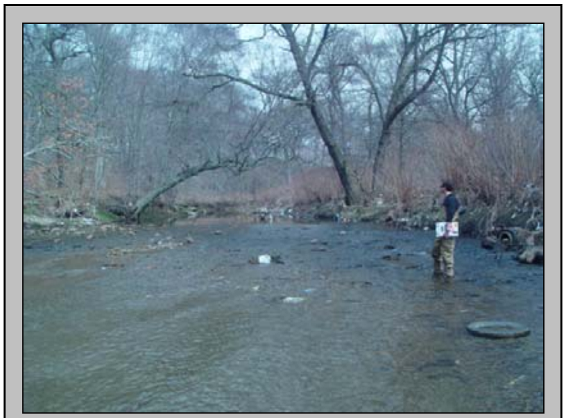
This report summarizes the Philadelphia Water Department's (PWD) Watershed Sciences Group 2003 comprehensive assessment of Darby-Cobbs Watershed. Since the last comprehensive assessment, conducted in 1999, the understanding of the watershed has been advanced by numerous studies and modeling exercises, funded largely by the Commonwealth of Pennsylvania (e.g., Acts 167, 104b3 and 537). These investigations, combined with considerable urban planning and community stewardship efforts, have culminated in the Cobbs Creek Integrated Watershed Management Plan (CCIWMP). Comprehensive watershed assessments conducted in 1999 and 2003 informed the decision-making and prioritization processes of the plan, and future assessments will complement state water quality criteria in providing a scientific means to measure improvements once restoration activities are implemented.

While improvements to the watershed are interrelated and will happen concurrently, the CCIWMP presents the overall goal of watershed restoration as a series of targets: A) dry weather water quality, B) healthy living resources, and C) wet weather water quality. Management plan targets are addressed by various components of this comprehensive watershed assessment, including physical habitat assessments, water quality monitoring, and algae, benthic macroinvertebrate, and fish surveys. Since components of an aquatic ecosystem are interrelated, this integrative approach allows for a greater understanding of factors affecting the aquatic ecosystem that would not be possible if individual elements were studied alone. Of primary importance is understanding how the physical and chemical attributes of streams affect algae, invertebrate, and fish communities, because healthy aquatic communities cannot survive in the absence of healthy habitats.

As impairments are identified and corrected, the Watershed Sciences Group is responsible for measuring improvements quantitatively. If improvements are unsatisfactory or absent, PWD and its CCIWMP partners must identify remaining causes of impairment. Many tools available to aquatic biologists were developed to identify impairments due to organic pollution from point sources and runoff. Traditional bioassessment tools may not be useful for monitoring BMPs. Reference site conditions may not be replicable due simply to differences in climate and geography. Interpretation of bioassessment data must integrate results of other data collection efforts so as not to misattribute impairment to less important, or even unrelated, causes. Lastly, our investigations suggest that biogeography and dispersal ability of sensitive indicator organisms may play an important role in how quickly improvements, as measured by bioassessment techniques, manifest themselves following stream restoration or improvements in water quality.

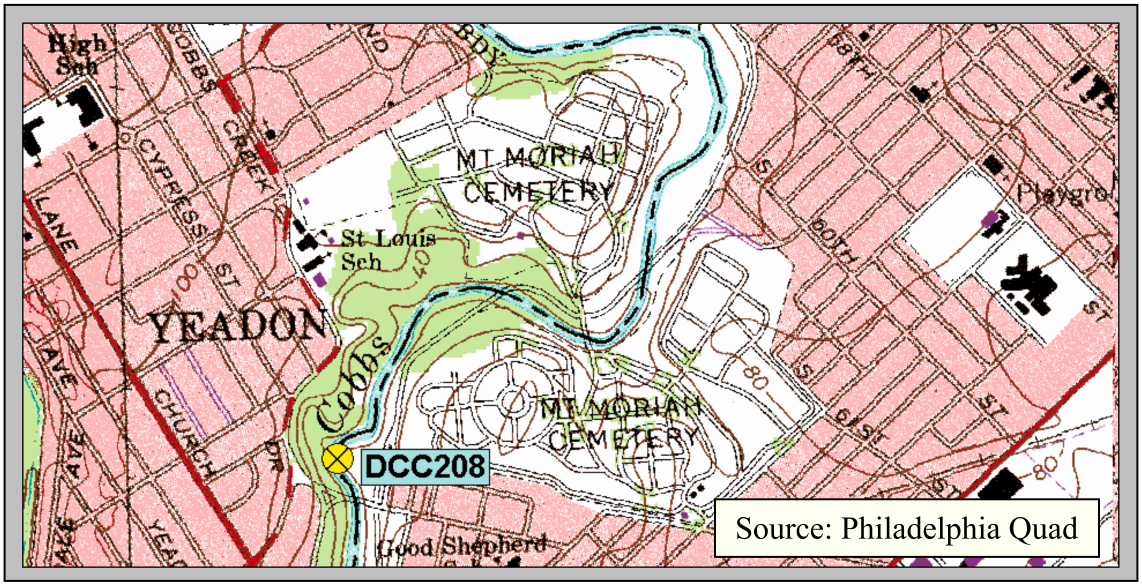
SECTION 2: SITE LOCATIONS AND DESCRIPTIONS

2.1. *DCC 208: Darby-Cobbs Study Area* **Philadelphia County**



Upstream view of DCC208

Downstream view of DCC208



Source: Philadelphia Quad

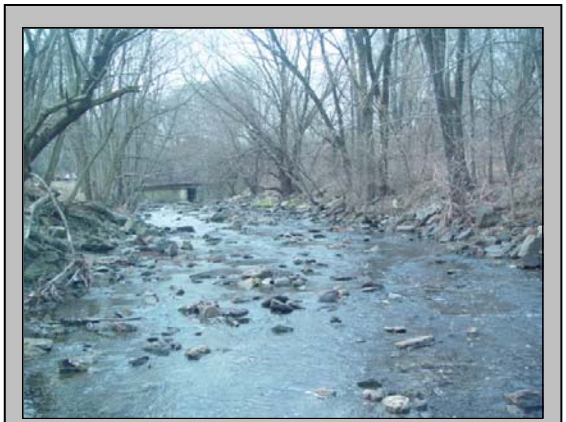
Location:

Access gained from 65th Street and the Cobbs Creek Parkway. (Latitude: -75.24459, Longitude: 39.93046)

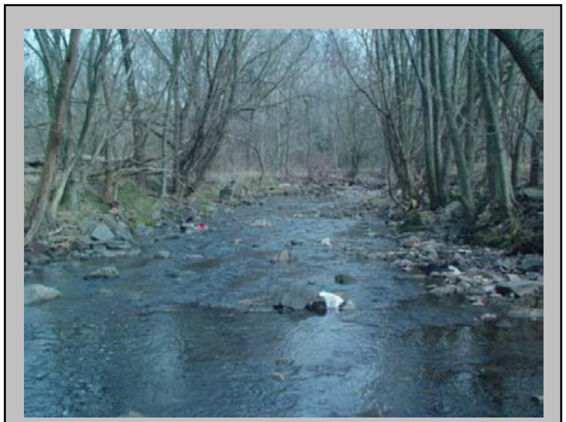
Description:

DCC208 is located upstream of a bridge near 65th Street and Cobbs Creek Parkway. The surrounding land use consists of a residential area and a cemetery. Cobbs Creek Parkway runs along the left bank of the creek at this location.

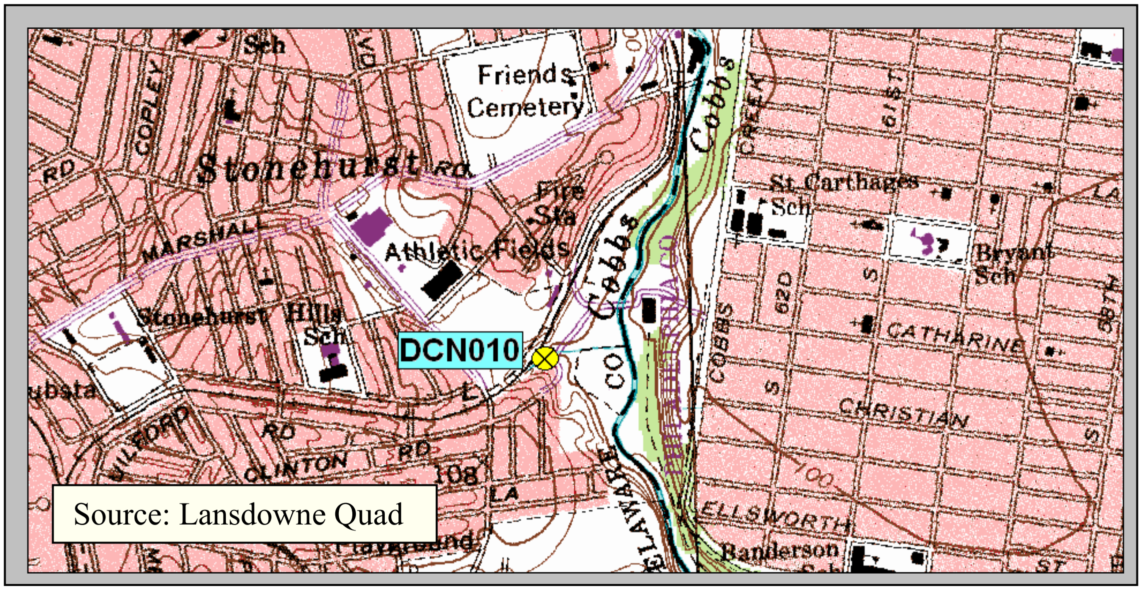
2.2. DCN 010: Darby-Cobbs Study Area Delaware County



Upstream view of DCN010



Downstream view of DCN010



Source: Lansdowne Quad

Location:

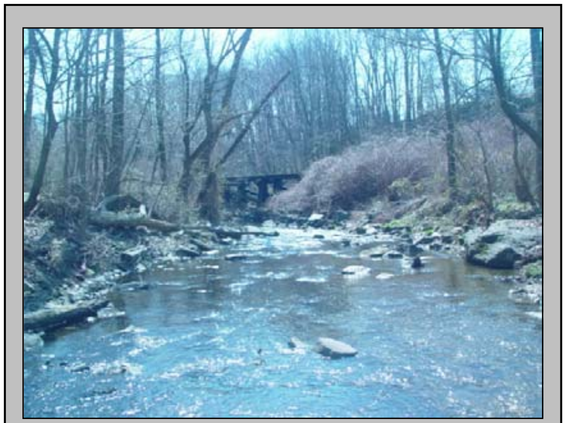
Access gained from Walnut Park Road off of 69th Street. (Latitude: -75.25336, Longitude: 39.95100)

Description:

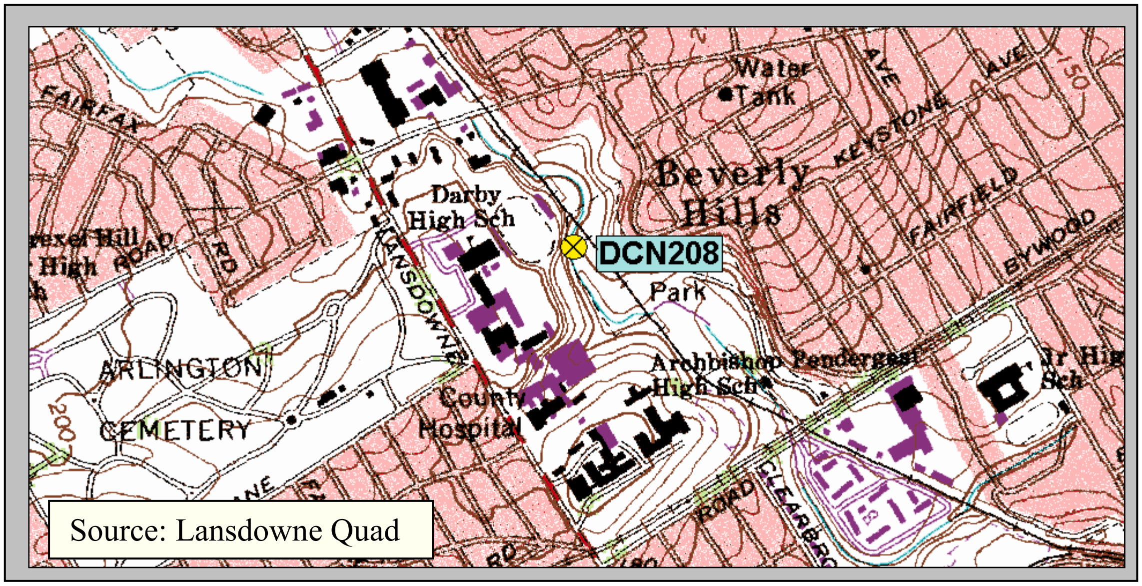
Site DCN010 is located on Naylors Run, just upstream of the confluence with Cobbs Creek. The site contains a lot of artificial substrate (concrete, bricks, etc.). The surrounding land use is field/pasture and residential.

2.3. *DCN 208: Darby-Cobbs Study Area* Delaware County

Upstream view of DCN208



Downstream view of DCN208



Source: Lansdowne Quad

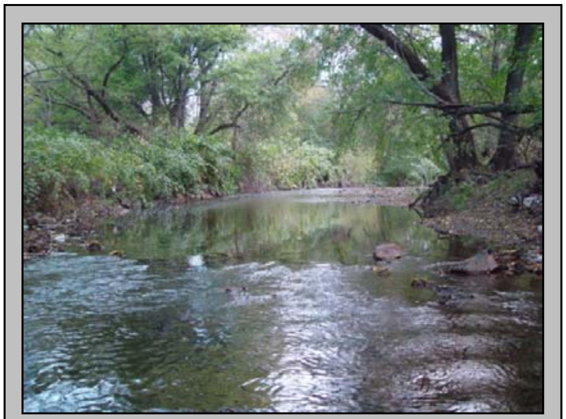
Location:

Access gained off of Garrett Road across from Barclay Square. (Latitude: -75.28287, Longitude: 39.95743)

Description:

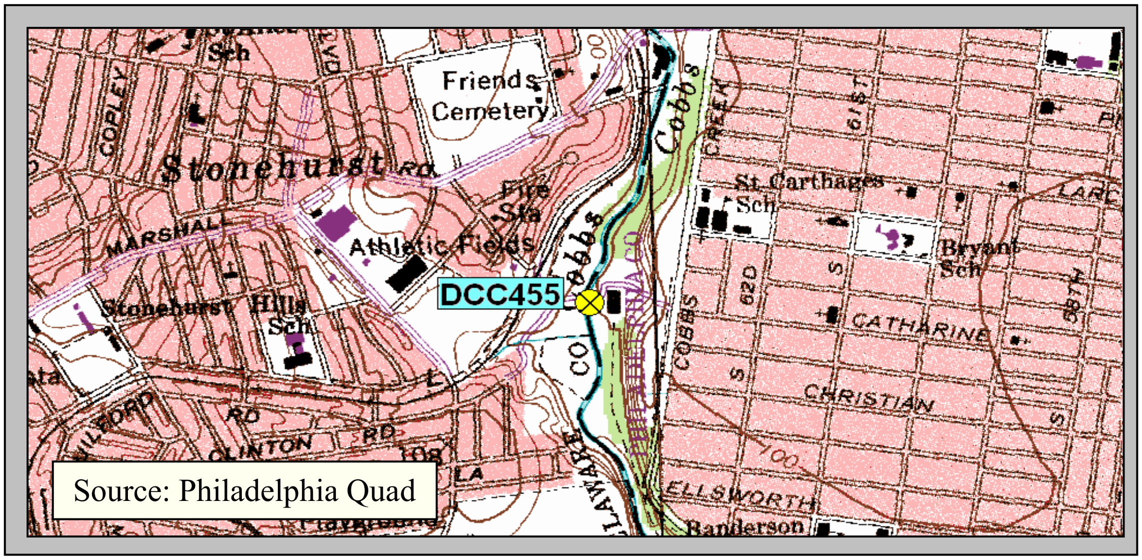
DCN208 is located on Naylors Run near Upper Darby High School. The surrounding land use is residential, and obvious sources of nonpoint source pollution exist near the site. A dam is present 250 meters downstream from the site, at which point the stream is also channelized.

2.4. DCC 455: Darby-Cobbs Study Area Philadelphia County



Upstream view of DCC455

Downstream view of DCC455



Source: Philadelphia Quad

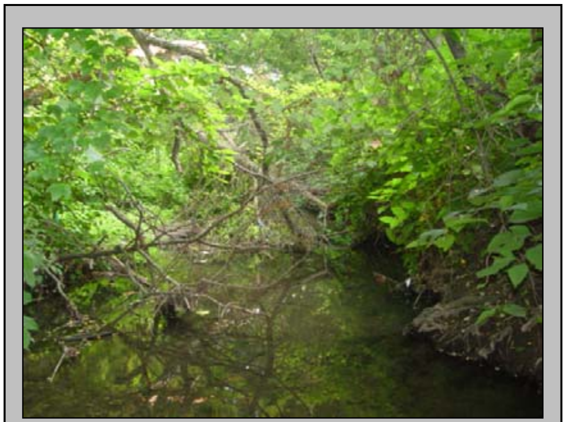
Location:

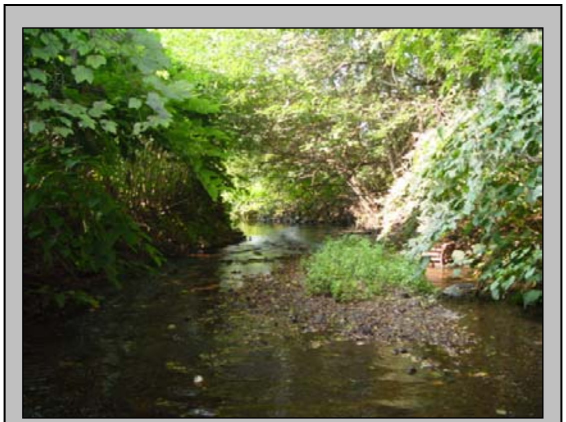
Access gained from the Cobbs Creek Community Environmental Education Center. (Latitude: -75.25203, Longitude: 39.95178)

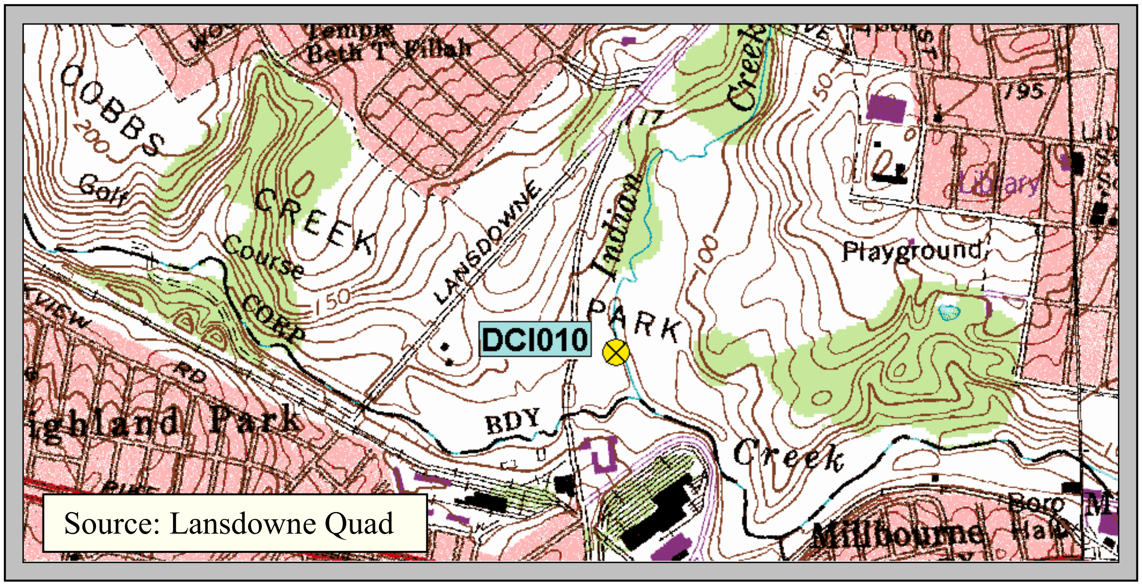
Description:

Site DCC455 is located 200 meters upstream of the footbridge behind the Cobbs Creek Community Environmental Education Center. The site is within the Cobbs Creek portion of Philadelphia's Fairmount Park. The surrounding land use is parkland and residential.

2.5. *DCI 010: Darby-Cobbs Study Area* Montgomery County


Upstream view of DCI010


Downstream view of DCI010



Source: Lansdowne Quad

Location:

Access gained from Cobbs Creek Golf Course near Haverford Avenue. (Latitude: -75.26084, Longitude: 39.96726)

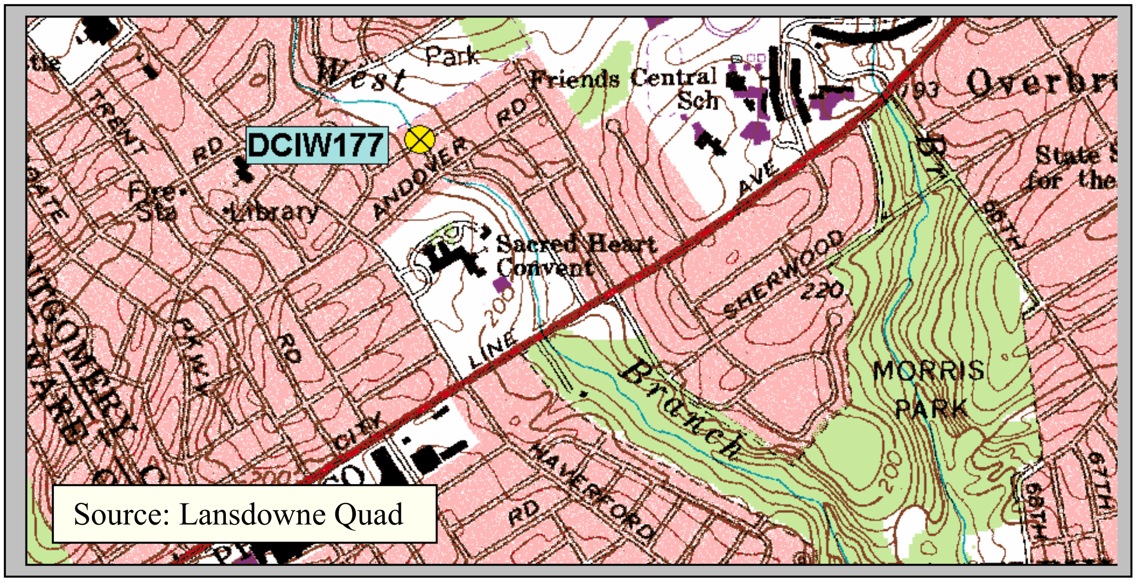
Description:

Site DCI010 is located within the Cobbs Creek Golf Course on Indian Creek. The site is positioned 100 meters upstream up a golf cart crossing. The surrounding land use is Cobbs Creek Golf Course.

2.6. *DCIW 177: Darby-Cobbs Study Area* Montgomery County

Upstream view of DCIW177

Downstream view of DCIW177



Source: Lansdowne Quad

Location:

Access gained at Manoa and Wiltshire Roads. The site is adjacent to Penn Wynne Playground. (Latitude: -75.27062, Longitude: 39.98483)

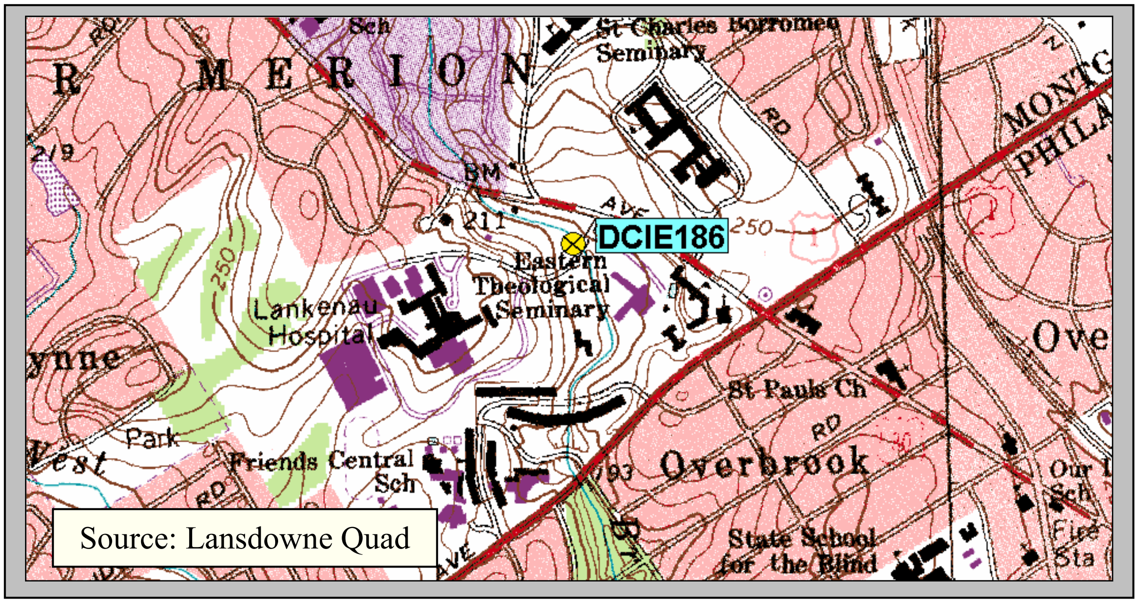
Description:

Site DCIW177 is located on the west branch of Indian Creek near City Line Avenue. The stream is channelized at this portion with vegetation established on the banks. The surrounding land use is a mowed grass ballfield.

2.7. DCIE 186: Darby-Cobbs Study Area Montgomery County

Upstream view of DCIE186

Downstream view of DCIE186



Source: Lansdowne Quad

Location:

Access gained from Lankenau Hospital parking area. (Latitude: -75.25912, Longitude: 39.98964)

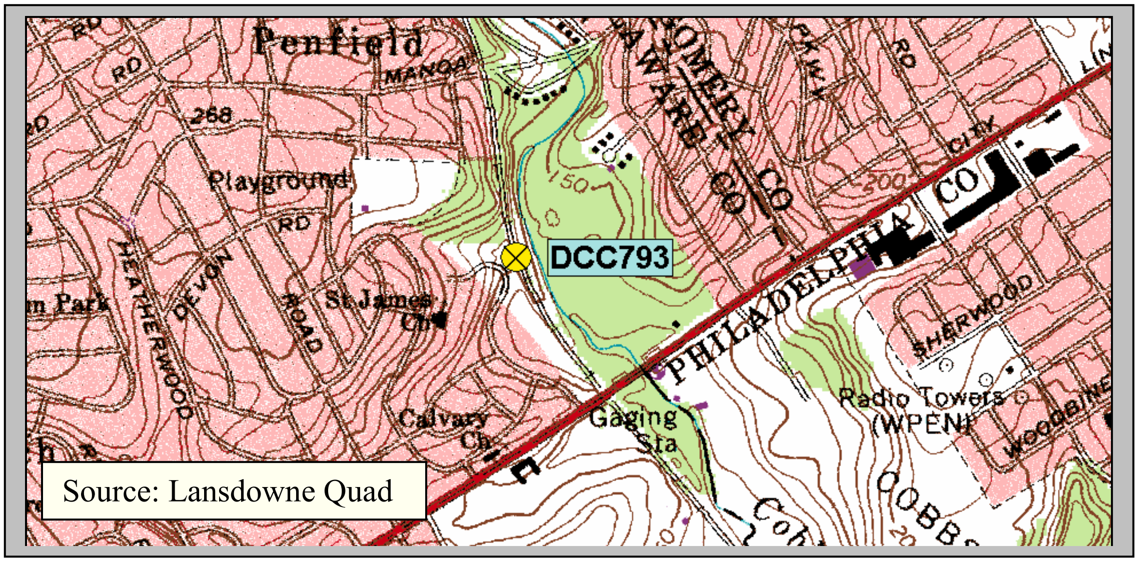
Description:

DCIE186 is located on the East Branch of Indian Creek near the Lankenau Hospital. The surrounding land use consists of the hospital as well as other commercial facilities and residential areas.

2.8. DCC 793: Darby-Cobbs Study Area Delaware County


Upstream view of DCC793


Downstream view of DCC793



Source: Lansdowne Quad

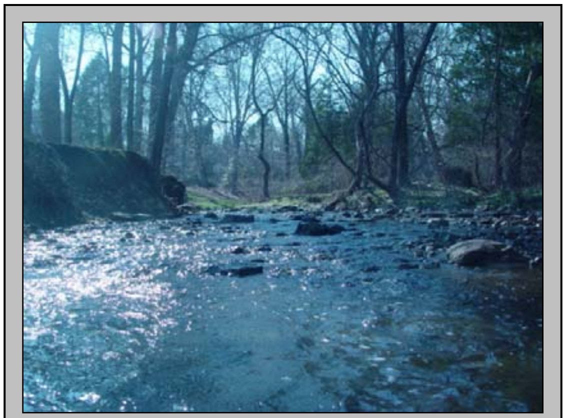
Location:

Access gained by a private road on the Grange Estate Property near City Line Avenue (official entrance off of Myrtle Street). (Latitude: -75.28322, Longitude: 39.97710)

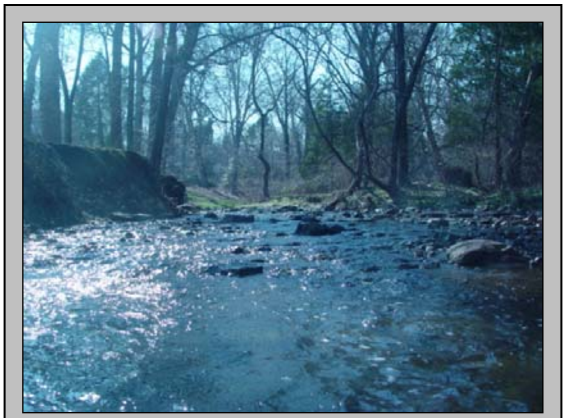
Description:

DCC793 is located on the edge of a private estate. The surrounding land use is residential and field/pasture land. The Creek passes underneath a railroad track close to the site.

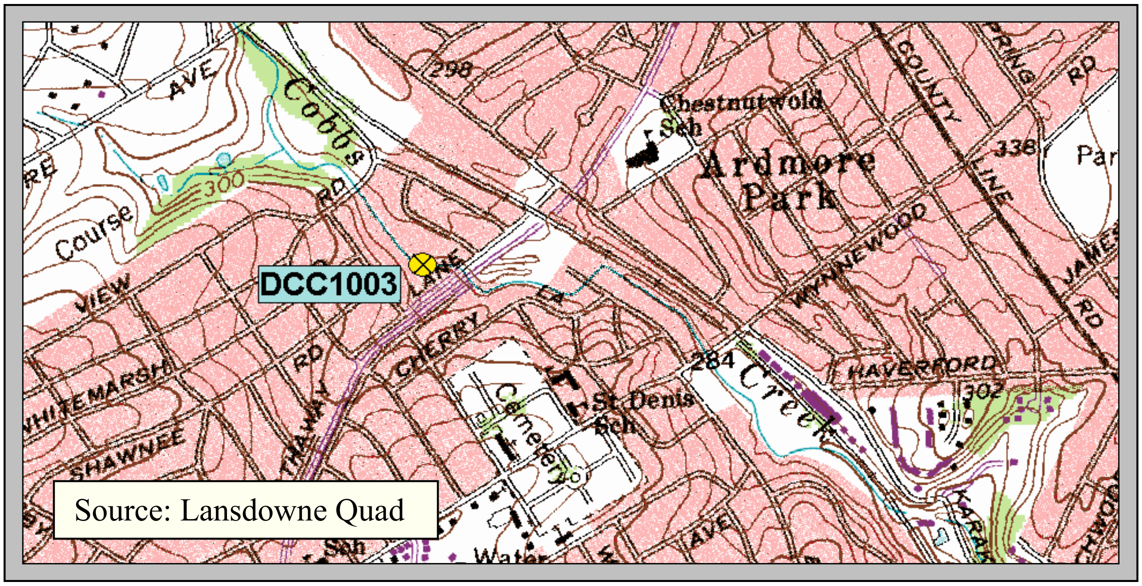
2.9. *DCC 1003: Darby-Cobbs Study Area* Delaware County



Upstream view of DCC1003



Downstream view of DCC1003



Source: Lansdowne Quad

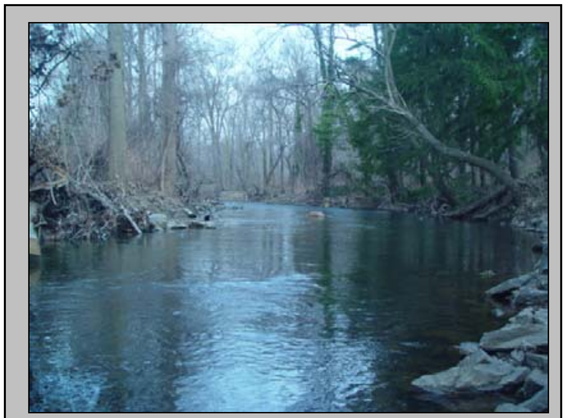
Location:

Access gained from Hathaway Bridge on Hathaway Lane off of Haverford Road. (Latitude: -75.30657, Longitude: 39.99499)

Description:

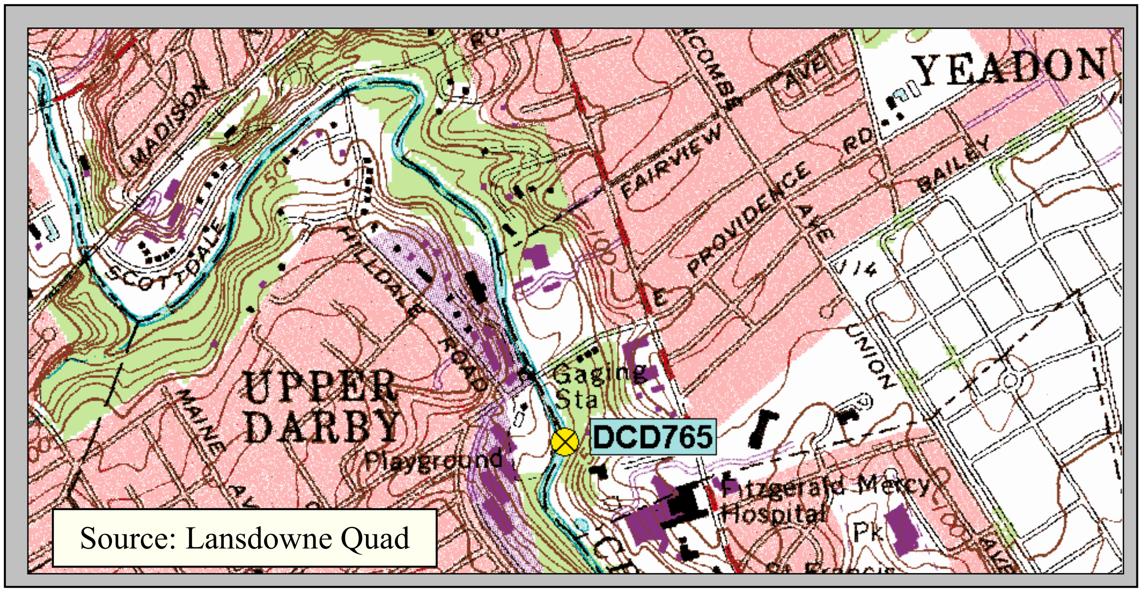
DCC1003 is the most upstream site on Cobbs Creek. It is located just upstream of the bridge on Hathaway Lane. The surrounding land use is single-family residential housing.

2.10. DCD 765: Darby-Cobbs Study Area Delaware County



Upstream view of DCD765

Downstream view of DCD765



Source: Lansdowne Quad

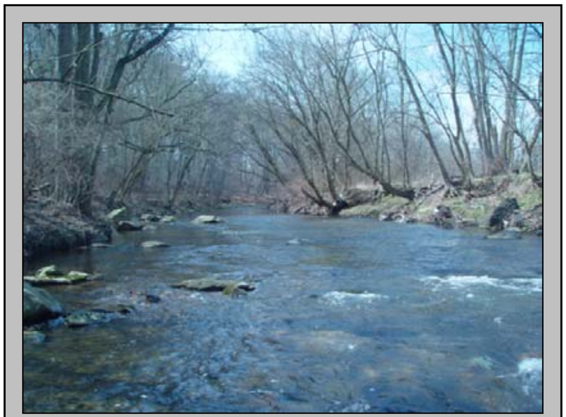
Location:

Access gained from the ballpark and playground located on Providence Road. The site is 100 meters downstream of Providence Road. (Latitude: -75.27214, Longitude: 39.92807)

Description:

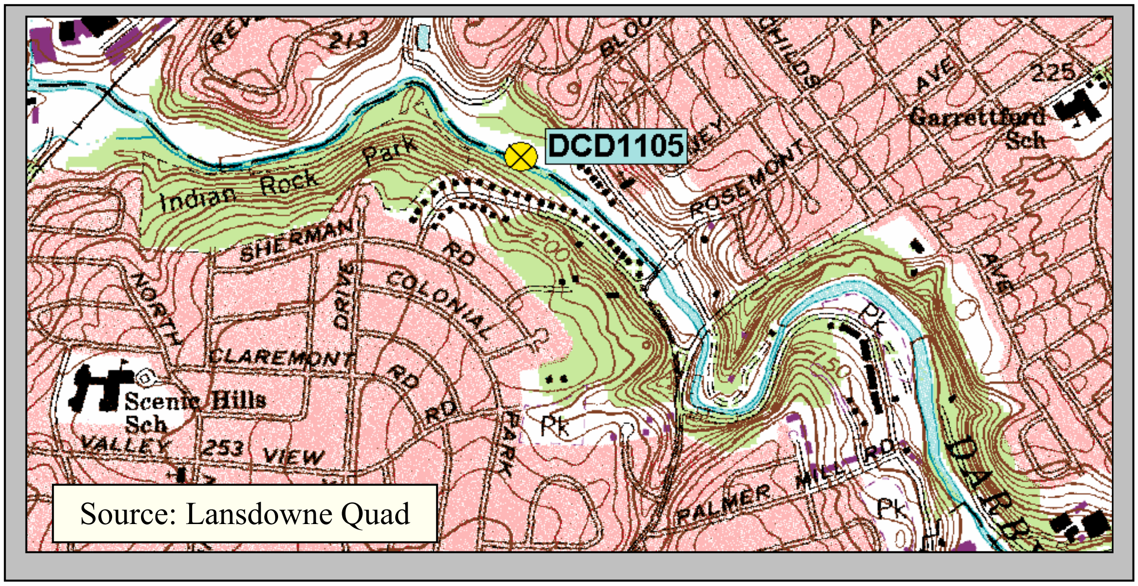
The general land use surrounding DCD765 is residential and commercial. The area immediately surrounding the site includes a baseball field and playground. The left bank of the stream reach has been modified with riprap.

2.11. DCD 1105: Darby-Cobbs Study Area Delaware County



Upstream view of DCD1105

Downstream view of DCD1105



Source: Lansdowne Quad

Location:

Access gained through the delivery entrance at Drexelbrook Apartments on Bloomfield Ave. The stream segment is reached by driving through the parking lot past a large white banquet facility and is 250 meters past a yellow gate. (Latitude: -75.31195, Longitude: 39.94261)

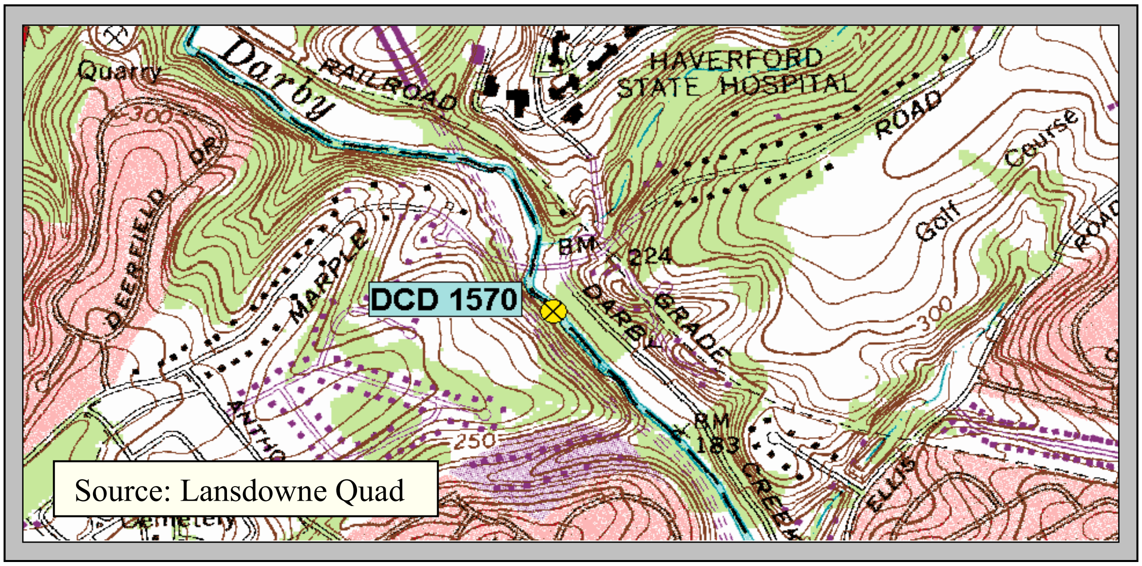
Description:

DCD1105 is located off of Bloomfield Avenue near Indian Rock Park. Forest and residential land use surround the site. Riprap has been placed on the left bank of the reach.

2.12. DCD 1570: Darby-Cobbs Study Area Delaware County

Upstream view of DCD1570

Downstream view of DCD1570



Source: Lansdowne Quad

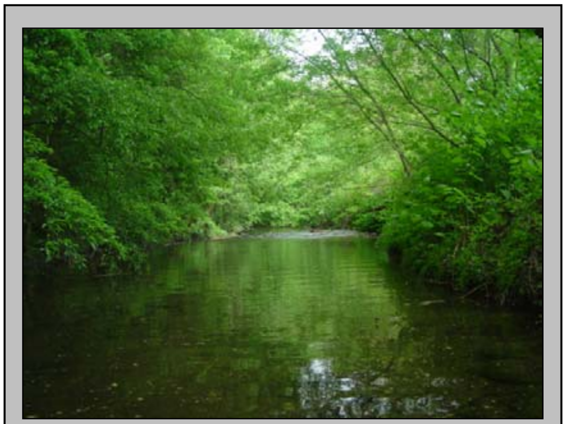
Location:

Access gained from Darby Creek Road. The creek was reached by use of an access road typically chained off by RHM Sewer Authority. (Latitude: -75.34313, Longitude: 39.98887)

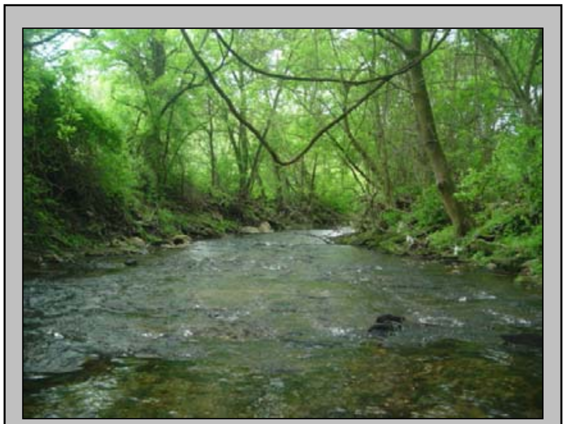
Description:

Site DCD1570 is located off of Darby Creek Road near the Marple Road overpass of Interstate 476. The site is situated alongside Interstate 476. The predominant land use surrounding the site is forest and the interstate highway.

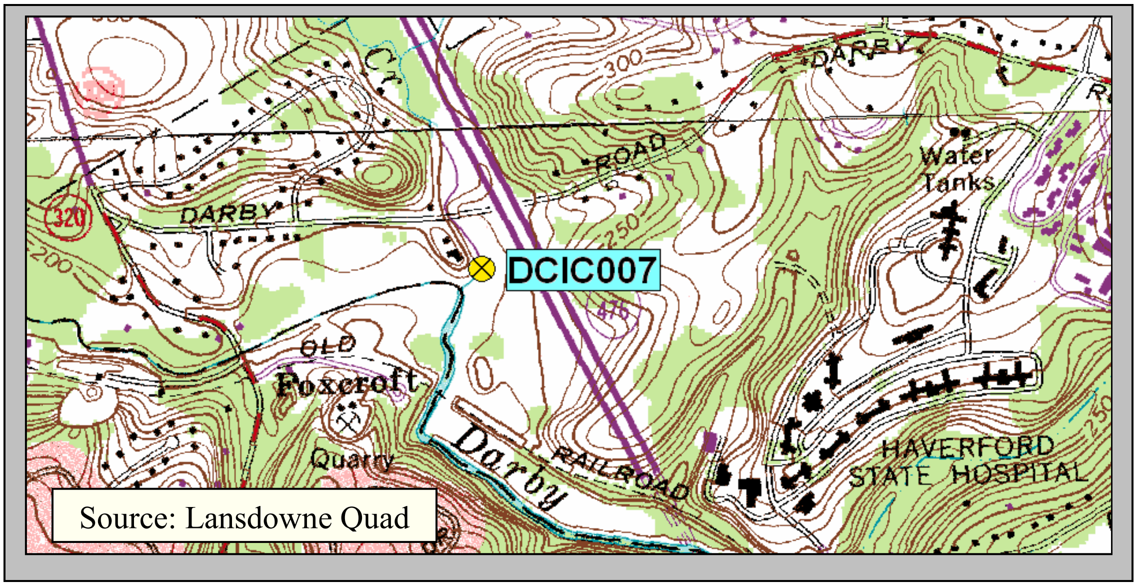
2.13. DCIC 007: Darby-Cobbs Study Area Delaware County



Upstream view of DCIC007



Downstream view of DCIC007



Source: Lansdowne Quad

Location:

Access gained from Darby Road in Radnor Township. Site is located 75 meters downstream of Darby Road. (Latitude: -75.35076, Longitude: 39.99756)

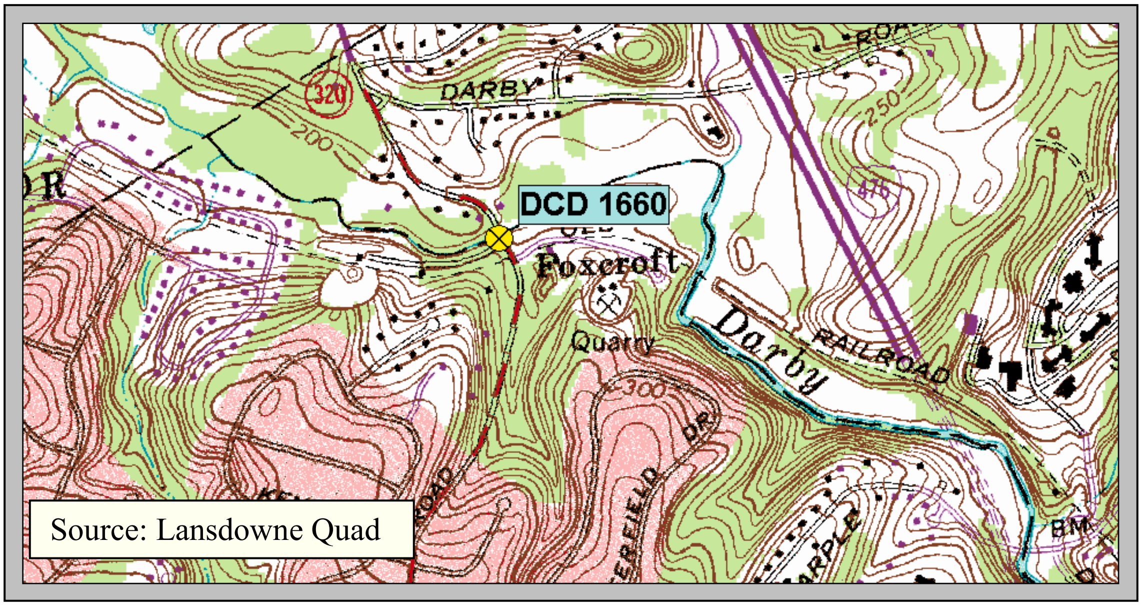
Description:

Site DCIC007 is located on Ithan Creek just downstream of Darby Road near the confluence of Ithan and Darby Creeks. The site is close to Interstate 476 and the Darby Creek Valley Park. The land use surrounding the site is field/pasture and residential.

2.14. DCD 1660: Darby-Cobbs Study Area Delaware County

Upstream view of DCD1660

Downstream view of DCD1660



Source: Lansdowne Quad

Location:

Access gained from Sproul Road (Route 320) near the intersection with Darby Road. (Latitude: -75.35633, Longitude: 39.99574)

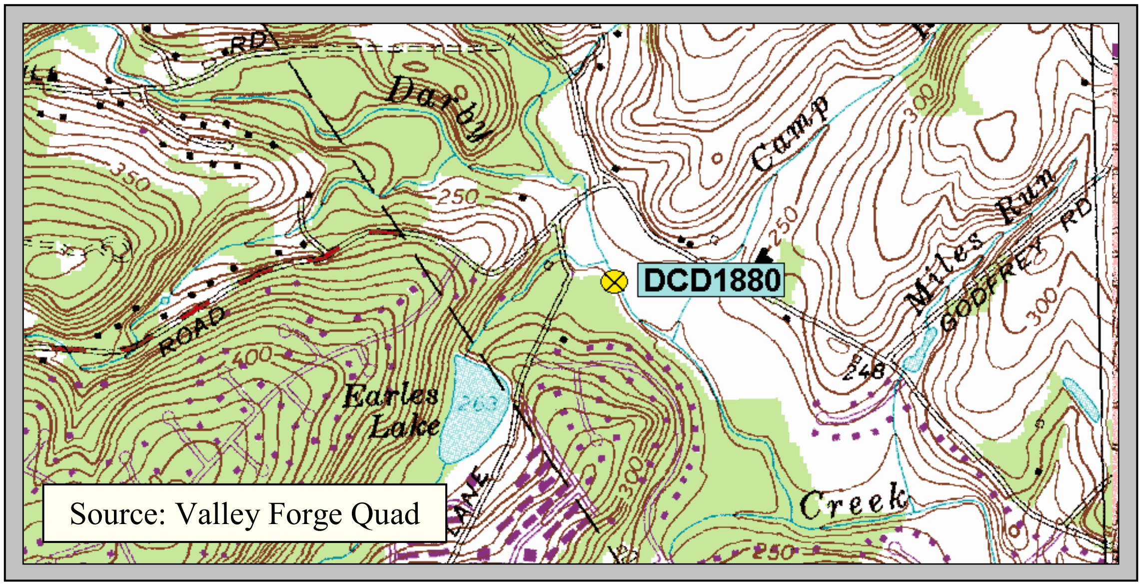
Description:

Site DCD1660 is located just downstream of Sproul Road near its intersection with Darby Road. The surrounding land use is residential.

2.15. DCD 1880: Darby-Cobbs Study Area Delaware County

Upstream view of DCD1880

Downstream view of DCD1880



Source: Valley Forge Quad

Location:

Access gained from Saw Mill Road near the intersection with Earles Lane.
(Latitude: -75.38683, Longitude: 40.01051)

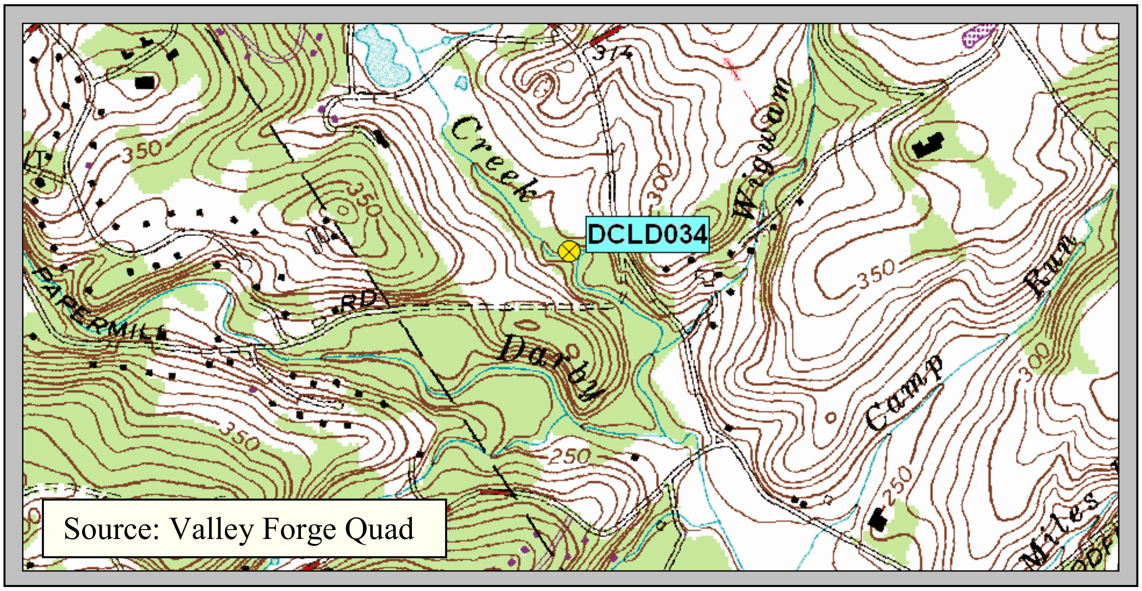
Description:

DCD1880 is located in Sawmill Park in Radnor Township, near the intersection of Saw Mill Road and Earles Lane. The site is just downstream of the confluence with Little Darby Creek. The surrounding land use is predominantly agricultural.

2.16. DCLD 034: Darby-Cobbs Study Area Delaware County

Upstream view of DCLD034

Downstream view of DCLD034



Source: Valley Forge Quad

Location:

Access gained from Darby-Paoli Road. The site is within The Willows Park in Radnor Township. (Latitude: -75.39029, Longitude: 40.01636)

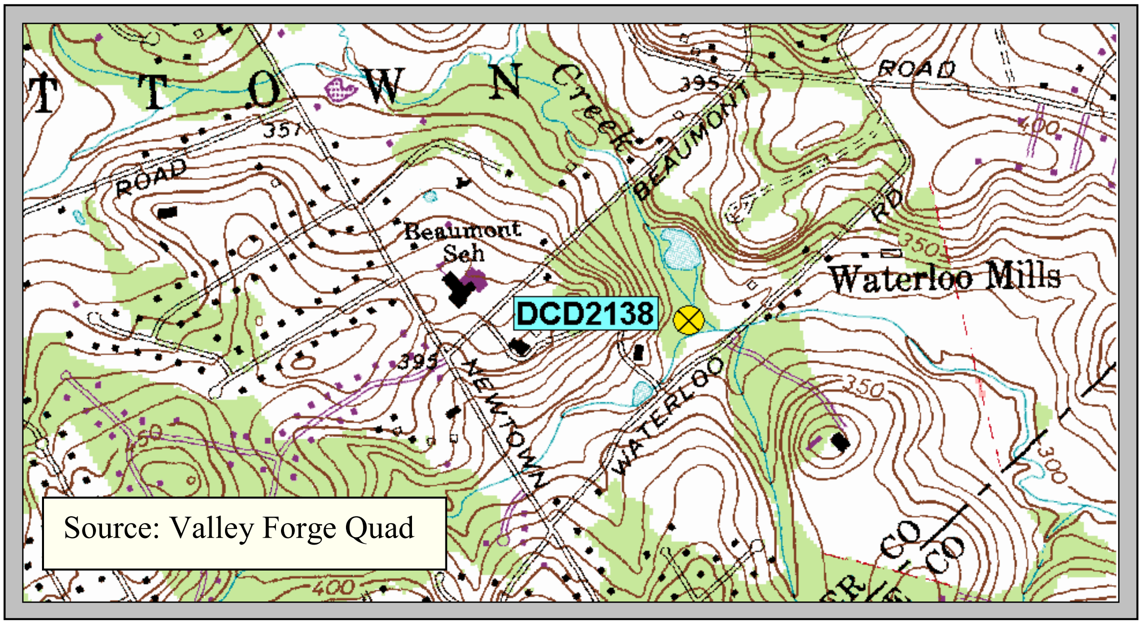
Description:

DCLD034 is located on Little Darby Creek in Radnor Township, Delaware County. The site is off of Darby-Paoli Road in The Willows Park. The surrounding area is field and pasture. A dam is located upstream of the sampled stream reach.

2.17. DCD 2138: Darby-Cobbs Study Area Chester County

Upstream view of DCD2138

Downstream view of DCD2138



Source: Valley Forge Quad

Location:

Access gained from Waterloo Road, east of Darby-Paoli Road. (Latitude: -75.42304, Longitude: 40.02276)

Description:

DCD2138 is the most upstream sampling site on Darby Creek. The site is located within an area managed by the Brandywine Conservancy on Waterloo Road in Chester County. The site is forested, and there is no evidence of nonpoint source pollution.

SECTION 3: WATERSHED DELINEATIONS AND MONITORING LOCATIONS

3.1. Watershed Location

The Darby-Cobbs Watershed is defined as the land area that drains to the mouth of Darby Creek at the Delaware Estuary, encompassing approximately 80 square miles of southeast Pennsylvania (Figure 1). This area includes portions of Chester, Delaware, Montgomery, and Philadelphia Counties. Cobbs Creek drains approximately 14,500 acres or 27% of the total watershed area, and discharges into Darby Creek. The Darby Creek Watershed drains approximately 29,000 acres or 55% of the total study area, and discharges to the Delaware River. Designated uses of Darby-Cobbs Watershed include warmwater fishery, trout stocked fishery, and migratory fishes (25 PA§ 93.9e).

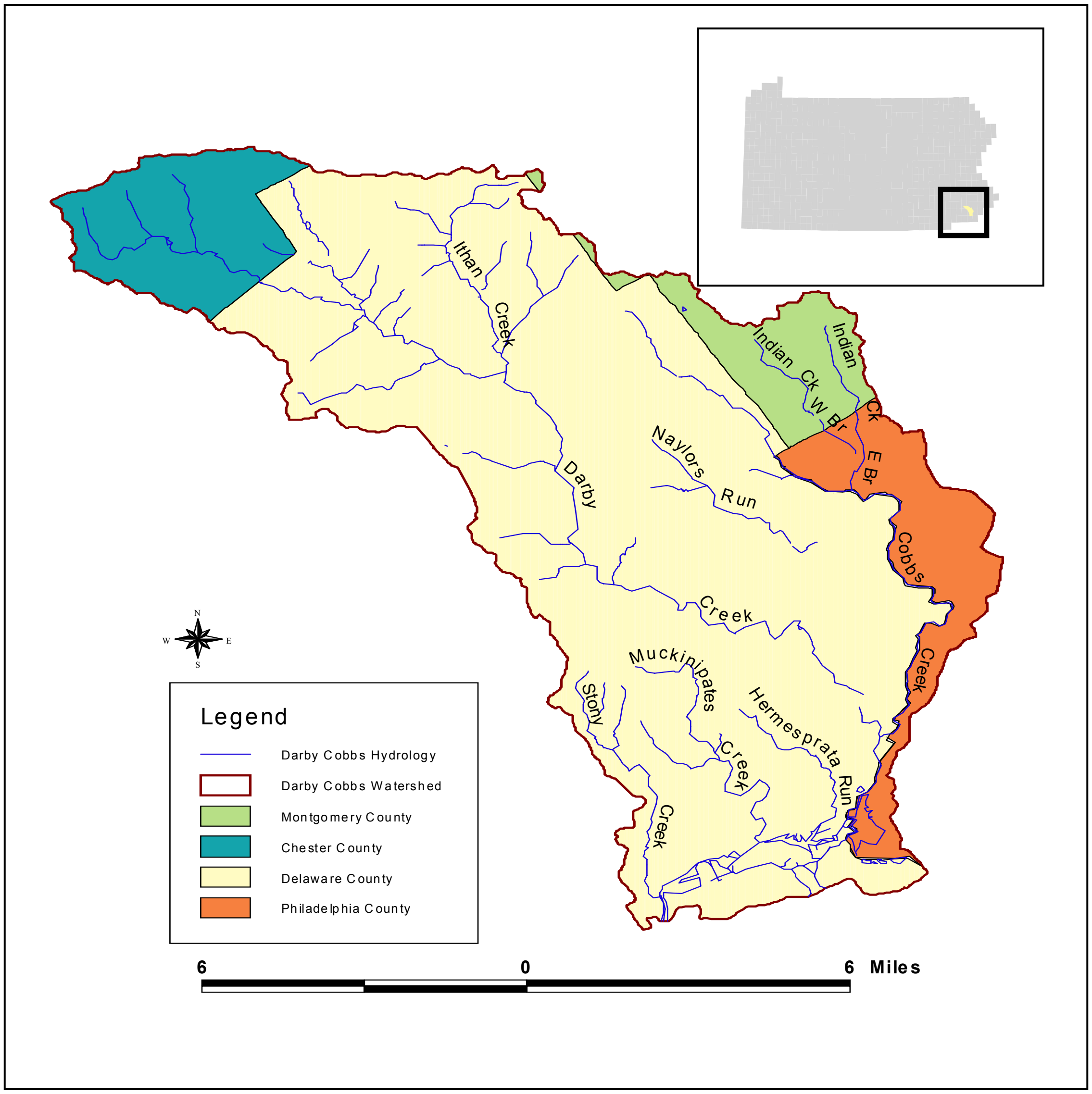


Figure 1. Darby-Cobbs Watershed and associated tributaries.

3.2. *Watershed Land Use*

Figure 2 shows land use patterns in the Darby-Cobbs Watershed consist primarily of single family residential areas (78.3%). Parklands (wooded and recreational areas), represent approximately three percent of land usage in the watershed, but make up a significant portion of land adjacent to Darby-Cobbs Watershed, providing buffer zones around the creek and its tributaries.

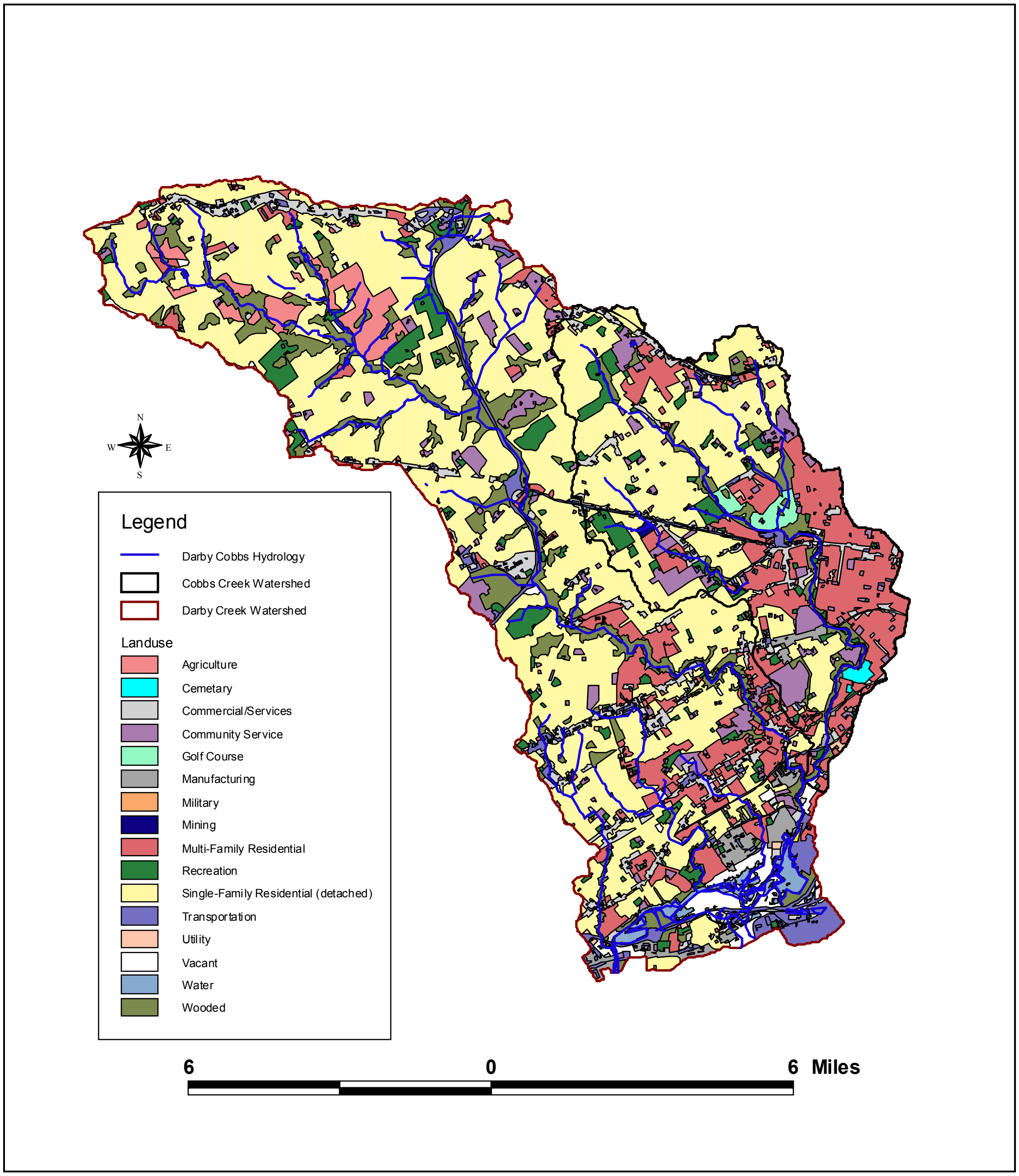


Figure 2. Darby-Cobbs Watershed land use patterns.

3.3. PWD Monitoring Locations (2003)

PWD has 27 monitoring locations in Darby-Cobbs Watershed, six of which are located on the main stem of Cobbs Creek, and 14 of which are located on the main stem of Darby Creek. The remaining seven are located on tributaries, namely the east and west branches of Indian Creek, Ithan Creek, Little Darby, and Naylor's Run. Figure 3 displays locations of these monitoring sites, as well as the type of assessments performed (i.e., discrete chemical, RBP III, habitat, RBP V, or tidal assessments).

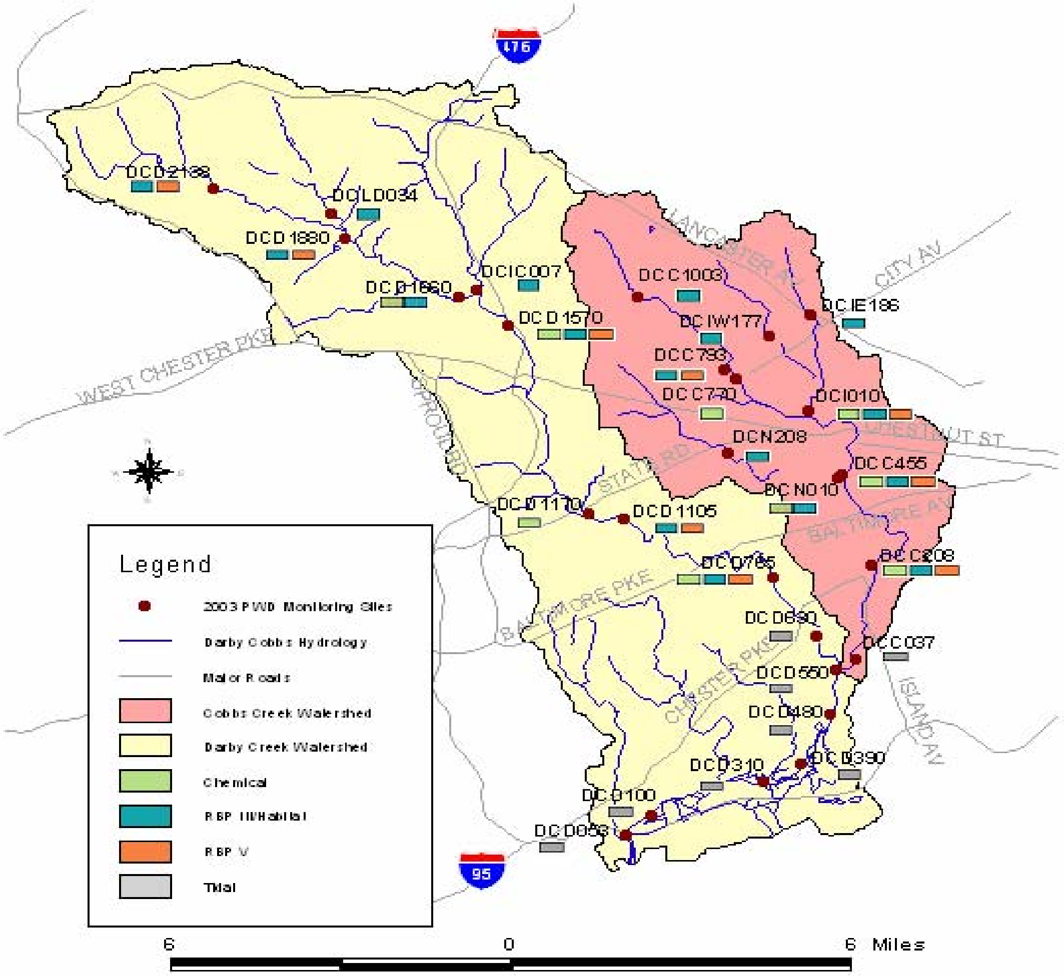


Figure 3. PWD monitoring locations in the Darby-Cobbs Watershed.

3.4. PWD Continuous and Wet Weather Monitoring Locations

Of 27 PWD monitoring locations in Darby-Cobbs Watershed, five sites were designated as continuous and wet weather monitoring locations in 2003 (Figure 4). More specifically, each location was a deployment site for an automated sampler (i.e., Sonde), which continuously measures dissolved oxygen, specific conductance, pH, depth, turbidity, and temperature, or an Isco automated sampler, which collects samples later analyzed in the laboratory for ammonia, fecal coliform, BOD_5, metals, and other relevant parameters at scheduled times during wet weather events.

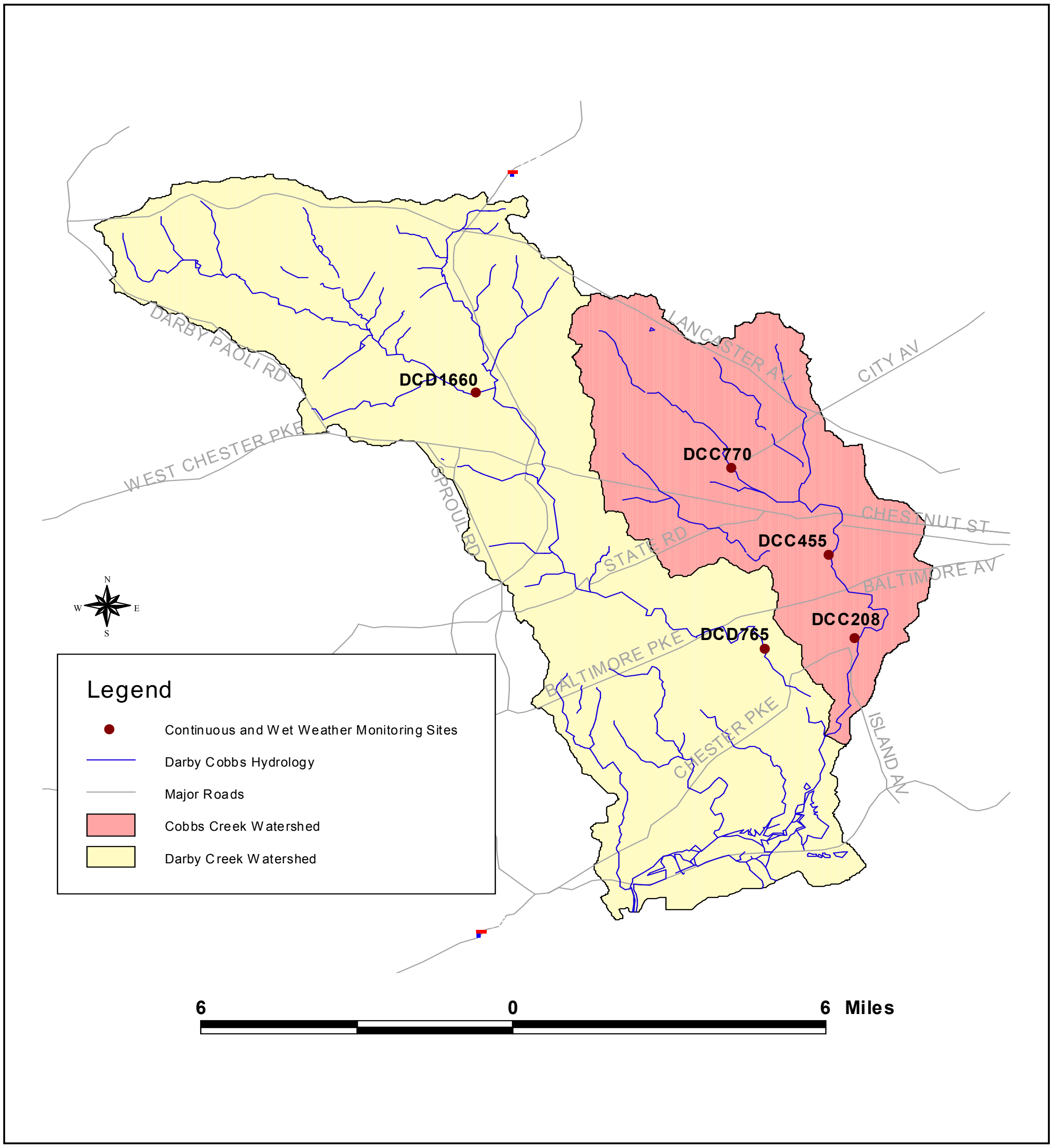


Figure 4. PWD continuous and wet-weather monitoring locations in Darby-Cobbs Watershed

3.5. PWD Tidal Assessment Monitoring Locations

Six of 27 PWD monitoring locations in Darby-Cobbs Watershed are tidal assessment sites (Figure 5). The tidal assessment area extends approximately 6.6 miles upstream from Darby Creek's confluence with the Delaware River. Tidal assessments also extended approximately 0.8 miles into the Darby main stem and approximately 0.4 miles into the Cobbs Creek main stem from the confluence of the two creeks.

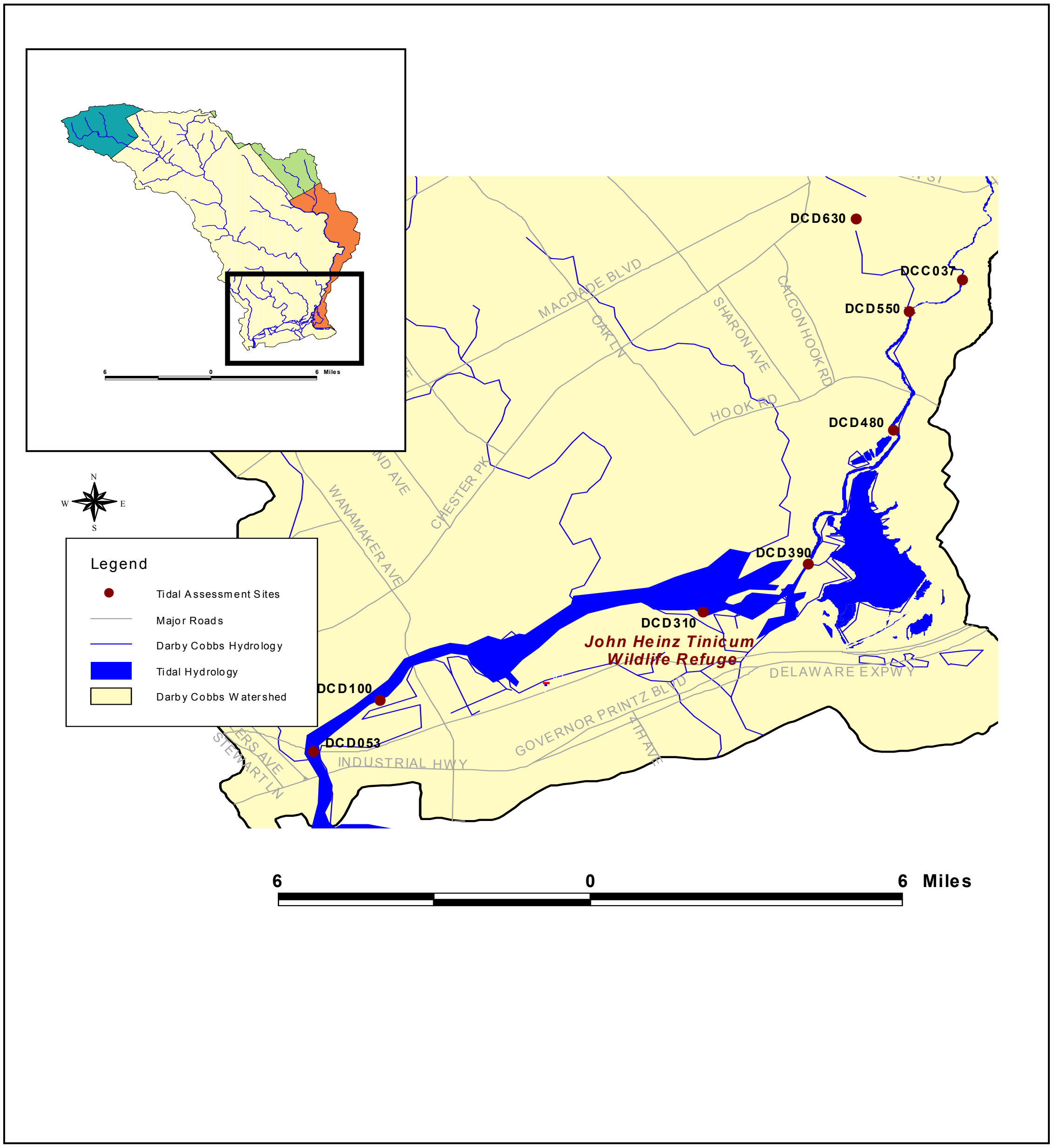


Figure 5. Tidal assessment locations in lower Darby Creek.

3.6. PADEP Monitoring Locations and Attainment Status

As part of its Statewide Surface Water Assessment Program, formerly the Unassessed Waters Program, PADEP conducted modified rapid bioassessment protocols at 28 locations in Darby-Cobbs Watershed. PADEP used benthic macroinvertebrate and habitat data collected during the assessments to determine the health of Darby-Cobbs Watershed and to identify potential stressors on stream segments determined to be impaired, or "not attaining" their designated uses. Figure 6 depicts PADEP's 28 monitoring locations as well as designations made by PADEP for stream segments in Darby-Cobbs Watershed.

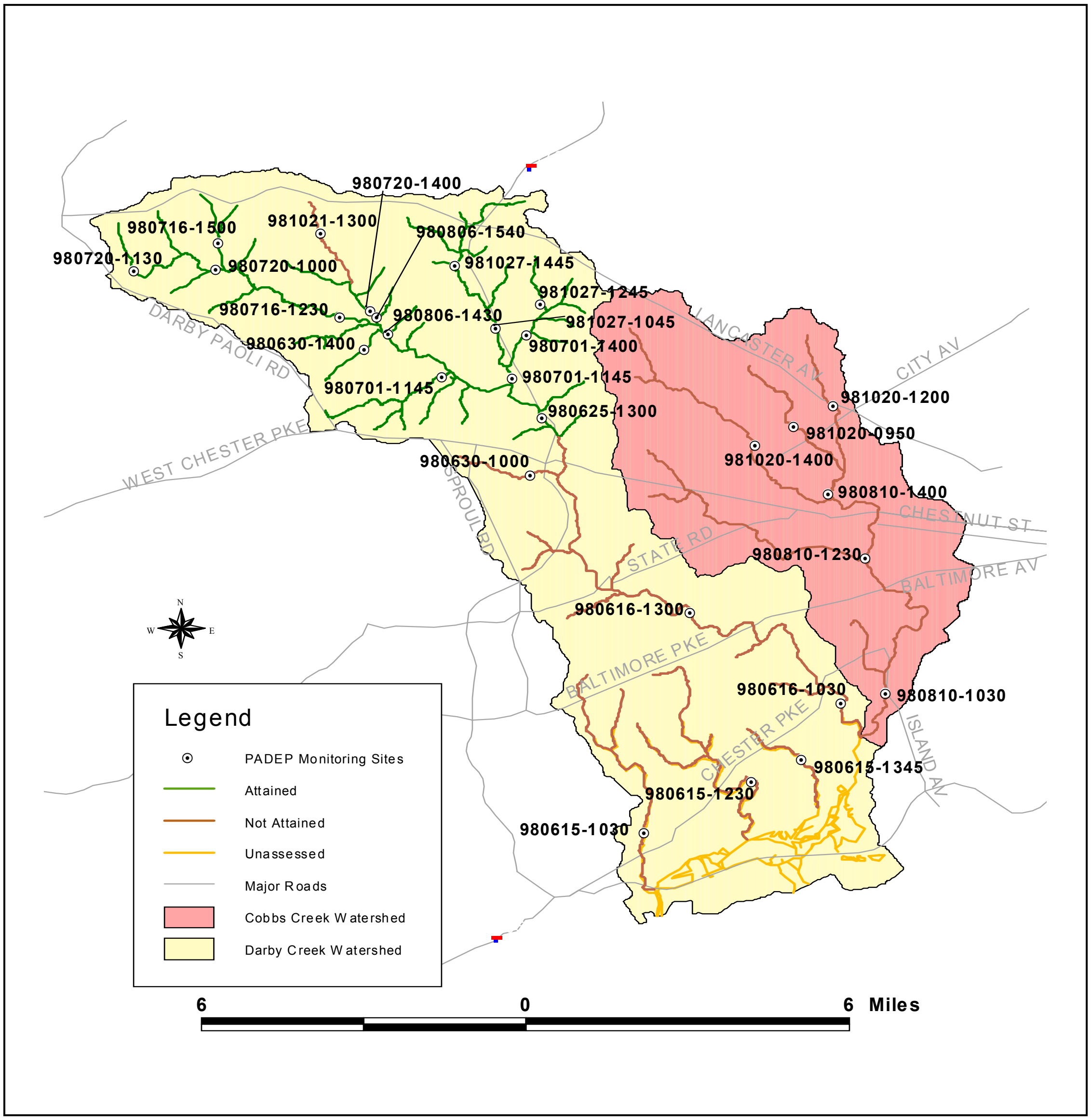


Figure 6. PADEP surface water assessment locations (1998-1999)

3.7. Historical United States Geological Survey (USGS) Monitoring Locations (1964-1990)

The United States Geological Survey (USGS) has historically monitored water quantity and quality at four locations in Darby-Cobbs Watershed (Figure 7). Water quality monitoring at the four stations in Cobbs Creek began in 1967, but was eventually terminated by 1983. Similarly, measurements of stream flow (Q) commenced in 1964 and were discontinued at all locations by 1990.

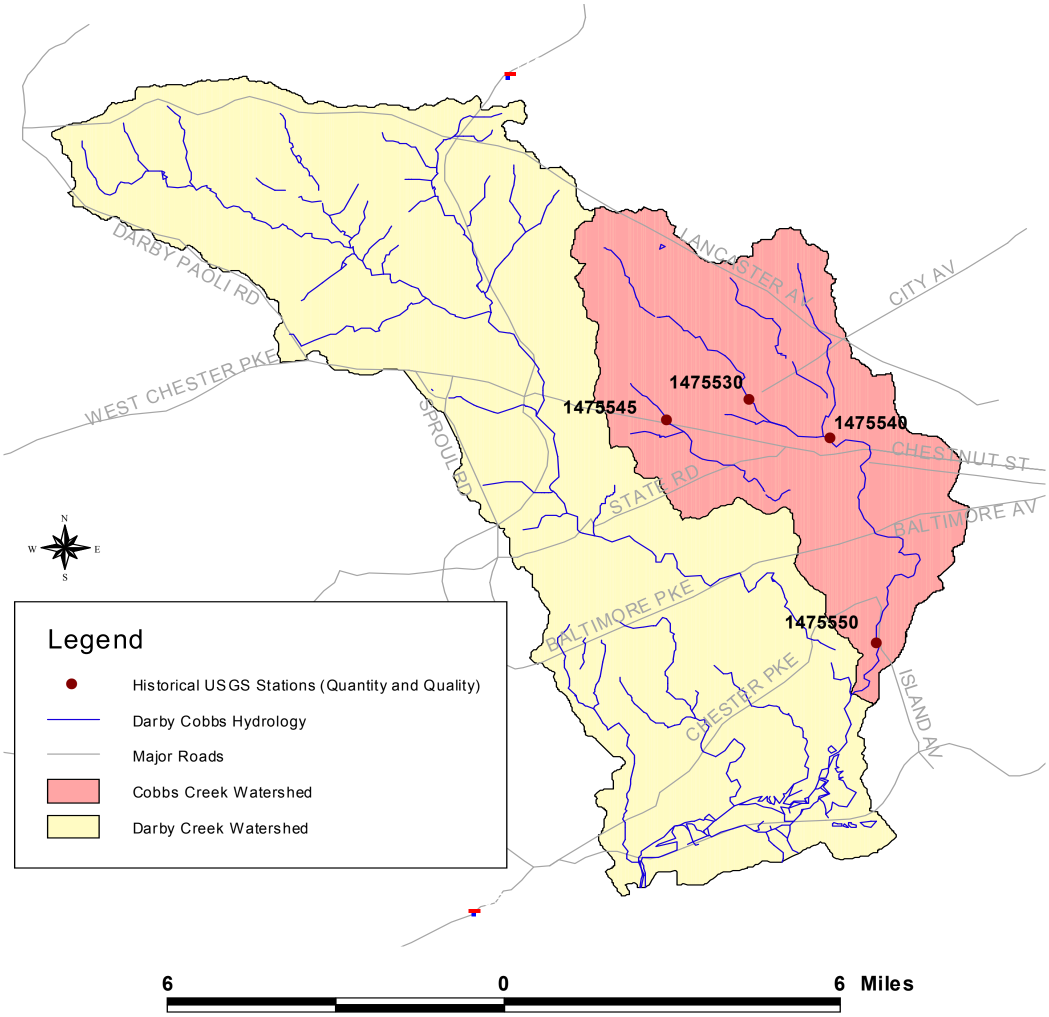


Figure 7. Historical USGS monitoring locations in Darby-Cobbs Watershed.

SECTION 4: METHODS

Standard Operating Procedures for Philadelphia Water Department's Watershed Assessment Program are available on the world-wide web at the following URL: http\\: phillywater.org

4.1. Benthic Macroinvertebrate Sampling

During 3/1/03 to 3/27/03, the Philadelphia Water Department conducted Rapid Bioassessment Protocols (RBP III) at seventeen (n=17) locations within Darby-Cobbs Watershed. Using EPA guidelines, macroinvertebrates were collected by placing a standard ($1m^2$) kicknet at the downstream portion of a riffle. The substrate was then kicked and scraped manually one meter from the net aperture to remove benthic invertebrates. Four rocks of varying size were randomly chosen within the sampling sites and manually scraped to remove benthic invertebrates. This procedure was repeated at another riffle location with less flow. Specimens were then preserved in 70% ETOH (ethyl alcohol) and returned to the laboratory in polyethylene containers. In the laboratory, samples were placed in an 11" x 14" gridded (numbered) pan and random "plugs" were examined until 100 individuals were collected. Macroinvertebrates were identified to genus, and population estimates were calculated.

4.1.1. Metrics:

Using the following chart, the biological integrity and benthic community composition was determined (EPA guidelines for RBP III and PADEP Modified Rapid Biological Assessments) (Table 1).

Table 1. Biological condition scoring criteria for RBP III.

Metric	Biological Condition Scoring Criteria			
	6	4	2	0
Taxa Richness (a)	>80%	79-70%	69-60%	<60%
Hilsenhoff Biotic Index (Modified) (a)	<0.71	0.72-1.11	1.12-1.31	>1.31
Modified EPT Index (a)	>80%	79-60%	59-50%	<50%
%Contribution of Dominant Taxon (a)	<10	11-16	17-22	>22
%Modified Mayflies (a)	<12	13-20	21-40	>40
Ratio of Scrapers/Filter (b) Collectors	>50%	35-50%	20-35%	<20%
Community Loss Index (b)	<0.5%	0.5-1.5	1.5-4.0	>4.0
Ratio of Shredders/Total (b)	>50%	35-50%	20-35%	<20%

[a] Metrics used to quantify scoring criteria (PADEP)

[b] Additional metrics used for qualitative descriptions of sampling locations (EPA)

Upon completion of the total biological scoring criteria, each site was compared to a reference site according to its drainage area and geomorphologic attributes. The reference sites chosen were French Creek, located at Coventry Road Bridge, South Coventry Township, Chester County and Rock Run, a tributary of French Creek (Appendix A). Using the following chart, benthic quality of each site was established to identify spatial trends of impairment along the river continuum (Table 2).

Table 2. Biological condition categories for RBP III.

% Comparison to Reference Score [(a)]	Biological Condition Category	Attributes
>83%	Nonimpaired	Comparable to the best situation within an ecoregion. Balanced trophic structure. Optimum community structure for stream size and habitat quality.
54-79%	Slightly impaired	Community structure less than expected. Species composition and dominance lower than expected due to loss of some intolerant forms. Percent contribution of tolerant forms increases.
21-50%	Moderately impaired	Fewer species due to loss of most intolerant forms. Reduction in EPT index.
<17%	Severely impaired	Few species present. If high densities of organisms, then dominated by one or two taxa.

(a) Percentage values obtained that are intermediate to the above ranges will require subjective judgment as to the correct placement. Use of the habitat assessment and chemical data may be necessary to aid in the decision process.

4.2. Ichthyofaunal (Fish) Sampling

4.2.1. Fish Collection in Non-Tidal Portions

Between 6/16/03-7/8/03, PWD biologists conducted fish assessments at nine (n = 9) locations within Darby-Cobbs Watershed (Figure 3). Fish were collected by electrofishing as described in EPA's Rapid Bioassessment Protocol V (RBP V) (Barbour et al., 1999). Depending on stream conditions, Smith-Root backpack or tote barge electrofishers were used to stun fish. A 100m reach of the stream was blocked at the upstream and downstream limits with nets to prevent immigration or emigration from the study site. Each reach was uniformly sampled, and all fish captured were placed in buckets for identification and counting. An additional pass without replacement was completed along the reach to insure maximum likelihood population and biomass estimates.

4.2.2. Fish Collection in Tidal Portions

Between 7/10/03-8/25/03, staff biologists completed fish assessments at eight (n=8) tidal locations in the Darby-Cobbs Watershed (Figure 5). Tote-barge electrofishers were used at the two most upstream tidal reaches of Darby and Cobbs Creeks (DCD 630 and DCC 037, respectively). Fish inhabiting nonwadeable tidal portions of the Darby-Cobbs Watershed were collected with Smith-Root electrofishing apparatus mounted aboard a small aluminum-hulled jonboat. Electrofishing was conducted for ten-minute intervals in a downstream direction, targeting areas with suitable fish habitat. It was not feasible to install block nets or otherwise prevent net movement of fish into or out of the sampling area.

4.2.3. Sample Processing

Fish were identified to species, weighed (± 0.01 g) with a digital scale (Model Ohaus Scout II) and measured to the nearest 0.1 cm using a Wildco fish measuring board. Large fish that exceeded the digital scale's capacity were weighed using spring scales (Pesola). Any external deformations, lesions, tumors, cysts, or disease were noted during processing. Species that could not be identified in the field (e.g., small or juvenile cyprinids) were preserved with 10% formalin solution and stored in polyethylene bottles for laboratory identification.

To facilitate the process of acquiring total fish biomass and to reduce field time, a simple linear regression was developed between weight (g) and length (cm). Approximately 20 individuals of each species were weighed, and total lengths were measured. Once 20 individuals of each species were measured (both weight and length), biomass (g) for each fish was calculated using the regression analysis. Results of the regression analysis on individual fish species can be found in Appendix B. Similar procedures were conducted at the reference locations (i.e., French Creek and Rock Run) to obtain a discrete measure of the condition of the fish assemblages at each assessment location.

4.2.4. Fish IBI Metrics:

The health of fish communities in Darby-Cobbs Watershed were based on the technical framework of the Index of Biological Integrity (IBI) developed by Karr (1981). The analysis entailed the definition of "ecoregional-specific" metrics pertinent to the fish assemblages located in the lower Schuylkill River Drainage. Standardized metrics (i.e., indices) were then integrated to provide an overall indication of the condition of fish assemblages at each assessment location. Individual metrics within the fish IBI framework were also used to provide quantitative information regarding a specific attribute of the respective assessment location (e.g., pollution tolerance values). In addition to IBI metrics, other metrics were incorporated into the design to evaluate the overall ecological health of fish assemblages and as a means of comparison of each assessment site. Tables 3 and 4 describe the various indices and scoring criteria used for the IBI metrics in the Darby-Cobbs Watershed. Additional metrics used in the analysis are displayed in Table 5.

Table 3. Metrics used to evaluate the Index of Biological Integrity (IBI) at representative sites. *

Metric	**Scoring Criteria**		
	5	3	1
1. Number Of Native Species	>67%	33-67%	<33%
2. Number Of Benthic Insectivore Species	>67%	33-67%	<33%
3. Number Of Water Column Species	>67%	33-67%	<33%
4. Percent White Sucker	<10%	10-25%	>25%
5. Number Of Sensitive Species	>67%	33-67%	<33%
6. Percent Generalists	<20%	20-45%	>45%
7. Percent Insectivores	>45%	20-45%	<20%
8. Percent Top Carnivores	>5%	1-5%	<1%
9. Proportion of diseased/anomalies	<1%	1-5%	>5%
10. Percent Dominant Species [a]	<40%	40-55%	>55%

*Metrics used are based on modifications as described in Barbour, *et al.*, 1999.

[a] Metric based on USGS NAWQA study (2002).

Table 4. Index Of Biological Integrity (IBI) score interpretation.*

IBI	Integrity Class	Characteristics
45-50	**Excellent**	Comparable to pristine conditions, exceptional assemblage of species
37-44	**Good**	Decreased species richness, intolerant species in particular
29-36	**Fair**	Intolerant and sensitive species absent; skewed trophic structure
10-28	**Poor**	Top carnivores absent or rare; omnivores and tolerant species dominant
<10	**Very Poor**	Few species and individuals present; tolerant species dominant; diseased fish frequent

* IBI score interpretation based on Halliwell, *et al*., 1999.

Table 5. Additional metrics used to evaluate fish assemblage condition.

Metric	Assessment Type
Species Diversity	Shannon (H') Diversity Index
Trophic Composition	Percentage of Functional Feeding Groups
Tolerance Designations	Percentage of Pollution Tolerant, Moderate And Intolerant Species
Modified Index Of Well-Being	MIwb Index

4.2.5. Species Diversity:

Species diversity, a characteristic unique to the community level of biological organization, is an expression of community structure (Brower, *et al*., 1990). In general, high species diversity indicates a highly complex community. Thus, population interactions involving energy transfer (e.g. food webs), predation, competition and niche distribution are more complex and varied in a community of high species diversity. In addition, many ecologists support species diversity as a measure of community stability (i.e., the ability of community structure to be unaffected by, or recover quickly from perturbations). Using the Shannon (H') Diversity Index formula, species diversity was calculated at each sampling location:

$$H' = -\Sigma\, n_i/N * \ln(n_i/N): \qquad \text{(eq. 1)}$$

where n_i is the relative number of the *i*th taxon.

4.2.6 Trophic Composition and Tolerance Designations:

Trophic composition metrics were used to assess the quality of the energy base and trophic dynamics of the fish assemblages (Plafkin *et al*., 1989). The trophic composition metrics offer a means to evaluate the shift toward more generalized foraging that typically occurs with increased degradation of the physiochemical habitat (Barbour et al., 1999). Pollution tolerance metrics were also used to distinguish low and moderate quality sites by assessing tolerance values of each species identified at the sampling locations. This metric identifies the abundance of tolerant, moderately tolerant and pollution intolerant individuals at the study site. Generally, intolerant species are first to disappear following a disturbance. Species designated as intolerant or sensitive should only represent 5-10% of the community; otherwise the metric becomes less discriminating. Conversely, study sites with fewer pollution intolerant individuals may represent areas of degraded water quality or physical disturbance. For a more detailed description of metrics used to evaluate the trophic and pollution designations of fish assemblages, see Barbour, *et al*., (1999).

4.2.7. Modified Index of Well-Being (MIwb):

Modified Index of Well-Being (MIwb) is a metric that incorporates two abundance and two diversity measurements. Modifications from the Ohio EPA (1987), which eliminate pollution tolerant species, hybrids and exotic species, were incorporated into the study in order to increase the sensitivity of the index to a wider array of environmental disturbances. MIwb is calculated using the following formula (equation 2):

$$\mathrm{MIwb} = 0.5*\ln N + 0.5*\ln B + H_N + H_B \qquad \text{(eq. 2)}$$

where;

N = relative numbers of all species
B = relative weight of all species
H_N = Shannon index based on relative numbers
H_B = Shannon index based on relative weight

4.2.8. Biomass Per Unit Area:

This metric evaluates the relative biomass of fish within a given site relative to the area sampled. In general, as streams increase in width, the biomass of fish tends to increase in areas of suitable habitat, physical stability and appropriate water quality. Decreases in biomass per unit area may be attributed to episodic or chronic periods of degraded water quality and/or poor habitat heterogeneity.

4.3. Habitat Assessment

4.3.1. EPA Habitat Assessment

Prior to benthic macroinvertebrate sampling procedures, habitat assessments at 17 sites were completed based on the *Stream Classification Guidelines for Wisconsin* (Ball, 1982) and *Methods of Evaluating Stream, Riparian, and Biotic Conditions* (Platts et al., 1983). Reference conditions were used to normalize the assessment to the "best attainable" situation. Habitat parameters are separated into three principal categories: (1) primary, (2) secondary, and (3) tertiary parameters. Primary parameters are those that characterize the stream "microscale" habitat and have greatest direct influence on the structure of indigenous communities. Secondary parameters measure "macroscale" habitat such as channel morphology characteristics. Tertiary parameters evaluate riparian and bank structure and comprise three categories: (1) bank vegetative protection, (2) grazing or other disruptive pressure, and (3) riparian vegetative zone width. The following chart lists the various parameters addressed during habitat assessments (Table 6):

Table 6. Habitat assessment criteria used at benthic monitoring stations.

Condition/Parameter	Condition			
	Optimal	Suboptimal	Marginal	Poor
Epifaunal Substrate/Available Cover	16-20	11-15	6-10	0-5
Pool Substrate Characterization	16-20	11-15	6-10	0-5
Pool Variability	16-20	11-15	6-10	0-5
Sediment Deposition	16-20	11-15	6-10	0-5
Embeddedness	16-20	11-15	6-10	0-5
Velocity/Depth Regime	16-20	11-15	6-10	0-5
Frequency of Riffles (or bends)	16-20	11-15	6-10	0-5
Channel Flow Status	16-20	11-15	6-10	0-5
Channel Alteration	16-20	11-15	6-10	0-5
Channel Sinuosity	16-20	11-15	6-10	0-5
Bank Stability**	10-9	8-6	5-3	2-0
Vegetative Protection**	10-9	8-6	5-3	2-0
Riparian Vegetative Zone Width**	10-9	8-6	5-3	2-0

**Both right and left banks are assessed separately.

4.3.2. Habitat Suitability Index (HSI) Model Methods

4.3.2.1. Model History and Assumptions

Prior to the development of Instream Flow Incremental Methodology (IFIM), a number of Habitat Suitability Index (HSI) models were developed by the U.S. Fish and Wildlife Service (USFWS). Based on empirical data and supported by years of research and comprehensive review of scientific literature, these models present numerical relationships between various habitat parameters and biological resources, particularly gamefish species and species of special environmental concern. Through evaluation of various input parameters, models arrive at a final index value between 0 and 1, a score of 1 corresponding to the ideal habitat condition, and zero indicating that some aspect of the habitat is unsuitable for supporting a naturally reproducing population of the species of interest.

Numerous assumptions are inherent with use and interpretation of the models. First and foremost is the assumption that habitat features alone are responsible for determining abundance or biomass of the species of interest at the study site. Clearly, no species exists in a vacuum; aside from habitat variables, other ecological and environmental interactions can strongly influence biological communities. HSI indices assume that users will use good professional judgment, consult with regional experts when necessary, and consider the possible effects of other factors (e.g., competition, predation, toxic substances and other anthropogenic factors) when interpreting model output.

4.3.2.2. Model Data Requirements

Most types of data required by HSI models were available for all sites within Darby-Cobbs Watershed. However, a number of habitat parameters were not directly measured in a fashion best suited for use with HSI models and required additional interpretation or normalization. Few water quality parameters were measured with equal sampling effort across all sites; some parameters were measured with continuous monitoring instruments at some sites and grab samples or hand-held meters at other sites. Some variables were not directly measured at some sites; to facilitate HSI analysis at these sites, (conservative) values were substituted based on sampling conducted at nearby sites and reference sites in neighboring watersheds. Turbidity data were excluded from the analyses entirely because all HSI were developed using Jackson Turbidity Units (JTU), which cannot be converted to/from modern Nephelometric Turbdity Unit (NTU) data. Any other significant modifications to the variables or the modeling approach are explained in Section 5.3.5. (Habitat Suitability Indices). A list of all HSI input variables for the seven HSI models applied to Darby-Cobbs watershed appears in Table 7.

Table 7. Habitat Suitability Index (HSI) variable matrix.

HSI Model Variable Matrix	Variable Type	Blacknose Dace	Common shiner	Creek Chub	Fallfish	Longnose Dace	Redbreast Sunfish	Smallmouth Bass
Total number of HSI variables		**16***	**9**	**20**	**6**	**6**	**10**	**13***
Avg. Temperature during growing season (May-Oct.)	temperature	X						X
Average Temperature in spawning season**		X	X		X		X	X
Maximum temperature sustained for 1 week			X			X	X	
Average Summer Temperature (Jul-Sep)				X	X			
Average temperature during spring (May-Jun)				X				
Average Turbidity (JTU)***	water quality	X	X	X	X		X	X
Average yearly pH value			X					X
Least suitable pH value (instantaneous)							X	
pH fluctuation classification				X				
Minimum dissolved oxygen concentration				X			X	X
Minimum dissolved oxygen conc. During spring				X				
% instream cover during avgerage summer flow	general stream characteristics			X		X	X	X
Instream cover classification					X			
% shading of stream between 1000 and 1500 hrs.		X		X				
% vegetative cover							X	
Availability of thermal refugia (winter)				X				
Stream gradient (m/km)		X		X				X
Average stream velocity during average summer flow				X		X		
Dominant substrate characterization					X		X	
Stream width		X		X			X	
Mode of stream depth during average summer flow					X			
Water level fluctuations								X
Stream margin substrate characterization		X						
Average velocity along stream margins		X		X				
Stream margin vegetation characterization				X				
Substrate food production potential				X				
% riffles	riffles					X		
Riffle substrate characterization		X	X	X		X		
Average velocity in riffles		X	X	X				
Average depth of riffles		X						
Average maximum depth of riffles						X		
% pools	pools	X	X	X			X	X
Pool substrate characterization		X						X
Pool classification			X	X				
Average depth of pools				X				X
Average velocity at 0.6 depth in pools		X	X					

* some variables used more than once, applied to different life stages

**spawning season varies by species

*** Turbidity relationships developed using Jackson candle units; cannot be converted to NTU values

4.3.2.3. Suitability Index Expressions

HSI models use three major types of Suitability Index (SI) expressions or mathematical relationships to compute the suitability of a given habitat variable; they are (in increasing order of complexity): 1.) categorized relationships, 2.) linear equations (or more commonly, series of linear equations bounded by inflection points), and 3.) suitability curves. Categorized relationships are used for a limited number of HSI variables in which the relationship between the habitat feature and suitability for the species of interest is fairly simple. Substrate size categorization is one example; many HSI models use dominant substrate type categories (e.g., silt, sand, gravel, cobble, boulder, bedrock). Other SI variables that may be defined by simple categorization are temperature, dissolved oxygen, pH or, or in some cases, the variability of these measurements (Figure 8). Categorized data were processed directly within Microsoft Excel spreadsheet HSI models.

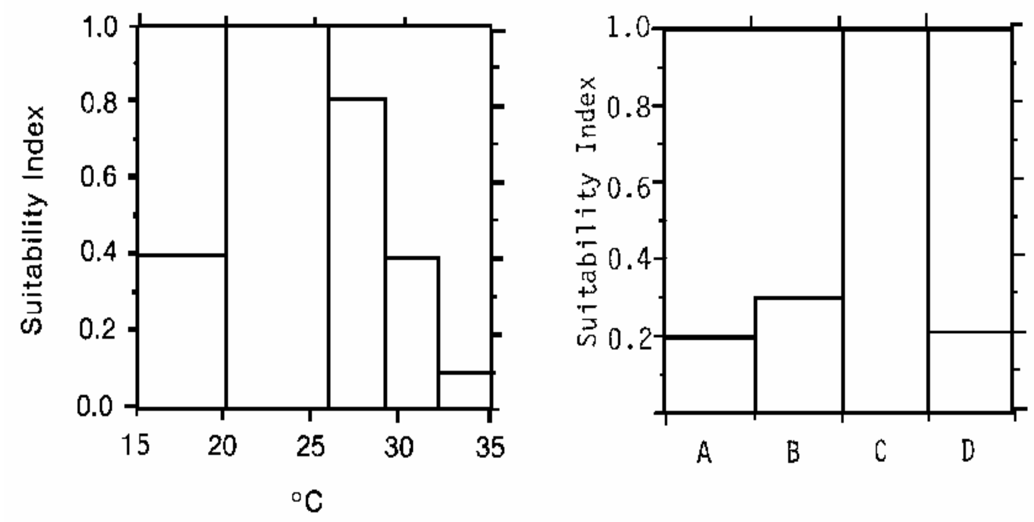


Figure 8. Categorized expressions in HSI models.

Many SI variables are defined by a series of linear relationships bounded by inflection points (i.e., a collection of linear relationships that roughly approximate a curve). Many of these relationships include a range of unsuitable (SI=0) values, a range of ideal (SI =1.0) values, or both. Although all types of SI variables were, in some cases, defined by series of linear relationships (Figure 9), these expressions were less likely to be employed as models increased in complexity. As models become more complex, there is a corresponding increased focus on development of SI curves. SI variables defined by linear relationships were processed using linear equations and boolean commands directly in Excel spreadsheet models.

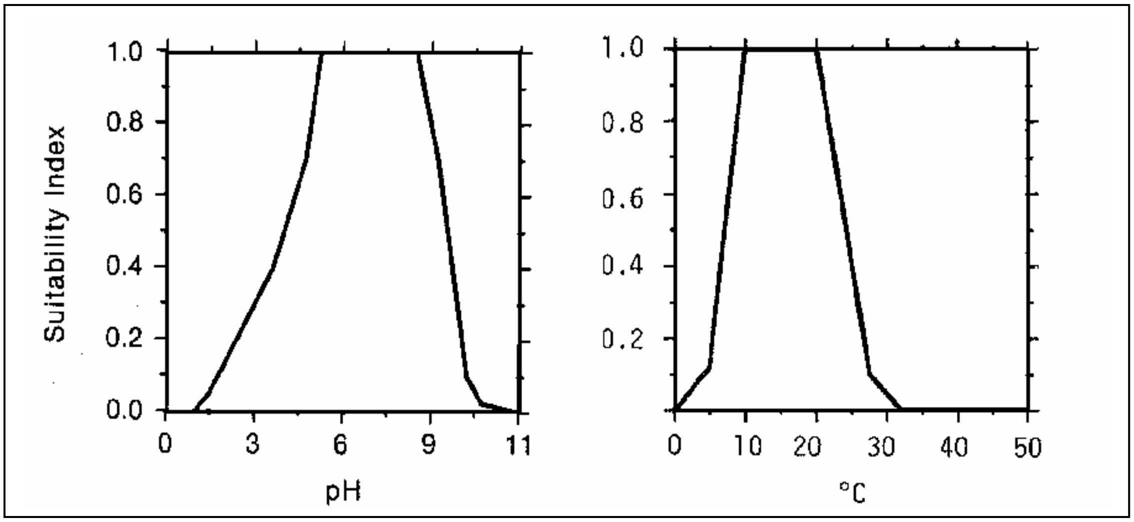


Figure 9. Linear expressions in HSI models.

SI curve relationships are considered the most precise and continuous of SI relationships, and therefore, appear more frequently in more complex HSI models. For example, curves allow models to accurately represent the non-linear, sub-asymptotic change in SI expected as a habitat variable approaches complete unsuitability or ideal suitability (SI score 0 or 1 respectively). Two general SI curve shapes were common, modified parabolae and "s-curves", though there was considerable variation in actual curve shape between different SI variables (Figure 10). As curve equations were not provided with HSI model documentation, lookup tables were generated by scanning curves with data extraction software (Data Thief). Subsequent data processing was handled in Excel.

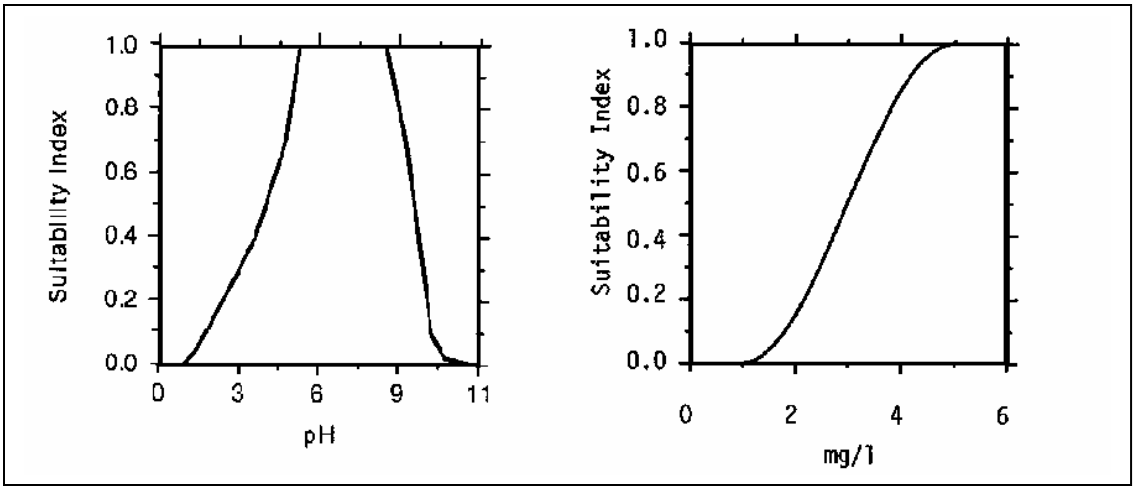


Figure 10. Curve relationships in HSI models.

4.3.2.4. Model Evaluation

HSI model output for each site was compared to EPA habitat data results. With the exception of Longnose dace HSI data, HSI model output was compared to observed fish abundance and biomass with correlation analyses. Several habitat models likely require modification in order to be useful in guiding or evaluating stream habitat improvement activities. While time constraints precluded the modification of models to better suit Darby-Cobbs Watershed, it is hoped that such modifications will increase the usefulness of these models in the future.

4.4. Chemical Assessment

4.4.1. Fixed Interval Chemical Sampling

Bureau of Laboratory Services staff collected surface water grab samples at nine locations within Darby-Cobbs Watershed for chemical and microbial analysis. Sampling events were planned to occur at each site at weekly intervals for one month during three separate seasons. Actual sampling dates were as follows: "winter" samples collected 2/13/03, 2/20/03, 2/27/03, and 3/20/03; “spring” samples collected 3/27/03, 5/22/03, 5/29/03, 6/05/03, and 6/12/03; “summer” samples collected 8/14/03, 8/21/03, 8/28/03, and 09/04/03. A total of 117 discrete, or “grab” samples were taken. To add statistical power, additional discrete water quality samples from PWD's wet-weather chemical sampling program were included in analyses when appropriate.

Locations of 2003 water quality sampling sites are depicted in Figure 3 of Section 3. Sites DCC770, DCC455, DCC208, DCD1570, DCD1170, DCD765, DCI010 and DCN010 were included in PWD's baseline chemical assessment of Darby-Cobbs Watershed in 1999. Sites in the Tinicum sub-basin (DCM300 and DCS170) were sampled in 1999 but not in 2003. A single new site (DCD1660), located on Darby Creek upstream of its confluence with Ithan Creek, was added for 2003.

Discrete sampling was conducted on a weekly basis and was not specifically designed to target wet or dry weather flow conditions. Depending on which definition of "dry weather" was used, six or seven sampling events occurred during dry weather. This data is most pertinent to Target A of the Watershed management Plan (Dry Weather water quality and aesthetics). Specifically addressed are indicators seven and eight- chemical and microbial constituents that are influential in shaping communities of aquatic systems or that are indicative of anthropogenic degradation of water quality in the watershed.

4.4.2. Wet-Weather Targeted Sampling

Target C of the Darby-Cobbs Integrated Watershed Management Plan addresses water quality in wet weather. Yet characterization of water quality at several widely spatially distributed sites simultaneously over the course of a storm event presents a unique challenge. Automated samplers (Isco, Inc. models 6712, 6700) were used to collect samples during two runoff-producing rain events in July and September 2003. The automated sampler system obviated the need for BLS team members to manually collect samples, thereby greatly increasing sampling efficiency. Automated samplers were equipped with vented instream pressure transducers that allowed sampling to commence beginning with a small (0.1ft.) increase in stage. Once sampling was initiated, a computer-controlled peristaltic pump and distribution system collected grab samples at 1 hr. intervals.

Use of automated samplers allows for a greater range of flexibility in sampling programs, including flow-weighted composite sampling based on a user defined rating curve, but stage discharge rating curves at these sites were poorly defined for larger flows. Furthermore, one automated sampler was an older model (model 6700) incapable of taking samples based on observed rate of change in stream stage. Though some difficulties were encountered due to a combination of mechanical failure, individual site characteristics, and/or vandalism, the one hour fixed interval was found to be generally satisfactory in collecting representative samples over a storm event (Appendix C). PWD continues to refine methods of sampling stormwater and experiment with alternative automated sampling programs.

4.4.3. Continuous Water Quality Monitoring

Physicochemical properties of surface waters are known to change over a variety of temporal scales, with broad implications for aquatic life. Several important, state-regulated parameters (e.g., dissolved oxygen, temperature, and pH) may change considerably over a short time interval, and therefore cannot be measured reliably or efficiently with grab samples. Self-contained data logging continuous water quality monitoring Sondes (YSI Inc. Models 6600, 600XLM) were deployed between 8/14/03-9/14/03 at five sites within Darby-Cobbs watershed in order to collect DO, pH, temperature, conductivity and depth data (Figure 4 in Section 3). Sondes continuously monitored conditions and discretized the data in 15 min increments.

Extended deployments of continuous water quality monitoring instruments in urban streams have presented many challenges: drastic increases in stream flow and velocity, probe fouling due to accumulation of debris and algae, manpower required for field deployment and maintenance, and the need to guard against theft or vandalism. With refinements to Sonde enclosures and increased attention to cleaning and maintenance, PWD's Bureau of Laboratory Services has made wide-reaching improvements in the quality and recoverability of continuous water quality data, particularly dissolved oxygen (DO) data.

4.4.4. RADAR Rainfall Data and Analysis

Because storm events are inherently variable and do not evenly distribute rainfall spatially or temporally, PWD contracted with Vieux and Associates to obtain discretized measurements of rainfall intensity during storm events targeted by wet weather sampling. For each 15 minute interval, RADAR tower-mounted equipment measured high frequency radio wave reflection in the atmosphere above Darby-Cobbs watershed. This information was provided to PWD as a series of relative reflectivity measurements for individual 1km^2 blocks. The resulting grid allowed for the summing of relative rainfall intensity within the sub-shed served by each sampling site over the course of each individual storm event (Figures 11 and 12). Individual intensity measurements were also graphed and arranged sequentially to produce animated time-series rainfall accumulation graphics. This analysis, combined with data from the PWD rain gauge network and stream stage measurements logged by the automated sampler, allowed for more thorough analysis of water quality data, particularly in determining whether some areas or subsheds may have contributed more runoff than others.

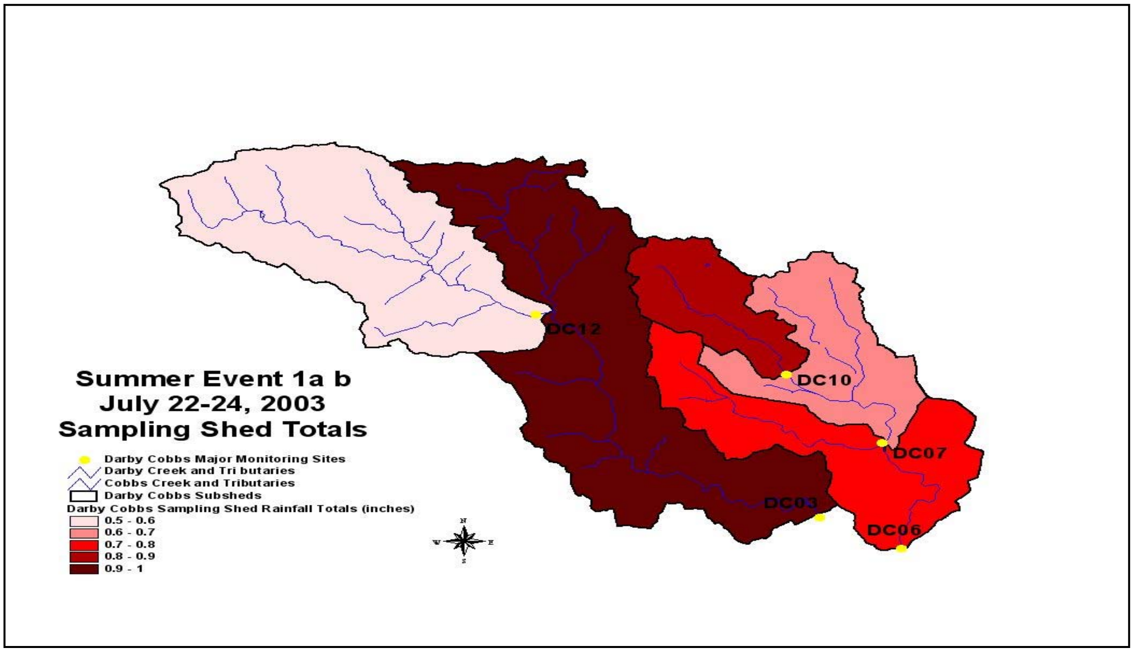


Figure 11. RADAR Rainfall totals by subshed (7/22/03-7/24/03).

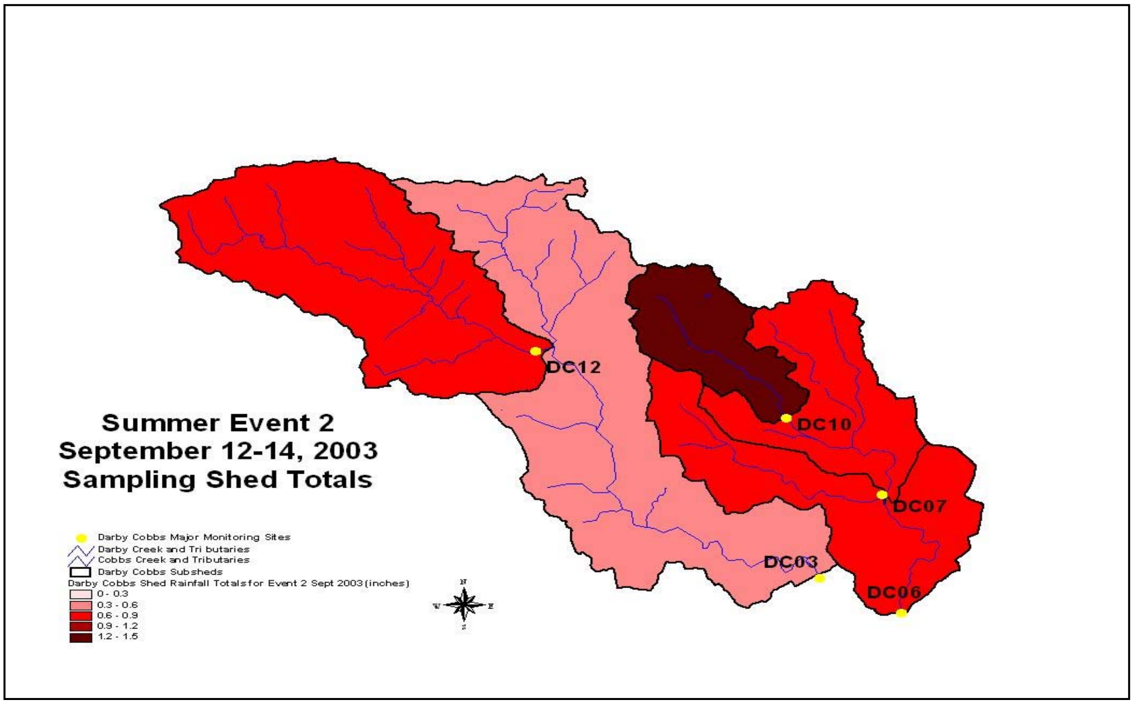


Figure 12. RADAR Rainfall totals by subshed (9/12/03-9/14/03).

SECTION 5: RESULTS AND DISCUSSION

5.1. Benthic Macroinvertebrate Assessment

Study of benthic macroinvertebrate communities has historically been one of the most important tools used in stream water quality assessment. While several key aspects of benthic macroinvertebrate ecology make them ideally suited as bioindicators, their widespread use as such is predicated upon practical concerns. Benthic macroinvertebrates are nearly cosmopolitan in distribution and can be collected by almost anyone in almost any wadeable stream without specialized skill or equipment. Furthermore, identification, to at least the family level, can usually be accomplished in the field without specialized equipment. Because of the ease of their collection and potential discriminatory power of sampling results, thousands of macroinvertebrate surveys are performed each year by governmental and tribal agencies, academic researchers, environmental organizations, volunteer groups, and students of all ages.

While some measures of macroinvertebrate community structure (e.g., diversity indices) may provide meaningful information alone, conclusions of most analyses and metrics are enhanced by, or require, comparison to an unimpaired reference site. However, unimpaired reference sites are often difficult to identify in southeastern Pennsylvania due to extensive development and agricultural land uses. The most logical application of the reference site approach is a pair of sites upstream and downstream of a suspected source of impairment. The downstream site in this scenario has a rather constant source of colonists, or "drift". In regions where impairments occur watershed-wide and first order streams have been eliminated, one cannot assume that study sites have a constant upstream source of immigrants. The most likely means of colonization of these sites is by winged adults. Life history attributes of many invertebrate taxa (e.g., short lifespan of adults, flight capability, and predilection to disperse over upland habitats) reduce the likelihood that impaired sites within a widely impaired region will be recolonized frequently.

Sites in Darby-Cobbs Watershed were compared to reference sites on French Creek and Rock Run, in Chester County, PA. Reference sites were chosen to reflect the range of stream drainage areas in Darby-Cobbs Watershed, yet extensive impervious cover in portions of Darby-Cobbs Watershed complicates this comparison. Due to exaggerated storm flows and concomitant erosion, many sites in Darby-Cobbs Watershed may be categorized as first or second order streams, yet exhibit geomorphological attributes (e.g., bankfull discharge area) similar to sites with much larger drainage areas. These details are addressed in greater detail in Section 5.3 Habitat Assessment

5.1.1. Watershed Overview

A total of 2,114 individuals of 40 taxa were collected and identified during the 2003 benthic macroinvertebrate survey of Darby-Cobbs Watershed. Mean taxa richness of all sites within the watershed was 14.3 (Table 8). Overall, moderately tolerant (89.74%) and generalist feeding taxa (75.72%) dominated the watershed. Mean Hilsenhoff Biotic Index (HBI) of all assessment sites was 5.63 (Figure 13). Overall, the watershed lacked

Table 8. Biological condition results for RBP III.

Watershed	Monitoring Site	Taxa Richness	Modified EPT Taxa	Hilsenhoff Biotic Index (modified)	Percent Dominant Taxon	Percent Modified Mayflies	Biological Quality (%)	Indicator Status
Cobbs	DCC208	12	0	7.06	42.42%	0.00	0.00	Severely Impaired
	DCC455	12	0	5.24	44.86%	0.00	26.67	Moderately Impaired
	DCC793	15	1	5.44	39.44%	0.00	40.00	Moderately Impaired
	DCC1003	13	0	5.88	57.80%	0.00	13.33	Severely Impaired
Darby	DCD765	11	1	5.69	68.70%	0.00	0.00	Severely Impaired
	DCD1105	17	1	5.38	32.08%	0.00	20.00	Moderately Impaired
	DCD1570	16	4	5.04	33.09%	100.00	46.67	Moderately Impaired
	DCD1660	14	1	5.45	61.42%	0.00	13.33	Severely Impaired
	DCD1880	17	3	4.81	23.14%	0.00	46.67	Moderately Impaired
	DCD2138	23	3	5.03	34.42%	100.00	73.33	Slightly Impaired
Tributaries	DCN010	16	1	6.13	15.04%	0.00	40.00	Moderately Impaired
	DCN208	13	0	6.02	23.97%	0.00	33.33	Moderately Impaired
	DCI010	12	0	5.97	60.29%	0.00	13.33	Severely Impaired
	DCIW177	12	1	5.83	37.82%	0.00	33.33	Moderately Impaired
	DCIE186	11	0	5.78	74.07%	0.00	6.67	Severely Impaired
	DCLD034	13	1	5.28	51.68%	0.00	13.33	Severely Impaired
	DCIC007	16	2	5.65	51.32%	0.00	6.67	Severely Impaired

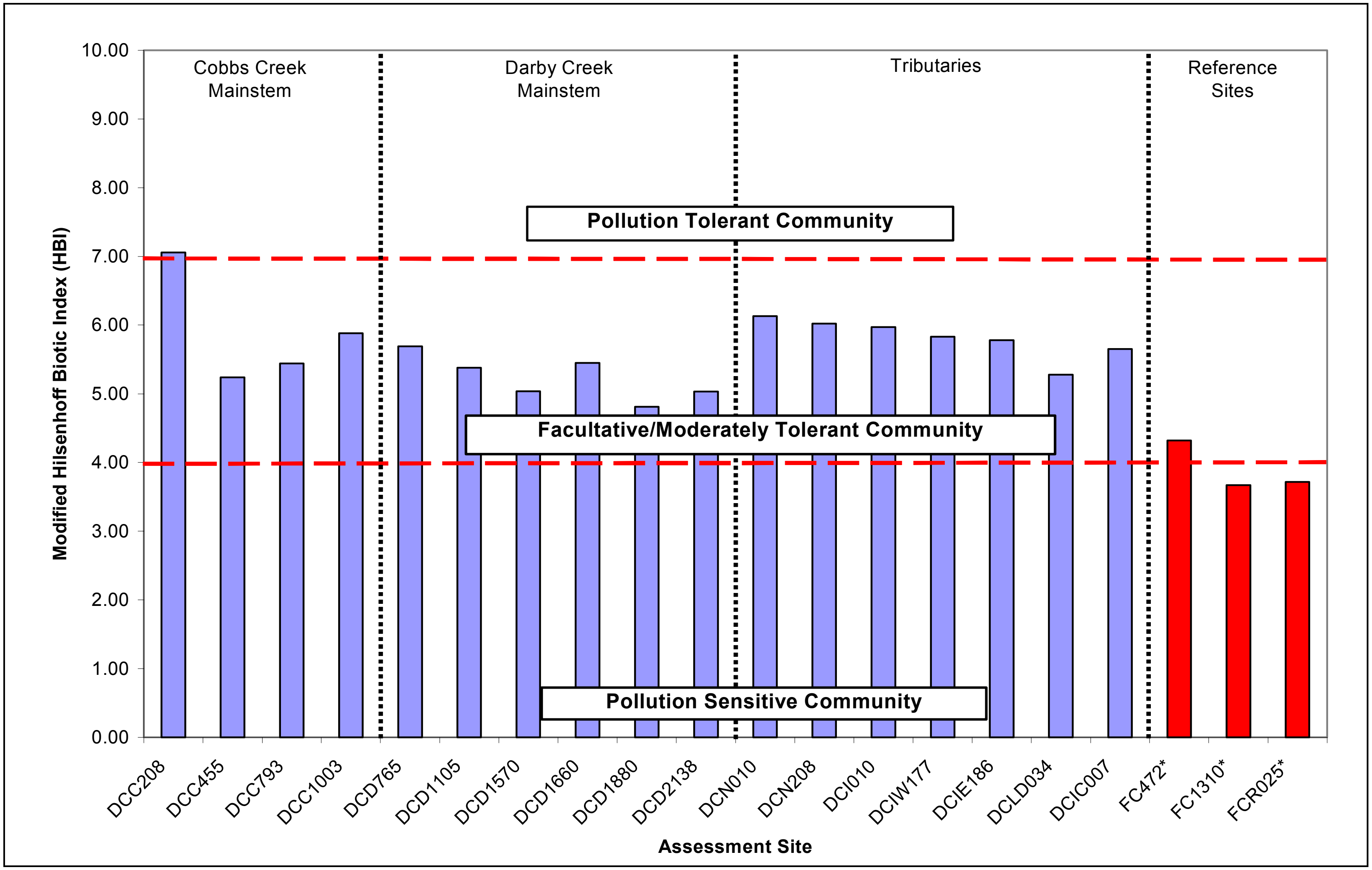


Figure 13. Modified Hilsenhoff Biotic Index (HBI) scores of assessment sites in Darby-Cobbs Watershed.

pollution sensitive Ephemeroptera, Plecoptera, and Trichoptera (EPT) taxa. While present at four upstream Darby Creek sites, abundance of EPT taxa was very low (Figure 14). Midges (family Chironomidae) and net-spinning hydropsychid caddisflies (*Hydropsyche* and *Cheumatopsyche*) dominated the benthic assemblage of most sites within the watershed (percent contribution ranged from 23.14% to 74.07%). Annelids, riffle beetles, isopods, amphipods, tipulids, gastropods, and oligochaetes were also present throughout the watershed.

Basic analysis of raw benthic macroinvertebrate abundance data yields a number of ecological community attributes, such as taxa richness, diversity and evenness, as well as metrics specific to the study of benthic macroinvertebrate communities: modified Ephemeroptera/Plecoptera/Trichoptera (EPT) and Mayfly indices; feeding categorizations; and tolerance measures, including the Hilsenhoff Biotic Index (HBI). While the sampling protocol (a modification of USEPA's RPBIII) was not designed as a quantitative method, the number of subsamples, or plugs, required to count the minimum number of organisms also provided some qualitative data.

The Hilsenhoff Biotic Index (HBI) is used to rate the overall pollution tolerance of a site’s benthic macroinvertebrate community. The HBI is reference site based and oriented toward the detection of organic pollution. HBI scores are unitless and can theoretically range from zero (very sensitive) to ten (very tolerant). Mean HBI score of sites within Darby-Cobbs Watershed was 5.63. The dominance of moderately tolerant individuals and general lack of pollution sensitive taxa contributed to the elevated HBI. Mean HBI score of reference sites was 3.90. Differences in HBI score between assessment and reference sites greater than 0.71 are considered an indicator of impairment. Mean HBI score of sites within Darby-Cobbs exceeded mean reference site score by 1.73, which suggests widespread impairment.

General Tolerance measures are intended to be representative of relative sensitivity to perturbation and may be expressed as numbers of pollution tolerant and intolerant taxa or percent composition (Barbour et al. 1999). Moderately tolerant individuals (89.72%) were collected with greatest frequency in Darby-Cobbs Watershed. Sensitive taxa were poorly represented (3.80%). Abundance of pollution-tolerant taxa may be a response to watershed-wide disturbances.

Feeding measures consider categorized functional feeding groups (e.g., scraper, shredder, collector-gatherer) and provide information regarding the balance of feeding strategies in the benthic community (Barbour et al. 1999). The trophic composition of benthic macroinvertebrate communities at most sites within Darby-Cobbs Watershed was skewed toward generalist-feeding filterers and collectors (75.72%) Generalist-dominated communities in the Cobbs and Indian Creek subsheds may be indicative of an unbalanced community responding to an overabundance of a food resource (i.e., fine particulate organic matter-FPOM) (Fiorentino, 2000). Limitation in food sources limits the competitive ability of specialized feeders.

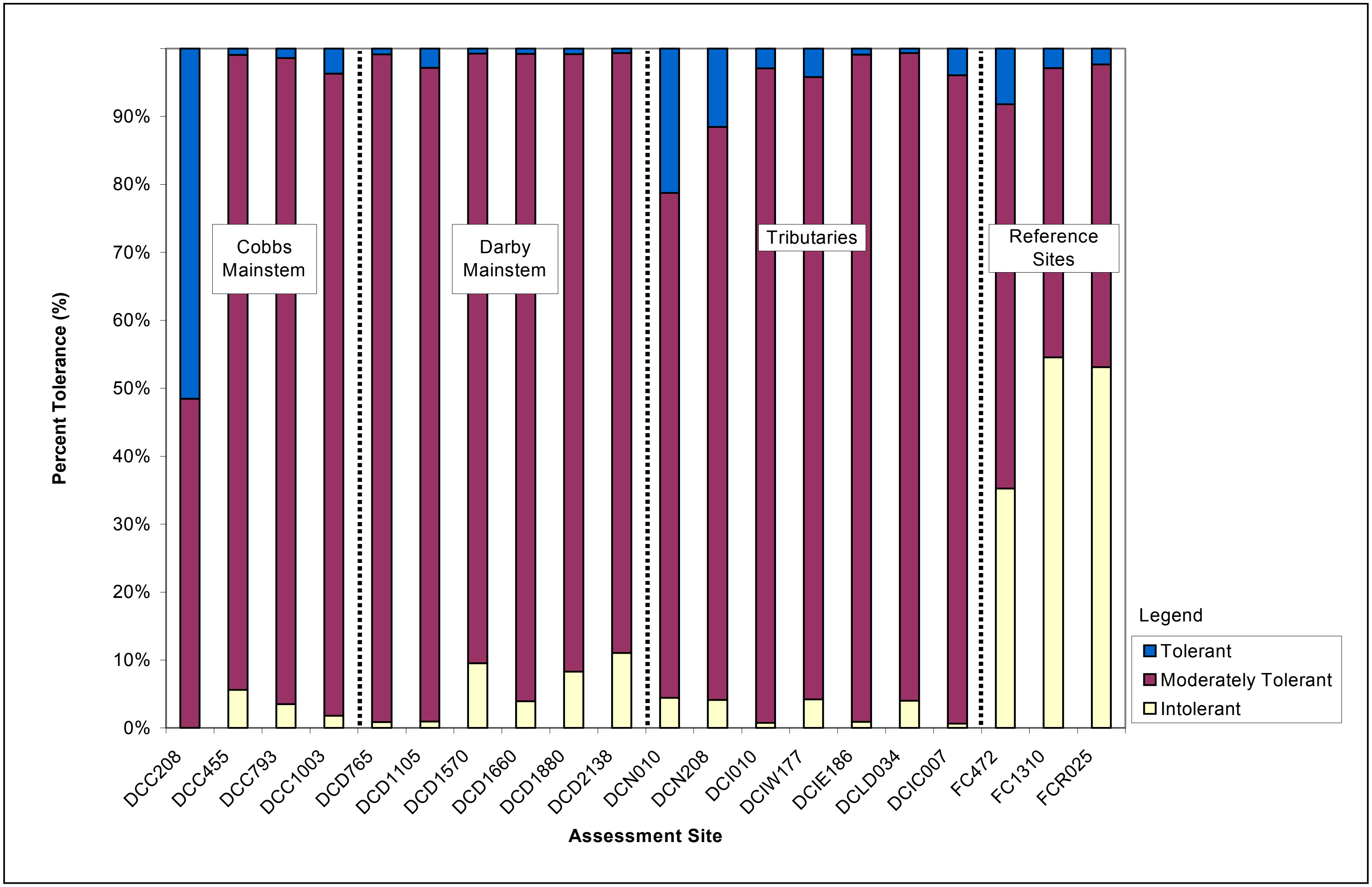


Figure 14. Pollution tolerance values (%) of macroinvertebrate assemblages at each assessment site in Darby-Cobbs Watershed.

However, specialized feeding groups are generally more sensitive to disturbance than generalist feeders. Generalist-dominated assemblages throughout the watershed, especially in Darby Creek watershed, may reflect effects of other environmental disturbances (e.g., flow modification) completely unrelated to organic enrichment. As most benthic macroinvertebrate metrics are aimed at detecting impairment due to organic enrichment, care must be taken not to misinterpret the findings of these tests, especially in light of potentially contradictory habitat and water chemistry data.

5.1.2. Cobbs Creek Mainstem Sites

5.1.2.1. DCC208

With a total biological score of four (4), DCC208 was designated "severely impaired" (13.3% comparison). Four plugs were sorted in order to obtain 100 individuals. DCC208 had low taxa richness (n=12) and no EPT taxa present. Physid snails dominated the benthic assemblage at the site (42.42%) which contributed to the highest HBI score (7.06) of all assessment sites. Due to the large snail population, scrapers (57.58%) and tolerant individuals (51.52%) dominated the assemblage.

5.1.2.2. DCC455

The total biological score at DCC455 was eight (8) out of 30. With a 26.67% comparison, the site was designated "moderately impaired". The site had a slightly elevated HBI score (5.24) and was dominated by net-spinning caddisflies (66.35% total; 44.86% *Hydropsyche* and 21.50% *Cheumatopsyche*). The abundance of Hydropsychidae skewed the trophic feeding structure of the site toward filterers (66.36%). No EPT taxa were collected, and the site had low taxa richness (n=12). A broken sanitary sewer upstream of the assessment discovered shortly after benthic sampling may have contributed to the impaired macroinvertebrate community.

5.1.2.3. DCC793

DCC793 earned a biological score of 12. This score was a 40.0% comparison to the reference condition at FCR025, and the site was deemed "moderately impaired". DCC793 had low taxa richness (n=15), although it was the highest of all assessment sites on Cobbs Creek. Only one EPT taxon was present (*Chimarra*), and the site had an elevated HBI score of 5.44. Similar to other downstream Cobbs Creek sites, DCC793 was dominated by filter feeding Hydropsychidae (*Hydropsyche* 39.44% and *Cheumatopsyche* 21.13%). Hydropsychids and chironomids comprised 83.10% of all individuals in the analyzed sample.

5.1.2.4. DCC1003

The assessment site at DCC1003 received a total biological score of four (4), which was a 13.3% comparison to FCR025. The relative density of macroinvertebrates was low at DCC1003. Three plugs were needed to acquire 100 individuals. There was low taxa richness (n=12) and an absence of EPT taxa at the site. The majority of individuals in the sample were midges (57.80% Chironomidae), and the trophic composition of the site was dominated by gatherers (61.47%). With most metrics scoring zero (0), DCC1003 was designated "severely impaired".

5.1.3. Darby Creek Mainstem Sites

5.1.3.1. DCD765

DCD765 received a total metric score of zero (0) out of a possible 30. The site was designated "severely impaired". To obtain 100 individuals, five sub-samples were sorted. DCD765 had the highest HBI score (5.69) and lowest taxa richness (n=11) of all mainstem Darby Creek assessment sites. The amphipod *Gammarus* dominated the benthic assemblage (68.70%), and the feeding structure at DCD765 consisted of mainly generalist collector-gatherers (75.65%). The low density of macroinvertebrates, dominance of moderately pollution tolerant taxa (98.26%) and high proportion of generalists contributed to the site's impairment designation.

5.1.3.2. DCD1105

The assessment at site DCD1105 received a biological score of eight (8). The site had a 20.0% comparison to FC472 and was designated "moderately impaired". DCD1105's metric comparison score fell between the moderate and severely impaired biological condition categories. A taxa richness of n=17 and relatively low percent dominant taxon (32.08% Chironomidae), lead to a "moderately impaired" status designation. Only one EPT taxon (*Chimarra*) was present, and the HBI score at DCD1105 was an elevated 5.38. All trophic levels were represented but generalist feeders dominated the sample (62.26% gatherers and 23.58% filterers). The site had a low relative density. Four sub-samples were sorted to obtain the necessary 100 individuals.

5.1.3.3. DCD1570

The total biological score at DCD1570 was 14—a 46.67% comparison to the reference condition at FC472. The site at DCD1570 was designated "moderately impaired". DCD1570 had one of the lowest HBI scores (5.04) and had the greatest number of EPT taxa (n=4) of all Darby-Cobbs assessment sites. The assemblage had relatively low percent dominant taxon (33.09% Chironomidae), but the trophic structure lacked shredders. The assemblage was dominated by gatherers (44.85) and scrapers (36.03%).

5.1.3.4. DCD1660

The macroinvertebrate assemblage at DCD1660 scored four (4) when compared to the reference conditions at FC1310. The site was designated "severely impaired". Impairment was due to the dominance of midge larvae (61.42%) and an elevated HBI score (5.45). DCD1660 had low taxa richness (n=14) and only one EPT taxon (*Chimarra*) was identified in the sub-sample. All feeding groups were present, but specialized feeders (scrapers, shredders, and predators) were not well represented. Generalist feeding gatherers (67.7%) dominated the assemblage.

5.1.3.5. DCD1880

DCD1880 had a total biological score of 10 out of 30, which represents a 33.33% comparison to FC1310. DCD1880 had the lowest HBI score (4.81) of all 2003 assessment sites, and also had low percent dominant taxon (23.14% Chironomidae). Three EPT taxa were present in the analyzed sub-sample, and the taxa richness (n=17) was fair. DCD1880 was designated "moderately impaired".

5.1.3.6. DCD2138

The assessment site at DCD2138 received a total biological score of 16, which was a 53.3% comparison to FC1310. The site was designated "slightly impaired". DCD2138 was the only site in the 2003 survey to be deemed only slightly impaired. DCD2138 had the highest taxa richness (n=23) of all assessment sites, and received an HBI score of 5.03. Three EPT taxa were identified in the sub-sample from DCD2138, and it had low percent dominant taxon (34.42% Chironomidae). The trophic structure at DCD2138 was balanced, and the site had the highest proportion of intolerant macroinvertebrates of all sites.

5.1.4. Darby-Cobbs Tributary Sites

5.1.4.1. DCN010

DCN010 had a total biological score of 12, and the site was designated "moderately impaired". The assemblage at the site had good percent dominant taxa, as the two major taxa (Lumbriculidae and *Hemerodromia*) each comprised 15.04% of all individuals, but Lumbriculidae and *Hemerodromia* are moderately tolerant and tolerant taxa, respectively. In addition, DCN010 had a balanced trophic structure. Despite the relatively favorable balance of the assemblage at DCN010, the sites had an overall lack of macroinvertebrates. Nine sub-samples were sorted in order to obtain the required 100 individuals for metrics. The site had an elevated HBI score (6.13) and a very high percentage of tolerant individuals (21.24%). The "moderately impaired" designation for DCN010 may not accurately reflect the biological condition at the site due to the low taxa richness of the reference site FCR025. This factor may have skewed the metric scores of DCN010.

5.1.4.2. DCN208

The total biological score at DCN208 was ten (10). The site was deemed “moderately impaired” based on a 33.33% comparison to the reference condition. Similar to other sites, DCN208 had an elevated HBI score (6.02) and an absence of EPT taxa. The community had low taxa richness, but good percent dominant taxa. Chironomid larvae and *Cheumatopsyche* each comprised 23.97% of the benthic assemblage. The total numbers of net-spinning caddisfly taxa (Hydropsyche and Cheumatopsyche) comprise 44.63% of all individuals. Generalist feeding gatherers and filterers composed 82.65% of the trophic structure of the site. The impaired biological conditions at DCN208 may be due in part to much of Naylors Run being encapsulated.

5.1.4.3. DCI010

The assessment site at DCI010 scored four (4) out of 30 when compared to FCR025. There was a 13.33% percent comparison to FCR025, and the site was designated “severely impaired”. DCI010 had very high percent dominant taxon (Chironomidae 60.29%), and no EPT taxa were present. The site also had low taxa richness and an elevated HBI score (5.97). The abundance of chironomids caused gatherers (66.91%) to dominate the trophic structure of the site. Generalist feeding macroinvertebrates composed 95.59% of the total number of individuals. Upon visiting DCI010, field personnel were informed by golf course staff that water at the site was frequently an opaque gray color, possibly due to sewage in the creek.

5.1.4.4. DCIW177

The benthic assemblage at DCIW177 received a total biological score of ten (10), which represents a 33.33% comparison to FCR025. The site was designated “moderately impaired”. One EPT taxon (*Glossosoma*) was identified in the sub-sample, but only one individual was found. The site had low taxa richness (n=12) and a high HBI score (5.83). All trophic levels were represented, but specialized feeders were almost absent. Generalist feeders comprised 94.96% of the macroinvertebrate community. The percent dominant taxon (37.82% Chironomidae) was fair.

5.1.4.5. DCIE186

DCIE186 scored only two (2) out of 30. With 13.33% comparison, the site was designated “severely impaired”. DCIE186 had an elevated HBI score (5.75), and no EPT taxa. The site had the lowest taxa richness (n=11) and the highest percent dominant taxon (74.07% Chironomidae) of all the assessment sites. All trophic groups were present at the site, but gatherers (82.41%) dominated the community. 98.15% of all individuals at the site were moderately tolerant.

5.1.4.6. DCLD034

The macroinvertebrate assemblage at DCLD034 scored four (4) out of 30. DCLD034 had an elevated HBI score (5.28) and high percent dominant taxon (51.68% Chironomidae). The site had only one EPT taxa (*Chimarra*) and low taxa richness (n=13). Moderately tolerant taxa dominated the benthic assemblage. The metrics at DCLD034 had a 13.33% comparison to FCR025 deeming it "severely impaired".

5.1.4.7. DCIC007

The total biological score at DCIC007 was two (2). The score of two corresponded to a "severely impaired" designation (6.67% comparison). The site had an elevated HBI score (5.65) and a taxa richness of n=16. There were two EPT taxa (*Agraylea* and *Chimarra*) present in the sub-sample analyzed. The trophic composition was skewed toward generalist feeding gatherers (59.21%) due to the abundance of chironomids (51.32% of individuals). The benthic macroinvertebrates at DCIC007 were sampled approximately two months (5/12/03) after all other assessment sites were sampled. The observed biological integrity could be due to seasonal changes and not degraded water quality conditions.

5.2. Fish Assessment

5.2.1. Overview

A total of 12,882 individuals of 44 species representing 13 families were collected throughout Darby-Cobbs Watershed in the 2003 bioassessment (Table 9). Blacknose dace (*Rhinichthys atratulus*) and Banded killifish (*Fundulus diaphanus*), two taxa highly tolerant of poor stream conditions, were most abundant and comprised approximately 33% of all fish collected. Other common species were White sucker (*Catostomus commersoni*), Mummichog (*Fundulus heteroclitus*), Common shiner (*Luxilus cornutus*), and Swallowtail shiner (*Notropis procne*). Of 44 species collected, seven species comprised 78% of the entire fish assemblage. Similarly, four species made up nearly 70% of total biomass, with white sucker and American eel (*Anguilla rostrata*) contributing greater than 55%. In general, Darby Creek had greater species richness, but Cobbs Creek had higher abundance, density (individuals per unit area), and catch rates (catch per unit effort).

Trophic composition evaluates quality of the energy base and foraging dynamics of a fish assemblage. This is a means to evaluate the shift towards more generalized foraging that typically occurs with increased degradation of the physicochemical habitat (Barbour et al., 1999). Generalist feeders (54.7%) and insectivores (38.2%) dominated Darby-Cobbs Watershed, with 6.1% top carnivores and approximately 1% herbivores and filter feeders. Trophic composition was fair compared to reference sites. In Cobbs Creek, top carnivore and insectivore taxa abundance decreased while abundance of generalist feeders increased in an upstream direction (Figure 15). Also, percentage of White suckers (*C. commersoni*) increased in an upstream direction, as White suckers typically increase in abundance in degraded streams. In Darby Creek, abundance of generalist feeders increased, whereas the percentage of insectivore taxa decreased in an upstream direction.

Table 9. Species list and relative abundance of fish taxa collected in the Darby-Cobbs Watershed.

Scientific Name	Common Name	Number Of Individuals Identified
Alosa aestivalis	Blueback Herring	42
Alosa sapidissima	American Shad	1
Ameiurus catus	White Catfish	1
Ameiurus natalis	Yellow Bullhead Catfish	1
Ameiurus nebulosus	Brown Bullhead Catfish	60
Ambloplites rupestris	Rock Bass	76
Anguilla rostrata	American Eel	555
Carassius auratus	Goldfish	11
Catostomus commersoni	White Sucker	831
Cyprinella analostana	Satinfin Shiner	219
Cyprinus carpio	Common Carp	32
Cyprinella spiloptera	Spotfin Shiner	9
Dorosoma cepedianum	Gizzard Shad	3
Esox lucius x Esox masquinongy	Tiger Muskellunge	1
Etheostoma olmstedi	Tessellated Darter	237
Exoglossum maxillingua	Cutlips Minnow	442
Fundulus diaphanus	Banded Killifish	1917
Fundulus heteroclitus	Mummichog	1088
Gambusia affinis	Mosquitofish	3
Hybognathus regius	Eastern Silvery Minnow	117
Ictalurus punctatus	Channel Catfish	2
Lepomis auritus	Redbreast Sunfish	651
Lepomis cyanellus	Green Sunfish	8
Lepomis gibbosus	Pumpkinseed Sunfish	129
Lepomis auritus x Lepomis gibbosus	Sunfish Hybrid	1
Lepomis macrochirus	Bluegill Sunfish	52
Luxilus cornutus	Common Shiner	1018
Micropterus dolomieui	Smallmouth Bass	23
Micropterus salmoides	Largemouth Bass	6
Morone americana	White Perch	1
Morone saxatilis	Striped Bass	1
Notemigonus crysoleucas	Golden Shiner	11
Notropis hudsonius	Spottail Shiner	200
Notropis procne	Swallowtail Shiner	1465
Oncorhynchus mykiss	Rainbow Trout	26
Pimephales notatus	Bluntnose Minnow	65
Pimephales promelas	Fathead Minnow	148
Pomoxis nigromaculatus	Black Crappie	1
Rhinichthys atratulus	Blacknose Dace	2157
Salvelinus fontinalis	Brook Trout	1
Salmo trutta	Brown Trout	31
Semotilus atromaculatus	Creek Chub	143
Semotilus corporalis	Fallfish	24
Umbra pygmaea	Eastern Mudminnow	1

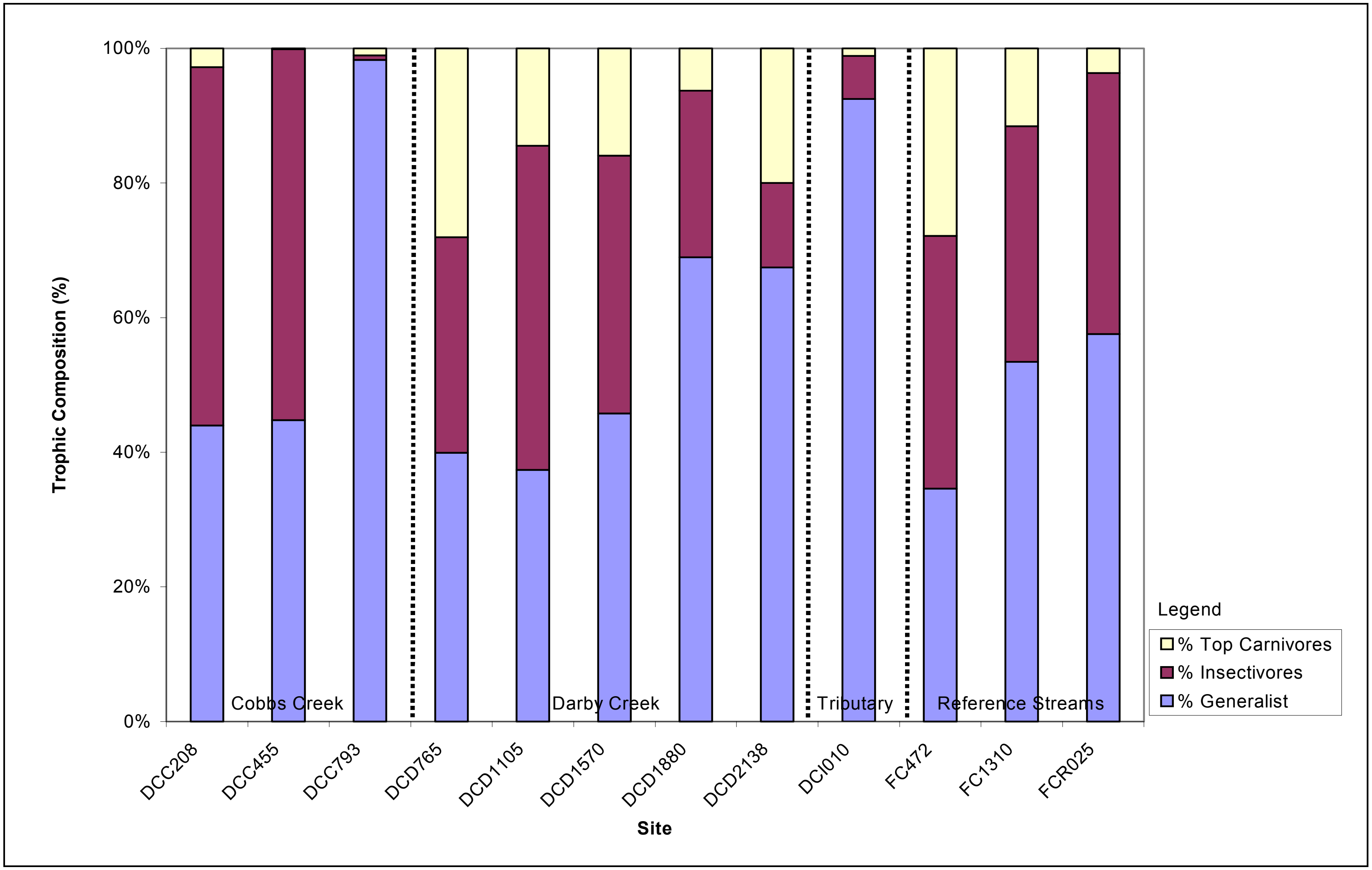


Figure 15. Trophic structure of fish assemblages in the Darby-Cobbs Watershed.

Relative abundance of insectivores decreases with degradation in response to availability of the insect supply, which reflects alterations of water quality and instream habitat (Daniels et al., 2002). Of particular concern was the absence of Longnose dace (*Rhinichthys cataractae*) in Darby-Cobbs Watershed. This benthic insectivore requires complex riffle systems of good quality and its complete absence in the watershed suggests impaired stream conditions. Though community composition varied between sites, the fish assemblage in Darby-Cobbs Watershed was skewed towards a tolerant, generalist feeding community.

Tolerance designations describe the susceptibility of a species to chemical and physical perturbations. Intolerant species are typically first to disappear following a disturbance (Barbour et al., 1999). Tolerant and moderately tolerant species composed 95% of the fish fauna in Darby-Cobbs Watershed (Figure 16). Cutlips minnow (*Exoglossum maxillingua*) and stocked trout (*Oncorhynchus mykiss, Salmo trutta, Salvelinus fontinalis*) were the only intolerant taxa found in the non-tidal sites. Eastern silvery minnow (*Hybognathus regius*) and Striped bass (*Morone saxatilis*) were additional intolerant species found in the tidal portions of the watershed. No more than one sensitive species was found at any given non-tidal site. Furthermore, all but two assessment sites were dominated by taxa tolerant of poor water quality. The non-tidal portion of Cobbs Creek was devoid of pollution-sensitive taxa. The relative low abundance of intolerant species implies a high level of disturbance that appears to increase upstream.

The Index of Biotic Integrity (IBI) is useful in determining long-term effects and coarse-scale habitat conditions because fish are relatively long-lived and mobile. A site with high integrity (i.e. high score) is associated with native communities that interact under natural community processes and functions (Karr 1981). Since biological integrity is closely related to environmental quality, assessments of integrity can serve as a surrogate measurement of health (Daniels et al., 2002). Mean IBI score for Darby-Cobbs Watershed was 31 (out of 50), placing it in the “fair” category (Figure 17). Skewed trophic structure and rare intolerant species are characteristics of a fish community in the “fair” category. The Modified Index of Well-Being and Shannon Diversity Index values, which are measures of diversity and abundance, decreased in an upstream direction. Overall, the more downstream sites had higher biological integrity than upstream sites.

5.2.2. Cobbs Creek Mainstem Sites

5.2.2.1. DCC208

In 1523.33 m^2 of stream surface area, a total of 1217 fish representing 13 species were collected during 80.95 minutes of electrofishing. DCC208 had the lowest abundance, biomass (9.50kg), density (0.8 fish/m^2), and standing crop (6.23g/m^2) in Cobbs Creek Watershed. Three species tolerant of poor stream conditions comprised over 80% of all fish collected, with Banded killifish (*F. diaphanus*) most abundant. Benthic insectivorous and intolerant species were absent from this monitoring location. Nearly

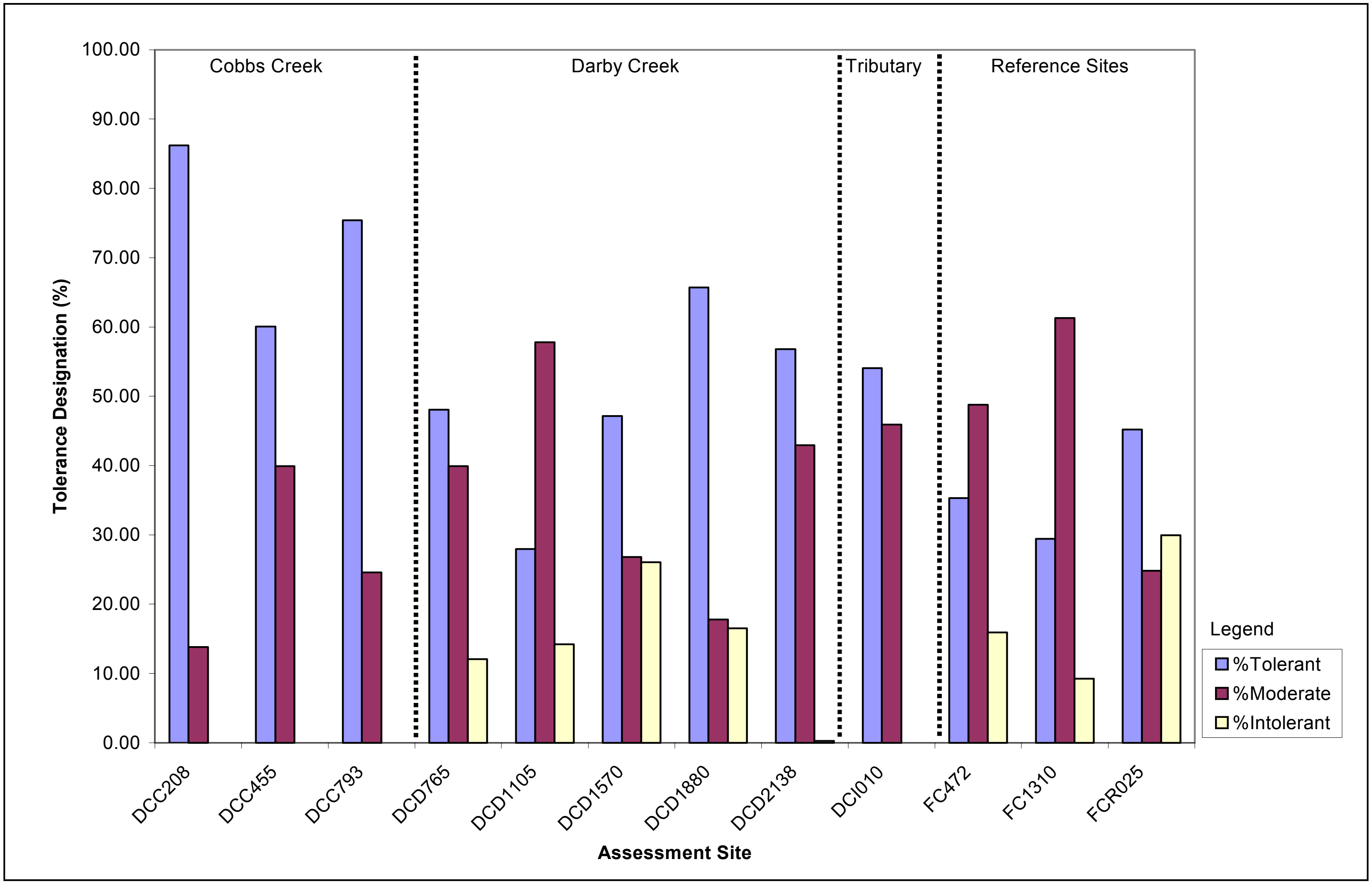


Figure 16. Pollution tolerance values at the monitoring sites in Darby-Cobbs Watershed.

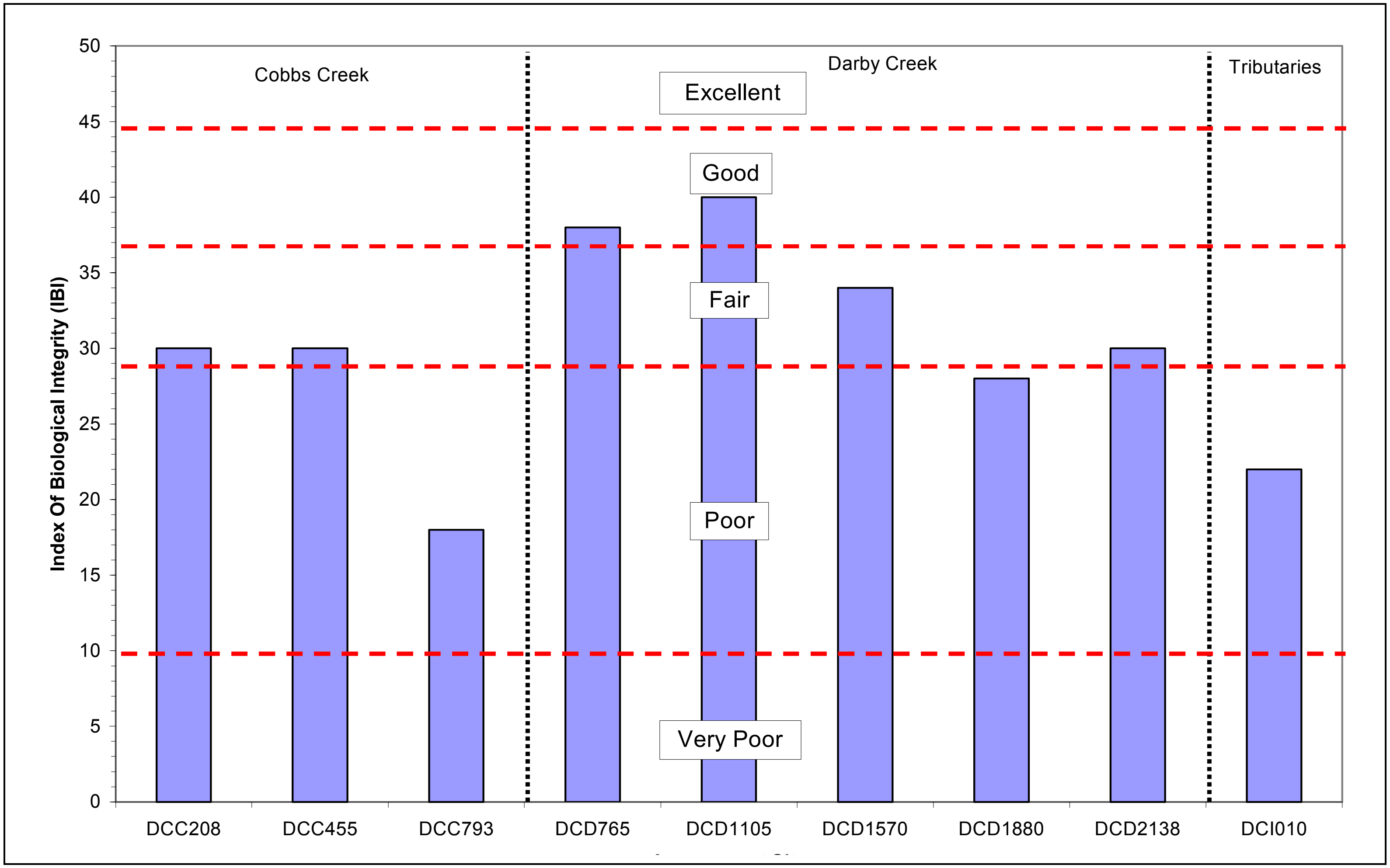


Figure 17. Index of Biological Integrity (IBI) scores at the nine assessment sites in Darby-Cobbs Watershed.

90% of the fish assemblage consisted of tolerant individuals and one single species accounted for 47% of all fish; three species contributed 68% of the total biomass at this location. The trophic composition was dominated by generalist feeders (44%) and insectivores (53%), with 3% top carnivores. The prevalence of tolerant taxa and unevenness of the assemblage indicated degraded stream conditions. The IBI score was 30 (out of 50), placing this site in the "fair" category. Absences of intolerant and sensitive species as well as a skewed trophic structure are characteristic of sites with fair biologic integrity. DCC208 had the lowest Modified Index of Well-Being value (9.51) of all main stem sites in the Darby-Cobbs Watershed and the Shannon Diversity Index (1.58) was well below reference condition values.

5.2.2.2. DCC455

A total of 1510 individuals of 17 species (including exotic and non-resident) yielded a biomass of 16 kg during 81 minutes of electrofishing. Based on a stream surface area of 1003 m^2, a density of 1.51 fish per m^2 and standing crop of 15.96 grams per m^2 were calculated. Of the 17 species collected at DCC455, four species accounted for 78% of the site's abundance and 86% of the total biomass. Banded killifish (*F. diaphanus*), a highly tolerant species, was most abundant (34%) and Brown bullhead (*Ameiuris nebulosus*) dominated the biomass (35%). Other common species were Mummichog (*F. heteroclitus*), Redbreast sunfish (*Lepomis auritus*), and Swallowtail shiner (*N. procne*). There were no intolerant taxa and benthic insectivorous species collected at this location; 60% of individuals were tolerant and 40% were moderately tolerant to pollution. The trophic composition was 55% insectivores, 45% generalist feeders, and less than 1% top carnivores.

The IBI score of 30 (out of 50) is characteristic of a "fair" quality fish assemblage. Since the IBI metric for total number of fish species excludes exotic and nonresident taxa, only 16 species were used to calculate the IBI score. This site had the highest Modified Index of Well-Being (11.13) and Shannon Diversity Index (1.94) for Cobbs Creek Watershed. However, these measures of abundance and diversity overestimate the quality of the assemblage because they do not account for the skewed trophic structure, lack of sensitive species, and elevated percentage of fish with disease and anomalies typically found in poor quality streams.

5.2.2.3. DCC793

DCC793 was the upstream-most fish assessment site within Cobbs Creek Watershed and located just upstream of the Philadelphia County line. This site had the greatest abundance and biomass, but the lowest diversity on the main stem of Cobbs Creek. The upstream site yielded 1907 individual fish of 12 species, accounting for 23.7 kg of biomass. Of 12 species collected at DCC793, 3 species comprised approximately 92% of all fish collected and 84% of the total biomass. Blacknose dace (*R. atratulus*), a tolerant species, was most abundant and accounted for more than half of the entire assemblage. Furthermore, no intolerant taxa were collected at DCC 793 and 98% of the assemblage was generalist feeders. Despite the highly skewed trophic structure (indicative of degraded stream conditions), this site had the greatest density (number of fish per unit area) and standing crop (biomass per unit area) in Cobbs Creek Watershed.

This site received an IBI score of 18 (out of 50), signifying a "poor" quality fish assemblage and therefore, poor environmental health. This was the lowest IBI score in Darby-Cobbs Watershed. In addition, nearly one third of assemblage had some type of disease or anomaly. The low values for the Modified Index of Well-Being (10.08) and Shannon Diversity Index (1.21) corroborate with the poor IBI score and represent an unhealthy stream reach.

5.2.3. Darby Creek Mainstem Sites

5.2.3.1. DCD765

Sampling at DCD765 took place several days following periods of rain. Discharge and stage height were slightly above normal, and may have accounted for reduced sampling efficiency. A total of 356 fish representing 18 species (including exotic and non-resident) were collected during 71.67 minutes of electrofishing in 1506.86 m^2 of stream surface area. This was the minimum number of fish collected at any site in Darby-Cobbs Watershed. Nevertheless, this site had good relative diversity and a balanced trophic structure. Trophic composition was evenly distributed, with 39% generalist feeders, 32% insectivores, and 28% top carnivores, representing the maximum percentage of top carnivores found at any site in the watershed. The most common fish were American eel (*Anguilla rostrata*), Cutlips minnow (*E. maxillingua*), and Redbreast sunfish (*L. auritus*), making up 58% of the fish assemblage. *A. rostrata* comprised 96% of the top carnivores and 41% of total biomass at DCD765. The presence of large American eels may have reduced the abundance of cyprinids and overall abundance through competitive exclusion or predation.

DCD765 received an IBI score of 38 (out of 50), placing it in the category of a "good" quality fish assemblage. The elevated percentage of intolerant individuals (12%) and low occurrence of DELT anomalies (5.9%) are characteristic of stream reaches with good biological integrity. The Modified Index of Well-Being (10.46) and Shannon Diversity Index (2.21), however, are relatively lower than expected in a "healthy" fish assemblage , and may be a result of decreased sampling efficiency due to high water velocities.

5.2.3.2. DCD1105

A total of 436 fish representing 17 species (including exotic, non-resident, stocked fishes) were collected during 75.33 minutes of electrofishing in 1450.67 m^2 of stream surface area. There were 2 benthic insectivorous species, 4 water column species, and only 1 intolerant taxa present at DCD1105. This site had the second lowest density and third lowest abundance of fish in Darby-Cobbs Watershed. Nonetheless, the small percentage of White suckers (3%) and a higher percentage of intolerant individuals (14%) are signs of a good quality fish assemblage. Also, this was one of only two sites with more moderately tolerant (58%) than tolerant (28%) fish. Functional feeding groups were well distributed between insectivores (48%), generalist feeders (37%) and top carnivores (15%).

The most common species included Swallowtail shiner (*N. procne*), Cutlips minnow (*E. maxillingua*), and Blacknose dace (*R. atratulus*), with American eel (*A. rostrata*) composing more than half of the biomass. This site had the highest IBI score in the Darby-Cobbs Watershed, with a value of 40 (out of 50). DCD1105 also received the highest Shannon Diversity Index value of 2.35. Based on the IBI score and Shannon Diversity Index, relative health of the fish assemblage at DCD1105 was the best in the watershed and characteristic of only slightly degraded streams.

5.2.3.3. DCD1570

The collection of 38 stocked trout (*Oncorhynchus mykiss* and *Salmo trutta*) from this site was the most in the watershed; however, the absence of juvenile trout suggests that there is no trout reproduction. Therefore, stocked trout were not included in several IBI metrics involving intolerant taxa and species richness. We collected 933 fish of 19 species (including exotic, non-resident, stocked fishes) during 87 minutes of electrofishing in 1208 m^2 of stream surface area. Of 19 species collected, six species accounted for 66% of all fish collected whereas four species comprised 87% of the total biomass. Blacknose dace (*R. atratulus*), a highly tolerant species, was most abundant (23%) and American eel (*A. rostrata*) was responsible for nearly half of the site's biomass. There were two benthic insectivorous species, four water column species, and only one intolerant species (*E. maxillingua*). DCD1570 had the greatest biomass (40.8 kg) and standing crop (biomass/m^2) of all Darby-Cobbs sites.

Biotic integrity of this site was "fair", receiving an IBI score of 34 (out of 50). Due to the high biomass and relative abundance, the Modified Index of Well-Being (10.46) and Shannon Diversity Index (2.27) overestimated the quality of the fish assemblage. This site was dominated by generalists feeders (46%) and had an elevated percentage of white suckers (12%), both signs of physical and chemical habitat deterioration (Barbour et al., 1999). Furthermore, this site had the greatest percentage of individual with DELT anomalies (43%) of all main stem sites in the watershed, suggesting possible subacute effects of chemical pollution.

5.2.3.4. DCD1880

The poor quality fish assemblage at this site was characterized by the high percentage of White suckers (15%), the dominance of generalist feeders (69%), lack of sensitive taxa, and high occurrence of individuals with DELT anomalies (25%). A total of 860 fish representing 22 species were collected at DCD1880; however, only 16 species were resident and non-stocked. Of 22 species collected, three species accounted for 72% of fish abundance and 74% of the total biomass (23.4 kg). Blacknose dace (*R. atratulus*), a highly tolerant species, comprised 41% of the fish assemblage and American eel (*A. rostrata*) was responsible for 37% of the site's biomass.

Tolerant taxa dominated this site and only one intolerant species (excluding stocked trout) was present. The Modified Index of Well-Being (11.21) and Shannon Diversity Index (1.91) values fell well below reference condition. The IBI score (28 out of 50) represented a fish assemblage of poor biological integrity. Local angler groups stock this portion of Darby Creek for an annual trout tournament and the potential effects of these introductions on native fish communities are uncertain.

5.2.3.5. DCD2138

Site DCD2138, positioned in a 2nd order reach of Darby Creek mainstem, was the uppermost site in Darby-Cobbs Watershed. This site had the lowest biomass and second lowest fish abundance in Darby Creek. A total of 375 individuals representing 12 species were collected during 70 minutes of electrofishing in 535.1 m^2 of stream surface area. Generalist feeders dominated this site (67%), but the percentage of top carnivores (20%) was much greater than expected for a stream this size. The piscivores, Rock bass (*Ambloplites rupestris*) and American eel (*Anguilla rostrata*), made up 78% of the biomass at this site. Furthermore, Blacknose dace (*R. atratulus*), a highly tolerant species, comprised 28% of the fish assemblage.

DCD2138 received an IBI score of 30 (out of 50), placing this site in the “fair” category. The Modified Index of Well-Being (10.26) value falls well below reference condition, but Shannon Diversity Index (2.12) is directly comparable to reference conditions. Over half of all individuals collected were tolerant and the fish assemblage was skewed towards a tolerant, generalist feeding community, suggesting a moderate level of chemical and/or physical perturbation.

5.2.4. Darby-Cobbs Tributary Sites

5.2.4.1. DCI010

This site was located on Indian Creek, a second order tributary to Cobbs Creek, and was the only tributary in which a fish assessment was conducted. Only six species were collected, compared to 18 species found at a second order reference stream. Species richness typically decreases with increased degradation. Common shiner (*L. cornutus*) and Blacknose dace (*R. atratulus*) were the most abundant species and White sucker (*C. commersoni*) constituted over half of the biomass. Intolerant taxa and benthic insectivorous species were absent. The trophic structure was biased towards generalist feeders (93%) and very few top carnivores were present. This site had the highest percentage of fish with disease and anomalies in Darby-Cobbs Watershed; more than half of all fish were affected. The extremely high incidence of DELT anomalies is symptomatic of a stressed community typically found downstream of point source pollution (Barbour et al., 1999).

Low species richness and composition scores combined with uneven trophic structure yielded an IBI score of 22 (out of 50), which is characteristic of a fish assemblage with “poor” biological integrity. To further support this point, DCI010 had the lowest

Modified Index of Well-Being (9.32) and second lowest Shannon Diversity Index (1.36) in the Darby-Cobbs Watershed. Also, this site had the maximum percentage of White suckers in the watershed (17%), indicative of degraded stream conditions.

5.2.5. Darby-Cobbs Tidal Sites

5.2.5.1. DCC037

Site DCC037 is located near the head of tide on the main stem of Cobbs Creek and was sampled at low to incoming tide. A total of 1710 individuals representing 25 species (including exotic and non-resident) were collected during 40.13 minutes of electrofishing in 1349.42 m^2 of stream surface area. This site had the greatest species richness, catch per unit effort (42.62 fish/min.) and second highest number of individuals collected in Darby-Cobbs Watershed. Despite the high diversity and abundance, two highly tolerant species, Banded killifish (*F. diaphanus*) and Mummichog (*F. hete*roclitus), comprised over 70% of the total fish assemblage. Furthermore, over 80% of all fish collected at DCC037 were tolerant of poor water quality, suggesting chemical and/or physical perturbation. It is important to note, however, that this is the only site in Cobbs Creek that contained an intolerant species (*Hybognathus regiu*s).

Due to the lack of tidal reference streams, an Index of Biotic Integrity (IBI) could not be determined. However, various metrics were used to estimate biological integrity. DCC037 had the highest percentage of top carnivores and the lowest percentage of individuals with disease, eroded fins, lesions, tumors, and anomalies (DELTA) in Cobbs Creek Watershed. Also, Modified Index of Well-Being (10.78) and Shannon Diversity Index (1.77) values indicate a fair quality fish assemblage.

5.2.5.2. DCD630

Site DCD630 is located near the head of tide on the main stem of Darby Creek and was sampled at low and incoming tide. A total of 1836 individuals representing 25 species (including exotic and non-resident) were collected during 47.34 minutes of electrofishing in 1366.7 m^2 of stream surface area. This site had the greatest species richness, catch per unit effort (42.62 fish/min.), density (1.34 fish/m^2), and number of individuals collected in the Darby Watershed. Despite high diversity and abundance, four species comprised over 70% of the total fish assemblage and 83% of total biomass. It is important to note, however, that this is the only site in Darby-Cobbs Watershed that contained two intolerant taxa (*Hybognathus regiu*s and *Exoglossum maxillingua*). Also, two benthic insectivorous species, five water column species and 11 cyprinid species were collected at DCD630.

Due to the lack of tidal reference streams, an Index of Biotic Integrity (IBI) could not be determined. However, various metrics were used to estimate biological integrity. Site DCC037 had the lowest proportion of generalist feeders (24%), most insectivores (68%), and lowest percentage of individuals with DELT anomalies in Darby-Cobbs Watershed. Also, this site had the highest Modified Index of Well-Being (11.78) in the watershed, indicating a good quality fish assemblage. DCD630 was only one of two sites that contained more moderately tolerant (62%) than tolerant (37%) fish.

5.3. Habitat Assessment

5.3.1. EPA Habitat Assessment Overview

Habitat impairments in Darby-Cobbs Watershed are numerous, mirroring those of other urban stream systems assessed by PWD. First and foremost, stream habitats within Darby-Cobbs Watershed are impaired due to effects of stormwater. Preponderance of impervious surfaces, particularly within Cobbs Creek Watershed, has diminished baseflow and caused small streams to exhibit increasingly “flashy” hydrographs in response to rain events (Appendix C). According to a baseflow separation analysis based on 27 years of flow data at USGS gauge 01475550, baseflow currently accounts for only 42% of mean total yearly flow from the Cobbs basin. In contrast, Darby Creek Watershed is less affected by impervious surfaces and has a yearly flow regime similar to the reference stream.

Exaggerated storm flows typical of urbanized watersheds result in erosion of banks and deposition of sediment in pools and on point bars. Many stream reaches in the watershed have been excessively overwidened and downcut; channels have been enlarged so severely that baseflow does not completely fill the channel or adequately cover riffle substrates. In many reaches, floodplain disconnection exists during almost all flow conditions. Due to ongoing erosion, nearly all stormwater forces are applied to a bare soil interface. Streambank erosion has also exposed sewer infrastructure (e.g., Manholes, interceptor sewers) increasing susceptibility of infrastructure to damage and leaks.

Fish and benthic macroinvertebrate sampling reinforced the view that stormwater flow is probably the most important factor shaping biological communities in most of the watershed. Stream organisms ill-adapted to extreme flows may be washed downstream and displaced from their optimum habitat. Erosion and sedimentation may decrease reproductive success of invertebrates and fish by washing away eggs, or alternately, covering eggs with sediment. Fish and benthic macroinvertebrate community responses to habitat modification were not consistent throughout the watershed. Serious effects were observed in Cobbs Creek and its tributaries, while upstream reaches of Darby Creek were similar in some aspects to reference conditions. Lower reaches of Darby Creek showed contrasting responses overall.

Common invertebrates of the most degraded portions of Cobbs and Lower Darby Creek have morphological or behavioral adaptations to increased stream velocities. Chironomid midges construct tubes made of silk that are firmly attached to stream substrates. The insect's body may be completely retracted within this protective tube. Similarly, hydropsychid caddisflies construct silk nets, which serve as refugia during exaggerated flow conditions. Free-living shredder taxa (e.g., case building caddisflies and tipulids) were not present at most degraded sites, and very few species with external gills were present.

Dominant fish in degraded reaches also exhibit morphological and behavioral adaptations to increased stream velocities. Blacknose dace and white suckers are generally more rounded in body cross-section (i.e., dorsoventrally flattened) than many other stream fish. This body shape may allow these fish to better hug the stream bottom or slope, thereby avoiding the highest velocities. American eels were dominant (in terms of biomass) at many sites. These fish have the ability to completely bury themselves in sediments, enter small crevices, and easily extract themselves from tight spaces by reversing their undulations and swimming backwards. American eels also have the advantage of reproducing at sea, only entering the watershed once they are able to swim freely. All other fish in the watershed are vulnerable to severe flows or smothering by silt during their embryo or larval stage.

Continuous DO and pH data suggest that periphyton biomass and community structure change fundamentally following severe storm events. Dense periphyton carpets are found in slower water throughout the watershed. While these algae have not been investigated taxonomically, filamentous greens (e.g., *Cladophora* sp.) appear to dominate the biomass of the periphyton climax community. Soil erosion and runoff, particularly during smaller storm events, may be a significant source of the phosphorus that drives these algal blooms.

Instream habitat was evaluated with EPA protocols at seventeen (n=17) sites targeted for benthic macroinvertebrate sampling. A much more detailed reach ranking survey, based in fluvial geomorphological principles, was conducted for Cobbs Creek, and West and East Indian Creeks in 2000. This document, entitled "Cobbs Creek Geomorphologic Survey-Level II: Guiding Principles for Fluvial Geomorphologic Restoration of Cobbs Creek" is available from PWD's Office of Watersheds.

5.3.2. Comparisons to Reference Site

Habitat features at Darby-Cobbs watershed sites were compared to those of the reference sites located in nearby Chester County. Mainstem and third order tributary sites were compared to French Creek reference sites, located in Coventry Township, Chester County, PA (Appendix A). Tributary sites, second order or less, were compared to Rock Run, a tributary to French Creek located in Coventry Township, Chester County, PA (Appendix A). Five Darby Creek sites had greater habitat scores than the reference site, indicating good habitat conditions along mainstem reaches of Darby Creek.

5.3.3. Factor Analysis

Principal components analysis (PCA) in Statistica (Statsoft, 1998) was used to reduce the number of variables needed to explain the variation between scores for 13 different habitat attributes among Darby-Cobbs sites. The first factor extracted accounted for 53% of the variance in the data matrix. Habitat attributes with high loading values for factor one included epifaunal substrate, velocity/depth regime, channel flow status, bank vegetative protection, and all pool attributes (Appendix E). The second factor extracted accounted for 19% of the variance, for a cumulative total of 72% variance explained. No habitat attributes showed high loading scores for factor two (Appendix E). An ordination plot of Darby-Cobbs sites and three reference sites showed the sites distributed widely across PCA axis one, with five highest-rated upstream Darby Creek sites grouped closely between French Creek and Rock Run reference sites.

Overall, the placement of sites along axis 1 correlated closely with total habitat scores and relative comparability to the reference sites (Figure 18). PCA axis 2 was not particularly useful, except for weak negative associations with channel alteration and riparian zone width and positive associations with frequency of riffles, sedimentation, and embeddedness.

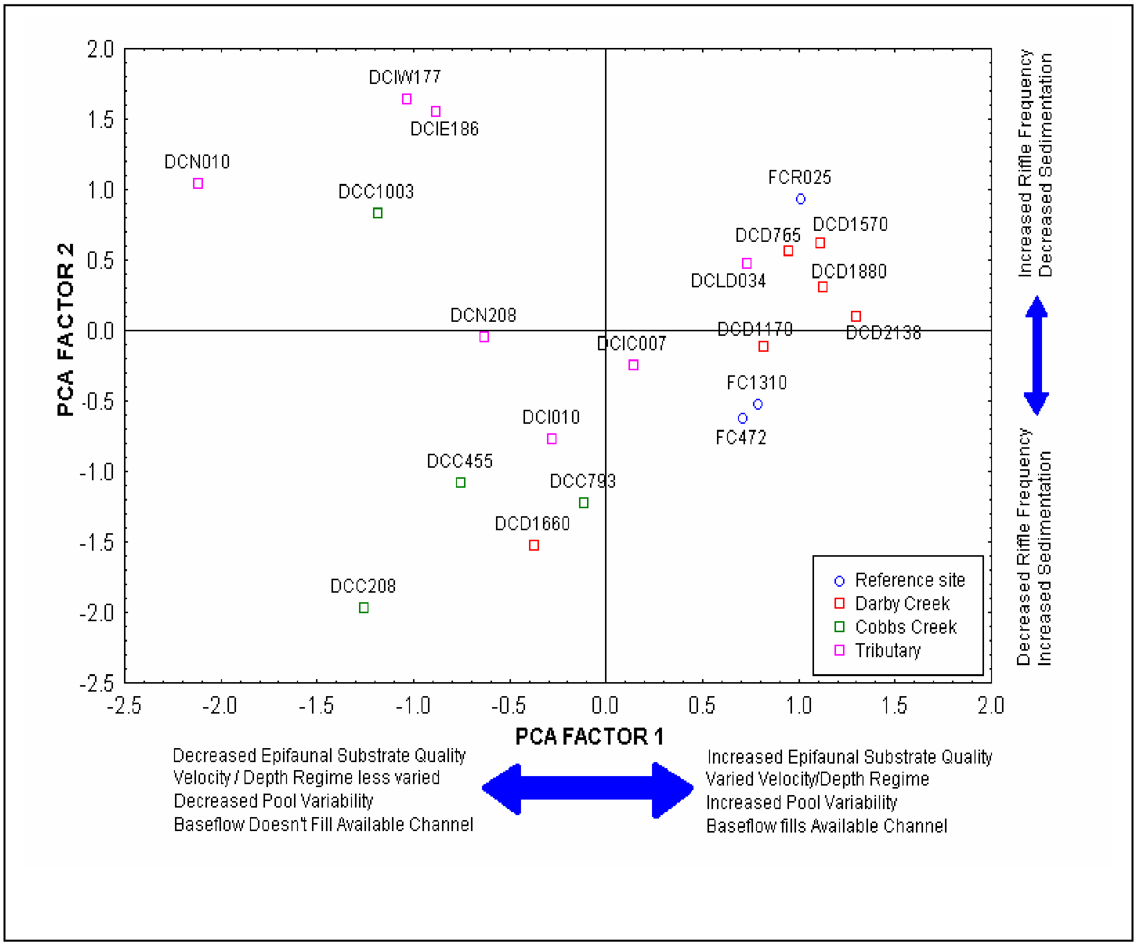


Figure 18. Principal Components Analysis ordination plot of 17 monitoring sites and 3 reference locations.

5.3.4. Individual Site Characterizations

5.3.4.1. Cobbs Creek Mainstem Sites

5.3.4.1.1. DCC208

Site DCC208 received a habitat assessment score of 127.5, and the habitat was deemed "partially supporting" (Figure 19). DCC208 was heavily impacted by sediment deposition (i.e., sand). The inorganic substrate of the site was 40% sand, and 60.0% of the macrohabitat was pools. Sedimentation, embeddedness, channel sinuosity, pool substrate, and epifaunal substrate all received marginal scores. These observations support the conclusion that the site was heavily impacted by stormwater. Poor scores were given for vegetative protection, bank stability and the left bank riparian zone. Overall habitat quality was marginal, with limited potential to support diverse aquatic communities.

5.3.4.1.2. DCC455

The habitat assessment score at site DCC455 was 142.5. This score represents a 75.2% comparison to the reference and classifies it as "supporting". DCC455 is just upstream of DCC208 and exhibited similar habitat impairments. The macrohabitat was a relatively even mix of pools, riffles and runs, but there was heavy sediment deposition throughout the stream reach (40% of substrate was sand). All of the habitat parameters were scored suboptimal or marginal. The stream banks were moderately stable, but were dominated by invasive emergent vegetation (Japanese knotweed). The riparian zone on the right bank was marginal due to areas mowed up to the stream bank. A strong sewage odor was present at the time of the habitat assessment.

5.3.4.1.3. DCC793

Site DCC793 received a habitat assessment score of 163.5, which represents an 86.3% comparison to the reference site ("supporting" designation). Macrohabitat at the site was well distributed among riffles, runs and pools, and the stream substrate was diversified, as well. Epifaunal substrate and available cover in the stream reach was optimal. The width of the riparian zone along the left bank was also favorable. Most other habitat features at DCC793 were suboptimal. Similar to other assessment sites on Cobbs Creek, moderate sand deposition was present throughout the stream reach. Most of the pools within the site were large and deep with a primarily sandy substrate. The riparian vegetative zone was much wider along the left bank of the stream than the right bank. Stability, however, was greatly reduced on the left bank where high flows had previously eroded much of the bank. The increased erosion of the left bank may be due to channel sinuosity at this location, which directs flow in that direction. Habitat at site DCC793 also may have been impacted by an exposed sewer line that crossed the stream at the upstream boundary of the assessment site.

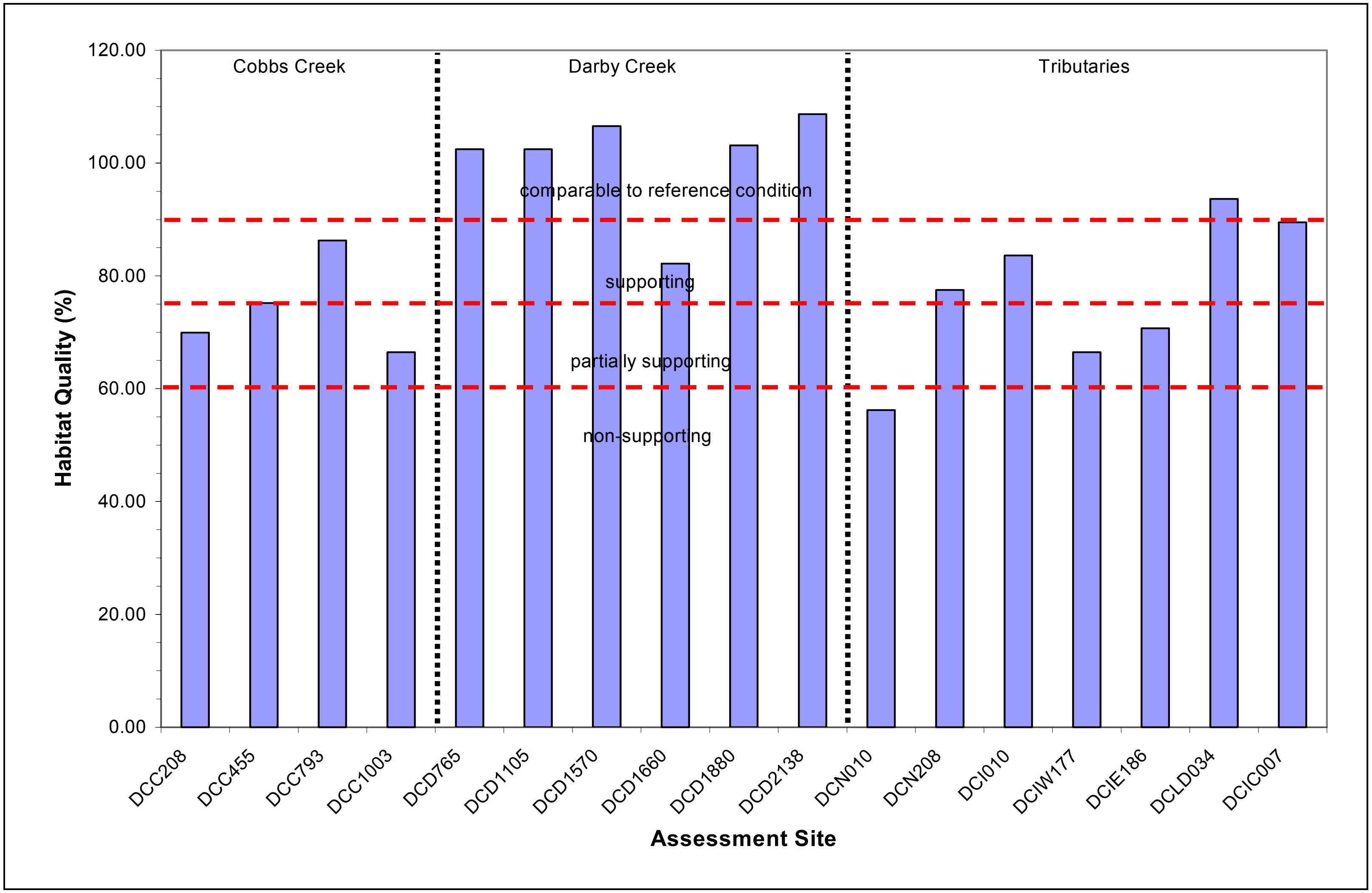


Figure 19. Habitat quality of 17 assessment sites in Darby-Cobbs Watershed. Values are represented as percent comparability to reference conditions.

5.3.4.1.4. DCC1003

Site DCC1003 received a habitat assessment score of 126.0. The site had the lowest score of all mainstem Cobbs Creek sites and was designated "partially supporting". The area surrounding the site was primarily residential with maintained lawns. The epifaunal substrate and available cover, pool substrate, and pool variability all received marginal scores. Evidence of heavy erosion was present throughout the site, and stream banks were moderately unstable. The riparian zone was insufficient, and vegetative protection was marginal. The stream was altered in areas by channelization, and the channel lacked sinuosity. The site appeared highly susceptible to erosion during periods of increased flow.

5.3.4.2 Darby Creek Mainstem Sites

5.3.4.2.1. DCD765

Site DCD765 received a habitat assessment score of 188.5, and the habitat was designated "comparable to reference" (102.4% comparison). Optimal habitat scores for epifaunal substrate and available cover, pool substrate characterization, pool variability, channel flow status, embeddedness, and velocity/depth regime all contributed to the site's excellent habitat score. The site also had an even combination of substrate components. All other condition categories were scored as suboptimal, except for the riparian vegetative zone width along the right bank, which was poor due to the presence of a mowed recreational area adjacent to the creek's right bank. A small area of stream bank was stabilized with rip-rap on the left bank. There was also moderate deposition throughout the stream reach.

5.3.4.2.2. DCD1105

The habitat assessment score of site DCD1105 was 188.5. This represents a 102.4 % comparison to the reference site and deems the habitat "comparable to reference". The habitat features of DCD1105 are very similar to that of DCD765. All of the habitat parameters were rated optimal or suboptimal except for the left bank riparian corridor, which received a marginal score due to an access road and mowed area that parallel the creek. The stream had an even distribution of macrohabitat types (i.e., pool, riffle, run). Both banks were relatively stable with decent vegetative protection.

5.3.4.2.3. DCD1570

Site DCD1570 received a habitat assessment score of 196.0, which represents a 106.5% comparison to the reference ("comparable to reference"). The macrohabitat at the site was primarily riffle (50%). The substrate components were mostly cobble and gravel (40% each), and there was light sand deposition. The predominant land use surrounding DCD1570 was forested area, but I-476 (i.e., the Blue Route) parallels the right bank of the stream. The highway was the main factor for the right bank's low riparian vegetative zone width score. DCD1570 had potential to be impacted by storm water run-off from the interstate highway. The channel sinuosity was marginal, but there were frequent riffles along the stretch.

5.3.4.2.4. DCD1660

The habitat score at DCD1660 was 156.5—an 82.2% comparison to the reference site ("supporting" designation). Most habitat parameters were scored suboptimal or marginal. Inorganic substrate was composed of 40% sand, and the site exhibited evidence of heavy sand deposition. The right bank at DCD1660 was moderately unstable, and the stream reach had low sinuosity. DCD1660 had the lowest habitat score of all mainstem Darby Creek sites.

5.3.4.2.5. DCD1880

Site DCD1880 received a habitat assessment score of 196.5, and the habitat was deemed "comparable to reference" (103.1% comparison). Most habitat attributes were scored optimal or suboptimal. The vegetative zone width on the left bank, however, was poor due to an adjacent pasture that was mowed close to the bank of the creek. An instream habitat restoration project was constructed upstream of the assessment site where submerged logs, snags and other stable habitat/fish cover features were installed along the banks to allow for greater colonization and maintenance of fish populations.

5.3.4.2.6. DCD2138

The habitat at site DCD2138 scored 207.0, and the site was designated "comparable to reference" (108.6% comparison). The site received the highest habitat score of all Darby-Cobbs assessment sites. DCD2138 is the farthest upstream assessment site on Darby Creek, and the site is located within a Brandywine Conservancy property. Habitat parameters were scored optimal or suboptimal. Macrohabitat types and inorganic substrate were both evenly distributed. Banks were stable, and a well-developed riparian corridor was present. Stable banks and not a lot of sedimentation suggest that the site had little impact from stormwater run-off and would have the potential to support a diverse biotic community.

5.3.4.3. Darby-Cobbs Tributary Sites

5.3.4.3.1. DCN010

Habitat assessment at site DCN010 returned a score of 106.5. The site was only 56.2% comparable to the reference site, and habitat was deemed "non-supporting". DCN010 had the lowest habitat score of all assessment sites. Field observations included a sewage odor and slightly turbid water. Inorganic substrate in the forms of boulder, cobble, and gravel was predominantly artificial (i.e. construction debris). The site was devoid of pools and had poor epifaunal substrate and available cover. Due to an overwidening of the stream channel, stream flow no longer reached the stream banks, and sediment bars were left exposed. The banks were moderately stable due to shoring structures (i.e. rip rap) and marginal vegetative protection.

5.3.4.3.2. DCN208

The assessment site at DCN208 scored 146.5 and was a 77.3% comparable to the reference site ("supporting" designation). Most habitat attributes were scored suboptimal or marginal. Field observations included heavy periphyton growth and a sewage odor emanating from the substrate. There was heavy local erosion with moderate sand deposition. Macrohabitat in the stream was predominantly riffle (50%), and substrate was evenly distributed. Suboptimal vegetative protection left the majority of the banks moderately unstable. Trees and Japanese knotweed were the predominant vegetation at DCN208.

5.3.4.3.3. DCI010

Site DCI010 received a habitat assessment score of 158.5, which classified the habitat as "supporting" (83.6% comparison). The site received suboptimal and marginal scores for most habitat condition parameters. Still, channel alteration at the site was optimal as the stream had retained a natural pattern and exhibited fair sinuosity. Cobble and sand dominated the substrate components, and evidence of erosion was moderate throughout the assessment site. The left bank was somewhat unstable, which could be a direct result of stormwater pulses.

5.3.4.3.4. DCIW177

Site DCIW177 received a habitat assessment score of 126.0. The habitat was designated "partially supporting", with a 66.5% comparison to the reference site. Most habitat parameters were scored suboptimal or marginal, with the exception of pool variability and riparian zone width which received "poor" scores. Pools composed only 20.0% of the macrohabitat type, and most of the pools present at DCIW177 were small and shallow. The riparian zone width was very much insufficient along both banks. Various sections of the stream bank within the assessment site were armored with rip-rap to protect against erosion. Excessive erosion rates in the stream segment may have been due to the lack of a satisfactory riparian area.

5.3.4.3.5. DCIE186

The assessment site at DCIE186 received a habitat assessment score of 134.0 which was a 70.71% comparison to the reference site ("partially supporting" designation). Frequency of riffles received an optimal score as riffles composed 50.0% of macrohabitat in the stream. All of the other habitat parameters were scored suboptimal or marginal. Lankenau Hospital is adjacent to the right bank of the assessment site and maintains a mowed field along this bank, decreasing the site's riparian vegetative zone score. Similar to West Branch Indian Run, only 20% of macrohabitat type was pools, and the pools at DCIE186 were all small and shallow.

5.3.4.3.6. DCLD034

The habitat assessment score at site DCLD034 was 177.5 and was 93.7% comparable to the reference site. Habitat conditions at the site were generally scored optimal or suboptimal. The stream segment had numerous riffles, and stream sinuosity was decent. There was moderate erosion along the stream banks and evidence of deposition in the pools. These latter attributes may be due to the lack of a sufficient riparian zone along the stream reach. The vegetative riparian buffers on both sides of the creek were less than desirable due to a maintained field cut short along both banks. The riparian zone width received a marginal score despite the "comparable to reference" designation of the site.

5.3.4.3.7. DCIC007

Site DCIC007 received a habitat assessment score of 170.5, which resulted in a "supporting" designation (89.5% comparison). Vegetative protection on both banks was scored optimal. Vegetation disruption was not evident, and banks were well covered with trees and understory shrubs. Most habitat parameters, however, were scored as suboptimal or marginal. The site was adversely affected by sediment deposition in the form of sand and by moderate erosion.

5.3.5. Habitat Suitability Indices

5.3.5.1. Overview

Habitat Suitability Indices (HSI) developed by The U.S. Fish and Wildlife Service (USFWS) were applied to sites in Darby-Cobbs Watershed targeted for fish sampling. These models integrate the expected effects of a variety of environmental, physicochemical, and hydrological variables on representative native species, as well as species of special environmental or economic concern. As stream restoration activities recommended under Target B of the watershed management plan are implemented, these indices will allow for habitat improvements to be measured quantitatively. Because freshwater fish communities are shaped by myriad inter-related environmental and ecosystem interactions and stressors (e.g., habitat degradation, flow modification, predation, competition, disease, invasive species, toxic substances, prey population dynamics, etc.), beneficial effects of habitat restoration may be obscured by other factors. Numeric HSI allow for habitat to be evaluated independently of these confounding factors.

While it may be possible to model habitat suitability for most (or even all) species found in a waterbody, this level of analysis is probably unnecessary. Habitat requirements of many species are so poorly understood that HSI have not been developed or are only generally applicable. Furthermore, many groups of species (e.g., sunfish) share many habitat requirements, obviating the need to model habitat suitability for each individual species. Best results may be obtained when HSI of a small number of sensitive, recreationally-sought, or economically important species of interest are considered.

5.3.5.2. HSI Model Selection

HSI models for seven species were selected for Darby-Cobbs Watershed. Models were chosen to reflect the range of habitat types and attributes needed to support healthy, naturally-reproducing native fish communities and provide recreational angling opportunities in non-tidal portions of the watershed. Five native minnow species were selected for HSI analysis: Blacknose dace (*Rhinichthys atratulus*), Common shiner (*Luxilis cornutus*), Creek chub (*Semotilus atromaculatus*), Fallfish (*Semotilus corporalis*), and Longnose dace (*Rhinichthys cataractae*). Of these, *R. cataractae* is not known to occur in Darby-Cobbs Watershed. However, this species' known affinity for stable, high quality riffle habitats is reflected in its HSI, prompting inclusion in the analysis as an important indicator of those macrohabitat features. The Longnose dace HSI may be considered a surrogate indicator of habitat suitability for other riffle species (e.g., darters) for which no HSI are available.

Two centrarchid fish, Redbreast sunfish (*Lepomis auritus*), and Smallmouth bass (*Micropterus dolomieu*), were included in the analysis. These species are tolerant of warmer water temperatures and require extensive slow, relatively deep water (i.e., pool) habitats with appropriate cover or structure to achieve maximum biomass. While black basses (*M. dolomieu* and its congener *M. salmoides*) are not native to southeastern Pennsylvania, they occupy the top carnivore niche and are among the most sought-after freshwater game fish in water bodies where they occur. Moreover, the only other large-bodied piscivores known to occur in non-tidal portions of Darby-Cobbs Watershed are American eels, native catadromous fish for which no HSI has been developed, and three salmonids (Rainbow trout, *Oncorhynchus mykiss*; Brown trout, *Salmo trutta*; and Brook trout, *Salvelinus fontalis*), "coldwater" species, maintained in the watershed solely through stocking.

5.3.5.3. Smallmouth Bass HSI Model

The small number of *M. dolomieu* (n=10) collected from non-tidal reaches of Darby-Cobbs watershed hindered data analysis. However, mean HSI score of three Darby Creek sites where these fish were collected was 0.82, while mean HSI score of the 6 sites where fish were not collected was 0.61. Sites where fish were collected had higher HSI scores than sites where fish were not collected in all cases. Correlations between HSI score and Smallmouth bass abundance and biomass were weak, largely due to lack of data. Results of HSI analyses (Table 10) corroborated findings of other research, particularly general habitat and continuous water chemistry analyses.

Table 10. Smallmouth bass HSI individual variable scores, total HSI score and fish data by site.

Habitat Variable	DCC208	SI	DCC455	SI	DCC793	SI	DCD765	SI	DCD1170	SI	DCD1570	SI	DCD1880	SI	DCD2138	SI	FC472	SI
substrate type category	B	0.30	B	0.30	C	1.00	C	1.00	C	1.00	C	1.00	A	0.20	C	1.00	C	1.00
percent pools	36.01	0.69	25.00	0.44	56.98	1.00	34.57	0.66	26.32	0.47	38.74	0.75	26.86	0.49	12.80	0.17	48.08	0.96
Avg. pool Depth	0.71	0.59	0.50	0.42	0.39	0.33	0.83	0.69	0.59	0.49	0.68	0.57	0.51	0.43	0.59	0.49	0.56	0.47
percent cover	12.50	0.50	11.87	0.47	20.63	0.83	21.25	0.85	20.00	0.80	20.00	0.80	21.88	0.88	20.00	0.80	21.25	0.85
average pH	7.45	0.98	7.48	0.99	7.32	0.96	7.86	0.96	7.60	0.99	7.51	0.99	7.20	0.94	7.10	0.92	7.90	0.93
Dissolved Oxygen	2.93	0.16	3.72	0.32	3.96	0.38	4.00	0.38	4.00	0.38	6.00	0.97	6.00	0.97	6.00	0.97	7.00	1.00
Turbidity	25.00	1.00	25.00	1.00	25.00	1.00	25.00	1.00	25.00	1.00	25.00	1.00	25.00	1.00	25.00	1.00	25.00	1.00
Temperature (adult)	19.50	0.83	20.00	0.86	20.20	0.86	19.30	0.82	18.30	0.76	18.10	0.76	18.70	0.79	18.00	0.75	18.00	0.75
Temperature (embryo)	16.95	1.00	19.70	1.00	18.40	1.00	19.10	1.00	18.80	1.00	18.70	1.00	20.30	1.00	17.00	1.00	17.00	1.00
Temperature (fry)	19.50	0.80	20.00	0.83	20.20	0.84	19.30	0.79	18.30	0.73	18.10	0.71	18.70	0.75	18.00	0.71	18.00	0.71
Temperature (juvenile)	19.50	0.84	20.00	0.86	20.20	0.87	19.30	0.83	18.30	0.78	18.10	0.77	18.70	0.80	18.00	0.76	18.00	0.76
Water fluctuations	A	0.30	A	0.30	A	0.30	A	0.30	A	0.30	A	0.30	A	0.30	A	0.30	A	0.30
Stream Gradient	15.10	0.50	4.70	1.00	12.70	0.50	3.50	1.00	3.80	1.00	2.40	1.00	2.40	1.00	12.00	0.50	10.00	0.50
Food (C_F) component		0.47		0.40		0.94		0.82		0.72		0.84		0.44		0.52		0.93
Cover (C_C) Component		0.52		0.41		0.79		0.80		0.69		0.78		0.50		0.62		0.82
Water Quality Component C_{WQ}		0.76		0.80		0.81		0.79		0.78		0.89		0.89		0.87		0.88
Reproduction (C_R) Component		0.49		0.54		0.71		0.72		0.71		0.81		0.65		0.81		0.82
Other (C_{OT}) component		0.50		1.00		0.50		1.00		1.00		1.00		1.00		0.50		0.50
H S I score		**0.49**		**0.54**		**0.73**		**0.82**		**0.77**		**0.86**		**0.66**		**0.65**		**0.77**
abundance		0.00		0.00		0.00		2.00		5.00		3.00		0.00		0.00		0.00
biomass		0.00		0.00		0.00		129.70		340.84		272.30		0.00		0.00		0.00

No smallmouth bass were collected from Cobbs Creek. Sites DCC208 and DCC455 had the lowest HSI scores in the watershed and were limited by dissolved oxygen concentration, cover, and pool substrate composition (Table 10). Site DCC793 was limited by stream gradient and depth of pools, indicating unsuitably high stream velocities in pool habitats. Sites in Cobbs Creek generally exhibited unsuitable characteristics (e.g., lack of cover, decreased substrate size, or increased velocity) in pool habitats; these factors force bass to expend more energy acquiring food. Competition from American eels and the frequency and magnitude of severe storm flow conditions cannot be discounted as factors making Cobbs Creek less suitable for Smallmouth bass.

Ten smallmouth bass individuals were collected from the three downstream-most sites within the non-tidal portion of Darby Creek watershed. The lack of Smallmouth bass at upstream sites is to be expected, as this species requires deeper, calmer water than is typically found in first- or second-order stream sites. It should be noted that Darby Creek watershed is generally less affected by urbanization than Cobbs creek watershed, and has more of its historic tributaries intact. Stream order and river mile-based comparisons between the two watersheds are probably not very meaningful. Within Darby Creek watershed, sites where Smallmouth bass were not collected had, in some cases, pool structure, substrate size and or cover numerically similar to downstream sites, suggesting that distribution may be related stream size.

Like most centrarchids, Smallmouth and Largemouth basses are able to acclimate to brief periods of suboptimal dissolved oxygen concentration. With few exceptions, such as sites in which DO concentrations may frequently drop below 3mg/l for extended periods, or sites in which spawning substrates are chronically anoxic with Hydrogen sulfide (H_2S) present, Smallmouth bass distributions are probably not strongly governed by DO concentrations. Furthermore, many centrarchid species' thermal preferenda are higher than temperatures typical of 2nd to 4th order streams in southeast PA. Most species are known to reach their maximum size in the non-temperate Southern U.S., growing fastest in lentic habitats where conditions are suitable for growth year-round and specific management techniques are employed. HSI model temperature output (Table 10) reflects the fact that optimum temperatures are seldom reached in Southeastern PA.

Stream restoration activities that increase the amount of instream and overhanging cover, or activities that create, expand or improve pool habitats probably will result in increased habitat suitability for Smallmouth bass. Re-meandering of the stream channel, installation of flow diverters such as rock vanes and J-hooks, as well as the creation of undercut banks through log sill cribbing and cantilevered banks should also enhance habitat for Smallmouth bass and forage fish by establishing low velocity refugia during storms.

Infrastructure assessments, inspections, and dry weather pollution source trackdown activities will likely reduce the severity of water quality (i.e., DO and pH related) impacts on HSI scores at some sites, particularly DCC208 and DCD765. It is unlikely that habitat impairment due to frequent water level fluctuations and the effects of erosion and sedimentation will be ameliorated in the near future without significant investments in streambank restoration and basin-wide implementation of stormwater BMPs.

5.3.5.4. Redbreast Sunfish HSI Model

As a generalist species, Redbreast sunfish (*Lepomis auritus*) are adaptable to a range of habitat attributes and may feed opportunistically upon a variety of prey types. Most SI variable expressions in this species' HSI include a large range of highly suitable values (or large area "under the curve"). HSI scores (Table 11) did not generally correlate well with observed *L. auritus* abundance or biomass. Limiting factors included pH, vegetative cover, temperature, and substrate-related variables, but the discriminatory power of the HSI was probably limited by lack of variability among sites.

Site DCC793 received the highest HSI score in the watershed, yet only 1 Redbreast Sunfish was collected at this site. DCC793 was the only site in the watershed that had a sizeable population of Pumpkinseed sunfish (*L. gibbosus*). At most other sites, Redbreast sunfish were more abundant than other sunfish species, though a longitudinal trend in sunfish species diversity increasing from downstream to upstream was observed in Darby Creek. Sunfish species' habitat needs are generally similar; there was no obvious explanation for the change in species relative abundance. Somewhat better correlations resulted from comparison of a modified version of the HSI to grouped *Lepomis* spp. abundance and biomass (Table 12).

pH limitation was indicated at sites DCD765 and DCC208, where pH fluctuations due to algal activity occasionally result in pH >9.0. The Redbreast sunfish HSI model was probably not designed to be used with the least suitable value picked from a continuous database. Because fish can avoid areas of unsuitable pH when they occur infrequently, it would be more suitable for the model to account for how frequently unsuitable pH conditions occur (e.g., take the 90th percentile value, disregard outliers, etc.).

Likewise, summer temperature during spawning may poorly reflect habitat suitability for this species. The HSI was developed for an industrial cooling water investigation in the southern U.S.; temperature parameters should not be expected to be "optimal" in the temperate northeast. Fish collected at upstream sites with less suitable spawning temperatures may spawn at warmer downstream locations or in sunnier, sandy backwaters that are not accounted for in the data.

Observations made during electrofishing surveys suggested that Redbreast sunfish (and congeneric sunfishes) are most frequently found associated with cover, which can be difficult to measure quantitatively. Cover measurements included in the Redbreast Sunfish HSI were normalized to a scale of 0-25 from EPA Habitat assessment variable 1: Epifaunal Substrate and Available cover (Section 5.3.1.). As most sites in Darby-Cobbs Watershed are known to be deficient in vegetative cover, the "% vegetative cover" variable was estimated as half this normalized Epifaunal substrate value (e.g., EPA Epifaunal Substrate and Available Cover score =20, HSI Cover % =25, HSI vegetative cover % = 12.5.)

Table 11. Redbreast sunfish HSI individual variable scores, total HSI score and fish data by site.

Habitat Variable	DCC208	SI	DCC455	SI	DCC793	SI	DCD765	SI	DCD1105	SI	DCD1570	SI	DCD1880	SI	DCD2138	SI	FC472	SI
% cover	12.50	0.70	11.87	0.68	20.63	0.90	21.25	0.91	20.00	0.88	20.00	0.88	21.88	0.93	20.00	0.88	21.25	0.91
vegetated cover	6.25	0.53	5.94	0.52	10.31	0.61	10.63	0.61	10.00	0.60	10.00	0.60	10.94	0.62	10.00	0.60	10.63	0.61
spawning temperature (summer)	19.50	0.40	20.00	1.00	20.20	1.00	19.30	0.40	18.30	0.40	18.10	0.40	18.70	0.40	17.00	0.40	18.00	0.40
% slow pools	36.01	0.96	25.00	0.70	56.98	0.92	34.57	0.93	26.32	0.73	38.74	0.81	26.86	0.74	12.80	0.35	48.08	0.87
% sand/gravel	58.00	1.00	70.00	1.00	43.00	1.00	17.00	0.40	39.00	1.00	47.00	1.00	49.00	1.00	35.00	0.90	16.00	0.39
least suitable pH observed	9.07	0.34	6.89	1.00	6.04	1.00	9.92	0.06	6.50	1.00	6.58	1.00	7.50	1.00	7.50	1.00	7.50	1.00
minimum DO (category)	B	0.70	B	0.70	B	0.70	B	0.70	A	1.00	A	1.00	A	1.00	A	1.00	A	1.00
max temp growing season	23.10	0.80	23.50	0.80	23.20	0.80	24.40	0.80	21.50	0.80	21.30	0.80	22.90	0.80	19.00	0.50	20.00	0.80
stream width	15.23	1.00	10.00	1.00	9.30	1.00	15.07	1.00	14.50	1.00	12.08	1.00	10.77	1.00	5.35	0.84	14.20	1.00
H S I score final		**0.34**		**0.52**		**0.61**		**0.06**		**0.40**		**0.40**		**0.40**		**0.35**		**0.39**
***L. auritus* abundance**		62		227		1		66		39		20		4		25		
***L. auritus* biomass**		638		3365		0		2005		1205		1076		162		1036		

Table 12. Sunfish species HSI individual variable scores, total HSI score and fish data by site.

Habitat Variable	DCC208	SI	DCC455	SI	DCC793	SI	DCD765	SI	DCD1105	SI	DCD1570	SI	DCD1880	SI	DCD2138	SI	FC472	SI
% cover	12.5	0.7	11.87	0.68	20.63	0.9	21.25	0.91	20	0.88	20	0.88	21.88	0.93	20	0.88	21.25	0.91
vegetated cover	6.25	0.53	5.94	0.52	10.31	0.61	10.63	0.61	10	0.6	10	0.6	10.94	0.62	10	0.6	10.63	0.61
spawning temperature (summer)	20	1	20	1	20.2	1	20	1	20	1	20	1	19	0.4	19	0.4	18	0.4
% slow pools	36.01	0.96	25	0.7	56.98	0.92	34.57	0.93	26.32	0.73	38.74	0.81	26.86	0.74	12.8	0.35	48.08	0.87
% sand/gravel	58	1	70	1	43	1	17	0.4	39.00	1	47	1	49	1	35	0.9	16	0.39
least suitable pH observed	8.5	1	6.89	1	6.04	1	8.5	1	6.5	1	6.58	1	7.5	1	7.50	1	7.5	1
minimum DO (category)	B	0.7	B	0.7	B	0.7	B	0.7	A	1	A	1	A	1	A	1	A	1
max temp growing season	23.1	0.8	23.5	0.8	23.2	0.8	24.4	0.8	21.5	0.8	21.30	0.8	22.9	0.8	19	0.5	20	0.8
stream width	15.23	1	10	1	9.3	1	15.07	1	14.5	1	12.08	1	10.77	1	5.35	0.84	14.20	1
H S I score final		**0.53**		**0.52**		**0.61**		**0.4**		**0.6**		**0.6**		**0.4**		**0.35**		**0.39**
***Lepomis* sp. abundance**		67		230		59		68		43		24		24		63		
***Lepomis* sp. biomass**		800		3424		650		2049		1235		1132		1195		1179		

EPA habitat assessment techniques may not be most appropriate to habitat investigations for this species. For example, the EPA habitat technique stipulates that "transitional and new fall" woody debris (e.g., tree limbs and branches) should be disregarded. However, this type of cover is often quite common (and largely beneficial) in urbanized streams that have forested margins and eroding banks, such as Cobbs and Darby Creeks. Though "transitional and new fall" woody debris may not be permanent at a site, it may persist for a year or more, particularly when aggregations form along stream margins. The microhabitat within an aggregation of this woody debris is very complex when compared to most types of permanent hard cover, and qualitative observations during electrofishing surveys suggest that tree limbs and branches are beneficial and a preferred cover type for many fish.

Of course, large aggregations of woody debris may threaten the structural integrity of bridges, culverts and other infrastructure. One of the chief functions of PWD's Waterways Restoration Unit (WRU) is to remove this type of debris. As stream segments are restored, a careful balance should be struck between cleaning the stream of trash and debris and overzealous elimination of beneficial natural habitat features. Another excellent solution to this problem is the selective installation of staked or cabled trees and large tree limbs, Christmas tree bundles, willow stakes, root wads, and, in still water, manufactured fish habitat structures.

5.3.5.5. Blacknose Dace HSI Model

The Blacknose Dace HSI model produced fair results. Site DCC793 had the highest HSI score in the watershed (0.85), as well as the greatest abundance and largest biomass. Sites DCC208 and DCD765 scored 0.15, and (respectively) had the lowest and second lowest abundance and biomass in the watershed. Aside from these extreme values, the HSI model was not a good predictor of Blacknose dace abundance or biomass (Table 13). The Blacknose dace is classified as a tolerant fish. In fact, along with *C. commersoni*, *A. rostrata*, and *Fundulus* spp., Blacknose dace is one of the most common piscine inhabitants of degraded streams in southeast PA. Despite its tolerance of degraded stream conditions, the species' HSI model is quite complex- it includes 16 raw variables, six life requisite components, as well as limiting and compensatory mechanisms.

Limiting variables identified by the model included stream width, stream margin substrate composition, and pool substrate composition. As some of these variables were estimated, results of the HSI model are only as good as the estimates. The model was found to be too sensitive in the range of stream gradient values observed and was adjusted slightly to exclude these effects, which would have been limiting at 5 of 9 sites. While greater stream gradients may be preferred, this species is routinely collected in sites of lower gradient. An overall pattern of increasing abundance from downstream to upstream was evident.

Blacknose dace is a stocky fish, moderate in body form and somewhat rounded (dorsoventrally flattened) in comparison to other, more vertically compressed minnows.

Table 13. Blacknose dace HSI individual variable scores, total HSI score and fish data by site.

Habitat Variable	DCC208	SI	DCC455	SI	DCC793	SI	DCD765	SI	DCD1105	SI	DCD1570	SI	DCD1880	SI	DCD2138	SI	FC472	SI
% Shaded	20.00	0.77	20.00	0.77	60.00	1.00	70.00	1.00	30.00	1.00	45.00	1.00	75.00	1.00	85.00	1.00	70.00	1.00
% Pools	36.01	0.95	25.00	0.81	56.98	1.00	34.57	0.93	26.32	0.83	38.74	0.98	26.86	0.84	12.80	0.66	48.08	1.00
Stream Gradient	15.10	1.00	4.70	0.05	12.70	1.00	3.50	0.05	3.80	0.05	2.40	0.05	2.40	0.05	12.00	1.00	10.00	1.00
Stream Width	15.23	0.15	10.00	0.68	9.30	0.76	15.07	0.15	14.50	0.21	12.08	0.46	10.77	0.60	5.35	1.00	14.20	0.24
Temperature (growing seas.)	19.50	1.00	20.00	1.00	20.20	1.00	19.30	1.00	18.30	1.00	18.10	1.00	18.70	1.00	18.00	1.00	18.00	1.00
Turbidity	25.00	1.00	25.00	1.00	25.00	1.00	25.00	1.00	25.00	1.00	25.00	1.00	25.00	1.00	25.00	1.00	25.00	1.00
Riffle Substrate Category	D	0.60	C	1.00	D	0.60	E	0.40	D	0.60	D	0.60	D	0.60	D	0.60	E	0.40
Riffle Depth	12.00	1.00	20.00	1.00	10.00	1.00	35.00	0.82	29.00	1.00	26.00	1.00	18.00	1.00	16.00	1.00	18.00	1.00
Velocity in Riffles	30.20	1.00	19.40	0.96	25.40	1.00	17.00	0.80	17.60	0.84	14.80	0.66	14.80	0.66	24.00	1.00	20.00	1.00
Temperature (spawning seas.)	16.95	1.00	19.70	1.00	18.40	1.00	19.10	1.00	18.80	1.00	18.70	1.00	20.30	1.00	17.00	1.00	17.00	1.00
Pool Substrate Category	C	1.00	C	1.00	D	1.00	E	0.20	A	0.80	E	0.20	A	0.80	E	0.20	E	0.20
Velocity in Pools	9.00	1.00	4.00	1.00	10.00	1.00	6.00	1.00	6.00	1.00	4.00	1.00	4.00	1.00	9.00	1.00	7.00	1.00
Riffle Substrate Category	D	0.50	C	1.00	D	0.50	E	0.30	D	0.50	D	0.50	D	0.50	D	0.50	E	0.30
Velocity in Riffles	30.20	1.00	19.40	1.00	25.40	1.00	17.00	1.00	17.60	1.00	14.80	0.99	14.80	0.99	24.00	1.00	20.00	1.00
Substrate in Stream Margins	A	1.00	B	0.70	A	1.00	A	1.00	C	0.40	D	0.30	D	0.30	E	0.20	E	0.20
Velocity in Stream Margins	4.00	1.00	4.70	1.00	6.00	1.00	3.50	1.00	3.80	1.00	2.40	1.00	2.40	1.00	12.00	0.85	10.00	1.00
Food/Cover Component C_{FC}		0.15		0.68		0.94		0.15		0.21		0.46		0.60		0.92		0.24
Water Quality Component C_{WQ}		1.00		1.00		1.00		1.00		1.00		1.00		1.00		1.00		1.00
Reproduction Component C_R		0.94		0.99		0.94		0.40		0.90		0.86		0.86		0.94		0.40
Adult Component C_A		1.00		1.00		1.00		0.20		0.89		0.20		0.89		0.20		0.20
Juvenile Component C_J		0.71		1.00		0.71		0.30		0.71		0.70		0.70		0.71		0.30
Fry Component C_F		1.00		0.84		1.00		1.00		0.40		0.30		0.30		0.20		0.20
H S I Score		**0.15**		**0.68**		**0.85**		**0.15**		**0.21**		**0.20**		**0.30**		**0.20**		**0.20**
Abundance		1		97		1126		5		50		213		353		103		
Biomass		1		204		1979		10		112		490		683		231		

Hydrodynamics may play a part in its adaptability to a variety of flow conditions and, in part, explain its abundance at degraded sites that are periodically exposed to intense scouring flows. Other minnow species may not be as well adapted at surviving these types of flows. As stormwater BMPs and streambank restoration proceed under Target B of the watershed management plan, perhaps these hydrologically-impaired sites will begin to support more diverse fish communities rather than being dominated by three or four tolerant species.

5.3.5.6. Creek Chub HSI Model

The Creek Chub HSI model produced satisfactory results overall. Sites where no fish were collected had the lowest HSI scores in the watershed (Table 14). The site with the highest HSI score had the greatest abundance and biomass in the watershed. While biomass increased at all sites as HSI scores increased, and abundance showed the same pattern in 8 of 9 cases, the HSI model's scale of resolution was greatly compacted. Five sites had HSI scores between 0.80 and 0.88, while the two lowest scores were 0.4 and 0.69. When the lowest score corresponding to zero fish collected was taken as the origin rather than (0,0), the strongest correlations between (log-transformed) HSI scores and fish biomass and abundance were observed (R^2 values 0.94 and 0.93, respectively).

With 20 habitat and water quality variables and 5 life requisite components, the Creek Chub HSI model was most complex of the models used. As many water quality variables returned optimum suitability values (i.e., SI= 1.0), and most had limited discriminatory power, the model could be made simpler without sacrificing predictability. It is likely that if a smaller number of critical habitat variables were focused on, the model could have better resolution over a larger scale of final HSI scores.

5.3.5.7. Common Shiner HSI Model

Common shiner HSI model output was not very useful. Much like the Redbreast sunfish model, the SI variables used are general in nature, and contain a large range of suitable values (Redbreast sunfish and Common shiners are both considered generalist species). With the exception of two sites that were severely limited by a single SI variable (pH at site DCD765 and % pools at site DCD2138), SI variable attributes of most sites were very similar and the resulting HSI scores were also similar, ranging from 0.80 to 0.93 (Table 15). If the influence of a single low pH value and the smaller proportion of pools at these sites were disregarded, all sites would have HSI scores within this narrow range.

Common shiner abundance and biomass were fairly similar at all sites with the exception of DCC793, where a much greater number were collected. Perhaps the most interesting finding with regard to Common shiners was the greatly reduced average size of individual fish collected at site DCC455 compared to other sites.

Table 14. Creek chub HSI individual variable scores, total HSI score and fish data by site.

Habitat Variable	DC208	SI	DCC455	SI	DCC793	SI	DCD765	SI	DCD1105	SI	DCD1570	SI	DCD1880	SI	DCD2138	SI	FC472	SI
% pools	36.01	0.98	25.00	0.74	56.98	1.00	34.57	0.97	26.32	0.79	38.74	1.00	26.86	0.81	12.80	0.39	48.08	1.00
Pool class (category)	A	1.00	B	0.60	B	0.60	A	1.00	B	0.60	A	1.00	B	0.60	B	0.60	B	0.60
% cover	12.50	0.37	11.87	0.35	20.63	0.61	21.25	0.63	20.00	0.59	20.00	0.59	21.88	0.64	20.00	0.59	21.25	0.63
Winter thermal cover	YES	0.91	YES	0.74	YES	0.92	YES	1.00	NO	0.45	NO	0.64	NO	0.48	NO	0.32	NO	0.52
Stream gradient	15.10	0.80	4.70	0.79	12.70	1.00	3.50	0.57	3.80	0.63	2.40	0.37	2.40	0.37	12.00	1.00	10.00	1.00
Stream width	15.23	0.30	10.00	0.56	9.30	0.63	15.07	0.30	14.50	0.32	12.08	0.42	10.77	0.50	5.35	1.00	14.20	0.33
Turbidity	25.00	1.00	25.00	1.00	25.00	1.00	25.00	1.00	25.00	1.00	25.00	1.00	25.00	1.00	25.00	1.00	25.00	1.00
pH (category)	B	0.80	A	1.00	B	0.80	C	0.40	A	1.00	A	1.00	A	1.00	A	1.00	A	1.00
Vegetation index	37.50	0.54	65.00	0.95	72.50	1.00	67.50	0.97	67.50	0.97	90.00	1.00	75.00	1.00	80.00	1.00	62.50	0.92
Substrate food index	C	0.50	B	0.70	B	0.70	C	0.50	B	0.70	C	0.50	B	0.70	B	0.70	B	0.70
Average summer water temp.	21.80	1.00	21.20	1.00	20.60	1.00	20.80	1.00	21.00	1.00	20.90	1.00	20.00	1.00	19.00	1.00	19.00	1.00
Minimum summer DO conc.	2.93	0.47	3.72	0.76	3.96	0.83	4.00	0.85	4.00	0.85	6.00	1.00	6.00	1.00	6.00	1.00	7.00	1.00
Average velocity (0.6 depth)	18.00	1.00	8.00	0.94	20.00	1.00	12.00	1.00	12.00	1.00	8.00	0.94	8.00	0.94	18.00	1.00	14.00	1.00
Average spring water temp	17.10	1.00	19.20	1.00	19.90	1.00	19.10	1.00	17.60	1.00	17.30	1.00	18.50	1.00	16.00	1.00	16.00	1.00
Minimum spring DO conc.	4.00	0.50	5.00	0.76	5.50	0.86	5.00	0.76	5.00	0.76	7.00	1.00	7.00	1.00	8.00	1.00	8.00	1.00
Average spring riffle velocity	45.30	1.00	29.10	1.00	38.10	1.00	25.50	1.00	26.40	1.00	22.20	1.00	22.20	1.00	36.00	1.00	30.00	1.00
Riffle substrate index	89.75	1.00	100.00	1.00	100.00	1.00	97.10	1.00	89.95	1.00	100.00	1.00	90.91	1.00	100.00	1.00	100.00	1.00
Average stream margin velocity	4.00	1.00	4.70	1.00	6.00	1.00	3.50	1.00	3.80	1.00	2.40	1.00	2.40	1.00	12.00	0.69	10.00	1.00
% summer shade	20.00	0.33	20.00	0.33	60.00	0.92	70.00	1.00	30.00	0.47	45.00	0.72	75.00	1.00	85.00	1.00	70.00	1.00
Average maximum depth	0.71	1.00	0.50	1.00	0.39	0.94	0.83	1.00	0.59	1.00	0.68	1.00	0.51	1.00	0.59	1.00	0.56	1.00
Food component		0.52		0.83		0.85		0.74		0.84		0.75		0.85		0.85		0.81
Cover component		0.83		0.69		0.83		0.92		0.71		0.84		0.72		0.56		0.76
Water Quality component		0.59		0.71		0.89		0.40		0.80		0.92		1.00		1.00		1.00
Reproduction component		0.87		0.95		0.97		0.95		0.95		1.00		1.00		1.00		1.00
Other component		0.70		0.78		0.86		0.62		0.65		0.59		0.62		1.00		0.78
H S I score		**0.69**		**0.79**		**0.88**		**0.40**		**0.78**		**0.81**		**0.82**		**0.86**		**0.86**
biomass		0		52.47		998		0		12.27		33.09		107.68		193.59		

Table 15. Common shiner HSI individual variable scores, total HSI score and fish data by site.

Habitat Variable	DCC208	SI	DCC455	SI	DCC793	SI	DCD765	SI	DCD1105	SI	DCD1570	SI	DCD1880	SI	DCD2138	SI	FC472	SI
Temperature	22.90	0.79	23.50	0.67	23.20	0.72	24.40	0.50	21.20	1.00	21.30	1.00	21.90	1.00	20.00	1.00	20.00	1.00
pH	9.07	0.88	6.89	1.00	6.04	0.58	9.92	0.14	6.50	0.99	6.58	1.00	7.50	1.00	7.50	1.00	7.50	1.00
turbidity	25.00	1.00	25.00	1.00	25.00	1.00	25.00	1.00	25.00	1.00	25.00	1.00	25.00	1.00	25.00	1.00	25.00	1.00
Riffle Substrate Category	D	0.80	C	1.00	D	0.80	E	0.20	D	0.80	D	0.80	D	0.80	D	0.80	E	0.20
% pools	36.01	0.85	25.00	0.56	56.98	0.99	34.57	0.80	26.32	0.59	38.74	0.89	26.86	0.59	12.80	0.07	48.08	0.99
Velocity in Pools	9.00	1.00	4.00	0.87	10.00	1.00	6.00	0.94	6.00	0.94	4.00	0.87	4.00	0.87	9.00	1.00	7.00	0.96
Pool Class	B	1.00	B	1.00	C	0.60	B	1.00	B	1.00	B	1.00	B	1.00	B	1.00	B	1.00
Temperature (Spawning seas.)	15.63	0.95	17.35	1.00	16.20	1.00	17.45	1.00	16.55	1.00	16.30	1.00	17.70	1.00	15.00	0.76	15.00	0.76
riffle Velocity	30.20	0.53	19.40	1.00	25.40	0.75	17.00	1.00	17.60	1.00	14.80	1.00	14.80	1.00	24.00	0.82	20.00	1.00
Food/Cover Component C_{FC}		0.91		0.86		0.85		0.20		0.83		0.89		0.82		0.07		0.20
Water Quality Component C_{WQ}		0.88		0.87		0.75		0.14		1.00		1.00		1.00		1.00		1.00
Reproduction Component C_R		0.75		1.00		0.83		0.20		0.89		0.89		0.89		0.80		0.20
H S I Score		**0.85**		**0.91**		**0.81**		**0.14**		**0.91**		**0.93**		**0.90**		**0.07**		**0.20**
Abundance		13		86		398		34		42		74		60		41		
Biomass		121.2		250		4324		288.5		316.3		389.2		530.1		437.8		

5.3.5.8. Fallfish HSI Model

Interpretation of Fallfish HSI model output was hindered by a lack of data; only 19 individuals were collected in total. Only one individual was collected in the Cobbs Creek sub-basin (site DCC793). The Fallfish HSI model is one of the simplest HSI models available, considering only six variables. Furthermore, as applied to the Darby-Cobbs Watershed, only five variables were considered because it was not possible to convert modern NTU turbidity data to JTU data. Differences between sites were not very large for most of the remaining five variables (Table 16).

Substrate type, however, is an important factor because Fallfish construct and spawn over gravel nest structures. Fallfish males push and carry gravel and smalls stones to create a nest pile which may be quite large. Following a spawning episode, eggs are buried, after which additional material may be added to the nest structure and the process repeated. Similar egg burying behavior is practiced by other minnow species (e.g., Cutlips minnow, Creek chub). Since developing eggs rely on oxygen exchange through interstitial spaces, clean, oxygenated gravel is necessary. Several phenomena arising from urbanization may reduce spawning success of these species.

Increased stream velocities resulting from increased impervious cover may be severe enough to damage or completely scour away nest structures. Alternately, nests built in depositional areas may become silted over, smothering eggs. Substrates may contain significant amounts of dead and decaying organic matter or be inhabited by other aerobic and chemosynthetic microbial communities. If oxygen-depleting biochemical processes within the sediments outpace re-oxygenation, or if the overlying water itself is low in dissolved oxygen, eggs may die. Decreased reproductive success may partially explain the very low abundance of Fallfish and complete absence of Cutlips minnow in the Cobbs Creek basin.

While Fallfish HSI model applicability was very limited, the biogeography of Fallfish and other egg-burying cyprinids may be helpful in identifying macro-scale impairments to run and pool stability, as well as the oxygen state and suitability of stream substrates for not only their eggs, but sediment dwelling benthic invertebrates as well. Site-specific conclusions should be avoided, however, because fish are mobile and may be collected far away from their spawning sites.

5.3.5.9. Longnose dace HSI Model

Longnose dace HSI model output predicted that water temperatures in all Cobbs Creek sites and site DCD765 would preclude survivorship of naturally reproducing population of Longnose dace (Table 17). Other sites were severely limited by stream velocity. Though the model requires average stream velocity data, it might be more appropriate to consider only riffle velocity, as sites chosen for fish surveys in Darby-Cobbs were selected based on a relatively even mix of macrohabitat features. If surveys were

Table 16. Fallfish HSI individual variable scores, total HSI score and fish data by site.

Habitat Variable	DCC208	SI	DCC455	SI	DCC793	SI	DCD765	SI	DCD1170	SI	DCD1570	SI	DCD1880	SI	DCD2138	SI	FCR024	SI
Temperature	21.80	0.78	21.20	0.86	20.60	0.93	20.80	0.90	21.00	0.88	20.90	0.89	20.00	1.00	19.00	1.00	19.00	1.00
Turbidity	25.00	1.00	25.00	1.00	25.00	1.00	25.00	1.00	25.00	1.00	25.00	1.00	25.00	1.00	25.00	1.00	25.00	1.00
Mode of Stream Depth	0.17	0.84	0.16	0.83	0.11	0.79	0.44	1.00	0.51	1.00	0.29	0.93	0.13	0.80	0.46	1.00	0.47	1.00
Spawning Temperature	15.63	0.53	17.35	1.00	16.20	0.84	17.45	1.00	16.55	1.00	16.30	0.89	17.70	0.56	15.00	0.20	15.00	0.20
Substrate Category	E	0.10	C	1.00	D	0.40	E	0.10	D	0.40	C	1.00	D	0.40	D	0.40	E	0.10
Cover category	C	0.40	C	0.40	B	0.70	B	0.70	B	0.70	B	0.70	A	1.00	B	0.70	B	0.70
Water Quality Component C_{WQ}		0.89		0.93		0.96		0.95		0.94		0.94		1.00		1.00		1.00
Reproduction Component C_R		0.18		0.69		0.57		0.41		0.65		0.84		0.56		0.20		0.20
H S I score		**0.53**		**0.81**		**0.77**		**0.68**		**0.80**		**0.89**		**0.78**		**0.60**		**0.60**
abundance		0		0		1		6		11		0		1		0		0
Total Biomass (g)		0		0		16.03		760		372.47		0		3.42		0		0

Table 17. Longnose dace HSI individual variable scores, total HSI score and fish data by site.

Habitat Variable	DCC208	SI	DCC455	SI	DCC793	SI	DCD765	SI	DCD1105	SI	DCD1570	SI	DCD1880	SI	DCD2138	SI	FC472	SI
Average Stream Velocity	18.00	0.33	8.00	0.07	20.00	0.39	12.00	0.15	12.00	0.15	8.00	0.07	8.00	0.07	18.00	0.33	14.00	0.21
Maximum Depth in Riffles	0.17	0.74	0.15	0.69	0.16	0.72	0.51	1.00	0.51	1.00	0.35	1.00	0.31	1.00	0.30	1.00	0.29	1.00
% Riffles	28.57	1.00	23.81	0.95	19.05	0.76	23.81	0.95	19.05	0.76	19.05	0.76	28.57	1.00	19.00	0.76	14.29	0.57
% of Substrate >5cm	42.00	0.84	30.00	0.60	57.00	1.00	83.00	1.00	61.00	1.00	53.00	1.00	51.00	1.00	65.00	1.00	84.00	1.00
Spring/Summer Maximum Temp.	22.90	0.00	23.50	0.00	23.20	0.00	24.40	0.00	21.20	0.64	21.30	0.56	21.90	0.08	20.00	0.90	20.00	0.90
% Cover	12.50	0.50	11.87	0.47	20.63	0.83	21.25	0.85	20.00	0.80	20.00	0.80	21.88	0.88	20.00	0.80	21.25	0.85
H S I Score		**0.00**		**0.00**		**0.00**		**0.00**		**0.15**		**0.07**		**0.07**		**0.33**		**0.21**

conducted strictly for riffle dwelling species such as Longnose dace, the average depth would be much smaller and average velocity would be much higher for a given "site".

The Longnose dace HSI model was applied to Darby-Cobbs Watershed despite the fact that this species was not collected from the watershed in the 2003 fish survey. A review of historical fish distribution records conducted for the Fairmount Park Commission by researchers at the Academy of Natural Sciences indicates that this species has never been recorded from the watershed. Longnose dace are, however, present in other streams in the Delaware and Schuylkill drainages. This species is considered a riffle specialist, feeding and spawning in fast water in higher gradient, clear and cool streams. High Longnose dace HSI scores may thus indicate favorable riffle conditions, not only for this species, but for a variety of other riffle dwellers, including sensitive macroinvertebrate bioindicator taxa.

5.4. Chemical Assessment

5.4.1. Overview

Discrete (fixed interval) chemical sampling was conducted weekly under a variety of conditions (e.g., wet weather, ice) that may have influenced results of many chemical and water quality analyses. For example, instream measurements of dissolved oxygen and grab samples taken for fecal coliform analyses may exhibit great variability in response to environmental conditions. The former is dependent on time of day and sunlight intensity, while the latter may vary with rainfall. For this reason, results of discrete chemical sampling are most useful for characterizing dry weather water quality under Target A of the Watershed Management Plan. Target C and indicator 9 of the Watershed Management Plan were specifically targeted by PWD's Wet Weather Monitoring Program and Continuous Water Monitoring Program, respectively.

Much of Darby-Cobbs Watershed is served by a combined sewer system. Wet weather overflows at CSO structures periodically cause releases of combined sewage to streams. Effects of these releases may extend beyond the times when rain is falling or overflows are occurring. CSO discharges, even when infrequent, may thusly be a significant factor in shaping a stream's water quality. Philadelphia's streams can not be expected to meet water quality criteria during wet weather (Target C) unless CSO discharges are addressed and stormwater is treated. Conversely, combined sewer systems may be more efficient than separate sewer systems at capturing (diverting) pollutants from small, diffuse, and/or periodic sources (e.g., very small storms, gradual snowmelt, car and equipment washing, intentional dumping in storm drains).

Many watersheds in developed and developing areas are poorly protected from surface runoff from landscapes, golf courses, industrial areas, etc., which may introduce nutrients to the stream. A wide buffer of riparian vegetation around the stream can intercept and filter this runoff, reducing nutrient concentrations before they reach the stream. Another important benefit of streamside vegetated buffer zones, especially those with mature trees, is shading. Beyond direct influences of shading on algal biomass, primary productivity and amplitude of diel fluctuations in dissolved oxygen, shading reduces temperature effects, thereby affecting dissolved oxygen levels indirectly. Though only 9% of the Cobbs Creek watershed is forested, nearly all this forest land lies within stream corridors.

Additionally, suburban and urban landscapes, such as the Darby Cobbs Watershed, abound in potential point and non-point sources of organic, thermal, microbial, and heavy metal pollution. Acute and chronic effects of these pollutants on stream habitats and organisms are difficult to quantify.

5.4.2. Indicator 7: Bacteria

Fecal coliform bacteria concentration is positively correlated with point and non-point contamination of water resources by human and animal waste and is used as an indicator of poor water quality (Indicator 7 of the Watershed Management Plan). PADEP has established a maximum limit of 200 colony forming units, or “CFUs,” per 100ml sample during the period 05/01-9/30, the “swimming season” and a less stringent limit of 2000CFUs/100ml for all other times. It should be noted that the state criterion is based on the geometric mean of five consecutive samples collected over a 30-day period. As bacterial concentrations can be significantly affected by rain events and otherwise may exhibit high variability, individual samples are not as reliable as replicate or multiple samples taken over a short period.

Based on data from numerous sources (PADEP, EPA, USDA-NRCS, volunteer and non-profit organizations, etc.), it appears likely that many, if not most, southeastern PA streams would be found in violation of water quality criteria given sufficient sampling effort. PWD has expended considerable resources toward documenting concentrations of fecal coliform bacteria and *E. coli* in Philadelphia's watersheds. The sheer amount of data collected allows for more comprehensive analysis and a more complete picture of the impairment than does the minimum sampling effort needed to verify compliance with water quality criteria. In keeping with the organizational structure of the watershed management plan, fecal coliform bacteria analysis has been broken into dry (Target A) and wet weather (Target C) components, defined by a period with at least 48 hours without rain as measured at the nearest gauge in PWD's rain gauge network.

5.4.2.1. Target A: Dry Weather Fecal Coliform Bacteria

All individual dry weather samples collected from Darby-Cobbs Watershed during the non-swimming season (n=18) showed fecal coliform bacteria concentration well below the water quality criterion of 2000CFU/100ml. But geometric means of fecal coliform concentration at all sites exceeded water quality criteria during the swimming season (Table 18 and Figure 20). Samples from sites DCI010, DCC208, and DCC455 on 6/12/03 were likely affected by a leaking sewer. The sewer leak was subsequently detected by PWD biologists conducting a fish assessment downstream. Geometric means of fecal coliform from these sites would be 366, 324 and 696, respectively, with these samples omitted.

With the exception of intense sampling upstream and downstream of a point source, surface water grab samples do not usually allow one to determine the source(s) of fecal contamination. Recent research has shown that fecal coliform bacteria may adsorb to sediment particles and persist for extended periods in sediments (VanDonsel, et al. 1967, Gerba 1976). Presence of bacterial indicators in dry weather may thus more strongly reflect past wet weather loadings than dry weather inputs (Dutka and Kwan, 1980). Clearly, there exist several possible sources of fecal coliform bacteria within the watershed, all or combinations of which may be acting within different spatial and

Table 18. Fecal coliform concentrations at the nine water quality monitoring sites.

Site	n	Max	Min	Median	Mean	Std. Dev.	Geometric Mean
DCC208	7	2600	140	410	674.29	859.03	437.06
DCC455	7	2900	390	540	1097.14	991.66	815.75
DCC770	7	1060	220	300	407.14	293.58	351.92
DCD765	7	530	160	310	311.43	118.80	292.60
DCD1170	4	700	120	400	412.50	32.02	411.61
DCD1570	4	320	210	240	252.50	49.92	249.00
DCD1660	7	380	160	240	257.14	68.97	249.36
DCI010	4	20000	150	600	5337.50	9778.40	995.67
DCN010	4	3000	770	1020	1227.50	598.02	1136.70

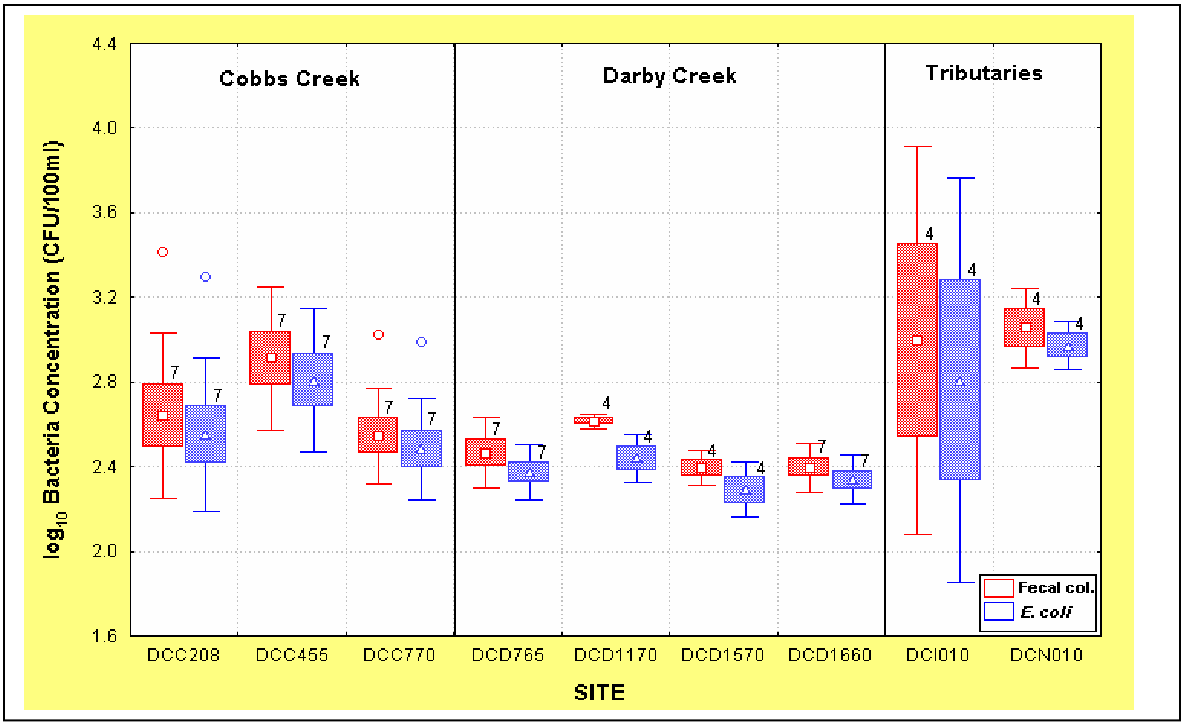


Figure 20. Dry weather fecal coliform and *E. coli* concentrations at the 9 monitoring sites.

temporal dimensions. PWD is piloting a Bacterial Source Tracking (BST) program that may eventually be useful in identifying the sources of fecal coliform bacteria collected in dry weather. Of particular interest is the relative proportion of the total bacterial load from human sources vs. domestic and wildlife animal sources.

5.4.2.2. Target C: Wet Weather Fecal Coliform Bacteria

Surface water grab samples (n=54) were collected at nine sites throughout Darby- Cobbs Watershed during or within 48 hours of wet weather as part of PWD's 2003 fixed interval (weekly) discrete chemical sampling program. Results of weekly discrete fecal coliform bacteria concentration analysis appear in Table 19. An additional 130 automatic sampler composite samples were collected from 5 sites during two individual wet weather events as part of PWD's intensive wet weather monitoring program. Hydrograph-matched scatterplots of fecal coliform bacteria concentration at each site for each event appear in (Appendix F). The data from these events is summarized in Tables 20 and 21.

Not surprisingly, wet weather fecal coliform bacteria concentration is elevated significantly at each site compared to dry weather concentrations. Both Cobbs and Darby Creeks exhibited a typical pattern of fecal coliform bacteria concentration increasing at downstream locations. Though all sites sampled probably could be in violation of state fecal coliform bacteria standards (e.g., many samples in excess of 1000 CFU/100ml, more than 10% of samples in excess of 400CFU/ml), Cobbs Creek and its tributaries within Philadelphia (i.e., Naylors Run and the Indian Creeks) appear more severely affected than suburban Delaware County sites.

Table 19. Fixed interval fecal coliform samples collected in wet weather.

Site	n	Max	Min	Median	Arithmetic Mean	Std. Dev.	Geometric Mean
DCC208	6	43,000	350	6,700	15,192	17,184	6,648
DCC455	6	36,000	310	2,550	8,162	13,838	2,629
DCC770	6	2,900	140	495	1,115	1,174	657
DCD765	6	4,000	440	710	1,452	1,402	1,040
DCD1170	6	3,000	320	675	1,288	1,274	802
DCD1570	6	4,000	160	325	1,133	1,537	532
DCD1660	6	5,300	30	275	1,772	2,474	449
DCI010	6	110,000	450	3,000	21,017	43,706	3,614
DCN010	6	4900	590	3,300	2,902	1,888	2,187

Table 20. Fecal coliform concentrations recorded at the 5 wet weather monitoring locations during storm event 1.

Site	n	Max	Min	Median	Arithmetic Mean	Std. Dev.	Geometric Mean
DCC208	18	182,000	350	78,500	71,275	54,242	28,423
DCC455	19	200,000	1,400	43,000	63,168	63,202	28,615
DCC770	18	20,000	420	2,300	6,004	7,424	2,378
DCD765	11	41,000	1,000	9,400	12,100	11,731	7,199
DCD1660	19	161,000	1,800	6,600	26,763	39,534	11,101

Table 21. Fecal coliform concentrations recorded at the 5 wet weather monitoring locations during storm event 2.

Site	n	Max	Min	Median	Arithmetic Mean	Std. Dev.	Geometric Mean
DCC208	9	82,000	25,000	29,000	41,000	21,529	36,891
DCC455	9	103,000	8,800	30,000	32,744	28,561	24,975
DCC770	9	46,000	2,200	6,600	14,167	16,827	8,387
DCD765	9	20,000	3,600	8,500	8,300	4,220	7,466
DCD1660	9	18,000	3,100	5,500	6,733	5,140	5,721

5.4.3. Indicator 8: Metals

Metals occur in all natural waters in varying concentrations due to runoff, erosion, atmospheric deposition, and interactions with streambed geological features. However, because certain metals may be toxic even in very small concentrations, toxic metals concentrations are included in the CCIWMP (indicator 8). Darby Creek Watershed (32.3 river miles including Darby Creek, Hermesprota Creek, Muckinipattis Creek, Stony Creek, Langford Run, and Whetstone Run) was listed by PADEP in 1996 as impaired due to metals in urban runoff/storm sewers, though individual segments were not identified. Cobbs Creek watershed (24.8 river miles, including Indian creek) was listed by PADEP in 2002 as impaired due to urban runoff/storm sewers and municipal point sources, but cause(s) of the impairment were not identified.

Metals of concern (e.g., lead, chromium, cadmium, copper, and zinc) were most often undetectable or present in minimal concentrations in water samples taken in 2003 from Darby-Cobbs watershed. However, increases in concentration during rainfall were observed for copper, iron, and lead. Though water column toxic metal concentrations may be generally small, many metals readily adsorb to sediment particles, interact with organic molecules, or otherwise precipitate or become deposited or incorporated into stream sediments. Since most aquatic organisms either inhabit sediments or feed upon benthic invertebrates, possible toxic effects may not be reflected by water column concentrations alone.

Calcium and magnesium concentrations of Darby-Cobbs watershed were not unusual, keeping with the predominant rock types in the watershed (schists and gneiss). As the major divalent cations in surface water, Calcium and Magnesium are used to compute hardness (expressed as mg/l $CaCO_3$). This is an important parameter, because toxicity of other metals generally has an inverse relationship with hardness. Most EPA and PADEP toxic metal water quality criteria are currently defined as linear regression equations that account for observed decreases in toxicity as hardness increases. Each sample metal concentration is evaluated against the criterion as calculated with sample hardness. Furthermore, two water quality criteria exist for each toxic metal, criteria continuous concentration (CCC) and criteria maximum concentration (CMC); these criteria address chronic and acute toxicity, respectively. Dry weather water samples were compared to CCC and wet weather samples were compared to CMC.

PADEP dissolved metal criteria are based on EPA toxic metals standards originally developed for total recoverable metals. Though these criteria have been modified to include a conversion factor for use with dissolved metals data, actual dissolved metal concentrations cannot be predictably determined as a proportion of total recoverable metals concentrations. Solubility of metals in natural waters varies with other environmental variables. Because of the degree to which metals may adsorb to sediment and form complexes with organic particles, it is likely that actual water column dissolved metal concentrations in Darby-Cobbs Watershed are smaller than those predicted using these conversion factors. To assess the effects of using these conversion factors, total recoverable metal concentrations were compared to both dissolved and total recoverable criteria.

5.4.3.1. Target A: Dry Weather Metals Concentrations

With the exception of copper, metals concentrations were relatively small in dry weather (Table 22). Cadmium and Chromium were not detected in any of 69 dry weather samples from Darby-Cobbs Watershed. Lead was detected in only 3 samples, 2 from site DCC208 and one from site DCC455; only one of these three detections was a possible violation of the dry weather (continuous) criterion (CCC) for lead. Aluminum and zinc were detected in approximately two thirds of dry weather samples. Aluminum concentrations were consistently small, the maximum value was less than 50% of the CMC and the mean concentration was less than 10% of the CMC (no CCC has been established for aluminum). Zinc concentrations were typically 10% or less of the CCC. Copper was detected in all dry weather samples; three samples may have exceeded the CCC. While standards for each sample vary with hardness, many samples had copper concentration at 50% or more of the CCC. Based on ICP-MS performance on individual check standards, reporting limits for some metals were higher than 1µg/l on some occasions.

Table 22. Metal concentrations collected during dry weather in Darby-Cobbs Watershed.

Metal	non-detects	Max	Min	Arithmetic Mean	Std. Dev.	Geometric Mean	WQ Violations
Aluminum	16	0.363	0.015	0.067	0.053	0.055	N/A
Cadmium	69	N/A	N/A	N/A	N/A	N/A	0
Calcium	0	52.0	24.0	34.89	6.573	34.311	N/A
Chromium	69	N/A	N/A	N/A	N/A	N/A	0
Copper	0	0.020	0.002	0.006	0.004	0.006	3
Iron	4	0.785	0.052	0.196	0.113	0.171	0
Lead	66	0.007	0.002	0.004	0.003	0.003	1
Magnesium	0	19.320	11.700	14.945	1.510	14.781	N/A
Manganese	3	0.142	0.010	0.033	0.024	0.027	0
Zinc	19	0.084	0.002	0.017	0.017	0.012	0

Water column total recoverable metals concentrations often do not accurately reflect bioavailability of toxic constituents and cannot be expected to reliably predict effects along and among stream sediments. Much recent research has been focused on metals toxicity and studies have focused on determination of toxic constituents of sediments themselves; toxic constituents of interstitial waters; re-suspension of toxicants by storm flows, recreational use, or bioturbation by benthic biota; controlled laboratory testing with experimental organisms; *in-situ* toxicity investigations; and development and refinement of sediment toxicity models.

EPA has begun the process of revising water quality criteria for toxic metals to incorporate the considerable body of research that has been conducted since the original criteria were published. These new criteria more appropriately reflect the chemical behavior of toxicants in surface waters and account for their bioavailability. For example, cupric ions (Cu^{2+}) have been recognized as the major cause of copper toxicity (Sunda and Guillard 1976; Sunda and Hansen 1979). However, complexes formed through ligand bonding with inorganic and organic molecules may reduce free copper concentrations by three or more orders of magnitude (Morel & Hering 1993) through competition for ligand bonding sites. EPA's draft copper water quality standard (2003) incorporates the Biotic Ligand Model (DiToro et al., 2001) and more reliably predicts the toxic effects of copper concentrations than linear regression equations that consider only hardness as a covariable.

5.4.3.2. Target B: Wet Weather Metals Concentrations

Wet weather metals concentrations were generally greater than concentrations in dry weather; the incidence of possible water quality violations was much higher overall in wet weather than in dry weather. For example, metals that may have violated water quality criteria only in wet weather included aluminum, cadmium, manganese, and zinc. Possible violations of copper and lead criteria were more frequent in wet weather as well. Hydrograph-matched scatterplots of toxic metal concentrations appear in (Appendix G).

While surface runoff undoubtedly contributes to increases in wet weather metals concentrations, it is likely that re-suspension of metals associated with sediments contributes to excursions from water quality criteria.

5.4.4. Indicator 9: Dissolved Oxygen Concentration

Continuous monitoring Sondes at sites within Darby-Cobbs Watershed measured, among other parameters, water column dissolved oxygen (DO) concentration. DO concentrations often strongly reflect autotrophic community metabolism and in turn, affect the heterotrophic community structure as a limiting factor for numerous organisms. Because sufficient DO concentration is critical for fish, amphibians, crustacea, insects, and other aquatic invertebrates, DO concentration is used as a general indicator of a stream's ability to support a balanced ecosystem. The Pennsylvania Department of Environmental Protection (PADEP) has established criteria for both instantaneous minimum and minimum daily average DO concentration. Criteria are intended to be protective of the types of aquatic biota inhabiting a particular lake, stream, river, or segment thereof.

All water chemistry monitoring sites within Darby-Cobbs Watershed, with the exception of DCD1660, are designated as Warm Water Fisheries (WWF). Site DCD1660, and all segments of Darby Creek north of PA Rte. 3 (West Chester Pike) are designated a Trout Stocking Fishery (TSF). PADEP water quality criteria require that minimum DO levels in WWF not fall below 4.0 mg O_2/L and that daily averages remain at or above 5.0 mg O_2/L. A Trout Stocking Fishery such as DCD1660 has more stringent DO standards to support more sensitive stocked salmonid fish species from February 15 to July 31 each year. During this period, a minimum daily DO average of 6.0 mg O_2/L is required, and allowable DO instantaneous minimum is 5.0 mg O_2/L. For the remainder of the year, TSF criteria align with WWF standards. These regulations, along with corresponding temperature criteria, form the foundation of stream protection in general and allow for propagation and maintenance of healthy fish communities.

Combinations of natural and anthropogenic environmental factors may affect DO concentration. Autotrophic and heterotrophic organisms are influenced by nutrient concentrations, solar radiation, temperature, and other environmental factors. Daily fluctuations of oxygen in surface waters are due primarily to the metabolic activity of these organisms. If temperature alone influenced DO concentration, saturation would increase at night, when water temperature drops, and decrease during the day as the water warms. Because the watershed is generally dominated by biological activity, the reverse occurs: DO concentrations in Darby-Cobbs Watershed rise during the day when autotrophic organisms are photosynthesizing and decrease at night when community respiration is the dominant influence. Another factor in the amount of oxygen dissolved in the water is re-aeration (diffusion of atmospheric oxygen). Barometric pressure, surface area, turbulence and oxygen saturation deficit influence the amount of oxygen transferred to the stream from the atmosphere. Effects of re-aeration tend to augment or diminish (rather than shift or change) effects of stream metabolism.

Stream sites that support abundant algal growth often exhibit dramatic diel fluctuations in dissolved oxygen concentration. Algal photosynthesis infuses oxygen during the day (often to the point of supersaturation), while algae and heterotrophic organisms remove oxygen throughout the night. These sites are more susceptible to oxygen deficits on cloudy days when the amount of photosynthesis is limited by sunlight and community respiration dominates system activity.

DO fluctuations were more pronounced at some sites than at others, due in part to specific placement of the continuous monitoring instrument (Sonde) at each site. When interpreting this continuous DO data, one must keep in mind that the instrument can only measure dissolved oxygen concentration of water in direct contact with the DO probe membrane. Furthermore, to obtain the most accurate readings of DO, probes should be exposed to flowing water or probes themselves must be in motion. Local microclimate conditions surrounding the probe and biological growth on the probe itself may also contribute to errors in measurement. It is possible for Sondes situated in subtly different areas of the same stream site to exhibit marked differences in DO concentration due to flow, shading, and local microclimate differences. Sonde measurements of DO concentrations during the summer period (8/14/03-9/14/03) are depicted in figures 21 thru 25.

The Sonde located at DCC208, for example, is located in a pool upstream of a dam. Additionally, the Sonde at DCC208 is not shaded. Deep pools, slower stream velocity, and ample sunlight provide excellent conditions for algal growth which are reflected in diel DO fluctuations (Figure 21). DCD765 is another site in which the Sonde is only

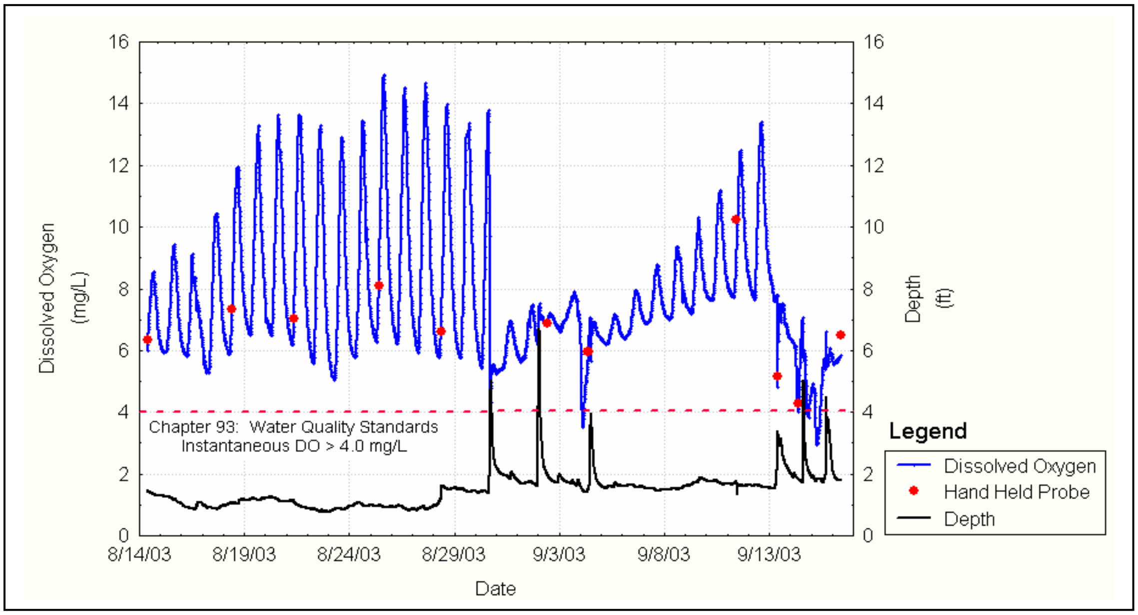


Figure 21. Continuous measurements of dissolved oxygen at DCC 208.

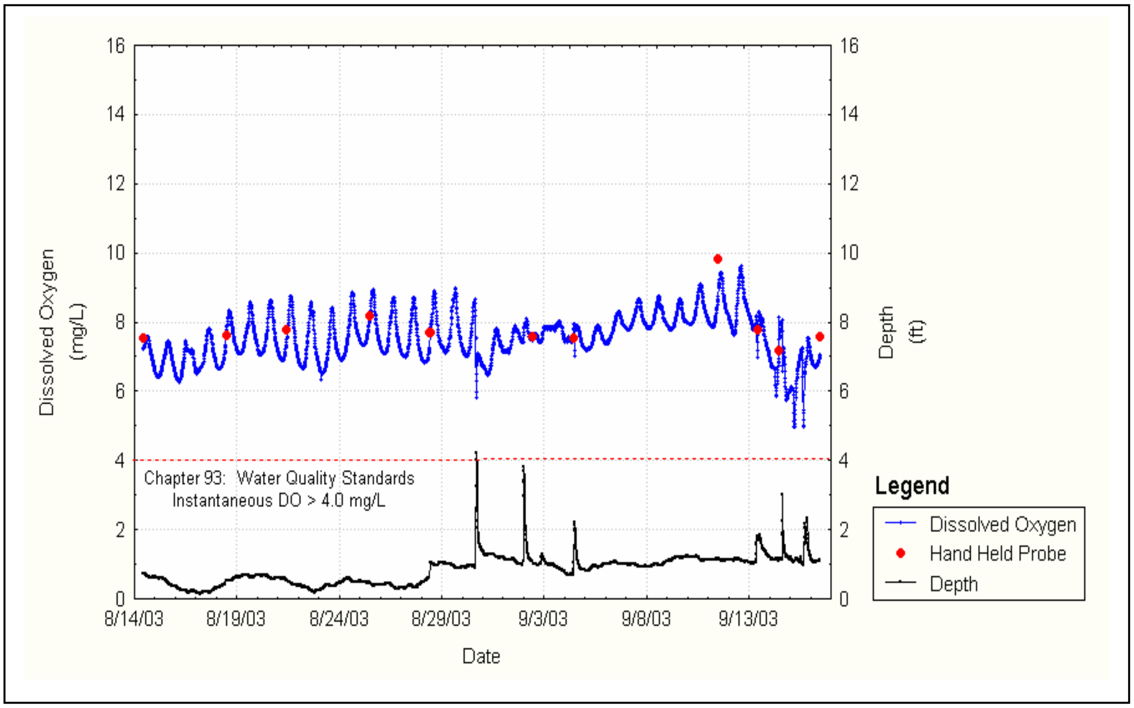


Figure 22. Continuous measurements of dissolved oxygen at DCC 455.

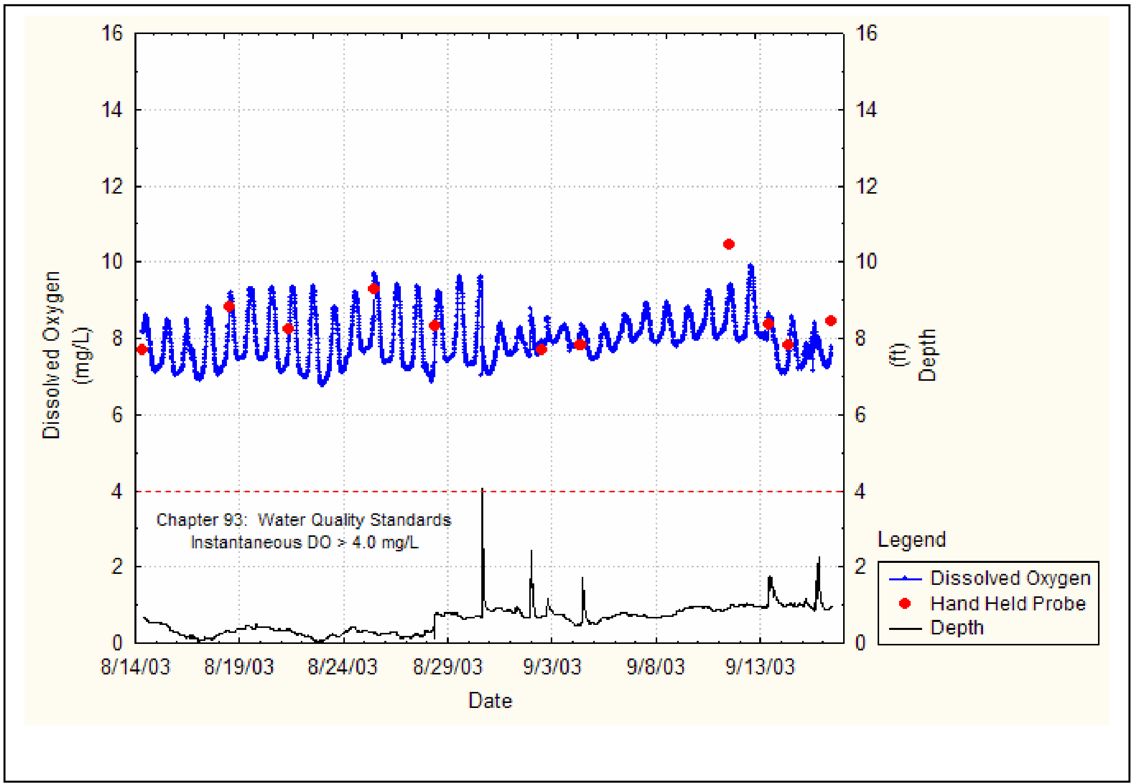


Figure 23. Continuous measurements of dissolved oxygen at DCC 770.

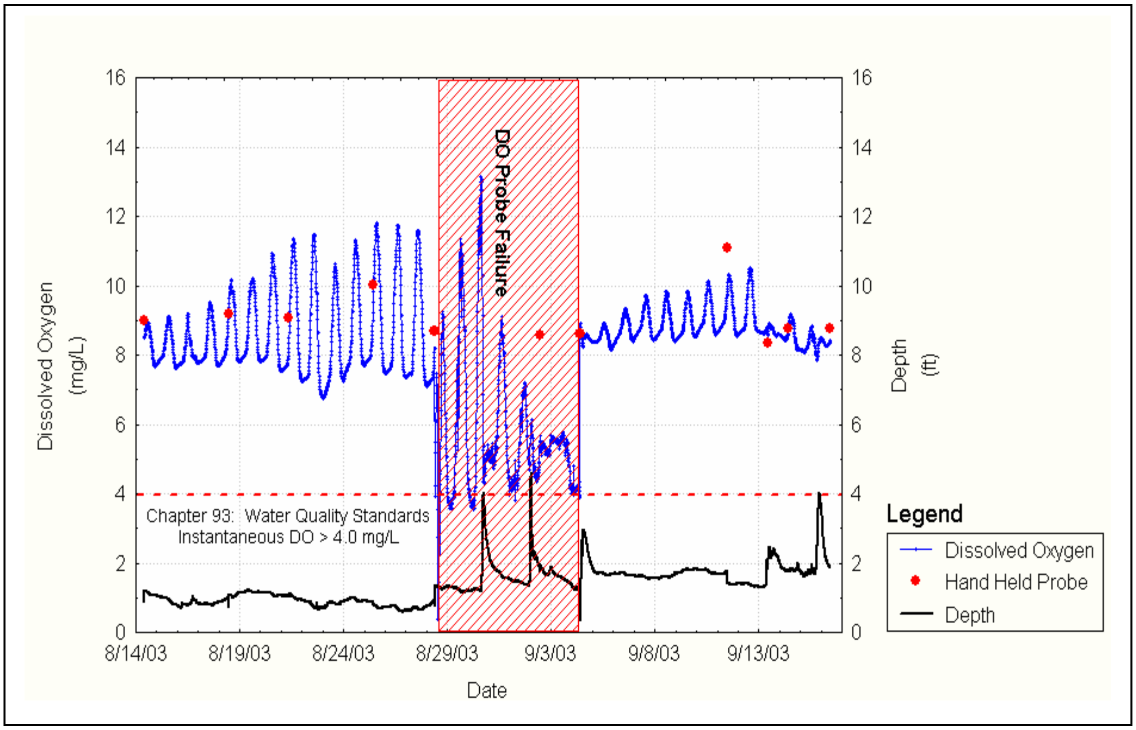


Figure 24. Continuous measurements of dissolved oxygen at DCD 765.

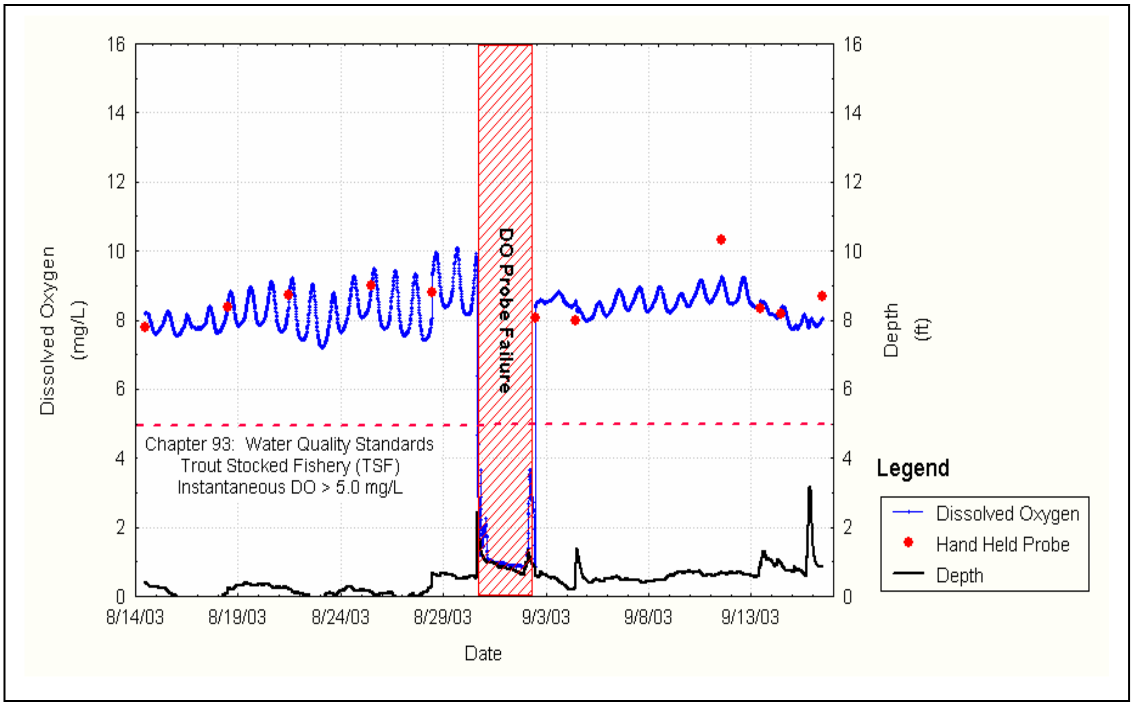


Figure 25. Continuous measurements of dissolved oxygen at DCD 1660.

partially shaded. While not as large as DCC208, the amplitude of DO fluctuations exceeded 3 mg/L at this site. In contrast, the Sonde at DCD1660 is located under a bridge in shallow water. While not measured quantitatively, it is likely that algal periphyton density was smaller at this site; resulting diel fluctuations are damped in comparison to sites exposed to more sunlight (Figure 25). Sondes at sites DCC455 and DCC770 are in areas that are mostly shaded (Figures 22 and 23, respectively).

Two separate rain events occurred during the period of Sonde deployments in Darby-Cobbs Watershed. During and following the rain events, DO concentrations decreased considerably. Following sloughing of algal periphyton (benthic algae, biofilm, *aufwuchs*), the stream exhibits effects of diminished productivity. An August 30, 2003 rain event demonstrated this phenomenon at all five continuously monitored sites. DCC208 is the only site in which DO suppression violated the state water quality standards for instantaneous dissolved oxygen. Site DCC208, as discussed earlier, has many site-specific attributes that result in dense algal periphyton communities. These same factors also make it more difficult to measure DO concentrations with veracity. (DO probe failure occurred at two sites during this rain event. Cleaning of debris from DO probes, in both cases, corrected the problem in time to record a period of diminished productivity due to sloughing at these sites). Following the disturbance, autotrophic communities became reestablished, as evidenced by the return of normal, exaggerated diel fluctuations in DO concentration.

5.4.5. pH

Continuous monitoring through the use of Sondes on the Darby and Cobbs Creeks recorded pH values at each of five sites. pH is a measure of acidity, or the concentration of hydrogen ions in a solution. In natural waters, the balance between acidity and alkalinity is determined by concentrations of various dissolved compounds, salts and gases and typically remains near neutral, or pH 7. Fluctuations in pH can occur in freshwater systems as a result of natural and anthropogenic influences. Interplay between inorganic carbon species, known as the bicarbonate buffer system, generally maintains pH within a range suitable for aquatic life.

The bicarbonate buffer system is a function of the equilibrium relationship between carbon dioxide (CO_2) and carbonic acid (H_2CO_3), as well as bicarbonate (HCO_3^-) and carbonate (CO_3^{2-}) ions. In natural waters, the predominant source of hydrogen ions is carbonic acid. Biochemical metabolism of carbon throughout the day continually shifts the equilibrium equation, causing fluctuations in pH. As plants and algae consume carbon dioxide during photosynthesis, carbonic acid dissociates to replenish the CO_2 and maintain equilibrium. Decreasing carbonic acid concentrations cause elevated pH. As photosynthetic rates decline after peak sunlight hours, respiratory activities of aquatic biota replenish carbon dioxide to the system, decreasing pH. Acidity in Darby-Cobbs watershed is chiefly determined by this metabolic activity; the watershed is not heavily influenced by bedrock composition, groundwater sources or anthropogenic inputs, such as acid mine drainage.

Water quality criteria established by PADEP regulate pH to a range of 6.0 to 9.0 in Pennsylvania's freshwater streams. pH values between 6 and 9 units do not negatively affect stream biota. Organisms can be indirectly affected by pH due to its influences on the dissociation of many compounds, such as ammonia. As pH increases, a greater fraction of ammonia N is present as unionized NH_3 (gas). For example, ammonia is ten times as toxic at pH 8 as at pH 7. Extreme pH values may increase dissociation of or general toxicity of other constituents. For example, pH levels affect the bioavailability of metals (e.g., copper), which have individually regulated criteria established by PADEP.

Continuous pH data was discretized to 15 min intervals and plotted against time and stream depth. Figures 26 through 30 depict pH trends at each of five continuously-monitored sites on the Darby-Cobbs watershed, including the large diel pH fluctuations that accompany highly productive sites with abundant periphytic algae. Community metabolism regulates the extent of pH fluctuations. Environmental conditions, including ample sunlight, led to a dense autotrophic community at sites DCC208 and DCD765, which exhibited greater diel pH fluctuations than the other monitored sites; these sites also generally came closest to and occasionally violated water quality criteria by exceeding pH 9.0 (Figures 26 and 29, respectively). pH at shadier sites (i.e., DCC770, DCC455 and DCD1660) is probably less influenced by metabolic activity, and oscillations in pH appear noticeably damped as a result.

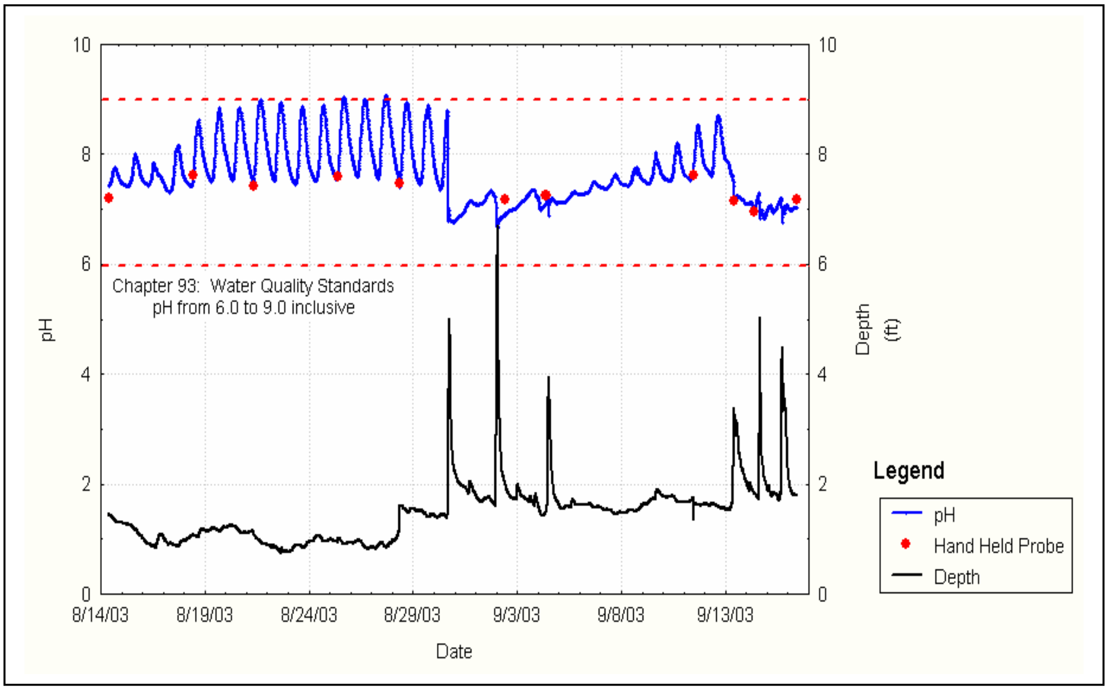


Figure 26. Continuous measurements of pH at DCC 208.

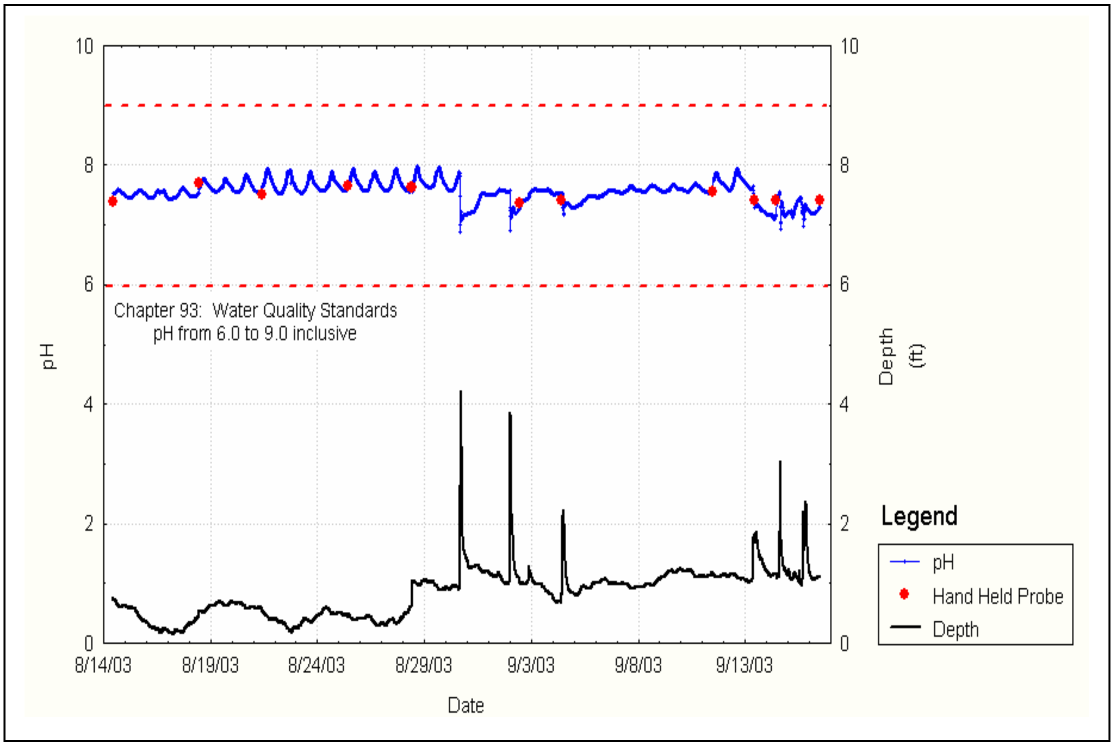


Figure 27. Continuous measurements of pH at DCC 455.

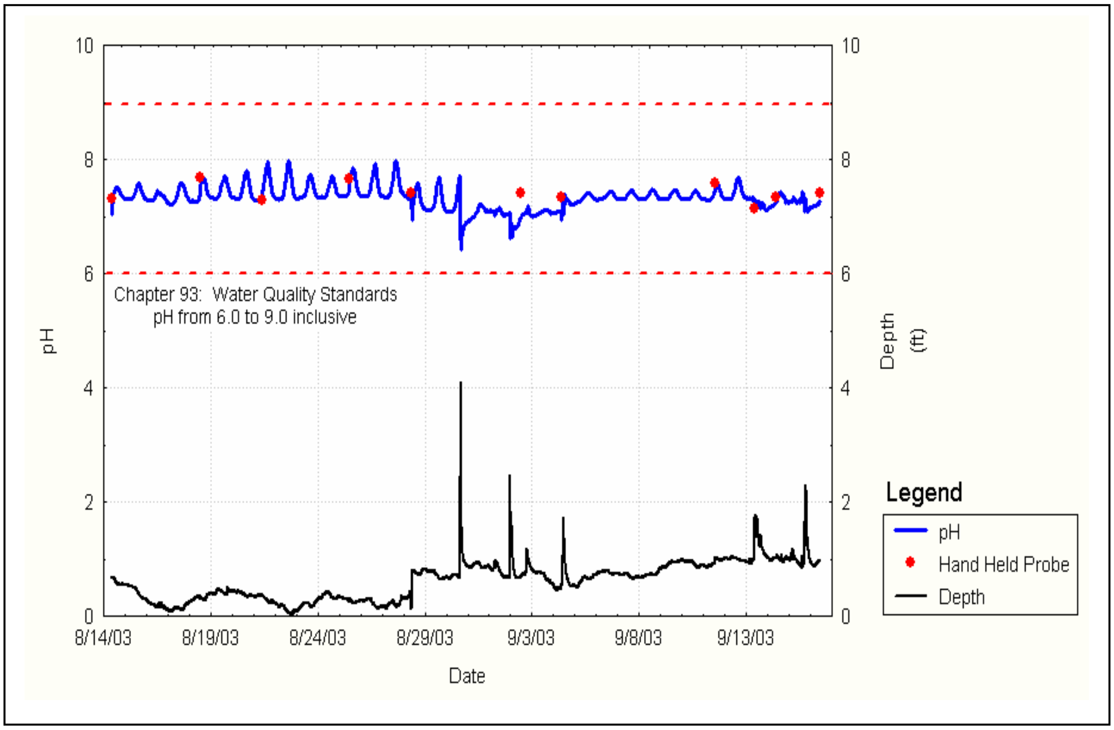


Figure 28. Continuous measurements of pH at DCC 770.

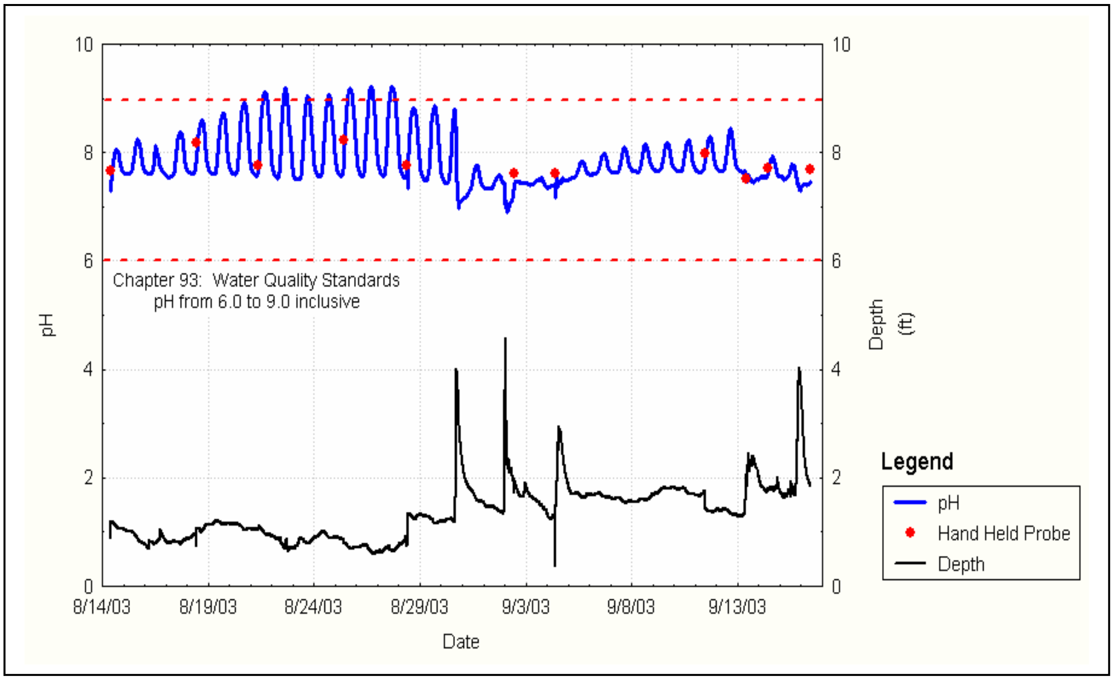


Figure 29. Continuous measurements of pH at DCD 765.

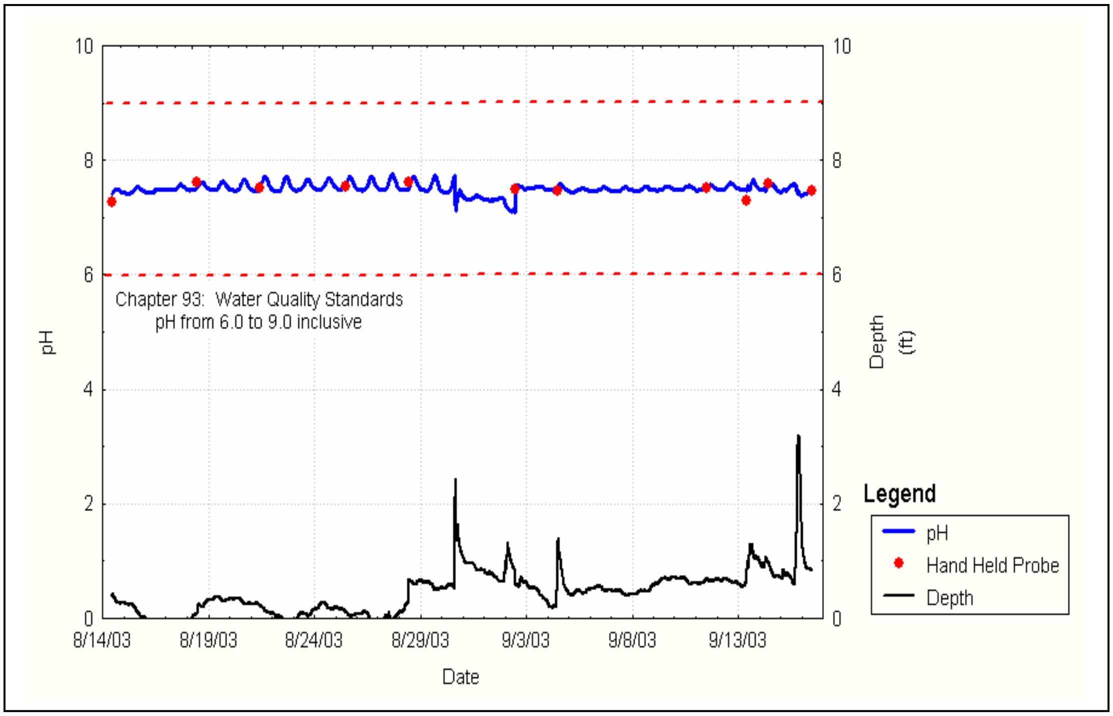


Figure 30. Continuous measurements of pH at DCD 1660.

Two separate rain events occurred during the period of Sonde deployments in Darby-Cobbs Watershed. Increased velocities and larger flows during wet weather swept away attached algae, macrophytes and suspended periphyton. Figures 26 through 30 demonstrate that without autotrophs to reduce carbon dioxide through photosynthesis, pH levels remain steady. The autotrophic community recovers from this disturbance over subsequent weeks and pH gradually returns to normal fluctuations at each site. Decreased pH levels during and following wet weather events did not violate minimum pH standards.

5.4.6. Specific Conductance

Specific conductance is a measure of waters' ability to pass electrical current and is an approximate predictor of total dissolved ions in solution. This measure is often used to monitor changes in water chemistry. Daily fluctuations in specific conductance result from biological activity changes that occur throughout the day. Sites DCC208 and DCD765 experienced more pronounced daily changes in specific conductance due to the presence of a denser biological community (Figures 31 and 34, respectively). Other factors affecting specific conductance include rain events, which decrease conductivity due to dilution of stream water by storm water and increases in total ionic strength due to application of de-icing compounds and road salts during cold weather. Following a large rain event, dissolved ion concentrations may remain below normal baseflow concentrations for more than a week as the stream's natural chemistry gradually reestablishes itself.

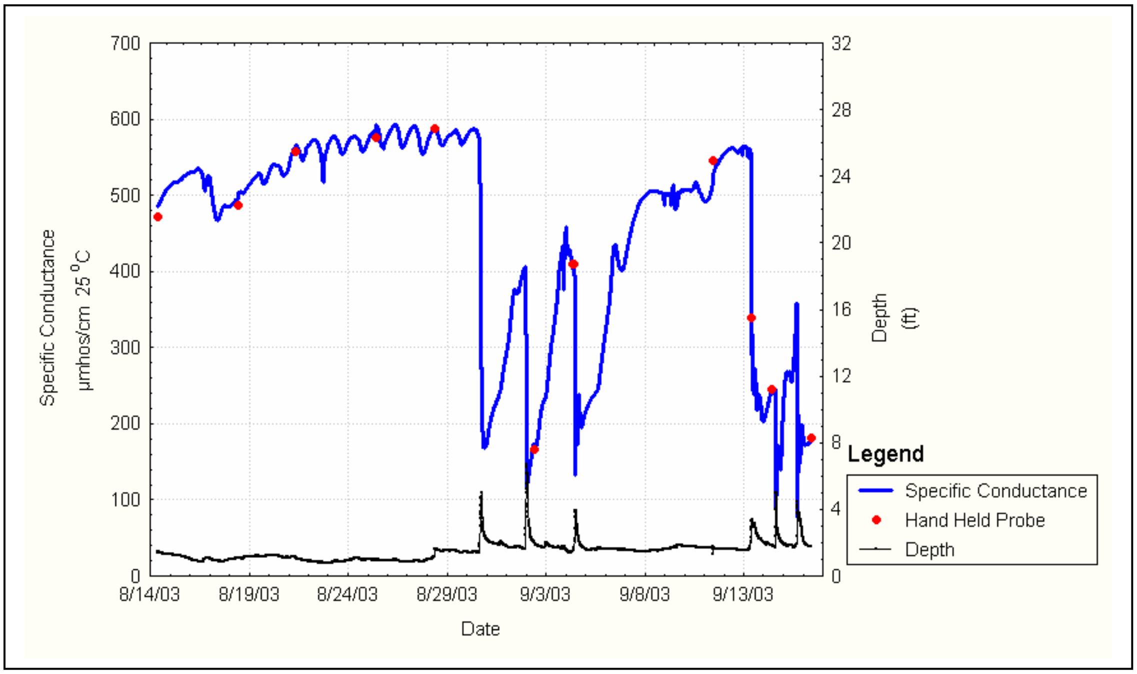


Figure 31. Continuous measurements of Specific Conductance at DCC 208.

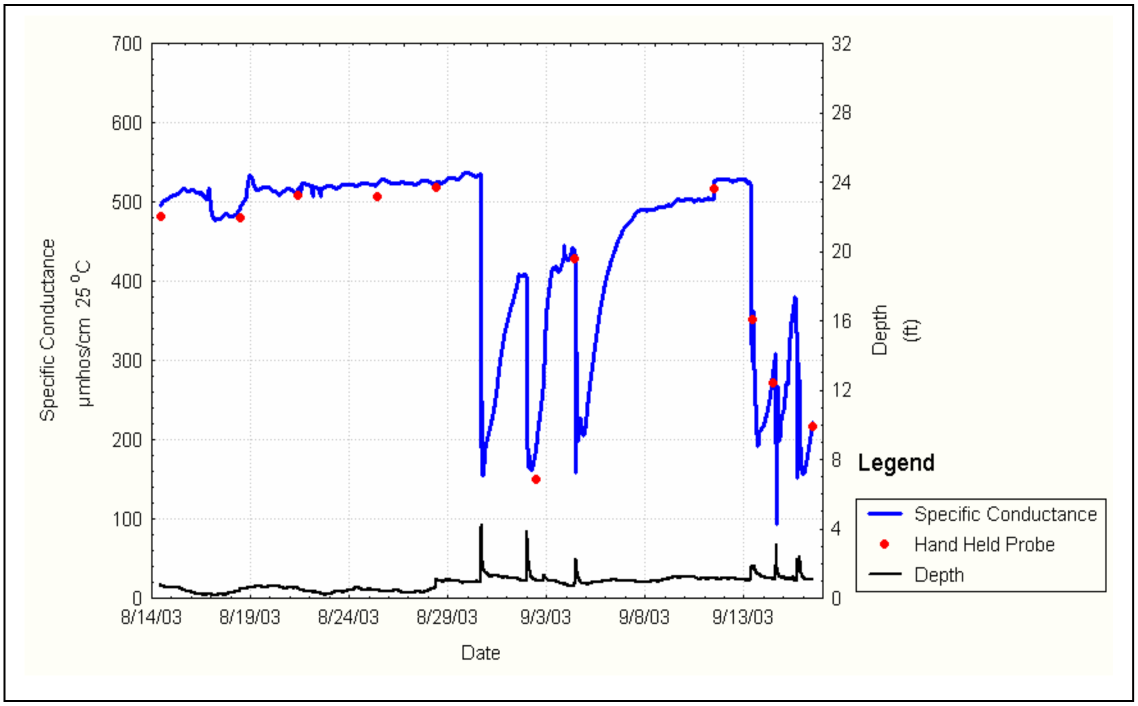


Figure 32. Continuous measurements of Specific Conductance at DCC 455.

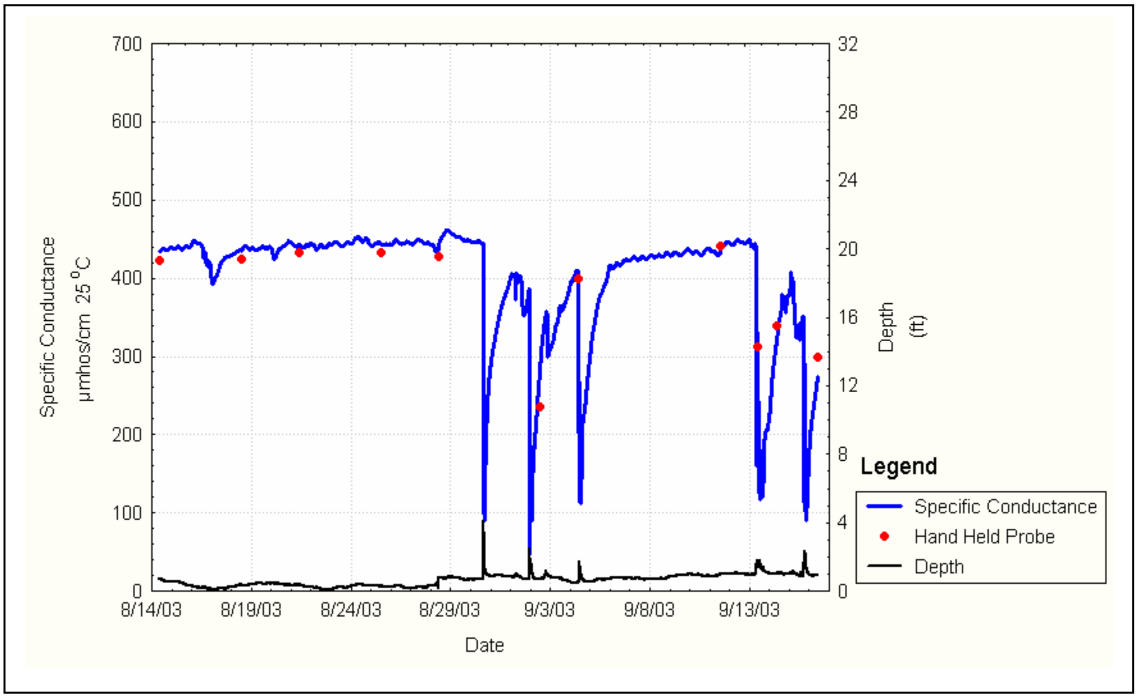


Figure 33. Continuous measurements of Specific Conductance at DCC 770.

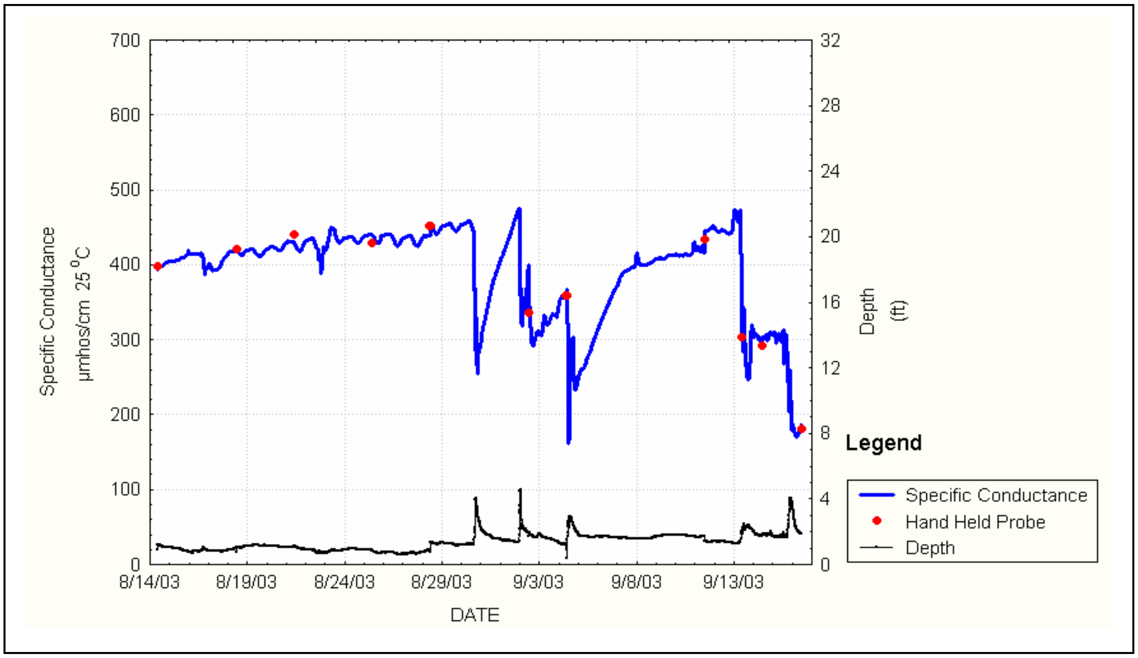


Figure 34. Continuous measurements of Specific Conductance at DCD 765.

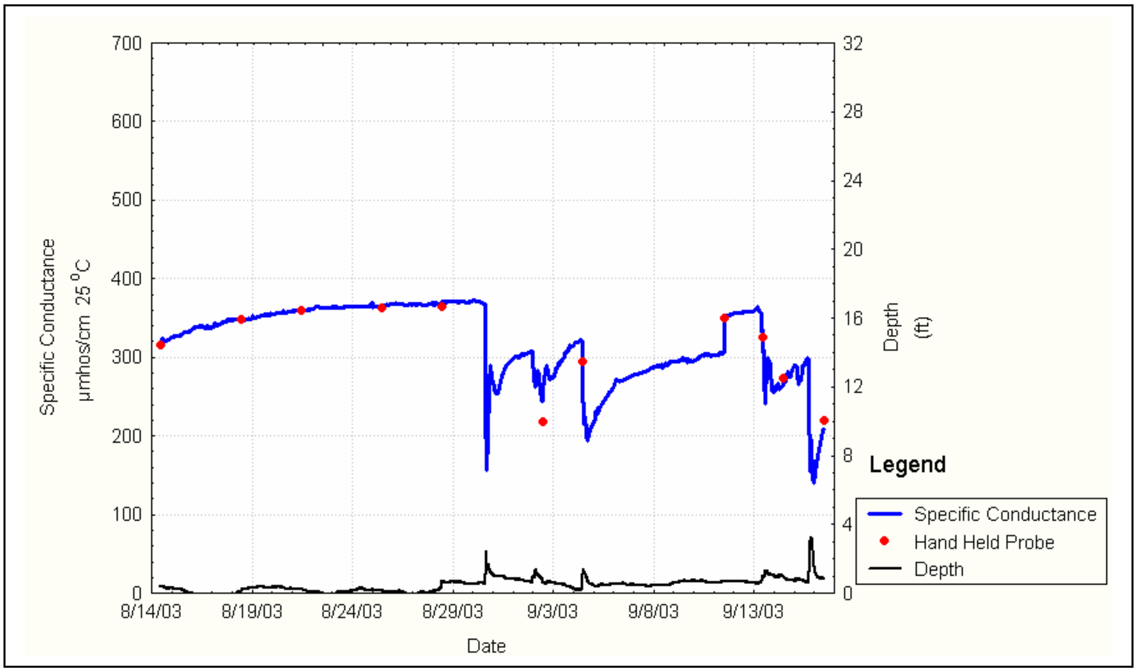


Figure 35. Continuous measurements of Specific Conductance at DCD 1660.

5.4.7. Temperature

The role of temperature in shaping aquatic communities cannot be understated. With the exception of birds and mammals, all freshwater aquatic organisms are poikilotherms ("cold-blooded"). Unable to regulate body temperature through metabolism, these organisms must select suitable temperature conditions within their habitats. PADEP has established temperature criteria for the waters of the commonwealth, largely to delineate areas requiring more stringent thermal protection for naturally-reproducing populations of sensitive ("cold water") fish species, recreationally-sought salmonids, in particular. Temperature criteria also serve to protect aquatic life from increases in temperature from industrial activity (e.g., cooling water). Darby-Cobbs Watershed does not support natural populations of coldwater fish, and is not known to be significantly affected by discharges of cooling waters.

Many water bodies that cannot support natural populations of cold water fish do have adequate thermal protection to maintain hatchery-raised adult trout. Segments of Darby Creek watershed north of PA Rte 3 (West Chester Pike) are so protected and are designated a trout stocking fishery (TSF); the remainder of Darby-Cobbs watershed is designated a warmwater fishery (WWF). Thermal maxima for sites in Darby Cobbs Watershed, as measured with continuous water quality monitoring equipment, never exceeded State water quality standards (Figures 36 through 40). Changes in temperature of 2°C or more were observed at most sites on a number of occasions; however, changes of this magnitude occurred in dry and in wet weather.

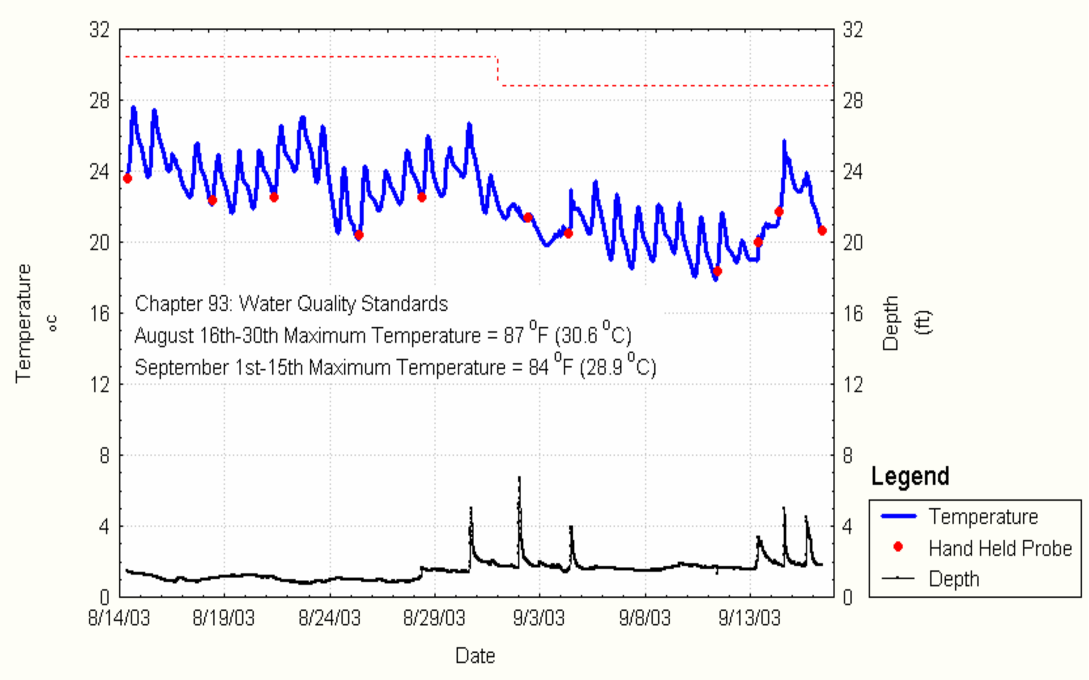


Figure 36. Continuous measurements of temperature at DCC 208.

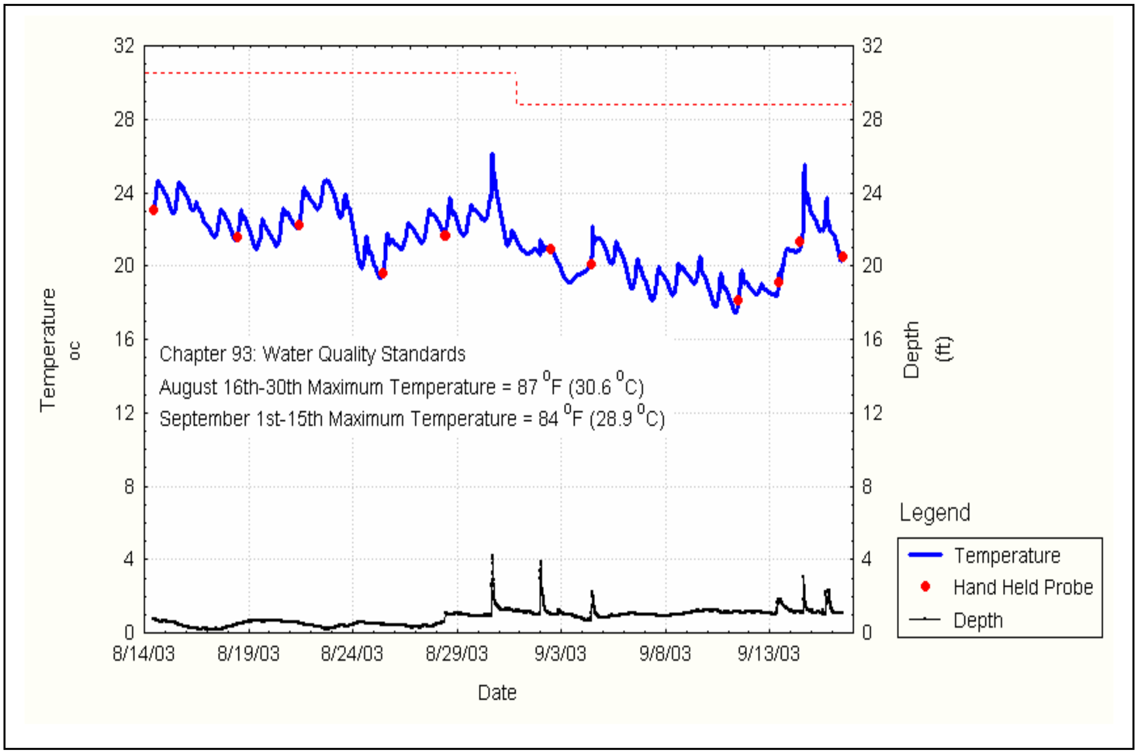


Figure 37. Continuous measurements of temperature at DCC 455.

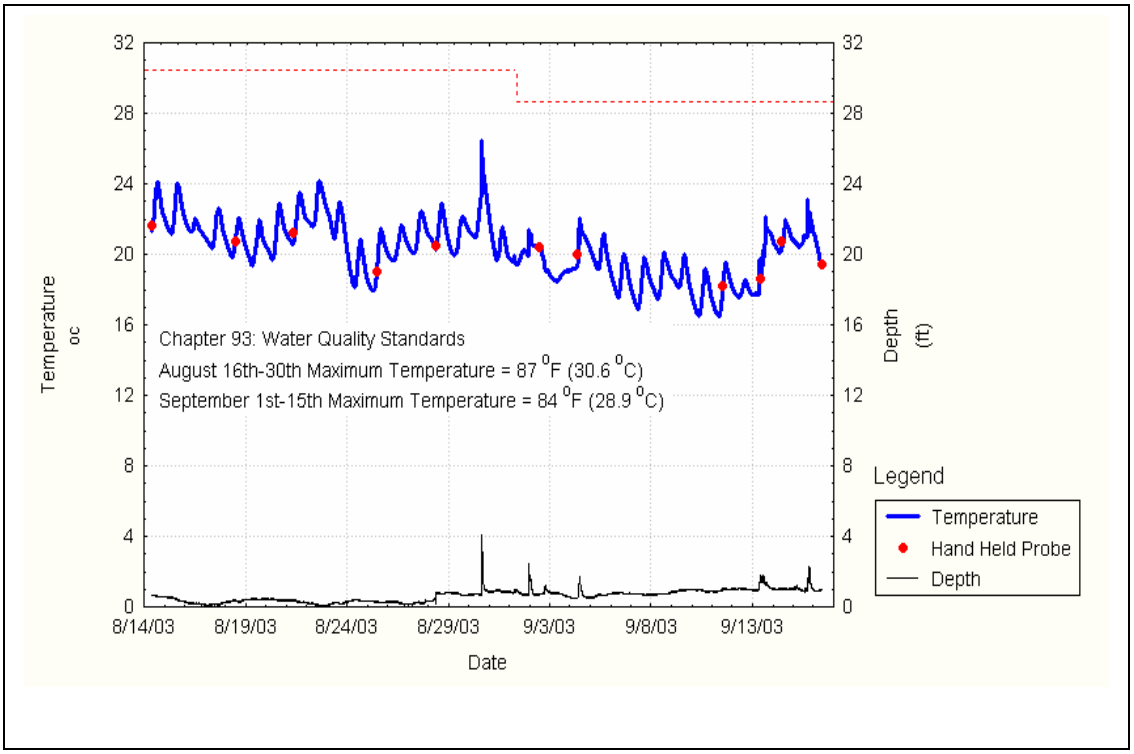


Figure 38. Continuous measurements of temperature at DCC 770.

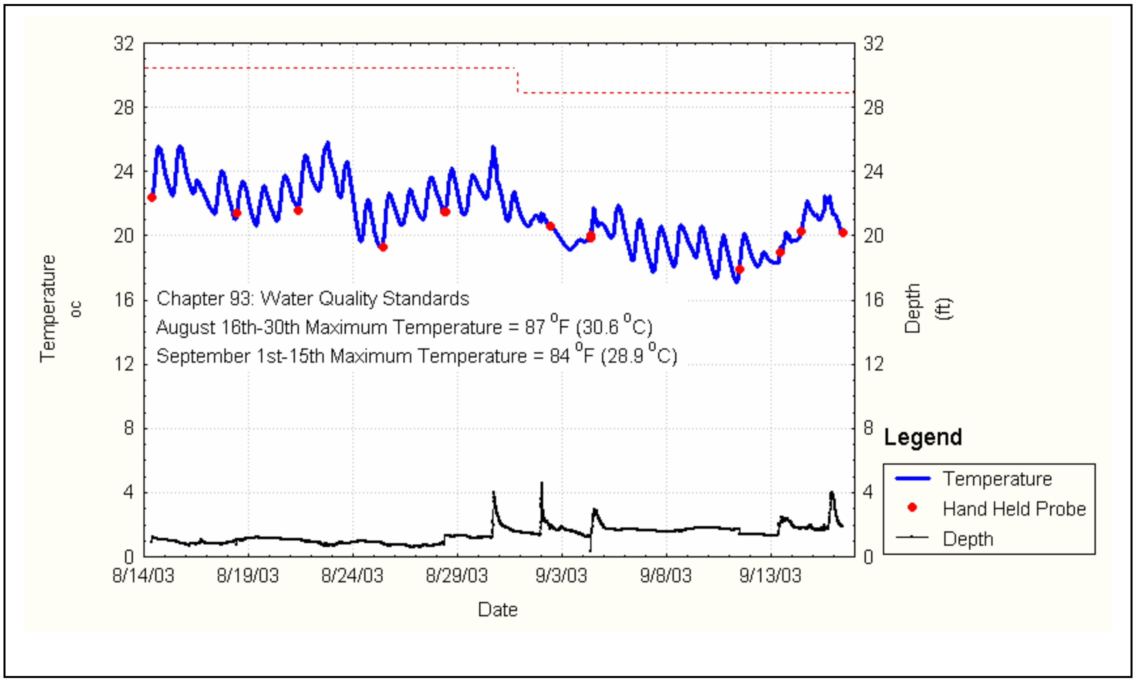


Figure 39. Continuous measurements of temperature at DCD 765.

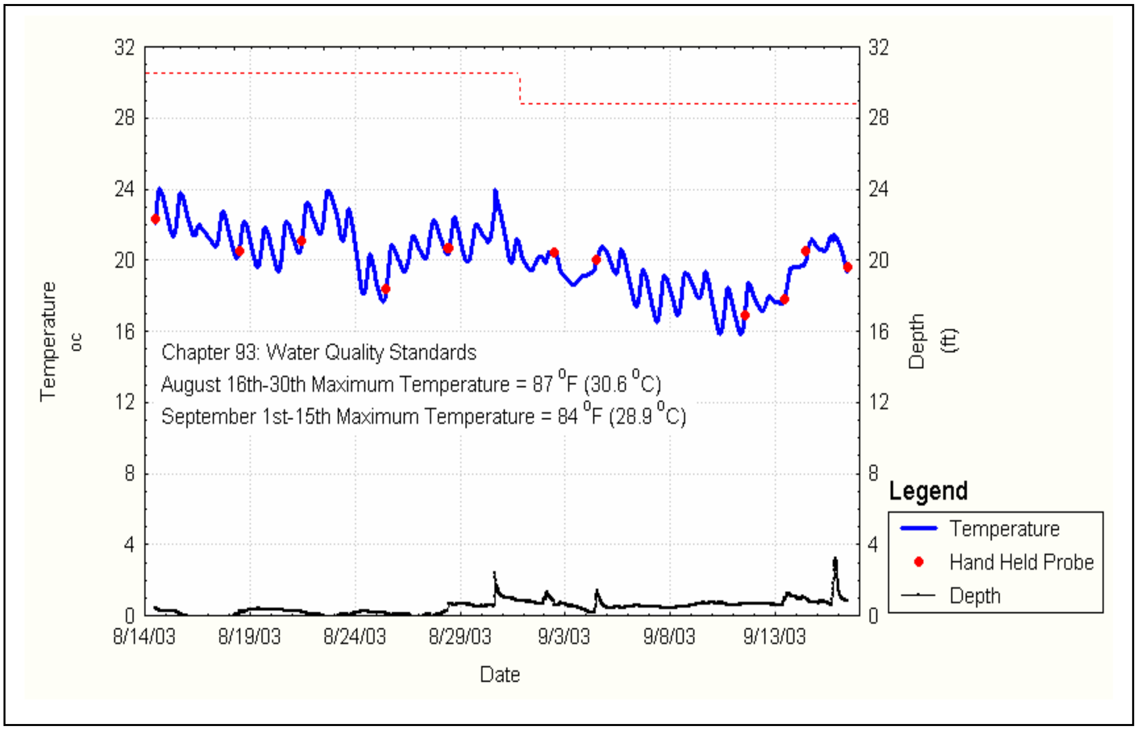


Figure 40. Continuous measurements of temperature at DCD 1660.

In addition to limiting effects of lethal and sublethal temperatures on fish survival, temperature regime has myriad implications for aquatic communities. These effects are discussed in greater detail in Section 5.3.5. (Habitat Suitability Indices).

5.4.8. Nutrients

Universally applicable minimum nutrient criteria for protecting water resources are difficult to establish. Furthermore, determining unimpaired, or “natural” nutrient conditions for streams in the Piedmont and Eastern Coastal Plain regions of Pennsylvania is made difficult by extensive land development and preponderance of agricultural land use. EPA has proposed nutrient criteria for protection of aquatic life in rivers and streams; though nutrient management strategies formulated to prevent (or reverse) eutrophication of one water body may not be appropriate for other water bodies. When a water body has been identified as nutrient impaired, thorough nutrient investigations may be conducted to determine Total Maximum Daily Loads (TMDLs) of pollutants that a water body can assimilate.

With the exception of ammonia, PADEP does not currently have aquatic life-based nutrient criteria, only a limit on oxidized inorganic nitrogen (i.e., nitrate and nitrite) that is intended to protect public water supplies. Elevated nutrient concentrations have been identified as the principal cause of nuisance algal blooms that may cause taste and odor problems in treated drinking water. A small number of algal taxa are known to produce toxins that represent a human, livestock, or wildlife health risk. While such effects are serious where and when they occur, increased biomass of naturally occurring attached periphyton algae communities is a far more widespread phenomenon that may negatively affect water quality. Data from minimally impaired sites in PADEP & EPA water quality databases have been included with Darby-Cobbs Watershed nutrient data for comparison where appropriate and/or applicable.

5.4.8.1. Nutrients: Nitrogen species

Surface water samples were analyzed for nitrate (NO_3), nitrite (NO_2) and ammonia nitrogen (NH_3-N) concentration. The Kjeldahl method of determining total organic N was also applied. All N species may be naturally present in aquatic systems; however, elevated levels of N are indicative of both point and non-point sources of pollution. Nitrate and ammonia (specifically ammonium ions, $NH4^+$) are the forms of N most useful to stream producers such as green plants, algae and cyanobacteria. Naturally occurring chemical reactions and metabolic activities of common bacteria (e.g., *Nitrosomonas*, *Nitrobacter*) are responsible for altering the ratio of inorganic N species in freshwater systems. In the presence of oxygen, ammonia is converted first to nitrite, then to nitrate (nitrification). Efficiency of the reactions in which ammonia N is converted to oxidized forms is dependent on environmental conditions (i.e., temperature, pH and dissolved oxygen concentration).

Though deep stagnant water is present in a few locations, particularly in pools behind dams and in "plunge pools", most of Darby-Cobbs Watershed consists of shallow, well mixed and (at a minimum, partially) oxygenated stream segments. Inputs of organic matter and inorganic N, particularly concentrated inputs from SSOs and CSOs, may tax dissolved oxygen levels and result in violations of water quality standards. These effects are most severe in summer, when the rate of N-oxidizing reactions is fastest, dissolved oxygen capacity of stream water is reduced, instream biomass is high, and baseflow may be at or near yearly minimum.

5.4.8.2. Nitrite

As an intermediate product in the oxidation of organic matter and ammonia to nitrate, nitrite is seldom found in unimpaired natural waters in great concentrations provided that oxygen and denitrifying bacteria are present. Nitrite was never detected in any 2003 samples from Darby Creek or Naylors Run regardless of weather conditions, but was detected in 21 of 100 wet weather samples and 3 of 69 dry weather samples from Cobbs Creek. Observed wet-weather nitrite concentrations are likely due to CSO/SSO discharge and runoff. On 6/12/03, nitrite was detected during dry weather at sites DCI010, DCC455 and DCC208. The inability to detect nitrite at site DCC770 and observed pattern of longitudinally diminishing concentrations (from upstream to downstream) suggested a point source, later determined to be a leaking sewer. PADEP has established a maximum limit of 10mg/l for total nitrate and nitrite N. Nitrite concentrations in Darby-Cobbs watershed never exceeded nitrate concentrations, and were never responsible for water samples exceeding this criterion.

5.4.8.3. Nitrate

Concentrations of nitrate are often greatest in watersheds impacted by (secondary) treated sewage and agricultural runoff, but elevated nitrate concentrations in surface waters may also be attributed to runoff from residential and industrial land uses, as well as atmospheric deposition and precipitation (e.g., HNO_3 in acid rain). Nitrate is a less toxic inorganic form of N than ammonia and serves as an essential nutrient for photosynthetic autotrophs. Availability of inorganic N can be a growth-limiting factor for producers, though usually only in oligotrophic (nutrient-poor) lakes and streams or acidic bogs.

According to US EPA's nutrient criteria database, samples collected from unimpaired surface waters in the eastern coastal plain region of Pennsylvania had mean nitrate concentration of 1.9mg/l (n = 786). The 75th percentile seasonal median nitrate + nitrite concentration in EPA ecoregion IV, sub region 64 watersheds was 2.9mg/l. Close examination of nitrate data collected from southeastern PA streams by PWD and PADEP showed at least some nutrient impaired streams could be assigned to one of two broadly defined categories- streams in which nitrate concentrations increase due to runoff, and streams in which nitrate concentrations are elevated during baseflow conditions and diluted by stormwater. The former stream type is characteristic of agricultural regions, while the latter is characteristic of streams affected by wastewater effluent.

PADEP has established a maximum limit of 10mg/l for total nitrate and nitrite N, but this limit is based on protection of drinking water and cannot reasonably be expected to prevent eutrophication of natural water bodies. No sites in Darby-Cobbs Watershed violated water quality criteria- the watershed is not affected by treated wastewater effluent, does not contain extensive areas of agricultural land use, and has not been listed as nutrient impaired by PADEP under section 303d of the Clean Water Act. However, all sites in Darby-Cobbs have mean nitrate concentration >1.5mg/l and would be considered "eutrophic" under the stream trophic classification system of Dobbs (1998).

During wet weather, nitrate concentrations were generally diluted; nitrate concentration was significantly higher (t-test, $p<0.05$) in dry weather at five of nine sites in Darby Cobbs Watershed (Figure 41). While nitrate concentrations were similar among Darby Creek sites, Cobbs Creek sites showed nitrate concentration decreasing in a downstream direction, suggesting uptake by producers, dilution as link magnitude increases, or denitrification by bacteria under anoxic conditions, where they exist. Indian Creek Watershed had the highest mean nitrate concentration of all sites. Land use in the Indian Creeks' basins includes golf courses as well as areas where resident Canada geese congregate; topography is steep upstream of the sampling site.

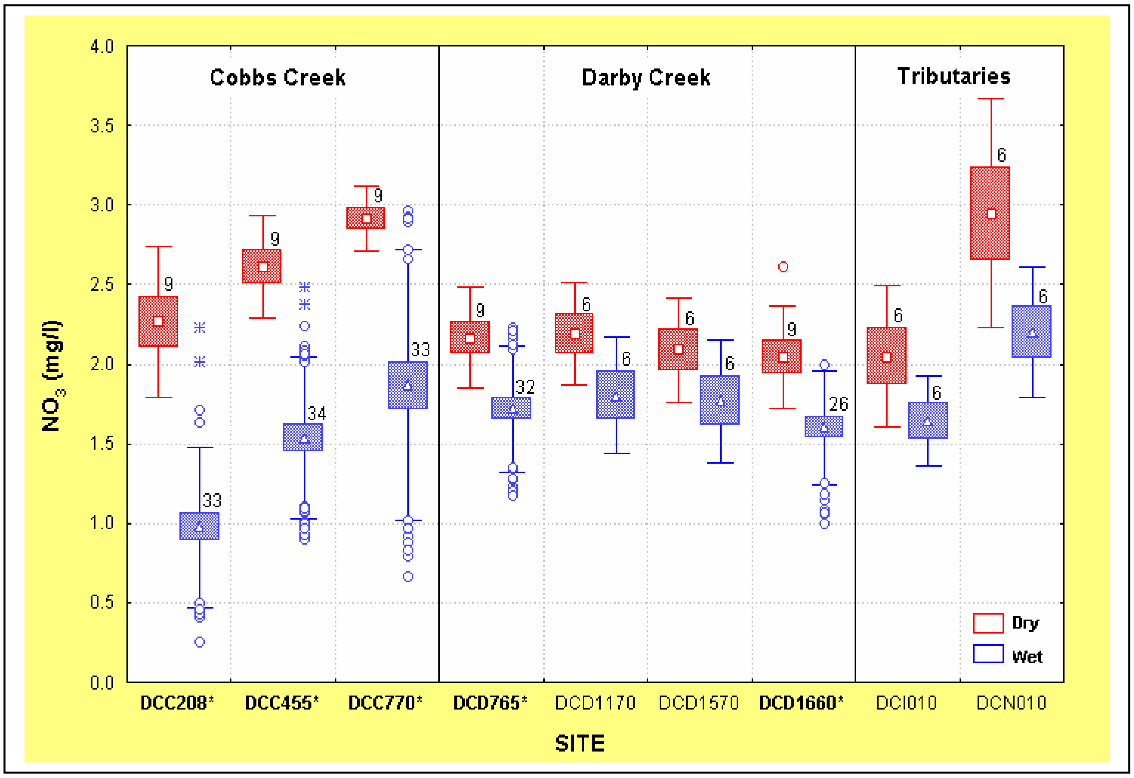


Figure 41. Dry and wet weather nitrate concentrations at the 9 monitoring sites

5.4.8.4. Ammonia

Ammonia, present in surface waters as un-ionized ammonia gas (NH_3), or as ammonium ion (NH_4^+), is produced by deamination of organic nitrogen-containing compounds, such as proteins, and also by hydrolysis of urea. Secondary treatment, as practiced in most modern sewage treatment facilities, removes dissolved organic compounds, effectively reducing ammonia concentrations in both the effluent and the receiving stream. In the presence of oxygen, ammonia is converted to nitrate by a pair of bacteria-mediated reactions, together known as the process of nitrification.

Overall, Darby Cobbs Watershed sites had relatively low ammonia concentration; 95 of 208 discrete grab samples (45%) taken in 2003 had ammonia concentration below detection limits. Mean ammonia concentration was highest at site DCI010, but this value was artificially high due to a sewage leak during dry weather on 6/12/03 (0.907mg/l). Wet weather impacts on ammonia concentration were most noticeable at Cobbs Creek sites DCC208 and DCC455 (Figure 42), which are likely affected by CSO discharge. Ammonia impacts from wet weather event 1 appeared more severe than from event 2.

PADEP has established maximum total ammonia nitrogen standards for the waters of the Commonwealth, but each sample must be compared individually to a standard that integrates sample temperature and pH to account for dissociation of ammonia in water. Higher temperatures and more alkaline pH allow more ammonia to be present in the toxic, unionized form. Total ammonia nitrogen concentration was above 1.0mg/l in only 1 of 208 samples, a wet weather sample from site DCC208. Despite pH values that occasionally exceeded 8.0, no violations of ammonia water quality standards were observed. However, continuous water quality monitoring instruments recorded pronounced fluctuations in pH at sites DCD765 and DCC110 due to algal blooms. It is likely that if ammonia nitrogen were present during periods of upper-range pH violations (i.e., measurements greater than 9.0), its toxicity would be high.

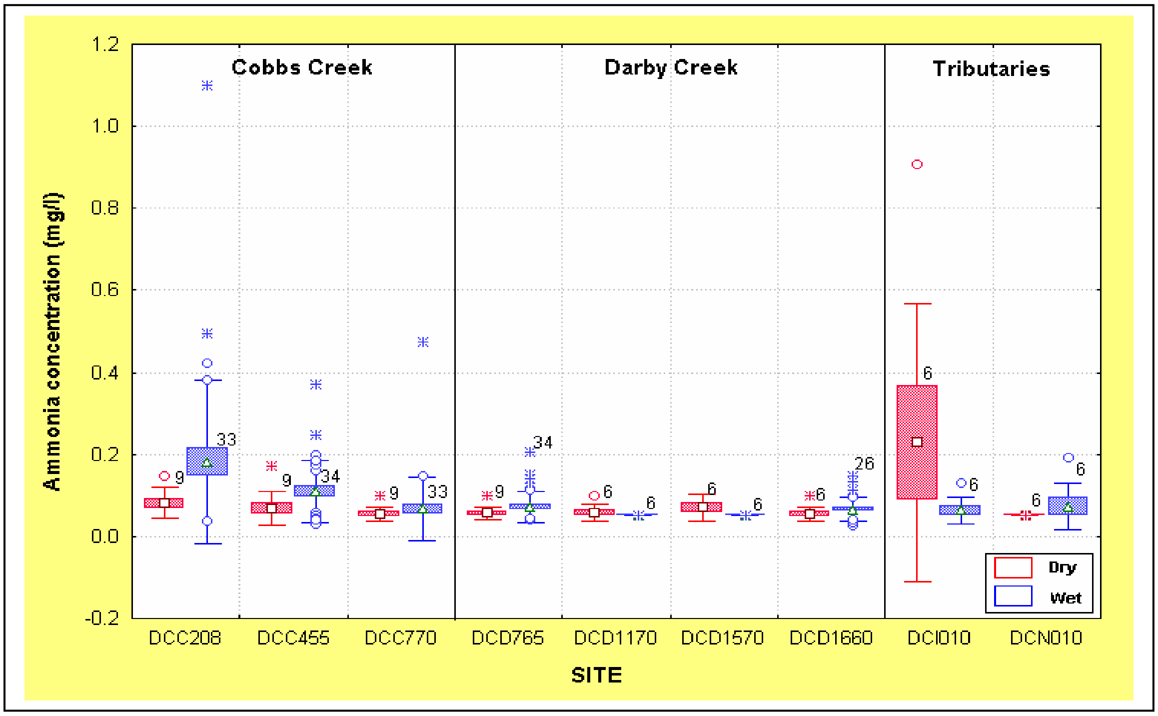


Figure 42. Dry and wet weather ammonia concentrations at the 9 monitoring sites.

5.4.8.5. Total Kjeldahl Nitrogen (TKN)

TKN provides an estimate of the concentration of organically-bound N, but the test actually measures all N present in the trinegative oxidation state. Ammonia must be subtracted from TKN values to give the organically bound fraction. TKN analysis also does not account for several other N compounds (e.g., azides, nitriles, hydrazone); these compounds are rarely present in significant concentrations in surface waters. Two outliers were excluded from the data analysis and graphics- these samples were collected from sites DCI010 and DCC455 during a sewer leak 6/12/03. TKN concentrations from these two sites were much greater than other dry weather samples and correspond with abnormally large concentrations of other parameters that serve as indicators of sewage contamination, (i.e., fecal coliform and *E.coli* bacteria, nitrate, ammonia, etc.) observed at these sites on this date.

Every site but DCC208 had TKN concentration less than the reporting limit of 0.3mg/l on at least one occasion. All sites experienced increases in TKN concentration during wet weather, but this phenomenon was more pronounced at Darby Creek sites. Increases during wet weather can probably be attributed to organic compounds in stormwater runoff, breakdown products of accumulated streamside (allochthonous) plant material, re-suspended organic sediment particles, and displaced (sloughed) algae. Much of the TKN present during larger flows in Darby-Cobbs Watershed may reach the Delaware estuary still in an organically-bound state.

5.4.8.6. Phosphorus

Phosphorus, like nitrogen, is a macronutrient (element required by plants in relatively large amounts); P concentrations are often correlated with algal density and are used as a primary indicator of cultural eutrophication of water bodies. Phosphorus readily adsorbs to soil particles and is generally less mobile in soils than nitrogen compounds. Potential non-point sources of P are decomposing organic matter in or near the stream, runoff from industrial parks, agriculture and residential areas, and inorganic P adsorbed to soil particles that are washed into the stream by erosive forces. In fact, soil erosion may be the greatest source of P in some portions of Darby-Cobbs watershed. Point sources of P include CSO and SSO discharges; though infrequent, they contribute large amounts of phosphorus where and when they occur.

Total P includes some smaller fraction of P that is considered to be bioavailable, or readily usable by stream producers. Bioavailable P (BAP) includes soluble reactive P (SRP) and, depending on other factors, some portion of particulate inorganic P. Furthermore, some producer taxa can obtain P through production of endogenous alkaline phosphatases. Nutrient dynamics and the effects of P limitation have been studied extensively in limnetic systems, but care should be taken when applying conclusions from phytoplankton dominated systems (i.e., lakes) to small streams. For example, in periphyton dominated streams, nutrients may be re-mineralized and recycled many times within the biofilm.

Stream producers in Darby-Cobbs Watershed are exposed to flow and a somewhat constant rate of nutrient delivery, albeit one that is punctuated with episodic inputs of greater P concentration due to runoff and erosion. These inputs, however, are coupled with physical disturbances (e.g., hydraulic shear stress, other abrasive forces, reduced light availability). These stressors respond to changes in flow in a non-linear fashion. Many taxa have the ability to store intercellular reserves of inorganic nutrients ("luxury consumption") when concentrations exceed immediate demands. It is thus very difficult to estimate the concentration of P available to stream producers and draw conclusions about stream trophic status from the (usually limited) data available.

Nevertheless, stream nutrient criteria have been proposed. For example, New Jersey's Department of Environmental Protection (NJDEP) has established a criterion of 0.10mg/l total P for streams and rivers and 0.05mg/l total P for lakes and their tributaries. USEPA has suggested the use of ecoregion-specific criteria based on the 75th percentile of total P concentration in unimpacted reference streams, or, in the case of insufficient reference stream data, the 25th percentile of TP for all streams in the ecoregion. For the ecoregion that includes Darby-Cobbs Watershed, this criterion is (0.14) mg/l. Dobbs (1998) suggested that the mesotrophic/eutrophic boundary for TP is 0.07mg/l.

Total P concentration was used in analysis of Darby-Cobbs Watershed because orthophosphate (PO_4) concentrations were nearly always below reporting limits. Two data points from 6/12/03 at sites DCI010 and DCC455 were excluded from the analysis, because TP concentrations at these sites (0.22 and 0.130 mg/l, respectively) were likely influenced by a sewer leak in the immediate area. This sample from DCI010 was also the only dry weather sample in which PO_4 was detected (0.149mg/l).

5.4.8.7. *Phosphorus Concentration: Dry Weather*

Darby Creek sites generally had less TP in dry weather than Cobbs Creek sites (Figure 43). Overall, 77% of Darby Creek dry weather samples had total P concentration below the reporting limit of 0.05mg/l, while only 21% of Cobbs Creek sites had dry weather TP concentration below reporting limits. Though only two samples were above reporting limits, greatest mean total P concentration in dry weather (0.106 mg/l) was observed at site DCI010, which is located downstream of golf courses and areas where resident Canada geese congregate. Excluding samples below reporting limits, the watershed overall had mean dry weather TP concentration of 0.073mg/l, which is below NJDEP's criterion, approximately half the proposed EPA criterion, and slightly greater than the mesotrophic-eutrophic boundary concentration proposed by Dobbs (1998).

5.4.8.8. *Phosphorus Concentration: Wet Weather*

Total P concentrations were significantly higher in wet weather than in dry weather at sites DCC208, DCC455, DCC770, and DCD767 (student's t-tests, $p<0.05$) (Figure 43). Total P concentrations were also higher at all other sites, but statistical power was limited

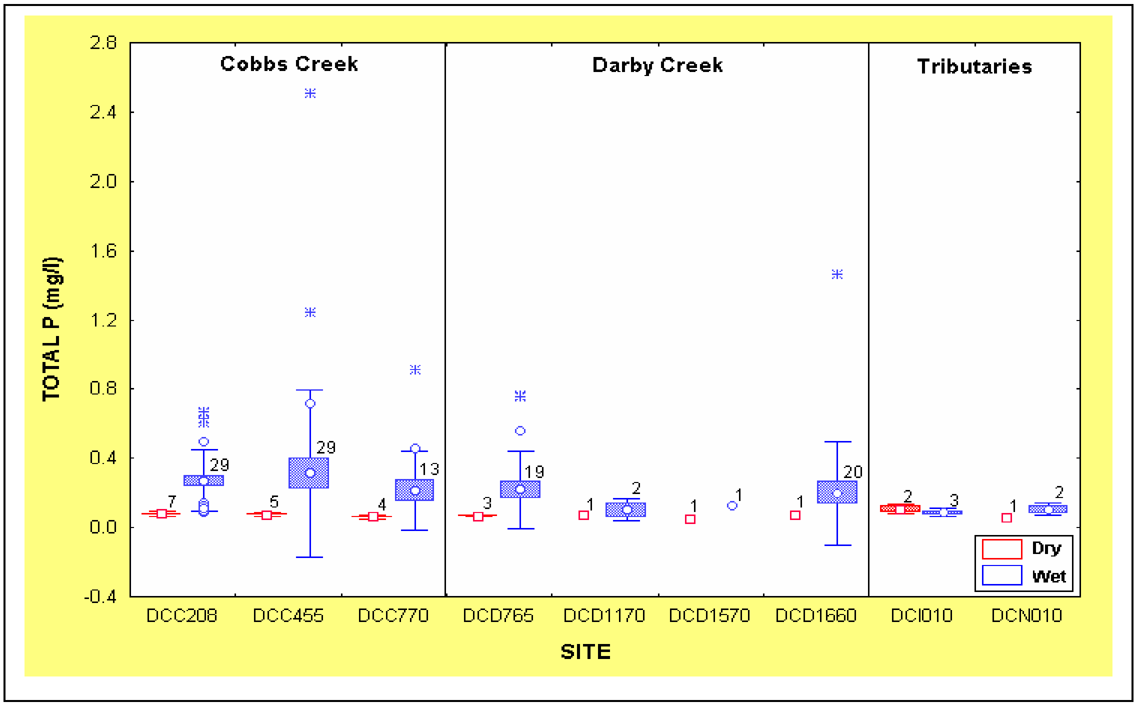


Figure 43. Dry and wet weather total phosphorus concentrations at the 9 monitoring sites.

with too few samples exceeding reporting limits. Despite greater total P concentrations in wet weather, PO_4 concentrations never exceeded reporting limits in wet weather, indicating that the majority of P within the watershed is adsorbed to sediment particles or organically-bound and is not immediately usable by stream producers. The degree to which wet weather P becomes bioavailable to stream producers depends on a variety of factors. Organically-bound macronutrients probably become transported out of the system (loading to the Delaware Estuary) during larger flows; P appears to be no exception.

5.4.8.9. Dry Weather N:P Ratios

Estimates of dry weather total N:P nutrient ratios were hindered by the number of samples with nitrite, total phosphorus, ammonia and/or TKN values below reporting limits. Only 3 of 69 samples could have nutrient ratios estimated directly. To generate a greater number of N:P ratio estimates, a value equal to half the reporting limit was substituted for all parameters with sample concentration less than the reporting limit (Figure 44). However, because of the lower reporting limit for total P, these values probably greatly overestimated N:P ratio. A more unorthodox comparison of NO_3 vs. actual TP observations was also used in an attempt to better estimate the relative proportions of these two nutrients (Figure 44). In any case, all sites within the watershed appear strongly P-limited.

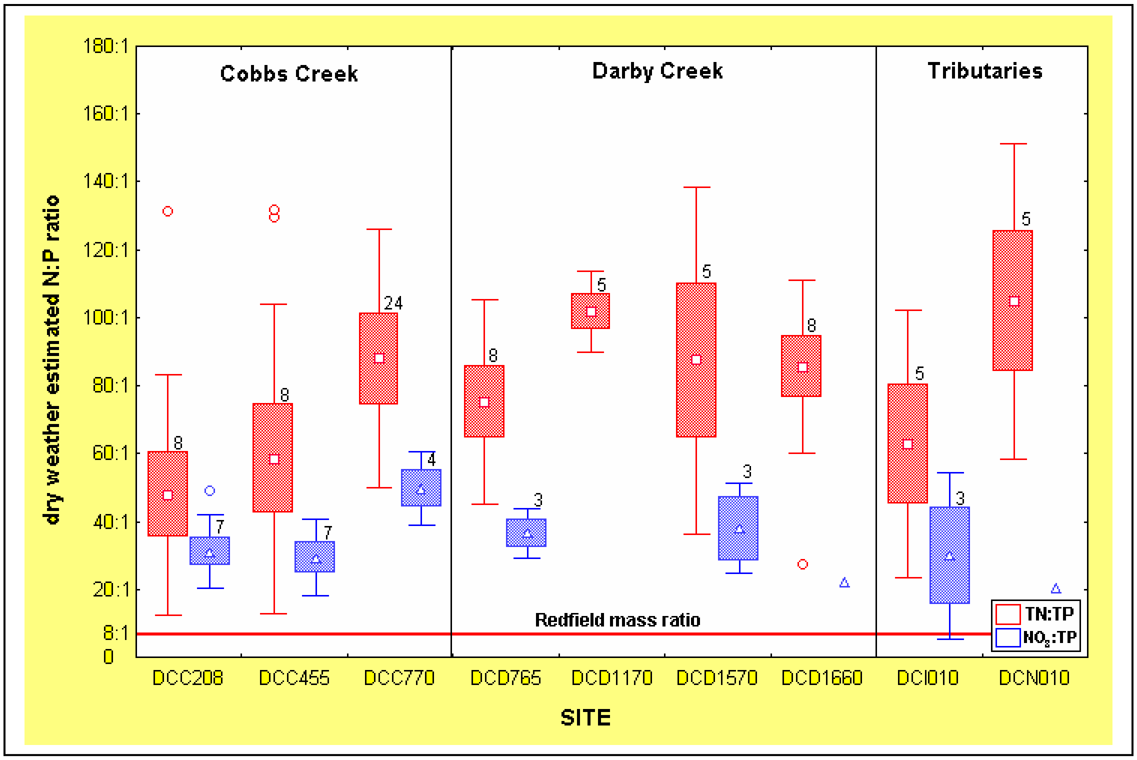


Figure 44. Estimated dry weather N:P ratios at the 9 monitoring sites.

5.4.8.10. Stream Nutrient Concentrations: Flow Implications

Stream nutrient concentrations in Darby-Cobbs Watershed are dynamic, often increasing in wet weather due to CSO discharge, runoff, and erosion. But concomitant increases in physical stressors probably impose limits on the degree to which stream producers can take advantage of these increased concentrations. Particle size selection, traditionally related to flow by entrainment velocity curves, may determine the effective P loading for a given sediment load. Smaller particles, due to their greater relative surface area, can adsorb relatively more P than larger particles. Smaller particles are also generally more readily eroded and entrained in stormwater flow than larger particles.

Smaller storm events in Darby-Cobbs Watershed probably contribute more to eutrophication than larger events. For example, if smaller sediment particles adsorb more P than larger particles as has been suggested, P loading becomes less efficient as larger particles are entrained in runoff. As shear stresses increase, streambank materials comprise a greater proportion of the sediment load. These particles are likely more similar to the soil parent material (i.e., lower in P concentration than more superficial soils layers that tend to incorporate more organic material). As flows increase, a greater proportion of the total load is transported out of the system, a greater proportion of the total nutrient load is inaccessible to producers, and much of the photosynthetic biomass (filamentous green algae and their associated epiphytes in particular) may be sloughed away and transported out of the system.

In areas served by combined sewers, the relative impact of small, intense storms is magnified. CSO discharge is minimally diluted by stormwater in the initial overflow phase, or "first flush". If nutrients present in these overflows can become deposited along with sediment or rapidly taken up by stream producers, discharges of short duration, particularly in which shear stresses do not result in major sloughing of algal communities, may have far-reaching consequences for stream nutrient dynamics and aquatic biota. A greater benefit may result from reducing frequency, number, and volume of small CSO discharges rather than attempting to capture releases from larger events.

SECTION 6: INDICATOR STATUS UPDATE

6.1. Overview

An important component of the Comprehensive Characterization Report is to provide concise updates on the biological, chemical and physical conditions within the Darby-Cobbs Watershed. Indicator status updates derived from this report will be used as a tool for identifying spatial and temporal trends of a particular stream reach or for the entire watershed. Moreover, indicators defined in the Cobbs Creek Integrated Watershed Management Plan will serve as benchmarks for future restoration projects. The indicators addressed in this report are as follows:

- Indicator 3: Stream Channels and Aquatic Habitat
- Indicator 5: Fish
- Indicator 6: Benthos
- Indicator 7: Effects on Public Health (Bacteria)
- Indicator 8: Effects on Public Health (Metals and Fish Consumption)
- Indicator 9: Effects on Aquatic Life (Dissolved Oxygen)

6.2. Indicator 3: Stream Channels and Aquatic Habitat

Indicator 3 of the Cobb Creek Integrated Watershed Management Plan stresses the importance of physical habitat features that will support healthy fish and benthic communities. As described in Section 5.3.1. EPA Habitat Assessment, thirteen habitat variables, ranging from instream parameters to riparian health, were compared against reference conditions to obtain an overall habitat integrity score.

In 2003, habitat at 17 sites throughout the Darby-Cobbs Watershed was surveyed by PWD staff biologists. Monitoring locations along Darby Creek mainstem received consistent scores, ranging from the highest value, “Comparable to Reference Conditions”, to the next incremental level, “Supporting” (Figure 45). Similarly, two tributary sites, Little Darby Creek and Ithan Creek, received ratings of “Comparable to Reference Conditions”.

In contrast to Darby Creek, habitat values along Cobbs Creek and its tributaries were less desirable. Of the four main stem locations, two sites received “Supporting” while the remaining two locations were designated as “Partially Supporting” (i.e., marginal). Naylor’s Run, a 2nd order tributary to lower Cobbs Creek, received rankings of “Supporting” in the upper portion and “Non-Supporting” near the confluence with Cobbs Creek. Similarly, sites on the east and west branches of Indian Creek were determined to be only “Partially Supporting” of aquatic communities.

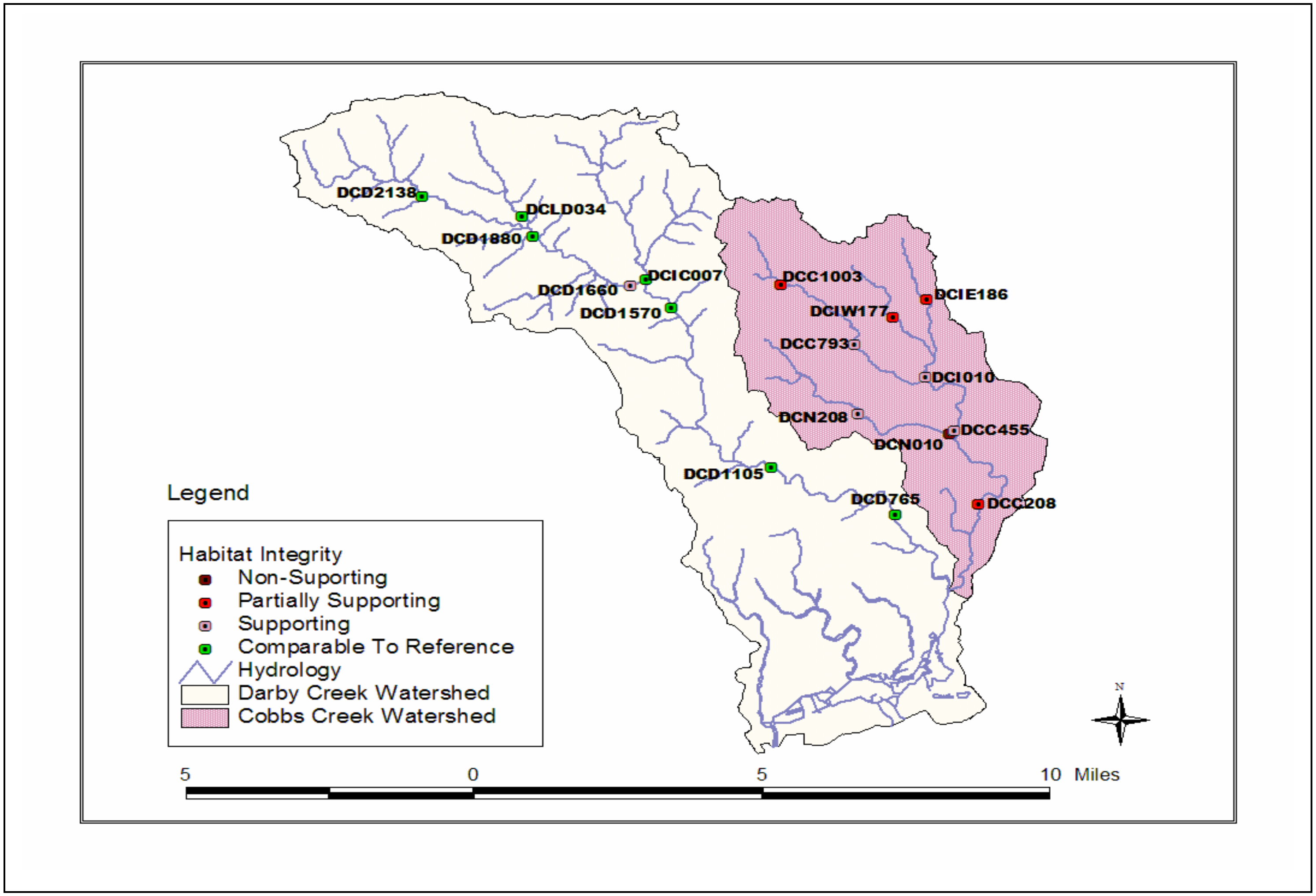


Figure 45. Stream channels and aquatic habitat indicator status update.

6.3. Indicator 5: Fish

During 1999, three surrogate indicators were used to define the integrity of fish communities in the Cobbs Creek Basin. Relative abundance (i.e., density), pollution tolerance and number of native species provided a semi-quantitative measurement of fish assemblage health. With the development of ecoregion-specific metrics, PWD has substituted the past indicators with the Index of Biological Integrity (IBI), a multi-metric approach that characterizes fish community health at a particular stream reach or at the watershed scale (Section 4.2.4. Fish IBI Metrics).

Fisheries data collected in 2003 revealed IBI scores varying among watersheds and spatially along the river continuum. More specifically, downstream sites on Darby Creek received scores of "good", while upstream locations were designated as "fair" or "poor" (Figure 46). Greater diversity, the presence of pollution-intolerant fish species and variation in trophic levels were among the major reasons for higher IBI scores in downstream portions of Darby Creek. Conversely, sites in Cobbs Creek received IBI scores in the "fair" to "poor" categories. Although fish density was generally greater in Cobbs Creek, community structure consisted of pollution-tolerant taxa with generalist feeding strategies.

After a thorough review of historical and recent data compiled on Cobbs Creek (i.e., 1999 and 2003), it is evident that active restoration strategies must be implemented and monitored over time to measure the efficacy of planned habitat restoration projects, as defined in the Darby-Cobbs Integrated Watershed Management Plan.

6.4. Indicator 6: Benthos

Benthic macroinvertebrate monitoring occurred at 17 sites in Darby-Cobbs Watershed during 2003. Similar to the 1999 sampling effort, Rapid Bioassessment Protocol III (RBP III) was chosen as the approved method for assessing the condition of the macroinvertebrate community in Darby-Cobbs Watershed.

The assessment conducted in 2003 reconfirmed findings of the Pennsylvania Department of Environmental Protection (PADEP) and Philadelphia Water Department (PWD). Benthic impairment in Cobbs Creek was omnipresent; stream designations ranged from "moderately impaired" to "severely impaired" (Figure 47). Darby Creek monitoring sites received the same designations, with the exception of one upstream site which scored as "slightly impaired".

The severity of impairment throughout Darby-Cobbs Watershed suggests that attaining healthy benthic communities in mainstem localities and associated tributaries is not a feasible option at this time. Habitat restoration, flow attenuation and active re-introduction (i.e., "invertebrate seeding") may be the only solutions to ensure a viable benthic community within this watershed.

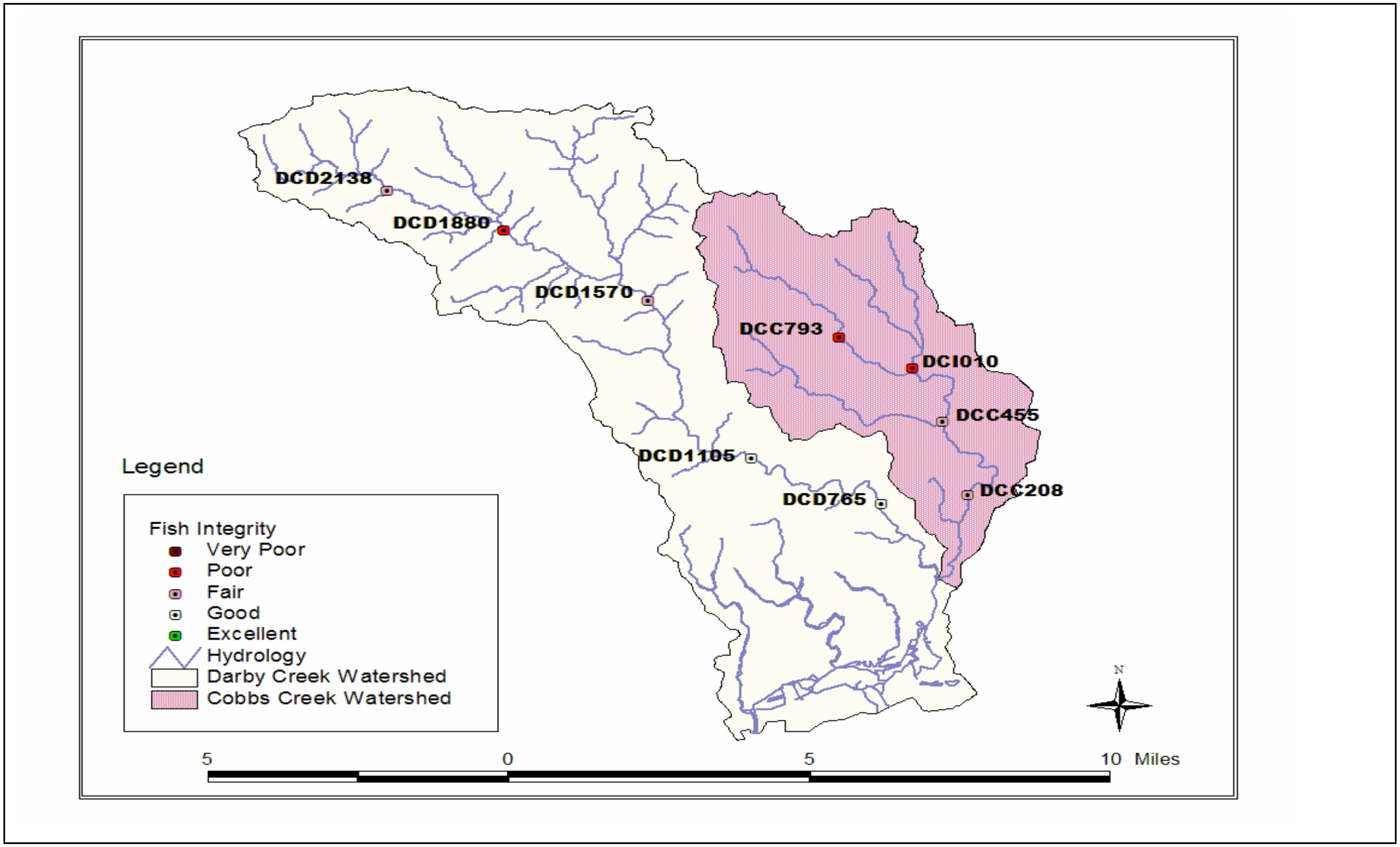


Figure 46. Fish indicator status update.

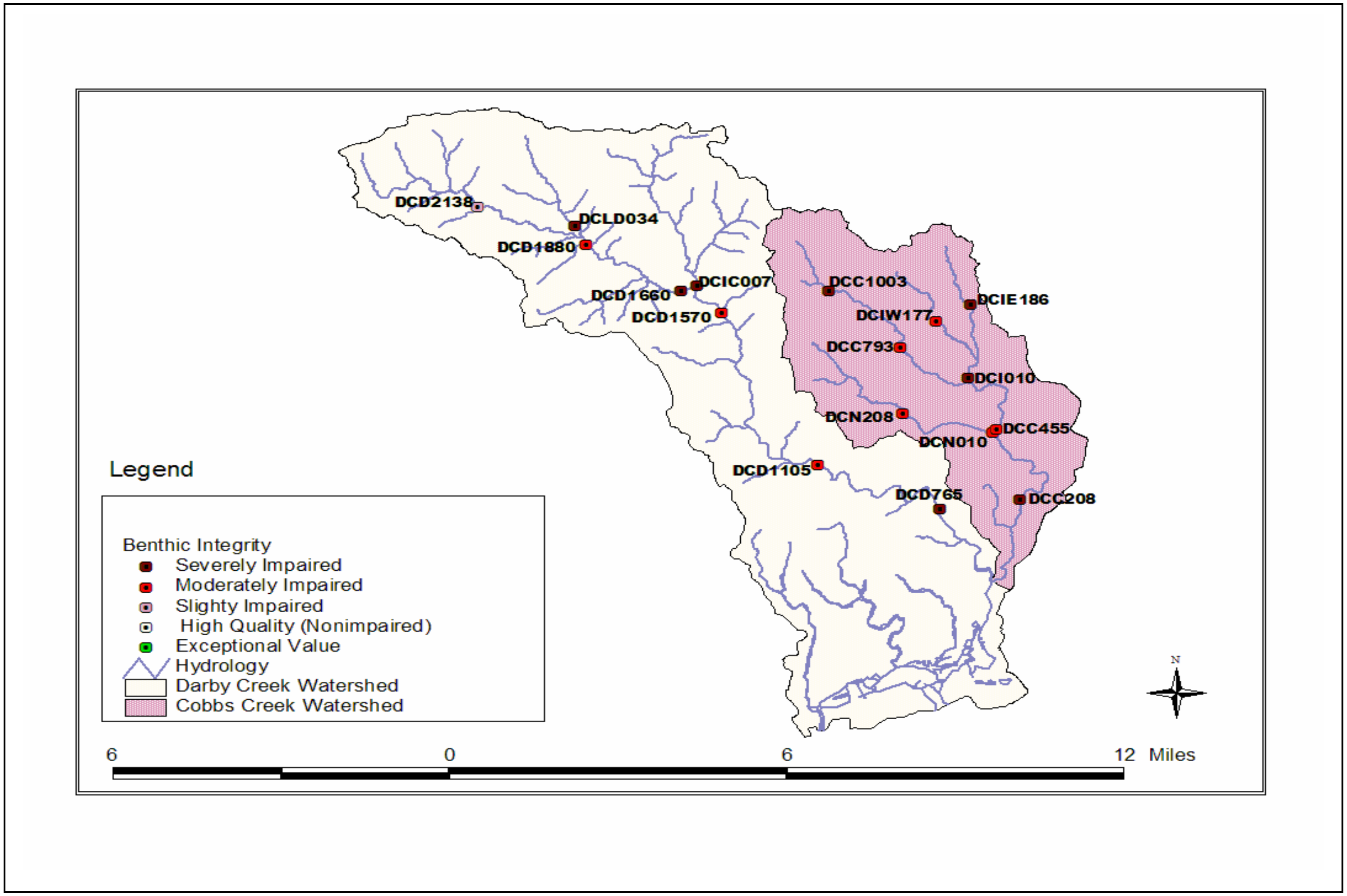


Figure 47. Benthic indicator status update.

6.5. Indicator 7: Public Health Effects (Bacteria)

Based on Pennsylvania's water quality criteria, the maximum fecal coliform concentration during the swimming season (i.e., May 1 through September 30) shall not exceed a geometric mean of 200 CFU per 100 ml for five nonconsecutive samples. During the remainder of the year, the maximum fecal coliform level should be equal to or less than a geometric mean of 2000 CFU per 100 ml based on five consecutive samples collected on different days.

During 2003, discrete chemical samples were taken at nine sites in Darby-Cobbs Watershed. Sampling events occurred at each site at weekly intervals for one month during three separate seasons (n= 12 sampling events per site). In addition, wet weather samples were collected during two runoff-producing storm events. Geometric means of fecal coliform concentrations were calculated during wet and dry periods for each site and compared to the appropriate standard.

Similar to 1999 and 2000 water quality sampling, mean concentration of fecal coliform during dry weather exceeded standards at all sites in Darby-Cobbs Watershed. In general, 33.3 % of all sites along Darby Creek mainstem met water quality standards during dry weather in 2003 (Figure 48). Geometric means calculated for Darby Creek sites revealed that values were generally between 2 to 4 times the season standards (i.e., 200 CFU/100 ml or 2000 CFU/100 ml) (Figure 49). In Cobbs Creek, sites DCI 010 and DCC 208 met water quality standards in 50.0 % and 33.3 % of the samples, respectively. Upstream and midstream sites (DCC 770 and DCC 455) had less desirable results, with standards being met only 22% of the time. No samples taken on Naylor's Run (DCN 010) met water quality standards during the swimming and non-swimming seasons.

Wet weather sampling results showed concentrations of fecal coliform exceeding water quality standards at all sites in Darby-Cobbs Watershed (Figure 50). Thirty-three percent of samples at Darby Creek sites met standards while only 16.7% of samples in Cobbs Creek were below water quality standards. Moreover, fecal coliform concentrations were between 2 to 10 times greater than standard values in Darby Creek (i.e., 400-2000 CFU/100 ml during the swimming season). Similarly, mean concentrations of fecal coliform were greater than the water quality standard but varied spatially along the river continuum (Figure 51). For example, concentrations at the upstream location (DCC 770) were between 2 to 10 times the standard limit and increased steadily until values reached between 50 to 200 times (i.e., 10,000-40,000 CFU/100 ml) the water quality standards at Site DCC 208. Similarly, concentrations of fecal coliform at tributary locations (i.e., DCN 010 and DCI 010 ranged between 2,000 to 10,000 CFU/100 ml during wet conditions.

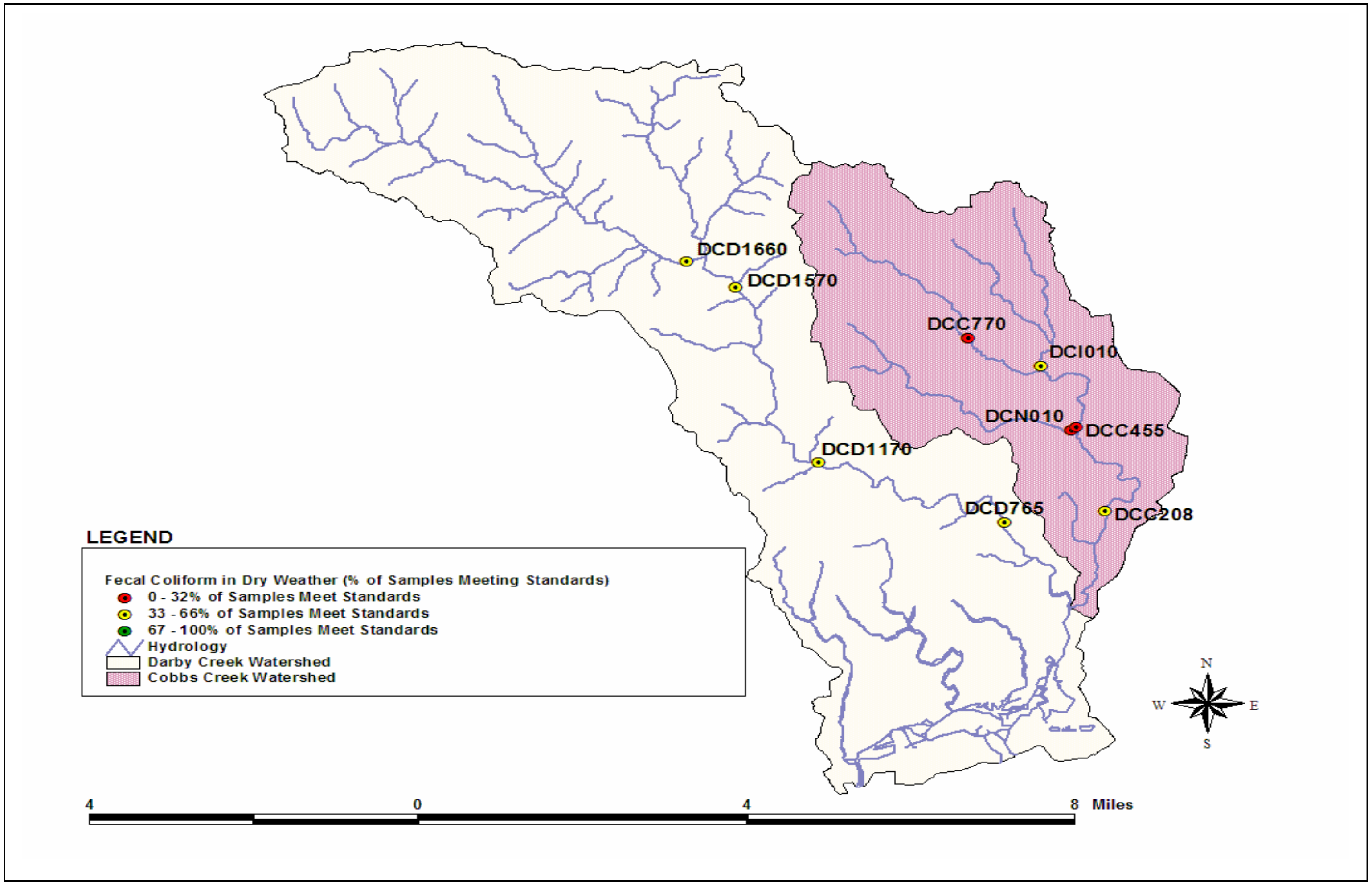


Figure 48. Dry weather fecal coliform indicator status update.

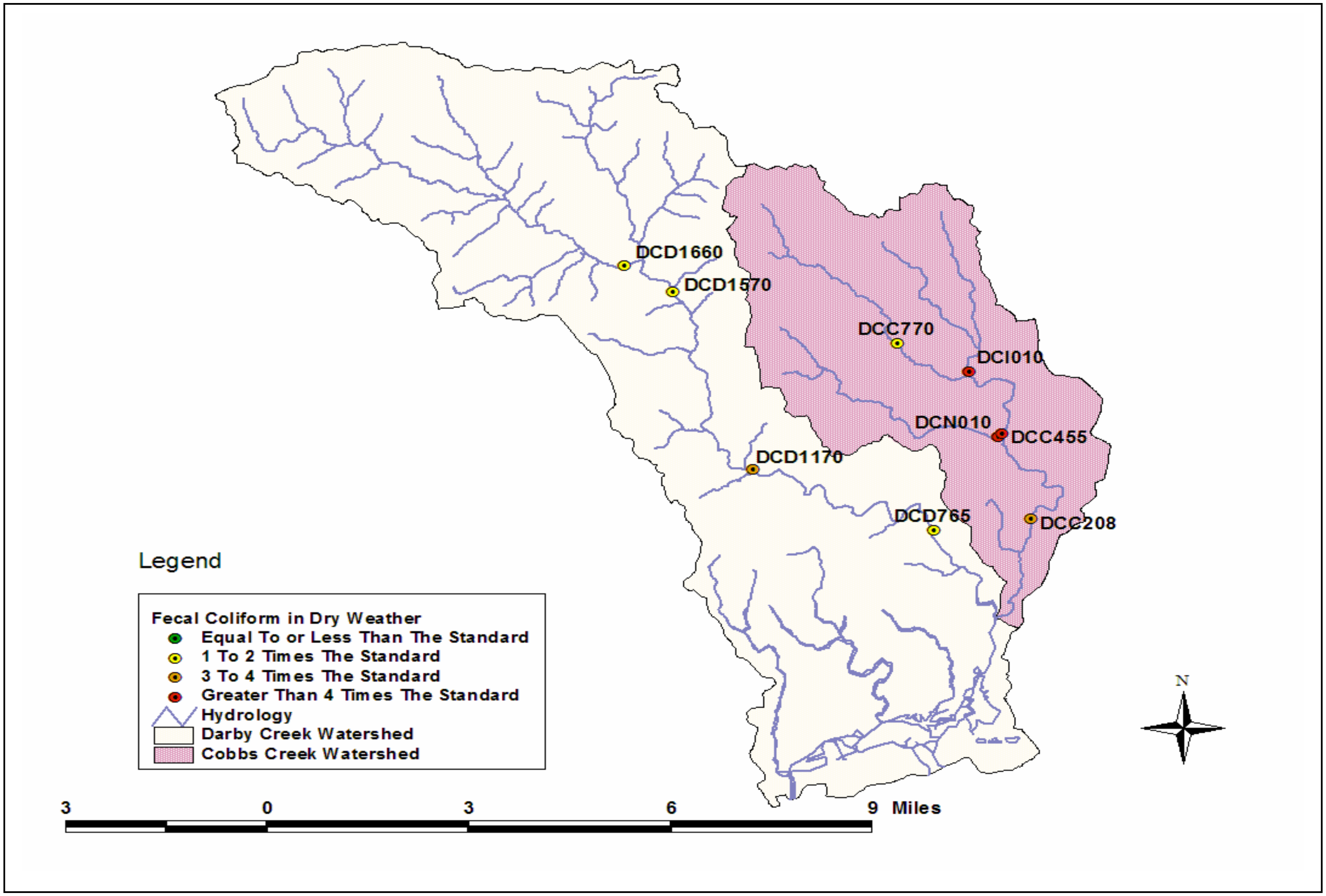


Figure 49. Geometric means of fecal coliform concentrations in dry weather

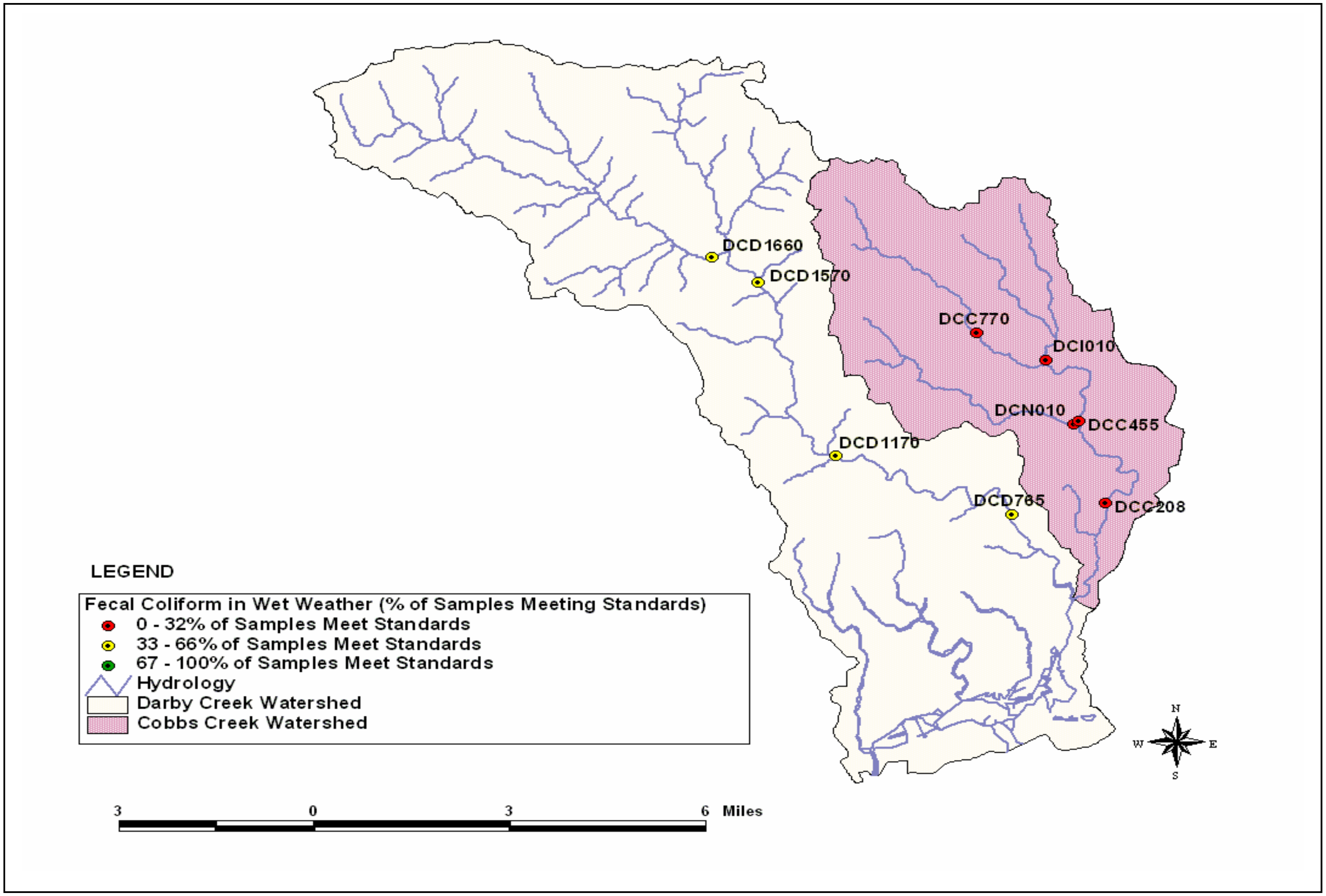


Figure 50. Wet weather fecal coliform indicator status update.

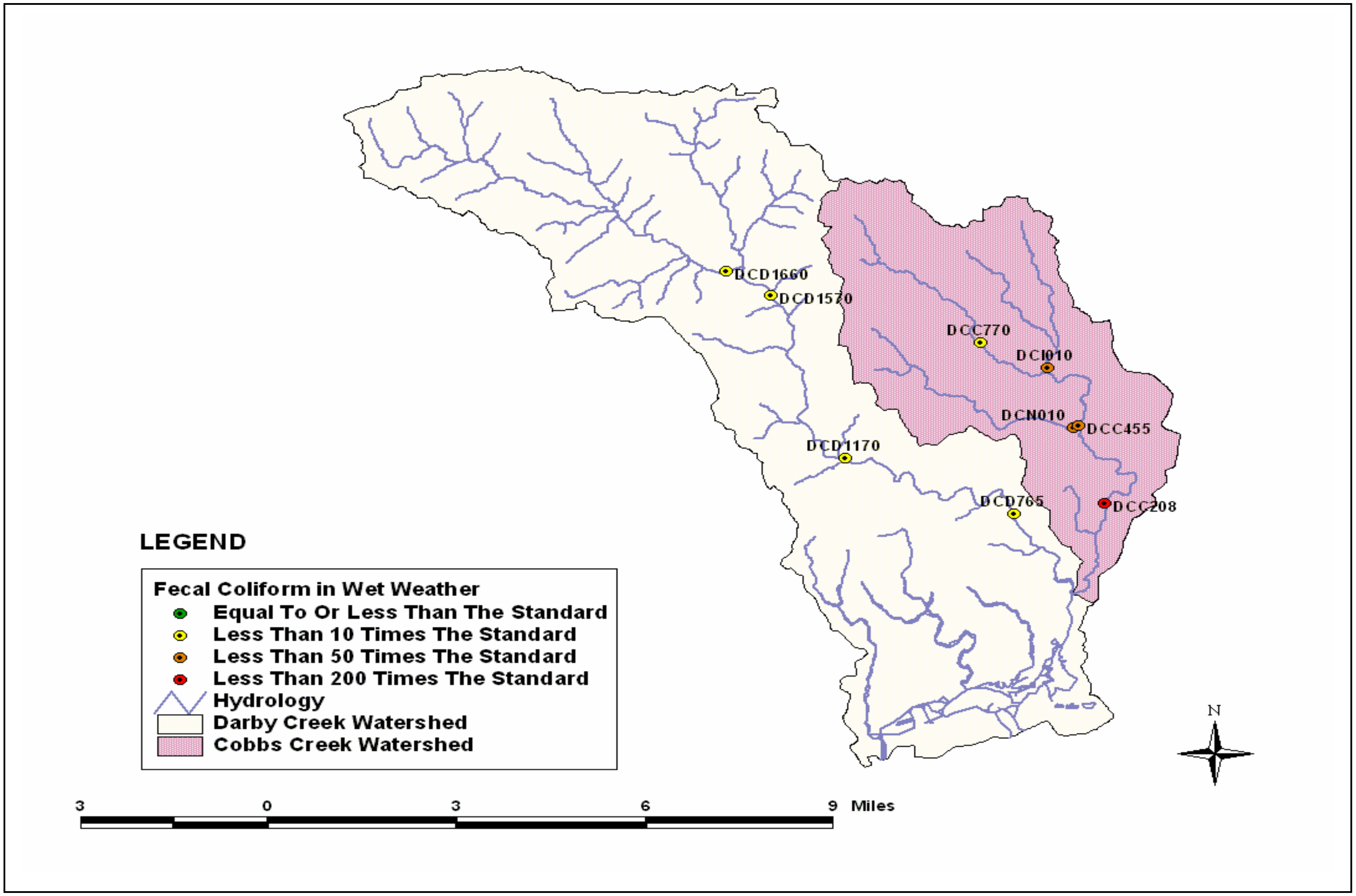


Figure 51. Geometric means of fecal coliform concentrations in wet weather.

6.6. Indicator 8: Public Health Effects (Metals and Fish Consumption)

Relatively small amounts of certain toxic compounds can kill aquatic life through acute poisoning, while chronic levels may be harmful to developmental stages of fish and macroinvertebrates. For example, bioaccumulation of toxins in fish may have a profound effect on fecundity and may also pose a threat to humans who regularly consume fish.

The established indicator measures the percent of cadmium, chromium, copper and zinc samples meeting state standards at various sites in Darby-Cobbs Watershed. In 2003, PWD scientists collected 48 samples at each site for Cd, Cr, Cu and Zn during dry and wet weather. An additional 48 to 56 samples were collected at each site during two wet-weather targeted events.

Results suggest standards intended to protect aquatic life were met at all locations during dry-weather in 2003 with the exception of copper in the upper reach of Darby Creek (Figure 52). Conversely, wet-weather exceedances were omnipresent on both the Darby Creek and Cobbs Creek (Figure 53). Of the metals, aluminum and copper generally exceeded standards more than 10 % of the time, while chromium and lead samples were greater than Pennsylvania's water quality criteria between 2% - 10% of the time.

6.7. Indicator 9: Aquatic Life Effects (Dissolved Oxygen)

During 2003, automated water quality monitors (i.e., Sondes) were deployed in Darby-Cobbs Watershed at three locations in Cobbs Creek and two locations in Darby Creek. Sondes were deployed for approximately one month, recording dissolved oxygen concentrations (mg/L) every 15 minutes. In total, approximately 792 hours of data were recorded at each site between 8/14/03-9/16/03.

Continuous data in from two Darby Creek sites indicated that DO concentrations did not fall below the instantaneous concentration standards (i.e., 5 mg/l in the upstream location and 4 mg/l in lower Darby Creek) (Figure 54). Similar results were observed in the upper reaches of Cobbs Creek (DCC 770). At site DCC 455, dissolved oxygen concentrations fell below the 4 mg/l limit less than one percent of the total recorded data. At site DCC 455, however, dissolved oxygen levels violated water quality criteria approximately 2.9 % of the time.

A probable explanation for this occurrence is the high level of algal activity as a result of stagnant flow, nutrient inputs and lack of forest canopy in this vicinity. As indicated in the Darby-Cobbs Integrated Watershed Management Plan, plans to increase stream velocity, such as dam removal and physical restoration, and increased vegetative protection will potentially eliminate the large diurnal DO swings associated with an overabundance of primary producers in downstream of Cobbs Creek sites.

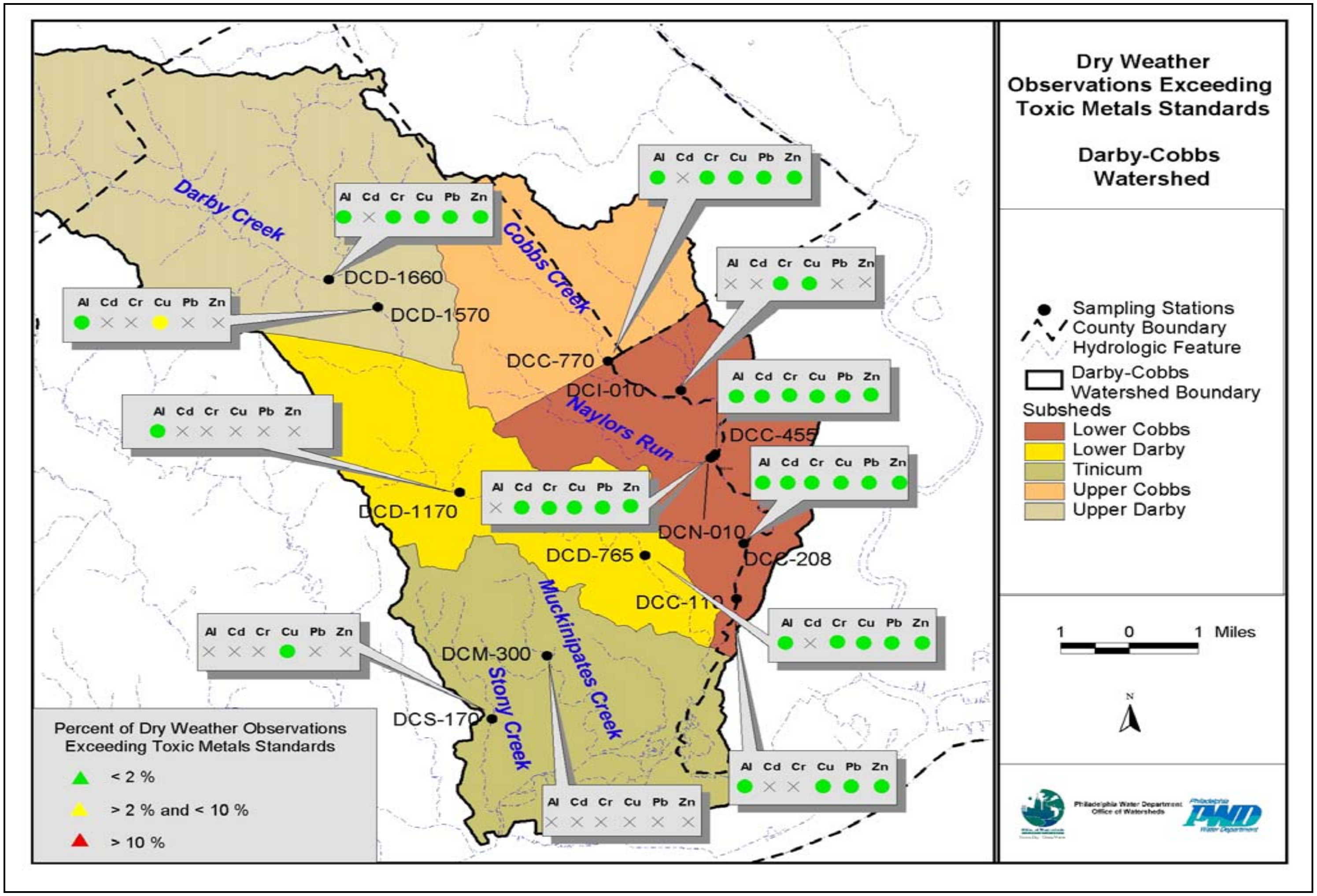


Figure 52. Dry weather metals indicator status update.

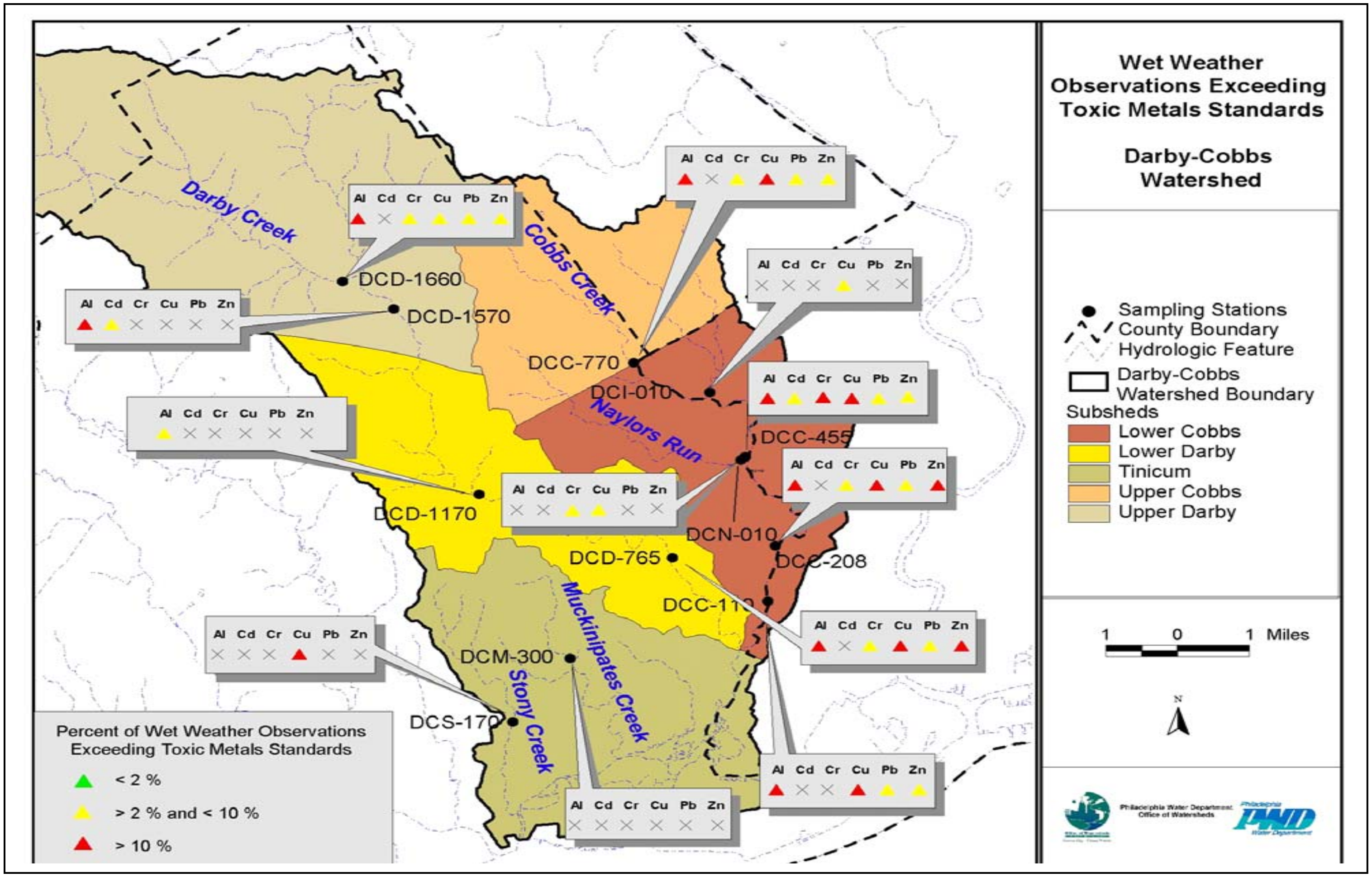


Figure 53. Wet weather metals indicator status update.

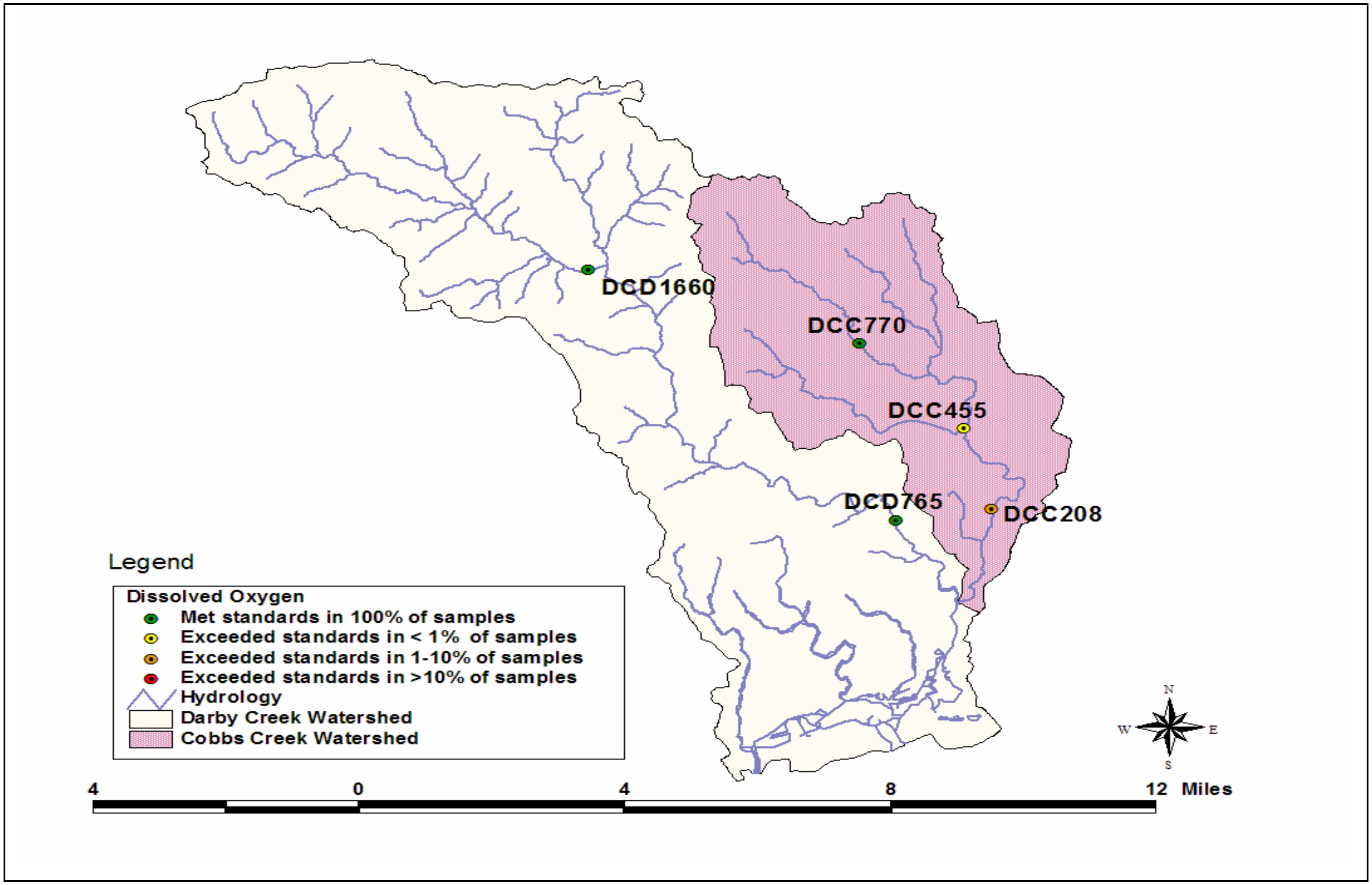


Figure 54. Dissolved oxygen indicator status update.

SECTION 7: EXECUTIVE SUMMARY

Problems faced by the Darby-Cobbs Watershed stem from many sources, but succinctly, the watershed suffers from excess land development and urbanization. These effects are evident in the physical habitat, and reflected by biological communities and water quality samples collected from the watershed. Though numerous impairments exist, habitat modification and physical disturbances stand out as the most important factors, underlying all other biological impairments. Healthy ecosystems cannot exist without healthy habitats.

With impervious cover contributing in excess of 30% of the land area in many subsheds, stormwater flows have de-stabilized much of the stream channels of the watershed. Many first order tributaries have been lost. Urbanization promotes a cumulative, self-reinforcing pattern of streambank erosion. As stream channels become physically larger and further disconnected from their historic floodplains, more stormwater forces are restricted to the stream channel, where compromised, heavily eroded banks are least suited to dissipate them.

Widespread urbanization, as present in the Cobbs Creek Watershed, magnifies flow modification by decreasing infiltration and groundwater recharge- establishing a hydrologic pattern of "feast or famine". Presently, baseflow accounts for only 42% of total mean annual flow in the Cobbs basin. Effects of urbanization and physical habitat degradation were evident in biomonitoring data, but these effects were more severe in Cobbs Creek Watershed. The Cobbs Creek Integrated Watershed Management Plan (CCIWMP) outlines several options for detaining, infiltrating, and treating stormwater to reduce its impact on the stream channel and aquatic habitats. The watershed cannot be restored without addressing these stormwater impacts.

Sunlight provides most energy to the Darby-Cobbs Watershed. Attached algae and aquatic mosses are the primary producers, and constitute the base of the aquatic ecosystem. Algae were not generally observed to grow to nuisance levels, with the possible exception of slow water areas behind dams and other obstructions. Continuous water quality monitoring and field observations at some sites suggest that periphytic algae are responsible for pronounced diurnal fluctuations in dissolved oxygen (DO) concentration and pH that may stress natural fish and invertebrate communities. Algal community structure and biomass also change drastically at some sites due to scouring storm events.

It is expected that activities recommended under Target B of the CCIWMP (i.e., streambank restoration, dam removal and modification, and re-engineering of slow water areas and scour pools) will greatly reduce the amount of stream area subject to severe DO and pH fluctuations. Identification and correction of dry weather sewage inputs, as required by existing regulations, should also help reduce nutrient inputs that drive algal production. Riparian shading reduces both algal biomass potential and the magnitude of DO fluctuations, but riparian zone management must balance stream shading needs with allowing enough light penetration to support a multi-tiered native plant community. If stream habitat is restored and dissolved oxygen conditions are favorable, invertebrate and fish communities can be restored as well.

Invertebrate communities in Darby-Cobbs Watershed sampled in 2003 generally indicated impairment when compared to reference conditions, but this impairment was more severe in Cobbs Creek than in Darby Creek. Most sites showed a simplified invertebrate community dominated by chironomid midges and net spinning caddisflies- moderately tolerant invertebrates with generalized food requirements. These invertebrates can resist scouring and frequent disturbance of their habitat by firmly attaching themselves to stream substrates with silk. Free-living active invertebrates, predators, sensitive species, and invertebrates with feathery external gills were rare at some Darby Creek sites and completely absent from most Cobbs Creek sites and tributaries. The role of sediment toxicity or anoxia on invertebrate communities remains unknown, but water chemistry samples from some sites showed that concentrations of metals of concern (e.g., copper, lead, aluminum, iron, and zinc) may exceed state water quality criteria.

Fish assessments generally mirrored results of the macroinvertebrate study, with most sites exhibiting less diversity and specialization than fish communities found at reference sites. As a whole, the watershed was dominated by a small number of moderately tolerant species with generalized feeding habits and life history strategies. Fish species that have been shown to be tolerant of habitat degradation and food source limitation were dominant, while species that have specialized habitat, food or reproductive needs were largely missing from the Cobbs Creek basin. The most important species (in terms of biomass) was American eel, a species that spawns in the ocean, can tolerate extreme flows, and epitomizes the term "generalist feeder". Though upper reaches of Darby Creek watershed support a put-and-take trout fishery, fishery restoration plans for the watershed as a whole must be realistic in view of the watershed's "warmwater" designation and the immutable constraints of climate, geology and geography. Temperature and DO regime are ultimately and absolutely bound by these constraints.

Water quality investigations documented many violations (or in the case of toxic metals, possible violations) of state water quality criteria, particularly in wet weather. Combined sewers periodically release a mixture of raw sewage and stormwater to many areas of Darby-Cobbs Watershed. Damaged, improperly sized, or choked sanitary sewers and illicit connections may also release raw sewage to the watershed. Because much of Darby-Cobbs Watershed is not meeting state water quality standards for fecal coliform bacteria during dry weather, investigation and abatement of dry weather sewage sources is one of the most important components of Target A of the CCIWMP. Streams must be safe during the times when people are most likely to come in contact with them. Dry weather source trackdown is the most cost effective step toward meeting water quality standards during dry weather.

However, research shows that fecal coliform bacteria may persist for extended periods of time in stream sediments. It is possible that the effects of periodic wet weather CSO discharge may be long-lasting and cause some streams to have "background" fecal coliform concentrations in excess of water quality standards even once dry weather sources are eliminated. Wildlife and domestic animals are also sources of fecal coliform bacteria that cannot be overlooked. Reducing wet weather sewage sources is the goal of The City of Philadelphia's CSO Long Term Control Plan (LTCP). Over the next two years PWD is committed to a 20% reduction in CSO volume citywide.

These CSO reductions may be realized through a number of technologies, but it is imperative that the chosen solution (or solutions) address the actual cause of impairment. For example, small storm events likely contribute maximally to nutrient enrichment and algal blooms, as the relative proportion of sanitary sewage is largest and physical stresses due to sloughing and turbidity are smallest. While large storm events cause a greater amount of nutrients to be passed through the system, sloughing and turbidity reduce the ability of the algal community to take advantage of these nutrients. The greatest improvements may arise from prioritizing, controlling, and eliminating sources of nutrients when and where conditions are favorable for algae.

Recognition of the need to protect people from water and sewage-borne diseases and parasites has extricated us from the "dark ages" of public health, spawning regulations and the technical innovations needed to meet them. As our knowledge of threats to people and the natural environment grows, water quality regulations are under continuous revision. Unfortunately, scientific research and environmental regulations often outpace practical implementation of corrective measures.

The current state of the Darby-Cobbs Watershed is the product of more than a century of neglect and abuse, and correcting these problems will require an enormous commitment. Furthermore, this effort will take many years and cost millions of dollars. As a group of engineers and scientists in the service of the public, the Philadelphia Water Department is working to ensure that Philadelphia's watershed improvements are cost-effective and based on sound science. We believe that the ideas and options presented in the Cobbs Creek Integrated Watershed Management Plan represent reachable goals and provide a road map for attaining those goals.

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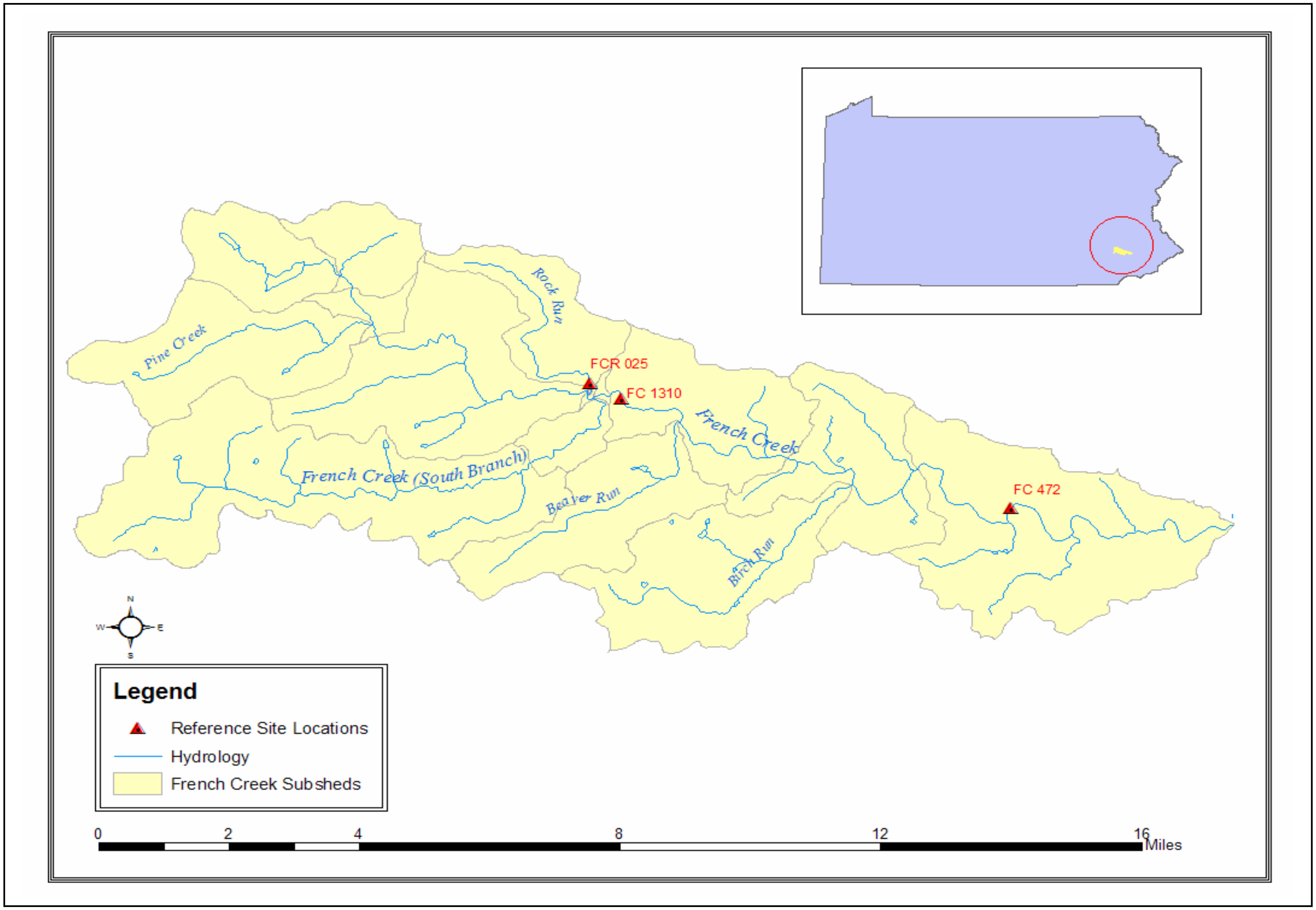
APPENDIX A: REFERENCE MONITORING LOCATIONS

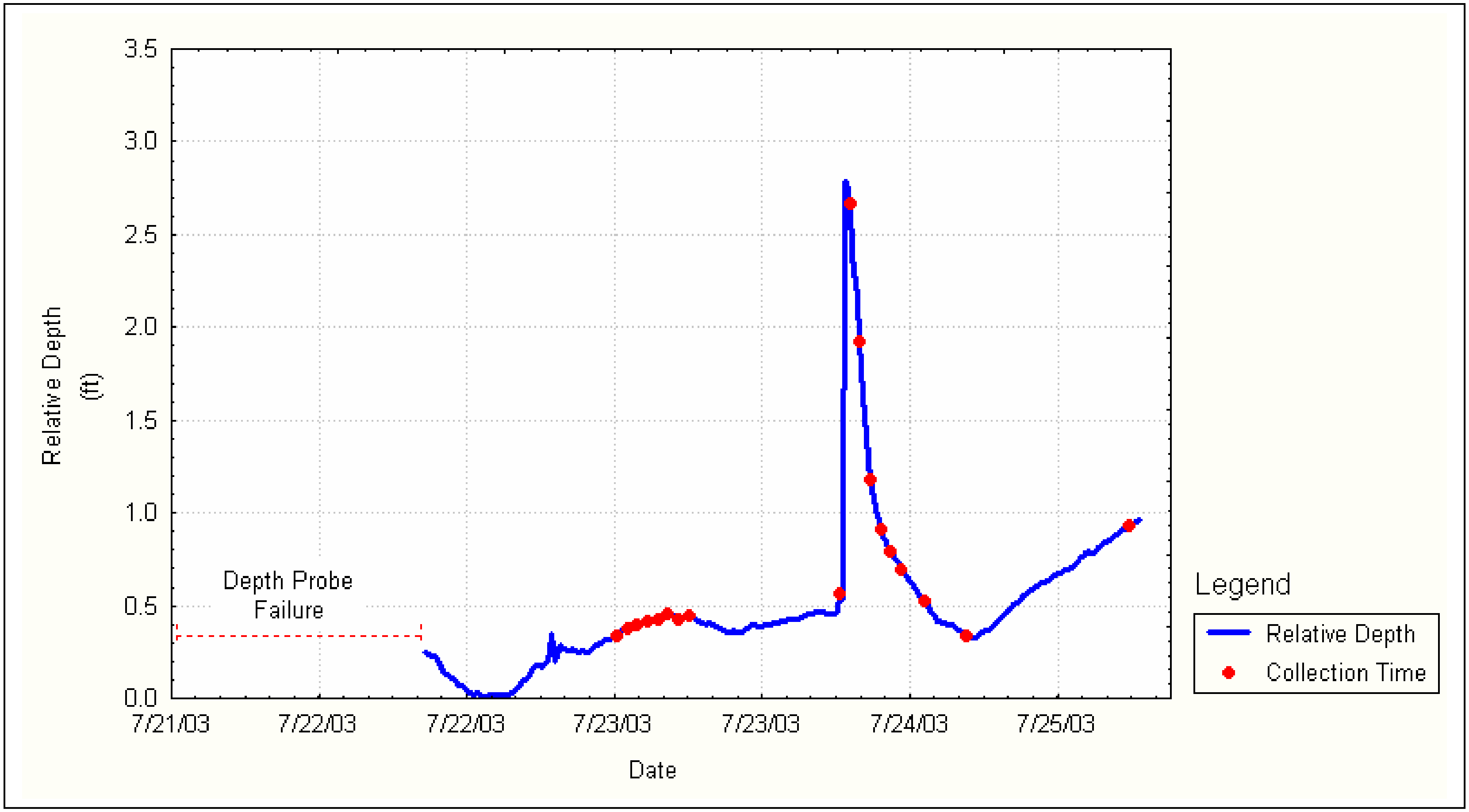

Rock Run
Pine Creek
FCR 025
FC 1310
French Creek
French Creek (South Branch)
Beaver Run
Birch Run
FC 472
N
W
E
S
Legend
Reference Site Locations
Hydrology
French Creek Subsheds
0
2
4
8
12
16
Miles

APPENDIX B: SIMPLE LINEAR REGRESSION (SLR) EQUATIONS OF FISH SPECIES IN DARBY-COBBS WATERSHED

SCIENTIFIC NAME	**COMMON NAME**	**SPECIES CODE**	**SLR EQUATION**	**R^2 VALUE**
Ameiurus nebulosus	Brown Bullhead Catfish	AMNEB	y = 3.1186x - 1.9473	R2 = 0.9938
Ambloplites rupestris	Rock Bass	AMRUP	y = 2.8935x - 1.5764	R2 = 0.9916
Anguilla rostrata	American Eel	ANROS	y = 3.3829x - 3.2737	R2 = 0.9958
Catostomus commersoni	White Sucker	CACOM	y = 3.0851x - 2.0466	R2 = 0.9956
Cyprinella analostana	Satinfin Shiner	CYANA	y = 2.7327x - 1.7254	R2 = 0.9081
Etheostoma olmstedi	Tessellated Darter	ETOLM	y = 2.6587x - 1.6963	R2 = 0.8395
Exoglossum maxillingua	Cutlips Minnow	EXMAX	y = 3.1629x - 2.032	R2 = 0.9915
Fundulus diaphanus	Banded Killifish	FUDIA	y = 3.1926x - 2.1244	R2 = 0.9741
Fundulus heteroclitus	Mummichog	FUHET	y = 3.2904x - 2.0907	R2 = 0.9859
Lepomis auritus	Redbreast Sunfish	LEAUR	y = 3.2349x - 1.9202	R2 = 0.9959
Lepomis gibbosus	Pumpkinseed Sunfish	LEGIB	y = 3.337x - 1.9906	R2 = 0.992
Lepomis macrochirus	Bluegill Sunfish	LEMAC	y = 3.2184x - 1.9574	R2 = 0.9976
Luxilus cornutus	Common Shiner	LUCOR	y = 3.4176x - 2.2849	R2 = 0.9895
Micropterus dolomieu	Smallmouth Bass	MIDOL	y = 2.6582x - 1.456	R2 = 0.9805
Micropterus salmoides	Largemouth Bass	MISAL	y = 3.0914x - 2.0213	R2 = 0.9938
Notropis hudsonius	Spottail Shiner	NOHUD	y = 2.9066x - 1.9642	R2 = 0.9743
Notropis procne	Swallowtail Shiner	NOPRO	y = 3.0687x - 2.0479	R2 = 0.9443
Oncorhynchus mykiss	Rainbow Trout	ONMYK	y = 2.9476x - 1.9371	R2 = 0.8555
Pimephales promelas	Fathead Minnow	PIPRO	y = 3.2744x - 2.1155	R2 = 0.9664
Rhinichthys atratulus	Blacknose Dace	RHATR	y = 3.1448x - 2.1292	R2 = 0.9874
Salmo trutta	Brown Trout	SATRU	y = 1.9894x - 0.6302	R2 = 0.326
Semotilus atromaculatus	Creek Chub	SEATR	y = 3.0031x - 1.9344	R2 = 0.9847
Semotilus corporalis	Fallfish	SECOR	y = 2.9238x - 1.8627	R2 = 0.994

APPENDIX C: WET-WEATHER SAMPLING FREQUENCIES

C.1.1. Sampling Times At DCC 770 (7/21/03-7/25/03)



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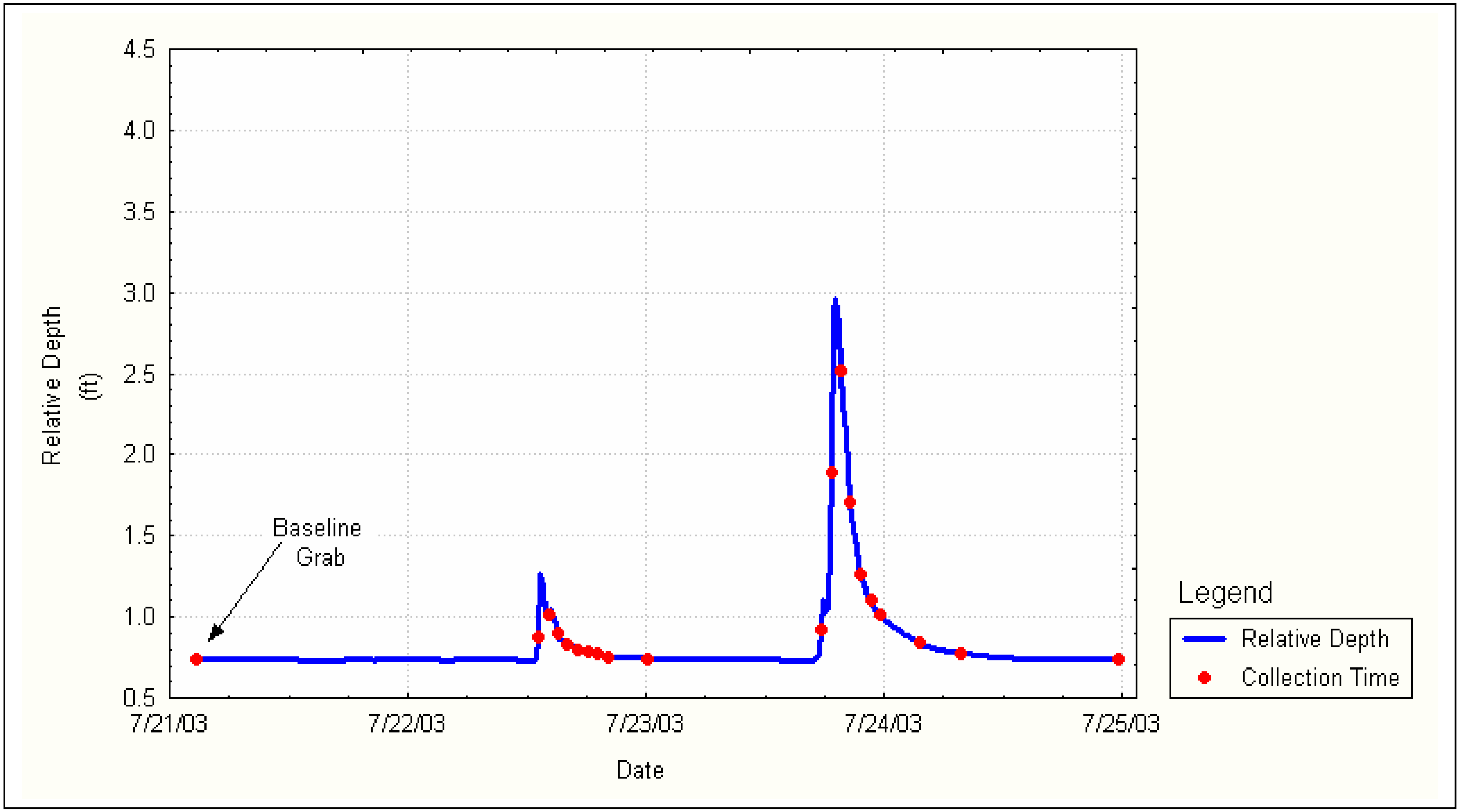

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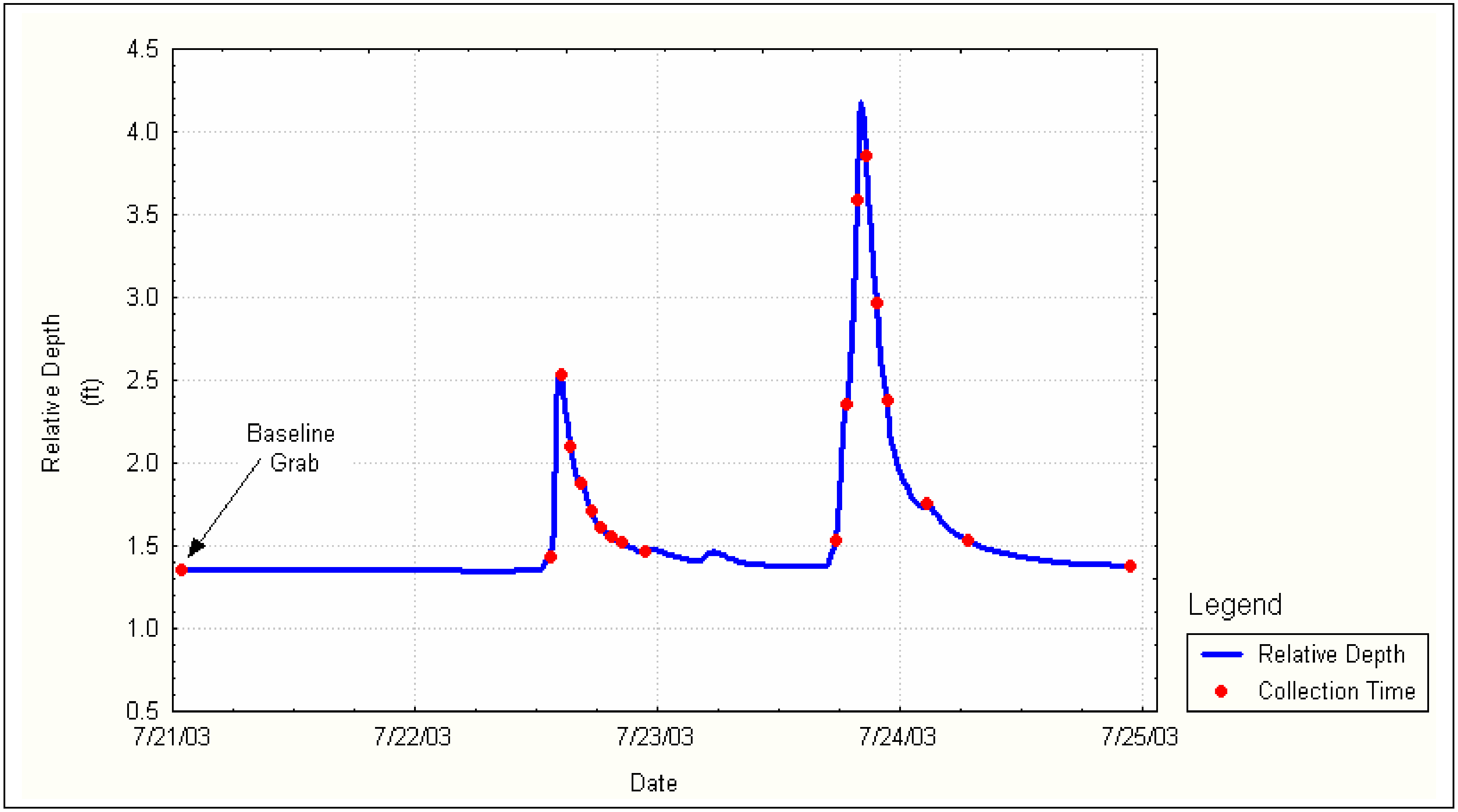
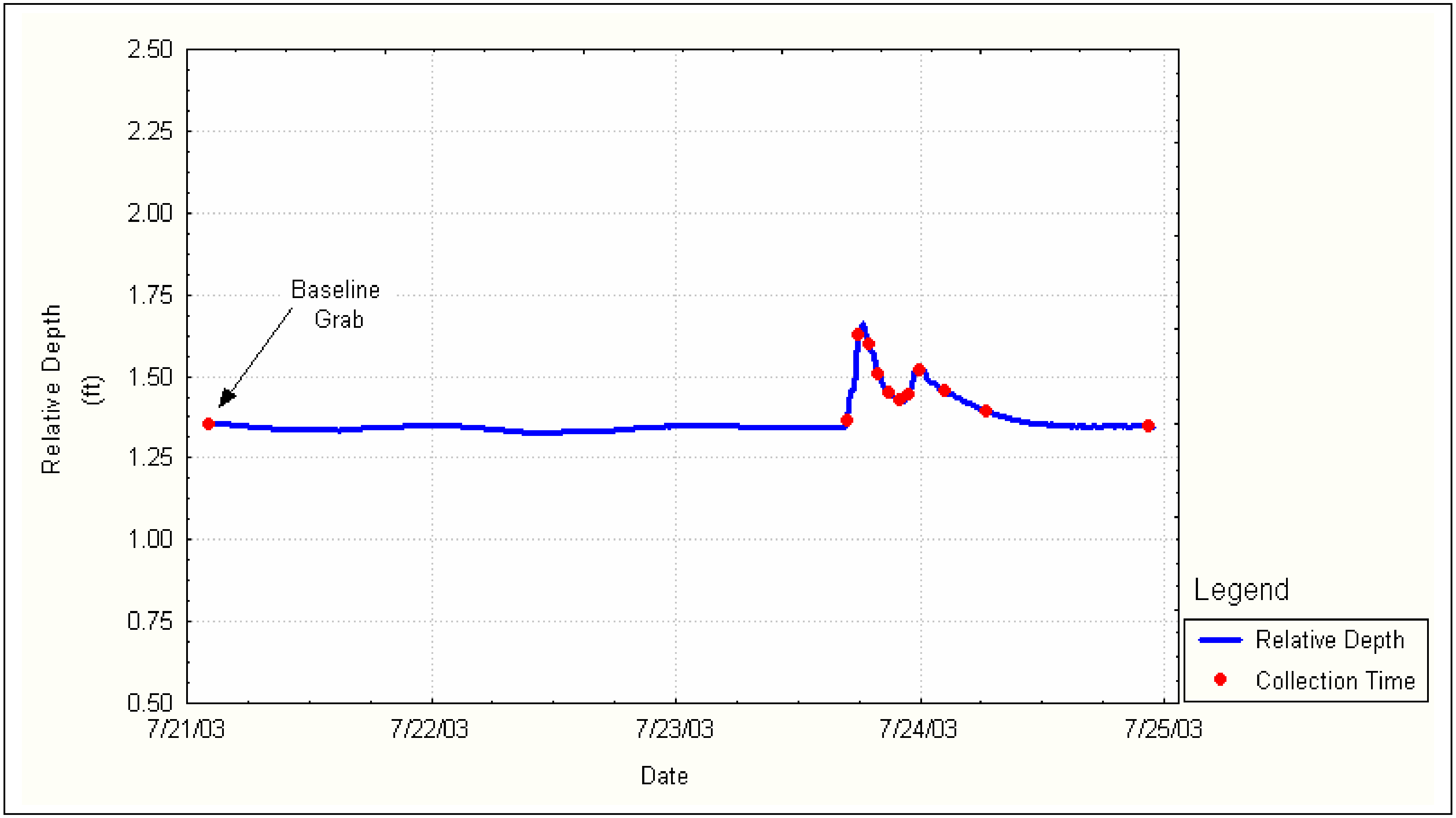
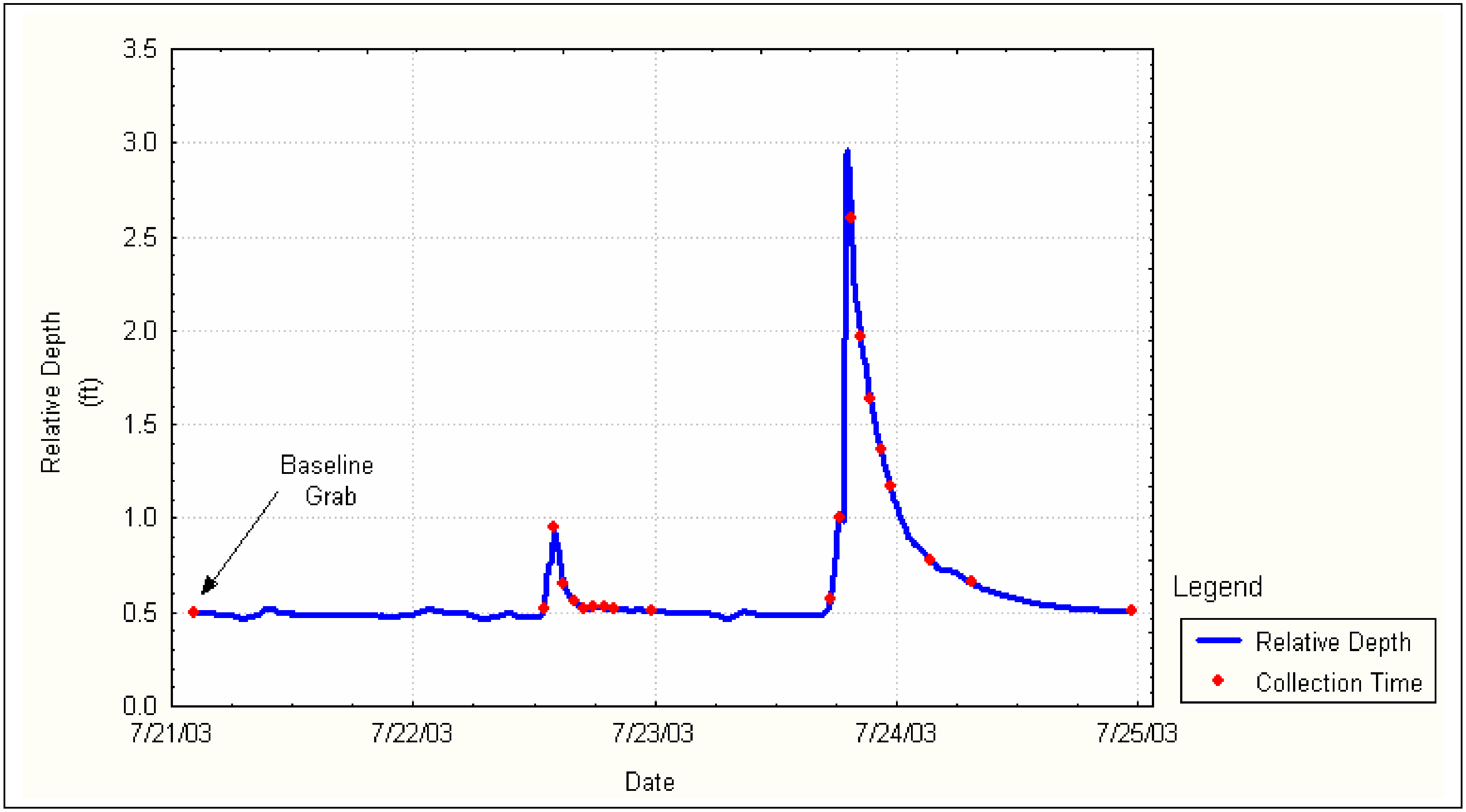


C.1.4. Sampling Times At DCD 1660 (7/21/03-7/25/03)



C.1.5. Sampling Times At DCD 765 (7/21/03-7/25/03)



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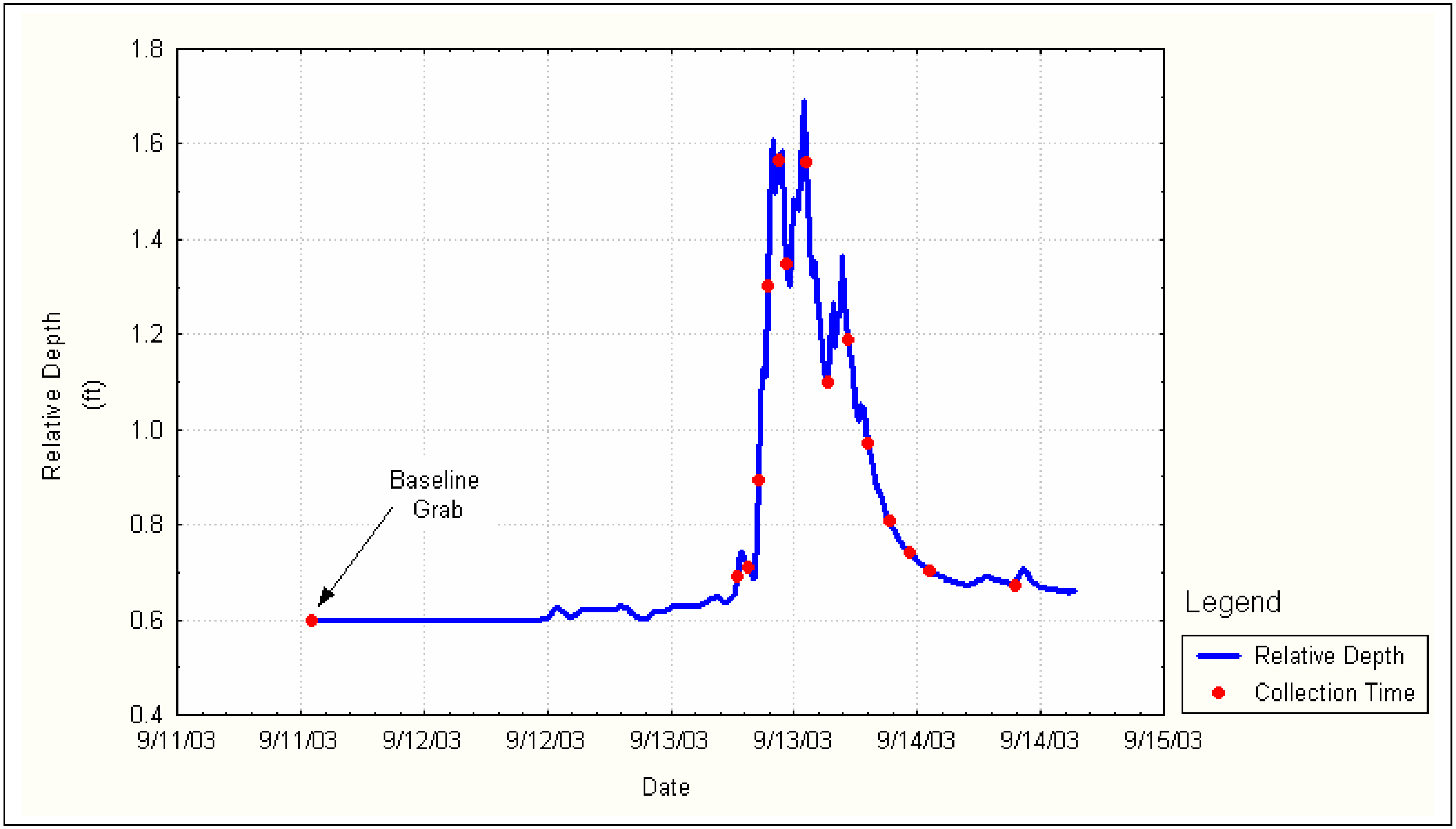

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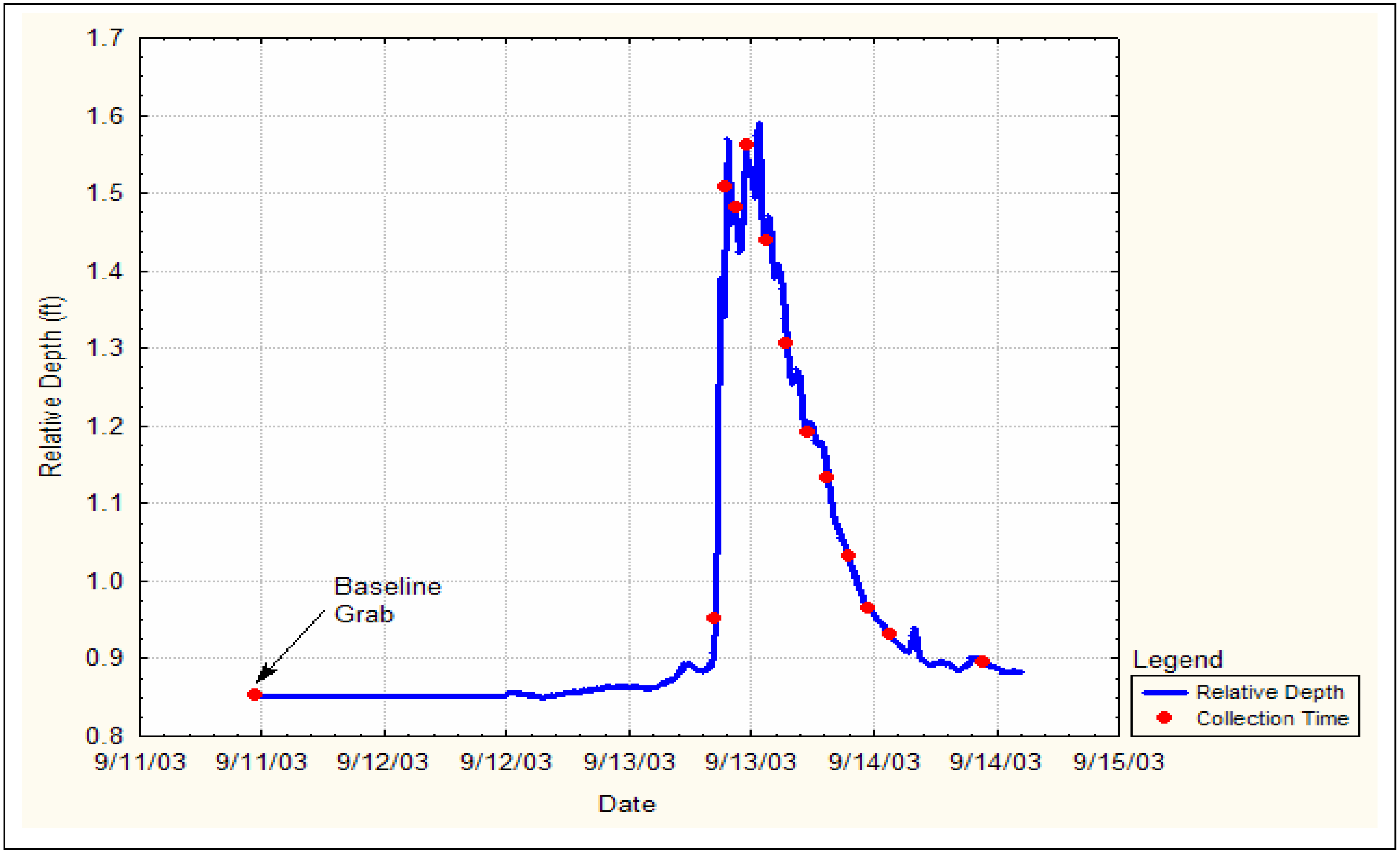

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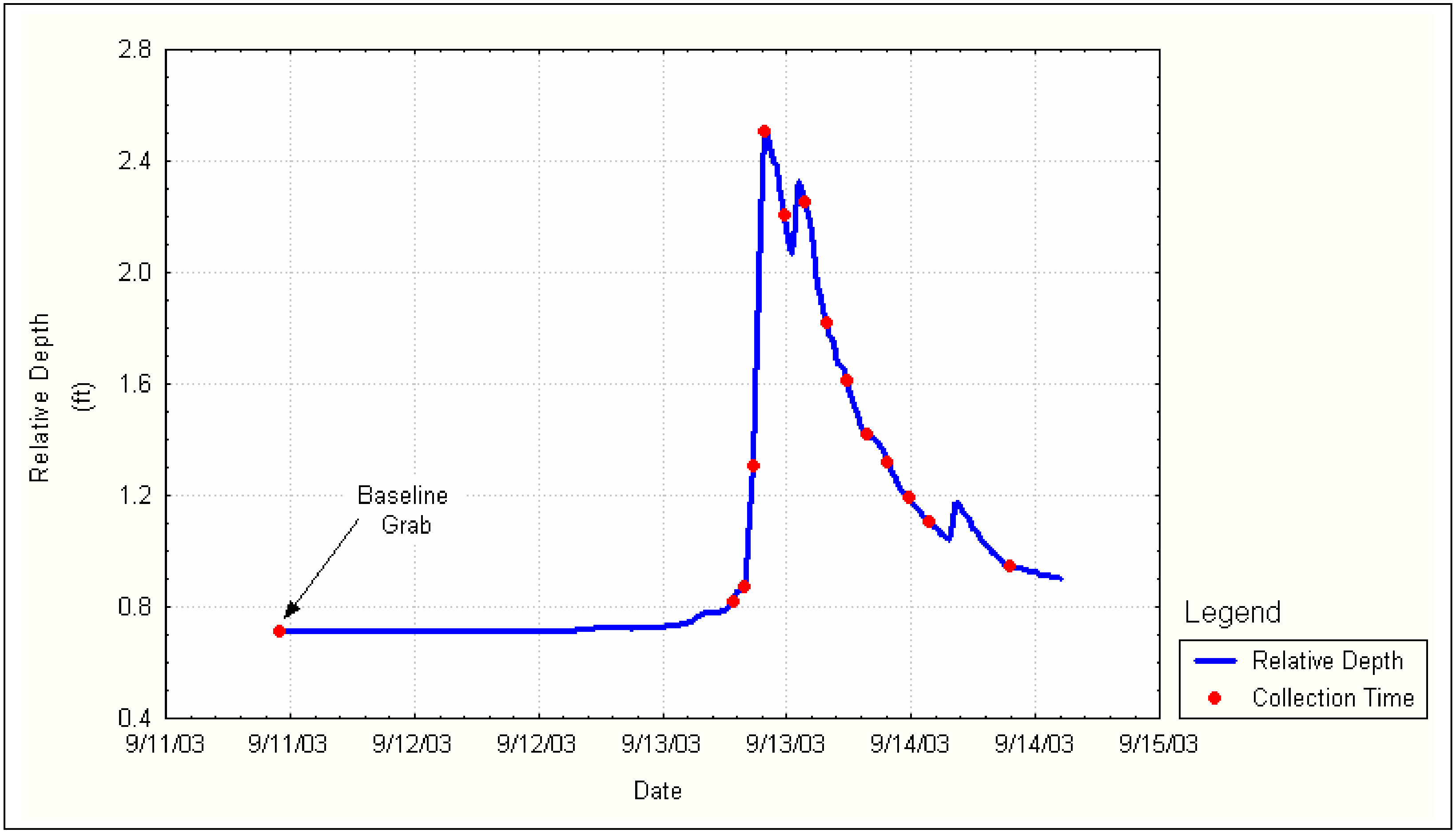
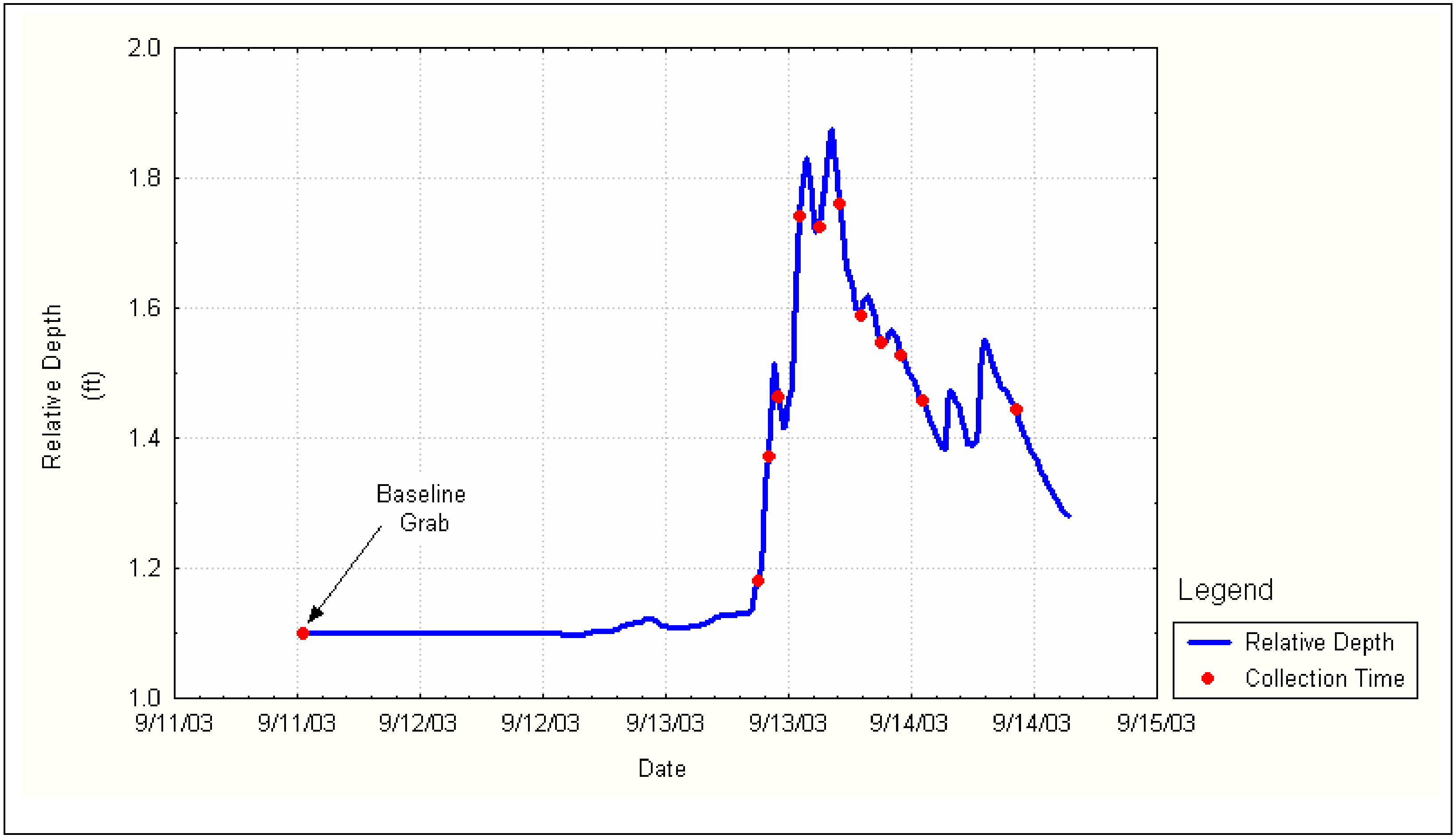


C.2.4. Sampling Times At DCD 1660 (9/11/03-9/14/03)



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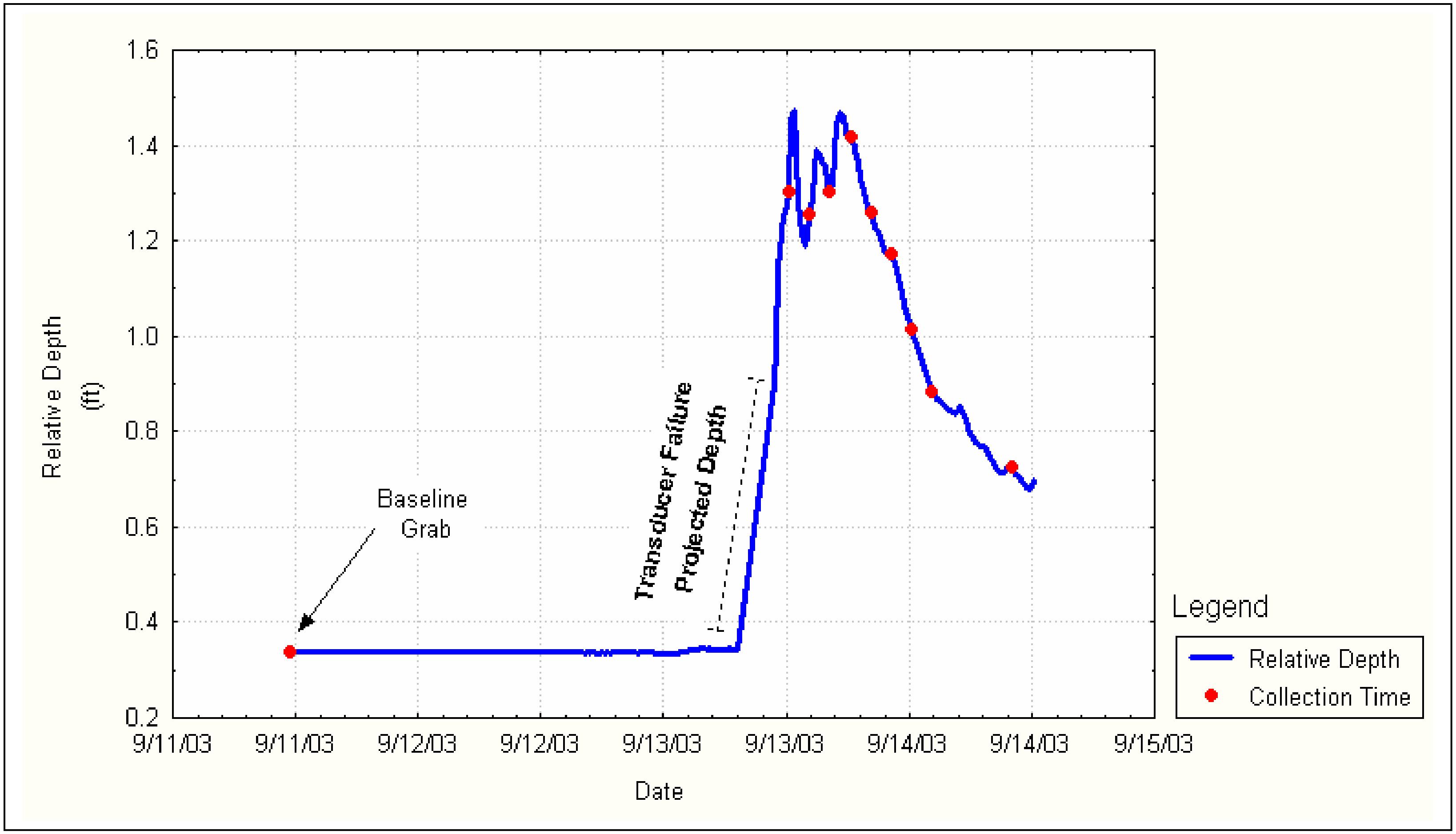


APPENDIX D: MASTER LIST OF MACROINVERTEBRATE TAXA COLLECTED IN DARBY-COBBS WATERSHED

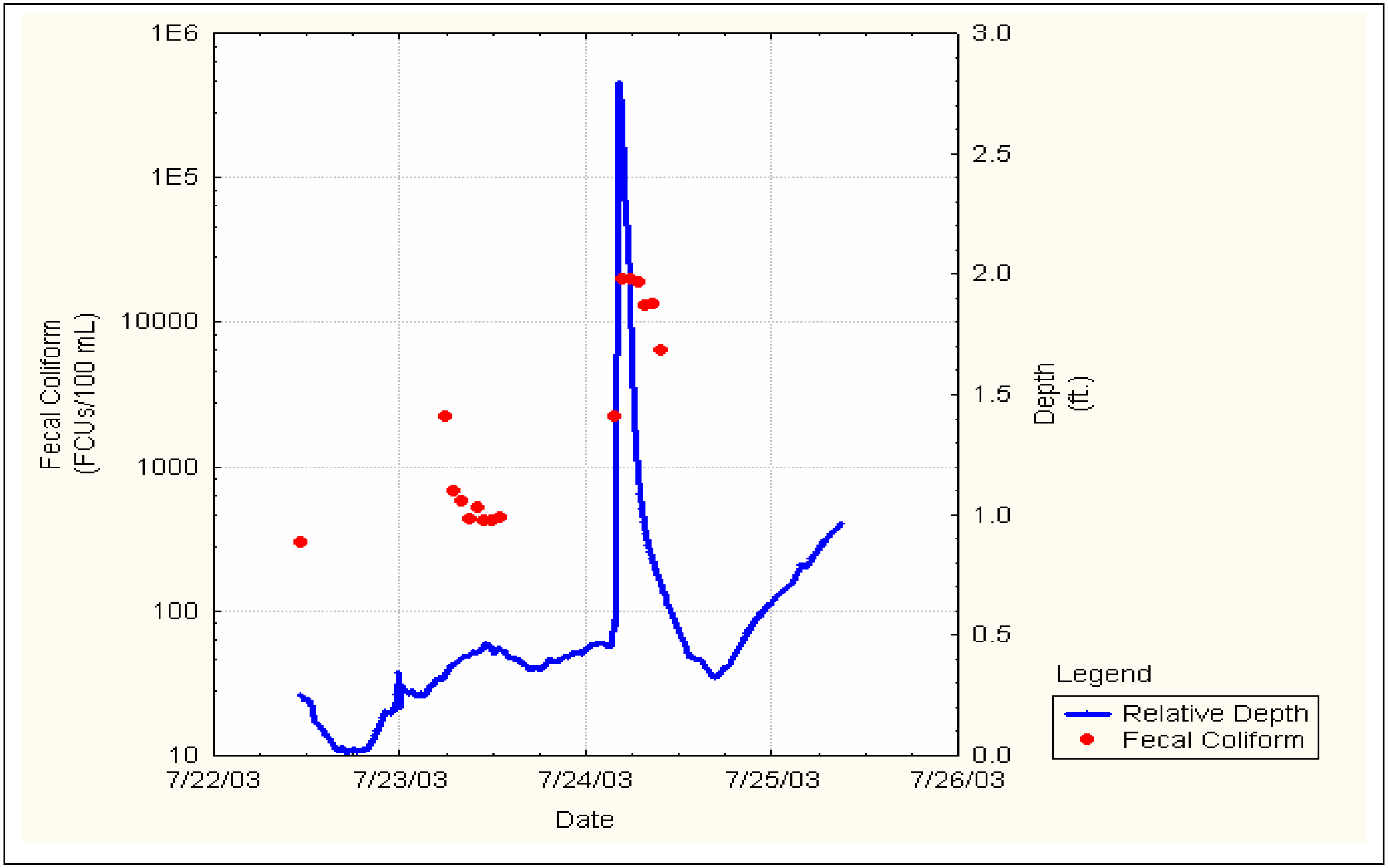
Family	Genus
Aeshnidae	*Boyeria*
Ancylidae	*sp.*
Asellidae	*Caecidotea*
Baetidae	*Baetis*
Cambaridae	*sp.*
Chironomidae	*sp.*
Coenagrionidae	*Argia*
Corbiculidae	*Corbicula*
Crangonyctidae	*Crangonyx*
Elmidae	*Macronychus*
Elmidae	*Optioservus*
Elmidae	*Stenelmis*
Epididae	*Hemerodromia*
Erpobdellidae	*sp.*
Gammaridae	*Gammarus*
Glossosomatidae	*Glossosoma*
Gomphidae	*Progomphus*
Helicopsychidae	*Helicopsyche*
Heptageniidae	*Stenacron*
Hydropsychidae	*Hydropsyche*
Hydropsychidae	*Cheumatopsyche*
Hydroptilidae	*Ochrotrichia*
Hydroptilidae	*Agraylea*
Lumbriculidae	*sp.*
Lymnaeidae	*sp.*
Muscidae	*sp.*
Nemouridae	*Prostoia*
Oxidae	*Oxus*
Perlidae	*Acroneuria*
Philopotamidae	*Chimarra*
Physidae	*sp.*
Planariidae	*Cura*
Planorbidae	*sp.*
Polycentropodidae	*Nyctiophylax*
Psephenidae	*Psephenus*
Simuliidae	*Simulium*
Simuliidae	*Prosimulium*
Tipulidae	*Antocha*
Tipulidae	*Tipula*
Tubificidae	*sp.*

APPENDIX E. PRINCIPAL COMPONENTS ANALYSIS (PCA) FACTOR LOADING SCORES

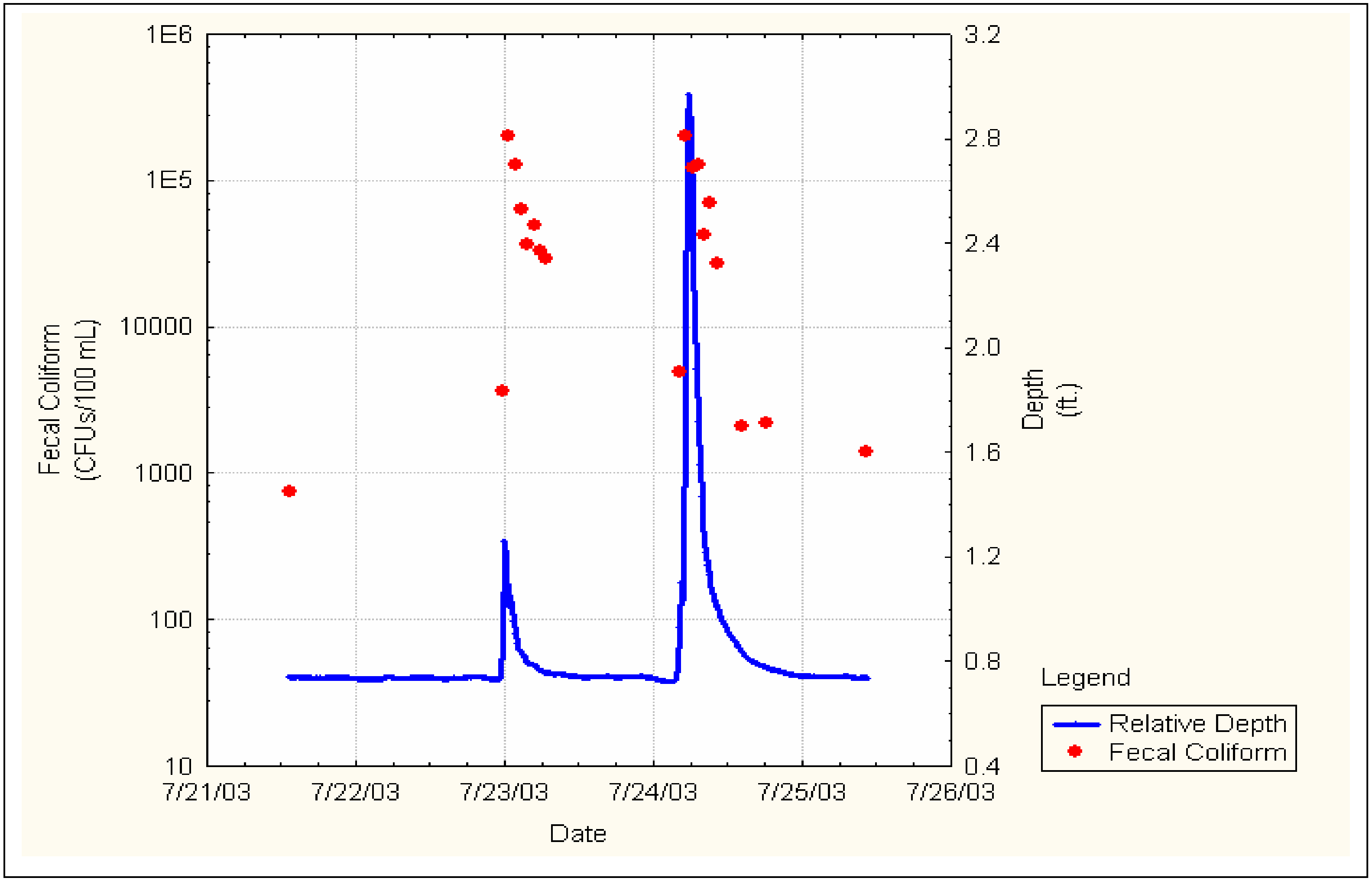
Habitat Variable	Factor 1	Factor 2
Bank Stability	0.624644334	0.534454383
Channel Alteration	0.68519826	-0.613778676
Channel Flow Status	0.887283517	-0.154711094
Channel Sinuosity	0.646498442	-0.162836359
Embeddedness	0.676814129	0.59480918
Epifaunal Substrate /Cover	0.928540686	-0.163641469
Riffle Frequency	0.478714469	0.628922847
Pool Substrate	0.884876311	0.098273276
Pool Variability	0.828192386	-0.473655723
Riparian Zone Width	0.108106765	-0.607800328
Sedimentation	0.664596427	0.606005429
Vegetative Protection	0.765062404	-0.022199009
Velocity/Depth Regime	0.914921054	-0.259234876
Variance Explained	**6.959027402**	**2.527304108**
Proportional Total Variance	**0.5353098**	**0.194408008**

APPENDIX F: WET-WEATHER FECAL COLIFORM CONCENTRATIONS

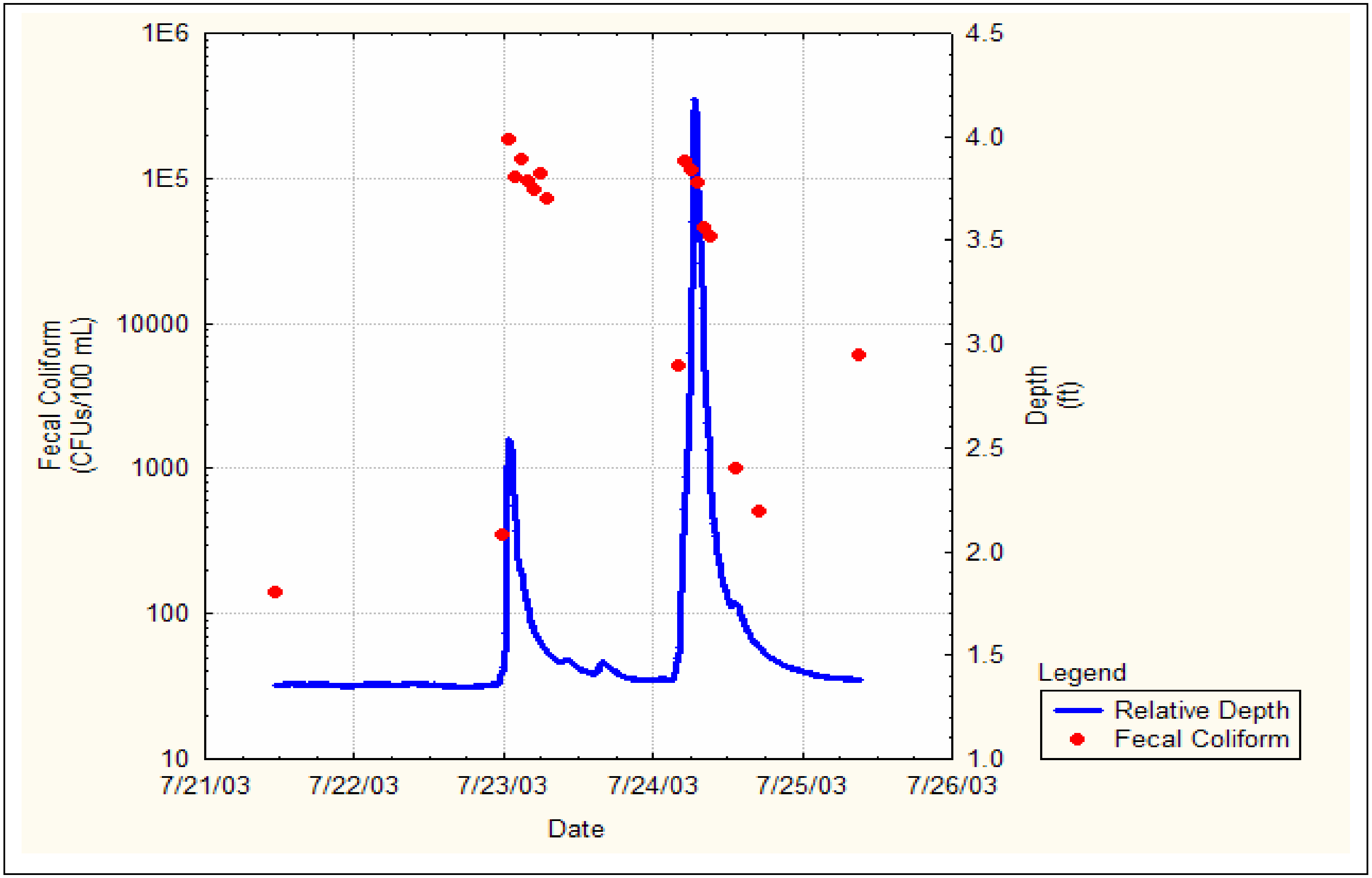
F.1.1. Fecal Coliform Concentrations At DCC 770 (7/21/03-7/25/03)



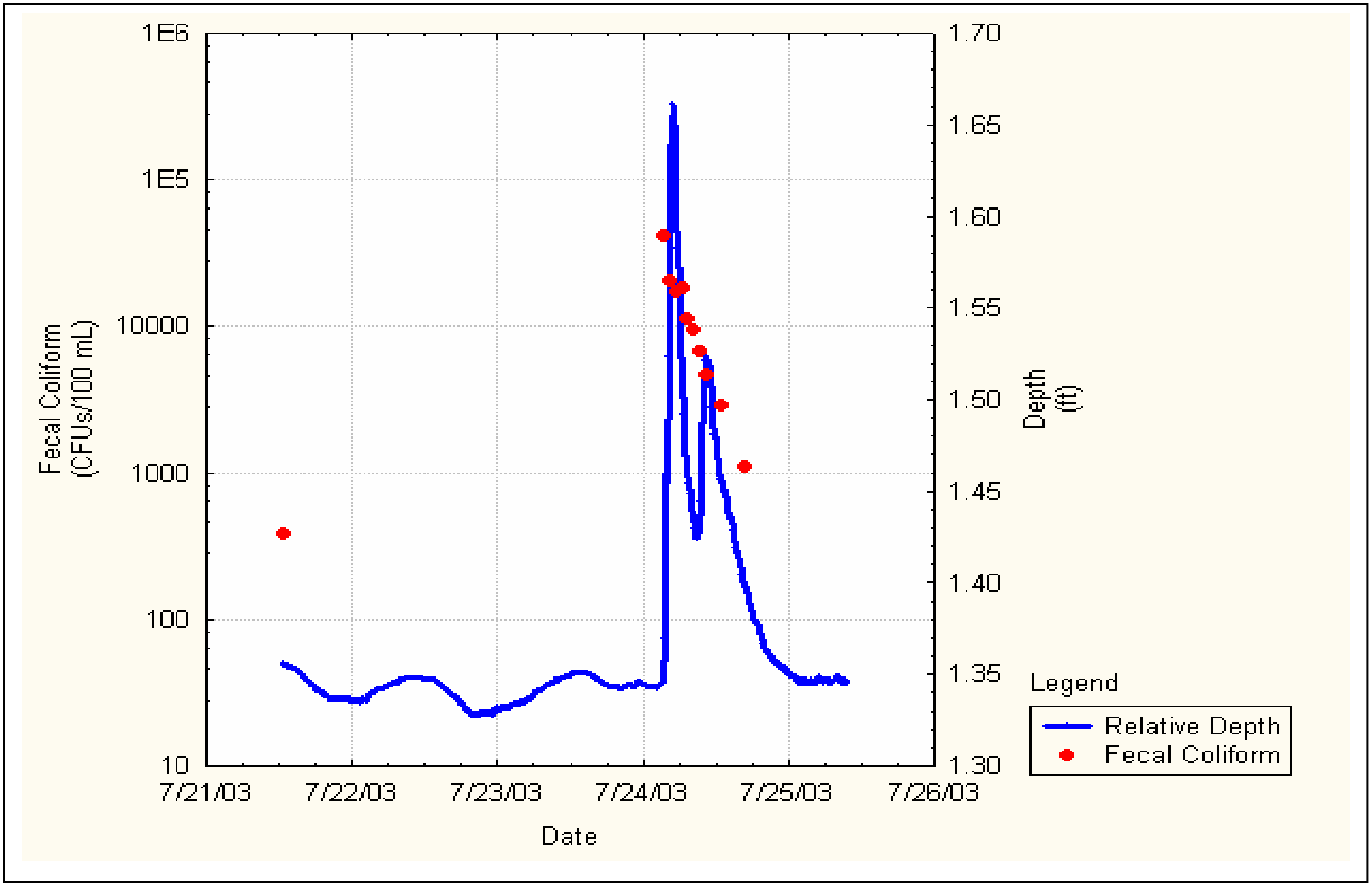
F.1.2. Fecal Coliform Concentrations At DCC 455 (7/21/03-7/25/03)



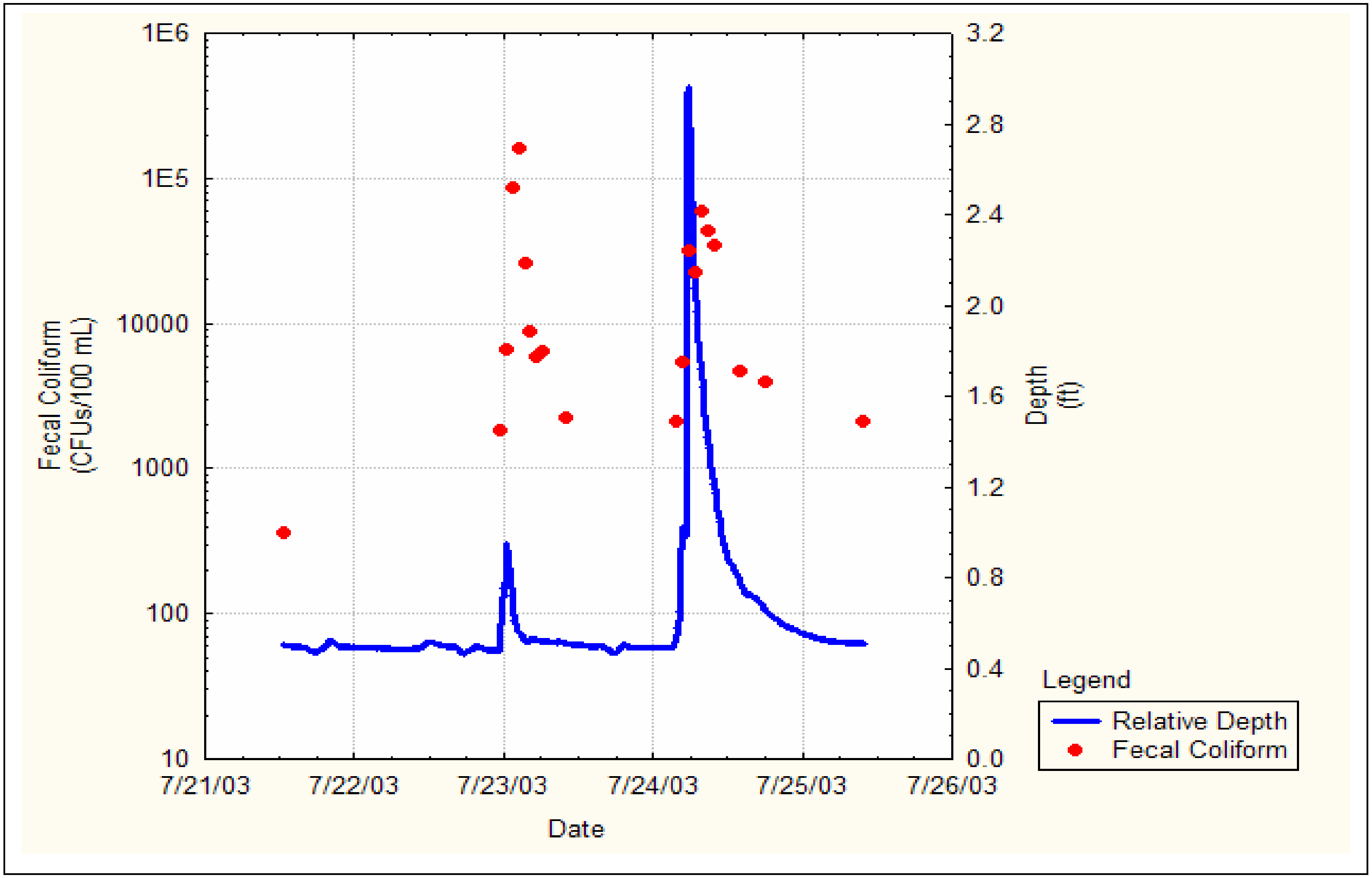
F.1.3. Fecal Coliform Concentrations At DCC 208 (7/21/03-7/25/03)



F.1.4. Fecal Coliform Concentrations At DCD 1660 (7/21/03-7/25/03)



F.1.5. Fecal Coliform Concentrations At DCC 765 (7/21/03-7/25/03)



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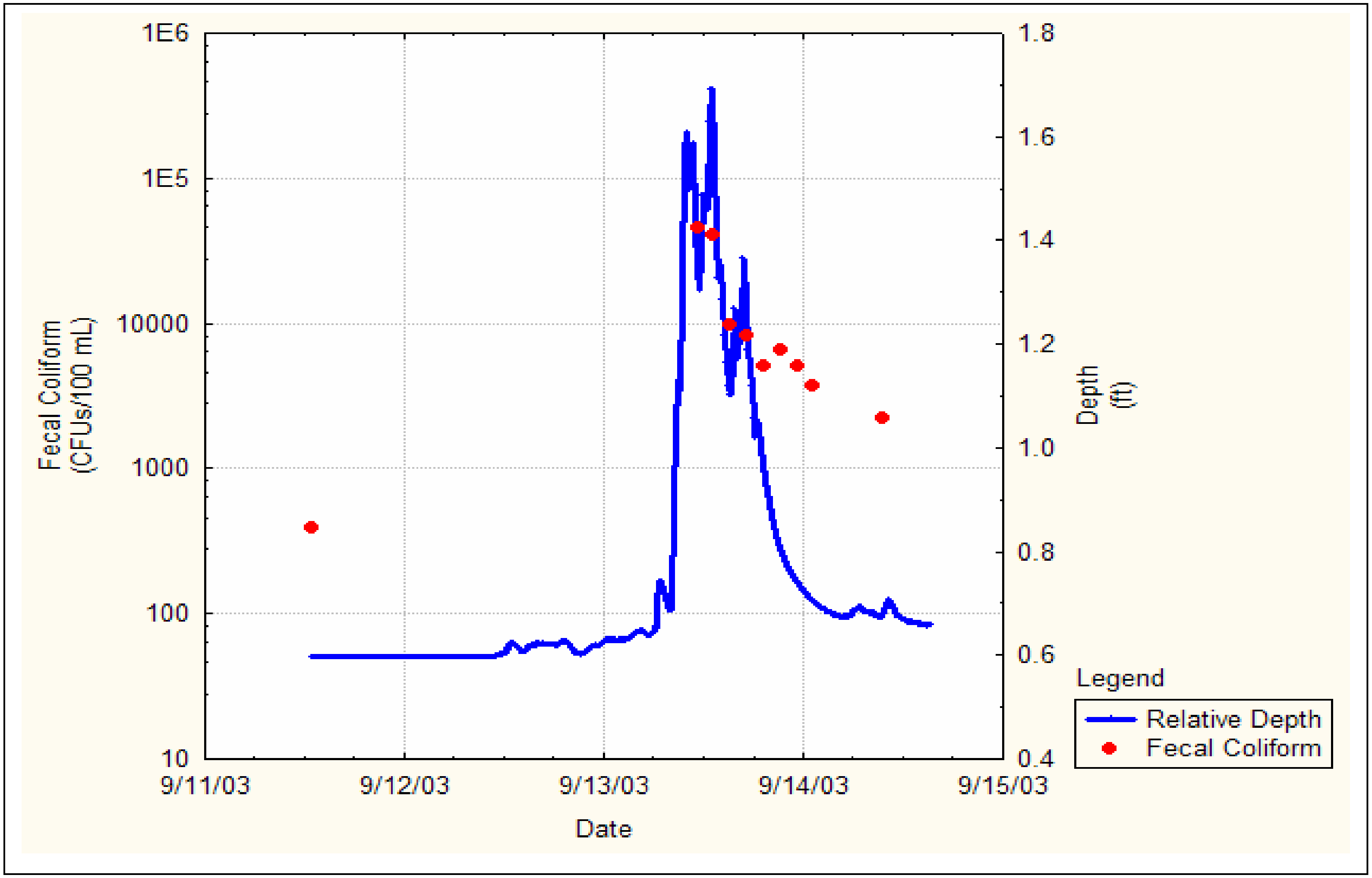

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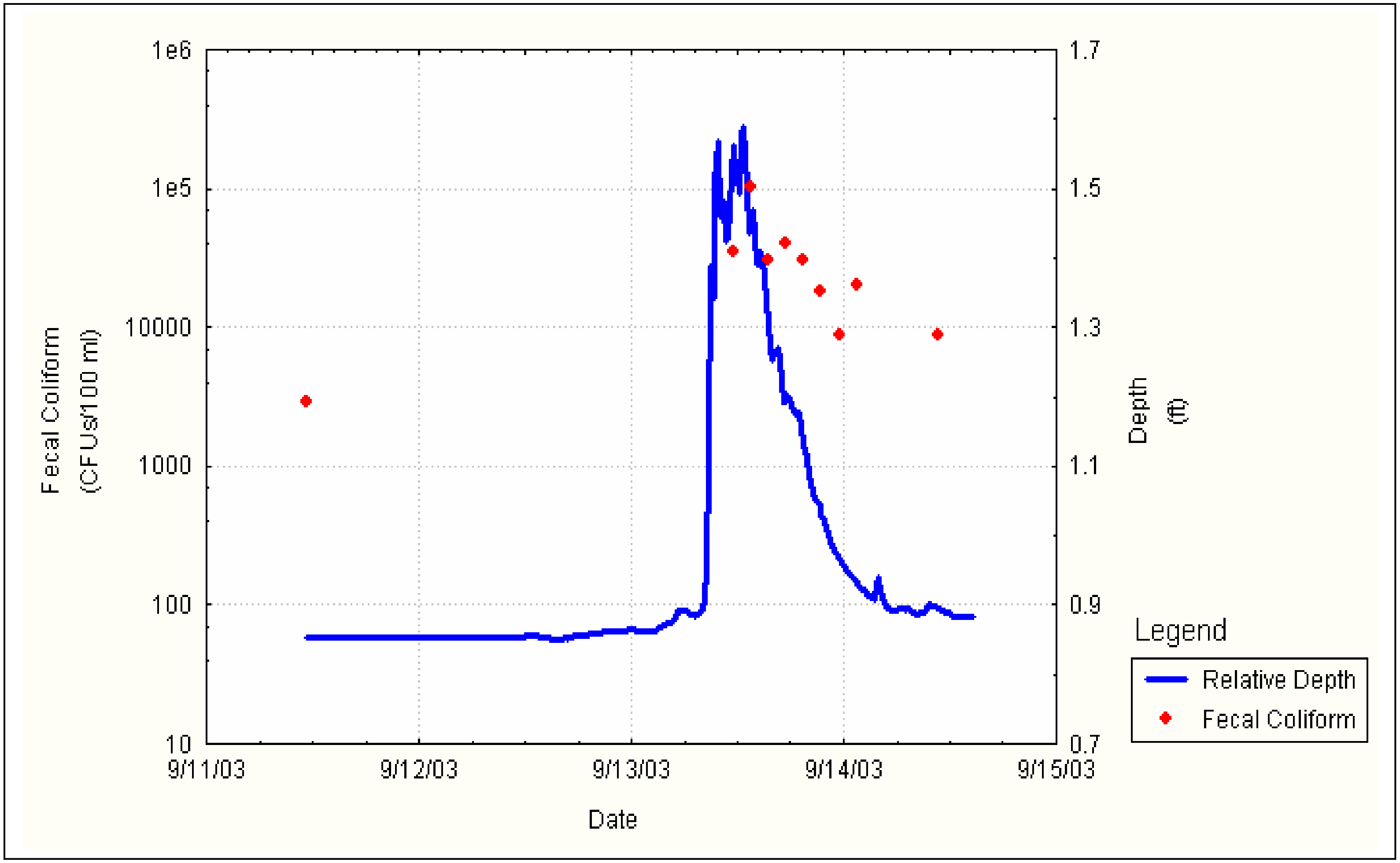

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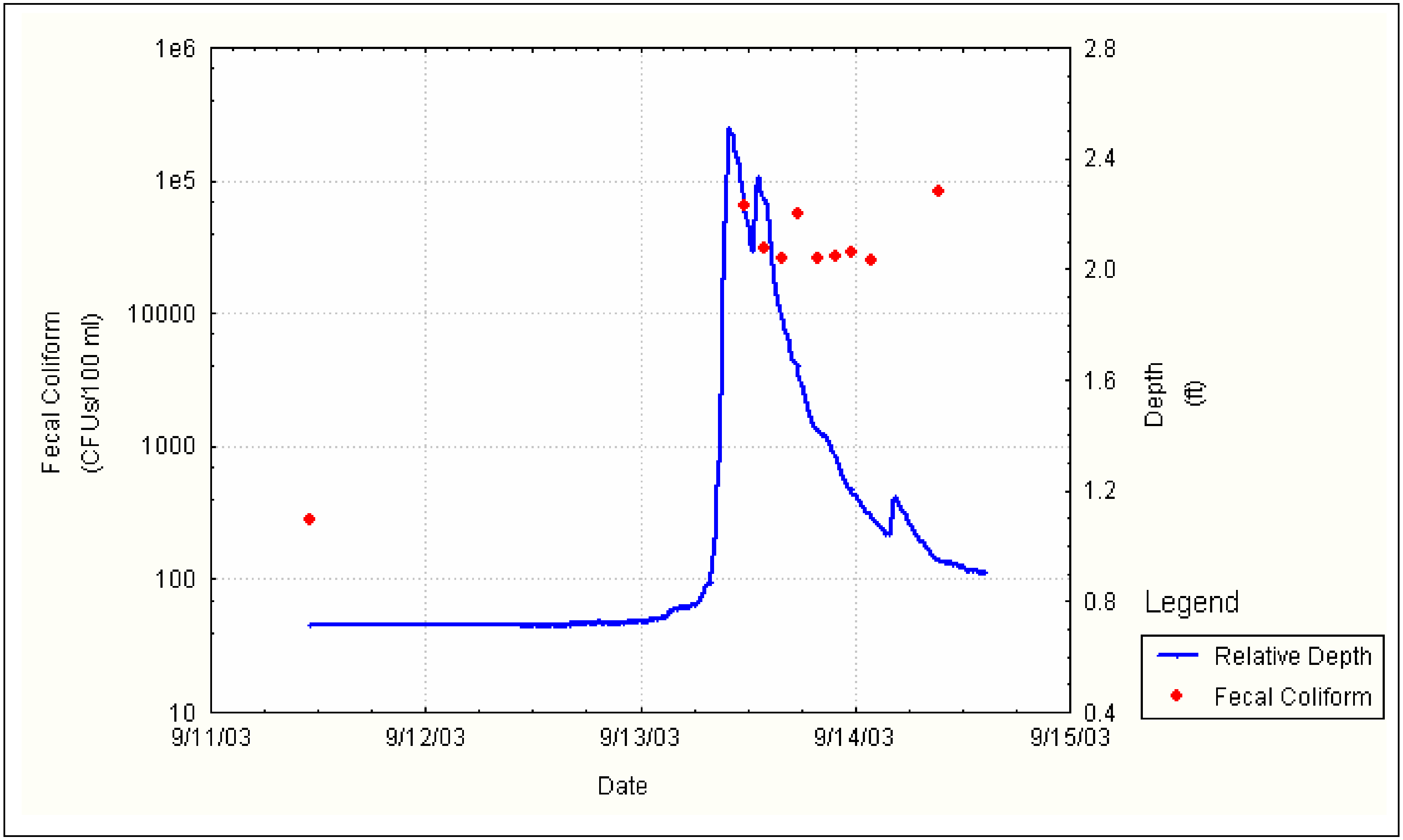

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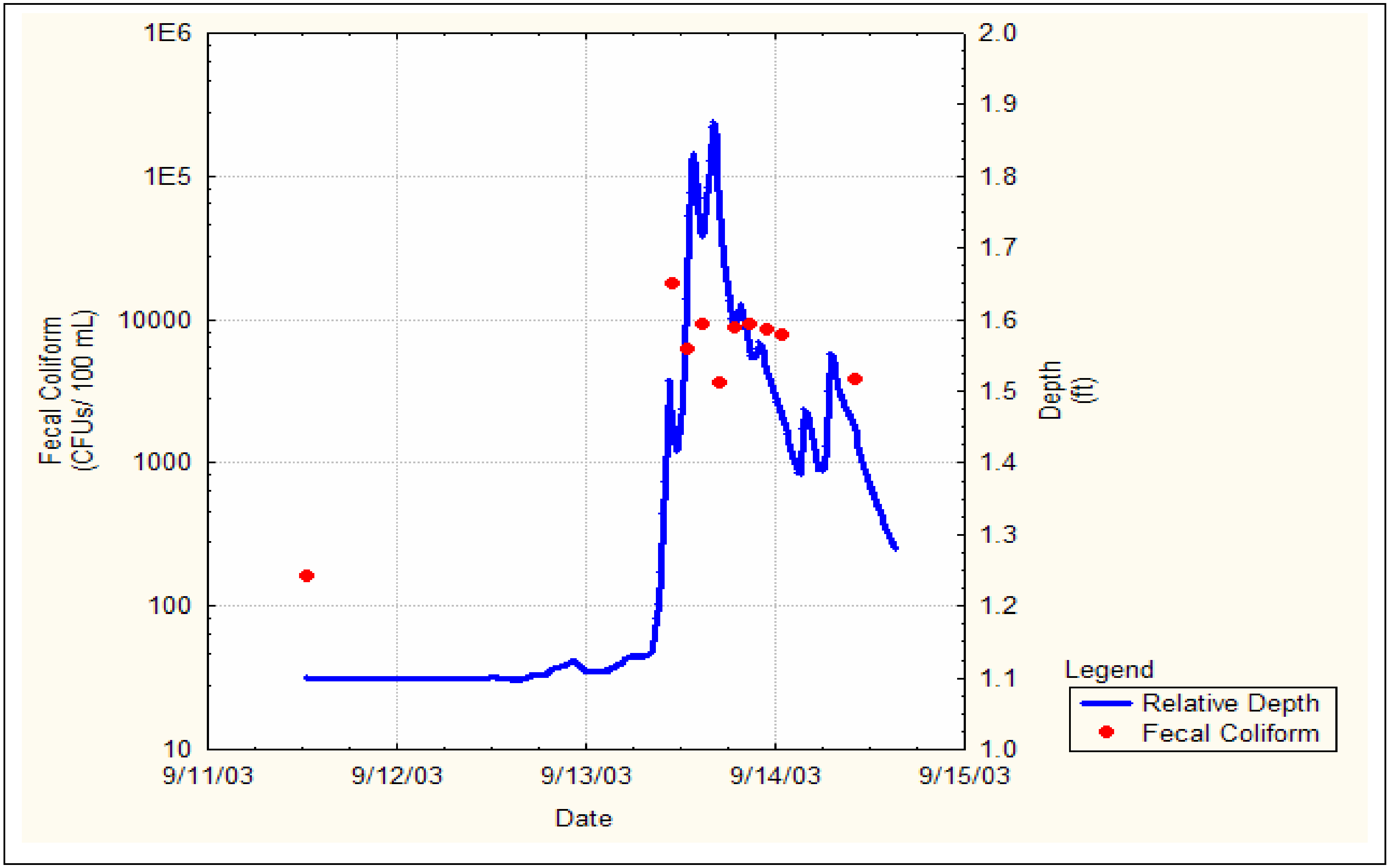

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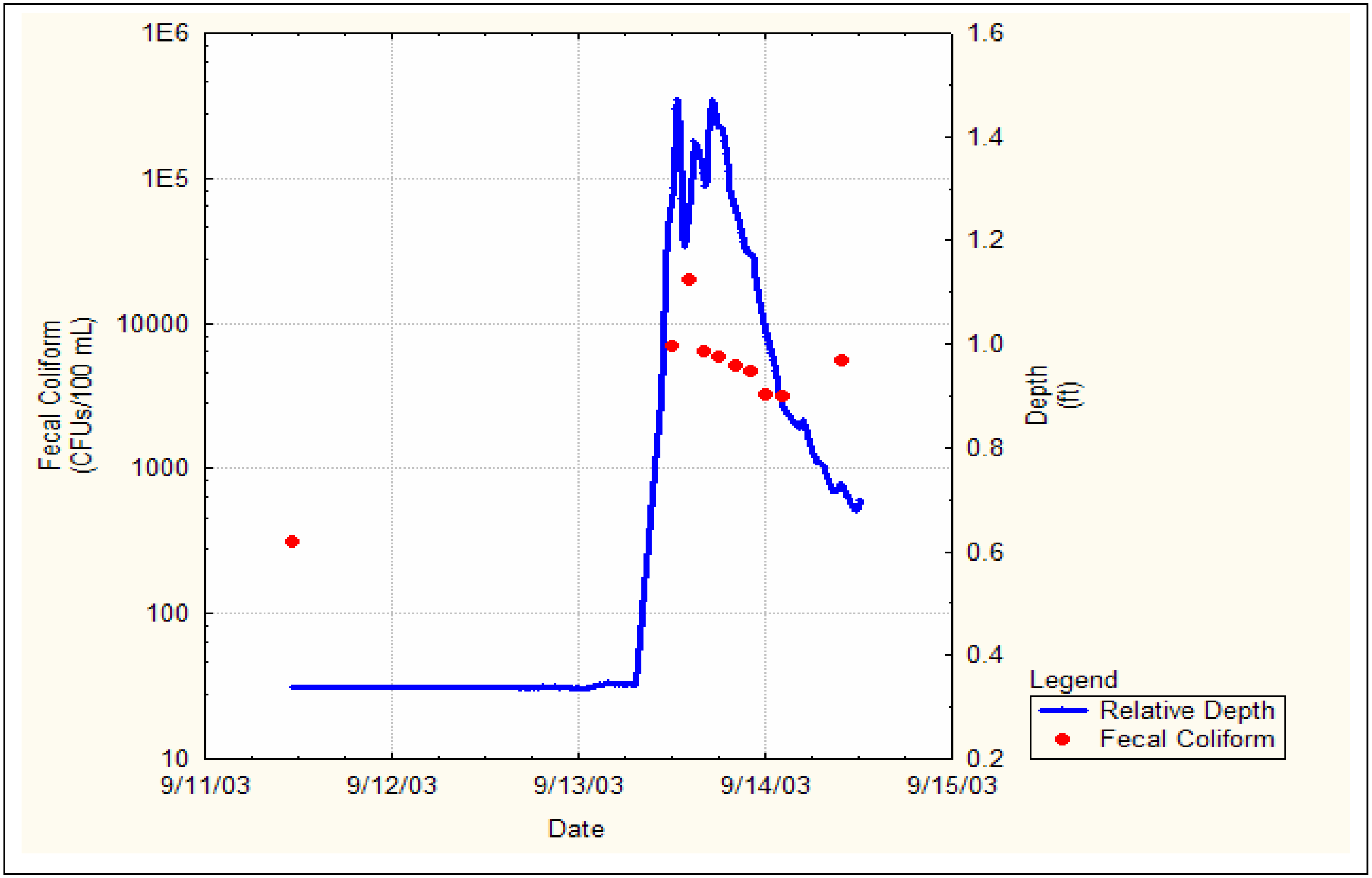

APPENDIX G. WET WEATHER METAL CONCENTRATIONS OF SAMPLES COLLECTED DURING STORM EVENTS

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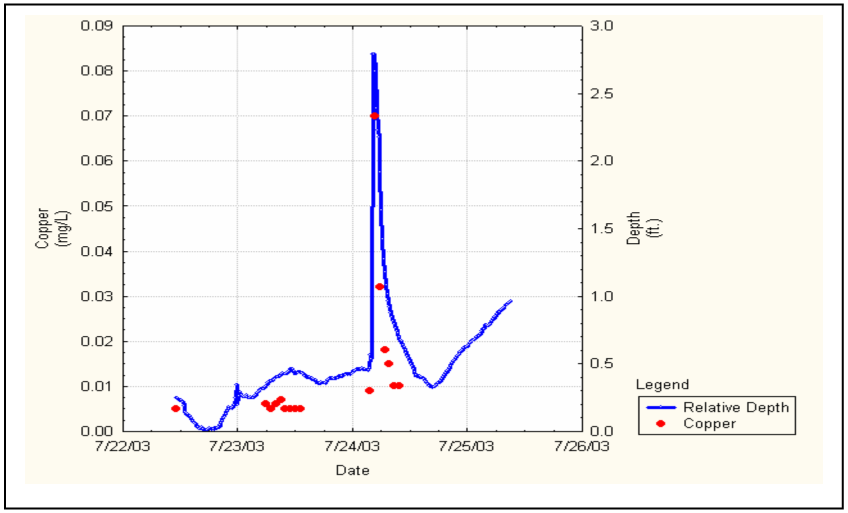

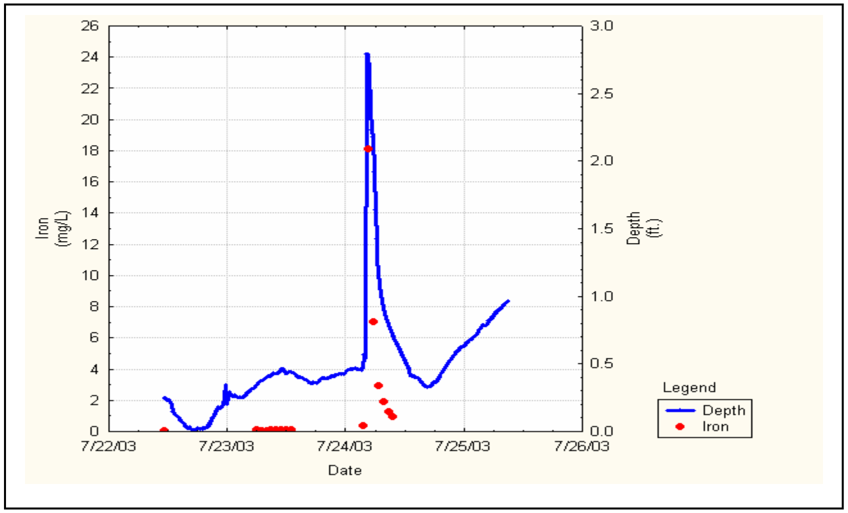

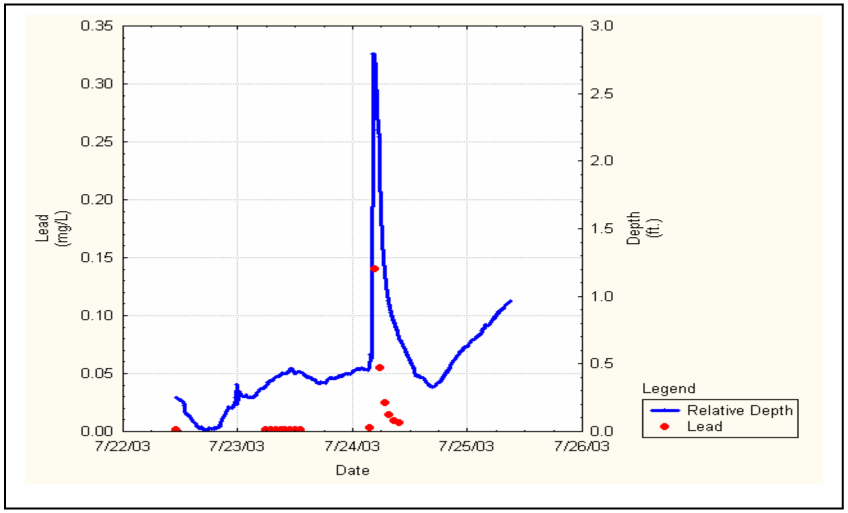

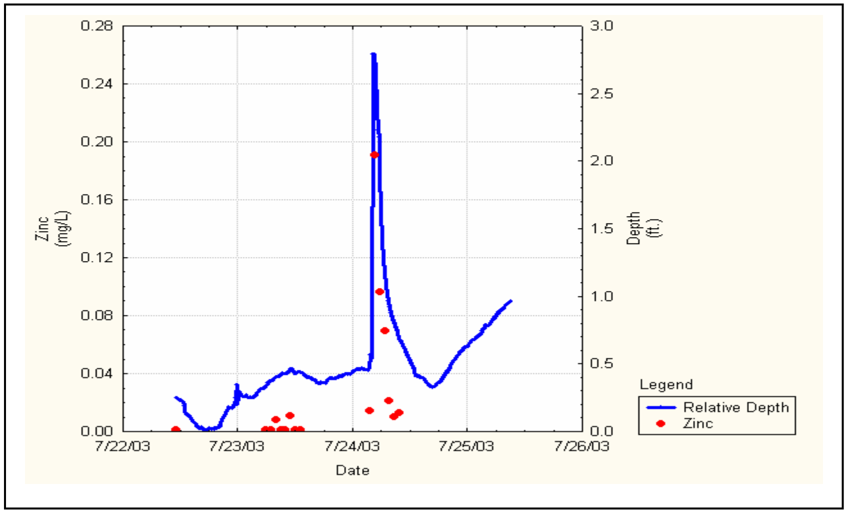

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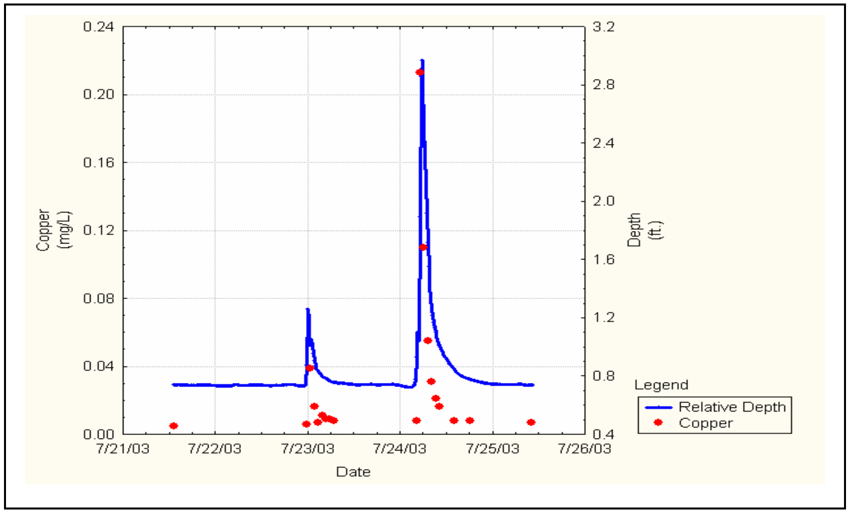

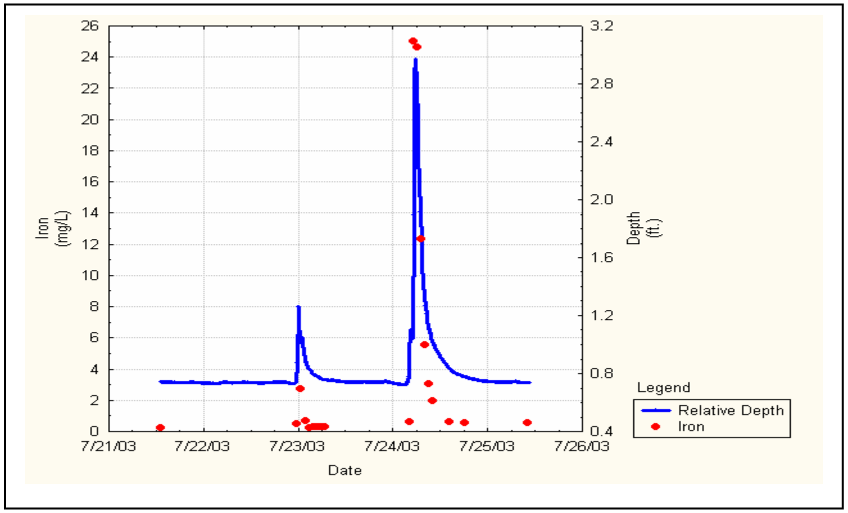

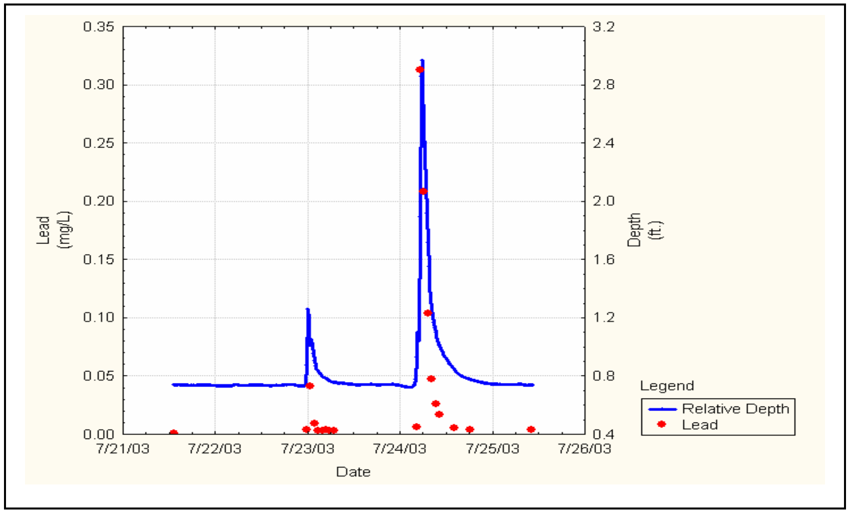

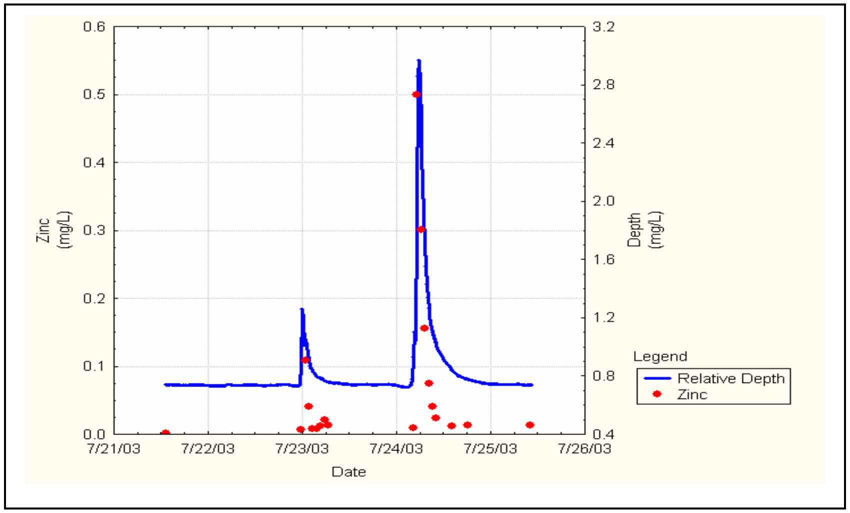

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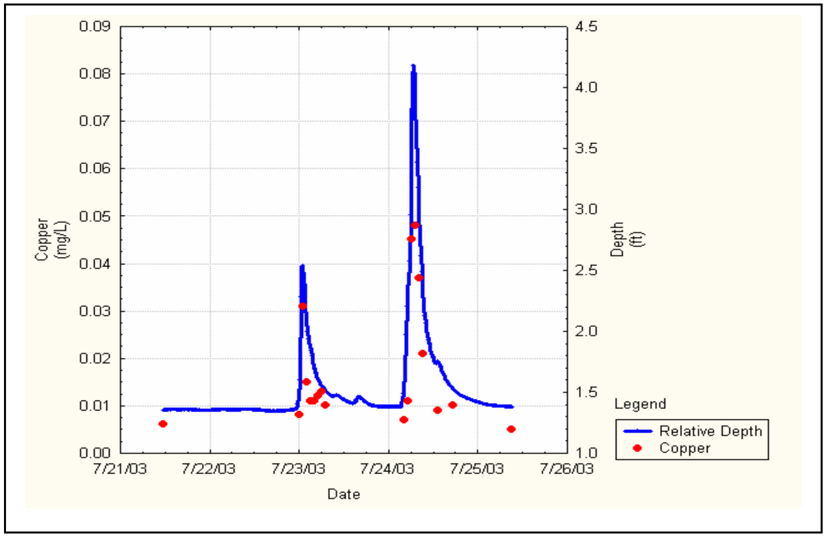

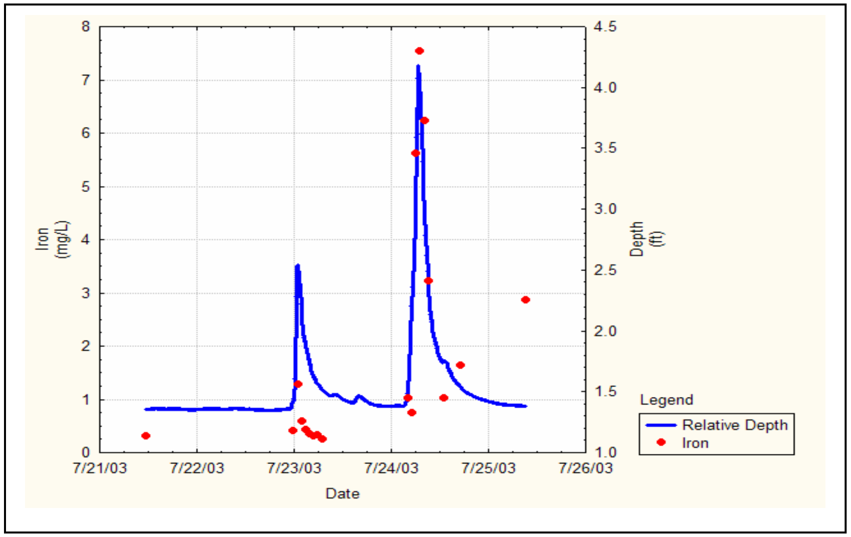

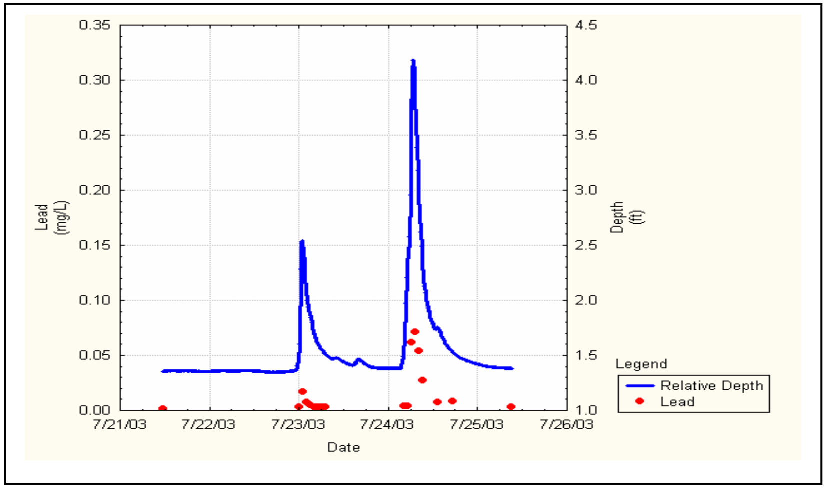

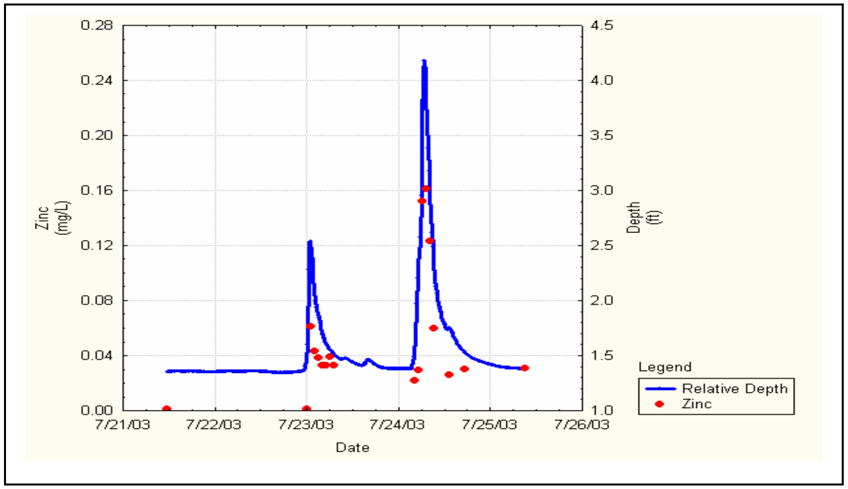

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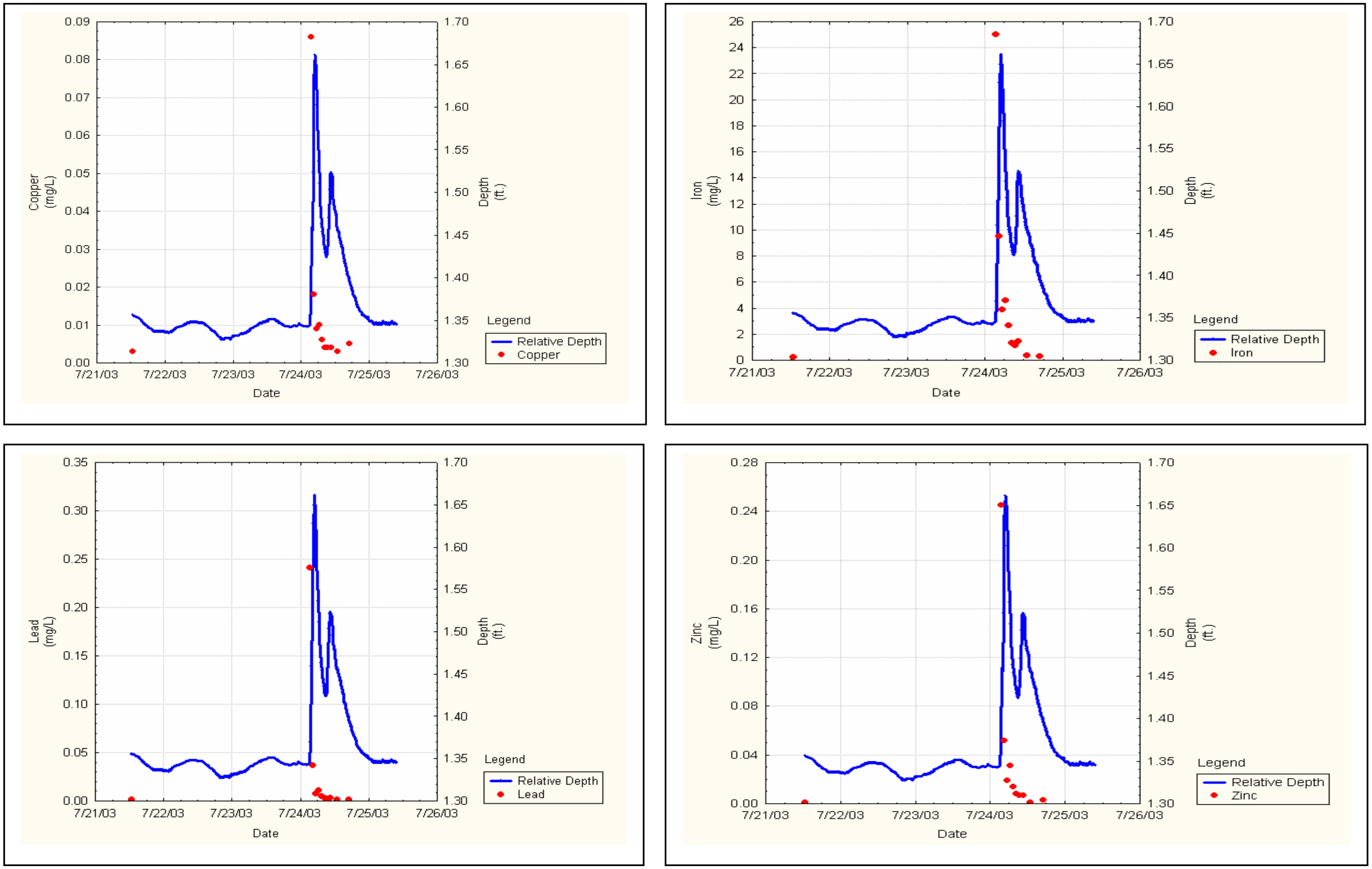

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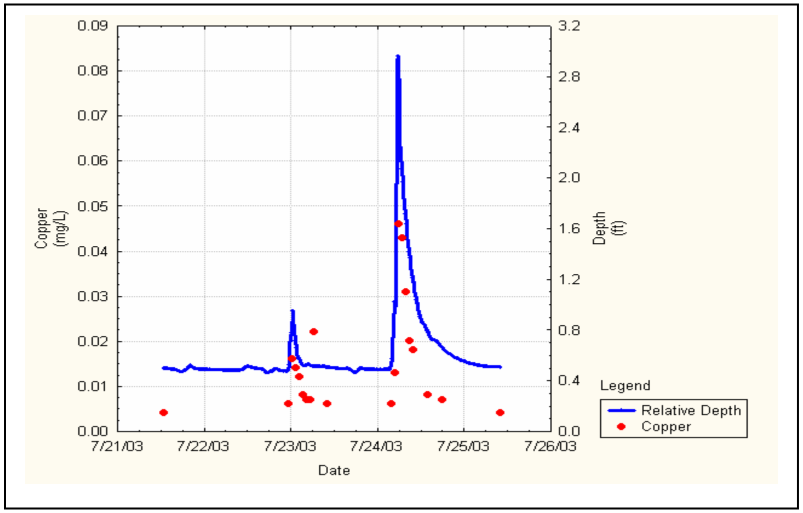

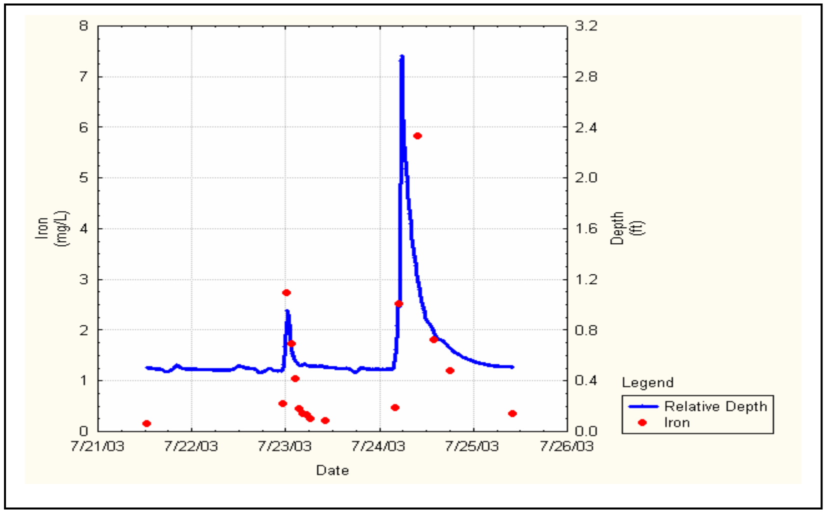

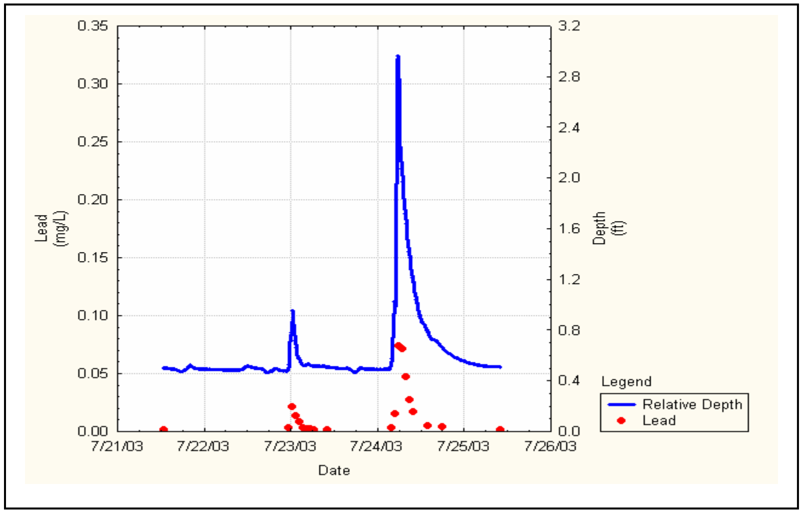

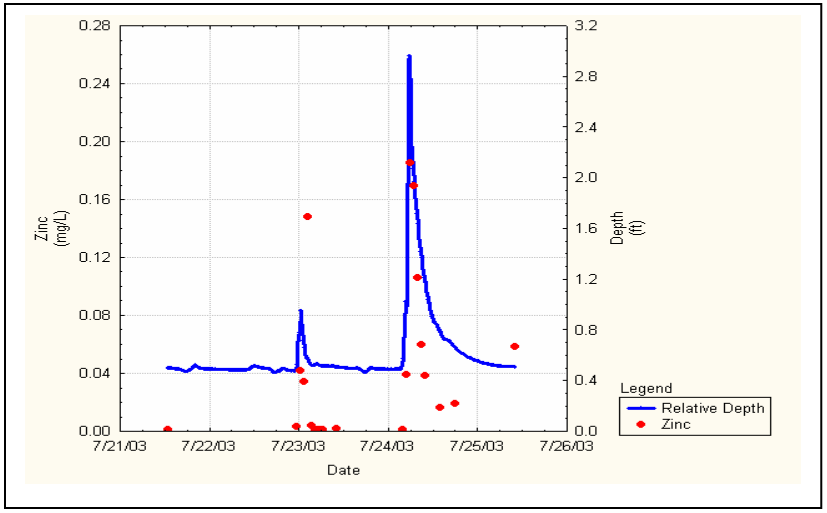

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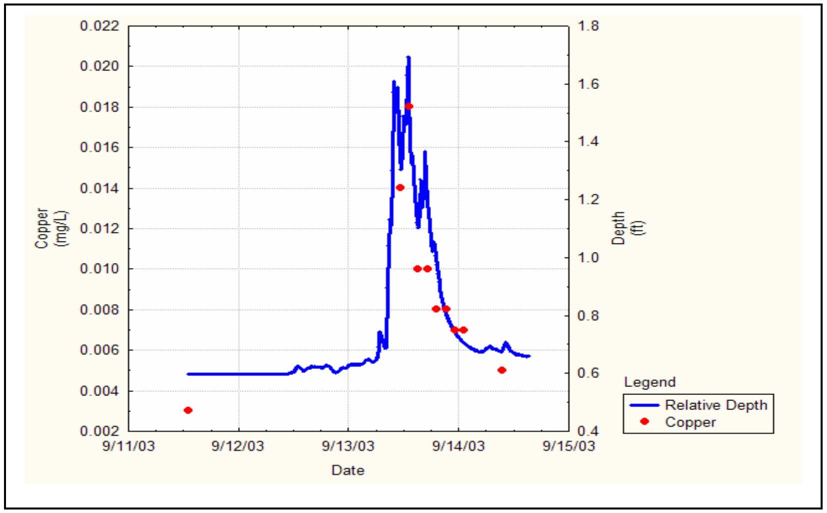

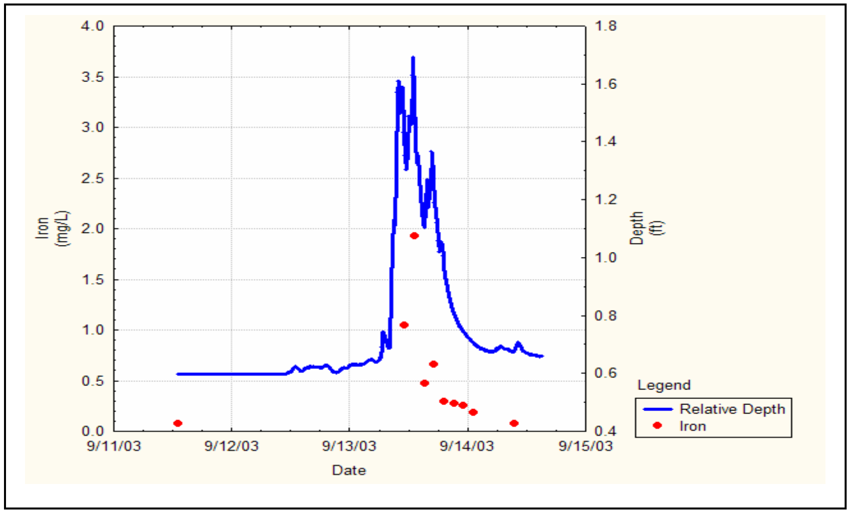

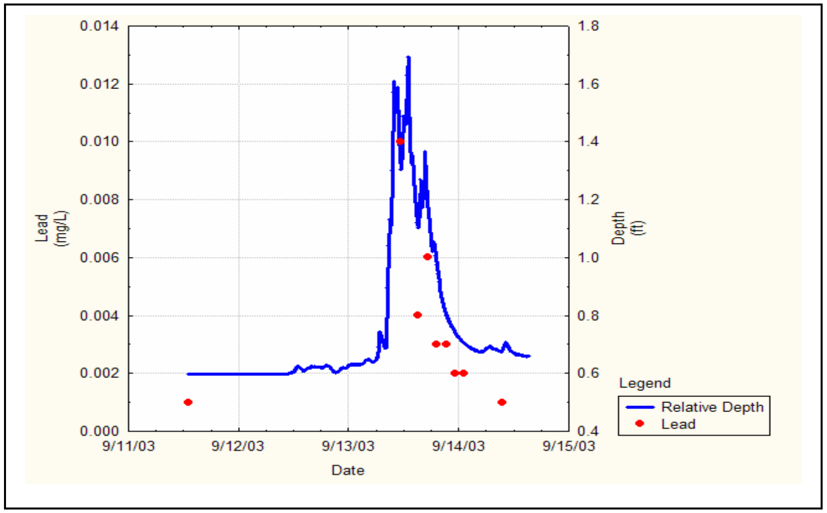

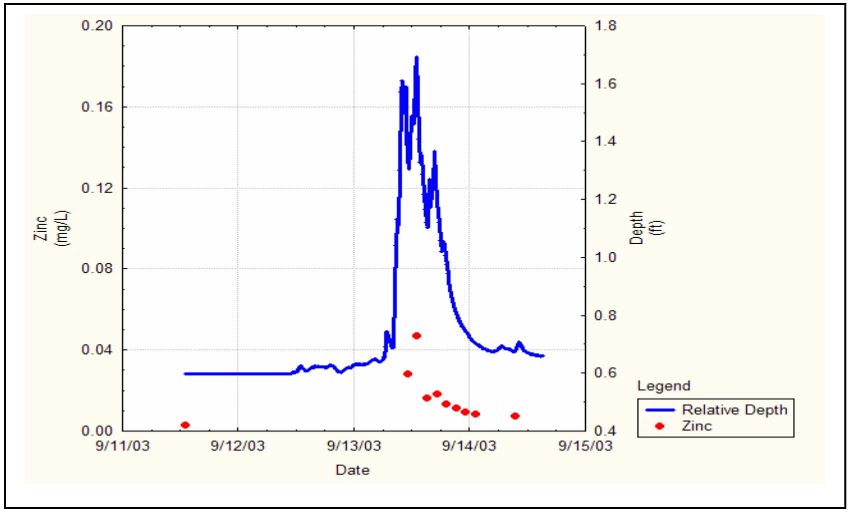

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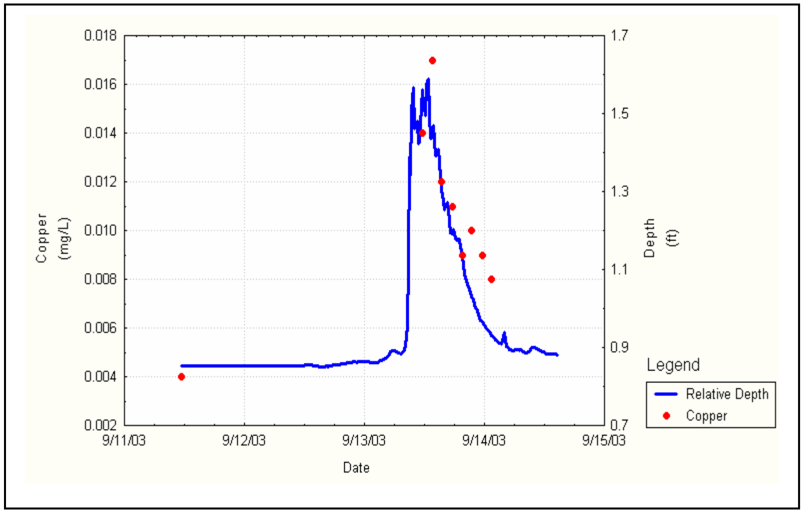

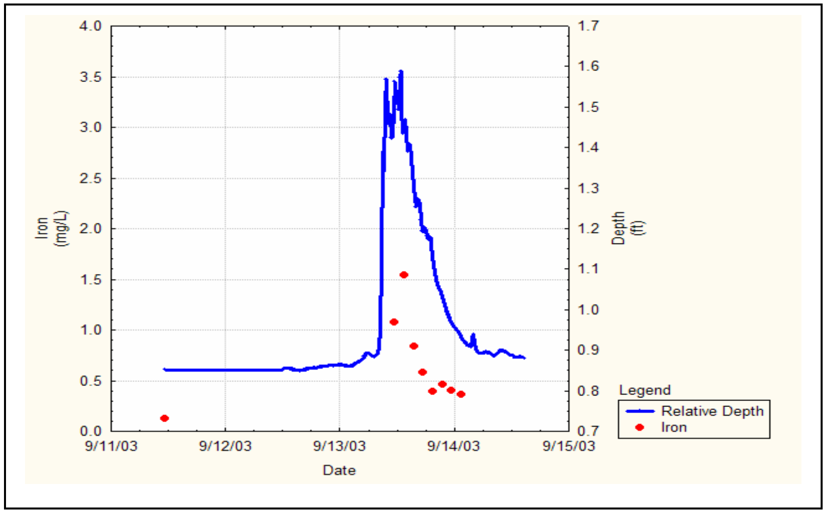

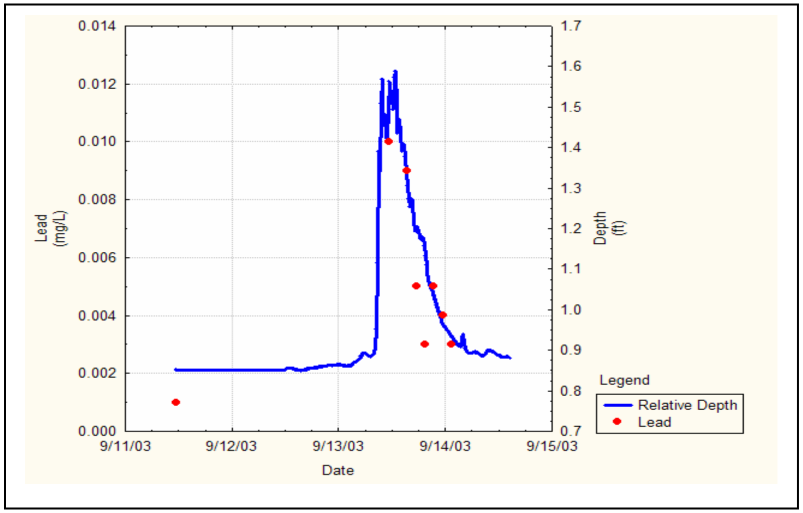

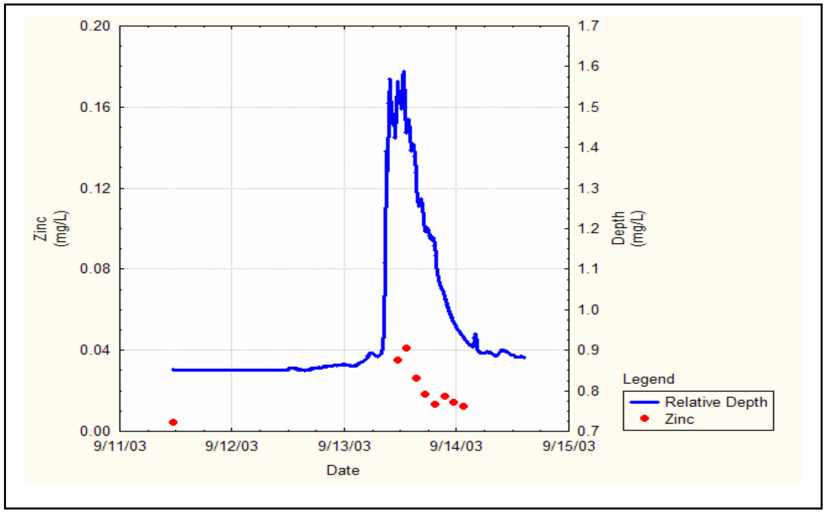

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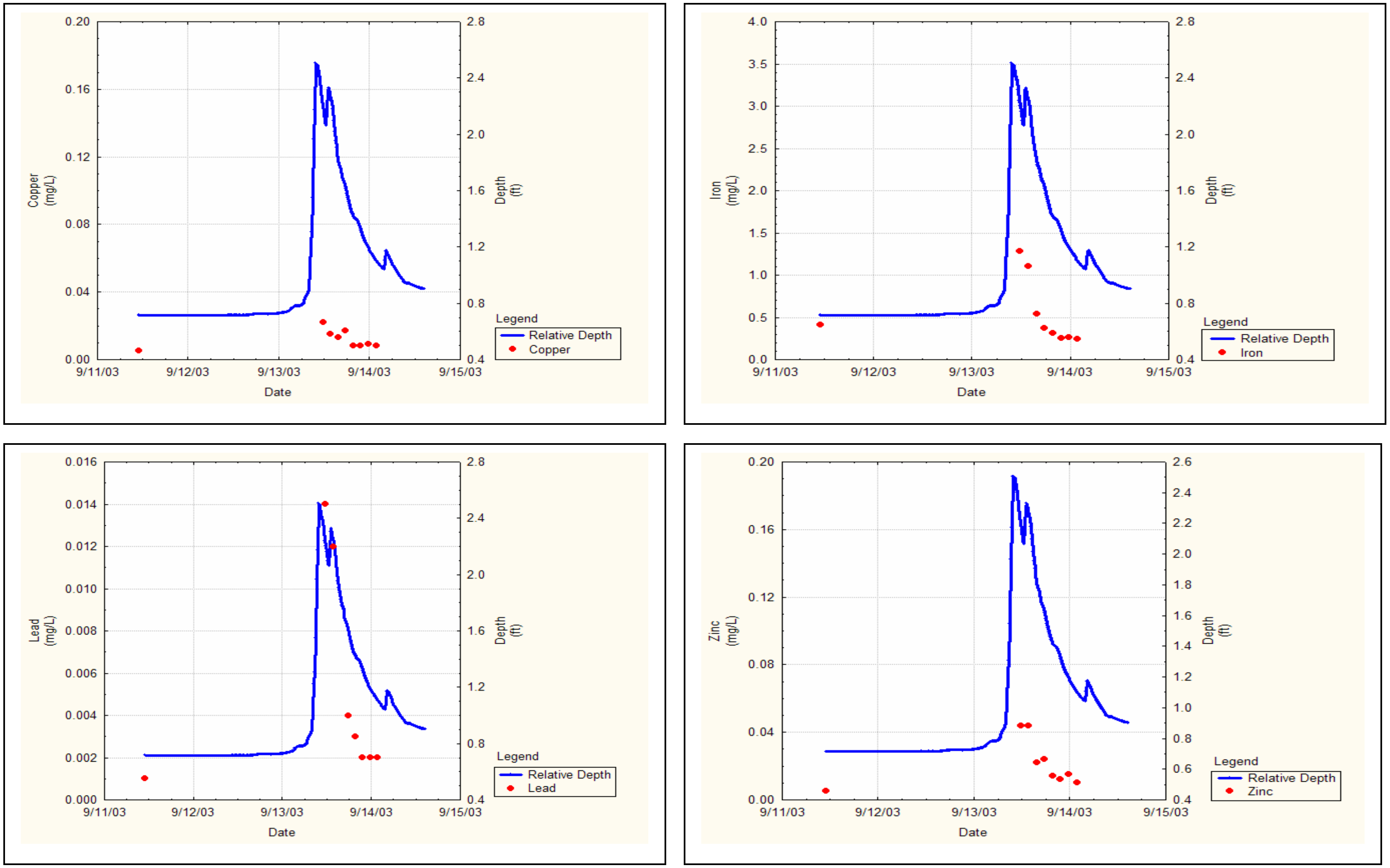

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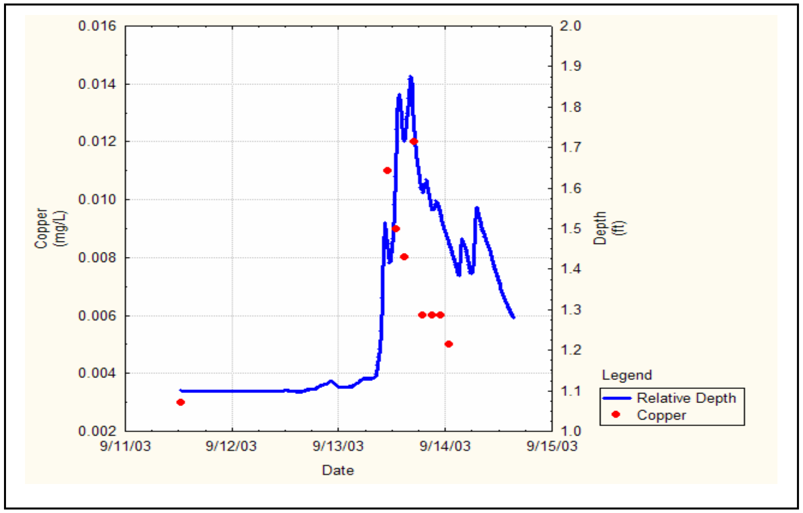

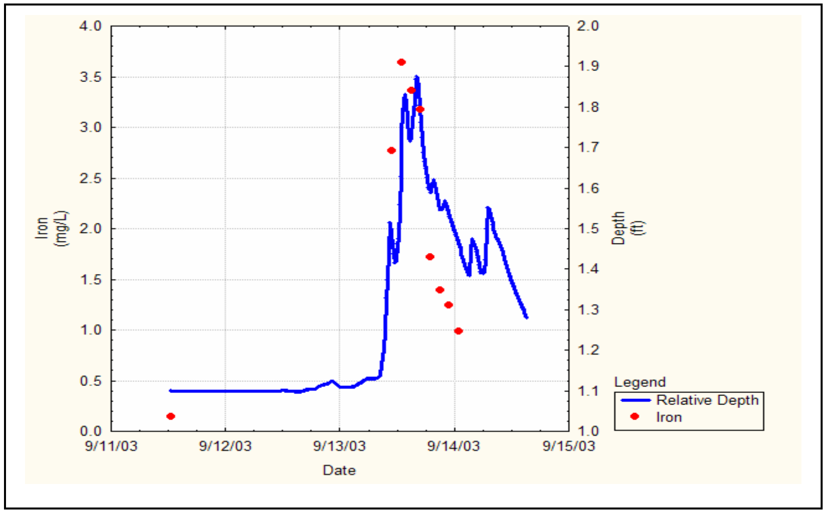

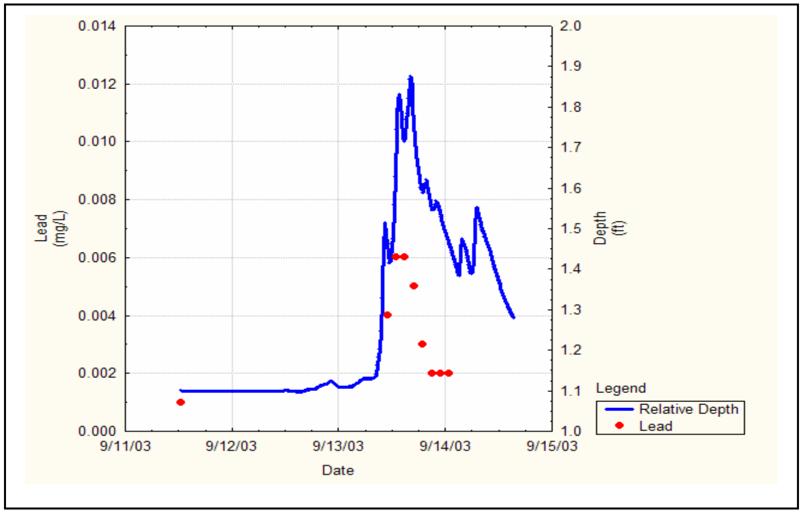

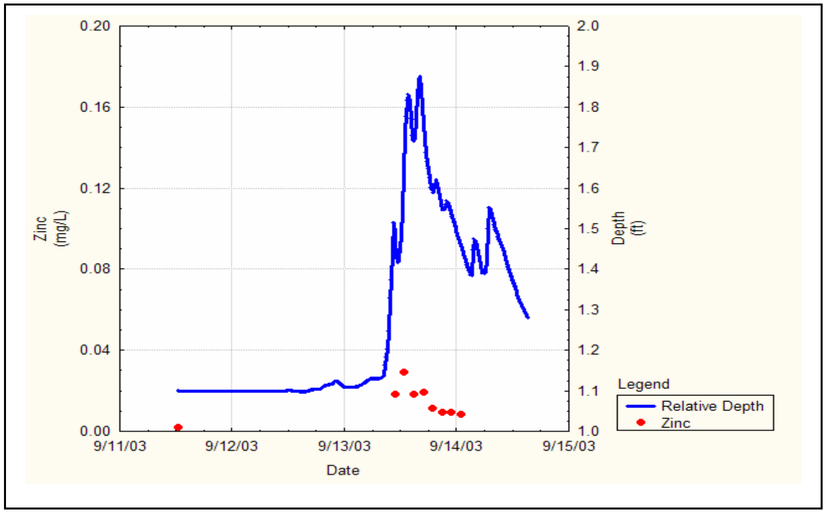

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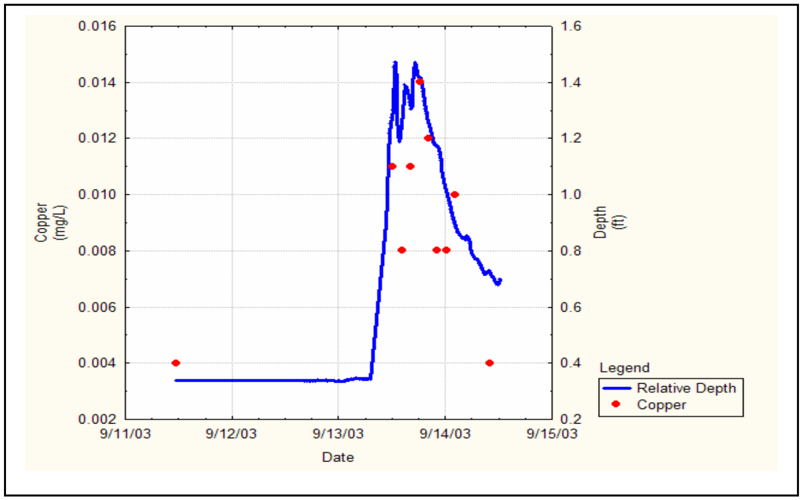

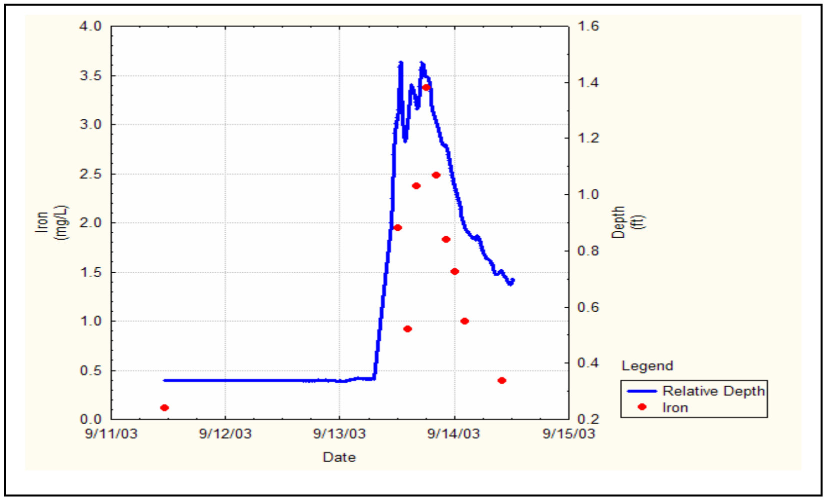

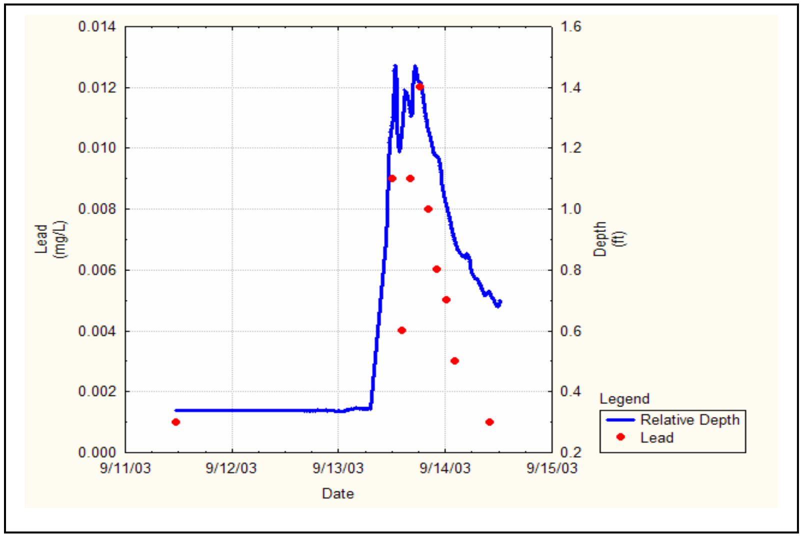

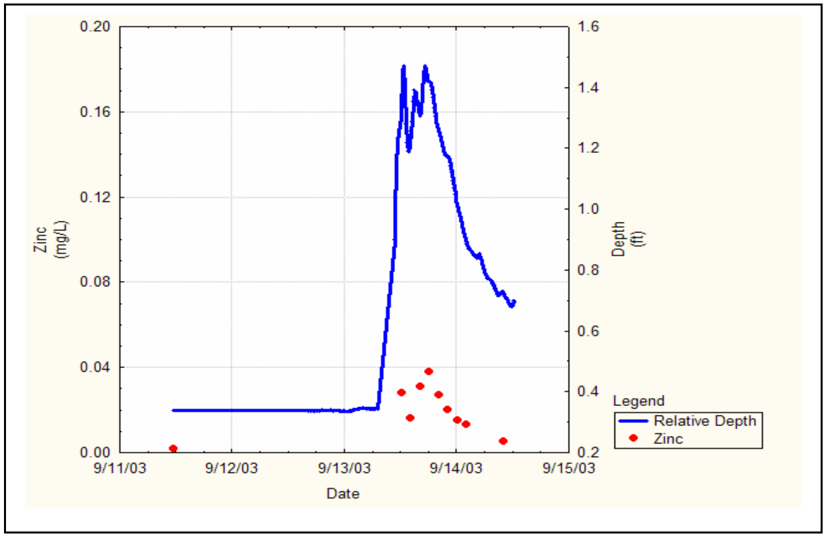

Philadelphia Combined Sewer Overflow Long Term Control Plan Update

Supplemental Documentation
Volume 15

Cobbs Creek Integrated Watershed Management Plan

Updated: September 1, 2009

Cobbs Creek Integrated Watershed Management Plan

October 2004

Prepared by:

Philadelphia Water Department
Darby-Cobbs Watershed Partnership

Darby-Cobbs Watershed

Tookany/Tacony-Frankford

Wissahickon Watershed

Pennypack Watershed

Poquessing Watershed

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Cobbs Creek Integrated Watershed Management Plan

Darby-Cobbs Watershed Partnership Mission Statement

"To improve the environmental health and safe enjoyment of the Darby-Cobbs watershed by sharing resources through cooperation of the residents and other stakeholders in the watershed. The goals of the initiative are to protect, enhance, and restore the beneficial uses of the Darby-Cobbs waterways and riparian areas. Watershed management seeks to mitigate the adverse physical, biological, and chemical impacts of land uses as surface and groundwater are transported throughout the watershed to the waterways."

Executive Summary

Foreword

This plan presents a logical and affordable pathway to restore and protect the beneficial and designated uses of the waters of the Cobbs Creek basin. Based on extensive physical, chemical and biological assessments, the plan explores the nature, causes, severity and opportunities for control of water quality impairments in the Cobbs Creek watershed. The primary intent of the planning process, as articulated by the stakeholders, is to improve the environmental health and safe enjoyment of the Cobbs watershed by sharing resources and through cooperation among residents and other stakeholders in the watershed. The goals of the initiative are to protect, enhance, and restore the beneficial uses of the Cobbs waterways and its riparian areas. The plan recommends appropriate remedial measures for the Cobbs Creek basin, provides a financial commitment to initiate the implementation of the plan, and seeks to provide the impetus for stakeholders of the Darby basin to follow suit.

The Darby-Cobbs Watershed Partnership worked with the Philadelphia Water Department to complete a comprehensive, multi-year watershed assessment covering the Darby, Cobbs, and Tinicum sub-basins (see Figure E-1). Results of the watershed-wide assessment suggests that at some times during dry weather periods, bacteria contamination of the Cobbs's waters prevents the achievement of water quality standards that would support swimming or other forms of primary contact recreation in the creek. Also, stream aesthetics, accessibility and safety are compromised due to illegal litter and dumping, trash from stormwater discharges, and bank deterioration along the stream corridors. Existing aquatic and riparian habitat, degraded by urban runoff, limit the diversity of fish and benthic life and prevent the development of healthy living resources conditions necessary to support recreational activities such as fishing. Wet weather water quality is limited by bacteria discharged from combined and separate storm sewers. High rates of urban runoff cause flood flows that erode the stream banks and bottoms and expose and compromise utility infrastructure.

The good news is that measurable progress can be made towards restoring the legislated designated beneficial uses of the stream. To this end, this plan provides an investment strategy for achieving definable levels of environmental return in the Cobbs Creek basin. It is estimated that significant progress towards improving the areas of environmental concern discussed above can be made for an investment of less than $100 per household per year over a 20-year horizon. The plan proposes that the other municipalities in the Cobbs basin make similar financial commitments to implementation that will ensure the restoration and preservation of the waters that flow from and through their communities, shaping their quality of life along the way. A significant portion of this funding is directed towards work that reflects the widely recognized national need to renew our water resources infrastructure. These efforts basically are things that should be done anyway. It is proposed that a combination of Federal, state, local government, and private funding be brought to bear to implement this plan. The Philadelphia Water Department expended over $1 million in the development of the plan, and will commit $2 million per year or more towards implementing its recommendations over the next 20 years. The plan proposes that the other municipalities in the Cobbs basin make similar financial commitments to implementation that will ensure the restoration and preservation of the waters that flow from and through their communities.

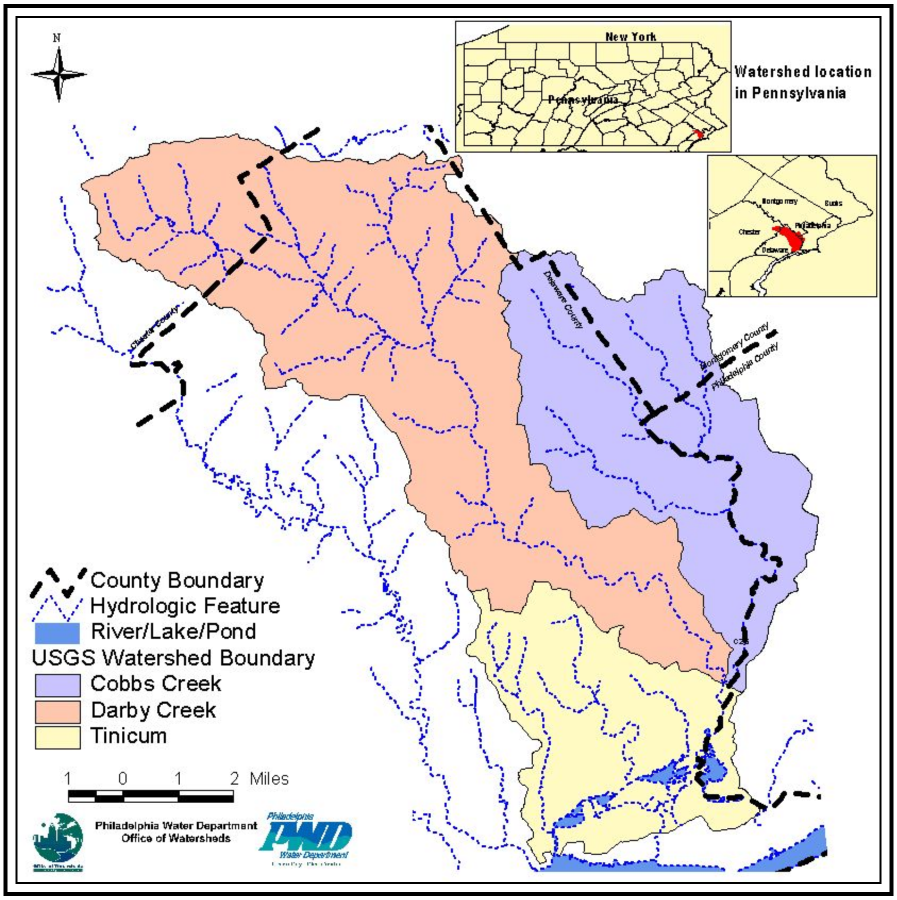


Figure E-1: Darby-Cobbs Watershed. This plan summarizes the results of watershed assessment activities in the Darby, Cobbs, and Tinicum basins. Detailed planning, alternatives analysis, and recommendations are provided for the Cobbs basin. The plan recommends appropriate measures for the Cobbs Creek basin and seeks to provide an example for stakeholders in the Darby and Tinicum basins to follow.

Introduction

Stewardship of a river must be built around the needs of the community. It will grow by making visible the critical way the health of the watershed is integral to basic quality of life issues. Once the seeds of stewardship have been planted, members of the community can be recruited to take action in protecting their watershed. In 1999, The Philadelphia Water Department (PWD) acted as the municipal sponsor of the Darby-Cobbs Watershed Partnership, an exciting and groundbreaking effort to connect residents, businesses and government as neighbors and stewards of the watershed. Since then, the Partnership has been active in developing a vision for the watershed and guiding and supporting subsequent planning activities within both the Darby and Cobbs sub-watersheds.

PWD, with the support of the Darby-Cobbs Watershed Partnership, has just completed a multi-year watershed planning effort to restore the Cobbs Creek Watershed to one that can boast fishable, swimmable and enjoyable streams. The planning process and implementation recommendations are contained in the recently completed Cobbs Creek Integrated Watershed Management Plan (CCIWMP). This executive summary presents the major findings of the CCIWMP.

Background

The Darby-Cobbs Watershed Partnership first worked with PWD to complete a comprehensive, multi-year watershed assessment covering the Darby, Cobbs, and Tinicum drainage basins (see Figure E-1). The assessment provides a snapshot of current conditions in the watershed, and lays the groundwork for the development of more detailed plans to improve conditions in each of the sub-basins within the Darby-Cobbs watershed. With portions of the Cobbs Creek watershed served by combined sewers, and with significant interest from the Partnership in improving water quality and riparian habitat conditions, PWD then took the next step by leading the development of the CCIWMP. During the stakeholder process, the Pennsylvania Environmental Council drafted a resolution for the partnership to establish common ground for municipal coordination required for the plan to be successful. The resolution and its signatories are reprinted below.

Partnership Resolution

Whereas, the Darby Creek watershed and its tributaries, the largest of which is the Cobbs Creek, constitute an important natural resource by providing aquatic and terrestrial habitat, an important cultural and historical resource with many key sites throughout the watershed, an important recreational resource providing fishing opportunities, and parkland for exploration and relaxation; and

Whereas, the Darby Creek and its tributaries have been degraded by development and historical absence of municipal stormwater management controls contributing to damaging floods, extensive erosion and low flows in times of drought; and

Whereas, the Pennsylvania Department of Environmental Protection has determined through its biological assessment process that the water quality of certain segments of the Darby Creek and its tributaries have become impaired; and

Whereas, various studies are underway to guide conservation and improvement of the Darby Creek including a Rivers Conservation Management Plan (under the auspices of the Darby Creek Valley Association), a Stormwater Management Plan prepared pursuant to the Stormwater Management Act of 1978; and

Whereas, cooperative action taken in coordination with municipalities and citizens located both up and downstream in the watershed is the key to enhancing the value of the Darby Creek for all its residents; and

Whereas, the Darby-Cobbs Watershed Partnership was created to serve that purpose and provides a structure for watershed-based planning and action to conserve and to improve the environmental health and safe enjoyment of the watershed; and

Whereas, the Darby-Cobbs Watershed Partnership will work to eliminate the impairment of the stream segments and restore the watershed to its unimpaired state for uses so designated by the Department of Environmental Protection.

Therefore, it is resolved that the «Governing_Body» does hereby declare support for the Darby-Cobbs Watershed Partnership and act freely to join as a Watershed Partner,

Furthermore, the «Governing_Body» does resolve to appoint a liaison who will participate in the Partnerships' conservation planning and action programs and will regularly (at the discretion of this body) provide reports on the Partnerships' activities.

Resolution Signatories

Counties:	Chester, Delaware, Philadelphia
Municipalities:	Colwyn Borough, East Lansdowne Borough, Folcroft Borough, Lansdowne Borough, Marple Township, Newtown Township, Radnor Township, Ridley Township, Sharon Hill Borough, Tinicum Township, Upper Darby Township, Lower Merion Township, Springfield Township, City of Philadelphia

With the addition of this plan, the watershed communities now have a blueprint for restoring this urban stream into a community asset, while making significant progress toward improving water quality during both dry and wet weather.

The primary intent of the plan, as articulated by the stakeholders, is to mitigate wet weather impacts caused by urban stormwater runoff and combined sewer overflow (CSO), identify ways to improve water quality, aesthetics, and recreational opportunities in dry weather; and restore living resources in the stream and along the stream corridor. PWD placed a high priority on the development of the CCIWMP because it represents one of the three major components of the City of Philadelphia's CSO Long Term Control Plan (LTCP) strategy. This component entails a substantial commitment by the City to watershed planning to identify long term improvements throughout its watersheds, including any additional CSO controls that will result in an improvement to water quality and, ultimately, the attainment of water quality standards.

PWD was not alone in this planning effort. Significant support from other agencies helped to fund various pieces of the plan in order to better integrate the planning effort with other regulatory programs. The USEPA provided funding under a Section 104(b)(3) Water Quality Cooperative Agreement, money that helped PWD to develop the modeling framework that underlies much of the analysis in the plan. USEPA also provided Wetland Program Grant money to help assess existing wetlands within Cobbs Creek and provide basic data for developing wetland restoration projects. PADEP provided funding, through a Growing Greener Grant, to partially fund stream assessment and restoration along a stretch of Cobbs Creek near Marshall Road. Through Act 167 money, PADEP also funded PWD modeling and analysis to support stormwater planning. Finally, initial planning efforts and the development of planning goals, embodied in a Rivers Conservation Plan, were funded by PA-DCNR.

At the outset, there was insufficient physical, chemical, and biological information on the nature and causes of water quality impairments, sources of pollution, and appropriate remedial measures for the Cobbs Creek. The lack of information made it impossible to determine what needed to be done for additional CSO control or control of other wet weather sources throughout the watershed. Lack of sufficient information is not unique to Cobbs Creek. In fact recognition of this deficiency, especially with respect to the effects of wet weather discharges and receiving water dynamics, has increased nationwide and led to a broader recognition of the need for watershed-based planning and management to properly define water quality standards and goals.

The USEPA Long Term Control Planning Guidance suggests that the sources of watershed pollution and impairment, in addition to CSOs, are varied and include other point source discharges; discharges from storm drains; overland runoff; habitat destruction; land use activities, such as agriculture and construction; erosion; and septic systems and landfills. The Guidance notes that the major advantage in using a watershed-based approach to develop a LTCP is that it allows the site-specific determination of the relative impacts of CSOs and non-CSO sources of pollution on water quality.

Plan Goals

Considerable stakeholder input towards developing watershed goals was sought from the beginning of this planning effort. Stakeholder input was primarily organized through the Partnership, which reached consensus on a set of planning goals and objectives. In addition, the plan sought to integrate goals derived from other relevant regulatory programs and plans to more fully achieve the ideal of integrated water resource planning. The resulting integrated planning goals, and their relation to the major regulatory programs, are summarized in Table E-1.

Table E-1 Regulatory Support for Stakeholder Goals for the Cobbs Creek Watershed

Goal Description	Act 167 Stormwater	Act 537 Sewage Facilities	TMDL Program	NPDES Stormwater	CSO Program	RCP
Streamflow and Living Resources. Reduce the impact of urbanized flow on the living resources to meet designated uses	x					x
Stream Habitat and Aquatic Life. Improve stream habitat and indices of aquatic integrity.			x	x	x	x
Stream Channels and Banks. Reduce streambank and stream channel deposition and scour to protect and restore the natural functions of aquatic habitat and ecosystems, streambanks, and stream channels.	x					x
Flooding. Decrease flooding.	x					x
Water Quality. Improve dry and wet weather stream quality.		x	x	x	x	x
Pollutant Loads. Decrease pollutant loads to surface waters.		x	x	x	x	x
Stream Corridors. Protect and restore stream corridors, buffers, floodplains, and natural habitats including wetlands.						x
Quality of Life. Enhance community environmental quality of life.	x	x	x	x	x	x
Stewardship. Foster community stewardship.				x	x	x
Coordination. Improve inter-municipal, inter-county, state-local, and stakeholder cooperation and coordination on a watershed basis.	x		x	x	x	x

Planning Approach

Once the Partnership had established the goals and objectives for the CCIWMP, a planning approach was designed to achieve the desired results through a cooperative effort between Philadelphia and the other watershed municipalities. The approach has four major elements:

- Data collection, organization and analysis
- Systems description
- Problem identification and development of plan objectives
- Strategies, policies and approaches

Figure E-2 summarizes the primary steps of the planning process. The right column shows the sections of the plan relevant to each step in the planning process.

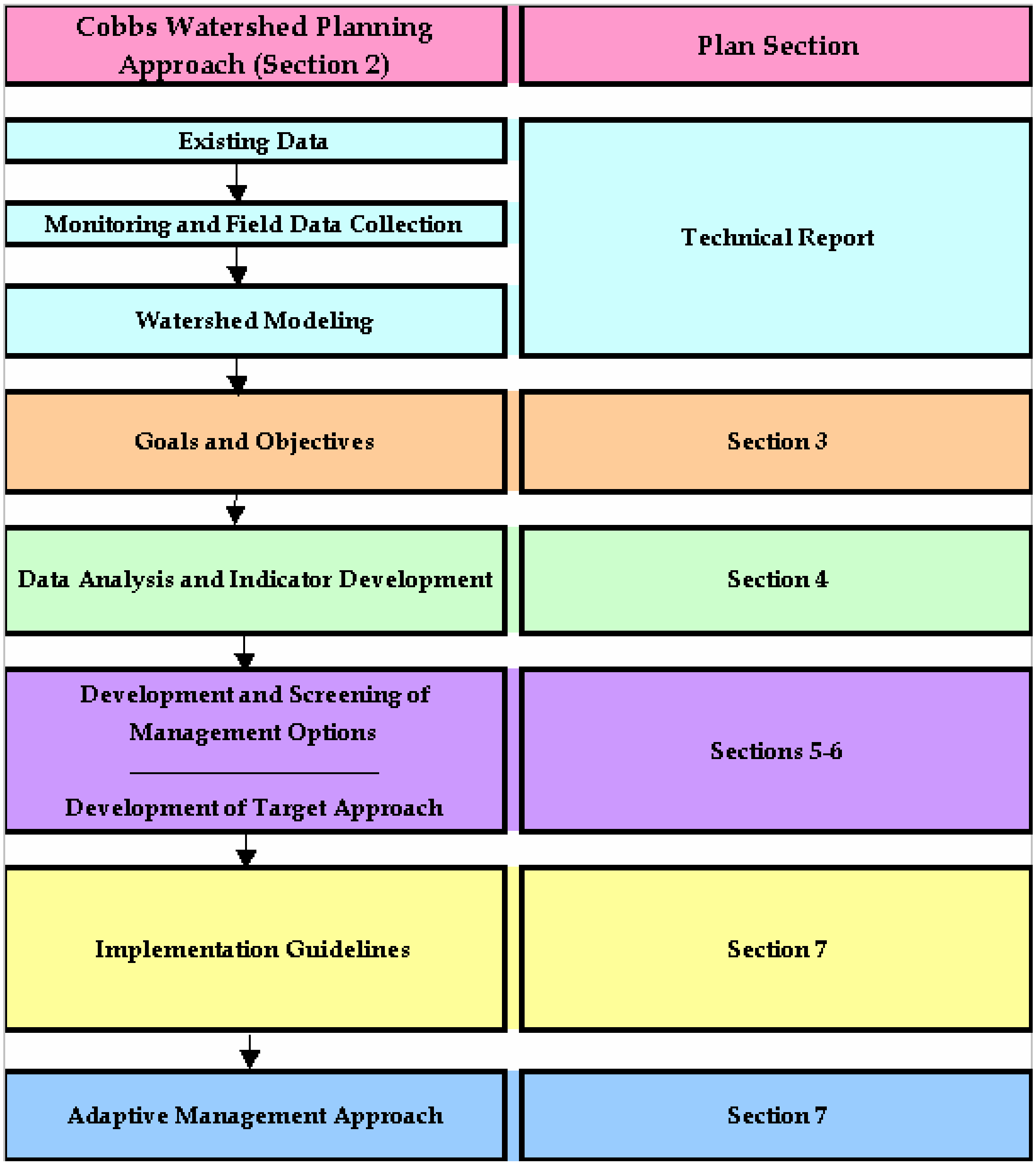


Figure E-2: Cobbs Planning Approach

Watershed Status and Problem Identification

An important aspect of the watershed management plan is a basic description of existing conditions within the watershed and streams. To accomplish this, a series of indicators were developed to represent the results of the data collection efforts and the data analysis and modeling. An indicator is a measurable quantity that characterizes the current state of at least one aspect of watershed health. The indicators were selected for their potential use both in assessing current conditions and assessing future progress in improving conditions.

Through the extensive field studies, modeling, and data analysis, the highest priority problems in the Cobbs Creek were identified, and the means for addressing the problems were developed. Given that the Cobbs Creek watershed is a highly urbanized watershed with both CSOs and significant stormwater flows, some of the highest priority problems included:

Dry Weather Water Quality and Aesthetics

- Water quality concerns including high fecal coliform during dry weather
- Dry weather sewage flows in separate sewered areas
- Trash-filled, unsightly streams that discourage residential use.
- Safety concerns along streams and stream corridors

Healthy Living Resources

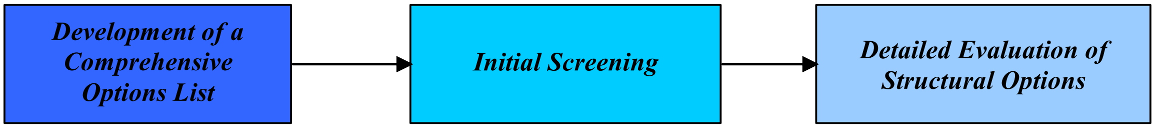
- Degraded aquatic and riparian habitats
- Limited diversity of fish and benthic life
- Periodic, localized occurrences of low dissolved oxygen primarily associated with plunge pools and areas of stagnant water behind dams
- Utility infrastructure threatened by bank and streambed erosion
- Limited public awareness and sense of stewardship for Cobbs Creek

Wet Weather Water Quality and Quantity

- Water quality concerns including high fecal coliform during wet weather, and nutrients and metals during wet weather flows
- CSO impacts on water quality and stream channels
- Little volume control and treatment of stormwater flows in separate sewered areas

Development and Screening of Management Options

Lists of management measures, called options, were developed to address the identified problems and to meet each of the goals and objectives established for the Cobbs Creek watershed. Only those options deemed feasible and practical for Cobbs Creek were considered in the final list of management options. Options were developed and evaluated in three steps:



Since the plan cannot prescribe actions to be undertaken by all the participants in the planning process, recommendations and guidelines for implementation were developed. Modeling and other analyses were used to develop six alternatives, each with a different approach and cost to achieve the goals and objectives. From an analysis of these six alternatives, the final recommendations were made.

Implementation Approach

In developing watershed management alternatives and discussing goals and objectives with stakeholders, it became clear that implementation could best be achieved by defining three distinct targets to meet the overall plan objectives. Two of the targets (A and B) were defined so that they could be fully met with a limited set of options that are fully implemented. For the third target (C), it was agreed to set interim objectives, recommend measures to achieve the interim objectives, implement those controls, and monitor and reassess the effectiveness of the plan in meeting the objectives.

TARGET A: Dry Weather Water Quality and Aesthetics

The first target is to meet water quality standards in the stream during dry weather flows. Target A was defined for Cobbs Creek with a focus on trash removal and litter prevention, and the elimination of sources of sewage discharge during dry weather.

TARGET B: Healthy Living Resources

Improvements to the number, health, and diversity of the benthic invertebrate and fish species in the Cobbs Creek will require investment in habitat improvement and measures to provide the opportunity for organisms to avoid high velocities during storms. Improving the ability of an urban stream to support viable habitat and fish populations must focus primarily on the elimination or remediation of the more obvious impacts of urbanization on the stream. These include loss of riparian habitat, eroding and undercut banks, scoured streambed or excessive silt deposits, channelized and armored stream sections, trash buildup, and invasive species.

TARGET C: Wet Weather Water Quality and Quantity

The third target is to restore water quality to meet fishable and swimmable criteria during wet weather and address flooding issues. Improving water quality and flow conditions during and immediately following storms is the most difficult target to meet in the urban environment. The only rational approach to achieve this target must include stepped implementation with interim targets for reducing wet weather pollutant loads and stormwater flows, along with monitoring for the efficacy of control measures.

Initial load reduction targets for parameters such as stormwater flow, metals, total suspended solids, and bacteria were set in conjunction with the stakeholders. Based on preliminary work by PWD, 20% reductions are a challenging but achievable interim target.

Implementation Guidelines

All measures or options were thoroughly screened and evaluated using a variety of approaches, including modeling, cost-effectiveness screening, and the use of a computerized multi-criteria evaluation tool. This resulted in the selection of only those options appropriate and deemed effective for the particular conditions found in the Cobbs Creek watershed. The implementation guidelines seek to present the options in such a way that each major stakeholder or responsible party understands what is expected. The guidelines are designed such that, if implementation follows the recommendations, all plan objectives associated with Targets A and B will be fully met, and the interim objectives for Target C will be met or exceeded.

In the plan, options are fully described, and the expected level of implementation is provided. Where possible, the locations where implementation is expected are also indicated. Implementation guidelines are presented in this executive summary in a series of tables. First, options are grouped by the party responsible for implementation. Second, options are grouped according to their applicability to the implementation targets. Finally, tables of planning level costs are provided.

Recommendations by Responsible Party

These summary tables present the recommended actions grouped according to the agency or organization primarily responsible for implementation. Tables E-2 through E-4 present the recommended actions for Philadelphia, Delaware, Montgomery, and Chester Counties; and PADEP.

Table E-2 Philadelphia Actions

Action	Where	When
Pet Waste, Litter, and Dumping Ordinances	Watershed-wide	Short-term
Public Education	Watershed-wide	Short-term
School-Based Education	All schools	Short-term
Public Participation and Volunteer Programs	Watershed-wide	Short-term
Inspection and Cleaning of Combined Sewers	Watershed-wide	Short-term
Combined Sewer Rehabilitation	Combined-Sewered Areas	Medium-term
Stream Cleanup and Maintenance	Cobbs Creek within or along City boundary	Short-term
Enhancing Stream Corridor Recreational and Cultural Resources	Along the stream corridor	Medium-term
Bed Stabilization and Habitat Restoration	Cobbs Creek 40%, West Indian Creek 44%	Short-term
Bank Stabilization and Habitat Restoration	Middle section of Cobbs Creek	Short-term
Channel Realignment and Relocation	Cobbs Creek, East and West Indian Creek	Short-term
Plunge Pool Removal	CSO and stormwater outfalls	Short-term
Improvement of Fish Passage	Woodland Avenue dam	Short-term
Wetland Creation	Riparian corridor	Short-term
Invasive Species Management	Riparian corridor	Short-term
Reforestation	Riparian corridor	Short-term
Requiring Better Site Design in Redevelopment	Watershed-wide	Short-term
Stormwater and Floodplain Management	Watershed-wide	Short-term
Post-Construction Stormwater Runoff Management	Municipalities required to do Phase II permit	Short-term
Sanitary Sewer Overflow Detection	Separate-Sewered Areas	Short-term
Sanitary Sewer Overflow Elimination: Structural Measures	Separate-Sewered Areas	Medium-term
CSO Control Program	Philadelphia combined sewer system	Short-term
Catch Basin and Storm Inlet Maintenance	All inlets	Short-term
Street Sweeping (Philadelphia Streets Department)	Streets and Parking Lots	Short-term
Responsible Landscaping on Public lands	Green space	Short-term
Responsible Bridge and Roadway Maintenance	Roadways and bridges	Short-term
Reducing Effective Impervious Cover through Better Site Design	Watershed-wide	Long-term
Increasing Urban Tree Canopy	Watershed-wide	Medium-term
Porous Pavement and Subsurface Storage	Parking lots watershed-wide	Long-term
Green Rooftops	Appropriate public buildings chosen by PWD	Medium-term
Capturing Roof Runoff in Rain Barrels or Cisterns	Homes where dry wells are not feasible	Medium-term
Maintaining/Retrofitting Existing Stormwater Structures	Watershed-wide	Short-term
Retrofitting Existing Sewer Inlets with Dry Wells	Inlets in combined-sewered areas	Long-term
Residential Dry Wells, Seepage Trenches, and Water Gardens	Homes and schools watershed-wide	Long-term
Bioretention Basins and Porous Media Filtration	Watershed-wide	Long-term
Treatment Wetlands: Onsite and Regional	Riparian corridor	Medium-term
Monitoring and Reporting	Watershed-wide	Ongoing

Table E-3 Delaware and Montgomery County Municipality Actions

Action	Where	When
On-Lot Disposal (Septic System) Management	All areas with septic systems	Short-term
Pet Waste, Litter, and Dumping Ordinances	Watershed-wide	Short-term
Public Education	All Cobbs Creek municipalities	Short-term
School-Based Education	All schools	Short-term
Public Participation and Volunteer Programs	All Cobbs Creek municipalities	Short-term
Capacity Management Operation and Maintenance	Separate-Sewered Areas	Short-term
Inspection and Cleaning of Sanitary Sewers	Separate and Combined Sewered Areas	Short-term
Sanitary Sewer Rehabilitation	Separate-Sewered Areas	Medium-term
Illicit Discharge, Detection, and Elimination (IDD&E)	All areas with a storm or combined sewer.	Short-term
Stream Cleanup and Maintenance	Cobbs Creek within or along City boundary	Short-term
Enhancing Stream Corridor Recreational and Cultural Resources	Along the stream corridor	Medium-term
Bed Stabilization and Habitat Restoration	Cobbs Creek 40%, West Indian Creek 44%	Short-term
Bank Stabilization and Habitat Restoration	Middle section of Cobbs Creek	Short-term
Channel Realignment and Relocation	Cobbs Creek, East and West Indian Creek	Short-term
Plunge Pool Removal	CSO and stormwater outfalls	Short-term
Improvement of Fish Passage	Woodland Avenue dam	Short-term
Wetland Creation	Riparian corridor	Short-term
Invasive Species Management	Riparian corridor	Short-term
Reforestation	Riparian corridor	Short-term
Requiring Better Site Design in Redevelopment	Watershed-wide	Short-term
Stormwater and Floodplain Management	Watershed-wide	Short-term
Post-Construction Stormwater Runoff Management	Municipalities required to do Phase II permit	Short-term
Sanitary Sewer Overflow Detection	All areas with separate sewers	Ongoing program
Reduction of Stormwater Inflow and Infiltration to Sanitary Sewers	Separate-Sewered Areas	Medium-term
Catch Basin and Storm Inlet Maintenance	All inlets	Ongoing program
Street Sweeping	Streets and Parking Lots	Short-term
Responsible Landscaping on Public lands	Green space	Short-term
Responsible Bridge and Roadway Maintenance	Roadways and bridges	Short-term
Reducing Effective Impervious Cover through Better Site Design	Watershed-wide	Long-term
Increasing Urban Tree Canopy	Watershed-wide	Medium-term
Porous Pavement and Subsurface Storage	Parking lots watershed-wide	Long-term
Capturing Roof Runoff in Rain Barrels or Cisterns	Homes where dry wells are not feasible	Medium-term
Maintaining/Retrofitting Existing Stormwater Structures	Watershed-wide	Short-term
Residential Dry Wells, Seepage Trenches, and Water Gardens	Homes and schools watershed-wide	Long-term
Bioretention Basins and Porous Media Filtration	Watershed-wide	Long-term
Treatment Wetlands: Onsite and Regional	Riparian corridor	Medium-term
Monitoring and Reporting	Watershed-wide	Ongoing

Table E-4: PADEP Actions

Action	Where	When
Industrial Stormwater Pollution Prevention	Industrial sites	Short-term
Construction Stormwater Pollution Prevention	Construction sites	Short-term
Pollution Trading	To be determined	Long-term
Use Review and Attainability Analysis	To be determined	Short-term
Stewardship/Advocacy of Watershed Management Plan	Watershed-wide	Short-term
Watershed-Based Permitting	To be determined	Medium-term
Monitoring and Reporting	Watershed-wide	Ongoing

Recommendations by Implementation Target

Another way to summarize the recommendations is to list options by the target they are designed to address. This grouping by implementation target is shown below. If implementation occurs according to the guidelines in the plan, Targets A and B will be fully met, and implementation of options to meet Target C will results in a more than 20% reduction in wet weather flow volume and pollutant loading.

Target A : Dry Weather Water Quality and Aesthetics

Regulatory Approaches

AR1 On-Lot Disposal (Septic System) Management
AR2 Pet Waste, Litter, and Dumping Ordinances

Public Education and Volunteer Programs

AP1 Public Education
AP2 School-Based Education
AP3 Public Participation and Volunteer Programs

Municipal Measures

AM1 Capacity Management Operation and Maintenance (CMOM)
AM2 Inspection and Cleaning of Combined Sewers
AM3 Sanitary Sewer Rehabilitation
AM4 Combined Sewer Rehabilitation
AM5 Illicit Discharge, Detection, and Elimination (IDD&E)
AM6 Stream Cleanup and Maintenance

AO1 Enhancing Stream Corridor Recreational and Cultural Resources

AMR Monitoring and Reporting

Target B : Healthy Living Resources

Channel Stability and Aquatic Habitat Restoration

BM1 Bed Stabilization and Habitat Restoration
BM2 Bank Stabilization and Habitat Restoration
BM3 Channel Realignment and Relocation
BM4 Plunge Pool Removal
BM5 Improvement of Fish Passage

Lowland Restoration and Enhancement

BM6 Wetland Creation
BM7 Invasive Species Management

Upland Restoration and Enhancement

BM8 Biofiltration
BM9 Reforestation

BMR Monitoring and Reporting

Target C : Wet Weather Water Quality and Quantity

Regulatory Approaches

Zoning and Land Use Control

CR2 Requiring Better Site Design in Redevelopment

CR3 Stormwater and Floodplain Management
CR4 Industrial Stormwater Pollution Prevention
CR5 Construction Stormwater Pollution Prevention
CR6 Post-construction Stormwater Runoff Management
CR7 Pollution Trading
CR8 Use Review and Attainability Analysis
CR9 Watershed-Based Permitting

Municipal Measures

CM1 Sanitary Sewer Overflow Detection
CM2 Sanitary Sewer Overflow Elimination: Structural Measures
CM3 Reduction of Stormwater Inflow and Infiltration to Sanitary Sewers
CM4 Combined Sewer Overflow (CSO) Control Program
  - Nine Minimum Controls
  - Long Term CSO Control Plan
  - Watershed-Based Planning

CM5 Catch Basin and Storm Inlet Maintenance
CM6 Street Sweeping
CM7 Responsible Landscaping Practices on Public Lands
CM9 *R*esponsible Bridge and Roadway Maintenance

CMR Monitoring and Reporting

Stormwater Management

Source Control Measures

CS1 Reducing Effective Impervious Cover Through Better Site Design
CS2 Increasing Urban Tree Canopy
CS3 Porous Pavement and Subsurface Storage
CS4 Green Rooftops
CS5 Capturing Roof Runoff in Rain Barrels or Cisterns

Onsite and Regional Stormwater Control Facilities

CS6 Maintaining/Retrofitting Existing Stormwater Structures
CS8 Retrofit of Existing Sewer Inlets with Dry Wells
CS9 Residential Dry Wells, Seepage Trenches, and Water Gardens
CS12 Bioretention Basins and Porous Media Filtration
CS13 Treatment Wetlands: Onsite and Regional

Planning Level Cost Tables

Planning-level costs have been developed for the majority of the options being recommended. Because costs are highly dependent on site specific conditions as well as the extent that implementation occurs, costs are only approximate. These costs are useful, however, in providing order of magnitude funding needs, and also, as a comparison to potential costs associated with more traditional approaches to CSO control, such as large scale storage tanks designed to reach the 85% capture goal.

Planning level costs are provided for each of the options discussed under the three Targets. In many cases, the cost is left blank. This means that costs are not applicable because they are relatively small, or the option would be implemented by existing municipal staff and do not represent an additional cost.

The mix of structural BMPs and implementation percentages in this section are suggested as a feasible plan that will equal or exceed the 20% discharge reduction target. The exact mix of BMPs implemented in each area of the watershed will be determined by local municipalities or by a government or institutional body to be chosen at a later time.

Tables E-5 and E-6 provide costs for implementation to meet Targets A and B. Table E-7 provides costs for non-structural measures aimed at meeting Target C. Table E-8 provides cost estimates for structural measures designed to meet Target C (when combined with the measures in Table E-9). PWD costs are separated from outside agency costs (primarily municipalities) by apportioning costs based on ownership of facilities or simply by the relative areas of the watershed within and outside of Philadelphia City limits. Cost ranges are provided based on the costs associated with the various alternatives that were evaluated. Actual costs are expected to fall within the range, and will depend on the exact mix of options ultimately implemented.

“Cost per acre” values are provided in Table E-9 as a simple measure of the way costs are apportioned in the table.

The affordability of the costs associated with this plan was also analyzed. The results of this analysis are presented in Table E-10 for Philadelphia and for the combined suburban communities comprising the remainder of the watershed. For Philadelphia, the affordability calculation indicates that the incremental cost of the Cobbs improvements would be approximately $10 per household per year, representing 0.03% of median household income. For the combined suburban communities the cost would be $90 per household per year, representing 0.14% of the weighted median household income for those areas. Both of these values are well within USEPA affordability guidelines, and represent relatively limited increases in the current rates being paid for water, sewer, and stormwater in Philadelphia. These calculations represent incremental costs. The overall impact on affordability would need to be evaluated in the context of all the programs comprising water quality improvement within a given community. For example, residents of Philadelphia will ultimately help pay for management programs in five or more watersheds. Residents of the smaller communities may only pay for this one program. Because residents of Philadelphia will ultimately pay for improvements in a number of watersheds, the total cost per household in Philadelphia likely will be similar to the cost for households in the suburban communities.

Tables E-11 and E-12 provide data to assist communities outside Philadelphia in placing projected CCIWMP costs in a local context. Table E-11 expresses estimated costs for communities per acre and per household inside the watershed boundaries; Table E-12 presents costs within the boundaries of all municipalities that intersect the watershed. These cost tables are but one illustration of a possible cost distribution, and are provided to aid municipalities in deciding what funding and institutional mechanisms may be most appropriate given local conditions.

Table E-5 Planning-level Cost Estimates for Target A Options

	Total		Philadelphia		Other Counties	
	Annual Cost	One-Time	Annual Cost	One-Time	Annual Cost	One-Time
Regulatory Approaches						
AR2 On-Lot Disposal (Septic System) Management	$75,000				$75,000	
AR2 Pet Waste, Litter, and Dumping Ordinances[1]						
Public Education and Volunteer Programs	$615,000		$276,000		$340,000	
Municipal Measures						
AM1 Capacity Management Operation and Maintenance (CMOM)[2]						
AM2 Inspection and Cleaning of Combined Sewers	$2,000,000	$21,120,000	$896,000	$8,448,000	$1,104,000	$12,672,000
AM3 Sanitary Sewer Rehabilitation[2]						
AM4 Combined Sewer Rehabilitation[2]						
AM5 Illicit Discharge, Detection, and Elimination (IDD&E)		$22,500,000		$10,125,000		$12,375,000
AM6 Stream Cleanup and Maintenance	$66,000	$31,000	$33,000	$15,000	$33,000	$15,000
AO1 Enhancing Stream Corridor Recreational and Cultural Resources[1]						
AMR Monitoring and Reporting[3]						
Total Cost for Target A Options	$2,756,000	$43,651,000	$1,205,000	$18,588,000	$1,552,000	$25,062,000
Cost per acre for Target A Options	$190	$3,070	$340	$5,220	$150	$2,360

1 - already in place in most locations, or costs difficult to quantify
2 - costs included in option AM2
3 - monitoring and reporting costs not included in this table

Table E-6 Planning-level Costs for Target B Options

	Total		Philadelphia		Other Counties	
	Annual Cost	One-Time	Annual Cost	One-Time	Annual Cost	One-Time
Channel Stability and Aquatic Habitat Restoration[1]	$33,000	$26,400,000	$16,500	$13,200,000	$16,500	$13,200,000
BM1 Bed Stabilization and Habitat Restoration[2]						
BM2 Bank Stabilization and Habitat Restoration[2]						
BM3 Channel Realignment and Relocation[2]						
BM4 Plunge Pool Removal[2]						
BM5 Improvement of Fish Passage		$130,000		$130,000		
Lowland Restoration and Enhancement						
BM6 Wetland Creation[2]						
BM7 Invasive Species Management[2]						
Upland Restoration and Enhancement						
BM8 Biofiltration[2]						
BM9 Reforestation[3]						
BMR Monitoring and Reporting[4]						
Total Cost for Target B Options	$33,000	$26,530,000	$16,500	$13,330,000	$16,500	$13,200,000
Cost per acre for Target B Options	$2.30	$1,870	$4.60	$3,740	$1.50	$1,240

1 – cost based on restoring high-priority reaches at a cost of $700/lineal ft. If actual cost is lower, medium priority reaches may also be restored
2 – costs included under general "Channel Stability and Aquatic Habitat Restoration" costs
3 – costs included in Target C urban tree canopy costs
4 - monitoring and reporting costs not included in this table

Table E-7 Planning-level Costs for Nonstructural Target C Options

	Total		Philadelphia		Other Counties	
	Annual Cost	One-Time	Annual Cost	One-Time	Annual Cost	One-Time
Regulatory Approaches						
Zoning and Land Use Control						
CR2 Requiring Better Site Design in Redevelopment[1]		$300,000		$100,000		$200,000
CR3 Stormwater and Floodplain Management[1]		$350,000		$175,000		$175,000
CR4 Industrial Stormwater Pollution Prevention[2]						
CR5 Construction Stormwater Pollution Prevention[2]						
CR6 Post-construction Stormwater Runoff Management[2]						
CR7 Pollution Trading[2]						
CR8 Use Review and Attainability Analysis[2]						
CR9 Watershed-Based Permitting[2]						
Municipal Measures						
CM1 Sanitary Sewer Overflow Detection[3]						
CM2 Sanitary Sewer Overflow Elimination: Structural Measures[3]						
CM3 Reduction of Stormwater Inflow and Infiltration to Sanitary Sewers[3]						
CM4 Combined Sewer Overflow (CSO) Control Program[4]						
CM5 Catch Basin and Storm Inlet Maintenance	$600,000		$269,000		$331,000	
CM6 Street Sweeping	$135,000		$45,000		$90,000	
CM7 Responsible Landscaping Practices on Public Lands[2]						
CM9 Responsible Bridge and Roadway Maintenance[2]						
CMR Monitoring and Reporting[5]						
Stormwater Management						
Source Control Measures						
CS1 Reducing Effective Impervious Cover Through Better Site Design[2]						
CS2 Increasing Urban Tree Canopy	$1,500,000	$15,000,000	$500,000	$5,000,000	$1,000,000	$10,000,000
Onsite and Regional Stormwater Control Facilities						
CS6 Maintaining/Retrofitting Existing Stormwater Structures	$20,000	$100,000	$10,000	$50,000	$10,000	$50,000
Use Review and Attainability Analysis		$300,000		$300,000		
Total Cost for Target C Options	$2,255,000	$16,050,000	$824,000	$5,625,000	$1,431,000	$10,425,000
Cost per acre for Target C Options	$160	$1,130	$230	$1,580	$130	$980

1 - estimated cost for ordinance development
2 - costs difficult to quantify
3 - costs included in option AM2
4 - costs included in AM2 or in Table E-8
5 - monitoring and reporting costs not included in this table

Table E-8 Range of Costs for Structural Target C Options

Cost	Philadelphia	Other Counties
Lowest	Alternative 1: RTC	Alternative 1: Cost-Effective Stormwater BMPs
	$1,750,000	$5,340,000
Highest	Alternative 5: Focus on Public and Parking BMPs	Alternative 5: Focus on Public and Parking BMPs
	$10,800,000	$25,500,000

Table E-9 Total Watershed Plan Cost

Total		Philadelphia		Other Counties	
Annual Cost	One-Time	Annual Cost	One-Time	Annual Cost	One-Time
$5,000,000	$93,000,000 - $122,000,000	$2,000,000	$39,000,000 - $48,000,000	$3,000,000	$54,000,000 - $74,000,000
$350/ac	$6,550/ac - $8,590/ac	$560/ac	$10,950/ac - $13,480/ac	$280/ac	$5,080/ac - $6,960/ac

Table E-10 Incremental Affordability Measure

		Philadelphia	Suburban Communities *(Combined)*
1	Capital:	$3,770,000	$5,820,000
2	Operating:	$2,000,000	$3,000,000
3	Total Annual Cost Associated with WMP	$5,770,000	$8,820,000
4	Cost per acre in watershed	$1,642	$826
5	2000 Median Household Income	$30,746	$61,962
6	Estimated Annual Sewer User Charge*	$343	$197
7	WMP cost per household in watershed (in entire municipalities)	$146.04 ($9.77)	$185.71 ($87.52)
8	WMP cost as % of MHI in watershed (in entire municipalities)	0.47% (0.03%)	0.30% (0.14%)
9	Existing sewer cost + WMP cost in watershed (entire municipalities)	1.59% (1.15%)	0.62% (0.46%)

* The sewer user charge in Philadelphia includes a stormwater collection and treatment fee. Stormwater-related charges outside Philadelphia were not investigated.

Table E-11 Distribution of Costs Among Rate Payers in Cobbs Watershed in Communities Outside Philadelphia

	Colwyn	Darby	East Lansdowne	Haverford	Lansdowne	Lower Merion	Milbourne	Narberth	Radnor	Upper Darby	Yeadon
Municipality area in watershed (ac)	96	140	132	3,873	111	2,375	44	268	32	2,700	910
Area of municipality in watershed (% of municipality total)	59%	27%	100%	60%	15%	16%	100%	85%	0.4%	56%	88%
Households in municipality and watershed	484	1219	939	12185	755	7151	366	1619	141	18357	4277
Annual cost associated with CCIWMP	$79,252	$115,576	$108,971	$3,197,315	$91,635	$1,960,656	$36,324	$221,245	$26,417	$2,228,957	$751,241
Cost per acre (within watershed)	$825.54	$825.54	$825.54	$825.54	$825.54	$825.54	$825.54	$825.54	$825.54	$825.54	$825.54
Cost per household (within watershed)	$163.74	$94.81	$116.05	$262.40	$121.37	$274.18	$99.25	$136.66	$187.36	$121.42	$175.65
Median household income ($/year)	$33,150	$30,938	$44,205	$65,714	$47,017	$86,373	$30,185	$60,408	$74,272	$41,489	$45,450
Cost per household (% of MHI)	0.49%	0.31%	0.26%	0.40%	0.26%	0.32%	0.33%	0.23%	0.25%	0.29%	0.39%

Table E-12 Distribution of Costs Among all Rate Payers in Communities Outside Philadelphia

	Colwyn	Darby	East Lansdowne	Haverford	Lansdowne	Lower Merion	Milbourne	Narberth	Radnor	Upper Darby	Yeadon
Municipality area (ac)	164	522	132	6,406	753	15,265	44	316	4,824	4,824	1,032
Watershed area in municipality (ac)	96	140	132	3874	111	2376	44	268	32	2701	910
Watershed area in municipality (% of watershed total)	0.7%	1.0%	0.9%	27.3%	0.8%	16.7%	0.3%	1.9%	0.2%	19.0%	6.4%
Households in municipality	857	3,411	939	18,069	4,688	22,845	368	1,895	10,383	32,594	4,730
Annual cost associated with CCIWMP	$79,252	$115,576	$108,971	$3,197,315	$91,635	$1,960,656	$36,324	$221,245	$26,417	$2,228,957	$751,241
Cost per acre (whole municipality)	$483.24	$221.41	$825.54	$499.11	$121.69	$128.44	$825.54	$700.14	$5.48	$462.06	$727.95
Cost per household (whole municipality)	$92.48	$33.88	$116.05	$176.95	$19.55	$85.82	$98.71	$116.75	$2.54	$68.39	$158.82
Median household income ($/year)	$33,150	$30,938	$44,205	$65,714	$47,017	$86,373	$30,185	$60,408	$74,272	$41,489	$45,450
Cost per household (% of MHI)	0.28%	0.11%	0.26%	0.27%	0.04%	0.10%	0.33%	0.19%	0.003%	0.16%	0.35%

Section 1: Background

The integrated watershed management plan, developed by the Darby-Cobbs Watershed Partnership, is based on a carefully developed approach to meet the challenges of watershed management in an urban setting. It is designed to meet the goals and objectives of numerous, water resource related regulations and programs, and draws from the similarities contained in many watershed-based planning approaches authored by DEP and EPA. Its focus is on attaining priority environmental goals in a phased approach by making use of the consolidated goals of the numerous existing programs that directly or indirectly require watershed planning.

1.1 What is a Watershed and Why a Plan?

A watershed is a natural formation including land and communities connected by water (Figure 1). Simply said, the health of a stream depends on the quality of the land surrounding it, which in turn relies on the people charged with the care for that land. How do you care for an urban watershed? By addressing practices of the past, including paving the land and piping the stormwater, which took place as the area was urbanized. These practices were deemed an important step in development at the time, but they have had a devastating impact on the natural environment. As scientific knowledge and values have changed over time, the maintenance of both a vibrant community and healthy natural resources can be achieved, and the two can reinforce one another.

To address the impacts of past development on Cobbs Creek, we must define and understand the problems in the watershed. To this end, extensive physical, chemical and biological assessments were carried out, coupled with interaction with stakeholders. These activities helped to define and focus planning objectives and form the basis for the entire planning effort. Our plan explores the nature, causes, severity and opportunities for control of water quality impairments in the Cobbs Creek watershed. The primary intent of the plan, as articulated by the stakeholders, is to improve the environmental health and safe enjoyment of the Cobbs watershed by sharing resources and through cooperation among residents and other stakeholders in the watershed. The goals of the initiative are to protect, enhance, and restore the beneficial uses of the Cobbs waterways and its riparian areas, goals that are currently only partially being addressed by a number of programs. A piecemeal approach through a variety of regulatory programs dealing separately with stormwater quantity, water quality, impacts to streams from sanitary and combined sewers, and wetland protection has proven to be ineffective and inefficient in dealing with the problems associated with urban streams. Integrated planning is the preferred approach.

An integrated watershed management plan is a long-term action plan designed to achieve the twin goals of a healthy community and healthy natural resources. An integrated plan embraces the laws designed to save streams, preserves the streams' ecology, and enhances the parkland and riparian buffers that shelter these streams. This plan reaches out to propose municipal action working in concert with conservation planning that strives to ensure that growth and redevelopment within the watershed proceeds with particular care to the environment. Most importantly, the plan incorporates a diversity of people who live, work, and dream in all areas of the watershed. People provide the catalyst for change, the energy to create the plan, and the vigilance to sustain the plan. These people, the stakeholders, become the watershed's guardians – the keepers of the integrated plan.

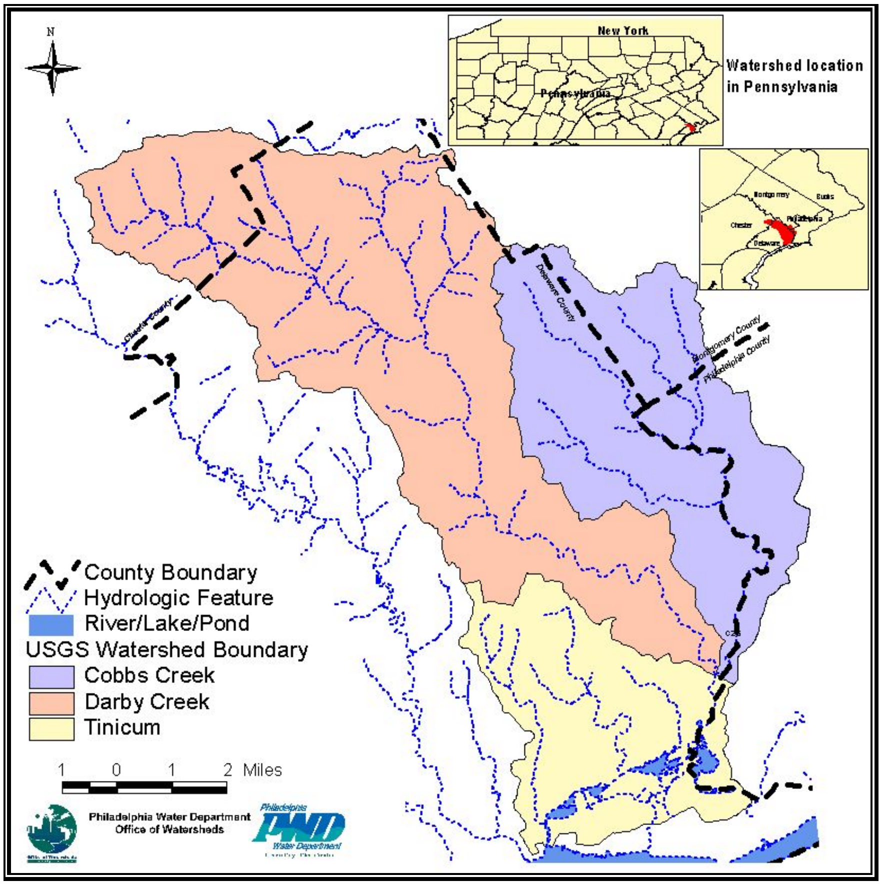


Figure 1-1 Darby-Cobbs Watershed

1.2 Brief History of the Darby-Cobbs Creek Watershed

The history of Cobb's Creek watershed is typical of many similar watersheds on the borders of Philadelphia County--a progression from natural fields and woodlands inhabited only by native peoples, to an agricultural and industrial era fueled by the energy of European immigrants, which eventually gave way to population pressures as open lands were developed into densely-built residential neighborhoods.

Before the beginning of European exploration and immigration, the area was home to Native Americans, particularly the Lenni Lenape tribe. They used Cobb's Creek (which they knew as "Karakung") and its surrounding tributaries and lands for fishing, hunting, transportation, and rudimentary agriculture.

Dutch, Swedish and finally the dominant English Quaker immigrants settled the area beginning in the mid-17th century. Marshes were diked or drained both for health reasons, and to provide dry ground for pastures or growing hay for sale. Streams were diverted into man-made millraces to provide power for a growing number of small mills. These Europeans began what became the wholesale clearing of woodland in the watershed, both to open up farming and pasture lands and to provide lumber for buildings in the growing city of Philadelphia. By the mid-18th century, these "plantations," as farmsteads were then known, were probably the most common landscape feature in and around the City.

It is likely that the removal of forests led to increased runoff and stream flows during storms, and increased sedimentation and erosion. But the actual historical effect of these and other man-made changes in the watershed on the aquatic and terrestrial life is difficult to quantify.

The oldest mill in Philadelphia, built by the Swedish settlers on Cobb's Creek in 1642, stood just upstream from where Woodland Avenue now crosses the creek, and subsequent mills on this site used water power to grind flour into the early 20th century. By the 19th century there were dozens of water-powered mills along Cobb's Creek and its major tributaries, Naylor's Run and Indian Creek. Besides the usual saw, grist and snuff mills, in the early 1800s a thriving gunpowder manufacturing center was located along the creek, in Haverford Township. Keystone Paper Mill stood at the confluence of Indian Creek and Cobb's Creek, and near 63rd and Market, in Millbourne Borough, the Millbourne Flour Mill of the Sellers family stood for more than 100 years. Numerous textile mills existed in the watershed, with clusters of factories in the Angora section of West Philadelphia (near 60th Street and Baltimore Avenue), the Cardington neighborhood of Upper Darby (where Marshall Road crosses the creek), and in the Haddington neighborhood of Philadelphia, where the east and west branches of Indian Creek joined (now Morris Park, at the intersection of 69th Street and Haverford and Lansdowne Avenues). Water used in various industrial processes, such as paper-making and textile dyeing and bleaching, was dumped directly back into the creek, untreated, which certainly had an adverse affect on water quality and aquatic life.

The wholesale transformation of the watershed, from mostly open space with scattered villages and small industrial centers into a mostly-developed residential area, began in the latter part of the 19th century. One factor in this change was the completion of the Mill Creek sewer in West Philadelphia. Entering Philadelphia at 63rd Street and City Avenue, Mill Creek cut a diagonal five-mile valley through West Philadelphia before emptying into the Schuylkill River at 43rd Street. In some places 35 or 40 feet below the current street levels, the creek served as an impediment to development, which tended to stop at its eastern edge. Encapsulation of this creek in a combined sewer, begun in 1869 and completed about 1895, and the subsequent filling and leveling of the valley, allowed the grid of rowhouse development to continue unimpeded toward Cobbs Creek, the City's western edge.

A second important factor in the watershed's transformation was the construction of the Market-Frankford Elevated Railroad. Begun in 1906 and completed by 1908, this line allowed quick access into the city for suburban dwellers, and greatly spurred residential construction in the western parts of Philadelphia and eastern Delaware County. In 1932, a newspaper article stated that more than half of West Philadelphia's 90,000 homes had been built after the El project began. The same article noted that by that time Upper Darby's population had mushroomed to 60,000, with much of that growth coming after 1920.

This rampant development contributed to the degradation of the stream quality in several ways. A number of Cobbs Creek tributaries were completely obliterated, the largest being Thomas Run, which once ran from about 53rd and Walnut streets to Cobbs Creek at about 60th Street; today it runs only underground, in a combined sewer. Thousands of feet of Naylor's Run were channeled into underground culverts to facilitate commercial and residential development in the filled land above the pipes. A massive increase in impervious surfaces in the watershed meant that runoff was reaching the creek more quickly, leading to higher storm flows, increased erosion and scouring of the stream bed.

Furthermore, sewers from the new neighborhoods in the watershed emptied directly into the creek and its tributaries, polluting the water with raw sewage. By 1914 Philadelphia had constructed an interceptor sewer which kept wastes from within its boundaries from entering the creek, but it took decades more before communities in neighboring Delaware and Montgomery counties did the same.

By the 1930s, most of the mills had left the watershed, leaving abandoned buildings as the main reminder of the area's once-thriving industrial heritage. Residential development continued to spread, with large sections of Overbrook Park in Philadelphia built up after World War II, and development continuing into Haverford and Lower Merion Townships in the 1950s and 1960s, although at a considerably lower density. In more recent times, polluted stormwater runoff and inadequate drainage systems, leaking and inadequate septic tanks, lack of open space and adequate recreation, illegal dumping, and an array of other urban ills have also taken their toll on the quality of human and natural life in the watershed.

On the bright side, beginning in the mid-19th century, a number of cemetery companies began buying up large tracts of the watershed, establishing Mt. Moriah, Fernwood, Holy Cross, and Arlington cemeteries. As the farmsteads in the watershed, one by one, were transformed into residential neighborhoods, these cemeteries served to preserve hundreds of acres of open space by keeping them out of the hands of developers.

The creation of Cobbs Creek Park and Morris Park in Philadelphia, in the beginning of the 20th century, also managed to preserve hundreds of acres of open space, and saved Indian Creek from being buried in an underground sewer, as is shown on various planning maps of the era.

Plans for an expressway up the Cobbs Creek valley (I-695), which would have begun at I-95 near Essington and connected with another expressway at Whitby Avenue in West Philadelphia, were finally killed in the mid-1970s, with the money diverted into mass transit projects.

For more historical information on Cobbs Creek see http://www.sewerhistory.net

1.3 Comprehensive Planning and the Regulatory Framework

Water Resource Management in Urban Streams

In many states, numerous federal and state regulations and programs are aimed at improving the water quality and flow patterns in urban streams, while at the same time reducing flooding. Pennsylvania is no exception; the USEPA and the Pennsylvania Department of Environmental Protection (PADEP) have a complex regulatory framework for managing water resources with frequently overlapping demands and requirements. There are several major regulatory programs that contain significant elements related to watershed management in the Cobbs Creek watershed. These are:

- Pennsylvania Title 25, Chapter 93 Water Quality Standards Regulations
- the Total Maximum Daily Load (TMDL) process to improve water quality on impaired streams and water bodies
- the Phase I and Phase II stormwater regulations to control pollution due to stormwater discharges from municipal stormwater systems
- the stormwater management PA Act 167 to address management of stormwater runoff quantity particularly in developing areas
- PA Act 537 sewage facilities planning to protect and prevent contamination of groundwater and surface water by developing proper sewage disposal plans
- EPA's Combined Sewer Overflow (CSO) Control Policy to minimize mixed sewage and stormwater overflowing directly into streams

Each of these regulatory programs supports very specific aspects of water resources management. The specific nature of the regulations sometimes negates the ability of a regulatory program to deal comprehensively with a water quality issue that benefits from more than one of these programs. For the development of this integrated plan, these regulations provide guidelines that are transformed into a series of planning objectives within the watershed management planning process.

These objectives then lead directly to the selection of watershed management options to address the stakeholder-defined goals for environmental quality. In this manner, the plan makes requests of each of these programs to go beyond their programmatic requirements and begin to represent their outcome within the context of the watershed plan goals.

Pennsylvania Title 25, Chapter 93 Water Quality Standards Regulations

Water quality criteria are the numeric concentrations, levels or surface water conditions that need to be maintained or attained to protect existing and designated uses of a stream. They are designed to protect the water uses appropriate to each stream. The streams are classified in Pennsylvania in Chapter 93, Title 25 of the Pennsylvania Code.

Usually the most sensitive of these protected uses are generally water supply, recreation and fish consumption, and aquatic life related. Therefore, criteria designed to protect these uses will normally protect the other uses listed in Chapter 93.

The designated uses for the non-tidal portion of Cobbs Creek include all the state-wide uses plus migratory fishes as shown below:

Symbol	Designated Use
	Aquatic Life
WWF	Warm Water Fishes
MF	Migratory Fishes
	Water Supply
PWS	Potable Water Supply
IWS	Industrial Water Supply
LWS	Livestock Water Supply
AWS	Wildlife Water Supply
IRS	Irrigation
	Recreation
B	Boating
F	Fishing
WC	Water Contact Sports
E	Esthetics

The regulations state that water may not contain substances attributable to point or non-point source discharges in concentration or amounts sufficient to be inimical or harmful to the water uses to be protected or to human, animal, plant or aquatic life.

Impairment Designations and the TMDL Process

Water quality standards provide the target against which the water quality in Cobbs Creek is measured. If water quality standards are not being met, and technology based controls of point and non-point sources are not sufficient to meet the standards, then the load of pollutants must be reduced. Section 303(d) of the Clean Water Act (CWA) and the USEPA's Water Quality Planning and Management Regulations (40 CFR Part 130) provide a framework for reducing pollutant loads based on calculation of Total Maximum Daily Loads (TMDLs). TMDLs are the sum of individual waste load allocations (point sources) and load allocations (non-point sources) plus a margin of safety. They establish a link between water quality standards and water quality based controls. The objective of TMDLs is to allocate allowable loads among different pollutant sources so that the appropriate control actions can be taken and water quality standards achieved.

The basic steps in the water quality based approach to TMDLs include:

- Identification of the water quality-limited waters and the quality parameters of concern
- Prioritizing the locations by ranking and targeting
- Establishing the TMDL
- Implementing the control actions
- Assessment of the control actions

Pennsylvania has listed water quality-limited waters according to point and non-point sources for toxic, conventional (BOD, TSS, fecal coliform, oil and grease), and non-conventional (ammonia, chlorine, and iron) pollutants. Streams that are listed under Section 303(d) of the CWA are particularly targeted for improvement (PADEP, 2004). The Cobbs Creek watershed is within Subbasin 03G, which also includes Crum Creek, Ridley Creek, and Chester Creek watersheds. Within the Cobbs watershed, the following stream segments are listed as impaired.

- The lower 10.09 miles of Darby Creek and 3.55 miles of unnamed tributaries are impaired due to habitat modification, siltation, and water/flow variability from urban runoff and from storm sewers.
- The entire 18.75 miles of Cobbs Creek and unnamed tributaries within the watershed are impaired due to urban runoff/storm sewers and habitat modification.

The next step in the statewide TMDL process includes prioritization of the list and the development of TMDLs for high-priority water bodies. It is this phase of the TMDL process that is of interest to the integrated watershed planning process.

Prioritization must take into account the severity of the pollution and the designated uses of the water body. It should consider the following:

- Risks pertaining to human health and aquatic life
- Degree of public interest and support
- Recreational, economic, and aesthetic importance

- Vulnerability or fragility of the aquatic habitat
- New permit applications for discharges or revisions to existing permits
- Court orders and decisions
- National policies and priorities

TMDL development requires the quantification of pollutant sources and the allocation of maximum discharge loads to contributing point and non-point sources in order to attain water quality standards. TMDLs are best developed on a watershed basis in order to efficiently and effectively manage the quality of the water. The TMDL process may be developed using a phased approach that includes monitoring requirements and it generally includes the following five activities:

- Selection of the pollutants
- Evaluation of the water body's assimilative capacity
- Assessment of the pollutants discharged from all sources
- Predictive analysis of the water body's response to pollution and determination of the total allowable pollutant load
- Allocation (with a margin of safety) of the allowable pollutant load among the different sources

The National Pollutant Discharge Elimination System's (NPDES) permitting process is used to implement control measures to limit effluent from point sources. In the case of non-point sources, state and local laws can be used to implement best management practices (BMPs), as well as Section 319 state management programs. These programs must be coordinated in order to effectively achieve the required non-point source reductions.

NPDES Stormwater Rules

In response to the 1987 Amendments to the Clean Water Act (CWA), the Environmental Protection Agency (EPA) developed Phase I of the NPDES Stormwater Program in 1990. Phase I required NPDES permits for all stormwater discharging from storm sewers (MS4s) of medium and large urban areas (UAs) with populations of 100,000 or more. It also required permits from eleven categories of industrial activity, including construction activities that disturb five or more acres of land. Permit coverage can be either under an individually tailored NPDES permit (used by MS4s and some industrial facilities) or a general NPDES permit (used by most industrial facilities and construction sites).

Phase II of the NPDES Stormwater Program was published in November 1999. The Phase II Regulation requires NPDES permit coverage - mostly under general permits - for stormwater discharges from most small-urbanized areas (small MS4s) and construction activities that disturb from 1 to 5 acres of land. A list of affected communities has been published in the Federal Register.

There are a minimum of six control measures that communities must implement as part of a municipal stormwater management program whose goal is Phase II compliance. These are:

1. Public Education and Outreach

Distributing educational materials and performing outreach to inform citizens about the impacts polluted stormwater runoff discharges can have on water quality.

2. Public Participation and Involvement

Providing opportunities for citizens to participate in program development and implementation, including effectively publicizing public hearings and/or encouraging citizen representatives to be part of a stormwater management panel.

3. Illicit Discharge Detection and Elimination

Developing and implementing a plan to detect and eliminate illicit discharges to the storm sewer system. Includes the developing of a system map as well as informing the community about hazards associated with illegal discharges and improper waste disposal.

4. Construction Site Runoff Control

Developing, implementing, and enforcing an erosion and sediment control program for construction activities that disturb one or more acres of land (controls could include for example, silt fences and temporary stormwater detention ponds).

5. Post Construction Runoff Control

Developing, implementing, and enforcing a program to address discharges of post-construction stormwater runoff from new development and redevelopment areas. Applicable controls could include preventative actions such as protecting sensitive areas (e.g. wetlands) or the use of structural BMPs such as grassed swales or porous pavement.

6. Pollution Prevention/Good Housekeeping

Developing and implementing a program with the goal of preventing or reducing pollutant runoff from municipal operations. The program must include municipal staff training on pollution prevention measures and techniques (e.g., regular street sweeping, reduction in the use of pesticides or street salt, or frequent catch-basin cleaning).

The EPA has listed the following municipalities within the Darby-Cobbs watershed for inclusion in the Phase II program. The permit cycle for these permits starts in 2003.

Aldan Borough, Clifton Heights Borough, Collingdale Borough, Colwyn Borough, Darby Borough, Darby Township, East Lansdowne Borough, Easttown Township, Folcroft Borough, Glenolden Borough, Haverford Township, Lansdowne Borough, Lower Merion Township, Marple Township, Millbourne Borough, Morton Borough, Narberth Borough, Newtown Township, Norwood Borough, Prospect Park Borough, Radnor Township, Ridley Park Borough, Ridley Township, Rutledge Borough, Springfield Township, Tinicum Township, Tredyffrin Township, Upper Darby Township, Upper Darby Township, Yeadon Borough.

Act 167 Stormwater Management Act of 1978 (32 PS § 680.3.)

The Stormwater Management Act 167 is administered by PADEP and is designed to address the inadequate management of accelerated stormwater runoff resulting from development. The plan must address a wide range of hydrologic impacts due to development on a watershed basis, and include such considerations as tributary timing, flow volume reduction, base flow augmentation, water quality control, and ecological protection. Watershed runoff modeling is usually a critical component of the study, with modeled hydrologic responses to 2, 5, 10, 25, 50, and 100-year storms.

The primary purposes of the act are to:

- Encourage planning and management of stormwater runoff
- Authorize a comprehensive program of stormwater management designed to preserve and restore the flood carrying capacity of Commonwealth streams;
- Preserve natural stormwater runoff regimes
- Protect and conserve groundwater

The act requires that each county--in consultation with affected municipalities --prepare and adopt a stormwater management plan for each watershed that falls wholly or partially within the county. The act focuses on reduction of stormwater runoff quantities, rather than on water quality. Each stormwater plan will include, but is not limited to:

- A survey of existing runoff characteristics in small as well as large storms, including the impact of soils, slopes, vegetation and existing development;
- A survey of existing significant obstructions and their capacities;
- An assessment of projected and alternative land development patterns in the watershed, and the potential impact of runoff quantity, velocity, and quality;
- An analysis of present and projected development in flood hazard areas, and its sensitivity to damages from future flooding or increased runoff;
- A survey of existing drainage problems and proposed solutions;

- A review of existing and proposed stormwater collection systems and their impacts;
- An assessment of alternative runoff control techniques and their efficiency in the particular watershed;
- An identification of existing and proposed state, federal, and local flood control projects located in the watershed and their design capacities;
- A designation of those areas to be served by stormwater collection and control facilities within a ten-year period;
- An estimate of the design capacity and costs of such facilities;
- A schedule and proposed methods for financing the development, construction and operation of the facilities;
- An identification of the existing or proposed institutional arrangements to implement and operate the facilities;
- An identification of floodplains within the watershed;
- Standards for the control of stormwater runoff from existing and new development which are necessary to minimize dangers to property and life;
- Priorities for implementation of action within each plan; and
- Provisions for periodically reviewing, revising and updating the plan.

After adoption and approval of a stormwater plan, the location, design, and construction within the watershed of stormwater management systems, flood control projects, subdivisions and major land developments, highways, and transportation facilities must all be conducted in a manner consistent with the approved plan.

As noted above, beginning in 2003, municipalities within the Cobbs Creek watershed also will have to obtain a NPDES permit for separate storm sewer systems. PADEP has developed a Protocol which meets the six Minimum Control Measures required of municipal permittees under the Phase II NPDES Stormwater Regulations (40 CFR §§ 122.26 – 123.35). If an MS4 municipality commits to implementing the provisions of the Protocol for any Minimum Control Measure (e.g., Construction Site Runoff Control), it does not need an independent review and approval of its stormwater management program by DEP for that Minimum Control Measure. The federal regulations also allow DEP and MS4 municipalities to use existing qualifying state and local programs to satisfy any of the NPDES General Permit requirements of MS4s. The Pennsylvania Stormwater Management Act ("Act 167") is an existing qualifying program, and integrating the planning required for Act 167 with the planning required to meet the six Minimum Control Measures is a logical approach to take. An integrated Act 167 Plan is presently under preparation for the Darby-Cobbs Creek watershed by Delaware County with assistance from Philadelphia, Chester, and Montgomery Counties.

Act 537 Sewage Facilities Planning

Act 537, enacted by the Pennsylvania Legislature in 1966, requires that every municipality in the state develops and maintains an up-to-date sewage facilities plan. The act requires proper mapping, assessment, and planning for future needs of all types of sewage facilities. In addition, this program provides requirements for the permitting of individual and community on-lot disposal systems, and uniform standards of design.

The main purpose of a municipality's sewage facilities plan is to ensure that the sewage collection and treatment systems have adequate capacity to convey present and future to sewage flows to a wastewater treatment facility. The planning process also requires correction for existing sewage disposal problems including malfunctioning on-lot septic systems, overloaded treatment plants or sewer lines, and improper sewer connections. The program is also designed to prevent future sewer problems and to protect the groundwater and surface water of the locality and specifically requires in-stream water quality to be evaluated during the planning process. To meet these objectives, PADEP uses the Official Sewage Planning requirements of Act 537 that prevent and eliminate pollution of the waters of the Commonwealth by coordinating planning for the sanitary disposal of sewage with a comprehensive program of water quality management.

Official plans contain comprehensive information, including:

- The location of treatment plants, main intercepting lines, pumping stations and force mains, including their size, capacity, point of discharge and drainage basin served.
- Descriptions of problems with existing sewerage facilities and operation and maintenance requirements
- Planning objectives and needs
- Physical description of planning area
- Evaluation of existing wastewater treatment and conveyance systems
- Evaluation of wastewater conveyance and treatment needs

Combined Sewer Overflow (CSO) Control Policy

EPA's CSO Control Policy, published in 1994, provides the national framework for regulation of CSOs under NPDES. The policy guides municipalities and state and federal permitting agencies in meeting the pollution control goals of the CWA in as flexible and cost-effective a manner as possible. As part of the program, communities serviced by combined sewer systems are required to develop long-term CSO control plans (LTCPs) that will result in full compliance with the CWA, including attainment of water quality standards.

As the first step under the CSO policy, nine minimum technology-based controls are required; these are measures that can reduce the prevalence and impacts of CSOs and that are not expected to require significant engineering studies or major construction.

- Proper operation and regular maintenance programs for the sewer system and the CSOs;
- Maximum use of the collection system for storage;
- Review and modification of pretreatment requirements to assure CSO impacts are minimized;
- Maximization of flow to the publicly owned treatment works for treatment;
- Prohibition of CSOs during dry weather;
- Control of solid and floatable materials in CSOs;
- Pollution prevention;
- Public notification to ensure that the public receives adequate notification of CSO occurrences and CSO impacts; and
- Monitoring to effectively characterize CSO impacts and the efficacy of CSO controls.

In the longer term, the CSO policy includes four requirements to ensure that the CSO systems meet the pollution control goals and local environmental objectives in a cost-effective manner:

- Clear levels of control to meet health and environmental objectives;
- Flexibility to consider the site-specific nature of CSOs and find the most cost-effective way to control them;
- Phased implementation of CSO controls to accommodate a community's financial capability; and
- Review and revision of water quality standards during the development of CSO control plans to reflect the site-specific wet weather impacts of CSOs.

One of the three major components of the City of Philadelphia’s CSO Long Term Control Plan (LTCP) strategy involves a substantial commitment by the City to watershed planning to identify long term improvements throughout its watersheds, including any necessary additional CSO controls, that will result in further improvements in water quality and, ultimately, the attainment of water quality standards. The need for this watershed initiative is rooted in the fact that insufficient physical, chemical and biological information currently existed on the nature and causes of water quality impairments, sources of pollution, and appropriate remedial measures. Because of this deficiency, at the time the CSO LTCP was developed, it was impossible to determine what needed to be done for additional CSO control or control of other wet weather sources throughout the watershed. This deficiency, especially with respect to the effects of wet weather discharges and receiving water dynamics, was increasingly recognized nationwide and led to a broader recognition of the need for watershed-based planning and management to properly define water quality standards and goals. The PWD suggested in its LTCP that the National CSO Policy, state and federal permitting and water quality management authorities, cities, environmental groups, and industry, recognized that effective long-term water quality management could be accomplished only through watershed-based planning.

The CSO Control Policy acknowledges the importance of watershed planning in the long term control of CSOs by encouraging the permit writer "... to evaluate water pollution control needs on a watershed management basis and coordinate CSO control efforts with other point and nonpoint source control activities" (1.B). The watershed approach is also discussed in the section of the CSO Control Policy addressing the demonstration approach to CSO control (II.B.4.b; and Chapter 3 of the USEPA Guidance for Long Term Control Planning), which, in recommending that NPDES permitting authorities allow a demonstration of attainment of WQS, provides for consideration of natural background conditions and pollution sources other than CSOs.

The EPA Long Term Control Planning Guidance suggests that EPA is committed to supporting the implementation of a comprehensive watershed management approach. EPA has convened a Watershed Management Policy Committee, consisting of senior managers, to oversee the reorientation of all EPA water programs to support watershed approaches.

Of particular importance to CSO control planning and management is the NPDES Watershed Strategy. This strategy outlines national objectives and implementation activities to integrate the NPDES program into the broader watershed protection approach. The Strategy also supports the development of basin management as part of an overall watershed management approach

The Long Term Control Planning Guidance suggests that the sources of watershed pollution and impairment, in addition to CSOs, are varied and include other point source discharges; discharges from storm drains; overland runoff; habitat destruction; land use activities, such as agriculture and construction; erosion; and septic systems and landfills. The benefits to implementing a watershed approach are significant and include:

- Consideration of all important sources of pollution or impairment
- Clearer definition of water quality benefits resulting from a given level of CSO reduction
- Greater flexibility to reflect the site-specific nature of CSO discharges
- Greater cost effectiveness (through coordination of monitoring programs, for example)

- Fostering of prevention as well as control
- Fairer allocation of resources and responsibilities.

The Guidance notes that the major advantage in using a watershed-based approach to develop an LTCP is that it allows the site-specific determination of the relative impacts of CSOs and non-CSO sources of pollution on water quality. For some receiving water reaches within a watershed, CSOs could well be less significant contributors to non-attainment than stormwater or upstream sources. In such cases, a large expenditure on CSO control could result in negligible improvement in water quality.

The EPA LTCP Guidance outlines a conceptual framework for conducting CSO planning in a watershed context (Figure E-1). The approach is intended to identify CSO controls for each receiving water segment based on the concepts of watershed management and use attainability. The Cobbs watershed planning approach outlined in this document is conceptually identical. It moved from data collection through analysis and modeling to arrive at a set of recommended measures or options designed to meet the goals and objectives agreed upon through the stakeholder process. Figure E-1 also identifies the section of the the Watershed Management Plan that documents each step in the process.

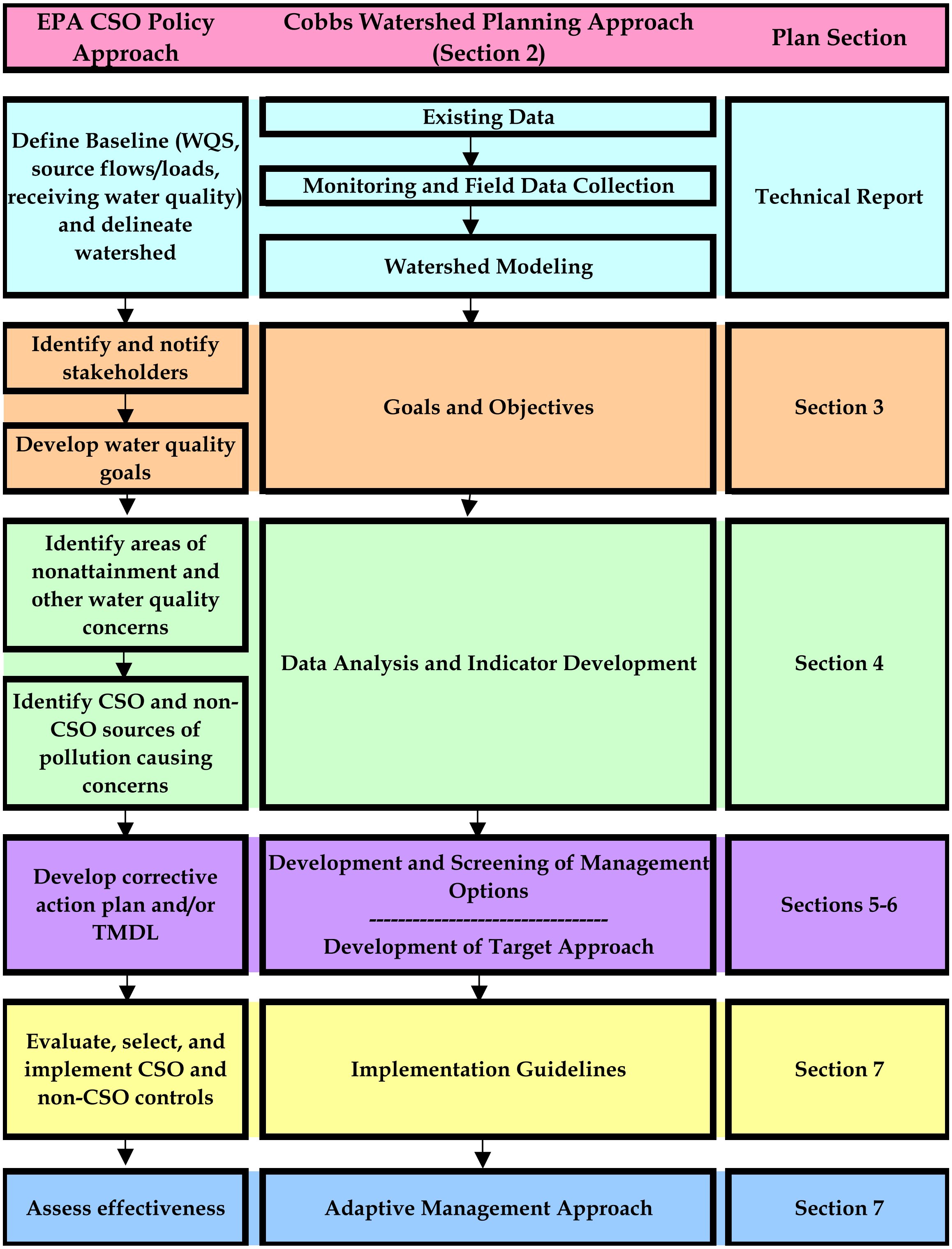


Figure 1-2: Cobbs Planning Approach

Watershed-Based CSO Control Planning Approach for a Receiving Water Segment – from USEPA Guidance for Long Term Control Plan (1995)

1.4 Overlapping Aspects of Regulatory Programs

Integrated watershed planning includes various tasks, ranging from monitoring and resource assessment to technology evaluation and public participation. The scope and importance of each task varies for each watershed, depending on the site-specific factors such as the environmental features of the watershed, regulatory factors such as the need to revise permits or complete TMDLs, available funding, extent of previous work, land use, and the size and degree of urbanization of watershed.

There are numerous activities required under each of the five programs mentioned above. Table 1-1 gives an overview of the types of activities required under each program, and Table 1-2 gives an overview of the types of data needed for each activity. Both tables highlight the fact that the task completed or the data collected under one program is often identical or very similar to the work done under other programs. It is clear that significant savings can be achieved through coordination of the programs and the development of one comprehensive plan for a watershed that meets all five program needs.

Table 1-1 Overview of Planning Tasks Required by Watershed Programs

Planning Tasks	Act 167 Stormwater	Act 537 Sewage Facilities	TMDL Program	NPDES Stormwater	CSO Program	RCP
Preliminary Reconnaissance Survey						
Existing data collection and assessment	X	X	X	X	X	X
Preliminary water quality assessment		X	X		X	X
Present/Future Land use and resource mapping	X	X	X		X	X
Inventory of point and non-point sources		X	X	X		X
Definition of regulatory issues and requirements			X		X	
Preliminary biological habitat assessment			X	X		X
Preliminary problem assessment	X	X	X		X	X
Public Involvement	X	X	X	X	X	X
Individual Watershed Plan						
Survey of runoff characteristics for storm events	X		X		X	
Survey of drainage problems, flood plains, drainage structures	X			X		X
Determination of Sewer System Capacity	X	X			X	
Mapping of point sources, sewer system	X	X	X	X	X	
Monitoring, sampling, and bioassessment			X		X	
QA/QC and data evaluation	X	X	X	X	X	X
Sewer system modeling		X			X	
Watershed Modeling	X		X		X	
Water body Modeling	X		X			
Problem Definition and goal setting	X	X	X	X	X	X
Identification and evaluation of runoff, flood control measures	X			X		
Identification of Combined Sewer Overflow				X	X	
Identification and evaluation of pollution control measures		X	X	X	X	
Economic assessment and funding requirements	X	X	X	X	X	X
Public Involvement	X	X	X	X	X	X
Development of a Watershed Management Plan	X	X	X	X	X	X*

*Note: An RCP includes some but not all elements of a comprehensive watershed management plan.

Table 1-2 Overview of Data Collection Required by Watershed Programs

Data collection	Act 167 Stormwater	Act 537 Sewage Facilities	TMDL Program	NPDES Stormwater	CSO Program	RCP
Geographic Data (Political, Transportation, Topographic, Hydrographic, Land Use, etc.)	x	x	x	x	x	x
Economic and Demographic		x		x	x	x
Meteorological	x	x	x	x	x	
Hydrologic Characteristics	x	x	x	x	x	x
Designated uses and impaired water bodies			x	x	x	x
Water Quality		x	x	x	x	x
Biological and Habitat assessment			x	x	x	x
Floodplains and flooding issues	x					x
Point Sources /Potential sources		x	x	x	x	x
Non-point sources of pollution			x	x		x
Sewer system performance and CSO	x	x	x	x	x	
Storm drainage system	x			x	x	
Historical and cultural resources	x					x

Watershed-based planning is now the preferred approach on both the federal and state level. General water quality and water quantity goals have been established at a state level, and the next step is to develop specific goals for each watershed. Table 1-3 shows the watershed planning goals for Cobbs Creek and how they correspond to many of the overlapping goals of the five major regulatory programs.

Table 1-3 Overview of the Statement of Goals of the Watershed Programs

Goal Description	Act 167 Stormwater	Act 537 Sewage Facilities	TMDL Program	NPDES Stormwater	CSO Program	RCP
Streamflow and Living Resources. Reduce the impact of urbanized flow on the living resources to meet designated uses	x					x
Stream Habitat and Aquatic Life. Improve stream habitat and indices of aquatic integrity.			x	x	x	x
Stream Channels and Banks. Reduce streambank and stream channel deposition and scour to protect and restore the natural functions of aquatic habitat and ecosystems, streambanks, and stream channels.	x					x
Flooding. Decrease flooding.	x					x
Water Quality. Improve dry and wet weather stream quality.		x	x	x	x	x
Pollutant Loads. Decrease pollutant loads to surface waters.		x	x	x	x	x
Stream Corridors. Protect and restore stream corridors, buffers, floodplains, and natural habitats including wetlands.						x
Quality of Life. Enhance community environmental quality of life.	x	x	x	x	x	x
Stewardship. Foster community stewardship.				x	x	x
Coordination. Improve inter-municipal, inter-county, state-local, and stakeholder cooperation and coordination on a watershed basis.	x		x	x	x	x

1.5 PADEP's Watershed Based Planning Approach

The approach and specific tasks behind the Cobbs watershed management plan are intended to meet the needs of the five major programs discussed above. The watershed based planning process utilizes a "Plan-Do-Check-Review" methodology that establishes environmental goals and identifies parameters or indicators with which to measure progress toward those goals. The three Commonwealth-wide environmental goals established are: (1) "sustain, conserve, protect, enhance and restore Pennsylvania's environment, natural resources, and ecological diversity"; (2) "reduce, towards the ultimate goal of eliminating, harmful effects from environmental contaminants and conditions"; and (3) "engage all Pennsylvanians as active and informed stewards of the environment." Problems requiring attention in the Darby, Crum, Ridley, Chester and Cobbs watersheds are outlined in the PADEP's Watershed Restoration Action Strategy (WRAS). WRAS also includes budget allocations for some organizations involved in restoration of the Darby-Cobbs watershed (PADEP, 2002).

The watershed based planning process is intended to:

1. Characterize the condition of the environment by evaluating data sources (i.e., establish a "baseline");
2. Identify possible causes of any impaired conditions;
3. Allow PADEP and stakeholders to develop objectives and activities intended to address the causes in order to improve the existing environmental conditions;
4. Measure progress of activities by using selected indicators to effectively track changes in the environment, and make adjustments to activities as necessary; and
5. Integrate the other planning programs within the watershed based planning program framework.

The Cobbs planning approach seeks to integrate sound science and stakeholder consensus-building to develop an effective plan. The approach is designed to satisfy each of the five elements of the watershed based planning process.

1.6 Other Relevant Programs

Other programs, both regulatory and non-regulatory, influence the watershed management planning approach and are briefly described under this section.

Rivers Conservation Program

One significant non-regulatory program is the Department of Conservation and Natural Resources' (PA-DCNR's) Rivers Conservation Program (RCP), which was developed to conserve and enhance stream resources by implementing locally initiated plans.

The program provides technical and financial assistance to municipalities and stream support groups for the conservation of local streams. Generally the RCP plan intends to assess the cultural and historic resources of a stream corridor, identify potential threats and recommend restoration/maintenance options. It involves the statement of goals to be accomplished and the listing of recommendations for the development and implementation of the plan.

The goals and recommendations from an RCP can be an important building block for a comprehensive watershed management plan (WMP). The programs are similar in structure and approach; they have the same geographic scope, require overlapping data collection, and involve the statement of goals and listing of recommendations. However, the RCP is narrower in scope than the WMP and focuses more on quality of life along the stream corridor rather than on regulatory compliance.

Sanitary Sewer Overflow (SSO) Policy

Requires revisions to the NPDES permit regulations to improve the operation of municipal sanitary sewer collection systems, eliminate the occurrence of sewer overflows, and provide more effective public notification when overflows do occur.

PADEP On-Lot Sewage Disposal Regulations

Require local agencies to administer a permitting program for the installation of on-lot sewage disposal systems.

PENNVEST State Revolving Fund Program

Provides funding for sewer, stormwater, and water projects throughout the Commonwealth.

Delaware River Basin Commission (DRBC) Programs

Regulate both groundwater and surface water use for withdrawals greater than 100,000 gpd based on average 30-day use in a large portion of the study area, which drains to the Delaware River

Delaware Valley Regional Planning Commission (DVRPC) Programs

Address transportation, land use, and environmental protection issues in addition to economic development. Also provide services in planning analysis, data collection, and mapping.

PADEP Greenways Program

An Action Plan for Creating Connections is designed to provide a coordinated and strategic approach to creating connections through the establishment of greenways in the State.

CWA Section 104(b)(3) Program

Promotes the coordination and acceleration of research, investigations, experiments, training, demonstrations, surveys, and studies relating to the causes, effects, extent, prevention, reduction and elimination of pollution.

CWA Section 208 Wastewater Planning

Intended to encourage and facilitate the development and implementation of area-wide waste treatment management plans.

CWA Section 319(b) Non-point Source Management Program

Designed to address mine drainage, agricultural runoff, construction/urban runoff, hydrologic and habitat modifications, on-lot wastewater systems, and silviculture.

1.7 Regulatory Agency and Stakeholder Partnerships

In 1999, PWD acted as the municipal sponsor of the Cobbs Watershed Partnership, an exciting and groundbreaking effort to connect residents, businesses and government as neighbors and stewards of the watershed. PWD hired the Pennsylvania Environmental Council (PEC), a well-respected, non-profit institution with a reputation for supporting watershed-based, holistic planning in the form of smart growth planning. PEC pulled together a diverse representation of the watershed – municipalities, "friends" groups, educators, citizens, agencies, and watershed organizations – for the first partnership meeting.

Meetings during the first year were devoted to general education about watershed concepts, about soliciting the visions and concerns of participants as they related to their communities' environmental health and to the creation of three subcommittees to assist in managing the groundwork required for foundation of a watershed management plan. Minutes from these meetings are available at http://www.phillywater.org/Darby-Cobbs under Partnership Involvement.

A steering committee was recruited, representing municipalities that already had some form of watershed planning under way, to develop the road map and timeline for the tackling of a watershed management plan. The steering committee assisted with the selection of topics to be covered, reviewed the technical data and suggested public education/outreach tasks, and helped select the plan's goals and objectives.

The technical committee was open to all members of the partnership; ultimately, participants consisted mainly of local, state, and federal government agencies. This committee reviewed the technical documents produced by PWD, including a watershed reconnaissance of past and existing water quality studies, a current water quality sampling and modeling report, a sediment pollutant loading report, and a bioassessment summary. This technical data is essential for justifying and prioritizing the goals and objectives of the watershed management plan.

The public participation committee, also open to all partnership members, largely consists of watershed organizations, educators, residents, and educational non-profits. The committee established a number of projects to raise general awareness about watershed issues and to recruit further partnership membership. Projects included: a watershed wide survey, press conferences, a state of the watershed report, teacher training workshops, and the development of a watershed video.

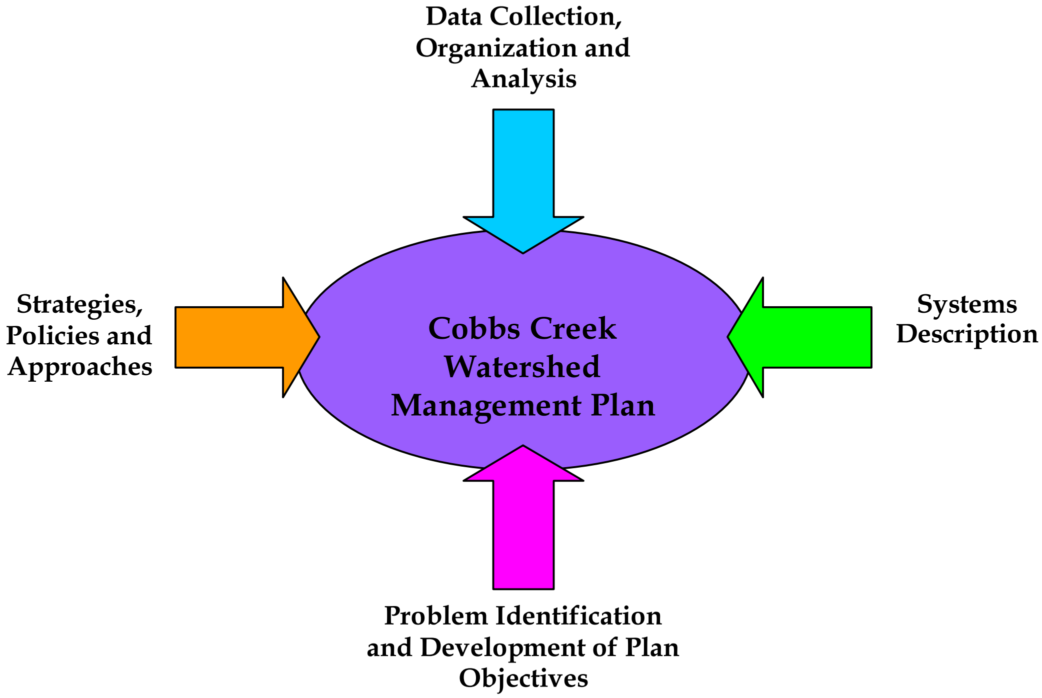
The partnership selected and prioritized the goals and objectives of the watershed management plan. Their role will continue as the recommendations of the plan are implemented in the coming years.

Section 2: Integrated Watershed Management for the Cobbs Watershed

Section 2.1 describes the general approach to watershed planning that serves as the framework for the Cobbs Creek watershed plan. The approach developed by the Darby-Cobbs Watershed Partnership for the Cobbs integrated watershed plan adopts the general approach discussed in Section 2.1 and includes many of the activities included in Philadelphia's Long Term Combined Sewer Overflow Control Plan. Section 2.2 describes the specific activities carried out to complete the plan.

2.1 General Planning Approach

The recommended approach for the Cobbs Creek watershed management plan coordinates each of the five programs discussed on Section 1.3. It has four major elements, each with multiple tasks specific to the planning efforts within the sub-basin of the Cobbs Creek watershed.



Data Collection, Organization and Analysis

The initial step in the planning process is the collection and organization of existing data on surface water hydrology and quality, wastewater collection and treatment, combined sewer overflows, stormwater control, land use, stream habitat and biological conditions, and historic and cultural resources. In addition, existing rules, regulations, and guidelines pertaining to watershed management at federal, state, basin commission, county, and municipal levels also are examined for coherence and completeness in facilitating the achievement of watershed planning goals.

Data is collected by many agencies and organizations in various forms, ranging from reports to databases and Geographic Information System (GIS) files. Field data collection efforts are undertaken early in the study once data gaps are identified.

Systems Description

The planning approach for an urban stream must focus on the relationship between the natural watershed systems (both groundwater and surface water) and the constructed systems related to land use that influence the hydrologic cycle, such as water supply, wastewater collection and treatment, and stormwater collection. A critical step in the planning process is to examine this relationship in all its complexity and to explore the adequacy of the existing regulatory structure at the federal, state, county, and municipal level to properly manage these natural and anthropogenic systems. In urban watersheds, the natural systems are, by definition, influenced by the altered environment, and existing conditions reflect these influences. It is not, however, always obvious which constructed systems are having the most influence, and what that influence is. Analyzing and understanding the water resources and water supply/wastewater/stormwater facilities and their interrelationship provides a sound basis for subsequent planning leading to the development of a realistic set of planning objectives. Concise descriptions of each of the constructed systems are presented, and a series of indicators that adequately describe the watershed and stream characteristics are identified and measured.

Problem Identification and Development of Plan Objectives

Existing problems and issues related to water quality, stream habitat, and streamflow related to the urbanization of the watershed can be identified through analyses of:

- Prior studies and assessments
- Existing data
- New field data
- Stakeholder input

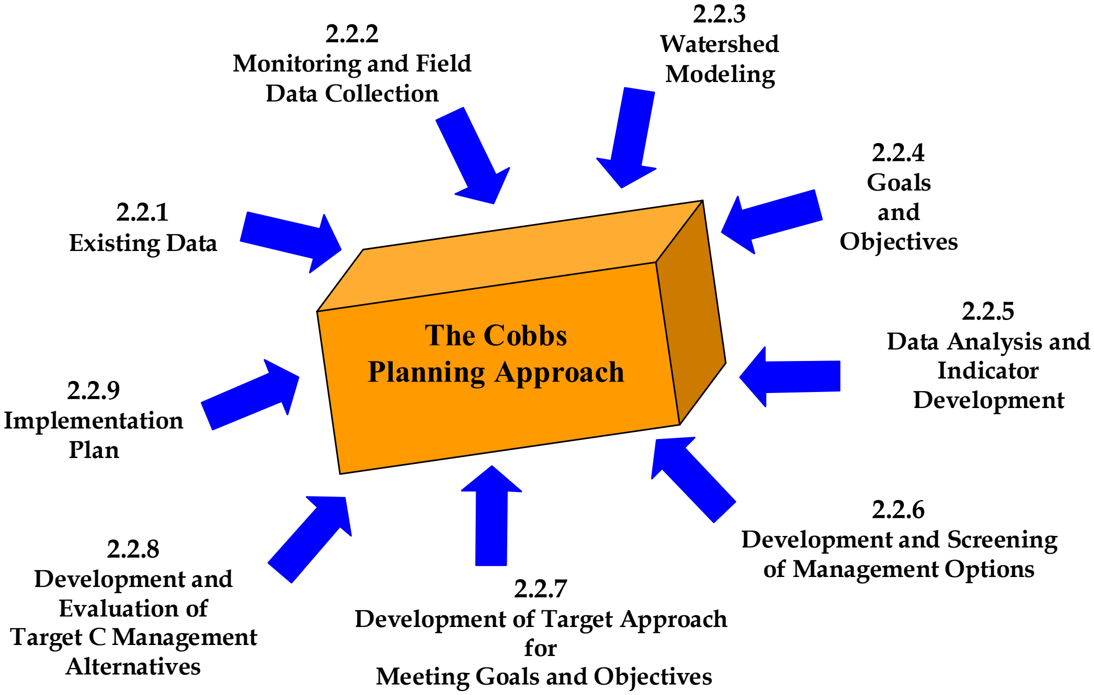
Problems and issues identified through data analysis must be compared with problems and issues brought forward by stakeholders. An initial list of problems and issues then are transformed into a preliminary set of goals and objectives. These goals and objectives may reveal data gaps and may require additional data collection and analysis. Ultimately, with stakeholder collaboration, a final list of goals and objectives is established that truly reflects the conditions of the watershed. These goals and objectives must be prioritized by the stakeholders based on the results of the data analysis.

The priority of objectives becomes the basis for developing planning alternatives. Potential constraints on implementation require that the objectives be broken down into phased targets, in which alternatives are developed to meet interim objectives.

In this way, the effectiveness of implementation can be monitored, and targets adjusted, as more is learned about the watershed, its physical characteristics, and evolving water quality regulations.

Strategies, Policies and Approaches

Once end targets and interim targets are established, with a clear list of associated planning objectives based on sound scientific analysis and consensus among stakeholders, effective sets of implementable management alternatives are developed to meet the agreed upon targets and objectives. These alternatives are a combination of options that may include suggested municipal actions, recommendations on water supply and wastewater collection system improvements, potential measures to protect water quality from point sources, best management practices for stormwater control, measures to control sanitary and combined sewer overflows, changes to land use and zoning, stream channel and streambank restoration measures, etc. These are combined in a coherent fashion within the context of the watershed-wide management alternatives. The alternatives then are evaluated based on cost, effectiveness in achieving priority objectives, and implementation feasibility. The plan ultimately should provide an implementation process to achieve the stated objectives over a specified period of time.



2.2 The Cobbs Planning Approach

The approach and specific tasks for the Cobbs Creek watershed management plan are intended to meet the criteria of the five major programs discussed in Section 1.3 as well as fit with PADEP's watershed based planning program approach.

In order to establish environmental goals and identify the indicators that measure progress toward these goals, the Cobbs planning strategy utilizes the "plan-do-check-review" methodology of the watershed based planning process. To satisfy the five elements included in this procedure, the Cobbs planning process moved from data collection and analysis to plan development in an organized manner, with constant interaction with the established stakeholder groups. The primary data collection, analysis, and technical planning activities of the Cobbs watershed management plan are outlined below, and the stakeholder process is discussed in Section 3.

2.2.1 Existing Data

PWD assembled relevant existing data and information collected in the past by other agencies and by prior studies. Several types of geographic and physical data were collected.

Geographic and Demographic Data. The base map for the project study area was prepared from U.S. Census Bureaus TIGER (Topologically Integrated Geographic Encoding and Referencing) database. These files contain local and state political boundaries, rivers and waterways, roads and railroads, and census block and block group boundaries for demographic analysis.

Meteorological Data. In addition to U.S. Census data, meteorological data was gathered to analyze streamflow responses to seasonal changes, climate variation, and storms, and to model stormwater flows. Long-term rainfall data were obtained from the National Oceanic and Atmospheric Administration's (NOAA) rainfall gage at the Philadelphia International Airport. This gage has over 100 years of hourly precipitation data, from January 3, 1902 through the present. In addition to this long-term rainfall gage, the PWD CSO Program has over 10 years of 15-minute rainfall data from 24 City rain gages. There are six of these gages in the vicinity of the Cobbs Creek watershed. The available rainfall data for each gauge is summarized in Table 2-1, and Figure 2-1 shows their locations. Data from each gage were analyzed for accuracy and completeness, and the data were subjected to statistical analyses to check for changes in the gage location or physical layout, as well as to explore correlations among gages to identify potential over-or under-catch trends.

Table 2-1 Rainfall Data Available for the Cobbs Creek Watershed Gages

Gauge Name	Available Data
RG-01	1991 - 2002
RG-02	1990 - 2002
RG-06	1991 - 2002
RG-09	1990 - 2002
RG-22	1990 - 2002
RG-23	1992 - 1998, 2001 - 2002

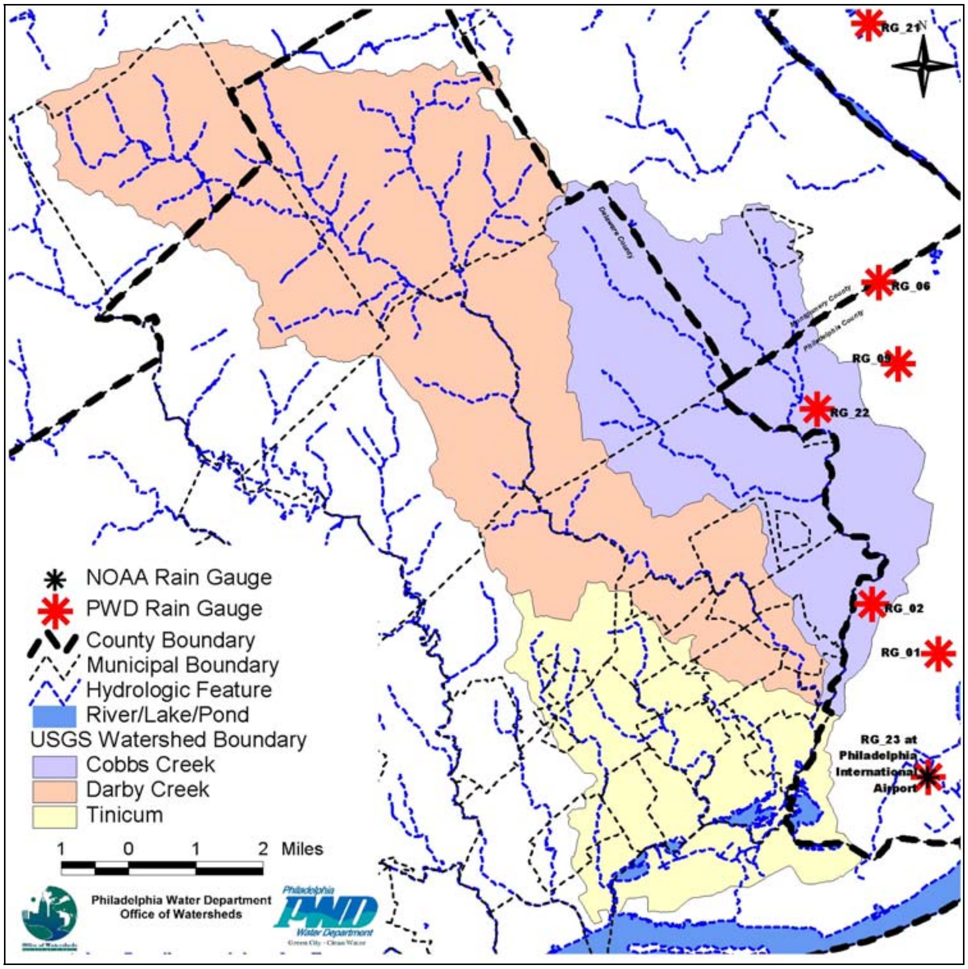


Figure 2-1 City Rain Gages in or near the Watershed

Land Use. Land use information for the Cobbs Creek watershed was obtained from the Delaware Valley Regional Planning Commission (DVRPC) for the counties of Chester, Delaware, Montgomery, and Philadelphia. The DVRPC land use maps are based on aerial photography from March through May of 1995. For a more useful representation of the existing land use information for hydrologic analyses, resulting in a land use map with 20 different categories shown in Figure 2-2.

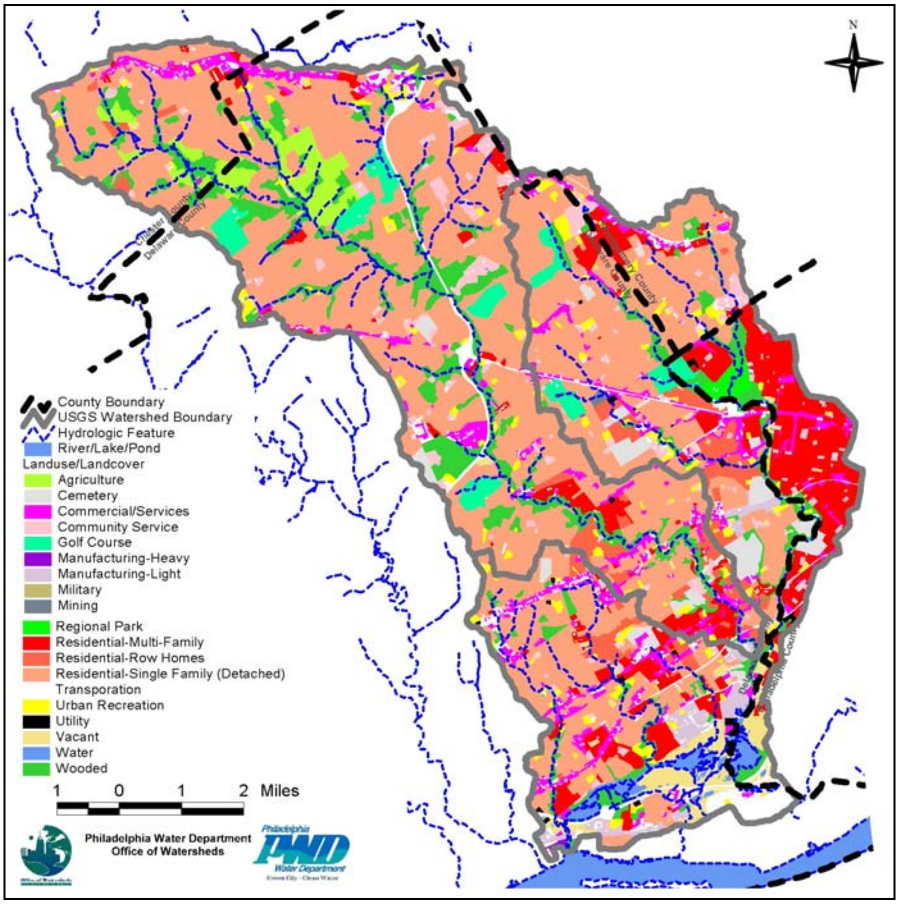


Figure 2-2 DRVPC Land Use Map for the Darby-Cobbs Creek

Streamflow. During the 1960's, the United States Geological Survey (USGS), in cooperation with PWD, established streamflow-gaging stations at six locations in the Darby-Cobbs Creek watershed. While only one of these gages still is active today, the two to three decades of historic record they provided is invaluable in characterizing the hydrologic response of the watershed. The locations of the gages are presented on Figure 2-3 and listed in Table 2-2. Daily streamflow records from the gages were analyzed, and baseflow separation performed to identify patterns along the stream of baseflow and stormwater runoff. The results of these analyses are presented in Section 4.

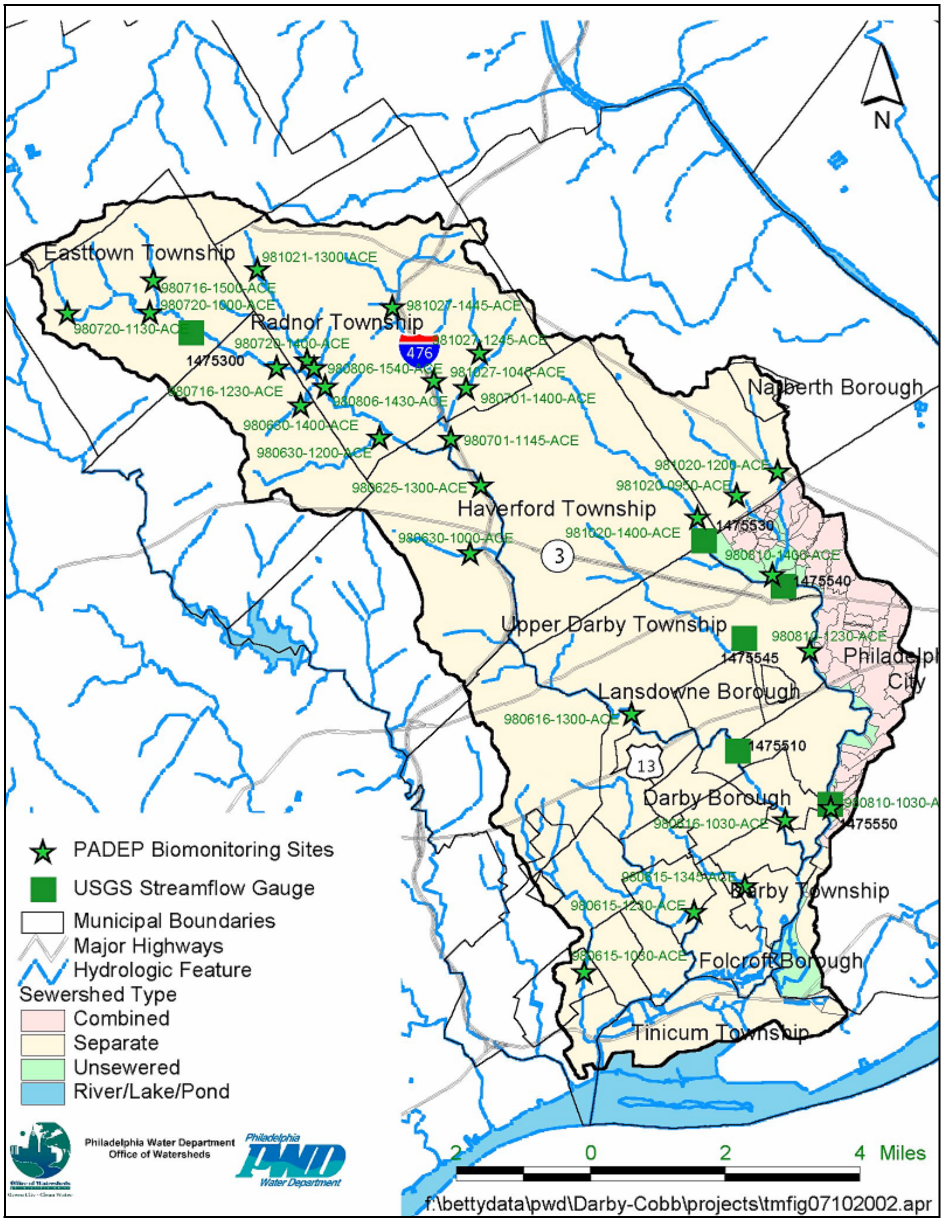


Figure 2-3 USGS Streamflow Gages

Table 2-2 USGS Gages and Periods of Record

Station ID	Location	Quality Data	Streamflow Data
01475300	Darby Creek At Waterloo Mills Near Devon, Pa.		4/28/1972-9/30/1994, 6/28/1996-present
01475510	Darby Creek Near Darby, Pa.		2/1/1964-10/3/1990
01475530	Cobbs Creek At U.S. Highway No. 1 At Phila., Pa.	1/1/1965-3/3/1980	10/1/1964-9/30/1981
01475540	Cobbs Creek Below Indian Creek Near Upper Darby, Pa.	10/10/1967-2/7/1973	10/1/1964-6/30/1973
01475545	Naylor Creek At West Chester Pike Near Phila., Pa.		6/1/1972-10/20/1978
01475550	Cobbs Creek At Darby, Pa.	11/9/70-3/3/80	1/1/1964-10/3/1990

Water Quality. In the early 1970's, the Philadelphia Water Department began a study in cooperation with the U.S. Geological Survey titled, "Urbanization of the Philadelphia Area Streams." The purpose of this study was to quantify the hydrology and pollutant loading of Philadelphia's streams, and possibly relate the degradation in water quality to urbanization. Two of the stations sampled for the study were in the Cobbs Creek watershed at USGS gaging locations: Station 12, Cobbs Creek at U.S. Route 1, and Station 15, Cobbs Creek at Darby. Monthly discrete water quality samples were collected at each site and analyzed for conductivity, BOD_5, total phosphate, ammonia, nitrite, nitrate, and fecal coliform. The program collected about 10 years of monthly samples. The majority of the data currently available from STORET, USEPA's water quality database, were collected as part of this study.

Stream Assessment and Biological Data. Some stream assessment data for the Cobbs watershed were also available. The Philadelphia Academy of Natural Sciences collected stream morphology data for four streams in the Cobbs Creek watershed in August 1998. The data were collected in Fairmount Park for Indian Run, Indian Creek, Bocce Tributary, and Cobbs Tributary 3. The data provide information about streambed slope, cross-sectional properties, and sediment grain size distribution.

At the request of PWD, PADEP performed a biological assessment of the non-tidal portions of the Cobbs Creek watershed. For the assessment, 28 stations were chosen that represent the watershed, based upon land use and stream order. Each station was evaluated using the Rapid Bio-assessment Protocol and USEPA's habitat assessment methods. The assessments occurred between June and late October in 1998. The decisions to consider a station impaired or unimpaired were based upon the quality and quantity of habitat and macroinvertebrates.

2.2.2 Monitoring and Field Data Collection

To supplement existing data, PWD's Office of Watersheds (OOW) conducted an extensive sampling and monitoring program to characterize conditions in the Darby-Cobbs Creek watershed. The program was designed to document the condition of aquatic resources, to provide information for the planning process needed to meet regulatory requirements imposed by EPA and PADEP, and to monitor long term trends as implementation of the plan proceeds.

Water Quality Sampling

Three types of water quality sampling were carried out by PWD for the Cobbs Creek. Figure 2-4 presents the locations of each sampling site along the creek during an initial assessment. Discrete sampling was performed weekly from May through July 1999 at each of the locations. Wet weather sampling involved the collection of discrete samples before and during a wet weather event, allowing the characterization of water quality responses to stormwater runoff and sanitary and combined sewer overflows. Of the ten sampling events, four are considered wet weather events. The third type of sampling was continuous monitoring, carried out by introducing YSI 6600-01 Sondes, shallow depth continuous water quality monitors, and probes that record dissolved oxygen, pH, and turbidity. The equipment was deployed to three locations periodically for a number of days to collect continuous data samples and observe water quality fluctuations.

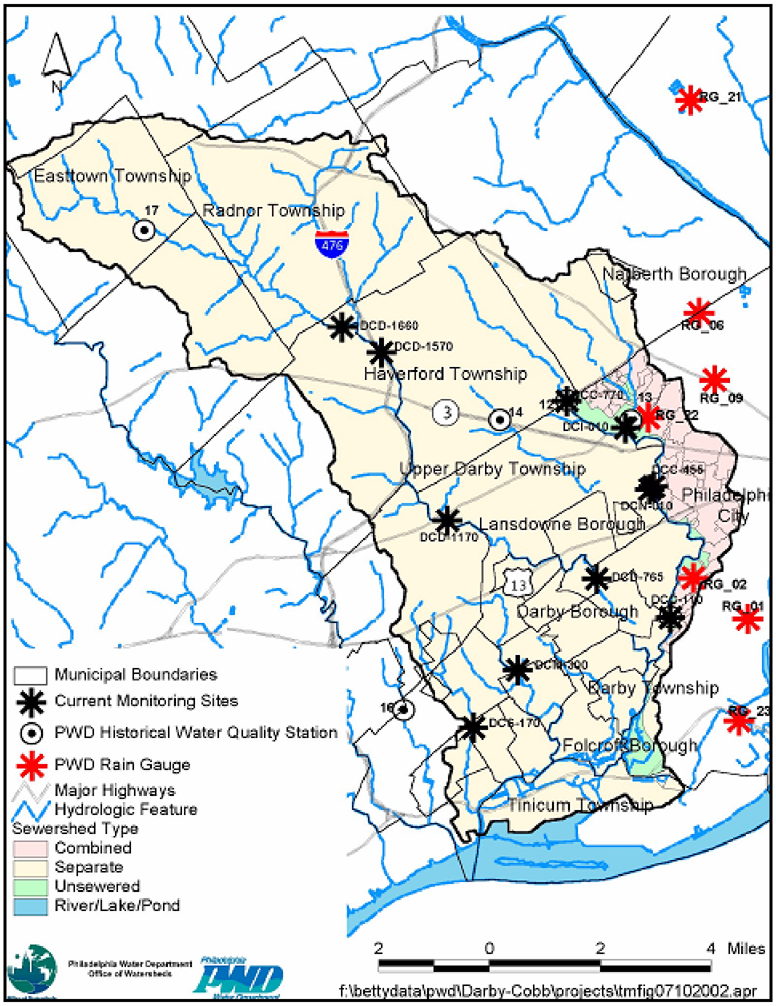


Figure 2-4 Ten Water Quality Monitoring Locations

Biological Monitoring

Biological monitoring is a useful means of detecting anthropogenic impacts to the aquatic community. Resident biota (e.g. benthic macroinvertebrates, fish, periphyton) in a water body are natural monitors of environmental quality and can reveal the effects of episodic and cumulative pollution and habitat alteration (Plafkin et. al. 1989, Barbour et al. 1995). The Philadelphia Water Department's Office of Watersheds and Bureau of Laboratory Services, along with the Philadelphia Academy of Natural Sciences and the Pennsylvania Department of Environmental Protection have been developing a preliminary biological database to assess the aquatic integrity of the Darby-Cobbs watershed. Macroinvertebrate and ichthyfauna monitoring was conducted at specific locations within the Cobbs Creek watershed.

Geographical Information Systems (GIS) databases and watershed maps were constructed to provide accurate locations of the sampling sites.

An ichthyfauna (fish) assessment occurred at five sampling stations on Cobbs Creek; three on the mainstem, and two on the smaller tributaries: West Branch Indian Creek and Naylor's Run. Six metrics were used to assess the quality of the fish assemblages in Cobbs Creek.

1. Species richness
2. Species diversity
3. Trophic composition relationships
4. Pollution tolerance levels
5. Disease and parasite abundance/severity
6. Introduced (exotic) species

In addition to the fish assessment, the results of a PADEP Rapid Bioassessment Protocol (RBP) assessment of seven sites in the Cobbs Creek watershed were also compiled. PADEP biologists used a combination of habitat and biological assessments to evaluate the Cobbs Creek under the Unassessed Waters Program. Biological surveys included kick screen sampling of benthic macroinvertebrates, which were identified by family and by their tolerance to pollution. Benthic macroinvertebrates mainly are aquatic insect larvae that live on the stream bottom. Since they are short-lived and relatively immobile, they reflect the chemical and physical characteristics of a stream and chronic sources of pollution. The biological integrity and benthic community composition was determined using USEPA guidelines for RBP III.

Upon completion of the total biological scoring, each site was compared to a reference site according to its drainage area and geomorphological attributes. The two reference sites chosen were Broad Run (located at the intersection of Chestnut Lane and Broad Run Road, West Bradford Township, Chester County) and French Creek (located at Coventry Road Bridge, South Coventry Township, Chester County). The comparison of the biological assessment of each site with the reference site was designed to create a baseline for monitoring trends in benthic community structure that might be attributable to improvement or worsening of conditions over time. Several Biological Condition Categories were developed:

- Non-impaired
- Slightly impaired
- Moderately impaired
- Severely impaired

Habitat Assessment

Habitat assessments evaluate how deeply the stream substrate is embedded, the degree of streambank erosion, the condition of riparian vegetation, and the amount of sedimentation. Data from the PADEP surveys were available for both the Darby and Cobbs Creeks. Habitat assessments at seven sites were completed based on the Stream Classification Guidelines for Wisconsin (Ball, 1982) and Methods of Evaluating Stream, Riparian, and Biotic Conditions (Platts et al., 1983). Reference conditions were used to normalize the assessment to the Cobbs Creek (mainstream) "best attainable" situation. Habitat parameters were separated into three principal categories to characterize the site:

- Primary or microscale habitat
- Secondary or macroscale habitat (stream channel)
- Tertiary or riparian and bank structure

Resource based Habitat Suitability Indices (HSI) were developed to add aquatic life-based habitat and flow requirement criteria to the watershed assessment. HSIs integrate the expected effects of a variety of physicochemical and hydrological variables on a target species of environmental or economic concern. Data are used to construct sets of suitability index curves, each of which relates a habitat parameter to its suitability for the species of interest. Curves rate habitat variables on a scale of 0 to 1.0, and were developed to measure food and cover, water quality, and reproduction (e.g. substrate type, percent pools, percent cover, depth of pools, pH, DO, turbidity, temperature).

Fluvial Geomorphological Assessment

For the Cobbs Creek watershed, Philadelphia performed a fluvial geomorphic assessment and baseline determination of stream stability. The measurement of geomorphic parameters and physical and hydraulic relationships were performed at both Level I and Level II of the Rosgen classification methodology (D.L. Rosgen Applied River Morphology 1996).

Level I: Desktop survey was desktop delineation of the stream using generalized major stream types based on available topographic information, geological maps, soils maps, and aerial photographs. The purpose of the inventory was to provide an initial framework for organizing and targeting subsequent field assessments of important reaches where problems are known to occur or are anticipated to occur. Available topographic information, geological maps, soils maps, and aerial photographs were reviewed.

Level II: Reach stream survey was performed for approximately 30 miles of the highest order streams and tributaries within the Cobbs Creek watershed. Field teams of two stream surveyors walked along the designated lengths of each stream and tributary and estimated several parameters related to channel morphology:

- Bankfull Elevation
- Bankfull Width
- Entrenchment Ratio range
- Width/Depth ratio range
- Sinuosity range
- Channel Slope range
- Channel Materials (pebble count)
- Meander Pattern

2.2.3 Watershed Modeling

An important tool for developing the watershed plan is a hydrologic and hydraulic model of the stream and stormwater system. In most streams in the eastern US, stormwater flows can range from less than 30% of total annual streamflow in less-developed watersheds to over 70% in highly urbanized settings. Modeling of stormwater flows is, therefore, a critical component of a watershed management plan. The model should, at a minimum, be built to provide storm-by-storm flows to the streams as well as estimates of pollutant loads carried by the stormwater reaching the streams.

A Stormwater Management Model (SWMM) was built for the entire Cobbs Creek watershed. SWMM is a comprehensive set of mathematical models originally developed for the simulation of urban runoff quantity and quality in storm, sanitary, and combined sewer systems. The model subdivides the watershed into approximately 100 subwatersheds and estimates flow and pollutant loading from each land use type within each of the subwatersheds. It simulates the hydraulics of combined sewers, the open channel of the creek itself, and the floodplain. Thus, the model is useful for simulation of stormwater runoff quantity and quality, combined sewer overflow, and streamflow. The model was calibrated by comparing stormwater runoff to estimated runoff, calculated through hydrograph separation at USGS gage 01475550, on Cobbs Creek upstream of the confluence with Darby Creek. Model simulations included:

- Existing conditions using a long-term rainfall record from Philadelphia Airport
- Annual average pollutant loads for key pollutants found in stormwater. The list of pollutants includes parameters such as nitrate and phosphorus, total suspended solids, heavy metals, BOD, and DO
- Numerous simulations to test the effectiveness of various BMPs within the Cobbs Creek watershed. Effectiveness was judged based on reductions in stormwater discharges, CSOs, and reduced pollutant loading during wet weather

- Simulations of six potential mixes of BMPs to assess the overall effectiveness of alternative watershed management plan approaches to achieving plan objectives

The model results also helped identify areas where stormwater runoff or pollutant loads are particularly high and in need of control. Model flow results, in combination with the results of the fluvial geomorphic assessment, provided excellent tools for identifying areas of the watershed that are undergoing stormwater-related stress and an efficient way of developing alternative integrated watershed management approaches, particularly with regard to the Wet Weather Target C objective.

2.2.4 Goals and Objectives

Early in the planning process, project goals and objectives were developed in conjunction with the stakeholders. In general, goals represent consensus on a series of "wishes" for the watershed. Ten project goals were established that represent the full spectrum of goals from all the programs relevant to the watershed (e.g. River Conservation Plan, TMDL programs, Act 167 Stormwater Plans etc.) A significant effort was made to consolidate the various goals into a single, coherent set that avoids overlap and is organized into clear categories.

Once the preliminary set of goals was developed, a series of associated objectives was developed. Objectives translate the "wishes" into measurable quantities; indicators are the means of measuring progress toward those objectives. This relationship is the link between the more general project goals and the indicators developed to assess the watershed and to track future improvement.

The preliminary planning goals and objectives were presented to stakeholders for initial review. However, the final, prioritized goals and objectives were subjected to final review and approval when the data analysis and modeling work were complete.

2.2.5 Data Analysis and Indicator Development

An important aspect of a watershed management plan is a basic description of existing conditions within the watershed and streams. To accomplish this, a series of indicators were developed to represent the results of the data collection efforts and the data analysis and modeling. An indicator is a measurable quantity that characterizes the current state of at least one aspect of watershed health. Every indicator is directly linked to one or more project objectives. Thus, they serve to describe the current conditions, and provide a clear method of monitoring progress and achievement of objectives as management alternatives are implemented over time. This approach was fashioned after the watershed based planning approach program.

The indicators selected for their potential use both in assessing current conditions, as well as assessing future progress in improving conditions, are shown below.

The Land Use and Stream Health Relationship

Indicators	
1	**Land Use and Impervious Cover**
2	**Streamflow**
3	**Stream Channels and Aquatic Habitat**
4	**Restoration Projects Lists of completed, in progress, and planned projects**
5	**Fish**
6	**Benthos**

Water Quality

Indicators	
7	**Effects on Public Health (Bacteria)**
8	**Effects on Public Health (Metals and Fish Consumption)**
9	**Effects on Aquatic Life (Dissolved Oxygen)**

Pollutants and Their Sources

Indicators	
10	**Point Sources**
11	**Non-point Sources**

The Stream Corridor

Indicators	
12	**Riparian Corridor**
13	**Wetlands and Woodlands**
14	**Wildlife**
15	**Flooding**

Quality of Life

Indicators	
16	**Public Understanding and Community Stewardship**
17	**School-Based Education**
18	**Recreational Use and Aesthetics**
19	**Local Government Stewardship**
20	**Business and Institutional Stewardship**
21	**Cultural and Historic Resources**

2.2.6 Development and Screening of Management Options

Clear, measurable objectives provided the guidance for developing options designed to meet the project goals. A management option is a technique, measure, or structural control that addresses one or more objectives (e.g., a detention basin that gets built, an ordinance that gets passed, an educational program that gets implemented).

The following example clarifies the difference among a goal, an objective, and a management option.

Goal: improve water quality

Objective: maintain dissolved oxygen levels above 5 mg/L

Management Option: eliminate deep, poorly mixed plunge pools where low DO is detected

Lists of management options were developed to meet each of the goals and objectives established for the Cobbs Creek watershed. Only those options deemed feasible and practical were considered in the final list of management options. Options were developed and evaluated in three steps:

1. ***Development of a Comprehensive Options List.*** Virtually all options applicable in the urban environment were collected. These options were identified from a variety of sources, including other watershed plans, demonstration programs, regulatory programs, the literature, and professional experience.
2. ***Initial Screening.*** Some options could be eliminated as impractical for reasons of cost, space required, or other considerations. Options that already were implemented, were mandated by one of the programs, or were agreed to be vital, were identified for definite implementation. The remaining options were screened for applicability to Cobbs Creek. This was accomplished by developing a database and creating every possible combination of options. These were scored based on their relative cost and the degree to which they met the project objectives. Only the most cost-effective options were considered further.
3. ***Detailed Evaluation of Structural Options.*** Structural best management practices for stormwater and combined sewage were subjected to a modeling analysis. Effects on runoff volume, overflow volume, peak stream velocity, and pollutant loads were evaluated at various levels of coverage.

The initial screening looked at the cost effectiveness of over 20 options for controlling stormwater using an automated database approach. The intent was not only to look at each option by itself, but also to assess the effectiveness of each option in combinations with other options. Figure 2-5 shows that the database developed over one million possible combinations of the options, and scored each for their cost effectiveness.

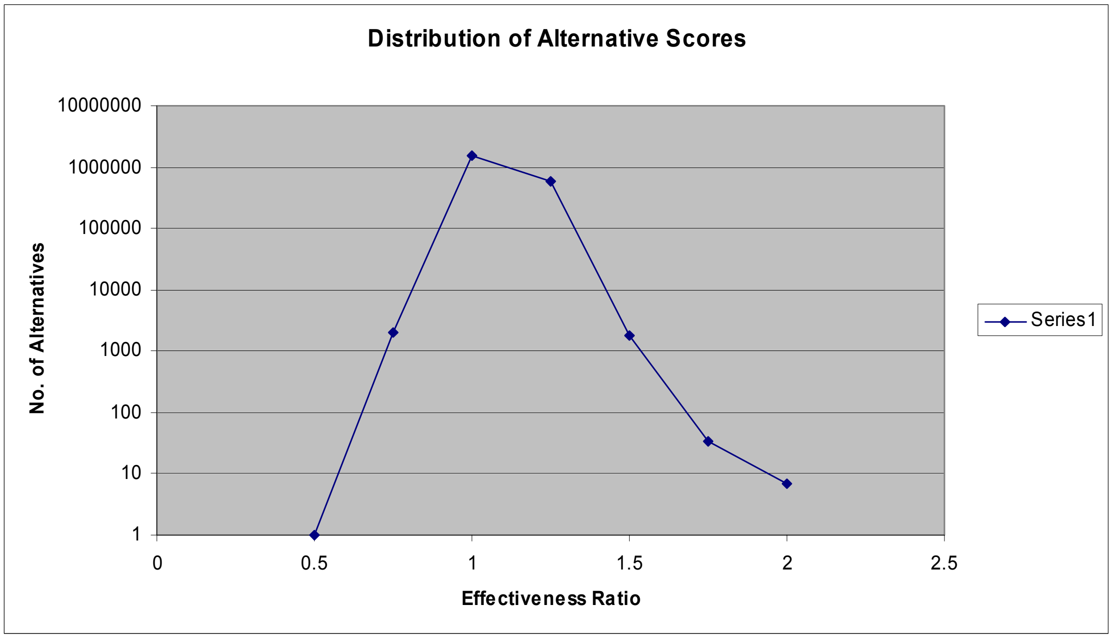


Figure 2-5 Distribution of Effectiveness Scores for Combined Options

The decision to include an option in the final set of alternatives was based on how well it performed in the cost-effectiveness evaluation, both as a stand-alone option, and also in combination with other options.

Detailed evaluation of structural options (step 3) used the SWMM model to assess the effectiveness of each option and by performing a planning-level cost estimate of each option. All options that had an effect on CSOs or stormwater-related pollutant loads were modeled at several degrees of implementation using the SWMM model. Graphs of effectiveness versus degree of implementation were developed, and the results then were combined with more careful cost estimates to provide guidance on selecting effective options or combinations of options.

The modeling and other analyses resulted in six alternatives selected for full evaluation.

2.2.7 Development of Target Approach for Meeting Goals and Objectives

In developing watershed management alternatives and discussing goals and objectives with stakeholders, it became clear that implementation could best be achieved by defining three distinct targets to meet the overall plan objectives. Two of the targets were defined so that they could be fully met with a limited set of options that are fully implemented. The third target fit better with the “plan-do-check-review” methodology of the watershed based planning process. In other words, it was agreed to set interim objectives, recommend measures to achieve the interim objectives, implement those controls to achieve these objectives, and reassess the capability to meet the objectives, or agree to raise the bar to more complete achievement of the final objectives.

Targets are defined here as groups of objectives that each focus on a different problem related to the urban stream system. They can be thought of as different parts of the overall goal of fishable and swimmable waters through improved water quality, more natural flow patterns, and restored aquatic and riparian habitat.

By defining these targets, and designing the alternatives and implementation plan to address the targets simultaneously, the plan will have a greater likelihood of success. It also will result in realizing some of the objectives within a relatively short time frame, providing positive incentive to the communities and agencies involved in the restoration, and more immediate benefits to the people living in the watershed.

The targets for the Cobbs Creek watershed management plan are defined as follows.

TARGET A: Dry Weather Water Quality and Aesthetics

Target A was defined for Cobbs Creek with a focus on trash removal and litter prevention, and the elimination of sources of sewage discharge during dry weather. Streams should be aesthetically appealing (look and smell good), be accessible to the public, and be an amenity to the community. Access and interaction with the stream during dry weather has the highest priority, because dry weather flows occur about 60-65 % of the time during the course of a year on the Cobbs Creek. These are also the times when the public is most likely to be near or in contact with the streams. The water quality of the stream in dry weather, particularly with respect to bacteria, should be similar to background concentrations in groundwater.

In many urban streams, monitoring indicates that the water quality rarely meets the water quality standard for bacteria, and exhibit occasional DO problems, even during baseflow or dry weather conditions. Thus, the first target focuses on dry weather water quality, coupled with the visual aesthetics of the stream, primarily the removal of trash and the elimination of illegal dumping so often associated with degraded, urban waterways. The first target also includes a range of regulatory and nonstructural options that address both water quality and quantity concerns. Because the options under consideration are aimed at the total elimination of dry weather sources of trash and sewage, all options related to this target were included in the implementation plan.

TARGET B: Healthy Living Resources

Based on the results of the water quality monitoring, habitat assessment, and biological monitoring, water quality was not identified as the primary cause of the low diversity and impaired nature of the fish population in the stream. Improvements to the number, health, and diversity of the benthic invertebrate and fish species in the Cobbs Creek need to focus on habitat improvement and the opportunity for organisms to avoid high velocities during storms. Fluvial geomorphological studies, wetland and streambank restoration/creation projects, and stream modeling should be combined with continued biological monitoring to ensure that correct procedures are implemented to increase habitat heterogeneity within the aquatic ecosystem.

Improving the ability of an urban stream to support viable habitat and fish populations focuses primarily on the elimination of remediating the more obvious impacts of urbanization on the stream. These include loss of riparian habitat, eroding and undercut banks, scoured streambed or excessive silt deposits, channelized and armored stream sections, trash buildup, and invasive species. The primary tool to accomplish this target is stream restoration. Restoration focuses on improving channel stability, improving instream and riparian habitat, providing refuges for fish from high velocity conditions during storms, and managing land within the stream corridor. Restoration strategies include:

- Bank stabilization, including boulder structures, bioengineering, root wads, plantings, and log and woody structures
- Bed stabilization, including rock/log vanes with grade control, rock/log cross vanes, and using naturally occurring boulders and bedrock
- Realignment & relocation, used only on severely degraded stream sections
- Dam and debris removal
- Reforestation, with priority to floodplains, steep slopes, and wetlands
- Invasive species management to increase biodiversity
- Wetland creation, often used in conjunction with stream realignment to improve floodplain areas subject to annual flooding
- Forest preservation
- Fish holding areas, with low to no current zones created to provide fish with places to hold position during high flows

Stream restoration measures to meet this target were identified, and all options required to meet the target are planned for implementation.

TARGET C: Wet Weather Water Quality and Quantity

The third target is to restore water quality to meet fishable and swimmable criteria during wet weather. Improving water quality and flow conditions during and after storms is the most difficult target to meet in the urban environment. Because wet weather conditions on Cobbs Creek occur to some degree about 35-40% of the time during the year, measures to improve wet weather quality have a somewhat lower priority than measures designed to address dry weather water quality. During wet weather, extreme increases in streamflow are common, accompanied by short-term changes in water quality. Stormwater generally does not cause immediate DO problems, but sampling data indicate that concentrations of some metals (such as copper, lead, and zinc) and bacteria do not meet water quality standards during wet weather. These pollutants are introduced by both stormwater and wet weather sewage overflows (CSOs and SSOs).

A comprehensive watershed management approach must also address flooding issues. Where water quality and quantity problems exist, options may be identified that address both. Any BMP that increases infiltration or detains flow will help decrease the frequency of damaging floods; however, the size of such structures may need to be increased in areas where flooding is a major concern. Reductions in the frequency of erosive flows and velocities also will help protect the investment in stream restoration made as part of the second target (B).

Target C must be approached somewhat differently from Targets A and B. Full achievement of this target means meeting all water quality standards during wet weather, as well as eliminating all flooding. Meeting these goals will be difficult. It will be expensive and will require a long-term effort. The only rational approach to achieve this target must include stepped implementation with interim targets for reducing wet weather pollutant loads and stormwater flows, along with monitoring for the efficacy of control measures.

Initial load reduction targets for parameters such as metals, total suspended solids (TSS), and bacteria were set in conjunction with the stakeholders. Based on preliminary work by PWD, 10-20% reductions are a challenging but achievable initial interim target.

It is expected that changes to the approach, and even to the desired results, will occur as measures are implemented and results are monitored. This process of continually monitoring progress and adjusting the approach is known as *adaptive management*. The NPDES permit programs for stormwater and CSO outfalls can lead to a cycle of monitoring, planning, and implementation that helps define a time frame to this process.

2.2.8 Development and Evaluation of Target C Management Alternatives

An alternative for meeting Target C, or wet weather water quality objectives, is a group of options designed to meet the established interim target of 10-20% reduction in stormwater flows and/or pollutant loading. For example, a management alternative might consist of a combination of all the following options:

- Establishing a program of uniform and coordinated municipal stormwater ordinances
- Installing rain barrels on 20% of the homes

- Installing porous pavement with underground stormwater storage in half of the parking lots in the watershed
- Developing a public education program

The results of the options screening and evaluation process discussed in Section 2.2.6 were used to assemble Target C alternatives. To develop a management alternative, options are grouped as to maximize effectiveness, minimize cost, and avoid combinations of options that conflict with each other (e.g. two options designed to occupy the same space or utilize the same pipe). Target C alternatives were developed based on unifying approaches such as minimum cost, BMPs on public property and BMPs on private property.

2.2.9 Implementation Guidelines

Six alternatives, each including a package of options to address all three targets, were evaluated using a multi-criteria evaluation program called EVAMIX. The program is designed to evaluate the alternatives against a series of criteria weighted according to priority by the stakeholders. The evaluation, along with the many individual SWMM model simulations, provided significant insight into the best approaches to meeting Target C objectives. The draft implementation plan developed provided:

- Specific recommendations and a schedule for meeting Target A objectives
- Specific recommendations and a schedule for meeting Target B objectives
- Guidance on which BMPs or mixes of BMPs were most effective in Cobbs Creek for meeting Target C objectives.
- Guidance on the needed degree of implementation to achieve Target C objectives
- Guidance on areas of the watershed where BMPs would be most effective
- Recommendations on Target C options for the CSO areas, and recommendations for Target C options for separate storm sewer areas

Section 3: Goals and Objectives

Developing a focused and prioritized list of goals (general) and objectives (specific, measurable) is critical to a successful planning process. Goals and objectives need to be:

- initially developed by stakeholders and regulatory agencies,
- analyzed and informed by the watershed data collection, analysis, and modeling carried out by the project team,
- finalized by the project team and prioritized by the stakeholders.

3.1 Stakeholder Goal Setting Process

Considerable stakeholder input towards developing watershed goals was sought from the beginning of this planning effort. Responses were summarized, and additional stakeholder input organized through further contacts with the stakeholders. The mission statement for the Darby-Cobbs Watershed Partnership planning effort, as well as related goals from other programs were developed by the stakeholders and are listed here.

Darby-Cobbs Partnership Mission Statement

To improve the environmental health and safe enjoyment of the Darby-Cobbs watershed by sharing resources through cooperation of the residents and other stakeholders in the watershed. The goals of the initiative are to protect, enhance, and restore the beneficial uses of the Darby-Cobbs waterways and riparian areas. Watershed management seeks to mitigate the adverse physical, biological, and chemical impacts of land uses as surface and groundwater are transported throughout the watershed to the waterways.

Goals of Related Studies and Programs

Other studies already have provided a list of goals. Generally the goals in this section are those identified through the rivers conservation planning process, supplemented by those goals that are required as a result of various environmental regulatory requirements. Additional goals identified in the Darby-Cobbs stakeholder meetings also were included once consensus was established. Existing goals included:

- Aquatic life designated use attainment goal (warm water fishery)
- Public health: contact recreation (bacteria, noxious plants)
- Aesthetics: visual and olfactory conditions (noxious plants, bank erosion, litter, odor, etc.)
- Riparian corridors
- Wetlands, woodlands & meadows
- Wildlife
- Act 167 plan goals
- Act 537 goals
- TMDL-related goals
- NPDES program goals (including stormwater management and CSO control)
- Environmental Futures Program goals
- River conservation plan goals

3.2 Consolidated Watershed Planning Goals and Objectives

The large list of goals from the existing stakeholder process needed to be organized. This was accomplished by consolidating goals from various sources into a coherent set for the integrated plan. Other considerations included stakeholders' desire to restore the living resources, and the steering committee preference for achieving goals through innovative, land-based, low-impact, and cost-effective management options. Consensus was reached eventually around the following ten goals. Under each goal, more specific objectives are listed.

1. **Streamflow and Living Resources.** Reduce the impact of urbanized flow on the living resources.
   1.1. Increase baseflow as a percentage of total flow.
   1.2. Increase groundwater recharge.
   1.3. Prevent increases in the stormwater flow peaks in future development/redevelopment areas.
   1.4. Reduce directly connected impervious cover in developed areas. Reduce the rate of growth in directly connected impervious cover in areas with new development.
   1.5. Based partially on Act 167 stormwater planning, revise municipal codes to encourage new development and redevelopment of existing, vacant, and abandoned lands using techniques that help reach stormwater and erosion control objectives.

2. **Stream Habitat and Aquatic Life.** Improve stream habitat and indices of aquatic integrity.
    2.1. Improve stream habitat to restore selected living resources to a pre-development condition.
    2.2. Improve quantitative measures of fishery health.
    2.3. Improve quantitative measures of benthic invertebrate quality.
    2.4. Adapt or develop quantitative measures of attached algae to assess current stream conditions.
    2.5. Improve migratory fish passage.

3. **Stream Channels and Banks.** Reduce streambank and stream channel deposition and scour to protect and restore the natural functions of aquatic habitat and ecosystems, streambanks, and stream channels.
    3.1. Increase miles of stable streambanks and stream channels.
    3.2. Reduce the frequency of occurrence of bankfull flow.

4. **Flooding.** Decrease flooding.
    4.1. Remediation should reduce the effects and frequency of out-of-bank flooding through management of stormwater.
    4.2. Remediate stream-related flooding in known problem areas without increasing the problem in other areas.
    4.3. Increase regular storm drain maintenance and cleaning programs throughout the watershed.
    4.4. Incorporate sound floodplain management principles in flood planning.
    4.5. Minimize the effects of structural floodway and stream encroachments with regard to sediment load and natural streamflow.

5. **Water Quality.** Improve dry and wet weather stream quality.
    5.1. Re-evaluate designated uses and develop a phased achievement approach to revised designated uses by meeting associated water quality criteria in Darby and Cobbs Creeks.
    5.2. Develop a phased approach to meeting appropriate water quality standards in dry weather and wet weather.
    5.3. Prevent fish consumption advisories.

6. **Pollutant Loads.** Decrease pollutant loads to surface waters.
    6.1. Identify "hot spots" of runoff pollution and define pollution reduction measures to decrease loads of targeted water quality parameters.
    6.2. Identify and eliminate SSOs and illicit storm sewer connections in a manner consistent with the Clean Water Act and the Clean Streams Law.
    6.3. Eliminate septic tank failures.
    6.4. Implement the Nine Minimum Controls for CSOs.
    6.5. Minimize CSO volume and frequency in accordance with the National CSO Policy.
    6.6. Decrease inputs of floatables, debris, and litter from all sources.
    6.7. Increase I/I studies, sewer cleanings and inspections.

7. **Stream Corridors.** Protect and restore stream corridors, buffers, floodplains, and natural habitats including wetlands.
    7.1. Decrease loss of open space and habitat by responsibly managing new development.
    7.2. Increase open space and habitat by responsibly managing redevelopment of existing, vacant, and abandoned lands.
    7.3. Inventory and protect existing wetlands.
    7.4. Identify and pursue opportunities for wetland enhancement and wetland creation for stormwater treatment.
    7.5. Improve floodplain conditions through restoration or improvement of the connections between streams and their floodplains.
    7.6. Protect and restore riparian habitat and stream buffer zones with native species where feasible.
    7.7. Protect and restore upland habitats along riparian corridors and throughout the watershed where feasible.
    7.8. Increase the number of municipalities with an invasive species control program.

8. **Quality of Life.** Enhance community environmental quality of life.
    8.1. Increase community green and open space.
    8.2. Increase community access and recreational activities in city parks and streams (e.g., by increasing miles of greenways and trails along stream corridors).
    8.3. Increase the public sense of security along stream corridors (e.g., by increased police presence, lighting, signage, park maintenance).
    8.4. Improve and protect aesthetics along stream corridors(e.g., by litter/graffiti removal, enforcement against illegal practices such as dumping, controls on ATV use).
    8.5. Identify and protect historical and cultural resources along stream corridors.

9. **Stewardship.** Foster community stewardship.
    9.1. Increase public awareness of the value of streams to the community.
    9.2. Improve business and institutional awareness of and accountability for activities that affect water quality.
    9.3. Encourage and support establishment of watershed organizations, EACs, etc. to bear the watershed banner.
    9.4. Engage local officials and planners.
    9.5. Increase volunteer participation in implementing management options.
    9.6. Increase school-based education.

10. **Coordination.** Improve inter-municipal, inter-county, state-local, and stakeholder cooperation and coordination on a watershed basis.
    10.1. Increase watershed-wide adoption of the resolution and expand it to include the goals of the watershed management plan.
    10.2. Gain state and federal support through grant funding. Increase synchronization of and coordination of permits and regulation on a watershed basis.
    10.3. Formally adopt a watershed management plan gaining county commissioners' approval.
    10.4. Improve data and information exchange between municipalities and stakeholders.
    10.5. Improve coordination with downstream communities and governments along the Delaware River and Estuary.

3.3 Goals Prioritization

The goals and objectives represent the collective idea of the stakeholders on what the watershed management plan should achieve. Not all goals, however, are of equal importance. It is important to elicit from the stakeholders a collective opinion on the relative importance of each goal for the Cobbs Creek. Because the achievement of goals is an important yardstick for measuring the effectiveness of the management plan, some numerical representation of the importance of each goal is useful.

To develop a set of numerical weights that represent the importance of each goal relative to the other goals, a workshop was held on October 29, 2002, with members of the partnership participating. The goal of the workshop was to work towards a consensus on a numerical set of weights that best represent the collective opinion on the importance of each goal. Each participant filled in a worksheet that described, as a percent, the individual contribution of each goal to the overall goal of watershed management. These sheets provided a variety of opinions on how the goals should be weighted, and served as a guide to a discussion on the relative importance of each goal. Through the group discussion, a consensus set of goal weights was developed that best represents the importance of each goal as defined by the stakeholders. Table 3-1 shows the weights assigned to each goal. The weights represent a percentage of the overall importance of each goal relative to all goals.

Table 3-1: Stakeholder Priorities as Weights for Goals

Streamflow and Living Resources. Reduce the impact of urbanized flow on the living resources (increase baseflow and recharge, reduce impervious area and runoff peaks, improve stormwater ordinances).	12
Stream Habitat and Aquatic Life. Improve stream habitat and indices of aquatic integrity (improve physical habitat, benthic, fish, algae).	9
Stream Channels and Banks. Reduce streambank and stream channel deposition and scour to protect and restore the natural functions of aquatic habitat and ecosystems, streambanks, and stream channels (increase stabilized areas, reduce frequency of bankfull flow).	7
Flooding. Decrease flooding (improve stormwater management, trouble spots, inlet cleaning, floodplain management and structures).	11
Water Quality. Improve dry and wet weather stream quality (meet designated uses, prevent fish advisories).	9
Pollutant Loads. Decrease pollutant loads to surface waters (decrease runoff, SSO, septic tank, CSO, and debris loads).	10
Stream Corridors. Protect and restore stream corridors, buffers, floodplains, and natural habitats including wetlands.	11
Quality of Life. Enhance community environmental quality of life (protect open space, access and recreation, security, aesthetics, historical/cultural resources).	12
Stewardship. Foster community stewardship (increase awareness and responsibility, volunteer programs, education).	11
Coordination. Improve inter-municipal, inter-county, state-local, and stakeholder cooperation and coordination on a watershed basis.	8

In addition to the weights assigned to each goal, the workshop participants also provided some insight into the relative importance of each of the objectives within the goals. These were provided as an opinion on whether a particular objective had a high, medium, or low priority as part of the goal. No consensus building process was attempted for all of the objectives, since these play a lesser role in the overall evaluation. The project team assigned a value of 1 point for a low designation, 2 points for a medium designation, and 3 points for a high designation. The point totals on all the sheets were tallied, and average scores were computed to distribute the overall consensus weight for each goal over its sub-objectives.

The weights assigned to each goal were important in screening and evaluating the many possible alternative water management approaches to arrive at the recommended alternative.

3.4 Target C Evaluation Criteria Weighting

The stakeholders also were asked to help provide weights for the process of evaluating the six alternatives developed to meet the wet weather water quality and quantity objectives (Target C, see section 2). These weights represented the relative importance of each of the criteria used in the evaluation, in much the same way the goals were assigned weights. In this case, however, each member organization's weights were tested using the EVAMIX evaluation program, and no consensus was attempted on a single set of weights. The various weight sets provided a type of sensitivity analysis and helped to clarify the strengths and weaknesses of various combinations of BMPs in meeting the Target C objectives of a 20 percent reduction in stormwater flow to the streams.

4. Darby-Cobbs Study Results

This section summarizes the results of the numerous studies that have already been carried out within the watershed. Many of the studies covered the entire Darby-Cobbs-Tinicum watershed, others only the Cobbs Creek watershed. When available, results are included for the Darby, Cobbs, and Tinicum portions of the watershed, to facilitate future planning for the Darby Creek watershed by Delaware County. The primary focus of the section, however, is to provide more detailed information on the Cobbs Creek watershed as the basis for CCIWMP.

4.1 Watershed Description and Demographics

The Darby-Cobbs watershed is defined as the land area that drains to the mouth of Darby Creek at the Delaware Estuary, encompassing approximately 80 square miles in southeastern Pennsylvania. This area includes portions of Chester, Delaware, Montgomery, and Philadelphia Counties. The watershed may be subdivided into the Cobbs Creek, Darby Creek, and Tinicum subwatersheds. Figure 4-1 includes the watershed boundaries, hydrologic features, and political boundaries. Much of the information is based on the U.S. Census Bureau's TIGER (Topologically Integrated Geographic Encoding and Referencing) database.

Cobbs Creek drains approximately 14,500 acres or 27% of the total watershed area. The upper portions and headwaters of Cobbs Creek, including East and West Branch Indian Creek, include portions of Philadelphia, Montgomery, and Delaware Counties. The lower portion of Cobbs Creek watershed, including the lower mainstem and Naylors Run, drain parts of Philadelphia and Delaware Counties. Cobbs Creek discharges to Darby Creek.

The Darby Creek watershed drains approximately 29,000 acres or 55% of the total study area. The watershed is located primarily in Delaware County. The northwest corner of the watershed, including the headwaters of the mainstem, is located in Chester County. Darby Creek has a number of small tributaries, including Little Darby Creek, Ithan Creek, and Foxes Run.

The Darby-Cobbs watershed discharges to the Delaware River through the wetlands of the Tinicum Refuge. The Tinicum watershed includes portions of Philadelphia and Delaware Counties and totals 9800 acres or 18% of the total. Much of the area consists of low-lying wetlands, including the John Heinz National Wildlife Refuge. Named streams in the subwatershed include Hermesprota, Muckinipattis, and Stony Creeks.

In a relatively undisturbed watershed, watershed boundaries follow topographic high points or contours. The U.S. Geological Survey (USGS) has further subdivided the Darby-Cobbs watershed based on topography, as shown in Figure 4-2. These USGS subwatersheds are determined from the land area draining to a particular point of interest, such as a stream confluence or gauging site. These boundaries allow initial determinations of drainage areas and modeling elements. However, it is important in the urban environment to include the effects of man-made changes to natural drainage patterns.

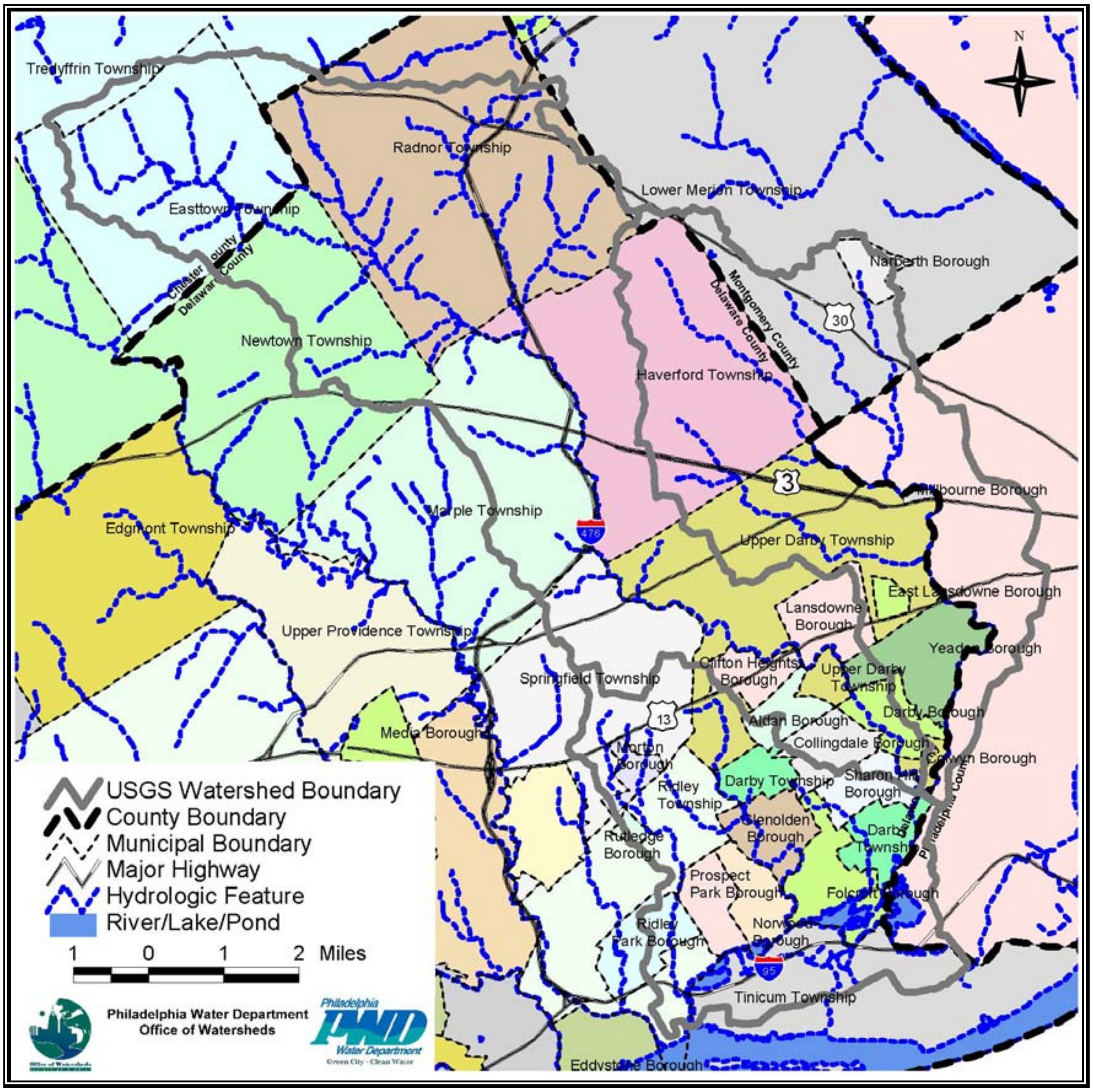


Figure 4-1 Darby-Cobbs Study Area

Geology and Soils

Geology and soils play a role in the hydrology, water quality, and ecology of a watershed. The Darby-Cobbs watershed falls within the Coastal Plain and Piedmont physiographic provinces. Geologic formations on the surface in the area include gneiss, schist, and serpentine formations in most of the watershed (Piedmont) and layers of sediment in the downstream reaches (Coastal Plain) as shown in Figure 4-3. Soils in the upper portions of the Darby Creek subwatershed include loams and silty loams, as shown in Figure 4-4. Soil in much of the rest of the watershed is classified as urban or made land and is not representative of the original undisturbed soil. Wetland soils are present in the Tinicum area.

Demographic Information

Population density and other demographic information in the watershed are available from the results of the 1990 census. Approximately 500,000 people live within the drainage area of the Darby and Cobbs Creeks. Figure 4-5 shows the population density in the watershed at the census block level. Spatial trends in population correspond closely to land use, with multi-family row homes displaying the greatest population density of 20 people per acre or more, single-family homes displaying a lower density, and other land use types displaying the lowest density. In addition to population data, the U.S. Census Bureau provides a range of socioeconomic data that are often useful in watershed planning and general planning studies. Median household income and mean home value (Figures 4-6 and 4-7) are two of the many sample datasets provided.

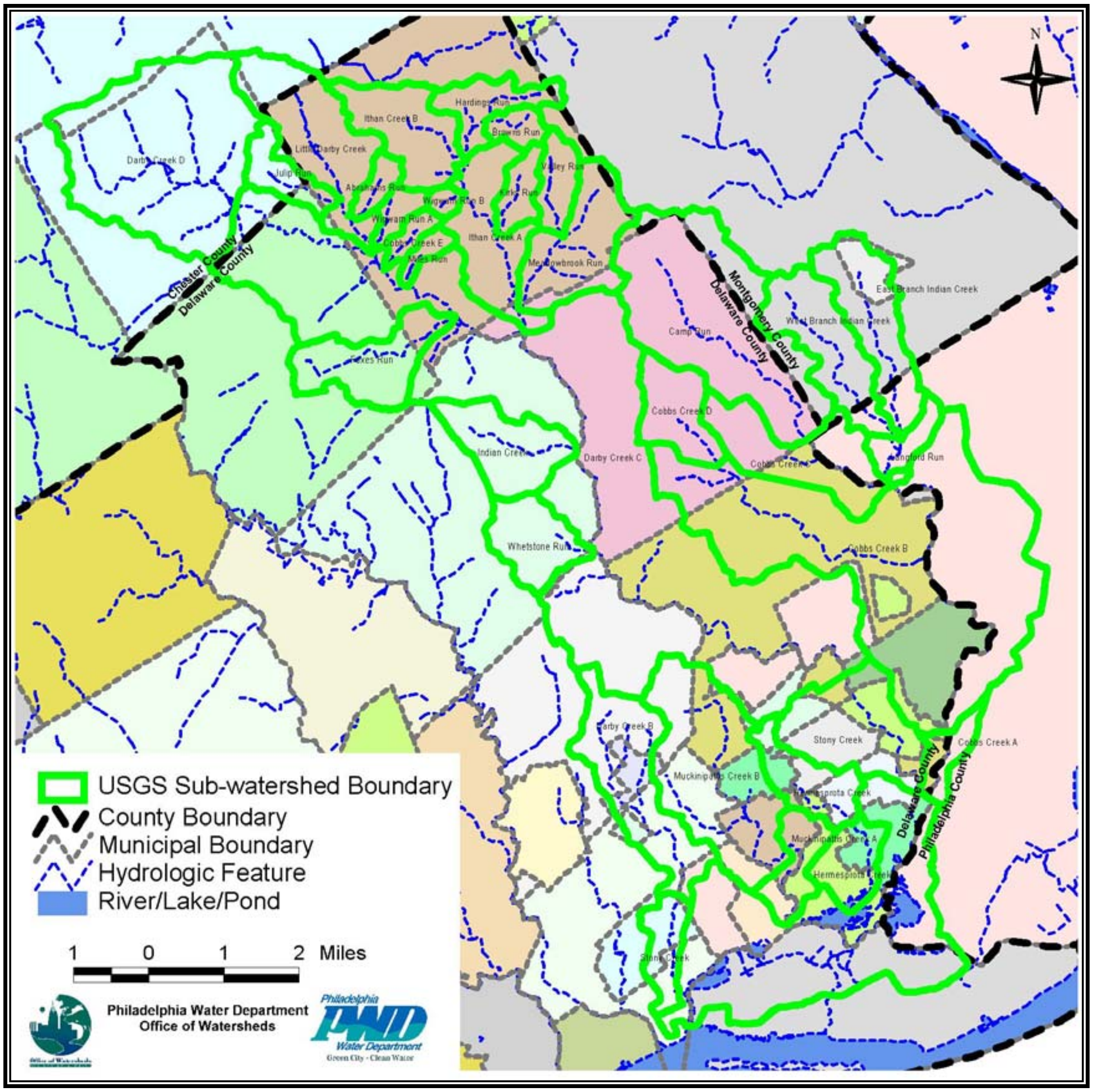


Figure 4-2 USGS Topographic Subwatersheds

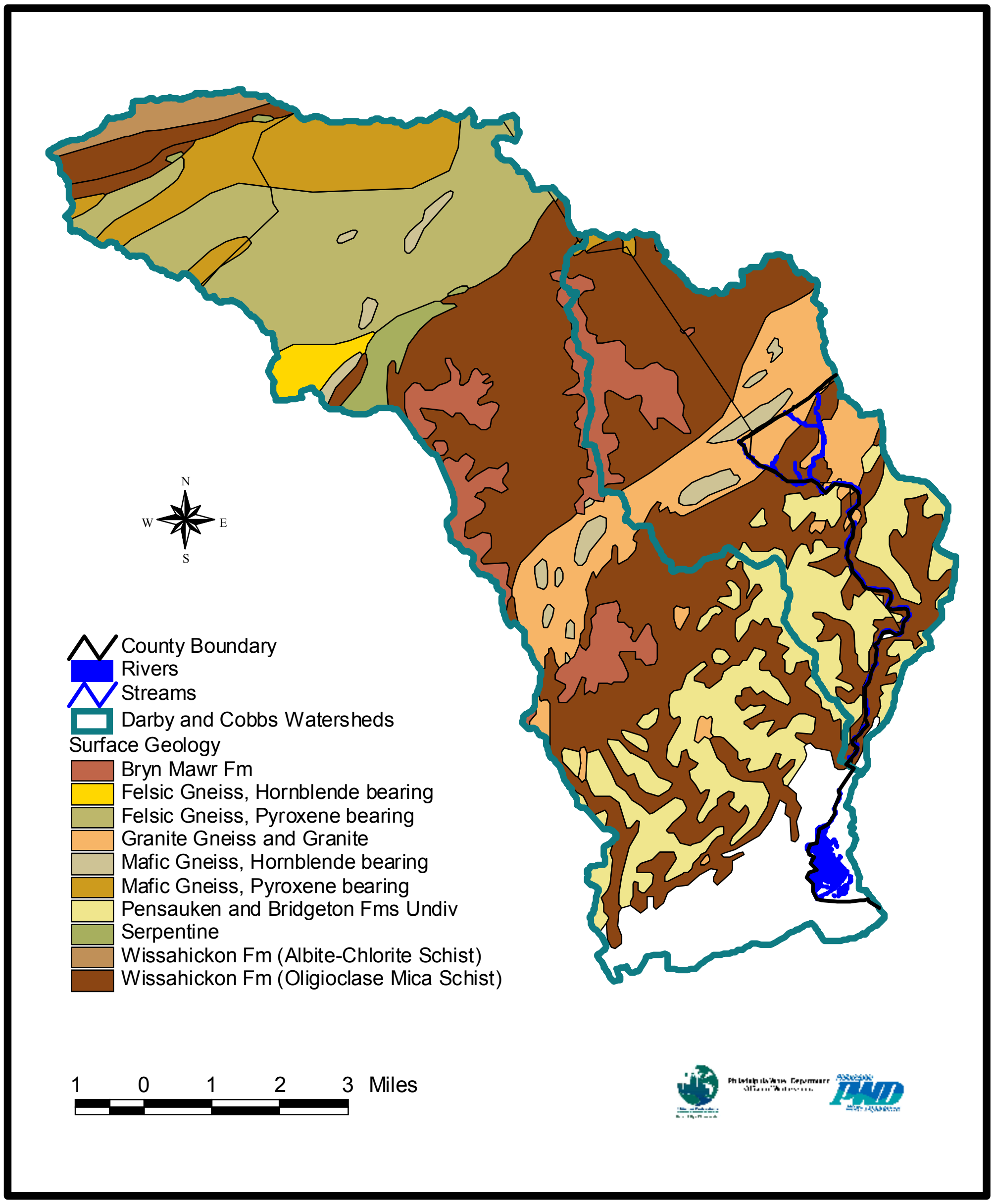


Figure 4-3 Surface Geologic Formations

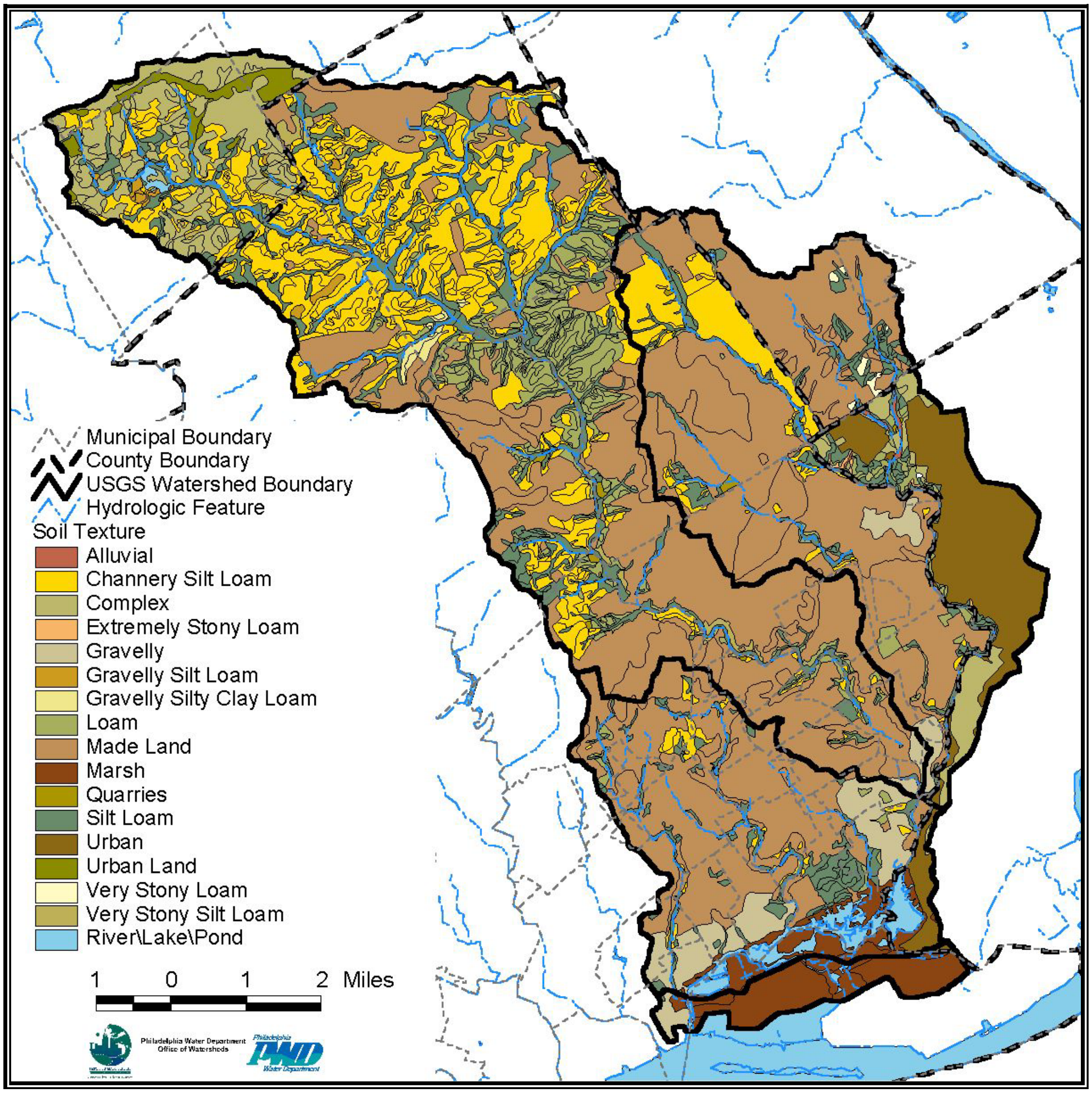


Figure 4-4 Soil Types in the Darby-Cobbs Watershed

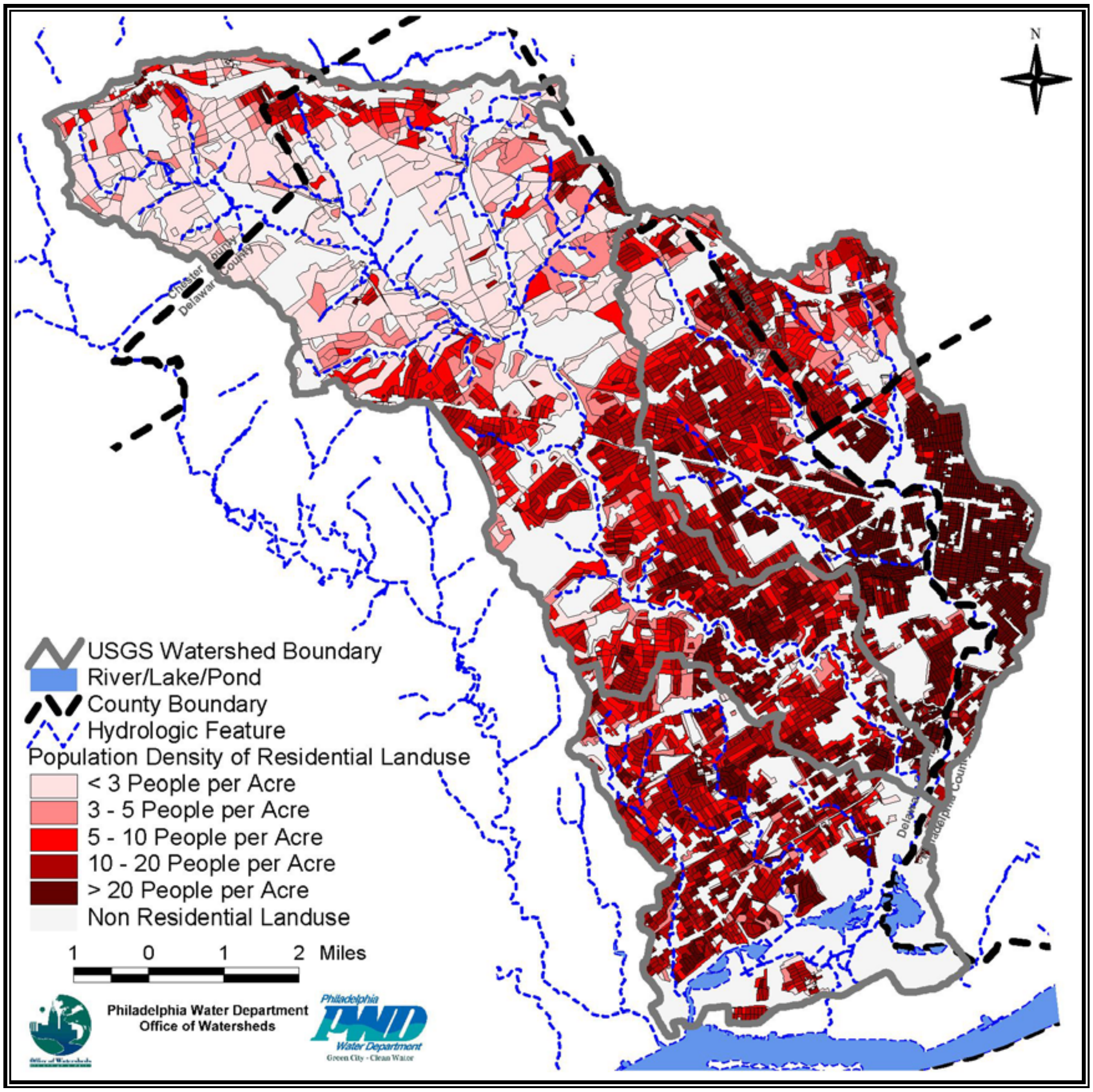


Figure 4-5 Population Density Based on 2000 Census Data

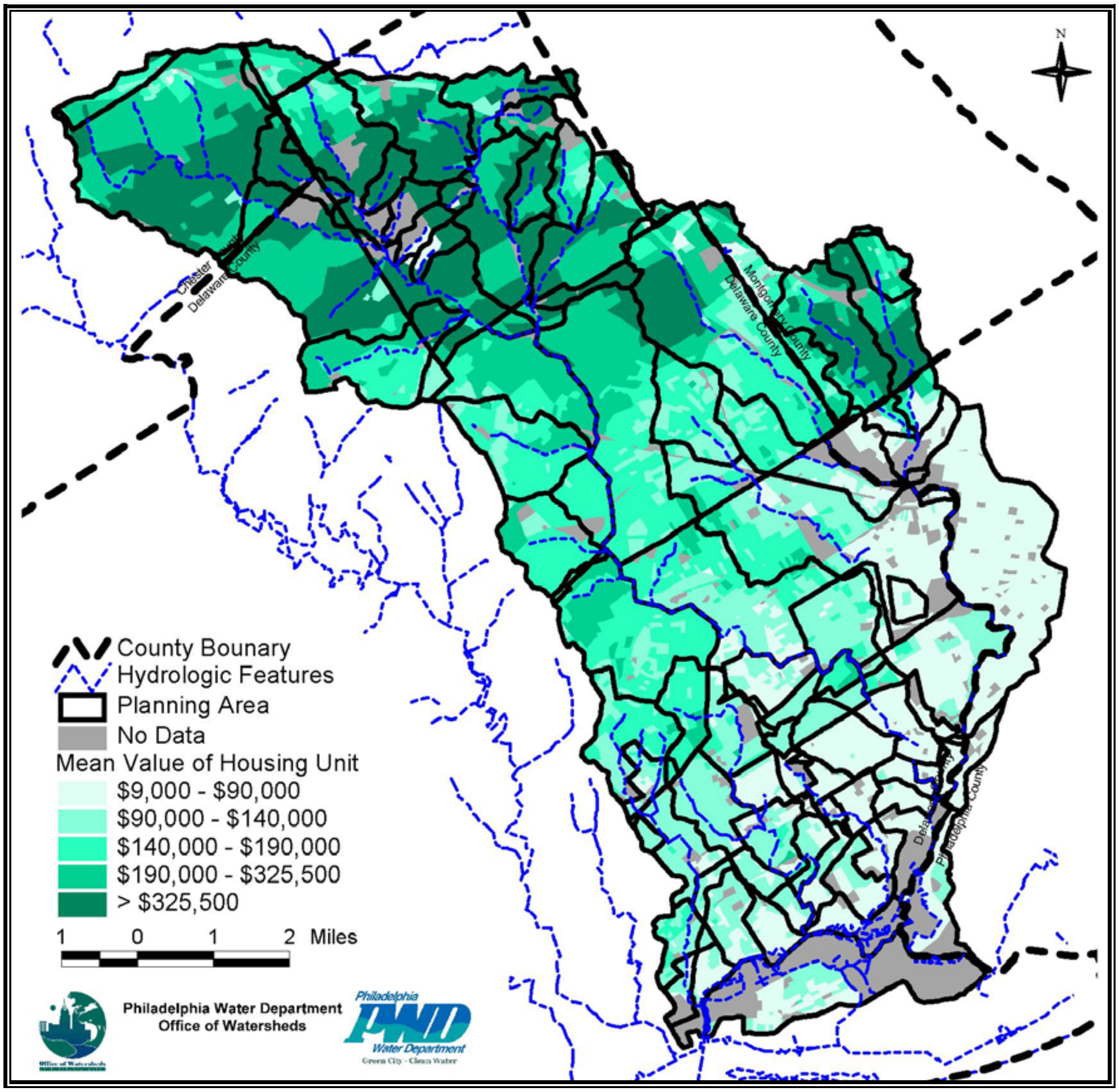


Figure 4-6 Mean Home Value

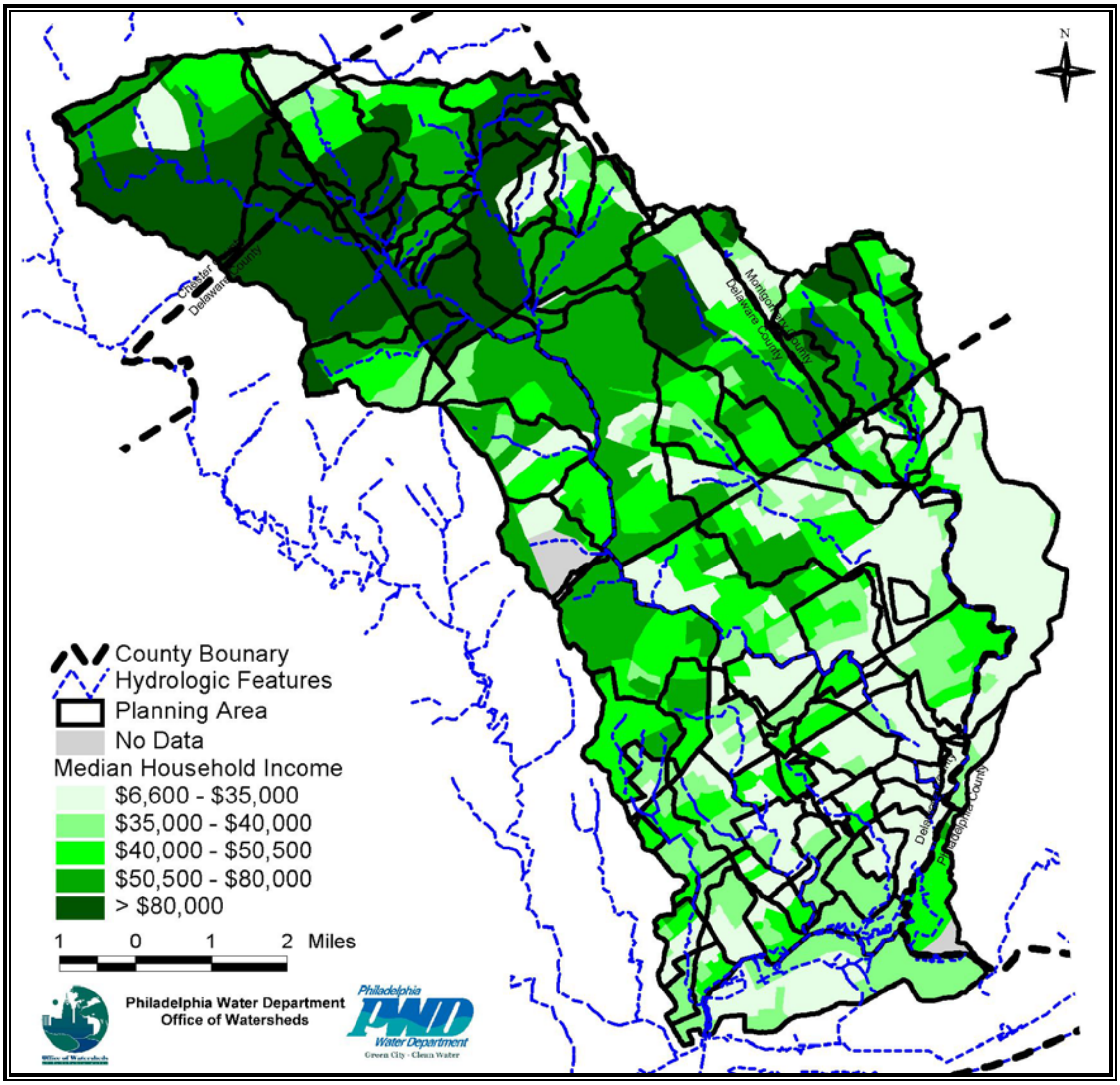


Figure 4-7 Mean Household Income

4.2 Watershed Status and Trends

This section was developed to serve as a basis for understanding the state of the Darby-Cobbs watershed, its relative environmental quality, and trends with respect to the management of factors that influence its quality. The report details the history and current conditions of the watershed and attempts to establish trends associated with a host of progress indicators. The results presented in this report were derived from past studies on the watershed and from recent data collection efforts conducted by the Philadelphia Water Department. 21 indicators were identified:

Land Use and Stream Health Relationship

Indicator 1: Land Use and Impervious Cover

Flow Conditions and Living Resources

Indicator 2: Streamflow
Indicator 3: Stream Channels and Aquatic Habitat
Indicator 4: Restoration Projects Lists of completed, in progress, and planned projects
Indicator 5: Fish
Indicator 6: Benthos

Water Quality

Indicator 7: Effects on Public Health (Bacteria)
Indicator 8: Effects on Public Health (Metals and Fish Consumption)
Indicator 9: Effects on Aquatic Life (Dissolved Oxygen)

Pollutants and Their Sources

Indicator 10: Point Sources
Indicator 11: Non-point Sources

Stream Corridor

Indicator 12: Riparian Corridor
Indicator 13: Wetlands and Woodlands
Indicator 14: Wildlife
Indicator 15: Flooding

Quality of Life

Indicator 16: Public Understanding and Community Stewardship
Indicator 17: School-Based Education
Indicator 18: Recreational Use and Aesthetics
Indicator 19: Local Government Stewardship
Indicator 20: Business and Institutional Stewardship
Indicator 21: Cultural and Historic Resources

Land Use and Stream Health Relationship

Indicator 1: Land Use and Impervious Cover

Urbanization of natural lands affects watershed hydrology, water quality, stream stability, and ecology. One of the primary indicators of watershed health is percent impervious cover in the watershed. Based on numerous research efforts, studies and observations, a general categorization of watersheds has been widely applied to watershed management based on percent impervious cover (Schueler 1995). Table 4-1 summarizes several impacts of traditional development on streams and watersheds, most of which are created by increased impervious cover.

Table 4-1 Impervious Cover as an Indicator of Stream Health (Schueler 1995)

Characteristic	Sensitive	Degrading	Non-Supporting
Percent Impervious Cover	0% to 10%	11% to 25%	26% to 100%
Channel Stability	Stable	Unstable	Highly Unstable
Water Quality	Good to Excellent	Fair to Good	Fair to Poor
Stream Biodiversity	Good to Excellent	Fair to Good	Poor
Pollutants of Concern	Sediment and temperature only	Also nutrients and metals	Also bacteria

This indicator measures:

- **GIS-estimated impervious cover of each subwatershed (% of total area)**
- **Model-estimated Directly Connected Impervious Area (DCIA) of each subwatershed (% of total area)**
- **Open space in each subwatershed (% of total area)**
- **Publicly-owned land in each subwatershed (% of total area)**

Where We Were:

By 1935, most of the early mills had left the lower Darby Creek watershed. Although its industrial base was in decline, large portions of the Darby Creek watershed area became occupied by dense housing developments, many of which were constructed before the emergence of zoning controls and other environmental and land management methods. As a result, the natural resources of the Darby Creek were negatively impacted by inadequate and polluted stormwater runoff and drainage systems, leaking and inadequate septic tanks, lack of open space and adequate recreation, illegal dumping, and an array of other urban ills.

Where We Are:

The upper reaches and headwaters of the Cobbs Creek watershed are characterized primarily by a mix of residential areas, while the lower portions are primarily high-density residential areas with commercial areas along highway corridors (Figure 4-8). Riparian lands within the City consist mainly of parkland left in a natural state. Land uses in the Darby Creek watershed consist of residential areas in the lower portions and a combination of low-density residential, commercial, parkland, and golf course uses in the upper reaches. The Tinicum watershed consists of residential and commercial development to the northwest and protected wetlands to the southeast. Based on these land uses, impervious cover is estimated for each portion of the watershed and listed in Table 4-2.

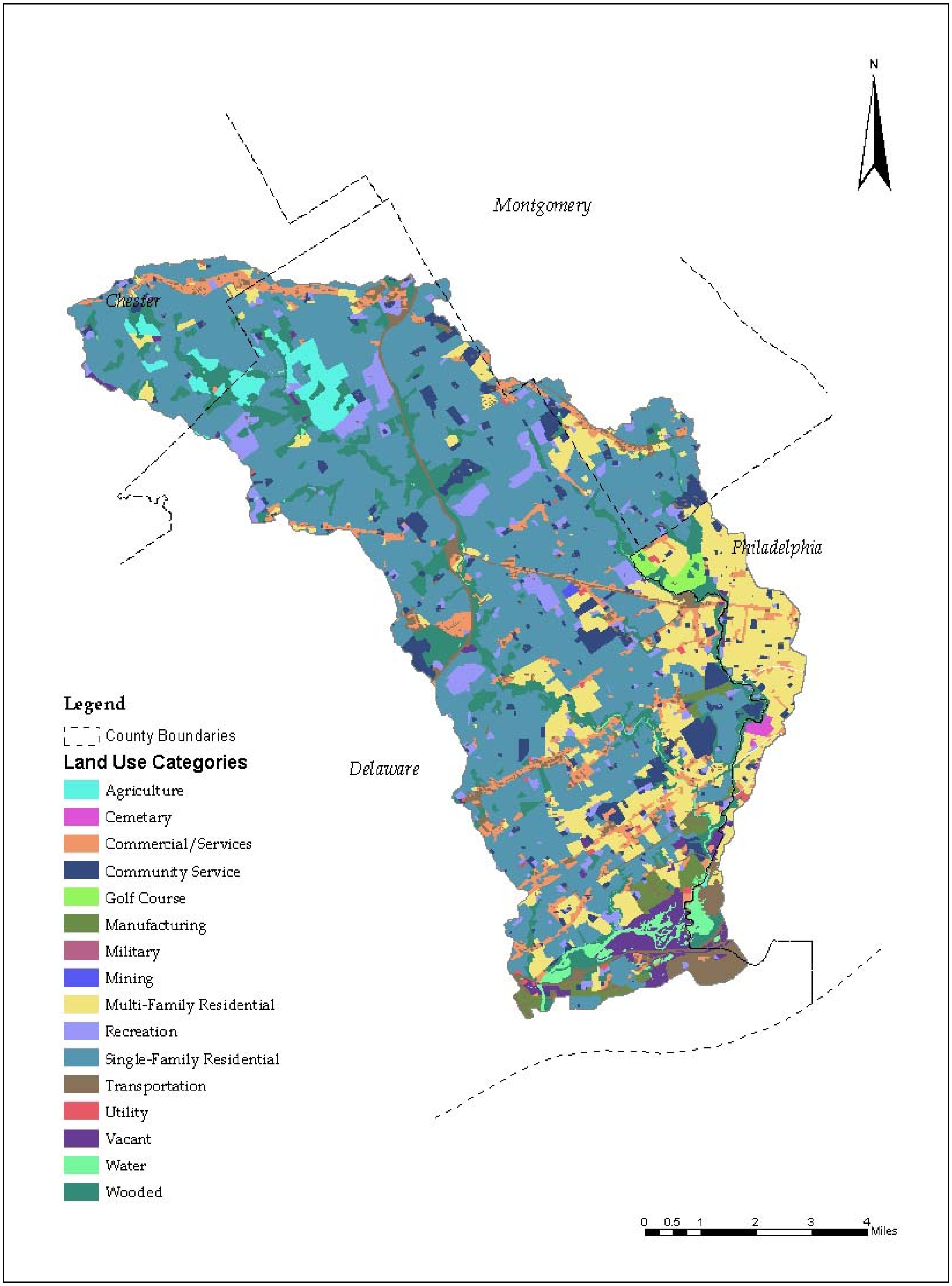


Figure 4-8 1995 DVRPC Land Use in the Darby-Cobbs Watershed

Table 4-2 Estimated Total Impervious Cover

Watershed	County	Area (ac)	% Impervious
Cobbs	Delaware	8,041	46.7%
Cobbs	Montgomery	2,644	40.6%
Cobbs	Philadelphia	3,562	60.2%
Darby	Chester	4,217	25.7%
Darby	Delaware	24,503	38.7%
Darby	Montgomery	70	44.2%
Darby	Philadelphia	558	66.7%
Tinicum	Delaware	5,811	49.4%

Tables 4-1 and 4-2 together suggest that the more developed areas of the watersheds are already degraded and that the developing portions can be expected to become degraded if action is not taken. The headwaters of Darby Creek in Chester County have the lowest estimated impervious cover at 25%. At this level, water quality and ecological health may still be fair to good, but erosion and sedimentation of the stream channel begin to become a problem. Philadelphia portions of the Cobbs and Darby Watersheds are the most impervious at over 60%. At this level, stream channels are highly unstable, and both water quality and ecological health tend to be poor. Remaining areas fall between these two extremes. It is estimated that about 50-75% of impervious area is directly connected (DCIA) to the drainage system.

The proportion of open space and publicly owned land are also informative indicators (Table 4-3). Analysis of the land use data reveals that over 90% of the Darby Creek watershed and the northern portion of the Cobbs Creek watershed is privately owned land. While the northern portion of the Darby Creek Watershed also has a high percentage of open space, it is made up primarily of privately owned land such as agricultural areas and golf courses. Other than the upper portion of the Darby Creek watershed, areas that have the most open space also tend to be those sections of the watershed with the most publicly-owned land. These include the Lower Cobbs, which has the most publicly-owned space due to Cobbs Creek Park, followed by Tinicum marsh which contains the John Heinz National Wildlife Refuge. Figure 4-9 indicates how the watershed is broken into subwatersheds.

Table 4-3 Estimated Open Space and Publicly Owned Land

Subwatershed	Total Area (acres)	Publicly Owned (% of total)	Open Space (% of total)
Upper Cobbs	6,473	7%	14%
Lower Cobbs	7,698	26%	25%
Upper Darby	16,910	6%	26%
Lower Darby	8,521	7%	21%
Tinicum	9,804	25%	27%

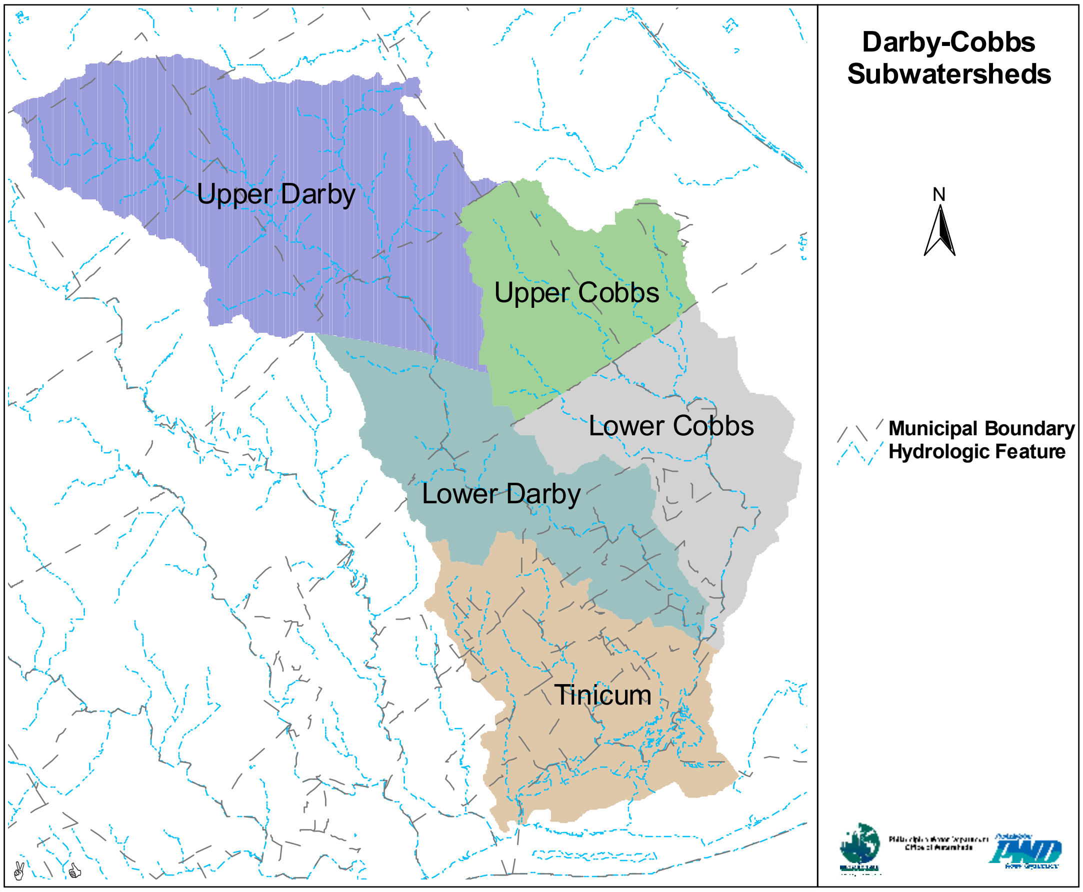


Figure 4-9 1995 Subwatersheds in the Darby-Cobbs Watershed

Flow Conditions and Living Resources

Indicator 2: Streamflow

As discussed in Indicator 1, urbanized land uses in a watershed affect stormwater runoff, streamflow, condition and shape of stream banks and channels, water quality, and aquatic habitat and ecosystems. Increases in impervious cover affect stream hydrology in a variety of ways:

- Increased magnitude and frequency of severe floods
- Increased frequency of erosive bankfull and sub-bankfull floods
- Reduced groundwater recharge leading to reduced baseflow
- Greater stream velocities during storm events

This indicator measures:

- **Average annual baseflow (% of total flow)**
- **Average annual baseflow (% of annual precipitation)**
- **Average annual stormwater runoff (% of annual precipitation)**

The Cobbs Creek watershed and the lower portions of the Darby Creek watershed are highly urbanized and contain a large proportion of impervious cover. Hydrologic impacts of urbanization can be observed through analysis of streamflow data taken from USGS gauges on Darby and Cobbs Creeks. In addition, data from French Creek in Chester County provide a picture of a nearby less-developed watershed.

Where We Were:
The analysis below represents a long-term period of record for each stream gauge. It is difficult to establish a trend over time, but an attempt will be made when the watershed is reassessed.

Where We Are:
Streamflow data were separated into their two main components: baseflow and stormwater runoff. In perennial streams, baseflow is the portion of streamflow caused by groundwater inflow and is present in dry and wet weather. Stormwater runoff is the portion of streamflow contributed by excess rainfall flowing over the land surface and through the drainage system. The results of this hydrograph decomposition exercise (Table 4-4) support the relationships between land use and hydrology discussed above. Based on the French Creek gauge and the two Darby Creek gauges, the hydrologic behavior of these two systems is similar. Pervious cover allows sufficient groundwater recharge to give streamflow relatively natural characteristics; a mean of approximately 20% of annual rainfall contributes to the stormwater component of streamflow, and baseflow represents approximately 65% of total annual streamflow. It is interesting to note that baseflow, as a percentage of precipitation, is higher in Darby Creek than in French Creek. Cobbs Creek exhibits behavior typical of a highly urbanized stream, with over 25% of rainfall contributing to stormwater runoff in a mean year and with mean baseflow comprising only 43% of mean annual streamflow.

Table 4-4 Summary of Hydrograph Separation Results over the Period of Record

	Period of Record (yrs)	Baseflow (% of Total Flow)	Baseflow (% of Precip)	Stormwater Runoff (% of Precip)
French Creek 01475127	33.0	64	31	17
Cobbs Creek 01475550	26.7	42	19	25
Darby Creek D/S 01475510	26.7	62	34	21
Darby Creek U/S 01475300	25.4	66	37	19

Indicator 3: Stream Channels and Aquatic Habitat

Healthy populations of fish and invertebrates require physical habitat features that allow them to feed, reproduce, and seek shelter during episodes of high flow. In the urban environment, where significant erosion and deposition occur, these features often are not available (Figure 4-10).

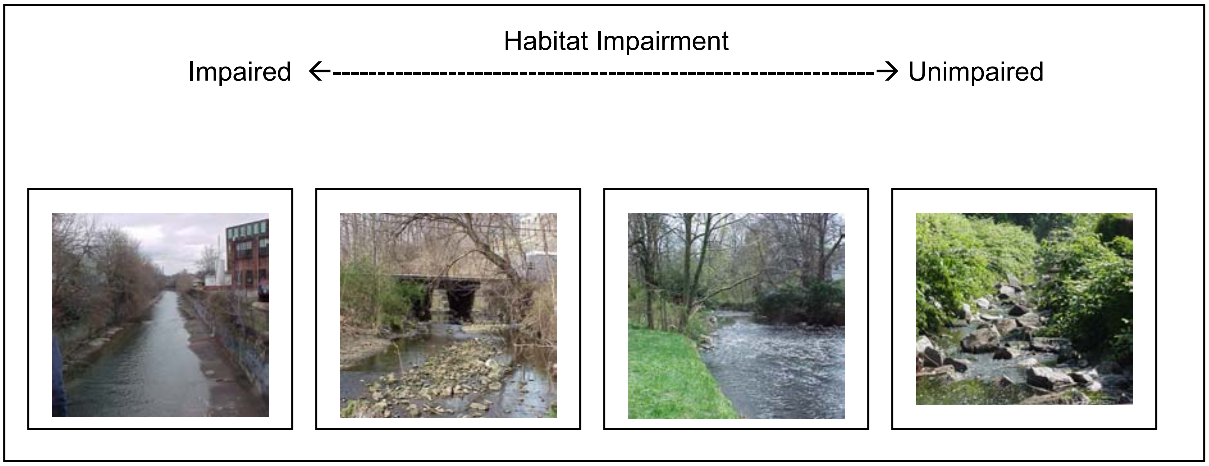


Figure 4-10 Habitat Impairment Comparisons

Fluvial geomorphology is the study of landforms associated with river channels and the processes that form them. The Rosgen classification system is commonly used to assess physical channel conditions. Of the channel types found in Cobbs, channels classified as “F” are highly impacted by urban flows, subject to erosion and deposition of sediment, and generally do not support diverse ecosystems. Channels classified as “B”, “C”, and “E” are generally stable under natural flow conditions and can support healthy stream habitats. Channels currently classified as one of the stable types may degrade into F channels over time when subjected to urban flows. Likewise, “F” channels can slowly start establishing new floodplains and can become “C” channels.

This indicator measures:

- **Habitat score relative to reference condition at various sites**
- **Channel type and expected trend**

Where We Were:
There is no historical data available for this indicator. Habitat and stream channels most likely degraded over a long period of time as the watershed developed. A trend will be established the next time this area is reassessed.

Where We Are:
In 1999, habitat at 7 sites throughout the Cobbs watershed was surveyed by PWD biologists (Figure 4-11). The sites were rated based on comparison to a reference reach, French Creek. The five sites in the headwaters received ratings of “Comparable to Reference” (1 site), “Supporting” (1 site), and “Partially Supporting” (3 sites), while the two downstream sites were determined to be “Partially Supporting” of aquatic communities.

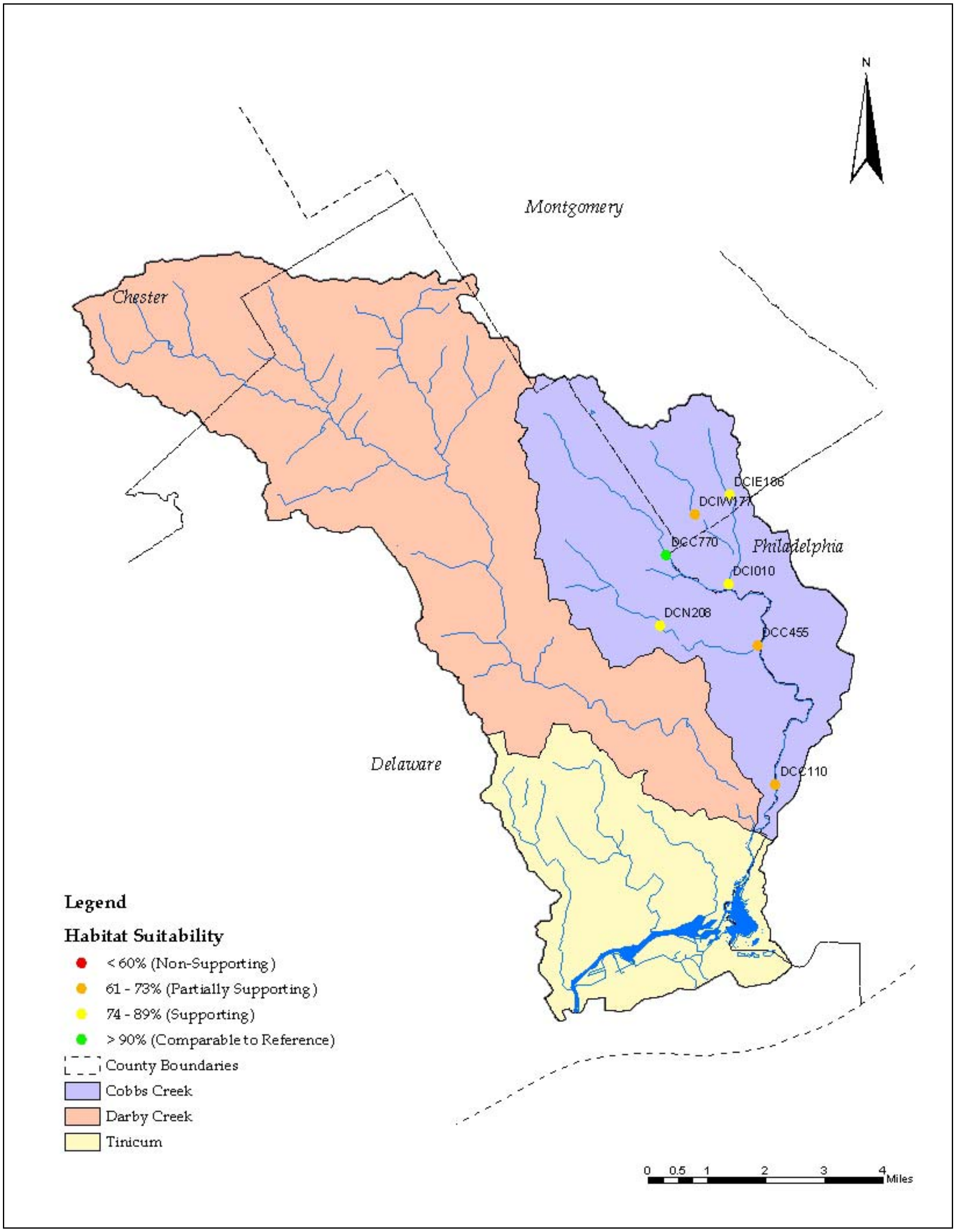


Figure 4-11 Cobbs Habitat Assessment (Philadelphia Water Department, 1999)

In 2002, Rosgen techniques were used to measure channel geometry and stability parameters to determine stream classification. Over 17 miles of stream were evaluated and selected reaches of Cobbs Creek, West Branch Indian Creek, and East Branch Indian Creek were classified.

Approximately 80% of the studied length was classified as a Rosgen type “F” channel (Figure 4-12). “B”, “C”, and “E” types are found in the headwaters, while the “F” types are found along most of the lower main stem. The Cobbs main stem is expected to continue widening through bank erosion, and upstream portions are expected to start downcutting and become more entrenched.

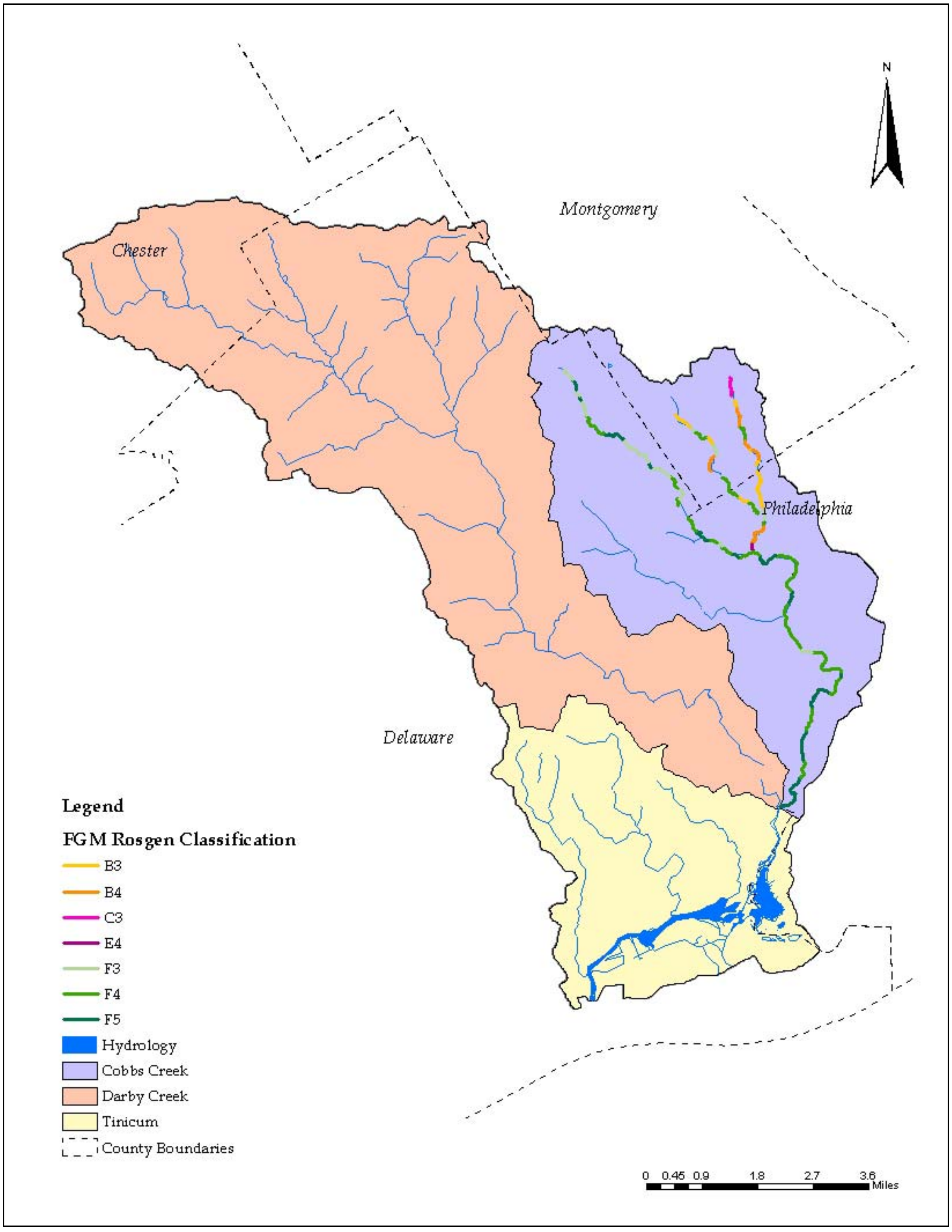


Figure 4-12 Fluvial Geomorphology Study - Rosgen Classification of Cobbs Reaches 2003

Indicator 4: Restoration and Demonstration Projects

Funding for watersheds and water–related projects has been increasing throughout the country in recent years. Grants are being issued to support various types of projects throughout the state of Pennsylvania. Begun in 1999, Pennsylvania's Growing Greener program has been an enormous source of environmental funding over the last few years. In fact, this program has become the largest single investment of state funds in Pennsylvania's history. There are also many other organizations and governmental agencies offering grant money and technical assistance for communities and other organizations to accomplish their environmental projects for improving our watersheds. Figure 4-13 depicts a stream reach that is planned for eventual restoration.

This indicator measures:

- **Lists of completed, in progress, and planned projects**

Figure 4-13 Bank Erosion in the Cobbs Creek Restoration Area

Where We Were:
The number of restoration projects in this watershed has increased with the introduction of the Growing Greener program and other funding programs.

Where We Are:
Many environmental projects have been funded in the Darby-Cobbs Watershed, from streambank restoration to environmental education programs. A list of grants issued over the last 6 years has been assembled. Table 4-5 represents a profile of the grants received and the projects being performed; this is in no way is a comprehensive list of all the projects in the watershed. 25 projects were identified with a total amount of received funding totaling over $1.5 million.

Table 4-5 Grants in the Darby-Cobbs Watershed

Funding Agency	Funding Program	Year	Lead Agency	Project	Amount Awarded
DCNR	Rivers Conservation Grants	1998	Darby Creek Valley Association and DelCo Anglers and Conservationists	Develop a river conservation plan for Darby Creek.	$69,000
DEP	Watershed Restoration Assistance Program (WRAP)	1998	Delco Anglers and Conservationists	Riparian enhancement of Darby, Ridley and Goose Creeks.	$1,000
DEP	Watershed Restoration Assistance Program (WRAP)	1998	Radnor Township	Restore 100 feet of Little Darby Creek streambank.	$24,470
DEP	Growing Greener	1999	Darby Borough	Restoration of streambanks and riparian buffers at a public park using various bioengineering techniques.	$25,000
DEP	Watershed Restoration Assistance Program (WRAP)	1999	Darby Borough Council	Bartram Memorial Park streambank and erosion control and riparian planting project	$25,000
DEP	Growing Greener	1999	Tinicum Township Delaware County	Replace existing Jansen Avenue tide gate with self-regulating tide gate	$261,203
DEP	Growing Greener	1999	Villanova University, Radnor	Villanova Stormwater Management Practice Demonstration Park -- Phase One Planning.	$10,120
DEP	Growing Greener	2000	Delco Anglers and Conservationists	Darby Creek Riparian Restoration Continuation	$1,047
DEP	Growing Greener	2000	Pennsylvania Environmental Council Inc.	Darby-Cobbs Watershed Partnership Education and Outreach Survey	$35,000
DEP	Growing Greener	2000	Marple Township	Lawrence Road/Darby Creek Bank Stabilization	$68,225
DEP	Growing Greener	2000	Friends' Central School	Cobbs Creek Watershed Monitoring and Restoration	$75,913
DEP	Growing Greener	2000	Pennsylvania Environmental Council, Inc.	Development of a series of informational products on environmental issues for municipal officials	$79,199

Flow Conditions and Living Resources

Indicator 4: Restoration and Demonstration Projects

Funding Agency	Funding Program	Year	Lead Agency	Project	Amount Awarded
DEP	Growing Greener	2000	City of Philadelphia Water Department	Sustainable Approach to Stream Habitat Restoration in an Impaired Urban Stream (Cobbs Cr.)	$150,000
DEP	Growing Greener	2000	Villanova University	Villanova stormwater bioretention traffic island	$59,112
League of Women Voters	Water Resources Education Network (WREN)	2001	Township of Lower Merion and Environmental Advisory Council	Produce a brochure entitled "Safeguarding our Streams" and produce a live television town meeting.	$5,000
DEP	Growing Greener	2001	Environmental Fund for Pennsylvania / Greenworks	The Value of Water	$24,174
DEP	Growing Greener	2001	Environmental Fund for Pennsylvania	Life on the Delaware River	$60,000
DEP	Act 167 Stormwater Management	2001	City of Philadelphia Water Department	Development of a Multi-Objective Model Framework for the Cobbs Creek Watershed	$62,100
DEP	Growing Greener	2001	Cobbs Creek Community Environmental Education Center	Cobbs Creek Watershed Stewards Initiative	$187,160
DEP	Growing Greener	2001	Villanova University-Institute for Environmental Engineering Research	Villanova stormwater porous concrete demonstration site	$85,500
EPA	104b3	2001	City of Philadelphia Water Department	Cobbs Creek Habitat Model	$250,000
EPA	Wetland Program Development Grants	2002	City of Philadelphia Water Department	Wetlands Program Inventory and Assessment	$175,000
DEP	Growing Greener	2002	Friends' Central School	Education and outreach on Cobbs and Darby Creeks	$31,380
DEP	CZM	2002	Delaware Riverkeeper Network	Bartram Park Streambank Restoration & Buffer Enhancement Project	$71,400
DEP	Growing Greener	2003	Villanova University	Project uses the Clean Water Fund to install storm water best management practices.	$39,300
Total Award for Darby-Cobbs (Years 1998 – 2003)					**$1,875,303**

Indicator 5: Fish

Fish are good indicators of stream health because their presence requires favorable environmental conditions within a certain range of stream flow, water temperature, water quality, and channel habitat. Abundance and diversity of fish are great indicators of water quality. Other indicators are the number of pollution tolerant fish and the proportion of fish with abnormalities. Dominance by a small number of pollution-tolerant species may indicate habitat and water quality degradation.

This indicator measures:

- **Abundance and pollution tolerance of species found at various sites**
- **Fish community integrity relative to reference condition at various sites**
- **Whether stream meets criteria for trout-stocking**

Where We Were:
There is no historical data available for this indicator. A trend will be established the next time this area is reassessed.

Where We Are:
During a 1999 Cobbs Creek assessment, fisheries data indicated that the fish community was numerically dense yet species poor. Figure 4-14 shows the percentage of pollution tolerant fish at each site. Both pollution tolerant and moderately pollution tolerant fish were found at each site. There was a range of diversity, with one site receiving a rating of good, two receiving a rating of moderate diversity, one a low diversity rating, and one a poor diversity rating (Figure 4-15). In all, 14 different species of fish were collected from in Cobbs Creek, West Indian Creek and Naylor's Run. (Figure 4-16).

Changes in trout stocking patterns have occurred over the last few years. The Cobbs Creek area has not been recently stocked with trout by the Philadelphia Fish and Boat Commission and does not meet quality criteria necessary to be stocked. During 2001-2003, Darby and Stony Creeks were stocked.

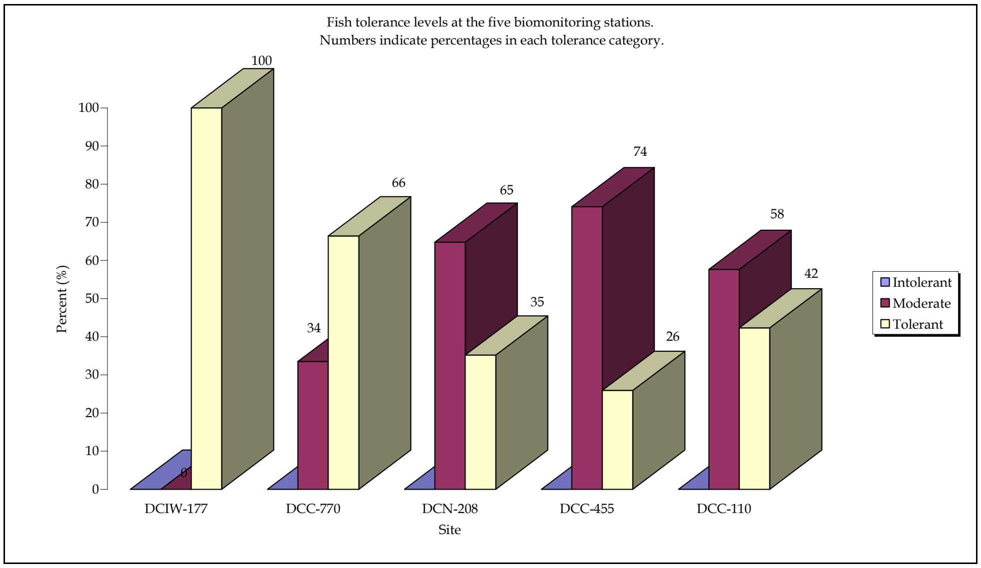


Figure 4-14 Fish Tolerance at Specific Monitoring Sites (1999)

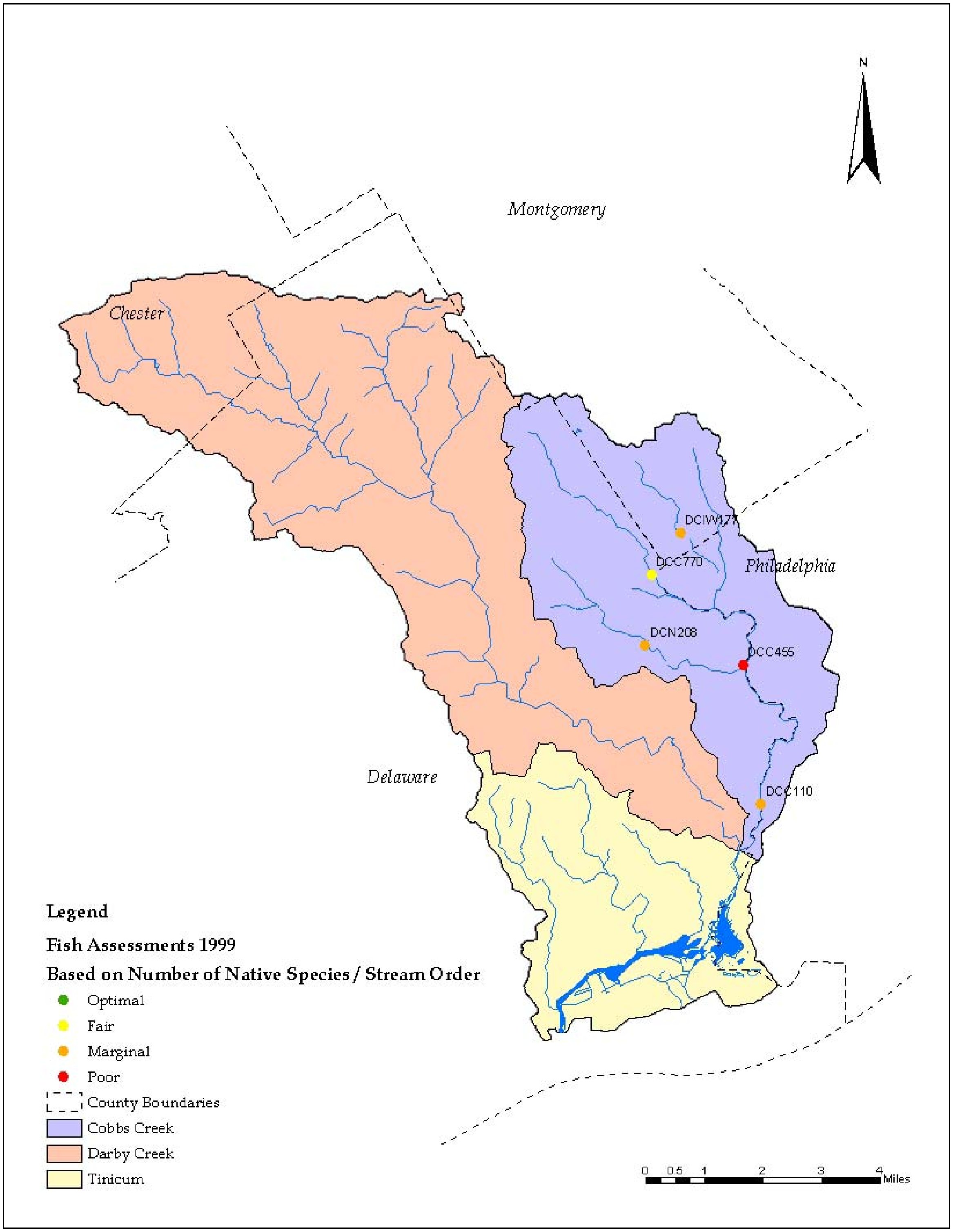


Figure 4-15 Cobbs Fish Assessment (Philadelphia Water Department, 1999)

	1	2	3	4	5		
	Site #						
Species	**DCC-455**	**DCC-770**	**DCC-110**	**DCN-208**	**DCIW-177**	**Pollution Tolerance**	**Picture**
American Eel	R	R	R	R	N	M	
Banded Killifish	N	N	R	N	N	M	
Common Shiner	R	C	R	R	N	M	
Pumpkinseed	R	R	R	R	N	M	
Redbreast Sunfish	N	N	R	R	N	M	
Spottail Shiner	R	N	R	N	N	M	
Swallowtail Shiner	C	R	R	C	N	M	
Blacknose Dace	R	C	R	C	A	T	
Brown Bullhead	N	N	R	N	N	T	
Creek Chub	N	R	R	N	R	T	
Fathead Minnow	N	N	R	N	N	T	
Green Sunfish	N	N	N	R	N	T	
Mummichog	R	N	C	R	N	T	
White Sucker	R	R	R	N	R	T	

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Indicator 5: Fish

Species Abundance	**Symbol**	**%**
Abundant	A	60% -100%
Common	C	30% - 60%
Rare	R	0% - 30%
None	N	0
Pollution Tolerance	**Symbol**	
Moderate	M	
Tolerant	T	

Figure 4-16 Fish Types and Abundance

Indicator 6: Benthos

The community of organisms on the bottom of water bodies is a good indicator of long-term water quality and the overall health of an aquatic system. Benthic organisms play roles in the aquatic ecosystem similar to the ones terrestrial small plant and animal species play in land-based communities. Benthic communities respond to changes in the aquatic environment and often provide an indication of concerns or evidence of successful restoration projects. Shown in Figure 4-17 is the life cycle of a mayfly, one example of a benthic macroinvertebrate.

This indicator measures:

- **State designation of attained and unattained reaches**
- **Benthic community integrity relative to reference condition at various sites**

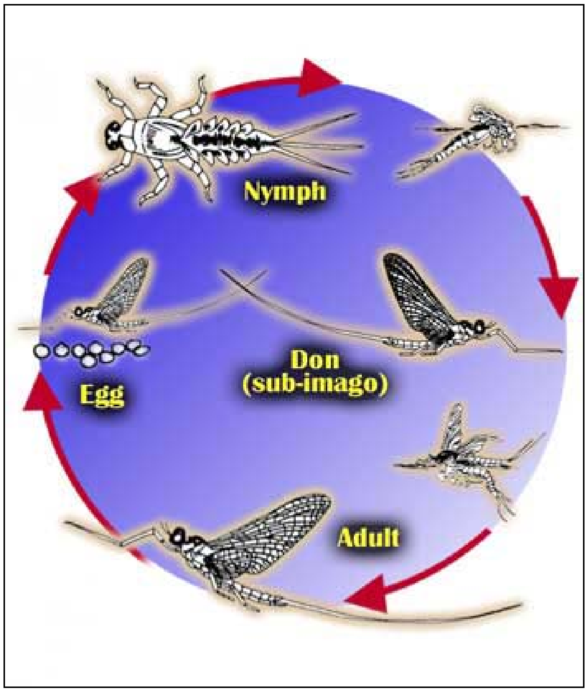

Figure 4-17 Life Cycle of a Mayfly

Where We Were:
There is no historical data available for this indicator. A trend will be established when this area is reassessed.

Where We Are:

PADEP classifies streams in the watershed as impaired, with the exception of upper Darby Creek. In Figure 4-18, the color green represents stream reaches that are not impaired and have attained designated water quality criteria; reaches in red are impaired and do not meet their designated criteria. Work by PWD biologists in the Cobbs portion (colored dots in Figure 4-18) confirm that benthic communities are moderately to severely impaired. According to the year 2004 proposed 303(d) list, sources of impairment are primarily habitat modification, municipal point sources, and urban runoff/storm sewers (PADEP, 2004). Impairment is caused by siltation, water/flow variability, habitat alterations, or other unknown causes in all cases. Much of the

Cobbs Creek impairment listing is based on assessment work in 2000, while Darby Creek was last assessed in 1996 or earlier.

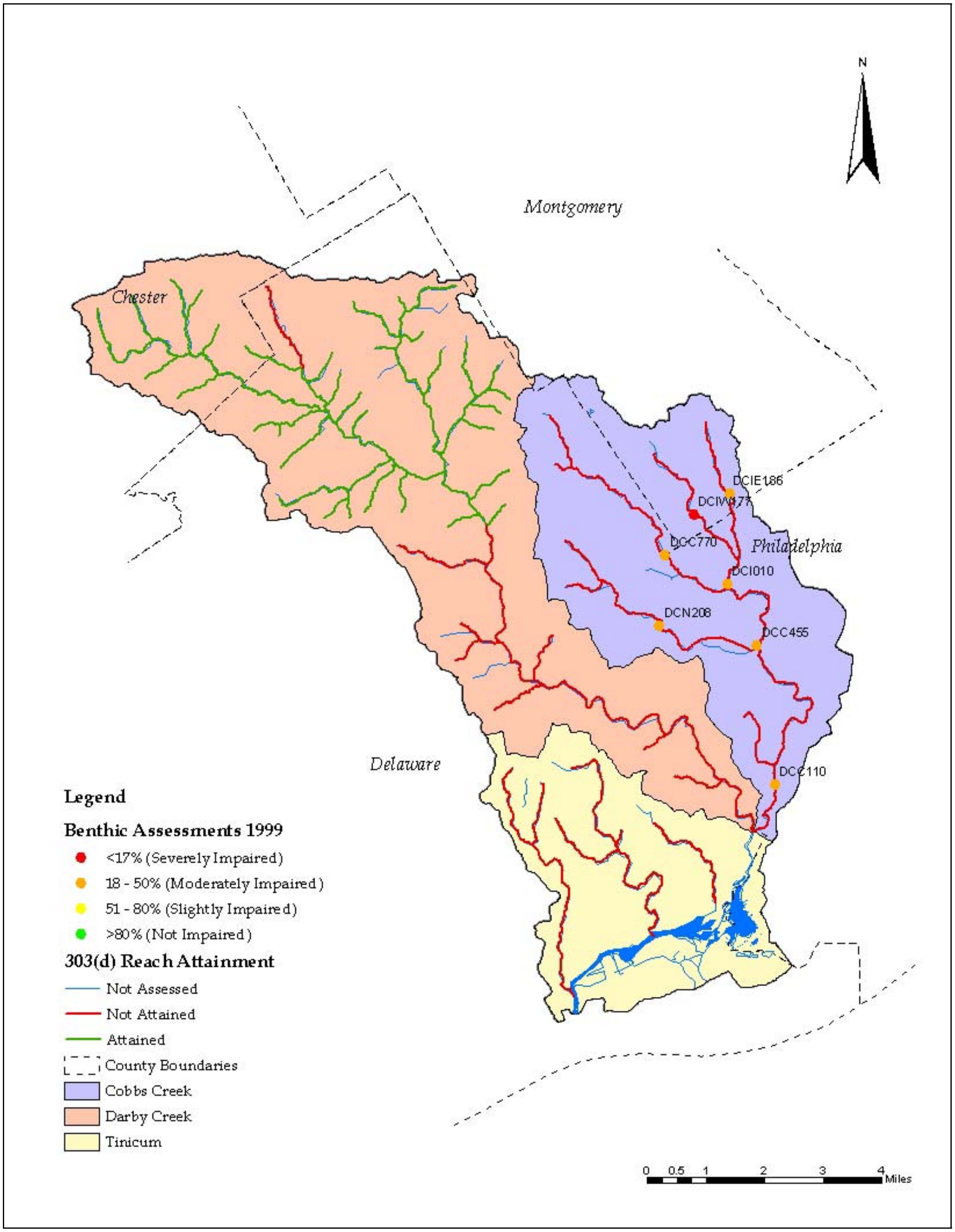

Figure 4-18 PWD Benthic Assessment Sites and State-Designated Impaired Reaches

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Flow Conditions and Living Resources

Indicator 6: Benthos

During a 1999 bioassessment of the Darby and Cobbs Watershed, pollution tolerance levels of macroinvertebrate communities showed all sites were dominated by moderately pollution-tolerant or pollution-tolerant macroinvertebrates, with a minimal number of pollution-intolerant macroinvertebrates. Due to increased flow over riffle systems, where most benthic organisms are found, reproductive and feeding strategies have been affected.

Water Quality

Indicator 7: Effects on Public Health (Bacteria)

Fecal contamination of natural waters may originate from both human and animal sources and may pose a threat to human health. Surface runoff transports waste material from pets, livestock, and wildlife to surface waters. Wet weather sewer overflows (both SSOs and CSOs) introduce domestic wastewater constituents to surface water. Illegal or accidental connection of sanitary sewers to storm sewers may also result in discharges of raw wastewater. Municipal wastewater treatment plants and septic systems release some bacteria to surface waters, but these inputs are generally small.

Fecal coliform bacteria are consistently very abundant in the intestines of warm blooded animals, including humans. Presence of fecal coliform bacteria is a fairly reliable indicator of fecal contamination of natural water, drinking water, and wastewater. Historically those bacteria have been used to indicate the possibility that other pathogens (e.g., bacteria, viruses, protozoa, etc.) may also be present. Measures taken to reduce the input of fecal coliform to natural waters are likely to reduce the input of other potential pathogens found in sewage and surface runoff.

Pennsylvania's water quality standard for fecal coliform bacteria in waters of the Commonwealth is as follows: during the swimming season (May 1 through September 30), the maximum fecal coliform concentration shall be a geometric mean of 200 CFU per 100 mL based on five consecutive samples each sample collected on different days; for the remainder of the year, the maximum fecal coliform level shall be a geometric mean of 2000 CFU per 100 mL based on five consecutive samples collected on different days.

This indicator measures:

- **Percent of fecal coliform samples meeting state standards at various sites**

Where We Were:
Approximately 100 surface water samples were tested for fecal coliform between 1970 and 1990 at a variety of sites. For samples taken in the headwaters of the system, approximately one-third to one-half met the current standard. At Cobbs Creek just above the confluence with Darby Creek, less than 10% of samples met the current standard.

Where We Are:
Samples were collected in 1999 and 2000 at several sites in the watershed (Figure 4-20). All these samples were taken in the summer months, when the strictest standard is in effect. In general, 0-20% of dry weather samples met the standard, and at most sites none of the wet weather samples met the standard. At Cobbs Creek site DCC-110, just above the confluence with Darby Creek, dry weather conditions seem to have improved over time; 25% of dry weather samples met the standard in 1999-2000 as compared to 4% in the 1970's. Overall, in the watershed, concentrations of fecal coliform bacteria seem to have remained about the same or increased slightly over time.

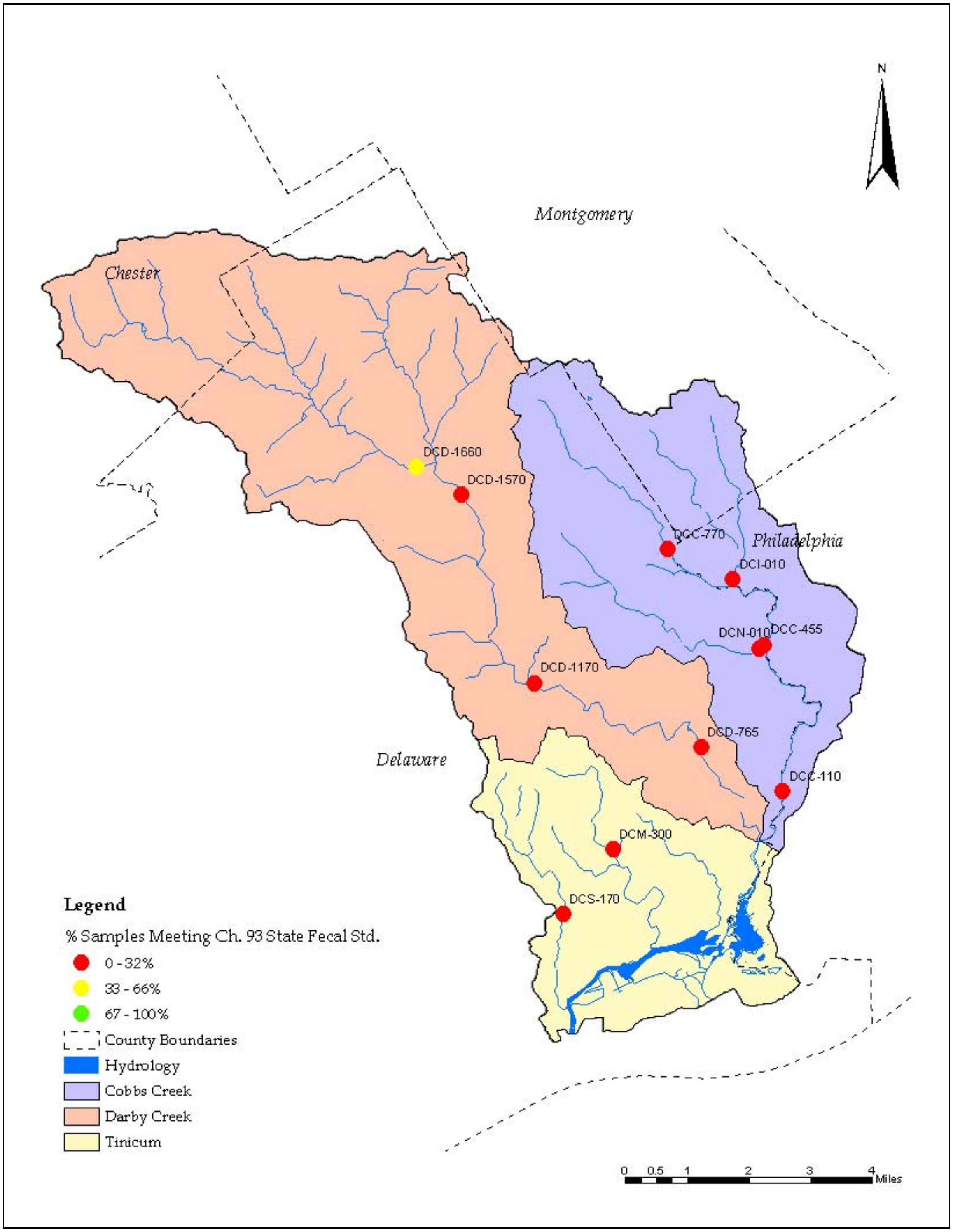


Figure 4-19 Water Quality Data for Fecal Coliform (1999)

Indicator 8: Effects on Public Health (Metals and Fish Consumption)

Toxic substances, including metals such as lead and organic substances such as PCBs, are sometimes introduced into the aquatic environment as a result of human activity. These substances exist in some sediments as a result of historical discharges, are introduced to the atmosphere through burning of fossil fuels, and are deposited on land surfaces through industrial and transportation activities. Precipitation and surface runoff introduce small concentrations of these substances to surface waters. Relatively small amounts of certain toxic substances can kill aquatic life through acute poisoning. Chronic exposure to toxins may be harmful at even smaller concentrations. Over time, fish may accumulate toxins from the water they live in and the food they eat. In some cases toxins may be present in harmful concentrations in their tissues.

Because toxic substances in the environment can affect aquatic life and humans who consume fish, PADEP has established maximum concentrations that are allowable in the water column. Standards based on aquatic life protection are generally much stricter than standards based on human health. In addition, Pennsylvania DEP samples fish tissue and issues fish advisories designed to warn the public as to what species may contain toxic chemicals. These contaminants can build up in the human body over time, possibly leading to health risks.

This indicator measures:

- **Percent of Cd, Cr, Cu, Pb, and Zn samples meeting state standards at various sites**
- **Areas with fish consumption advisories**

Where We Were:
Historical information on concentrations of toxins in fish tissue is not readily available. Information on concentrations of some metals was collected in the 1970's, and this can be compared to current water quality standards. Approximately 50 samples were collected at several sites between 1970 and 1980 for cadmium, lead, chromium, copper, and zinc together. Concentrations were generally low in the headwaters of the system but frequently exceeded standards in the downstream portions, especially during wet weather. Approximately 85-90% of dry weather samples and 75-80% of wet weather samples taken in the headwaters of the system met standards intended to protect aquatic life. At Cobbs Creek just above the confluence with Darby Creek, about 75% of dry weather and 60% of wet weather samples met standards.

Where We Are:
Comparing estimated historical loading rates data from the 1970's with data collected in 1999, the estimated loads for metals for the 1999 period are lower, with two exceptions. The loading rate for nitrate increased and the estimated upstream cadmium load is slightly higher.

Fish advisories are most often due to metals or organic chemicals. The April 2001 fish advisory for this watershed advises to limit consumption of white perch, striped bass, and carp to one meal a month, and to limit consumption of channel catfish to one meal every two months. American eel should not be eaten at all. This is all due to PCB pollution.

The number of permitted discharges in the watershed appears to have decreased over recent decades, but there are some indications of residual contamination due to past industrial activity. A search of US EPA's BASINS database identified 12 permitted industrial and municipal dischargers that have been active at some time in the last few decades. However, only 7 of these permits are currently active, indicating that five sources have become inactive since records were first kept. However, the lower portion of the Darby Creek watershed has recently been listed as a Superfund site, indicating the potential for introduction of toxic chemicals.

In 2000, between 50 and 100 samples were collected at each site for cadmium, lead, chromium, copper, and zinc together (Figure 4-20). The data indicate that standards intended to protect aquatic life are still sometimes exceeded. The data also shows that the situation has improved at all sites when compared to the 1970's. For most sites, 90-100% of samples meet the standards. At Cobbs Creek just above the confluence with Darby Creek, 93% of dry weather and 72% of wet weather samples meet the standard.

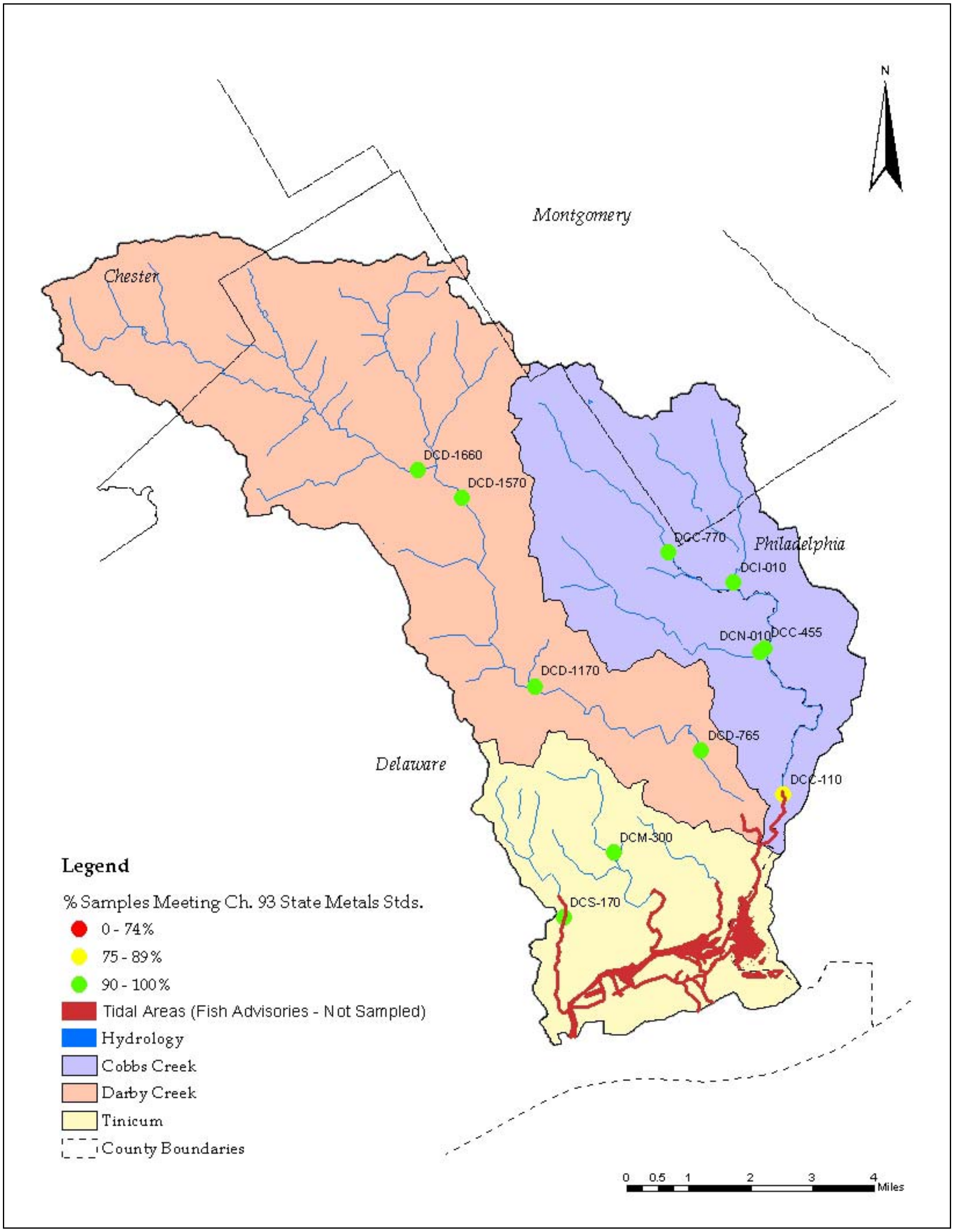


Figure 4-20 Water Quality Data for Metals (1999)

Indicator 9: Effects on Aquatic Life (Dissolved Oxygen)

Just as humans require oxygen gas for respiration, most aquatic organisms require dissolved oxygen (DO) in order to perform vital functions. Oxygen dissolves in water through air-water interaction at the surface of the flow and through photosynthesis of plants and algae. At the same time, DO is depleted through the respiration of microorganisms, animals, plants, and algae. In a healthy system, the balance between oxygen-depleting and oxygen-providing processes maintains DO at a level that allows aquatic organisms to survive and flourish. In a less healthy system, dissolved oxygen may be depleted below levels needed by aquatic organisms. The minimum dissolved oxygen concentration required by many common fish species found in rivers and streams is approximately 5 mg/L. PA DEP has set a water quality standard, or minimum allowable concentration, of 5 mg/L as a daily average and 4 mg/L as an instantaneous value for Cobbs Creek. Criteria in portions of Darby Creek are stricter to accommodate trout.

This indicator measures:

- **Percent of DO samples meeting state standards at various sites**

Where We Were:
Approximately 100 samples of DO were taken between 1970 and 1990. For all sites except one, DO was never less than 5 mg/L. On Cobbs Creek just above the confluence with Darby Creek, site DCC-110, low-DO conditions appear to have been common. Measurements were less than the standard approximately 20% of the time in dry weather and 10% in wet weather. These conditions may have been related to more frequent dry and wet weather sewer overflows. The low-DO conditions probably had an adverse impact on aquatic life.

In an aquatic biological investigation performed in 1995-1996, the overall water quality in Darby Creek was determined to be good. Iron, aluminum, total suspended solids, and fecal coliform were occasionally above the limit, but not at levels harmful to aquatic life. Some samples taken from Cobbs Creek showed low dissolved oxygen and elevated levels of ammonia, phosphorus, iron, lead and manganese. In the areas where fish quality was reported, the quality ranged from fair to good.

Where We Are:
Both discrete and continuous samples were collected between 1999 and 2003. Discrete samples produce a single DO value at the time the sample is taken. Continuous monitoring is preferred, as it records data from early morning, when DO is typically lowest due to respiration. Discrete samples suggest that dissolved oxygen is rarely below the instantaneous minimum allowable concentration standard under dry or wet conditions. Two sampling sites recorded concentrations below the standard of 4 mg/L. At DCD1660, in the headwaters of Darby Creek, 1 discrete sample out of 5 total indicated DO below 4 mg/L under wet weather conditions; continuous samples did not indicate any low DO values. At site DCC110, just above the confluence of Cobbs and Darby Creeks (Figure 4-21), 1 of 9 dry weather samples and 6 of 24 wet weather samples did not meet the 4 mg/L standard. This site is just below the Woodland Avenue dam and is most likely affected by poorly mixed water just above the dam.

Continuous DO data have been collected over approximately 10,000 hours between 1999 and 2003. Between 1999 and 2002, DO measurements were observed to be below the state criteria only at sites DCC110 and DCC115, just below and above the dam, respectively. At DCC-115, 19% of observations were less than 5 mg/L and 5% were less than 4 mg/L. At DCC110, 5% of samples were less than 5 mg/L and less than 1% were below 4 mg/L. The most recent data, collected in August-September 2003, show similar trends. DO reaches a minimum of 3-4 mg/L during wet weather at DCC110. The dry weather diurnal range, or difference between maximum and minimum DO concentration over the 24-hour cycle, varies from 1-2 mg/L at upstream sites to as high as 8-9 mg/L at DCC110. This difference suggests a high level of algal activity in the pool behind the dam. Figure 4-22 displays the trends mentioned above: an increase in diurnal amplitude as biological activity increases in dry weather, and a drop in DO as low-DO water is flushed over the dam in wet weather. A possible explanation is that upstream inputs of nutrients from sewage and stormwater sources lead to increased biological activity in the slow-flowing conditions found at sites DCC110 and DCC115.

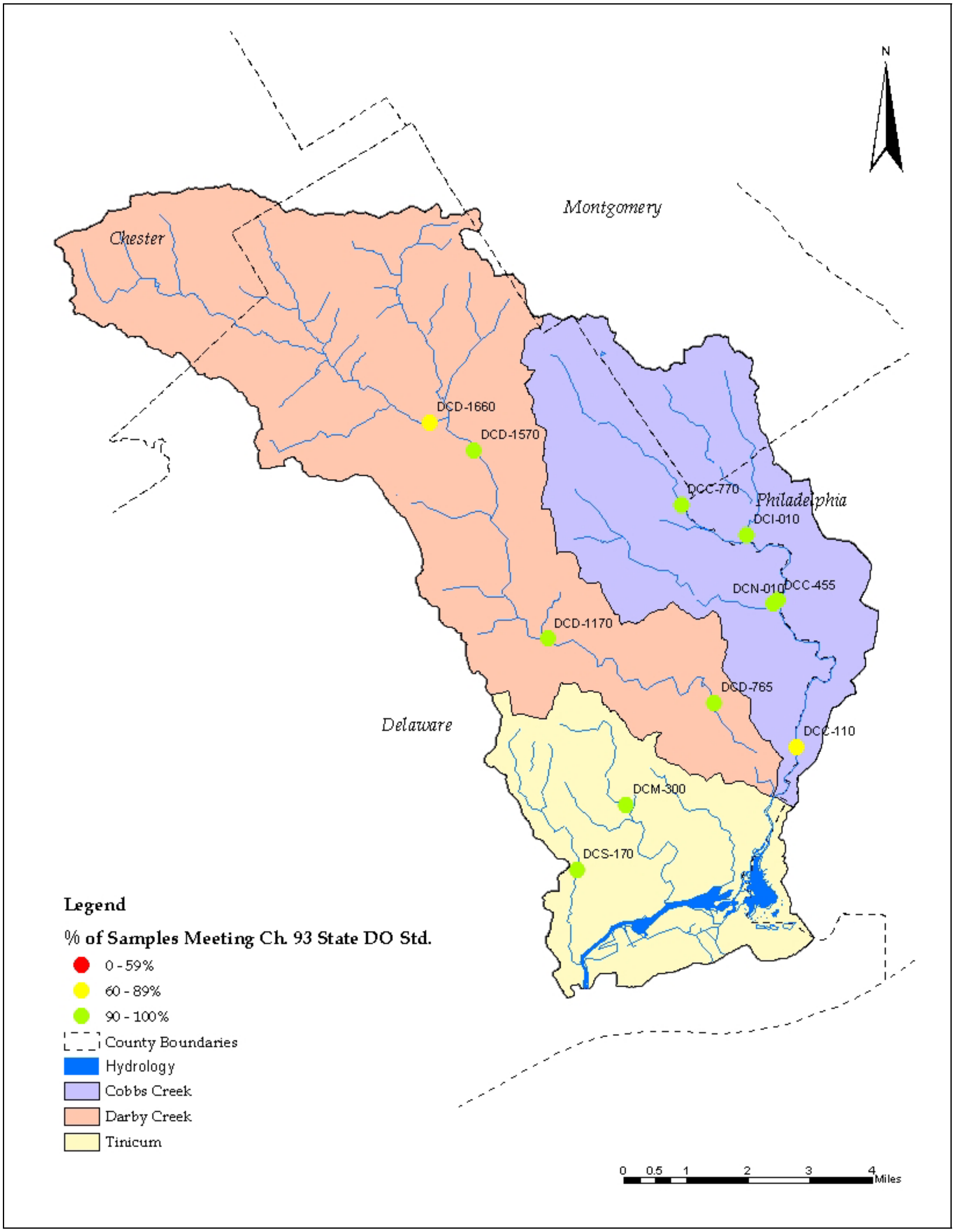


Figure 4-21 Water Quality Data for Dissolved Oxygen

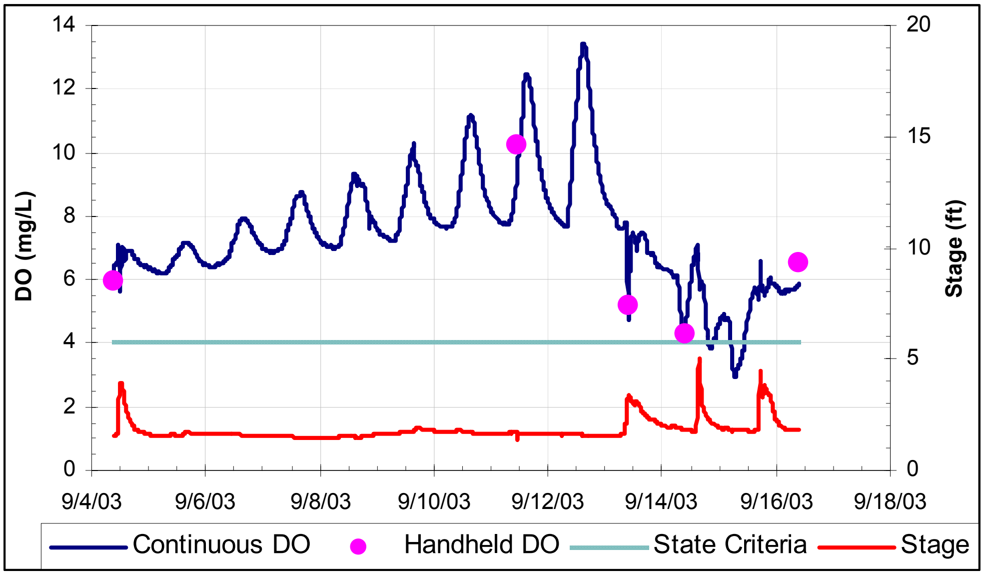


Figure 4-22 Stage and Dissolved Oxygen at DCC110 in September 2003

Pollutants and Their Sources

Indicator 10: Point Sources

A point source is any point where discharged water and pollutants can enter a water body, such as a pipe, channel, or ditch (Figures 4-23 through 4-25). Point source discharges that could include treated municipal wastewater, combined sewer overflows (CSO), separate sanitary overflows (SSOs), industrial process water, municipal separate storm sewer system (MS4) discharges, and/or cooling waters. Point sources are regulated under the Clean Water Act by the National Pollutant Discharge Elimination System (NPDES).

Figure 4-23 Stormwater Outfall

Figure 4-24 CSO Outfall

Figure 4-25 Municipal Wastewater Treatment Plant

A **municipal separate storm sewer system (MS4)** collects stormwater runoff from the land surface and discharges it directly to a receiving stream.

Combined sewer systems use one pipe to convey sanitary sewage and stormwater runoff to a combined sewage regulator chamber. The regulator captures all of the sanitary sewage in dry weather, and some of the combined sewage in wet weather, sending it to a wastewater treatment plant. The balance of wet weather flow is discharged to an area water body through a CSO outfall.

Sanitary Sewer Overflows (SSOs) occur when a municipal separate sanitary sewer system becomes overcharged in wet weather and overflows unintentionally to an area water body.

Municipal Wastewater Treatment Plants are facilities that process municipal sanitary waste and industrial and commercial discharges to the sewer system. These facilities treat the waste stream and discharge it to a local stream.

Industrial processes use water in manufacturing, power generation, or other activities to produce a product. By-products from the process can be discharged to area waterways with varying levels of treatment.

Pollutants and Their Sources

Indicator 10: Point Sources

This indicator measures:

- **Number of permitted industrial and municipal point sources**
- **Estimated annual percent capture of combined sewage**
- **Estimated pollutant contributions of industrial/municipal, CSO, and stormwater sources**

Where We Were:

Point source discharges from treatment plants and industrial facilities were a priority for increased control during the 1970s and 1980s as secondary wastewater treatment requirements and industrial pre-treatment regulations were imposed. Historical data indicate that there were 35 facilities in the watershed with National Pollutant Discharge Elimination System (NPDES) Permits.

Historical SSO and CSO discharges are not well documented, and there is only limited current data on SSOs. However, it can be inferred from water quality data that dry weather sewage discharges were much more common in the past (see Indicator 8). It is reasonable to conclude that the frequency and volume of CSO discharges in the Philadelphia portion of the Cobbs watershed have decreased over the past 20 years due to improved sewer maintenance and CSO control measures. These measures are discussed in detail later in this section.

Where We Are:

Active Industrial and Municipal Point Source Dischargers

There are believed to be 8 active industrial point source dischargers in the Darby-Cobbs Watershed. Current facilities with NPDES permits to discharge into the watershed are believed to be Sun Oil Company, SEPTA Victory Terminal, Meenan Oil Company, Mobil Oil Company, Boeing Defense and Space Group, Tinicum Township Sewerage Authority, and Township of Haverford Public Works Landfill. Several of the facilities that were once listed as active dischargers have since been eliminated. Kistler Fredrick, 2 Sunoco Service Stations, and Mobil Oil Corporation are no longer active dischargers. Wastewater treatment plants that once discharged in the watershed no longer do so, such as Township of Haverford public.

Estimated Annual Percent Capture of Combined Sewage

Portions of Philadelphia County, including 20% of the Cobbs Creek watershed, are serviced by combined sewers. The City of Philadelphia has 38 regulator structures within the watershed, as shown in Figure 4-26. Since the 1980s, PWD has made significant progress in reducing CSO discharges to Cobbs Creek. As required under EPA's CSO Control Policy, PWD has developed and implemented a CSO Long-Term Control Plan (LTCP) to improve and preserve the water environment in the Philadelphia area. Table 4-6 lists estimated capture percentages for regulator structures in the Cobbs Creek watershed, based on the modeling results listed in PWD's CSO Annual Reports.

Capture percentage is defined as the percentage of combined sewage (mixed sanitary sewage and stormwater) that is sent to a treatment plant during rainfall events over the course of a year. 85% capture is considered to be an ultimate goal for many communities as they implement CSO long term control plans. It is important to note that percent capture for a given year is strongly dependent on the frequency and magnitude of rainfall events during that year. The seven years of data listed in Table 4-6 are not sufficient to determine whether an increasing or decreasing trend has taken place. However, as the amount of data increases throughout implementation of the Long Term Control Plan, it will ultimately be possible to evaluate the effectiveness of control measures.

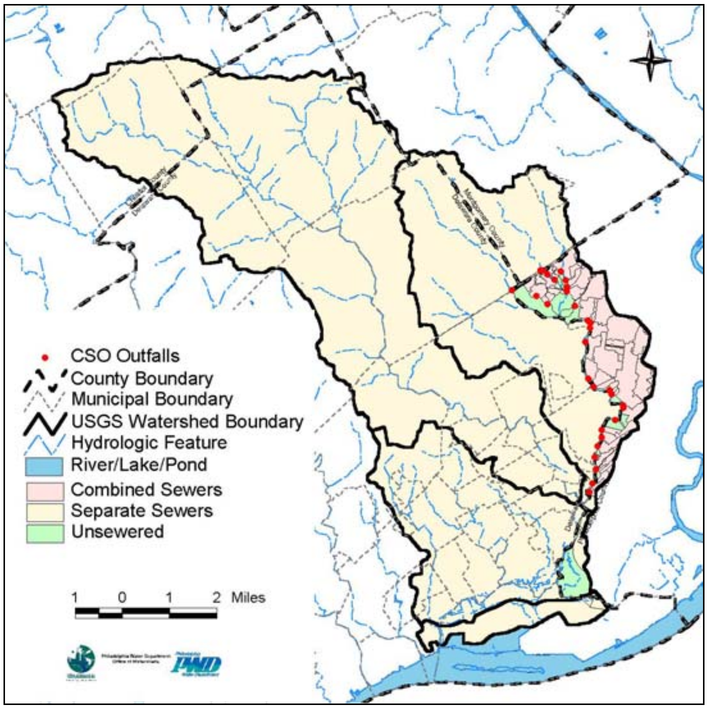


Figure 4-26 Types of Sewer Service and Locations of Regulator Structures

Table 4-6 Estimated Annual Combined Sewage Capture Percentages

Year	Precipitation (in)	Capture (%) – Lowest and Highest Structure	
		Cobbs Creek High Level	Cobbs Creek Low Level
2001	31.1	61 – 62	84 – 85
2000	43.2	51 – 52	74 – 75
1999	48.6	49 – 50	73 – 74
1998	30.7	65 - 67	87 - 88
1997	32.0	59 – 63	88 – 92

Model-Estimated Pollutant Contributions of Different Sources

Estimated annual pollutant contributions for the Darby and Cobbs watersheds are shown in Figure 4-27. For both systems, stormwater outfalls are the largest source of pollutants associated with urban and suburban runoff, including nutrients such as phosphorus and metals such as lead. For the Cobbs Creek watershed, CSO is a smaller but significant source of these constituents. CSO discharges are the dominant source of fecal coliform in the Cobbs watershed. Permitted industrial and municipal point source discharges make up less than 2% of annual streamflow in both systems. SSOs are thought to occur in both watersheds but have not been well documented to date.

Darby-Cobbs Watershed Status Report 2003

Pollutants and Their Sources

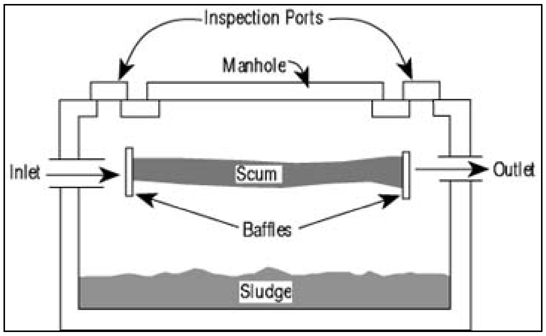
Indicator 10: Point Sources

Figure 4-27 Estimated Annual Proportional Contribution of Pollutant Source (Watershed Pollutant Loading Model)

Indicator 11: Nonpoint Sources

Nonpoint source pollution is any source of water contamination not associated with a distinct discharge point. This type of pollution is a leading cause of water quality degradation in the United States. Nonpoint sources include atmospheric deposition, stormwater runoff from pasture and crop land, and individual on-lot domestic sewage systems discharging through shallow groundwater. Stormwater from urban and suburban areas is considered a point source for regulatory purposes because it is collected in a pipe system and discharged at a single point.

Figure 4-28 Pasture Land



Source: Ohio State University Extension

Figure 4-29 Septic System

Agricultural activity is a major source of nonpoint source pollution in many areas. Animal manure and fertilizers applied to crops may lead to pollutant inputs to surface water and groundwater.

A properly sited and maintained **septic system** should not result in excessive inputs of nutrients to groundwater. However, failing septic systems are common and can result in nutrient inputs to shallow groundwater and ultimately to stream baseflow.

Background concentrations of some water quality constituents are present in groundwater and may be transferred to stream baseflow. Some constituents may be introduced through agricultural activity or failing septic systems, while others may be present as a result of local geology.

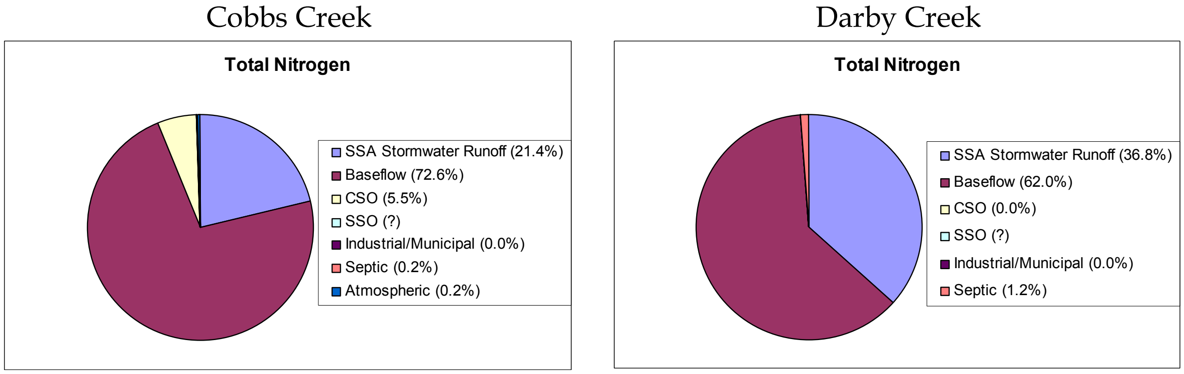
This indicator measures:

- **Model-estimated percent of total pollutant loads contributed by septic tanks**
- **Evidence that sanitary sewers are leaking during dry weather, or are in direct contact with the stream**

Where We Were:

Since most point sources were addressed in the 1970s and 1980s, regulatory agencies have been turning attention towards controlling nonpoint sources of pollution. Many of these sources began to be addressed only during the 1990s.

Where We Are:
Nonpoint sources in the Darby-Cobbs Creek watershed include atmospheric deposition, stormwater runoff from a very small amount of agricultural land, background concentrations in groundwater, and individual on-lot disposal systems (OLDS) discharging through shallow groundwater. The number of septic tanks within the watershed is hard to accurately quantify; 1990 census data indicated that about 2000 septic tanks were present in the watershed; this number is believed to be a high estimate of the actual number. Based on modeling estimates (Figure 4-30), septic tanks contribute up to 2% of total nitrogen and phosphorus loads. Atmospheric loads to wetlands and open water were estimated only for the Cobbs Creek system and were less than 1%. Background groundwater concentrations of total nitrogen were the largest source of that constituent in streamflow (60-70% of the estimated annual load). Dry weather contributions from leaking sanitary sewers could not be estimated based on current data, however, evidence that leaking is occurring is presented below.


Cobbs Creek

Darby Creek

Figure 4-30 Estimated Nutrient Inputs from Septic Tanks

Stream Corridor

Indicator 12: Riparian Corridor

The riparian areas buffering streams, rivers, lakes, and other water bodies are especially sensitive watershed zones. In their naturally vegetated and undisturbed state, floodplains and riparian areas provide stormwater management and flood control functions, both in terms of water quantity and water quality. An example of floodplain and riparian zone conservation and protection is Cobbs Creek Park (Figure 4-31). Philadelphia had the foresight years ago to establish greenways along Cobbs Creek and its tributaries, both for conservation and recreational purposes. With the exception of Heinz National Wildlife Refuge, Cobbs Creek Park and related facilities constitute the most significant conservation and recreation zone in the Watershed.

This indicator measures:

- **Miles of stream with a minimum buffer of 50 feet and 50 percent canopy cover**

Figure 4-31 Riparian Corridor in Cobbs Creek Park

Where We Were:
There is no historical data available for this indicator. A trend will be established the next time this area is reassessed.

Where We Are:
The areas adjacent to the creeks in Fairmount Park have been used as picnic and recreational areas, leading to alteration of natural vegetation. This invasive plant has a shallow root mass that does not affectively anchor the soil. Stream banks that are disturbed or dominated by invasive plants may be more vulnerable to erosion during storms. These disturbed areas are very susceptible to colonization by invasive plants, especially Japanese knotweed. The areas in Fairmount Park are superior in quality compared to most of the areas in the watershed. Many other areas in the watershed have completely lost their riparian buffers.

Stream Corridor

Indicator 12: Riparian Corridor

Buffers along stream corridors can be an important factor in enhancing stream habitat and preventing erosion. In 2002, the Heritage Conservancy was funded to develop a rapid assessment method to identify and map sections of stream lacking riparian forest buffers. The conservancy then assessed watersheds in southeastern Pennsylvania and mapped waterways lacking riparian forest buffers. Interpretation of 1" = 200' black-and-white high altitude aerial photographs and videotape from helicopter overflights were used to determine the presence or absence of a forested buffer for 975 miles of stream. For this analysis, a stream bank was classified as having a forested buffer if it was determined to have a 50 foot wide buffer of trees and 50 percent canopy cover. Each stream bank was analyzed independently. Table 4-7 shows that there are about 30 miles of stream within the watershed that are lacking forested riparian buffers on one or both banks.

Table 4-7 Lack of Riparian Forested Buffer

Riparian Buffer	Length (Stream Miles)
Buffer Lacking on One Bank	15.8
Buffer Lacking on Both Banks	13.7

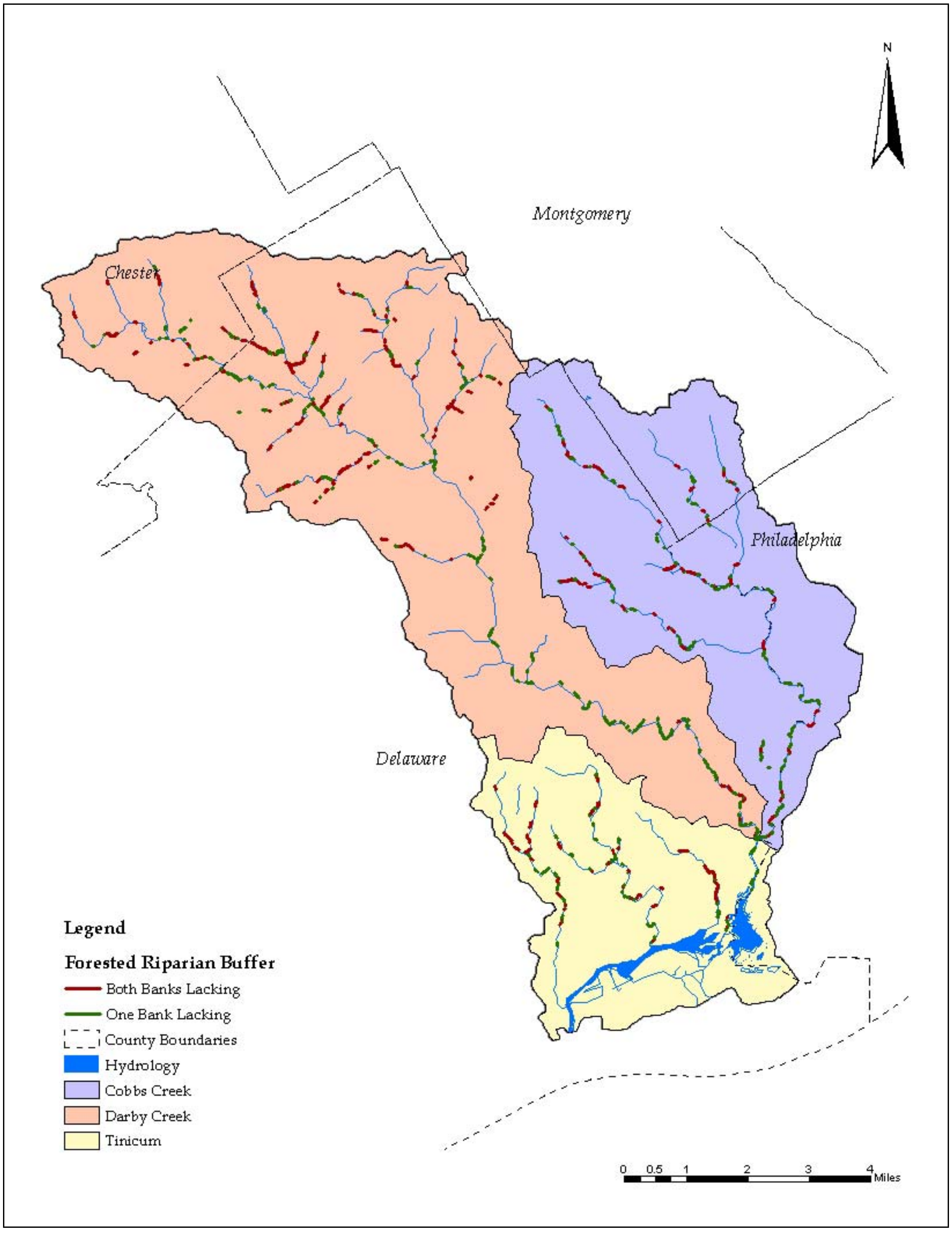


Figure 4-32 The Heritage Conservancy's Forested Riparian Buffer Analysis (2002)

Indicator 13: Wetlands and Riparian Woodlands

Wetlands and riparian woodlands are important natural filters for pollutants in stormwater. Wetlands and woodlands increase vegetation diversity, providing feeding and nesting habitat for birds and animals. They are important in preventing slope erosion and mitigating flood peaks by controlling runoff, and they allow for natural infiltration of rainfall and groundwater recharge.

The most significant functions that wetlands perform are:

- Wildlife Habitat
- Fish Habitat
- Water Quality Improvement (nutrient and toxicant reduction)
- Hydrologic (flood flow) modification
- Groundwater recharge

The location and size of a wetland may determine what functions it will perform. For example, the geographic location may determine its habitat functions, and the location of a wetland within a watershed may determine its hydrologic or water-quality functions. Many factors determine how well a wetland will perform these functions; such as climatic conditions, quantity and quality of water entering the wetland, and disturbances or alteration within the wetland or the surrounding ecosystem.
Wetlands of the Cobbs Creek watershed were evaluated for the first four of the functions noted above, and were further studied to understand their sensitivity to future disturbance and their potential for enhancement and improvement, where they may have experienced degradation.

This indicator measures:

- **Acres of wetland in the watershed**
- **Area of riparian buffer along waterways**
- **The quality of the wetlands**
- **The ability of the wetland and woodlands to improve water quality**

Figure 4-33 Example of a Wetland Area

Indicator 13: Wetlands and Riparian Woodlands

Where We Were:

There is little data available about the historical presence of wetlands and riparian woodlands in the watershed. The Fairmount Park Commission's Natural Lands and Restoration and Environmental Education Program (NLREEP) compiled some information regarding historic wetlands in their 1999 Natural Lands Restoration Master Plan. NLREEP reported that Philadelphia had an abundance of wetlands along the Delaware and Schuylkill Rivers in pre-colonial times. These included a variety of intertidal channels, marshes and mudflats, and gravel bars. Much of the south and southwestern parts of the city, including what is now FDR Park, were a mix of tidal channels and marshes. Nontidal wetlands were present inland from the tidal marshes and along streams (NLREEP,1999).

Urban and suburban development has resulted in the piping of historic streams, destruction of wetlands, and deforestation and modification of historic floodplains. Stormwater is piped directly to waterways rather than flowing overland through vegetation, wetlands, and woodlands. Also, because stormwater runoff frequently flows over impervious surfaces, and is then piped to the streams, the flow and volume of runoff is intensified. Stream channels of the Cobbs Creek watershed exhibit many effects of urbanization: degradation of the stream channel (including overwidening), erosion, loss of sinuosity, loss of the floodplain, stream connection, and loss/degradation of aquatic habitat. Because most stormwater is piped directly to the waterways of the Cobbs watershed, there is no longer a source of water to maintain many of the wetlands that once existed.

In a geomorphologic study of Cobbs Creek conducted in 2002, the creek was divided into 63 stream segments for analysis. Results suggest that increases in stormwater runoff intensity have widened the waterway channel, and reduced its depth. Stability of the streambed was evaluated, and 26 stream segments were observed to experience continuing streambed deterioration. In many reaches, the stream channel now occupies much of the land that once functioned as floodplain and wetland, reducing the presence of wetlands and riparian woodlands.

Finally, extensive development in the Cobbs Creek watershed has resulted in conversion of natural riparian lands to residential and active recreational land use. Primary land uses in the watershed, for the most part, preclude the existence of natural vegetated areas, due to the high density of development. For example, 25%of the residential land uses are row or multi-family homes, which typically have relatively little vegetated open area to control and improve stormwater runoff.

In summary, the number and combined areas of wetlands and riparian woodlands in the Cobbs Creek watershed have fallen over time as a result of development close to the stream edges and changes to the floodplain from concentrated stormwater flows.

Indicator 13: Wetlands and Riparian Woodlands

Where We Are:

Wetland information presented here for the Darby and Tinicum subwatersheds is based on limited information found in the National Wetlands Inventory; information presented for the Cobbs is based on a much more detailed study conducted by the Philadelphia Water Department. As shown in Figure 4-34 and Table 4-8, small, scattered wetlands are present throughout the riparian areas of Darby Creek and its tributaries. Cobbs Creek has far fewer riparian wetland areas. A large wetland system is present in the Tinicum subwatershed. Wetland communities of native vegetation are scarce in the Fairmount Park system.

Based on land use data, approximately 10% of the Darby-Cobbs watershed land area may be considered woodland. However, the greatest proportion of woodland occurs in the Darby subwatershed, although forested areas in the Cobbs watershed are more contiguous due to Cobbs Creek Park lands. There are large areas of woodland found in the park, though they are more extensive in the northern portion. In areas where trash dumping and encroachment of recreational activities occur, wooded areas have become fragmented, creating open habitat for exotic, aggressive tree species. Regrowth of understory and herbaceous layers is usually limited once these exotic species become established. Exotic control, replanting and trash removal are components of woodlands restoration.

The Cobbs Creek watershed is 14,200 acres in size, or about 22 square miles. The watershed in nearly totally developed - 92% of the watershed now supports homes, businesses, industries, and utilities. Of the land that is not developed (i.e., wooded, waterway, or vacant), only 5% still exists as riparian wetland and woodland, most of it serving as public open space (see Indicator 1: Land Use and Impervious Cover).

If runoff from the developed parts of the watershed (92%of the watershed) were settled and filtered using all of the vegetated riparian wetlands and woodlands in the watershed (5% of the watershed), almost 80% of the total solids in the stormwater could be removed before it discharged into the stream. However, most of the stormwater in Cobbs Creek watershed is piped directly to the stream channel, bypassing the wetlands and riparian woodlands that could improve the water quality through detention and trapping sediment. Also, the riparian woodlands along Cobbs Creek and its tributaries are now largely public open spaces (or in some cases, privately owned residential yards). Return of these lands to their original function of filtering and improving the quality of stormwater requires a public examination and decision-making process for resolving competing uses for riparian lands.

The total area of wetland in the Cobbs Creek watershed is relatively small considering the 22.4 linear miles of waterways. Field investigation of wetland presence and quality in the watershed indicates that only 46 wetlands, totaling 36.4 acres, remain along Cobbs Creek and its tributaries. The wetlands range in size from 0.01 acre to approximately 6 acres. Most wetlands are small; 26 of the wetlands surveyed were less than one-quarter acre in size.

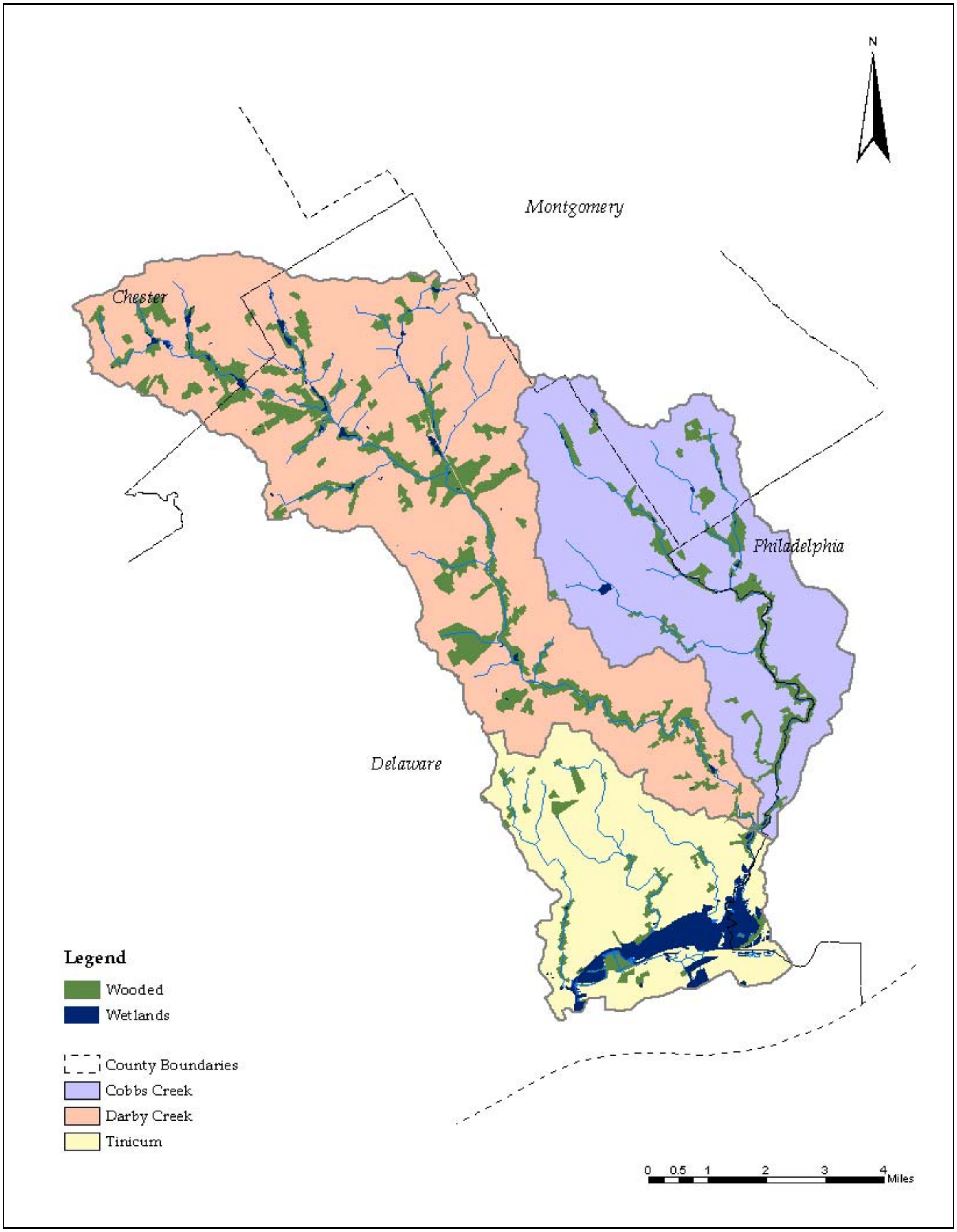


Figure 4-34 National Wetlands Inventory and PWD Surveyed Wetlands (2002 – 2003)

Table 4-8 Estimated Woodland and Wetland Area

Subwatershed	Total Area (acres)	Woodland (% of total)	Wetland (% of total)
Upper Cobbs	7500	4%	0.4%
Lower Cobbs	6700	13%	0.1%
Upper Darby	16,910	14%	1%
Lower Darby	8,521	14%	0.2%
Tinicum	9,804	6%	11%

The remaining Cobbs Creek wetlands were evaluated for their value as wildlife habitat, fish habitat, water quality improvement (nutrient and toxicant reduction), and hydrologic (flood flow) modification. Nearly all wetlands in the Cobbs Creek watershed exhibit impaired functions that indicate extensive disturbance and deterioration.

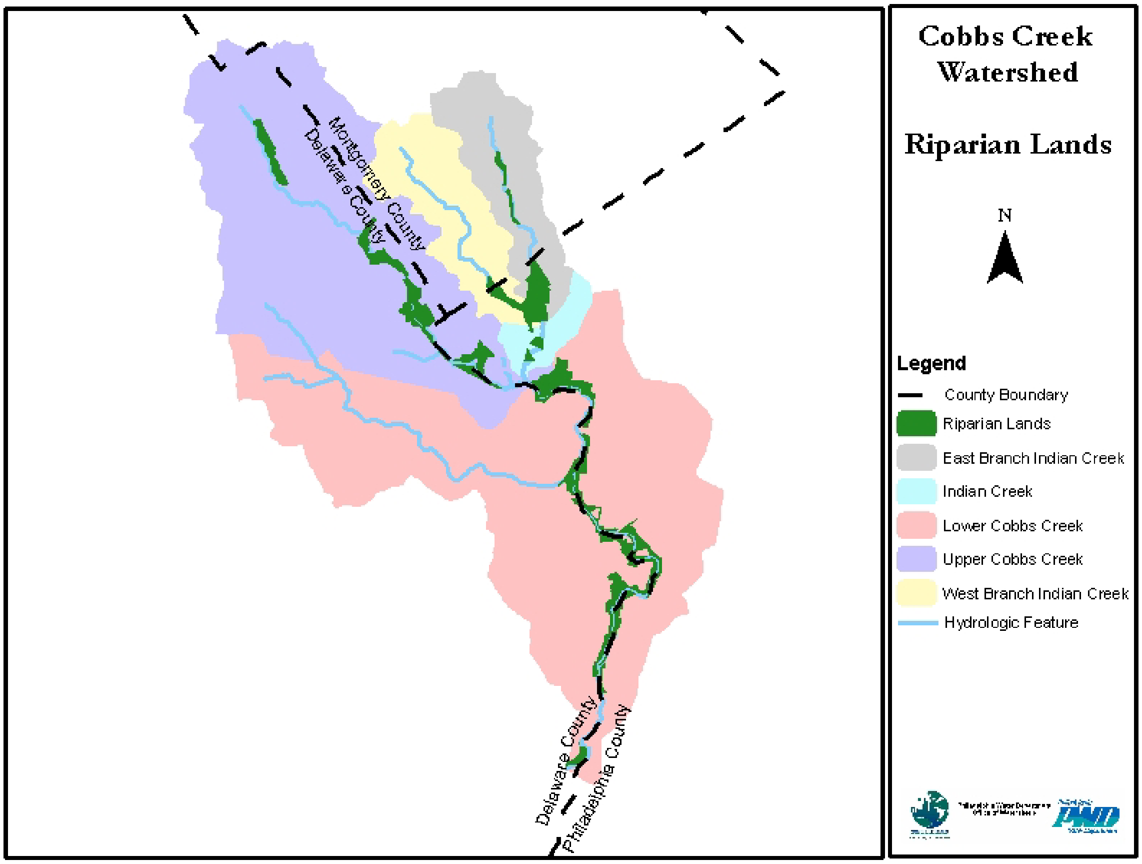


Figure 4-35 Open Lands in the Riparian Corridor

Results of the functional assessment indicate that the remaining wetlands in the Cobbs Creek watershed are degraded, and cannot serve as high quality habitats or perform many of their water quality improvement functions. If stormwater was redirected to the small areas of remaining wetlands, rather than being rerouted directly to the streams in the Cobbs Creek watershed, water quality improvement would be minimal given the current compromised conditions of the wetlands.

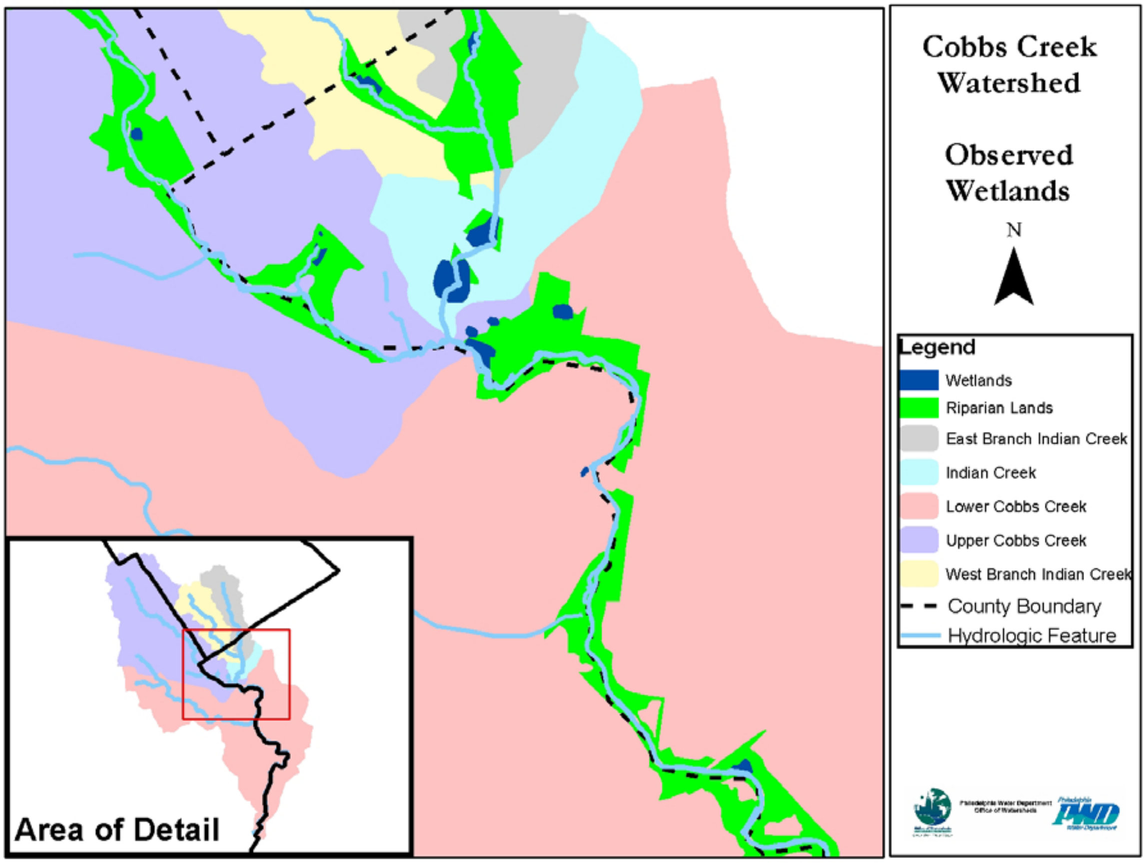


Figure 4-36 Wetlands Identified in the Cobbs Creek Watershed (2002 – 2003)

Table 4-9 Wetland Functional Assessment Results for Cobbs Creek Watershed (based on 45 wetland locations)

Function	Number of Wetlands with Stated Condition
Wildlife Habitat	
Diverse Habitat	12
Moderate	33
Fish Habitat	
Intact Habitat	3
Degraded	7
Lost / Not Present	35
Water Quality Improvement	
Intact Function	12
Degraded	33
Hydrologic Connection to Stream	
Intact Connection	36
Degraded	7
Lost / Not Present	2

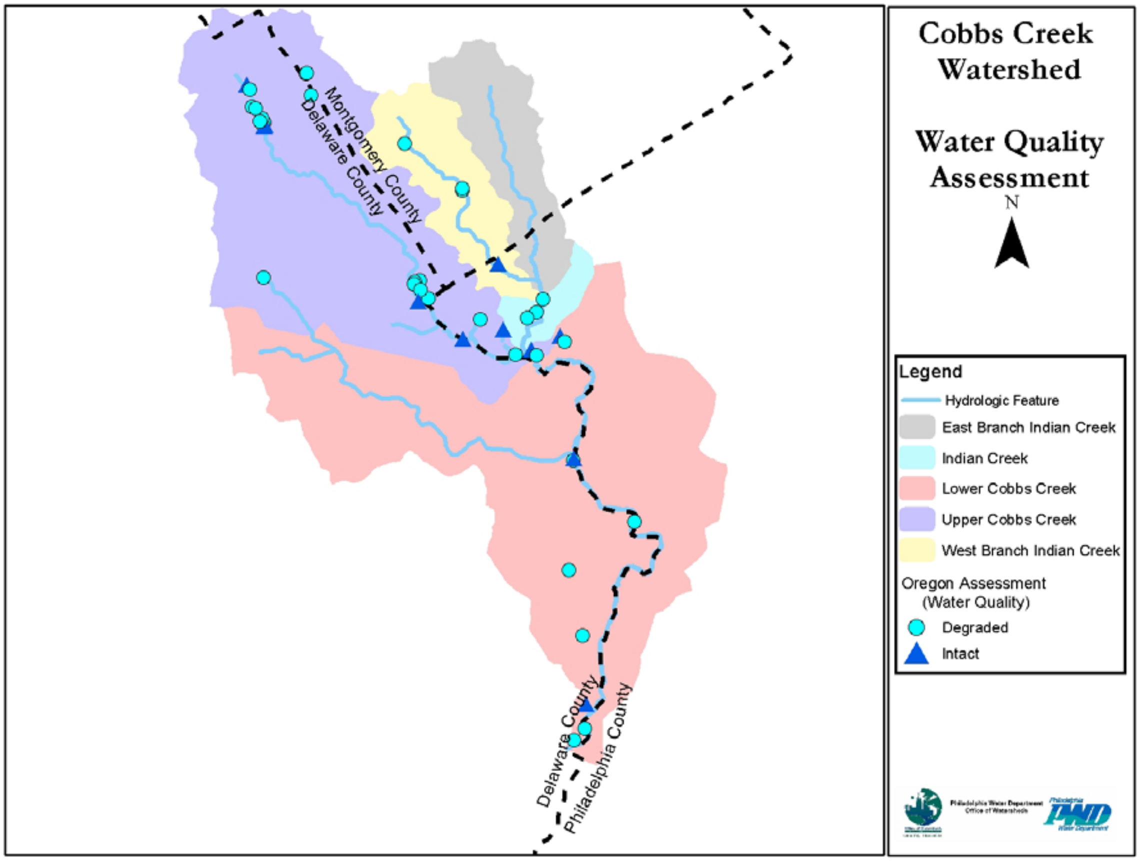


Figure 4-37 Results of Cobbs Creek Wetland Assessments (2002 – 2003)

Indicator 14: Wildlife

Wildlife includes birds, amphibians, and other animals that make their home in the watershed. Quality and diversity of wildlife habitats is also an indicator of watershed quality. Many species have specific habitat requirements. Their presence or absence indicates the health of the habitats. For example, healthy, naturally reproducing amphibian communities indicate the presence appropriate habitats. The red-bellied turtle (Figure 4-38) is one PA listed threatened species found in the watershed.

This indicator measures:

- **Species inventory, identification of any threatened and endangered species**

Figure 4-38 Juvenile Red Bellied Turtle

Where We Were:
There is no historical data available for this indicator.

Where We Are:
A wildlife assessment was completed for Cobbs Creek Park during the “Bio-blitz” in 2001 in which volunteers recorded observed species (Table 4-10). The species of reptiles and amphibians that were found in Cobbs Creek Park were red-backed, northern dusky and two-lined salamanders, snapping and painted turtles, eastern garter, northern water, and brown snakes, and green frogs and bullfrogs. An abundance of several bird species were observed, including Kingbirds, Robins, Catbirds and Chipping Sparrows. No birds or macroinvertebrates that were observed during the Bio-blitz were on the endangered species list. The assessment also determined that Cobbs Creek Park has a low density of deer.

Table 4-10 Species found during 2001 Bio-blitz in Darby-Cobbs Watershed

Birds (72 species)	
Great Blue Heron	Northern Mockingbird
Wood Duck	Brown Thrasher
Mallard Duck	Cedar Waxwing
Cooper's Hawk	European Starling
Red-tailed Hawk	Warbling Vireo
Solitary Sandpiper	Red-eyed Vireo
Spotted Sandpiper	Tennessee Warbler
Rock Dove	Nashville Warbler
Mourning Dove	Northern Parula
Ruby-throated Hummingbird	Yellow Warbler
Chimney Swift	Chestnut-sided Warbler
Red-bellied Woodpecker	Magnolia Warbler
Downy Woodpecker	Black-throated Blue Warbler
Hairy Woodpecker	Yellow-rumped Warbler
Northern Flicker	Black-throated Green Warbler
Eastern Wood-pewee	Blackburnian Warbler
Acadian Flycatcher	Prairie Warbler
Eastern Phoebe	Blackpoll Warbler
Great Crested Flycatcher	Black-and-white Warbler
Eastern Kingbird	American Redstart
Tree Swallow	Ovenbird
Northern Rough-winged Swallow	Northern Waterthrush
Barn Swallow	Mourning Warbler
Blue Jay	Common Yellowthroat
American Crow	Wilson's Warbler
Carolina Chickadee	Canada Warbler
Tufted Titmouse	Scarlet Tanager
White-breasted Nuthatch	Northern Cardinal
Carolina Wren	Indigo Bunting
House Wren	Eastern Towhee
Blue-gray Gnatcatcher	Song Sparrow
Veery	Red-winged Blackbird
Swainson's Thrush	Common Grackle
Wood Thrush	Baltimore Oriole
American Robin	American Goldfinch
Gray Catbird	House Sparrow
Aquatic Macroinvertebrates (12 taxa)	
Mayfly	Sow bugs
Caddisfly	Scuds
Damselfly	Leech
Blackfly	Aquatic Earthworm
Midge	Snails
Cranefly	Crayfish
Reptiles and Amphibians (4 species)	
Bullfrog	Two-lined Salamander
Northern Water Snake	Red-backed Salamander

Indicator 15: Flooding

This indicator measures:

- **Modeled peak flood stage at 3 bridge crossings along lower Cobbs Creek**

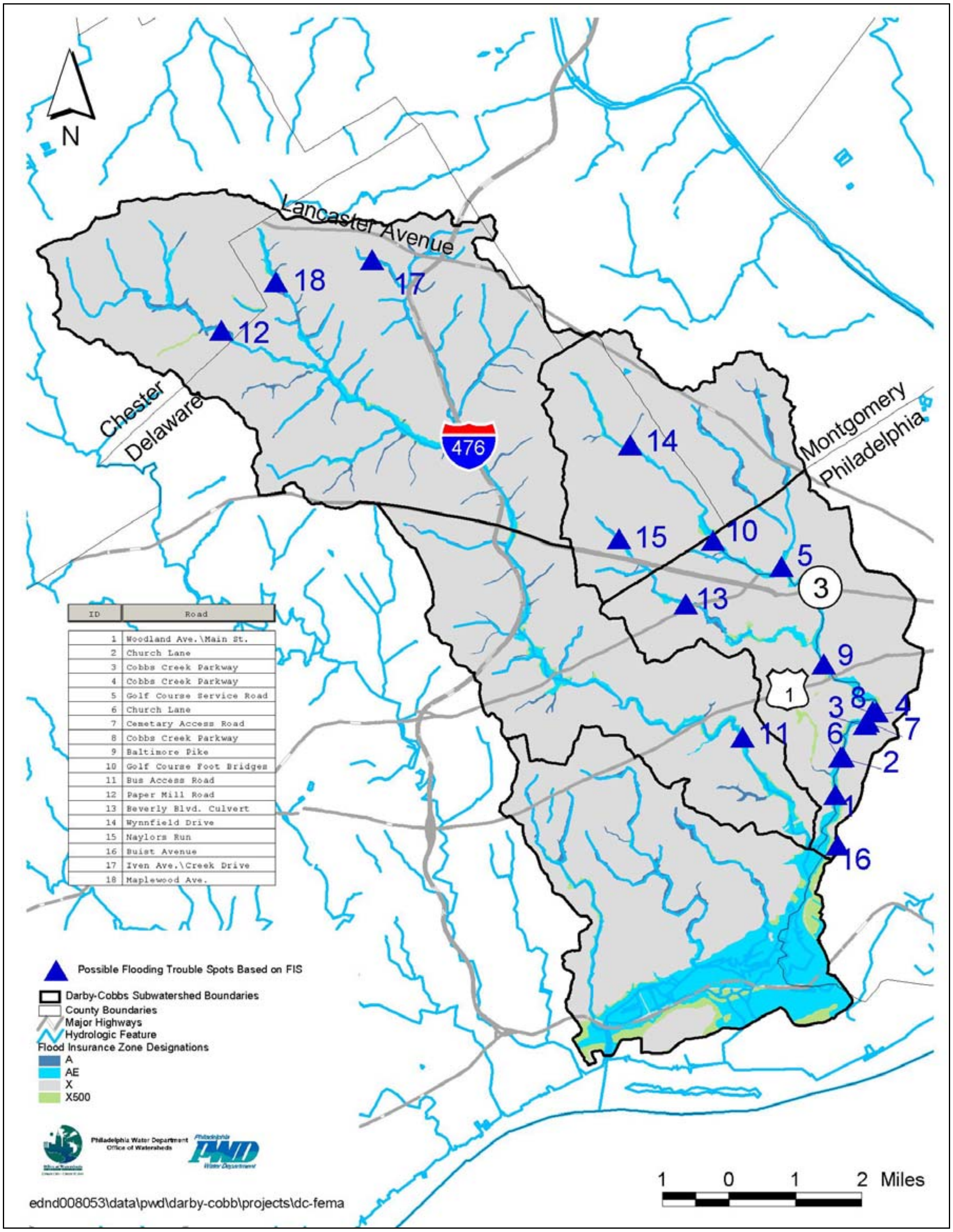
Impervious cover and improperly sized or maintained drainage systems in urban watersheds occasionally lead to flooding. Act 167, the Storm Water Management Act of 1978, requires each county in Pennsylvania to prepare and adopt a stormwater management plan for each designated watershed in the county. An official plan provides a mechanism for municipalities to plan for and manage increased runoff associated with possible future development and land use change.

Where We Were:
Frequent, serious flooding has not been a major concern in the Darby-Cobbs watershed. Floodplain mapping studies were conducted by FEMA to establish flood insurance rates for Delaware County in 1993 and for Philadelphia County in 1996. These studies include anecdotal evidence of major flooding during tropical storms. Additional anecdotal evidence is discussed in the Darby Creek River Conservation Plan, prepared by the Darby Creek Valley Association. A number of trouble spots are shown in Figure 4-39, including areas on Cobbs Creek, Naylors Run, Darby and Little Darby Creeks, and Ithan's Run. According to FEMA, flooding at several of these trouble spots may be caused by undersized culverts.

Where We Are:
FEMA studies include stream cross-sections at major road crossings. Figure 4-39 identifies several road crossings where bridge decks are in the 10-year floodplain. As an indicator, 3 cases were chosen where bridge decks along Cobbs Creek Parkway fall within the 10-year floodplain. A simulation was run for a large (3.3 in. total), intense (1.7 in/hr peak) storm on July 21-22, 1988. Table 4-11 indicates that the deck of each bridge was most likely impassable during this storm, which has a return period of about 12 years.

Table 4-11 Peak Flood Stage at 3 Bridges

Trouble Spot	Bridge	Deck Elevation (ft above city datum)	EsrimatedPeak Flood Stage (ft above city datum)
1	Woodland Ave./Main Street (just above 10-yr)	16.4	17.5
3	Cobbs Creek Parkway (below 10-yr)	25.6	27.9
4	Cobbs Creek Parkway (below 10-yr)	25.5	31.1



ID	Road
1	Woodland Ave.\Main St.
2	Church Lane
3	Cobbs Creek Parkway
4	Cobbs Creek Parkway
5	Golf Course Service Road
6	Church Lane
7	Cemetary Access Road
8	Cobbs Creek Parkway
9	Baltimore Pike
10	Golf Course Foot Bridges
11	Bus Access Road
12	Paper Mill Road
13	Beverly Blvd. Culvert
14	Wynnfield Drive
15	Naylors Run
16	Buist Avenue
17	Iven Ave.\Creek Drive
18	Maplewood Ave.

Figure 4-39 Reported / Estimated Flood-prone Areas

Quality of Life

Indicator 16: Public Understanding and Community Stewardship

Because a connection to the natural world and its waterways is less apparent in some communities of the Darby-Cobbs Watershed, the notion of environmental stewardship does not always top the list of daily priorities for many residents. Stewardship, therefore, must be built around the needs of the community as users of the watershed, as well as by making visible the critical ways the health of the watershed is integral to basic quality of life issues. Once this has been established, members of the community can be recruited to take action in protecting their watershed.
Within this context, citizens need to 1) become aware of the meaning of watershed and the watershed in which they live, 2) become informed about the actions they can take to improve watershed health and 3) move from understanding into action.

Stakeholders are those who care with their minds and hearts because they already understand their vital connection to the environmental health of their community. The watershed stakeholders include state and federal regulators, those whose jobs empower them to guard the quality of our rivers and streams. The stakeholders include all of the municipalities, separate entities on paper yet bound together by nature. The stakeholders include all those others – neighborhood groups, religious groups, schools, groups who define themselves as environmental advocates because their personal priorities demand they place their time there.

This indicator measures:

- **Number of responses to surveys**
- **Number of newspaper stories and letters to the editor about watershed-related issues**
- **Changes in membership in the Darby-Cobbs Watershed Partnership, DCVA, Cobbs Creek Community Environmental Education Center, and other current groups**
- **Number of Environmental Action Committees (EACs)**

Where We Were

A historical baseline has not been established for this indicator. Progress will be assessed next time this plan is updated.

Where We Are

A survey of watershed residents was conducted in 2000 in which there were about 342 respondents. Figure 4-40 shows the number of responses received in each municipality. Figure 4-41 shows the actual responses gauging citizen awareness and concern about watershed issues. Of note, a large proportion (47%) of residents live within 4 blocks of a stream, and many enjoy recreational activities along the stream corridor such as nature walks, picnics, and fishing. 57% of respondents indicated that they are concerned about pollution and would not eat fish from Darby or Cobbs Creeks.

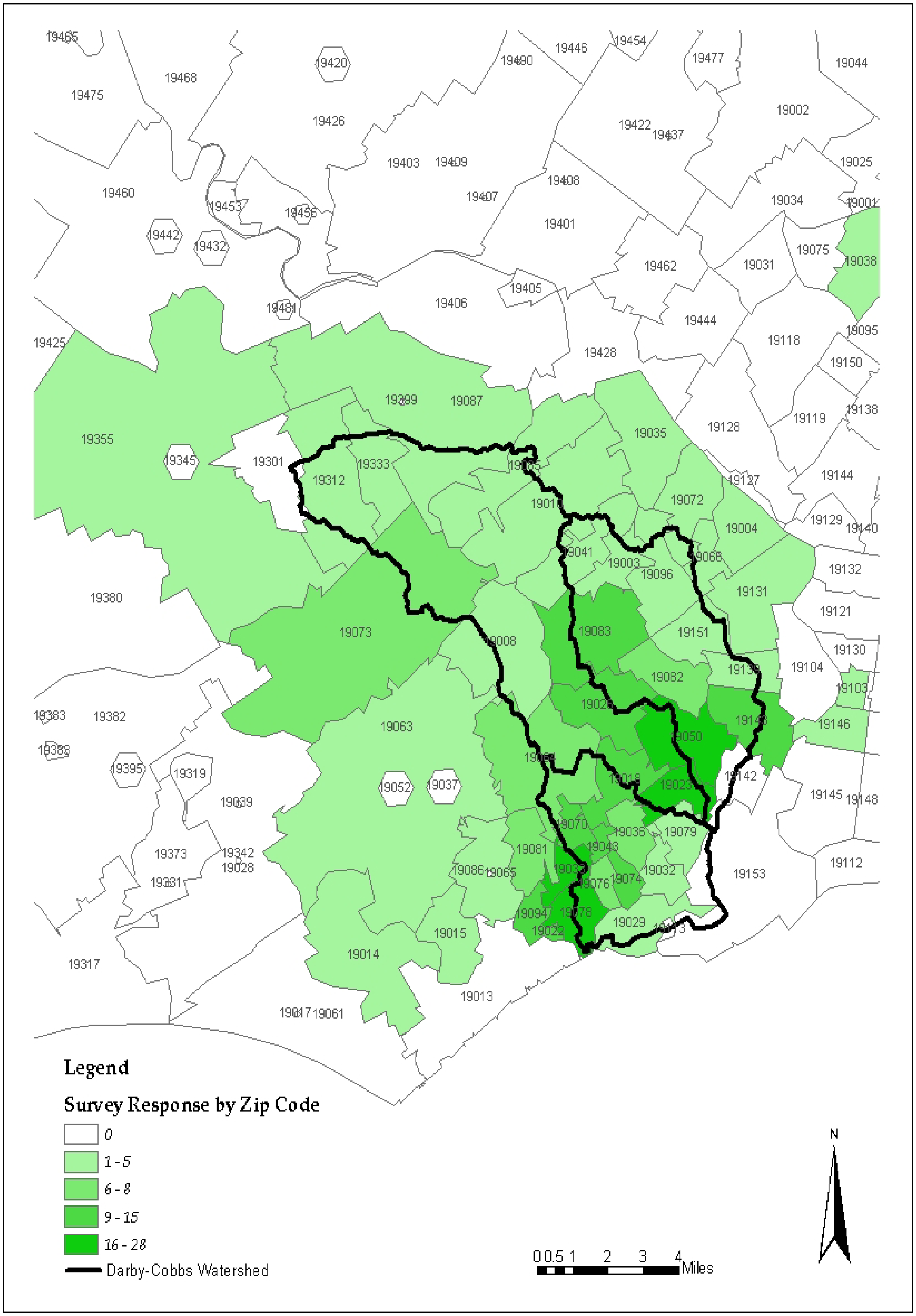


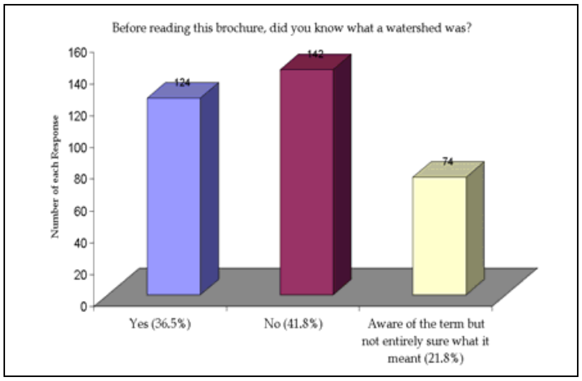
Figure 4-40 Residence Location of Respondents to Darby-Cobbs Watershed Survey

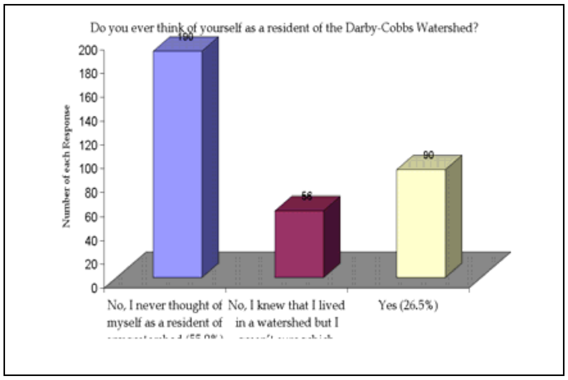
Quality of Life

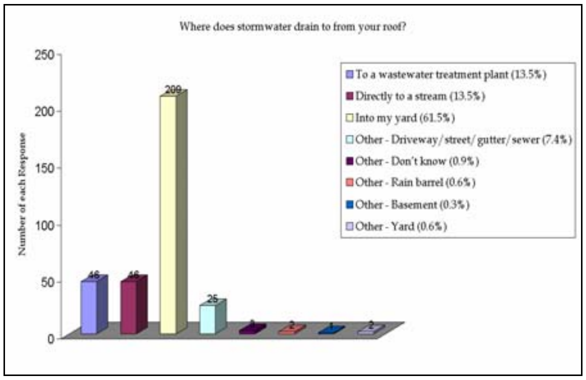
Indicator 16: Public Understanding and Community Stewardship

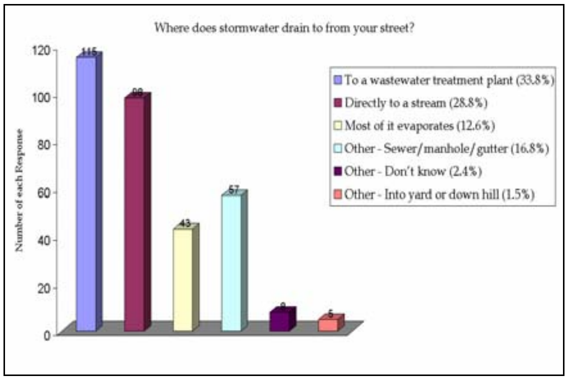
The media greatly influences community perception and may indicate, via public reaction, which events and issues are important to the community. A newspaper clipping survey of articles and letters to the editor in local weekly and daily papers that serve the watershed found nine articles specific to the watershed or the partnership since 2000.

Attendance at meetings held by watershed-related groups is another way to gauge interest among citizens. Eighteen stakeholders consistently attend meetings sponsored by the Partnership, Darby Creek Valley Association (DCVA), Cobbs Creek Community Environmental Education Center (CCCEEC) and other watershed-related forums. Four municipalities in the watershed have municipal appointed Environmental Action Committees (EACs) - Radnor, Marple, Lower Merion, Haverford. Active EACs indicate citizen advocacy for and support of actions needed on the municipal level.









Quality of Life

Indicator 16: Public Understanding and Community Stewardship

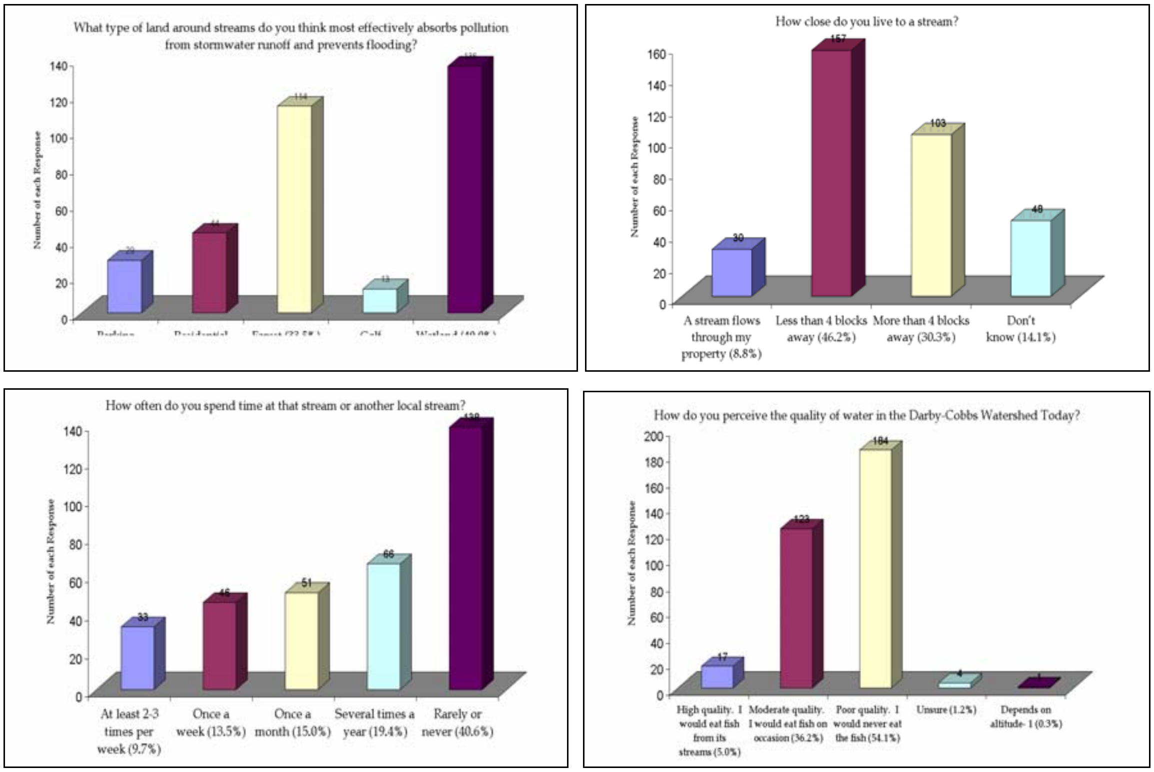


Figure 4-41 Darby - Cobbs Resident Survey Results

Indicator 17: School-Based Education

School aged children of today are the watershed stewards of the future. As such, school based education is an integral component of the long-term health of the watershed. School based education takes many forms, from lesson plans within the classroom, to hands-on activities outside of the classroom such as field trips to Cobbs and Darby creeks and nearby nature centers, as well as actual restoration projects. Teacher training programs, developed to assist teachers in bringing watershed concepts to their students, are critical to bringing watershed education to the students, as are partnership with groups like the Cobbs Creek Community Environmental Education Center and the John Heinz Wildlife Refuge at Tinicum. Being engaged in actual restoration projects, either through service learning, after school clubs, or as part of lesson plans, translates lessons into action. There are several ways to measure the success of school based education programs and each depends on the other.

Figure 4-42 Electrofishing in the Cobbs

This indicator measures:

- **Number of schools that have environmental or watershed management curricula**
- **Number of teachers trained through the Darby-Cobbs Teacher Training Program**
- **Number of schools participating in programs sponsored by the Cobbs Creek Community Environmental Education Center**

Where We Were
A historical baseline has not been established for this indicator. Progress will be assessed next time this plan is updated.

Where We Are
To date, 11 schools have interactive – incorporating lesson plans with hands on activities - environmental or watershed management curricula, including participation in the Earth Force Program. The schools are Turner Middle School (Phila.), Friends Central (Wynnewood), Nativity BVM (Media), St. Gabriel (Folsom), Pennwood JH, Beverly Hills MS (Phila), Sayre MS (Phila.), St. Cyprian (Phila.), Shaw MS (Phila.), Pepper MS (Phila.), Patterson ES. Forty-eight schools participate in programs sponsored by the Cobbs Creek Community Environmental Education Center.

With the creation of the Darby Cobbs Watershed Partnership, an opportunity arose to incorporate the concepts of an urban watershed environment into school-based curricula to better instruct students in pollution prevention concepts and stormwater runoff quantity issues within their neighborhoods. With the assistance of a Growing Greener grant, the Partnership developed a Darby-Cobbs Watershed Teacher Training program. Twenty teachers from various reaches of the watershed participated in five Saturday workshops, beginning in December of 2000 and ending in May 2001, built around the following modules: watershed management, stormwater management, water quality, ecological restoration, and a workshop session to develop service projects. Each session was taught through a combination of classroom and field experience.

Additionally, the new Academic Standards for Science and Technology and Environment and Ecology became a core requirement of the public school curriculum in January 2002 and testing on these topics commenced for the first time in spring 2003 as part of the PSSA. The standards establish the basic elements of what students should know and be able to accomplish at the end of grades four, seven, 10 and 12. Section 4.1 of these standards is dedicated to watersheds and wetlands. Goals for this topic area are for students to gain knowledge about water cycles, role of watersheds, physical factors, characteristics and functions of wetlands and impacts of watersheds and wetlands. A scope and sequence has been predetermined for each of the aforementioned grades.

Indicator 18: Recreational Use and Aesthetics

People seem to be innately drawn to water and areas of natural beauty. Not surprisingly then, park and recreational areas are often centered on scenic water features, such as lakes or rivers. Indeed, many acres of parkland are already developed along the Darby and Cobbs Creeks. However, many miles of Cobbs Creek are not accessible to the public. If the public has no way to get to a particular stream, it is less likely to be enjoyed. Parks, and the waterways that flow through them, serve many functions, some obvious and others unseen. For instance, parks and waterways are areas of active and passive recreation. Active recreation includes football, baseball, and canoeing, while passive recreation implies areas intended for quiet contemplation or conversation, an essential respite from the concrete and asphalt of the urban world. Natural amenities, when protected and preserved, elevate the quality of life for residents by providing a myriad of recreational, educational and other activities, in addition to enhancing the market value of homes and institutions.

This indicator measures:

- **Stream accessibility score for Cobbs Creek and tributaries**
- **Tons of trash removed from creek and buffer area**

Where We Were

A historical baseline has not been established for this indicator. Progress will be assessed next time this plan is updated.

Where We Are

An accessibility indicator was developed to determine the degree to which a community is able to reach their waterways (Table 4-12 and Figure 4-43). Accessibility was determined on a scale from 0 through 5, with zero representing a particular segment of stream that is inaccessible and 5 representing a completely accessible stream segment. The greater the availability of parking, trails, and public recreational land adjacent to the stream, the higher the accessibility rating. A segment of stream running through a private, industrial, or commercial site was given a rating of 0. A segment of stream running through a public park that has parking and trails leading to the stream was given an accessibility rating of 5. The number of stream miles and the percentage of the total stream miles with each particular accessibility rating were calculated. 1/3 of the waterways within the Cobbs watershed were given a rating of completely accessible. An additional 1/3 of the stream miles were rated as somewhat accessible.

Table 4-12 Accessibility by Stream Miles

Accessibility	Description	Length (Stream Miles)	% Of Stream Miles
0	Not Accessible	0.61	3%
1	Minimally Accessible	5.18	22%
2	Moderately Accessible	1.50	6%
3	Somewhat Accessible	8.06	34%
4	Highly Accessible	0.52	2%
5	Completely Accessible	7.81	33%

Maintenance records indicate that 26 tons of trash and debris have been removed from creeks and riparian buffer areas in Cobbs Creek and its parks between July and December 2003 by the Water Department's Waterways Restoration Team (WRT). The WRT is dedicated to removing large trash and debris – cars, appliances, shopping carts, from our streams in addition to restoring streambanks and streambeds that have been eroded as a result of pipe outfalls. The WRT partners on clean up and restoration efforts with the Fairmount Park Commission, CCCEEC and dedicated volunteers. A common vision is shared by all – to restore the grandeur and beauty of Cobbs Creek for the enjoyment of all residents.

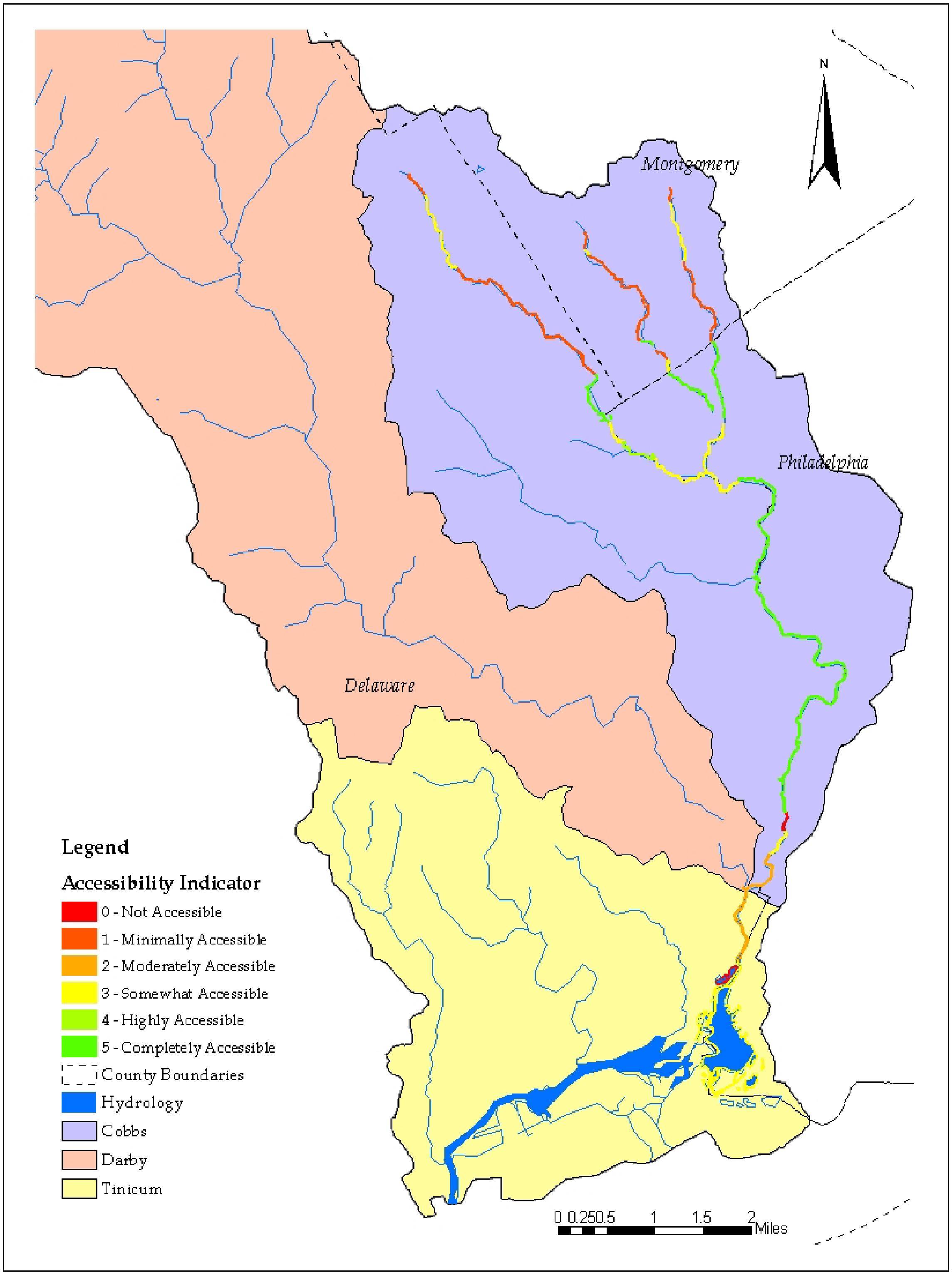


Figure 4-43 Stream Accessibility and Parks in Cobbs Creek Watershed (2003)

Indicator 19: Local Government Stewardship

Local government leadership is essential to ensuring that improvements made under watershed restoration planning are sustainable. Local governments must also support, encourage and complement the stewardship efforts of individuals, environmental groups, and businesses. A major goal is for local governments to work within their regulatory and statutory obligations while actively supporting the stewardship efforts within the watershed. It is also important that local governments implement voluntary actions to restore the watershed. Most importantly, to ensure the success of the watershed management plan, each local government within the watershed must embrace the goals and implementation strategies of the plan. A formal adoption of this plan would multiply its chance for success tremendously.

This indicator measures:

- **Municipalities participating in watershed-related surveys and having up-to-date sewage facilities plans**

Where We Were

A historical baseline has not been established for this indicator. Progress will be assessed next time this plan is updated.

Where We Are

Figure 4-44 shows the municipalities in the Darby-Cobbs watershed. For each municipality, responses have been tabulated (Table 4-13) for several surveys and requests. Sixteen of 44 jurisdictions (including municipalities, townships, boroughs and counties) have signed the Darby-Cobbs Resolution drafted by the Partnership. Five municipalities responded to a survey as part of the Darby Creek River Conservation Plan (RCP), while seven responded to a request letter. Approximately half of municipalities have responded to a survey under the Act 167 Storm Water Planning program. Legally, all municipalities have an Act 537 Plan, a plan that provides for the resolution of existing sewage disposal problems, future sewage disposal needs of new land development and future sewage disposal needs of the municipality. However, some plans are newer and more detailed than others.

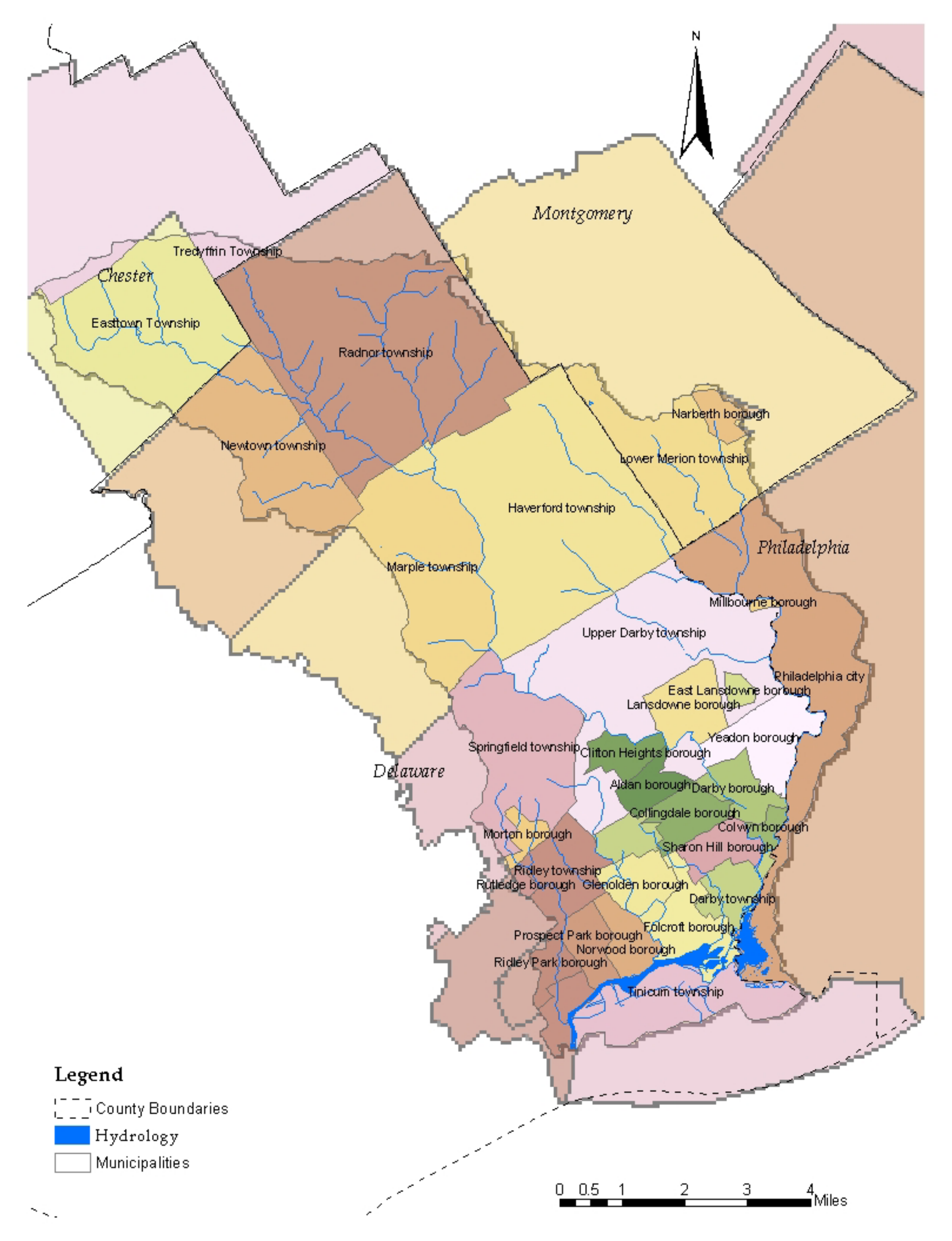


Figure 4-44 Map of Darby-Cobbs Watershed Municipalities and Counties

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Indicator 19: Local Government Stewardship

Table 4-13 Municipalities and Counties signing resolutions and completing surveys

County/Municipality	Resolution	Darby RCP Municipal Survey	Darby RCP Request Letter	Act 537 Municipal Sewage Facilities Plans (# Years Old)	Act 167 Municipal Survey
Chester County	C	☒	☒	☒	50 % of Municipalities have completed. No distinctions as to which ones are available.
Easttown Township	N	N	C	< 5	
Tredyffrin Township	N	N	N	5 > 10	
Delaware County	C	☒	☒	☒	
Aldan Borough	N	N	C	> 20	
Clifton Heights Borough	N	N	N	> 20	
Collingdale Borough	N	N	N	> 20	
Colwyn Borough	C	N	N	> 20	
Darby Borough	N	N	N	> 20	
Darby Township	N	N	N	> 20	
East Lansdowne Borough	C	N	N	> 20	
Folcroft Borough	C	N	N	> 20	
Glenolden Borough	N	N	N	> 20	
Haverford Township	N	C	N	> 20	
Lansdowne Borough	C	N	N	> 20	
Marple Township	C	N	N	< 5	
Millbourne Borough	N	N	N	> 20	
Morton Borough	N	C	N	< 5	
Newtown Township	C	N	N	< 5	
Norwood Borough	N	N	N	< 5	
Prospect Park Borough	N	N	C	< 5	
Radnor Township	C	C	C	> 20	
Ridley Park Borough	N	N	N	< 5	
Ridley Township	C	N	N	< 5	
Rutledge Borough	N	N	N	< 5	
Sharon Hill Borough	C	N	C	> 20	
Tinicum Township	C	N	C	10 > 20	
Upper Darby Township	C	N	C	> 20	
Yeadon Borough	N	N	N	> 20	
Montgomery County	N	☒	☒	☒	
Lower Merion Township	C	N	C	5 > 10	
Narberth Borough	N	N	C	> 20	
Springfield Township	C	C	C	> 20	
Philadelphia	C	C	☒	5 > 10	

Completed	C
Not Completed	N
Not applicable	☒

Indicator 20: Business and Institutional Stewardship

Awareness is growing regarding the role of businesses and institutions in watershed degradation and restoration. Success of the watershed management plan will require stewardship on the part of stakeholders who represent the diversity of land uses in the watershed, including conservation groups, commercial, industrial, institutional and residential users. The goal of the Partnership is to have a proportional representation of these groups.

This indicator measures:

- **Number of businesses represented at Partnership meetings as a percentage of all citizens and organization present.**

Where We Were

A historical baseline has not been established for this indicator. Progress will be assessed next time this plan is updated.

Where We Are

Figure 4-45 shows the number of representatives of each type of group that have attended Partnership meetings. To date, 6 business representatives have attended, representing 2% of the total.

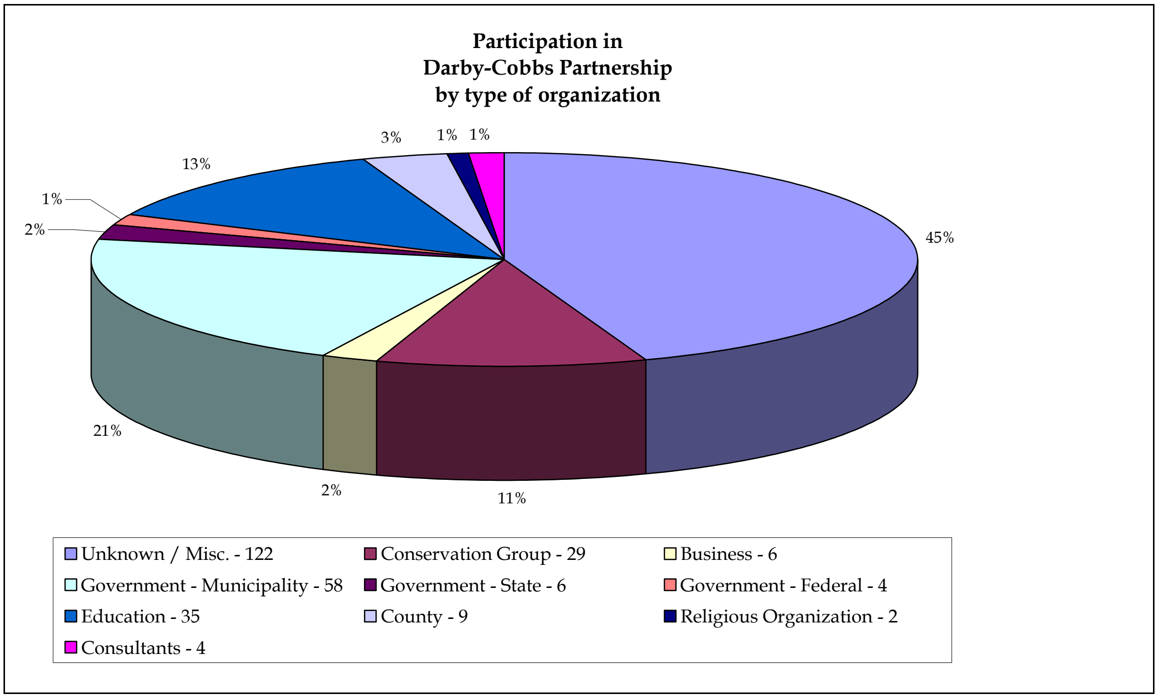

Figure 4-45 Distribution of Partnership Members' Affiliations (2003)

Indicator 21: Cultural and Historic Resources

Waterways have always been cradles of civilization, providing, among many things, a means of travel and rich floodplain soils in which to cultivate crops. Much later, waterways provided power for mills and fueled the beginnings of the industrial revolution. Consequently, historical and cultural resources are often concentrated in and along waterways. These resources enable us to better understand and appreciate different cultures and traditions, to recognize the struggles endured by our ancestors, and to comprehend the technologies of past generations. These cultural and historical resources can also be an invaluable tool to inform our understanding of our present conditions. Cultural and historic resources in the Darby-Cobbs watershed have been tabulated by DCVA in the Darby Creek River Conservation Plan.

This indicator measures:
- **National Register of Historic Places inventory**
- **Number of communities with historical management programs**
- **Number of nonprofit historical/cultural management organizations**

Where We Were
A historical baseline has not been established for this indicator. Progress will be assessed next time this plan is updated.

Where We Are
Figure 4-46 shows the locations of historic sites identified by the RCP planning process. A total of 171 sites were identified. Additionally, the RCP identifies 14 historical societies and commissions at the local level, four at the county level, and three located in Philadelphia. The RCP details many of the historically significant sites and structures.

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Indicator 21: Cultural and Historic Resources

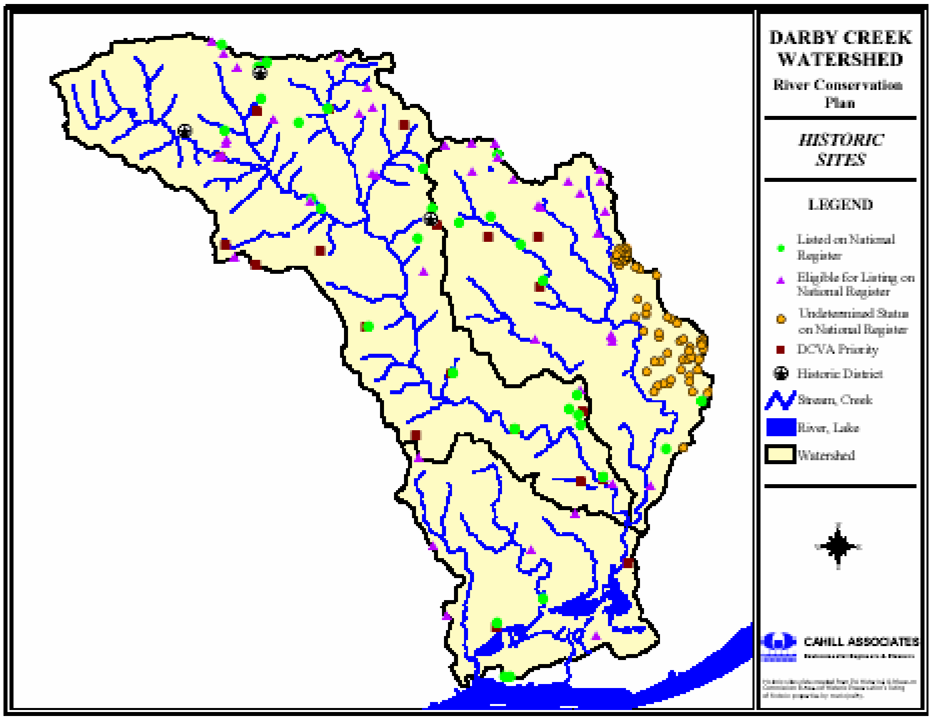


Figure 4-46 Historic Sites Identified in the RCP (2003)

Section 5: Development and Screening of Management Options

5.1 Menu of Options

This section summarizes a comprehensive list of stormwater and watershed management options that the Darby-Cobbs Watershed Partnership thinks may be applicable in the Cobbs watershed. This list serves as the starting point for the screening (Section 5) and evaluation (Section 6) steps that lead to the recommendations contained in the implementation guidance in Section 7. A large amount of detailed information on these options is available from existing sources. Rather than reproducing this information, this section provides references and links to these sources. The options are grouped under the three targets introduced in Section 2:

Target A: Dry Weather Water Quality and Aesthetics
- Regulatory Approaches
- Public Education and Volunteer Programs
- Municipal Measures
- Enhancing Stream Corridor Recreational and Cultural Resources
- Monitoring and Reporting

Target B: Healthy Living Resources
- Channel Stability and Aquatic Habitat Restoration
- Lowland Restoration and Enhancement
- Upland Restoration and Enhancement
- Monitoring and Reporting

Target C: Wet Weather Water Quality and Quantity
- Regulatory Approaches
- Public Education and Volunteer Programs
- Municipal Measures
- Stormwater Management
- Monitoring and Reporting

Target A

Target A is defined for Cobbs Creek as focusing on trash removal and litter prevention, and the elimination of sources of sewage during dry weather. Streams should be aesthetically appealing (look and smell good), accessible to the public, and be an amenity to the community.

Regulatory Approaches

AR1	On-Lot Disposal (Septic System) Management
AR2	Pet Waste, Litter, and Dumping Ordinances

These typical pollution reduction and aesthetic ordinances are already in effect in most locations, and can be effective at controlling diffuse sources of pollutants. They are particularly important in urban watersheds; however, they must be consistently enforced to be effective.

Public Education and Volunteer Programs

AP1 Public Education
AP2 School-Based Education
AP3 Public Participation and Volunteer Programs

Municipal Measures

AM1 Capacity Management Operation and Maintenance (CMOM)
AM2 Inspection and Cleaning of Combined Sewers
AM3 Sanitary Sewer Rehabilitation
AM4 Combined Sewer Rehabilitation
AM5 Illicit Discharge, Detection, and Elimination (IDD&E)
AM6 Stream Cleanup and Maintenance
AM7 Household Hazardous Waste Collection

AO1 Enhancing Stream Corridor Recreational and Cultural Resources

AMR Monitoring and Reporting

AO1 - Enhancing Stream Corridor Recreational and Cultural Resources
Preservation and enhancement of recreational and cultural resources may be integrated into comprehensive watershed management. These resources are part of the link between the human population and natural resources in a watershed. Strategies to provide access to water resources for recreational purposes encourage appreciation for and stewardship of these areas. Strategies to protect water-based historic structures should be implemented to insure that flooding and other impacts are avoided.

AMR - Monitoring and Reporting
Monitoring and reporting under Target A include monitoring of progress toward achievement of objectives (as measured by indicators) and monitoring of implementation of recommended management measures. For example, indicator 18 measures the tons of trash removed from streams and riparian areas (a measure of option implementation) and derives a stream accessibility score for reaches of the Creek (a measure of progress toward an objective).

Target B

Improving the ability of an urban stream to support viable habitat and fish populations focuses primarily on remediating the more obvious impacts of urbanization on the stream. These impacts include loss of riparian habitat, eroding and undercut banks, scoured streambed or excessive sediment deposits, channelized and armored stream sections, and invasive species. The primary tool to address these problems is stream restoration. Restoration focuses on improving channel stability, improving instream and riparian habitat, providing refuge that allows fish to avoid high velocity conditions during storms, and managing land within the stream corridor.

Channel Stability and Aquatic Habitat Restoration

BM1 Bed Stabilization and Habitat Restoration
BM2 Bank Stabilization and Habitat Restoration
BM3 Channel Realignment and Relocation
BM4 Plunge Pool Removal
BM5 Improvement of Fish Passage

Lowland Restoration and Enhancement

BM6 Wetland Creation
BM7 Invasive Species Management

Upland Restoration and Enhancement

BM8 Biofiltration
BM9 Reforestation

BMR Monitoring and Reporting

Many of the stresses faced by aquatic life in urban streams are the result of alternating extremes of high and low flow, and sediment scour and deposition. While stormwater BMPs that promote infiltration do help to reduce these extremes, a recent modeling analysis conducted by PWD indicates that impervious cover would have to be reduced by half or more to have a significant effect. This result indicates that stream restoration measures may be a more feasible means of improving the aquatic habitat in the short term. Modern design techniques may create areas of reduced velocity where aquatic life is protected during high flow. Techniques appropriate to our area are summarized in "Guidelines for Natural Stream Channel Design for Pennsylvania Waterways", by the Alliance for the Chesapeake Bay in March 2003. This publication is available online at http://www.acb-online.org/toolkits.cfm.

The Darby and Cobbs Creeks and their tributaries have numerous low dams that impede fish migration. As part of a stream channel and habitat restoration program, some of these dams may need to be modified or fitted with fish ladders to restore natural migratory patterns.

BMR - Monitoring and Reporting

Monitoring and reporting under Target B includes monitoring of progress toward achievement of objectives (as measured by indicators) and monitoring of implementation of recommended management measures. For example, Indicator 3 measures the channel condition and trend for each reach of the stream. This indicator is both a measure of implementation and a measure of progress toward the goal of reducing streambank and stream channel deposition and scour to protect and restore the natural functions of aquatic habitat and ecosystems, streambanks, and stream channels.

Target C

The third target is to restore water quality to meet fishable and swimmable criteria during wet weather. A comprehensive watershed management approach also must address flooding issues.

Regulatory Approaches

Zoning and Land Use Control

- *CR1* Requiring Better Site Design in New Development
    - Open Space Preservation Plan
    - Stream Buffer/Corridor Protection Ordinance
    - Wetlands Protection Ordinance
    - Steep Slope Ordinance
    - Cluster Development Ordinance
    - Transfer of Development Rights Ordinance
- *CR2* Requiring Better Site Design in Redevelopment (may include options in CR1)

CR3 Stormwater and Floodplain Management
CR4 Industrial Stormwater Pollution Prevention
CR5 Construction Stormwater Pollution Prevention
CR6 Post-construction Stormwater Runoff Management
CR7 Pollution Trading
CR8 Use Review and Attainability Analysis
CR9 Watershed-Based Permitting

The regulatory authority for controlling land use is vested in the municipalities through their ability to develop ordinances that regulate zoning and development practices. In areas that are undergoing development pressures, these ordinances are some of the most effective tools for watershed protection. In fully developed, urban watersheds such as the Cobbs Creek watershed, they are less effective, needed primarily to help improve conditions in areas that are re-developing.

A variety of approaches to environmentally responsible land use controls have been developed in recent years, and some are being implemented in the areas adjacent to Philadelphia that are undergoing rapid development. The Delaware Valley Regional Planning Commission (DVRPC) has collected information on these practices and local applications on their web site at http://www.dvrpc.org/planning/protectiontools.htm.

<u>*CR3* - Stormwater and Floodplain Management</u>

Ordinances that are important in both developing and developed areas deal directly with the way that stormwater is handled and floodplains are developed or re-developed. Municipal ordinances for stormwater and floodplain management should be consistent with the "Comprehensive Stormwater Management Policy" (Document 392-0300-002) released by PADEP in September 2002. This policy is intended "to more fully integrate post-construction stormwater planning requirements, emphasizing the use of ground water infiltration and volume and rate control best management practices (BMPs), into the existing NPDES permitting programs and the Stormwater Management Act ('Act 167') Planning Program." This policy and a draft model ordinance are available on the PADEP's web site at http://www.dep.state.pa.us/dep/deputate/watermgt/wc/subjects/stormwatermanagement.htm.

<u>*CR4* - Industrial Stormwater Pollution Prevention</u>

- Good Housekeeping
- Preventive Maintenance
- Visual Inspections
- Spill Prevention and Response
- Sediment and Erosion Control
- Employee Training
- Record Keeping and Reporting
- Fueling
- Maintaining Vehicles and Equipment
- Painting Vehicles and Equipment
- Washing Vehicles and Equipment
- Loading and Unloading Materials
- Liquid Storage in Above-Ground Tanks
- Industrial Waste Management and Outside Manufacturing
- Outside Storage of Raw Materials, By-Products, or Finished Products
- Salt Storage
- Flow Diversion
- Exposure Minimization Structures (dikes, drains, etc.)
- Erosion Prevention and Sediment Control
- Infiltration Practices

Detailed guidance on these industrial measures is available in EPA publication 832-R-92-006, "Storm Water Management for Industrial Activities: Developing Pollution Prevention Plans and Best Management Practices", released in September 1992. Municipalities may choose to adopt more stringent controls at the local level, or may work with state authorities to enforce the existing requirements. These measures are also appropriate for commercial and government operations involved in similar activities. The publication mentioned above is available online at http://www.epa.gov/clariton/clhtml/pubtitleOW.html.

CR5 - Construction Stormwater Pollution Prevention

- Sediment and Erosion Control Practices
- Good Housekeeping
- Waste Disposal
- Minimizing Offsite Vehicle Tracking of Sediments
- Sanitary/Septic Disposal
- Material Management
- Spill Response
- Control of Allowable Non-Stormwater Discharges
- Maintenance and Inspection
- Stormwater Management

Detailed guidance on these measures is available in EPA publication 832-R-92-005, "Storm Water Management for Construction Activities: Developing Pollution Prevention Plans and Best Management Practices", released in September 1992. Municipalities may choose to adopt more stringent controls at the local level, or may work with state authorities to enforce the existing requirements. These measures are also appropriate for commercial and government operations involved in similar activities. The publication mentioned above is available online at http://www.epa.gov/clariton/clhtml/pubtitleOW.html.

CR6 - Post-construction Stormwater Runoff Management

Post-construction Stormwater Runoff Management is part of the NPDES Phase 2 stormwater management plan.

CR7 - Pollution Trading

USEPA is exploring market-based measures as a way of reaching targeted overall pollutant load reductions in a watershed. EPA's "Final Water Quality Trading Policy" was released on January 13, 2003, and may be accessed at http://www.epa.gov/owow/watershed/trading/tradingpolicy.html. As this policy is adopted by the states and incorporated in regulations, it may increase incentives for cooperation and coordination between the municipalities and counties that share a watershed.

CR8 - Use Review and Attainability Analysis

USEPA provides procedures for reviewing the applicability and attainability of designated uses. This process may be appropriate for urban watersheds like the Cobbs. EPA document 833-R-01-002, "Coordinating CSO Long-Term Planning with Water Quality Standards Reviews", provides a framework for the process in areas served by combined sewers. This document is available on the EPA web site at http://cfpub.epa.gov/npdes/cso/guidedocs.cfm.

CR9 - Watershed-Based Permitting

A holistic watershed management approach provides a framework for addressing all stressors within a hydrologically defined drainage basin instead of viewing individual sources in isolation. Within a broader watershed management system, the watershed-based permitting approach is a tool that can assist with implementation activities. The utility of this tool relies heavily on a detailed, integrated and inclusive watershed planning process. Watershed planning includes monitoring and assessment activities that generate the data necessary for clear watershed goals to be established and permits to be designed to specifically address the goals. The policy statement and implementation guidance are available on the EPA's web site at http://cfpub.epa.gov/npdes/wqbasedpermitting/wspermitting.cfm

Public Education

CP1 Public Education and Volunteer Programs

Municipal Measures

CM1 Sanitary Sewer Overflow Detection
CM2 Sanitary Sewer Overflow Elimination: Structural Measures
CM3 Reduction of Stormwater Inflow and Infiltration to Sanitary Sewers
CM4 Combined Sewer Overflow (CSO) Control Program
  - Nine Minimum Controls
  - Long Term CSO Control Plan
  - Watershed-Based Planning

CM5 Catch Basin and Storm Inlet Maintenance
CM6 Street Sweeping
CM7 Responsible Landscaping Practices on Public Lands
CM8 Household Hazardous Waste Collection
CM9 Responsible Bridge and Roadway Maintenance

The first three measures above apply primarily to municipalities with separate sanitary sewer systems. The second, reduction of sanitary sewer overflow, is believed to be of critical importance in the Darby-Cobbs watershed. Inspection, cleaning, and when necessary, rehabilitation of aging sanitary sewers may be the single most important pollution reduction measures that should be implemented immediately in this watershed. Reduction of pollutant loads due to stormwater may be of secondary importance if significant loads are being introduced by sanitary sewage.

Structural Stormwater Management Facilities

Detailed information on structural BMPs for stormwater management is available in existing BMP manuals and is not reproduced here. Links to many of these manuals are available in Appendix A of the PADEP's Comprehensive Stormwater Management Policy (see link provided earlier in this document), and three are reproduced below:

Center for Watershed Protection Stormwater Manager's Resource Center
http://www.stormwatercenter.net/

Maryland Stormwater Design Manual
http://www.mde.state.md.us/Programs/WaterPrograms/SedimentandStormwater/stormwater_design/index.asp

New Jersey: Best Management Practices for Control of Nonpoint Source Pollution
http://www.state.nj.us/dep/watershedmgt/bmpmanual.htm

Stormwater Management

Source Control Measures

CS1	Reducing Effective Impervious Cover Through Better Site Design
CS2	Increasing Urban Tree Canopy
CS3	Porous Pavement and Subsurface Storage
CS4	Green Rooftops
CS5	Capturing Roof Runoff in Rain Barrels or Cisterns

The first measure, reducing effective impervious cover, refers to a variety of measures, including encouraging homeowners to reduce the size of paved areas on their properties. Porous pavement is an alternative to reduction of paved areas. Rooftops represent a large proportion of the impervious area in highly urbanized watersheds such as the Cobbs; constructing rooftop gardens over public and private buildings can be an effective structural measure to reduce urban runoff. This technology is catching on slowly in the United States, but there are some examples in our area.

Rain barrel programs are being sponsored by watershed partnerships in the greater Philadelphia area. Rain barrels are inexpensive but need to be implemented throughout a watershed to be effective as a runoff reduction measure. It is also important that their owners are properly trained and committed to operate and maintain them. Cisterns are similar to rain barrels in function; they also must be drained on a regular basis to provide effective stormwater control.

Tree planting and urban reforestation programs provide hydrologic benefits in addition to quality of life improvements. Leaf surfaces intercept some rainfall that might otherwise fall on impervious surfaces. The rainfall then either evaporates or is conveyed more slowly to the ground along plant stems and trunks.

Municipalities have the opportunity to provide incentives for private landowners to implement these innovative measures through ordinances, tax advantages, or a stormwater fee linked to impervious cover.

Onsite and Regional Stormwater Control Facilities

CS6	Maintaining/Retrofitting Existing Stormwater Structures
CS7	Modifying Catch Basins to Delay Stormwater Inflow
CS8	Retrofit of Existing Sewer Inlets With Dry Wells
CS9	Residential Dry Wells, Seepage Trenches, and Water Gardens
CS10	Infiltration Basins
CS11	Vegetated Swales and Open Channels
CS12	Bioretention Basins and Porous Media Filtration
CS13	Treatment Wetlands: Onsite and Regional
CS14	Dry Detention Basins
CS15	Wet Retention Basins
CS16	BMPs for Highway Runoff (may include various structural options in this list)

The options above are documented in the state manuals. Most of them may be implemented on the small scale of an individual property. Residential dry wells are an inexpensive way to infiltrate residential roof runoff and provide a benefit distributed over the watershed. Infiltration basins are similar but typically used on a larger scale requiring more land. Porous media filters and bioretention basins are most often used to detain, treat, and infiltrate parking lot runoff. Water gardens are similar to bioretention and can be implemented in backyards or public land such as school grounds. Proper design and maintenance, along with an effective public relations campaign, can alleviate typical concerns about mosquito control and basement flooding.

Retrofit of existing sewer inlets with dry wells is an innovative option that, while expensive, may be attractive in a completely urbanized area with very little land available for traditional BMPs. Using this technology, existing catch basins are retrofitted to provide some measure of storage and infiltration; with full implementation and favorable soil conditions, the resulting outflows may resemble the pre-development condition. The City of Portland, Oregon has implemented this approach and has provided some documentation in its Stormwater Management Manual (http://www.cleanrivers-pdx.org/tech_resources/2002_swmm.htm).

Dry detention and wet retention basins are traditional BMPs that typically provide detention and treatment functions but only limited infiltration. Their design is extensively documented in the state manuals. Constructed wetlands, either on-site or regional, provide similar detention and treatment functions; in addition, they may provide a cooling function and removal of some stormwater through evapotranspiration.

CMR - Monitoring and Reporting

Monitoring and reporting under Target C includes monitoring of progress toward achievement of objectives (as measured by indicators) and monitoring of implementation of recommended management measures. For example, indicator 7 measures the percent of water quality samples where the state fecal coliform standard is met. This indicator is a measure of progress toward the goal of improved water quality in wet weather.

5.2 Screening of Options

The extensive lists of management options described in the previous section were developed to meet each of the goals and objectives established for the Cobbs Creek watershed. Only those options deemed feasible and practical, however, were considered in the final list of management options. To identify these applicable options required a two-step evaluation.

Initial Screening. Some options could be eliminated as impractical for reasons of cost, space required, or other considerations. Options that were already being implemented, were mandated by one of the programs, or were agreed to be vital, were identified for definite implementation. The remaining options had to be screened for applicability to Cobbs Creek. This was done by developing a database and creating every possible combination of options, as described below.

Detailed Evaluation of Structural Options. Structural best management practices for stormwater and combined sewage were subjected to a more rigorous modeling analysis. Effects on runoff volume, overflow volume, peak stream velocity, and pollutant loads were evaluated at various levels of coverage. This is described in section 5.3

Table 5-1 lists the options chosen for each evaluation step.

Table 5-1 Options Chosen for Initial Screening and Detailed Evaluation

Option	Clearly Applicable	Initial Screening	Detailed Model Evaluation
Target A	X		
Target B	X		
Target C			
Regulatory Approaches			
Zoning and Land Use Control			
CR1 Requiring Better Site Design in New Development		X	
CR2 Requiring Better Site Design in Redevelopment	X		
CR3 Stormwater and FloodPlain Management	X		
CR4 Industrial Stormwater Pollution Prevention	X		
CR5 Construction Stormwater Pollution Prevention	X		
CR6 Post-Construction Stormwater Runoff Management	X		
CR7 Pollution Trading		X	
CR8 Use Review and Attainability Analysis		X	
CR9 Watershed Based Permitting	X		
Public Education and Volunteer Programs	X		
CP1 Public Education and Volunteer Programs	X		
Municipal Measures			
CM1 Sanitary Sewer Overflow Detection	X		
CM2 Sanitary Sewer Overflow Elimination: Structural Measures	X		
CM3 Reduction of Stormwater Inflow and Infiltration to Sanitary Sewers	X		
CM4 Combined Sewer Overflow (CSO) Control Program	X*	X*	X*
CM5 Catch Basin and Storm Inlet Maintenance	X		
CM6 Street Sweeping	X		
CM7 Responsible Landscaping Practices on Public Lands	X		
CM8 Household Hazardous Waste Collection	X		
CM9 Responsible Bridge and Roadway Maintenance	X		
CMR Monitoring and Reporting	X		

X*: some sub-options fall within each category shown

Table 5-1 Continued

Option	Clearly Applicable	Initial Screening	Detailed Model Evaluation
Target C			
Stormwater Management			
Source Control Measures			
CS1 Reducing Effective Impervious Cover Through Better Site Design		X	X
CS2 Porous Pavement and Subsurface Storage		X	X
CS3 Green Rooftops		X	X
CS4 Capturing Roof Runoff in Rain Barrels or Cisterns		X	X
CS5 Increasing Urban Tree Canopy	X		
Onsite and Regional Stormwater Control Facilities			
CS6 Maintaining/Retrofitting Existing Stormwater Structures		X	
CS7 Modifying Catch Basins to Delay Stormwater Inflow		X	
CS8 Retrofit of Existing Sewer Inlets With Dry Wells		X	X
CS9 Residential Dry Wells, Seepage Trenches, and Water Gardens		X	X
CS10 Infiltration Basins		X	X
CS11 Vegetated Swales and Open Channels		X	
CS12 Bioretention Basins and Porous Media Filtration		X	X
CS13 Treatment Wetlands: Onsite and Regional		X	X
CS14 Dry Detention Basins		X	X
CS15 Wet Retention Basins		X	X
CS16 BMPs for Highway Runoff		X	

Screening Methodology

Many of the options described above are appropriate to the Cobbs and did not require further evaluation or screening. Others, such as regulatory approaches for areas with new development were eliminated because the potential for new development in the watershed is limited, with the exception of the low-impact design (LID) techniques that can be adapted to redevelopment in urbanized areas. Eventually, the list was consolidated to 21 options that required more sophisticated analysis to test their appropriateness to the Cobbs Creek watershed (Table 5-2). It was decided that a semi-quantitative analysis based on cost-effectiveness would be appropriate, but the analysis should consider not just the cost-effectiveness of the individual option, but also the cost-effectiveness of the options in combination with each other. Thus, an initial screening approach for the 21 options was devised to examine the cost effectiveness of each option for controlling stormwater using an automated database approach.

Table 5-2 Options Chosen for Initial Screening

CR1	Requiring Better Site Design in New Development
CM8	Household Hazardous Waste Collection
CR7	Pollution Trading
CR8	Use Review and Attainability Analysis
CS1	Reducing Effective Impervious Cover through Better Site Design
CS2	Porous Pavement and Subsurface Storage
CS3	Green Rooftops
CS4	Capturing Roof Runoff in Rain Barrels or Cisterns
CM4-1	Increasing Size of Sewer Pipes (1 sub-option of CSO control program)
CM4-2	Structural CSO Storage Facilities (1 sub-option of CSO control program)
CS6	Maintaining/Retrofitting Existing Stormwater Structures
CS8	Retrofitting of Existing Sewer Inlets with Dry Wells
CS7	Modifying Catch Basins to Delay Stormwater Inflow
CS14	Dry Detention Basins
CS15	Wet Retention Basins
CS9	Residential Dry Wells and Seepage Trenches
CS10	Infiltration Basins
CS11	Vegetated Swales and Open Channels
CS12	Bioretention Basins and Porous Media Filtration
CS9	Water Gardens
CS13	Treatment Wetlands: Onsite and Regional

With 21 options under consideration, there are over 1 million ways in which the options can be combined, and it is not readily apparent whether certain combinations are better or worse than others when looking at their ability to meet the planning objectives in a cost-effective manner. Therefore, a computer program was written that worked through each possible combination. The program assigned qualitative cost and effectiveness scores to each option, determined the normalized cost and effectiveness of both individual options and all possible combinations, and tallied a final score as the ratio of effectiveness to cost. In this way, all the combinations were compared to each other in a consistent pattern.

To perform this screening, a cost algorithm was first developed to make an initial, qualitative assessment of the cost of each option. This assessment was taken as the cost of a realistic level of coverage (e.g., fitting 25% of all households with rain barrels may be a realistic goal but fitting 100% is not a realistic goal). A qualitative cost was developed for each option. The cost was given a score of 0 to 3 based on land acquisition, construction, and total salary as shown below.

Criteria for Assigning Initial Cost Classification

Cost	Description
High (3)	significant urban construction involved; or significant land acquisition required
Medium (2)	light construction involved; or field crew needed on a regular basis
Low (1)	non-structural; covered by existing staff salaries

The effectiveness of each option was scored on a similar scale based on the impact it has on short and long term goals as shown below.

Criteria for Assigning Initial Effectiveness Classification

Cost	Description
High (3)	may help meet one or more objectives in short term; instrumental in meeting objectives in long term
Medium (2)	leads to progress in short term, instrumental in meeting objectives in long term
Low (1)	does not lead to progress in short term; leads to limited progress in long term
None (0)	does not apply to a particular goal

Each option was then assigned a single cost-effectiveness score based on the difference or ratio of total effectiveness to total cost. Goal weighting factors were used to balance the relative magnitude of the effectiveness and cost scores. The weighting of these options was discussed in Section 3.

Once each option was assigned a cost effectiveness score they were placed in an alternative scenario with other options. The number of options in each alternative can vary from 1 option to all the options (21). The computer program created all possible combinations of 1 through 21 options, with each combination considered a unique "potential alternative". The following example illustrates the possible alternatives in a simplified case with three goals and three options.

	Effectiveness			Cost
	Goal 1	Goal 2	Goal 3	
Goal Priority	50%	30%	20%	
Option A	2	0	2	1
Option B	0	1	3	2
Option C	0	3	1	3

Possible Alternatives:
A, B, C
AB, AC, BC
ABC

The effectiveness score of an alternative was defined as the sum of option cost-effectiveness scores, weighted by objective priority:

$$E_{ABC} = E_{A1P1} + E_{A2P2} + E_{A3P3} + E_{B1P1} + E_{B2P2} + E_{B3P3} + E_{C1P1} + E_{C2P2} + E_{C3P3}$$

$$C_{ABC} = C_A + C_B + C_C$$

With: E = Effectiveness, C = Cost, and P = Priority. The subscripts denote options and goals; for example, E_{A1} is the effectiveness of option A with respect to goal 1.

Thus, E_{ABC} represents a simple way to measure the effectiveness of the combination of options a, b and c. C_{ABC} is the combined cost of options a, b and c.

The computerized analysis was not intended to provide a definitive answer on which options should or should not be included in the implementation plan. Rather, it was designed to provide insight into options that appear promising, and that appear to combine well with other options. Figure 5-1 shows the results of the cost effectiveness analysis for each option if installed on its own. The normalized scores (0 to 1) represent relative effectiveness at meeting goals (e.g., decreasing stormwater flows, increasing habitat), and cost to build. Cost-effective options are those with a high effectiveness score and a low cost score.

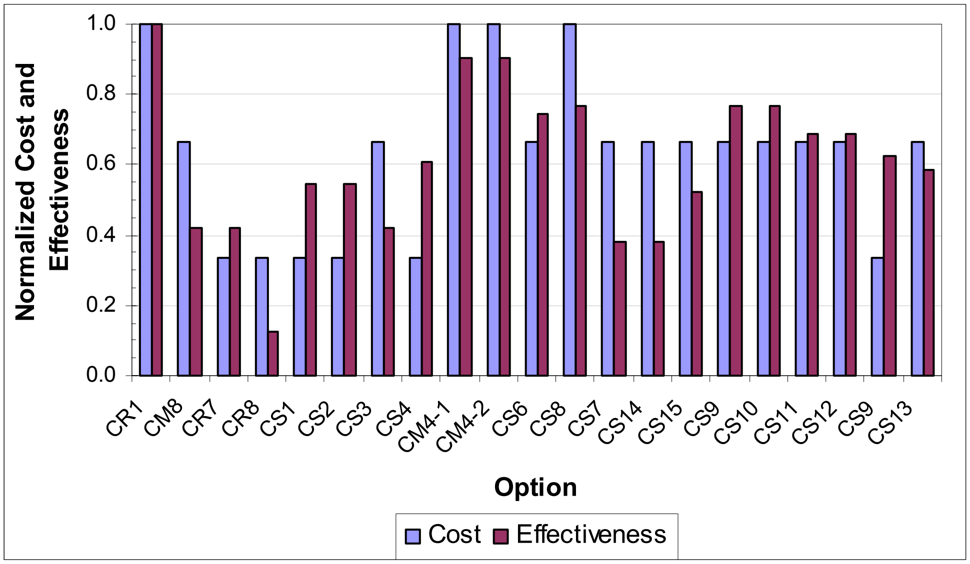


Figure 5-1 Cost–Effectiveness of Individual Options

Figure 5-2 attempts to assess the effectiveness of an option in combination with other options. The bars represent the results of the computerized analysis of all possible option combinations (over one million) by charting the earliest appearance of an option in combination with others. Thus, options 5 (reducing effective impervious cover through better site design) and 6 (porous pavement and subsurface storage) appear early, meaning they had a very high cost-effectiveness score ranking. Option 12 (retrofitting of existing sewer inlets with dry wells) had a low cost-effectiveness score, and made its first appearance only after more than 450 other combinations were rated as superior.

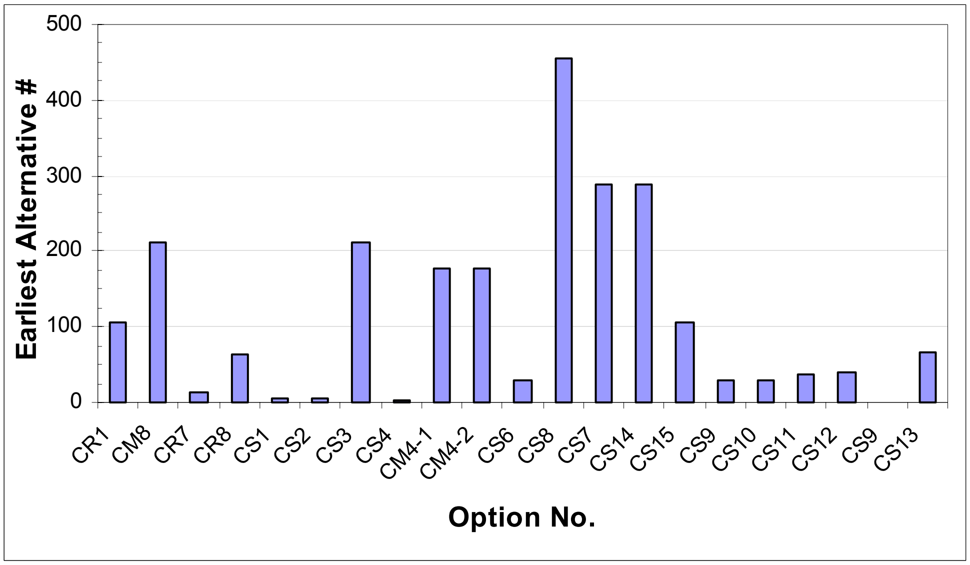


Figure 5-2 Effectiveness of Options in Combination

Table 5-3 summarizes the results of the option screening analysis. Each of the 21 options under consideration for inclusion in the implementation plan is shown in column 1.

Whether or not an option was included in the final set of alternatives was based on how well it did in the cost-effectiveness evaluation. Individually, each option has an effectiveness/cost ratio. How well the option did when combined with other options was judged by how early the option first appeared when results from the more than 1 million possible option combinations were sorted by the effectiveness/cost ratio of the combinations. The first appearance of an option was one way to judge, and its appearance within the 40 highest ranked option combinations was another. Table 5-3 shows the option results with color shading. Green options rated highly, and were likely to be included in the implementation plan. Yellow shaded options were ranked medium, and were possible options for inclusion. The pink highlighted options were the least cost effective options, and were the least likely to be included for implementation.

Table 5-3 Results of Initial Screening

🟩 High Score; 🟨 Medium Score; 🟥 Low Score

Opt. No.	Option Description	Normalized Cost Score	Normalized Effectiveness Score	Normalized E/C Ratio for Option Alone	First Alternative Appearance
CR1	Requiring Better Site Design in New Development	1.00	1.00	1.00	105
CM8	Household Hazardous Waste Collection	0.67	0.42	0.63	212
CR7	Pollution Trading	0.33	0.42	1.27	13
CR8	Use Review and Attainability Analysis	0.33	0.13	0.38	63
CS1	Reducing Effective Impervious Cover through Better Site Design	0.33	0.55	1.64	4
CS2	Porous Pavement and Subsurface Storage	0.33	0.55	1.64	5
CS3	Green Rooftops	0.67	0.42	0.63	211
CS4	Capturing Roof Runoff in Rain Barrels or Cisterns	0.33	0.61	1.83	2
CM4-1	Increasing Size of Sewer Pipes	1.00	0.91	0.91	178
CM4-2	Structural CSO Storage Facilities	1.00	0.91	0.91	177
CS6	Maintaining/Retrofitting Existing Stormwater Structures	0.67	0.74	1.11	30
CS8	Retrofitting Existing Sewer Inlets with Dry Wells	1.00	0.77	0.77	455
CS7	Modifying Catch Basins to Delay Stormwater Inflow	0.67	0.38	0.57	288
CS14	Dry Detention Basins	0.67	0.38	0.57	289
CS15	Wet Retention Basins	0.67	0.52	0.79	106
CS9	Residential Dry Wells and Seepage Trenches	0.67	0.77	1.15	28
CS10	Infiltration Basins	0.67	0.77	1.15	29
CS11	Vegetated Swales and Open Channels	0.67	0.69	1.03	38
CS12	Bioretention Basins and Porous Media Filtration	0.67	0.69	1.03	39
CS9	Water Gardens	0.33	0.63	1.88	1
CS13	Treatment Wetlands: Onsite and Regional	0.67	0.59	0.88	65

5.3 Modeling Assessment of Structural BMPs

The automated option screening described above was done in a qualitative sense based on the options only, with no direct consideration of their ability to function under the specific circumstances of Cobbs Creek. Those BMPs that were deemed to be generally effective in meeting wet weather or Target C objectives were further assessed using the SWMM model. In this way, the BMPs could be assessed for their cost-effectiveness when implemented in Cobbs Creek. BMPs (or options) that appear to cost-effectively decrease stormwater flows or combined sewer overflows, or significantly reduce pollutant loading during wet weather were subjected to a series of model runs. BMPs were simulated at various levels of implementation within the watershed, and the results graphed. For the assumed level of implementation, the results in terms of pollutant reduction and amount of stormwater treated were then combined with planning level cost estimates, and the options were ranked according to their cost effectiveness. The modeling analysis is documented in more detail in the Comprehensive Characterization Report.

The results are shown in Tables 5-4 through 5-6. Note that the analysis was carried out separately for BMPs placed in CSO areas and in separate storm sewered areas to test the effects of location. There are clear differences in the efficiency of BMPs depending on where they are located. The analysis was also carried out for the cost effectiveness at removal of pollutants using TSS as surrogate for most pollutants, and for cost effectiveness at reducing or treating stormwater quantity reaching the creek. This is important because some BMPs appear to be more efficient at pollutant removal, while others are more efficient at reducing the volume of stormwater reaching the stream. Both are objectives of the watershed management plan.

Table 5-4 shows the estimated cost per gallon of stormwater treated, and the cost per pound of TSS removed for simulations of feasible levels of implementation for each of the types of BMPs under consideration. The results show that there is a wide range of costs, and that costs differ depending on whether a BMP is implemented in a CSO area, or in an area served by separate storm sewers. Table 5-5 shows the relative ability of each of the BMPs to either store stormwater, treat stormwater, or remove TSS, based on simulations of feasible implementation of each of the BMPs in the Cobbs Creek Watershed. Table 5-6 shows the list of options, ranked from most cost-effective to least cost-effective, grouped into highly effective (green), moderately effective (yellow), and least effective (pink) options.

Table 5-4 Cost Analysis Results Using SWMM Model

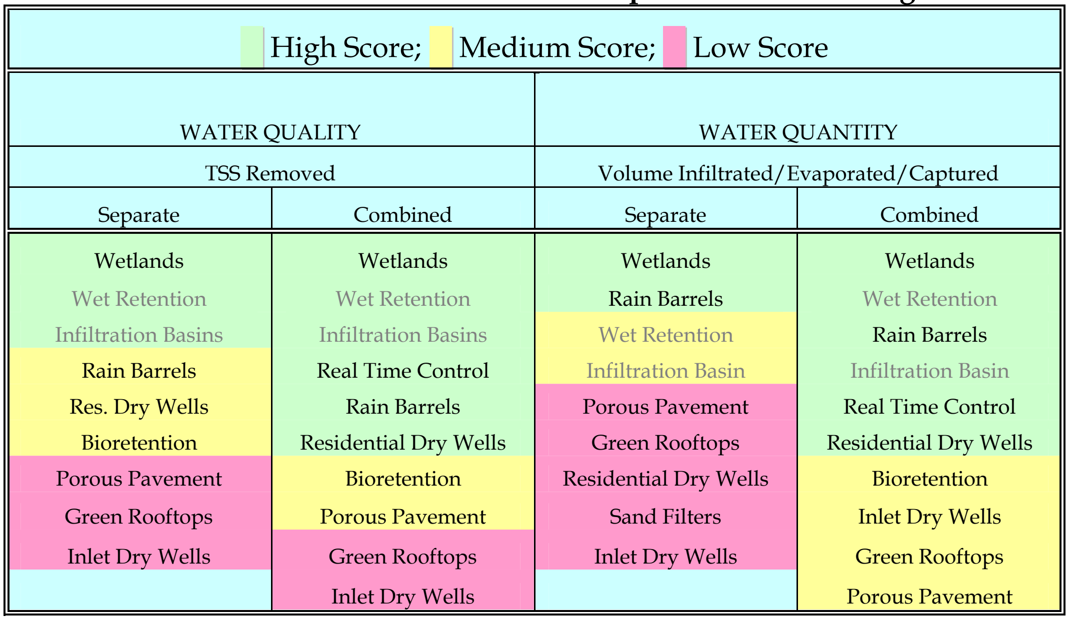
🟩 High Score; 🟨 Medium Score; 🟪 Low Score

	WATER QUALITY			WATER QUANTITY		
	TSS Removed			Volume Infiltrated/Evap/Captured		
BMP	Separate ($/lb)	Combined ($/lb)	Watershed ($/lb)	Separate ($/10^3 gal)	Combined ($/10^3 gal)	Watershed ($/10^3 gal)
Treatment Wetlands	0.98	0.43	0.71	2.89	0.38	0.98
Wet Retention Basins	2.94	2.18	2.66	15.02	2.42	5.91
Rain Barrels and Cisterns	13.83	3.68	7.62	9.06	2.50	5.10
Infiltration Basins	3.39	2.51	3.07	17.33	2.79	6.82
Real Time Control	N/A	3.47	N/A	N/A	3.15	N/A
Residential Dry Wells	16.52	8.69	13.05	82.26	8.29	22.62
Bioretention Basins	36.25	15.20	25.73	162.48	13.31	37.71
Dry Wells in Sewer Inlets	1067.59	38.03	118.70	789.61	26.26	82.38
Porous Pavement	92.61	50.46	74.28	63.88	35.23	51.51
Green Rooftops	107.10	50.96	80.81	72.33	35.23	55.17

Table 5-5 Relative Ranks of BMPs for Total Stormwater Storage, Volume of Stormwater Treated, and Simulated Reduction in TSS

BMP Ranking	Potential Storage	Volume Affected	TSS Load Reduction
Highest	Porous Pavement	Infiltration Basins	Inf. Basin
↓	Infiltration Basins	Wet Retention	Wet Retention
	Wet Retention	Res. Dry Wells	Priv. Dry Wells
	Bioretention	Inlet Dry Wells	Porous Pavement
	Res. Dry Wells	Real Time Control	Real Time Control
	Inlet Dry Wells	Porous Pavement	Green Rooftops
	Green Rooftops	Bioretention	Bioretention
	Wetlands	Green Rooftops	Wetlands
	Rain Barrels	Wetlands	Inlet Dry Wells
Lowest		Rain Barrels	Rain Barrels

Table 5-6 Relative Cost-Effectiveness of Options in Descending Order



🟩 High Score; 🟨 Medium Score; 🟥 Low Score

WATER QUALITY		WATER QUANTITY	
TSS Removed		Volume Infiltrated/Evaporated/Captured	
Separate	Combined	Separate	Combined
🟩 Wetlands	🟩 Wetlands	🟩 Wetlands	🟩 Wetlands
🟩 Wet Retention	🟩 Wet Retention	🟩 Rain Barrels	🟩 Wet Retention
🟩 Infiltration Basins	🟩 Infiltration Basins	🟨 Wet Retention	🟩 Rain Barrels
🟨 Rain Barrels	🟩 Real Time Control	🟨 Infiltration Basin	🟩 Infiltration Basin
🟨 Res. Dry Wells	🟩 Rain Barrels	🟥 Porous Pavement	🟩 Real Time Control
🟨 Bioretention	🟩 Residential Dry Wells	🟥 Green Rooftops	🟩 Residential Dry Wells
🟥 Porous Pavement	🟨 Bioretention	🟥 Residential Dry Wells	🟨 Bioretention
🟥 Green Rooftops	🟨 Porous Pavement	🟥 Sand Filters	🟨 Inlet Dry Wells
🟥 Inlet Dry Wells	🟥 Green Rooftops	🟥 Inlet Dry Wells	🟨 Green Rooftops
	🟥 Inlet Dry Wells		🟨 Porous Pavement

The results of the SWMM model BMP simulations support a number of general conclusions about the implementation of BMPs in Cobbs Creek.

- The cost of runoff volume reduction is always higher in separate-sewered than in combined-sewered areas because temporary storage and release results in additional capture at CSO regulator structures. Larger cost differences between CSO and separate storm sewer areas occur where evapotranspiration and/or infiltration are minor components of the BMP (e.g., retrofitting sewer inlets with dry wells, residential dry wells and seepage trenches, bioretention and porous media filters).

- Generally speaking, if pollutant removal is significant for a given BMP, the cost difference between separate and CSO areas is smaller. Examples are porous pavement with subsurface storage, due to significant infiltration, and green rooftops, due to significant ET.

- Traditional BMPs like infiltration basins and wet retention basins can be effective where land is available to build them. These facilities typically have much larger capacities, are regional in nature, and exhibit economies of scale. They are not thought to be practical alternatives for the Cobbs watershed, but they are included for completeness.

- For the combined-sewered areas, real time control (RTC) is among the most competitive options in terms of both volume (5th) and load (4th) reduction. The RTC configuration being considered is highly specific to the Cobbs, and these results may not hold generally for other watersheds.

- In highly urbanized areas, large storage volumes can be achieved only through options such as porous pavement and gravel under parking facilities. Figure 5-3 shows the maximum amount of storage that could be built in the Cobbs watershed given a reasonable level of coverage for each BMP. Subsurface gravel under parking facilities represents over 60% of the storage that could feasibly be built. Bioretention and porous media filters represent the second largest volume at approximately 8%.

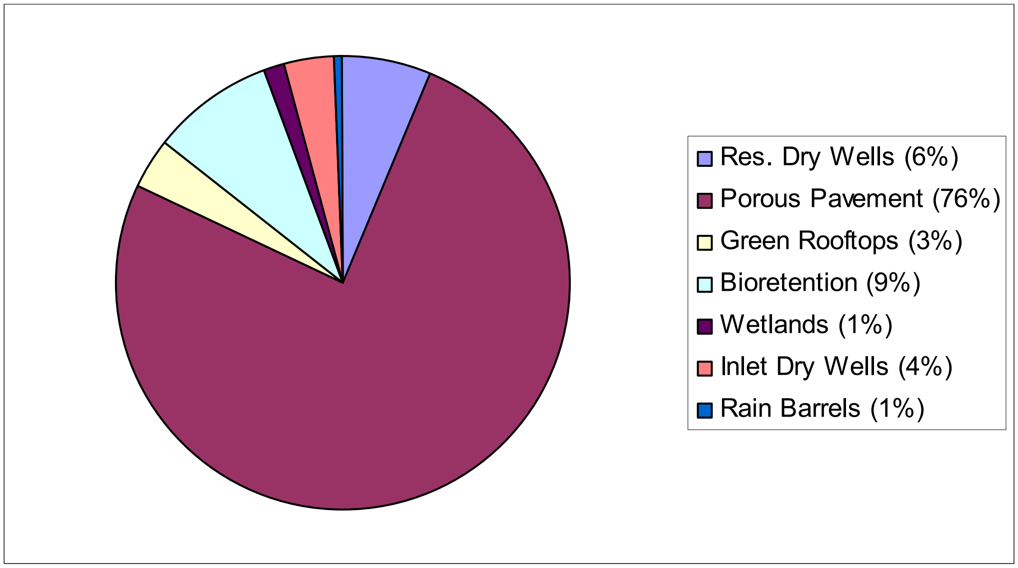


Figure 5-3 Total Storage Volume Feasible for Cobbs Watershed

- Given the urban conditions and soil in the Cobbs, only two of the modeled BMPs are capable of removing large quantities of stormwater (Figure 5-4). If porous pavement covered all parking lots, approximately 12% of stormwater could be removed through infiltration on an annual basis. If green rooftops covered all buildings, approximately 10% of stormwater could be removed through evapotranspiration.

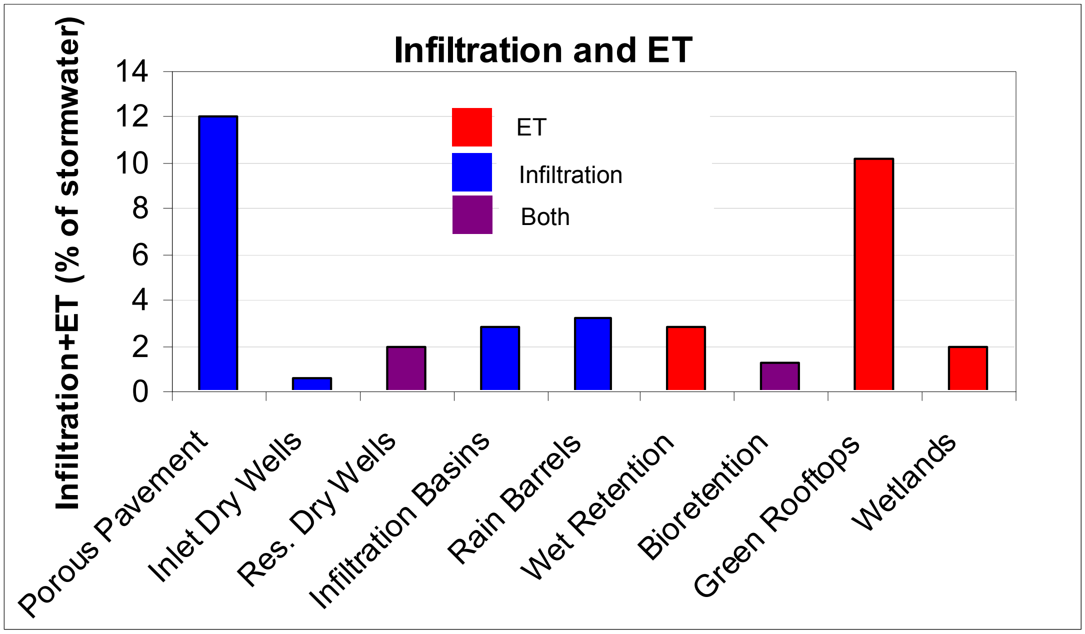


Figure 5-4 Potential Stormwater Volume Removal Given Full Coverage

The cost analysis of alternatives in areas of separate storm sewers shows:

- Wet Retention, wetlands, and infiltration basins are the most cost effective options for TSS removal on a dollar per pound basis. Wetlands and rain barrels are cost effective on a dollar per gallon stormwater treated basis.

- Dry wells in sewer inlets (>$1000/lb), green rooftops and porous pavement (~$100/lb) are particularly expensive for TSS reduction. Dry wells in sewer inlets and bioretention basins are expensive on a per gallon basis for stormwater treatment because of their relatively small area of infiltration.

The cost analysis of alternatives in areas of combined sewers shows:

- Wetlands, wet retention, rain barrels, infiltration basins, real time control, and residential dry wells are all relatively cost effective options on the basis of dollars per pound TSS removed and on the basis of dollars per gallon of stormwater treated.

- Green rooftops and porous pavement (both about $50/lb) are expensive choices either on the basis of TSS removal or on the basis of dollars per gallon stormwater treated.

It is also clear that the most expensive options in combined-sewered areas are more than an order of magnitude lower than the most expensive options in separate-sewered areas. Because hydraulic detention is the most important mechanism in combined-sewered areas, there is less difference in cost-effectiveness between the different types of BMPs.

In combined areas, the regulator structures represent an investment already made in pollution reduction. Thus money spent on stormwater best management practices results in greater load and volume reductions per dollar spent than in separate areas where no stormwater controls are in place. To meet an overall load reduction target in watersheds served by both combined and separate areas, it may be most efficient to focus management measures on the combined areas.

In Section 6, all the results presented above are used to assemble management alternatives that meet watershed goals in a cost-effective manner.

Section 6: Development and Evaluation of Management Alternatives

6.1 Development of Alternatives

BMPs, stream restoration measures, stormwater and CSO management technologies, and public education measures must be combined into coherent, integrated management plan alternatives that address the multiple objectives of the Darby-Cobbs Watershed Partnership. In highly urbanized watersheds, however, it is very difficult to develop appropriate water quality, quantity, and habitat objectives. For Cobbs Creek, PWD's approach is to define three separate sets of objectives or targets, and recommend BMPs and programs to achieve each of the targets. Targets are defined here as groups of objectives that each focus on a different problem related to the urban stream system. They can be thought of as different parts of the overall goal of fishable and swimmable waters through improved water quality, more natural flow patterns, and restored aquatic and riparian habitat.

The three targets of watershed restoration for Cobbs Creek are:

- TARGET A: Dry Weather Water Quality and Aesthetics
- TARGET B: Healthy Living Resources
- TARGET C: Wet Weather Water Quality and Quantity

By defining clear and achievable targets, and designing the alternatives and implementation plan to address the targets simultaneously, the plan will have a much higher likelihood of success. It will also result in realizing some of the objectives within a relatively short time frame, providing positive incentive to the communities and agencies involved in the program to continue and expand their efforts. This approach will also result in more immediate benefits to people living in the watershed than would an approach that attempts to meet all objectives completely in one implementation plan.

6.1.1 Target A: Options for Dry Weather Water Quality and Aesthetics

For Cobbs Creek, the focus of Target A is trash removal, litter prevention, and elimination of sources of sewage during dry weather. Because the options under consideration are aimed at the total elimination of trash and dry weather sources of sewage, no complex analysis was required to help define the program or assess its potential benefits. All options related to this target are included in the implementation plan.

Streams should be aesthetically appealing (e.g., look and smell good), accessible to the public, and be an amenity to the community. Access to and interaction with the stream during dry weather have the highest priority, because dry weather flows occur about 60-65% of the time during the course of a year, and are also the times when the public is most likely to be near or in contact with the streams. The water quality of the stream in dry weather, particularly with respect to bacteria, should be similar to background concentrations in groundwater. Many urban streams rarely meet water quality standards for bacteria, and urban streams often have significant BOD problems, even during baseflow or dry weather conditions.

The following outline shows the list of options recommended for inclusion in the implementation plan to achieve the objectives associated with Target A.

Regulatory Approaches

AR1 On-Lot Disposal (Septic System) Management
AR2 Pet Waste, Litter, and Dumping Ordinances

Public Education and Volunteer Programs

AP1 Public Education*AP2* School-Based Education
AP3 Public Participation and Volunteer Programs

Municipal Measures

AM1 Capacity Management Operation and Maintenance (CMOM)
AM2 Inspection and Cleaning of Combined Sewers
AM3 Sanitary Sewer Rehabilitation
AM4 Combined Sewer Rehabilitation
AM5 Illicit Discharge, Detection, and Elimination (IDD&E)
AM6 Stream Cleanup and Maintenance

AO1 Enhancing Stream Corridor Recreational and Cultural Resources

AMR Monitoring and Reporting

The outline shows that the options relevant to Target A focus on dry weather water quality and visual aesthetics of the stream, primarily removal of trash and elimination of illegal dumping. Also included are a range of regulatory and nonstructural options that address both water quality and quantity concerns. The measures in Table 6-1 may be grouped into three broad categories:

- Measures to Eliminate Sources of Trash and Litter
- Measures to Eliminate Sanitary Waste Inputs in Dry Weather
- Measures to Improve Public Access to Streams

Measures to Eliminate Sanitary Waste Inputs in Dry Weather

Measures to restore water quality during dry weather are fundamental to the plan. Elimination of dry weather sewer discharges due to blockages can be achieved by regularly cleaning and maintaining sewers. Leaking sewers are addressed by rehabilitating broken or leaking sewers, and identifying and correcting cross-connections (sanitary connections to stormwater lines).

In addition to sewage discharges, a program must be implemented to identify and eliminate any other pollutant sources (e.g., point sources or leaking septic tanks) that might be leading to instances of dry weather dissolved oxygen (DO) depression bacteria water quality standard exceedances.

Measures to Eliminate Sources of Trash and Litter

Another aspect of Target A objectives is to improve aesthetics by cleaning up trash and taking measures to reduce littering and illegal dumping. Many stakeholders in area watersheds have indicated that these measures are a primary concern. Options to achieve this include stream cleanup activities and the implementation of a wide range of nonstructural measures to educate the community about the importance of the stream, and about the direct consequences of their actions on the quality of the streams. Example implementation measures include school-based education, establishment of stakeholder and watershed groups, improved street sweeping and litter control, the establishment of municipal "clean stream teams" to clean up trash in the stream, and improved enforcement of existing littering and anti-dumping ordinances.

Measures to Improve Public Access to Streams

A significant portion of Cobbs Creek offers opportunities to improve access and use of the stream for passive recreation through the creation of trails, access points, and improved habitat within the riparian corridor. Areas where access can be improved will be indicated in the implementation plan.

6.1.2 TARGET B: Options for Healthy Living Resources

Improving the ability of an urban stream to support viable habitat and fish populations focuses primarily on the elimination of the more obvious impacts of urbanization on the stream. These include loss of riparian habitat, eroding and undercut banks, scoured streambed or excessive silt deposits, channelized and armored stream sections, trash buildup, and invasive species. The primary tool to accomplish this is stream restoration. Restoration focuses on improving channel stability, improving instream and riparian habitat, providing refuges for fish from high velocity conditions during storms, and managing land within the stream corridor.

Channel Stability and Aquatic Habitat Restoration

BM1	Bed Stabilization and Habitat Restoration
BM2	Bank Stabilization and Habitat Restoration
BM3	Channel Realignment and Relocation
BM4	Plunge Pool Removal
BM5	Improvement of Fish Passage

Lowland Restoration and Enhancement

BM6	Wetland Creation
BM7	Invasive Species Management

Upland Restoration and Enhancement

BM8 Biofiltration
BM9 Reforestation

BMR Monitoring and Reporting

Options for stream restoration were developed based on extensive studies carried out in the watershed by PWD in preparation for the Cobbs Creek Watershed Management Plan. Studies included a geomorphologic channel survey (stream assessment) of the entire creek, stormwater modeling, habitat and biological assessments, and modeling of stream velocities along a critical stretch of the creek. Assessment results indicate that the moderately impaired benthic community and pollution tolerant fish assemblages in Cobbs Creek reflect habitat deterioration and episodic water quality degradation throughout the entire watershed. Cobbs Creek watershed is a highly urbanized region where traditional methods of stream bank “reconstruction” and stormwater management have significantly channelized the stream and disconnected it from its historic floodplain, creating a system which is not in dynamic equilibrium (i.e., the amount of erosion and sedimentation is not equal to the amount of sediment transport out of the system). Furthermore, the stream has lost much of its link magnitude (e.g., small first order streams) and wetland systems due to development and increased impervious surfaces. Due to these changes, the stream’s hydrologic profile has been altered, decreasing the time to peak flow and increasing peak flow concentration. In doing so, storm events reaching or exceeding bankfull stage are no longer managed by the stream channel and floodplain.

Typical events scour stream banks, fill pools with sediment, and cover riffle structures with sediment at an accelerated rate. As a result, a highly ephemeral (short-lived) system with increased sediment deposition, decreased habitat heterogeneity (e.g. pool-riffle-run systems) and unstable stream banks has been created. These changes have had a deleterious effect on the benthic and ichthyfaunal communities inhabiting Cobbs Creek.

Results of water quality monitoring, habitat assessment, and biological monitoring, suggest the primary impact on the number, health, and diversity of fish species in Cobbs Creek is habitat modification. Restoration efforts, therefore, need to focus on habitat improvement and fishes’ ability to avoid high velocity flows during storms. Wetland and streambank restoration/creation projects and stream modeling will be combined with continued biological monitoring to ensure that appropriate procedures are being implemented to increase habitat heterogeneity within the aquatic ecosystem.

The options in Table 6-2 may be further broken into measures necessary used for stabilization of the stream channel, measures for habitat creation, measures to manage infrastructure in restoration areas, and measures to improve fish passage.

Measures for Channel Stabilization

- Bank stabilization, including boulder structures, bioengineering, root wads, plantings, and log and woody structures
- Bed stabilization, including rock/log vanes with grade control, rock/log cross vanes, and naturally occurring boulders and bedrock
- Realignment and relocation of the stream channel, to be used only on severely degraded stream sections

Measures for Habitat Restoration in the Stream and Stream Corridor

- Restoring stream banks, channels, and habitat features
- Restoring riparian (streamside) habitat, including wetlands
- Eliminating deep, poorly mixed pools to improve dissolved oxygen (DO) concentration
- Restoring pools and riffles, healthy banks, and creating safe areas of low flow velocity during storms
- Reforestation, with priority to floodplains, steep slopes, and wetlands
- Invasive species management, needed to increase biodiversity
- Wetland creation, often used in conjunction with stream realignment to improve floodplain areas subject to annual flooding
- Forest preservation

Measures to Manage Infrastructure in the Restoration Area

- Where possible, reducing impervious cover during corridor restoration
- Infrastructure retrofit or relocation of structures within the floodplain or encroaching on the channel
- Road and culvert maintenance

Measures to Improve Fish Passage

- Fish ladders, which allow fish to pass around obstructions
- Modification or removal of dams

A more detailed presentation of the above measures is included in the implementation guidance section (Section 7).

6.1.3 TARGET C: Options for Wet Weather Water Quality and Quantity

Improving water quality and flow conditions during and after storms is the most difficult target to meet in the urban environment. During wet weather, extreme increases in streamflow are common, accompanied by short term changes in water quality. Stormwater generally does not have DO problems, but sampling data indicate that concentrations of metals (such as copper, lead, and zinc) and bacteria do not meet water quality standards during wet weather. These pollutants are introduced by both stormwater and wet weather sewer overflows (CSOs and SSOs).

Target C options also must address flooding issues. Where water quality and quantity problems both exist, options must be identified that address both. Any BMP that increases infiltration or detains flow will help decrease the frequency of damaging floods; however, the size of such structures may need to be increased in areas where flooding is a major concern. Reductions in the frequency of erosive flows and velocities will also help protect the investment in stream restoration made as part of the implementation of Target B options.

Target C must be approached somewhat differently from the first two targets. Full achievement of this target means meeting all water quality standards during wet weather, as well as eliminating all flooding. Full achievement of these goals will be difficult, particularly with regard to wet weather water quality. It is certainly extremely expensive, and would require a long term effort. The only rational approach to full achievement of Target C goals is through stepped implementation with interim targets for reducing wet weather pollutant loads and stormwater flows. During implementation, monitoring must continue to continuously assess the effectiveness of the program. Based on the extensive modeling analysis carried out for Cobbs Creek to date, an initial goal of a 20% reduction in stormwater flows and stormwater/CSO related pollutant loads is challenging but achievable.

It is expected that changes to the approach, and even to the desired results, will occur as measures are implemented and results are monitored. With permits of 5-year duration for most discharge permits, discharge targets and reduction targets must be set and implementation designed in the first 5 years. Implementation for meeting Target C should occur over the next 5 years, with monitoring for effectiveness taking place for 5 years subsequent to implementation. During the last 5-year period, PWD will also work with the regulatory agencies to review water quality standards and determine whether any adjustments to them may be appropriate based on the results of monitoring.

On the Cobbs Creek, data indicate that restoring water quality to meet fishable and swimmable criteria during wet weather primarily means controlling sources of fecal coliform and restoring degraded stream habitat. Because urban streams are subject to extreme changes in flow and very heavy loading of fecal coliform from CSOs and stormwater, options focus on reducing stormwater and CSO overflows by:

- Reducing CSOs from reaching the stream
- Treating or infiltrating stormwater before it reaches the stream
- Implementing floodplain management, planning, and ordinances (e.g., restrict development in the 100-year floodplain)

Options related to Target C are divided into two groups. The first group, listed in the following outline, includes options recommended for full implementation regardless of what alternative is ultimately chosen. These options include a range of ordinances and regulatory measures, public education, measures related to existing municipal infrastructure, selected source controls, and possibilities for pollution trading and use review. The municipal measures focus on the elimination of sanitary sewer overflows and the causes of overflows such as blockages and excessive infiltration. Recommendations for implementing these options are included in Section 7.

Regulatory Approaches

Zoning and Land Use Control

CR2 Requiring Better Site Design in Redevelopment

CR3 Stormwater and Floodplain Management
CR4 Industrial Stormwater Pollution Prevention
CR5 Construction Stormwater Pollution Prevention
CR6 Post-construction Stormwater Runoff Management
CR7 Pollution Trading
CR8 Use Review and Attainability Analysis
CR9 Watershed-Based Permitting

Municipal Measures

CM1 Sanitary Sewer Overflow Detection
CM2 Sanitary Sewer Overflow Elimination: Structural Measures
CM3 Reduction of Stormwater Inflow and Infiltration to Sanitary Sewers
CM4 Combined Sewer Overflow (CSO) Control Program
  - Nine Minimum Controls
  - Long Term CSO Control Plan
  - Watershed-Based Planning

CM5 Catch Basin and Storm Inlet Maintenance
CM6 Street Sweeping
CM7 Responsible Landscaping Practices on Public Lands
CM9 *R*esponsible Bridge and Roadway Maintenance

Stormwater Management

Source Control Measures

CS1 Reducing Effective Impervious Cover Through Better Site Design
CS2 Increasing Urban Tree Canopy
CS3 Porous Pavement and Subsurface Storage
CS4 Green Rooftops
CS5 Capturing Roof Runoff in Rain Barrels or Cisterns

Onsite and Regional Stormwater Control Facilities

CS6 Maintaining/Retrofitting Existing Stormwater Structures
CS8 Retrofit of Existing Sewer Inlets with Dry Wells
CS9 Residential Dry Wells, Seepage Trenches, and Water Gardens
CS12 Bioretention Basins and Porous Media Filtration
CS13 Treatment Wetlands: Onsite and Regional

CMR Monitoring and Reporting

The second group of Target C options includes structural measures designed to achieve specific, measurable discharge and pollutant load reductions. Table 6-1 lists the eight measures, a feasible implementation level for each, and the discharge and pollutant load reductions that are possible with each. Table 6-2 lists six alternatives, or combinations of these eight options that result in approximately a 20% reduction in wet weather flows and loads to the stream system.

Table 6-1 Available Options to Meet Flow and Load Reduction Targets

	Maximum Feasible Implementation	Volume Reduction		Pollutant Reduction
		CSO	Stormwater	
Municipal Measures				
CM4 Combined Sewer Overflow (CSO) Control Program				
• Real Time Control	15 Sites in PWD's SWDD	11%	0%	14%
Structural Stormwater Management Facilities				
Source Control Measures				
CS3 Porous Pavement and Subsurface Storage	50% of parking lots	3%	4%	8%
CS4 Green Rooftops	5% of rooftops	6%	7%	14%
CS5 Capturing Roof Runoff in Rain Barrels or Cisterns	25% of homes	4%	2%	6%
Onsite and Regional Stormwater Control Facilities				
CS8 Retrofit of Existing Sewer Inlets with Dry Wells	100% of inlets	5%	0%	6%
CS9 Residential Dry Wells, Seepage Trenches, Water Gardens	school grounds; 25% of homes	6%	1%	19%
CS12 Bioretention Basins and Porous Media Filtration	50% of parking lots	2%	0%	6%
CS13 Treatment Wetlands: Onsite and Regional	100% of identified potential	5%	1%	12%

Notes:
1. Volume reductions are % of total discharge (sum of CSO and stormwater)
2. “Maximum Feasible” considers technical feasibility and social acceptance, but not cost.

Each alternative is designed to fully meet the goal of 20% reduction in untreated stormwater reaching the stream, and a 20% reduction in pollutant loading through stormwater and/or CSOs. They differ in approach and cost, with each representing a slightly different “design approach”.

Table 6-2 Six Alternatives for Meeting 20% Flow and Load Reduction Target

	Unit	Alternative					
		1	2	3	4	5	6
Municipal Measures							
CM4 Combined Sewer Overflow (CSO) Control Program							
• CSO Storage Tanks	Yes/No	No	Yes	No	No	No	No
• Real Time Control	Yes/No	Yes	No	No	No	No	No
Structural Stormwater Management Facilities							
Source Control Measures							
CS3 Porous Pavement and Subsurface Storage	% of parking lots	0%	0%	0%	0%	50%	25%
CS4 Green Rooftops	% of rooftops	0%	0%	0%	2%	0%	2%
CS5 Capturing Roof Runoff in Rain Barrels or Cisterns	% of homes	25%	25%	25%	25%	0%	20%
Onsite and Regional Stormwater Control Facilities							
CS8 Retrofit of Existing Sewer Inlets with Dry Wells	% of sewer inlets	0%	0%	0%	0%	40%	0%
CS9 Residential Dry Wells, Seepage Trenches, Water Gardens	% of homes	25%	25%	15%	25%	0%	10%
CS12 Bioretention Basins and Porous Media Filtration	% of parking lots	5%	5%	0%	2%	50%	25%
CS13 Treatment Wetlands: Onsite and Regional	% of identified potential	100%	100%	100%	0%	0%	50%

Alternative 1: Real Time Control and Low-Cost Stormwater BMPs

This alternative combines real time control of CSOs within the combined sewered area of the watershed with BMPs that were identified as being cost-effective within the conditions found in Cobbs Creek. Stormwater BMPs are applied only to the areas served by separate storm sewers. The options applied to the separate sewered areas include the use of wetlands for all areas identified as suitable for wetland creation, installation of rain barrels on 25% of all homes, installation of residential dry wells for roof runoff on another 25% of homes, and sand filters or bioretention facilities installed on 5% of the parking lots within the watershed.

Alternative 2: Structural Storage and Low-Cost Stormwater BMPs

This alternative uses large scale retention of combined sewer flows through the use of large CSO tanks. In separate sewered areas, it is assumed that rain barrels are installed on 25% of the households, that 25% of the residences have dry wells to catch roof runoff, and that bioretention basins and/or sand filters are installed in 5% of parking lots.

Alternative 3: Low-Cost Stormwater BMPs throughout Watershed

This alternative uses only stormwater BMPs throughout the watershed; CSOs are addressed by infiltrating and detaining stormwater before it reaches the combined sewer. It includes wetlands at all feasible locations, rain barrels on 25% of all homes, and dry wells on 15% of all homes in the watershed.

Alternative 4: Stormwater BMPs with Focus on Private Property

This alternative uses only stormwater BMPs throughout the watershed. The concept is to examine the effectiveness of stormwater BMPs that are applied primarily to private properties through voluntary or incentive programs. It includes rain barrels on 25% of all homes, dry wells on 25% of all homes, sand filters or bioretention facilities installed on 2% of the parking lots within the watershed and green roofs installed on 2% of all homes in the watershed.

Alternative 5: Stormwater BMPs with Focus on Public Property and Parking

This alternative uses only stormwater BMPs throughout the watershed; however, the focus is primarily on BMPs applied to public lands and facilities. BMPs include bioretention and/or sand filters in 50% of the parking lots in the watershed, porous pavement with storage in 50% of the parking lots, and dry wells replacing 40% of the manholes along both combined and separate sewers throughout the watershed.

Alternative 6: A Mix of Stormwater BMPs

This alternative examines an implementation program that results in a mixture of BMPs that could be applied throughout the watershed. It includes wetland creation on 50% of the feasible locations, rain barrels installed on 20% of all homes, dry wells installed on 10% of the residences to collect roof runoff, sand filters/bioretention on 25% of the parking lots, porous pavement with underground stormwater storage on 25% of the parking lots, and green roofs on 2% of the homes.

6.2 Evaluation of Alternatives

The six alternatives described above are all designed to meet an interim target of 20% reduction in pollutant loading to Cobbs Creek during wet weather. Each represents a different approach to meeting this interim target. All achieve similar reduction in total load, but can have significantly different results when assessed in other ways. For example, costs for each approach are very different, and each approach differs in the degree that it might meet other planning objectives.

Ultimately, Target C options will be implemented within the watershed by a variety of stakeholders (counties, municipalities, watershed groups, State agencies, private businesses, etc.). In order to gain insight into the strengths and weaknesses of the various approaches, the six alternatives were evaluated using a multi-criteria evaluation program called EVAMIX.

6.2.1 Multi-Criteria Evaluation Using EVAMIX

EVAMIX is a matrix-based, multi-criteria evaluation program that makes use of both quantitative criteria (such as cost that are measured with numbers such as millions of dollars), and qualitative criteria (such as implementability, measured only as high, medium, or low) within the same evaluation, regardless of the units of measure. The use of EVAMIX requires the development of a two dimensional matrix consisting of the alternatives to be evaluated (columns) and a set of evaluation criteria (rows). For every combination of alternative and criteria, a score is assigned. Many of the quantitative criteria were scored using model simulation results, while a number of qualitative criteria were scored based on clearly defined definitions and professional judgment.

The other important input to EVAMIX is the selection of weighting factors for each of the criteria. Weights were provided by the Technical Advisory Group, and a separate EVAMIX simulation was run for each set of weights provided.

In summary, the following were used in carrying out the EVAMIX evaluation:

- The six Target C alternatives being evaluated
- A set of clearly defined criteria used to compare the alternatives
- Scores assigned to every alternative for each criterion
- Weighting factors assigned to each criterion. These weights represent the relative importance of each criterion as provided by the stakeholders.

6.2.2 Evaluation Criteria

Eighteen evaluation criteria were developed to assess the ability of the six Target C alternatives to meet planning objectives in a cost effective manner. Each criterion is described below.

Cost

Capital Cost

(quantitative, dollars)

Capital cost includes the cost of constructing best management practices. Cost estimates are based on unit costs (per gallon, per acre, etc.), are planning-level, and do not account for economies of scale or specific local conditions.

Operations and Maintenance (O&M)

(quantitative, 2003 dollars per year)

O&M cost is the annual cost to maintain the set of BMPs over an appropriate design life. A design life of 20 years is assumed if no specific information is available. When a dollar cost for O&M is not readily available in the literature or local experience, O&M is assumed to be a reasonable percentage of construction cost.

Stream Habitat and Aquatic Life

Peak Stream Velocity

(quantitative, % reduction)

This criterion is based on the maximum stream velocity generated in the SWMM model by the one-year synthetic rainfall record used for alternatives modeling. The percent reduction relative to existing conditions is recorded at the following model cross-sections: CC07986, CC13397, CC14215, CC23213, CC26523, CC33332, CC51627, EIC0639, and WIC0252. The number entered into EVAMIX is the average of the six cross-sections.

Groundwater Infiltration and ET

(quantitative, MG)

Infiltration and evapotranspiration that occur due to BMP addition are added throughout the watershed based on model results. Infiltration and evapotranspiration that occur over the land surface, outside of BMPs, are not included.

Stream Channels and Banks

Frequency of Bankfull Flow

(quantitative, years)

This criterion estimates the return interval of bankfull flow under existing conditions for each of the alternatives. Based on the known 50-year record of streamflow, 12 peak flow events with return intervals of 0.05 to 2 years were chosen. These storms were compiled into a synthetic rainfall record and run for each alternative. Frequency of bankfull flow was estimated through a regression of peak streamflow vs. the original return period under existing conditions.

Flooding

Peak Flood Stage (3 criteria for the 3 locations)

(quantitative, peak stage in feet above city datum)

Three cases were chosen where a bridge deck is located in the 10-year floodplain as defined by FEMA. A storm was identified that just inundates the bridge decks under existing conditions. Each alternative was modeled using the storm, and peak stage was recorded.

Reduction in Peak Streamflow

(quantitative, % reduction)

This criterion is based on the maximum streamflow generated in the SWMM model by the one-year synthetic rainfall record used for alternatives modeling. The percent reduction relative to existing conditions is recorded at the following model cross-sections: CC07986, CC13397, CC14215, CC23213, CC26523, CC33332, CC51627, EIC0639, and WIC0252. The number entered into EVAMIX is the average of the six values.

Water Quality and Pollutant Loads

Annual Average Fecal Coliform Load

(quantitative, col/year)

This criterion measures the estimated annual input of fecal coliform to the stream system from all sources. Fecal coliform is intended to act as a surrogate for a range of disease-causing microorganisms.

Annual Average TSS Load

(quantitative, lb/year)

This criterion measures the estimated annual input of total suspended solids to the stream system from all sources. TSS is intended to act as a surrogate for a range of pollutants, including metals such as copper, lead, and zinc.

Stream Corridors

Area of Wetlands Created

(quantitative, acres)

The creation of wetlands is considered a positive result. This criterion estimates created wetlands intended mainly for stormwater and CSO treatment.

Feasibility

Technical Implementability

(Qualitative; High/Medium/Low)

This qualitative criterion uses the following scoring approach.

High	The technologies in the alternative have been widely and successfully applied. Several local contractors will have experience with the technologies.

Medium	The technologies have been successfully applied in other cities or have been successfully demonstrated locally. At least one local contractor will have experience with the technologies. (“Medium” may also be appropriate for an alternative with a mix of technologies classified as “High” and “Low”).
Low	The technologies have been applied only in pilot or demonstration programs and only in a few places. It may be impossible to find a local contractor with experience.

Length of Time to Implement

(Qualitative; High/Medium/Low)

This qualitative criterion uses the following scoring approach.

High	The technologies in the alternative can be implemented in 2 years or less.
Medium	The technologies can be implemented in 2 to 5 years, or the alternative contains a mix of “High” and “Low” technologies.
Low	The technologies take more than 5 years to implement.

Feasibility Within the Legal Structure

(Qualitative; High/Low)

This qualitative criterion uses the following scoring approach.

High	Existing laws require or provide an incentive for implementation. For example, measures proposed may overlap with the “six minimum controls” required by NPDES Phase II regulations.
Low	Existing laws do not affect or provide disincentives for different aspects of the plan.

Social/Political Support

(Qualitative; High/Low)

This qualitative criterion uses the following scoring approach.

High	Overall, the measures proposed will be seen as positive by a majority of stakeholders (citizens, local governments, and non-profits).
Medium	The measure has both positive and negative aspects.
Low	Overall, the measures proposed will be seen as negative by a majority of stakeholders (citizens, local governments, and non-profits).

Degree of Construction Disturbance

(Qualitative; High/Medium/Low)

The proposed BMP that causes the most disturbance will control the assignment of this criterion. Low construction disturbance is positive.

High	Construction will require removal of large amounts of pavement (streets, parking lots) and/or construction will significantly affect parking, movement of people and vehicles, and the noise level. Examples include porous pavement and installation of dry wells in sewer inlets.
Medium	Some pavement removal is required. Effects on parking, traffic patterns, and noise are moderate.
Low	Pavement removal is not required or is minimal. Effects on parking, traffic patterns, and noise are minimal. Rain barrels are one example.

Maintenance Required

(Qualitative; High/Medium/Low)

Low maintenance is positive.

High	Existing public programs, staff, and funding will not cover maintenance, or maintenance will be a large burden on private land owners. Or, frequent maintenance is absolutely critical to BMP effectiveness, as with rain barrels.
Medium	Private land owners will be responsible for minor maintenance chores (e.g., minor landscape maintenance for a bioretention basin that would have been a parking island anyway). Public agencies can handle maintenance with existing staff and budget, and/or will dedicate staff time to outreach, workshops, etc.

Low	Maintenance can be performed through existing programs and existing funding. For example, maintenance of RTC will be integrated into current sewer maintenance.

6.2.3 Criteria Weights

A workshop was held with the Technical Advisory Group for Cobbs Creek to obtain stakeholder input on the relative importance of each of the criteria used in the evaluation. Since the implementation plan consists of recommendations to the various potential partners for implementing a variety of BMPs, it was not necessary to reach consensus on the weights or to select one alternative for implementation. In fact, results for every weight set provided by the participating stakeholders were used in the analysis.

Table 6-3 shows the various weight sets used in the evaluation, as well as an average of all the weights. The weights show the range of priorities tested, and indicate that the various weights provide a good measure of the sensitivity of the results to differing opinions on the importance of each criterion.

Table 6-3 Criteria Weights

Criteria		Average	Stakeholder or Stakeholder Group											
			1	2	3	4	6	7	8	9	10	11	12	13
1	Construction Cost	15.1	20	15	15	25	10	20	3	5	25	30	10	20
2	Operations and Maintenance Cost	10.2	10	10	15	15	10	0	3	15	15	15	10	5
3	Peak Stream Velocity	4.6	9	5	5	1	4	5	1	10	2	10	10	7
4	Groundwater Infiltration	4.7	6	5	5	2	10	0	2	10	3	5	10	3
5	Frequency of Bankfull Flow	7.9	10	10	10	2	14	10	3	10	3	15	5	10
6	Frequency of Flooding	6.9	5	5	5	12	10	10	1	5	10	2	5	8
7	Peak Streamflow	4.3	3	5	5	3	4	0	9	5	5	2	5	2
8	TSS Load	8.4	4	15	5	4	7	30	1	5	5	2	5	6
9	Fecal Coliform Load	6.7	4	10	5	1	7	0	24	5	5	2	5	4
10	Wetland Creation	6.4	6	10	5	1	10	15	5	5	2	2	5	10
11	Technical Implementability	5.1	7	2	5	2	6	10	5	5	5	5	10	5
12	Length of Time to Implement	3.8	3	2	0	6	2	2	10	5	5	5	2	1
13	Feasibility within the Legal Structure	5.2	2	2	10	8	2	3	10	5	5	0	6	1
14	Social/Political Support	6.9	9	2	10	8	2	2	20	5	5	5	10	12
15	Degree of Construction Disturbance	3.8	3	2	0	10	2	3	5	5	5	0	2	6

Table 6-4 EVAMIX Criteria Scores and Result Summary

Criterion	Alternative	5	1	3	6	4	2
	Ave Rank	1.2	1.8	3.2	4.2	4.8	5.8
Capital Cost	$ (million)	36.0	7.1	7.4	19.7	13.8	75.8
Operations and Maintenance Cost	$/yr	5.31E+04	1.05E+05	5.40E+03	2.52E+05	2.25E+05	7.01E+06
Reduction in Peak Velocity	%	1.07	0.29	0.61	1.1	0.69	0.15
Infiltration and ET in BMPs	MG	374	83.2	96.9	211	86.1	83.2
Frequency of Bankfull Flow at Downstream USGS Gauge	Yr	0.39	0.35	0.35	0.35	0.35	0.33
Peak Flood Stage at Cr-Sec 1 (CC-05876)	Ft	17.0	17.3	17.4	17.2	17.4	17.2
Peak Flood Stage at Cr-Sec 2 (CC-13139)	Ft	27.5	27.8	27.9	27.8	27.8	27.7
Peak Flood Stage at Cr-Sec 3 (CC-14540)	Ft	30.7	30.9	31.0	30.8	31.0	30.9
Reduction in Peak Streamflow	%	5.1	2.2	1.4	3.8	1.3	2.8
Annual Average Fecal Coliform Load	#/yr	1.10E+16	7.78E+15	1.14E+16	1.15E+16	1.16E+16	9.32E+15
Annual Average TSS Load	lb/yr	2.65E+06	2.57E+06	2.72E+06	2.80E+06	2.75E+06	2.60E+06
Area of Treatment Wetland Created	Ac	50	25	50	25	50	25
Technical Implementability	L/M/H	H	H	H	M	M	H
Length of Time to Implement	L/M/H	H	L	L	M	M	M
Feasibility Within the Legal Structure	L/H	L	H	L	L	L	H
Social-political support	L/M/H	H	M	L	M	L	L
Degree of Construction Disturbance	L/M/H	H	L	L	M	L	M
Maintenance Required	L/M/H	L	L	M	M	M	H

6.3 Evaluation Results

Table 6-5 shows the scores assigned to each alternative and the units the scores represent across all criteria. The first row of the table shows the alternatives in order of their ranks, from most desirable to least desirable. The second row indicates the average rank that the alternative achieved using all of the weight sets provided by the stakeholders. In general, the results were consistent.

- **Highly Ranked:** Alternative 5 was ranked as the best for 10 of the thirteen stakeholder weight sets, and was ranked 2nd on three of the weight sets. Alternative 1 ranked 1st on three of the weight sets, and 2nd on all the others. These two were clearly the highest ranked alternatives, as evidenced by their average rankings.

- **Moderately Ranked:** Alternative 3 was either ranked as the 3rd best or 4th best alternative for all weight sets. Alternative 6 was very sensitive to the selected weight set, and was ranked anywhere for 3rd best to 6th best.

- **Lowest Ranked:** Alternative 4 ranked anywhere from 4th best to 6th, and was one of the less highly ranked alternatives. Alternative 2 was clearly the worst alternative, scoring 5th best for two weight sets, and 6th best (last) on all the others.

Table 6-8 shows the alternatives in order of preference, highest to lowest. The table presents a summary of the strengths and weaknesses of each of the alternatives.

Table 6-5 Alternative Evaluation Summary

Target C: Wet Weather Alternatives	Avg. Rank	Strengths	Weaknesses	Comments
Alt. 5: Stormwater BMPs: Focus on Public Property/Parking - bioretention in 50% of parking lots - porous pavement in 50% of parking lots - dry wells in 40% of sewer inlets	1.23	Reductions in peak flow and peak velocities; significant recharge through porous pavement; favorable political/social climate	Relatively expensive; difficult to implement, with a long period of time to full implementation	Overall best ranked (first or second best using all weights). Indicates that main strength comes through high implementation of porous pavement
Alt.1 Real Time Control and Low-Cost Stormwater BMPs - RTC in combined areas - all feasible wetlands in separate-sewered areas - rain barrels on 25% of homes (sep. areas) - dry wells for 25% of homes (sep. areas) - bioretention in 5% of parking lots (sep. areas)	1.77	Lowest capital cost due to use of Real Time Control option; full implementation is relatively rapid; implementation relatively easy with low construction disturbance	Relatively little recharge; relatively low reduction in peak flow and peak velocity; relatively low fecal coliform/TSS removal; low implementation of wetland option	Overall, 2nd ranked alternative. Main strength comes from cost and ease of implementation. Use of private-based alternatives with limited treatment or storage means poorer ranking in water quality aspects.
Alt. 3: Low-Cost Stormwater BMPs throughout Watershed - all feasible wetlands - rain barrels on 25% of homes - dry wells for 15% of homes	3.23	Generally low cost (capital and O&M together); easy to implement; short time frame for implementation; minimal construction disturbance; full realization of wetland potential	Poor infiltration; poor peak flood and velocity reductions; weak political/social support	Mid-ranked alternative. Reliance on private sector solutions (dry wells, rain barrels) is low cost, but requires significant cooperation from citizens, thus harder to implement.
Alt. 6: A Mix of Stormwater BMPs - half of feasible wetlands - rain barrels on 20% of homes - dry wells for 10% of homes - bioretention in 25% of parking lots - porous pavement in 25% of parking lots - green roofs on 2% of buildings	4.15	Mid-range cost; good peak flow and velocity reduction; excellent reduction in TSS and fecal coliform	Relatively high O&M and capital costs; moderate to low feasibility; limited use of wetlands	BMP mixture, which would be done for practicality and to provide a variety of BMP approaches, results only in a moderately effective solution.

Alt. 4: Stormwater BMPs Focusing on Private Property - rain barrels on 25% of homes - dry wells for 25% of homes - green roofs on 2% of buildings	4.77	Full use of wetlands; limited construction disturbance	Poor reduction in peak flows, flooding, and peak velocity; poor infiltration; moderate to high cost; focus on private property implementation makes it harder to achieve full implementation	Relatively poorly ranked alternative across all weight sets
Alt 2: Structural Storage and Low-Cost Stormwater BMPs - tank storage for combined sewage - all feasible wetlands (separate-sewered areas) - rain barrels on 25% of homes (sep. areas) - dry wells for 25% of homes (sep. areas) - bioretention in 5% of parking lots (sep. areas)	5.85	Technically feasible; easy to implement within regulatory structure	Extremely high cost; fairly limited effect on peak stream flow and peak velocity; relatively poor reduction in fecal coliform and TSS	Ranked as poorest of the alternatives. Main drawbacks are high cost and limited water quality benefit.

6.4 General Conclusions

The alternatives analysis presented above is not meant to yield an exact scenario for implementation. Rather, the computerized option screening results, the extensive modeling of BMPs, and the evaluation of the alternatives for Target C were all designed to help with developing a cost-effective approach to management of the Cobbs Creek watershed. Each analysis yielded additional insight into approaches that are most applicable to the specific conditions found in the watershed. The general conclusions resulting from the various computer analyses are presented here. These conclusions form the basis for the recommended implementation plan provided in section 7.

The primary conclusion is that *no single approach can achieve all the goals and objectives. The use of Targets with associated management approaches and schedules is considered the most practical and efficient way to achieve the planning objectives.*

Target A and Target B have specific measures that must be implemented, and full achievement of the targets is envisioned. For Target C, no single option or BMP is sufficient, and none are clearly superior to all others. This indicates that flexibility, “seeing what works where, and adjusting”, is probably the best approach to implementation. A mixed approach (not having a plan to implement certain BMPs as a primary approach), however, appears to lead to only moderately successful alternatives.

Some general conclusions are:

- Alternatives that rely on the use of public property provide more ability to control implementation than those that rely on private property.
- Private property BMPs (rain barrels, residential dry wells) can be effective and low cost, if reasonable levels of implementation and regular maintenance can be achieved.
- Porous pavement and parking lot options are extremely effective at meeting Target C objectives for infiltration.
- Real time control is an attractive option for the CSO areas of Cobbs Creek because it is effective and low cost.
- Structural controls such as large retention tanks for CSO control are a poor choice in terms of cost-effectiveness and effectiveness at restoring lost resources.
- Placing BMPs in CSO areas tends to maximize their effectiveness when compared to the same BMP in a separate sewered area. This is shown by the lower cost-per-gallon of stormwater treated in CSO areas.
- Use of wetlands for stormwater treatment is both effective and relatively inexpensive.
- Regional basins (infiltration, wet retention) can be cost-effective but are probably not feasible on a large scale in the Cobbs Creek watershed due to space constraints.
- There are larger differences in cost-effectiveness when considering implementation in CSO areas vs. implementation in separate-sewered areas when ET and/or infiltration are minor components of the BMP (e.g., dry wells in sewer inlets, residential dry wells, sand filters). These low ET/infiltration BMPs are more effective when placed in CSO areas rather than in separate sewered areas.
- Because there is generally a greater load and volume reduction per dollar spent in CSO areas, pollution trading options may be an interesting implementation approach to consider.

Section 7: Implementation Guidelines

This section presents the plan for implementation of those water management options that were identified by the Darby-Cobbs Watershed Partnership as best meeting the planning goals and objectives under the site specific conditions of Cobbs Creek. Following extensive screening and evaluation, only those options that are cost-effective and feasible under the specific conditions found in the Cobbs Creek watershed are included in the implementation plan. The section starts with summary tables of the recommended options, organized by the level of government or agency responsible for carrying out the recommendation under current regulations. More detailed information on each recommended option is then presented for each of the three targets.

Summary Tables

The summary section first presents the options in tables. A separate table was made presenting recommended actions for PADEP, Montgomery County, Philadelphia, watershed municipalities, and other stakeholders. Tables indicate which options are the responsibility of that agency or level of government for each of the three targets. In the following sections, more detailed information about recommended options is presented, organized in groups under each of three water management targets. Each option is first presented in a summary table format (what, who, where, and when), followed by text and figures that further describe the option and the implementation approach being recommended.

PADEP Actions

Action	Where	When
Industrial Stormwater Pollution Prevention	Industrial sites	Short-term
Construction Stormwater Pollution Prevention	Construction sites	Short-term
Pollution Trading	To be determined	Long-term
Use Review and Attainability Analysis	To be determined	Short-term
Stewardship/Advocacy of Watershed Management Plan	Watershed-wide	Short-term
Watershed-Based Permitting	Watershed-wide	Medium-term
Monitoring and Reporting	Watershed-wide	Ongoing

Philadelphia Actions

Action	Where	When
Pet Waste, Litter, and Dumping Ordinances	Watershed-wide	Short-term
Public Education	Watershed-wide	Short-term
School-Based Education	All schools	Short-term
Public Participation and Volunteer Programs	Watershed-wide	Short-term
Inspection and Cleaning of Combined Sewers	Watershed-wide	Short-term
Combined Sewer Rehabilitation	Combined-Sewered Areas	Medium-term
Stream Cleanup and Maintenance	Cobbs Creek within or along City boundary	Short-term
Enhancing Stream Corridor Recreational and Cultural Resources	Along the stream corridor	Medium-term
Bed Stabilization and Habitat Restoration	Cobbs Creek 40%, West Indian Creek 44%	Short-term
Bank Stabilization and Habitat Restoration	Middle section of Cobbs Creek	Short-term
Channel Realignment and Relocation	Cobbs Creek, East and West Indian Creek	Short-term
Plunge Pool Removal	CSO and stormwater outfalls	Short-term
Improvement of Fish Passage	Woodland Avenue dam	Short-term
Wetland Creation	Riparian corridor	Short-term
Invasive Species Management	Riparian corridor	Short-term
Reforestation	Riparian corridor	Short-term
Requiring Better Site Design in Redevelopment	Watershed-wide	Short-term
Stormwater and Floodplain Management	Watershed-wide	Short-term
Post-Construction Stormwater Runoff Management	Municipalities required to do Phase II permit	Short-term
Sanitary Sewer Overflow Detection	Separate-Sewered Areas	Short-term
Sanitary Sewer Overflow Elimination: Structural Measures	Separate-Sewered Areas	Medium-term
CSO Control Program	Philadelphia combined sewer system	Short-term
Catch Basin and Storm Inlet Maintenance	All inlets	Short-term
Street Sweeping (Philadelphia Streets Department)	Streets and Parking Lots	Short-term
Responsible Landscaping on Public lands	Green space	Short-term
Responsible Bridge and Roadway Maintenance	Roadways and bridges	Short-term
Reducing Effective Impervious Cover through Better Site Design	Watershed-wide	Long-term
Increasing Urban Tree Canopy	Watershed-wide	Medium-term
Porous Pavement and Subsurface Storage	Parking lots watershed-wide	Long-term
Green Rooftops	Appropriate public buildings chosen by PWD	Medium-term
Capturing Roof Runoff in Rain Barrels or Cisterns	Homes where dry wells are not feasible	Medium-term
Maintaining/Retrofitting Existing Stormwater Structures	Watershed-wide	Short-term
Retrofitting Existing Sewer Inlets with Dry Wells	Inlets in combined-sewered areas	Long-term
Residential Dry Wells, Seepage Trenches, and Water Gardens	Homes and schools watershed-wide	Long-term
Bioretention Basins and Porous Media Filtration	Watershed-wide	Long-term
Treatment Wetlands: Onsite and Regional	Riparian corridor	Medium-term
Monitoring and Reporting	Watershed-wide	Ongoing

Delaware and Montgomery County Municipality Actions

Action	Where	When
On-Lot Disposal (Septic System) Management	All areas with septic systems	Short-term
Pet Waste, Litter, and Dumping Ordinances	Watershed-wide	Short-term
Public Education	All Cobbs Creek municipalities	Short-term
School-Based Education	All schools	Short-term
Public Participation and Volunteer Programs	All Cobbs Creek municipalities	Short-term
Capacity Management Operation and Maintenance	Separate-Sewered Areas	Short-term
Inspection and Cleaning of Sanitary Sewers	Separate and Combined Sewered Areas	Short-term
Sanitary Sewer Rehabilitation	Separate-Sewered Areas	Medium-term
Illicit Discharge, Detection, and Elimination (IDD&E)	All areas with a storm or combined sewer.	Short-term
Stream Cleanup and Maintenance	Cobbs Creek within or along City boundary	Short-term
Enhancing Stream Corridor Recreational and Cultural Resources	Along the stream corridor	Medium-term
Bed Stabilization and Habitat Restoration	Cobbs Creek 40%, West Indian Creek 44%	Short-term
Bank Stabilization and Habitat Restoration	Middle section of Cobbs Creek	Short-term
Channel Realignment and Relocation	Cobbs Creek, East and West Indian Creek	Short-term
Plunge Pool Removal	CSO and stormwater outfalls	Short-term
Improvement of Fish Passage	Woodland Avenue dam	Short-term
Wetland Creation	Riparian corridor	Short-term
Invasive Species Management	Riparian corridor	Short-term
Reforestation	Riparian corridor	Short-term
Requiring Better Site Design in Redevelopment	Watershed-wide	Short-term
Stormwater and Floodplain Management	Watershed-wide	Short-term
Post-Construction Stormwater Runoff Management	Municipalities required to do Phase II permit	Short-term
Sanitary Sewer Overflow Detection	All areas with separate sewers	Ongoing program
Reduction of Stormwater Inflow and Infiltration to Sanitary Sewers	Separate-Sewered Areas	Medium-term
Catch Basin and Storm Inlet Maintenance	All inlets	Ongoing program
Street Sweeping	Streets and Parking Lots	Short-term
Responsible Landscaping on Public lands	Green space	Short-term
Responsible Bridge and Roadway Maintenance	Roadways and bridges	Short-term
Reducing Effective Impervious Cover through Better Site Design	Watershed-wide	Long-term
Increasing Urban Tree Canopy	Watershed-wide	Medium-term
Porous Pavement and Subsurface Storage	Parking lots watershed-wide	Long-term
Capturing Roof Runoff in Rain Barrels or Cisterns	Homes where dry wells are not feasible	Medium-term
Maintaining/Retrofitting Existing Stormwater Structures	Watershed-wide	Short-term
Residential Dry Wells, Seepage Trenches, and Water Gardens	Homes and schools watershed-wide	Long-term
Bioretention Basins and Porous Media Filtration	Watershed-wide	Long-term
Treatment Wetlands: Onsite and Regional	Riparian corridor	Medium-term
Monitoring and Reporting	Watershed-wide	Ongoing

7.1 Target A: Dry Weather Water Quality and Aesthetics

Regulatory Approaches

AR1 On-Lot Disposal (Septic System) Management
AR2 Pet Waste, Litter, and Dumping Ordinances

Public Education and Volunteer Programs

AP1 Public Education
AP2 School-Based Education
AP3 Public Participation and Volunteer Programs

Municipal Measures

AM1 Capacity Management Operation and Maintenance (CMOM)
AM2 Inspection and Cleaning of Combined Sewers
AM3 Sanitary Sewer Rehabilitation
AM4 Combined Sewer Rehabilitation
AM5 Illicit Discharge, Detection, and Elimination (IDD&E)
AM6 Stream Cleanup and Maintenance

AO1 Enhancing Stream Corridor Recreational and Cultural Resources

AMR Monitoring and Reporting

7.1.1 Regulatory Approaches

On-Lot Disposal (Septic System) Management (AR1)
Related goals: 5, 6
Related Indicators: 7, 11, 19, 20

What	Who	Where	When
Septic tank management program required as part of the municipality's Official Act 537 Sewage Facilities Plan	Municipalities through state certified Sewage Enforcement Officers (SEO) • All Act 537 plans are outdated and should be updated with exception of Lower Merion Township	All areas with septic systems; See Table 7-1	Within next 5 years;

Septic tank management programs are presently required of all Pennsylvania municipalities as part of their Official Act 537 Sewage Facilities Plans. Keeping these plans up to date, including provisions related to operation and maintenance of on-lot sewage disposal systems (OLDS) is an important means of controlling the release of pathogens and nutrients within the watershed.

The Pennsylvania Sewage Facilities Act (Act 537) requires that all Commonwealth municipalities develop and implement comprehensive official plans that provide for resolution of existing sewage disposal problems, provide for future sewage disposal needs of new land development, and provide for future municipal sewage disposal needs (See Section 1). When a municipality adopts a plan, the plan is submitted for review and approval by the Pennsylvania Department of Environmental Protection (PADEP). By regulation, the planning process is not final until an Act 537 Plan has been approved by PADEP. Municipalities are required to revise (unless they are exempt from revising) the "Official Plan" if a new land development project is proposed or if unanticipated conditions or circumstances arise, making the base plan inadequate. There are two basic types of plan changes. "Plan revisions" resulting from new land development are completed using "planning modules" that are specific to individual projects. An "update revision" is used by municipalities to make broad changes to their Official Plan.

Act 537 planning has been a municipal requirement since July 1, 1967. Legally, all municipalities have an Act 537 Plan; however, some plans are newer and more detailed than others. A list of municipalities within the Cobbs Creek Watershed indicating the age and status of their Act 537 Plans is presented in Table 7-1 below. Note that all municipalities have outdated plans, with the possible exception of Lower Merion Township and the City of Philadelphia. Municipalities are shown in Figure 7-1.

Table 7-1 Act 537 Plans in Cobbs Creek Watershed

Municipality	County	Plan Approval Date	Status
Colwyn Borough	Delaware	1/1/1972	> 20 years; update in progress
Darby Borough	Delaware	1/1/1972	> 20 years; update in progress
East Lansdowne Borough	Delaware	1/1/1972	> 20 years; update in progress
Haverford Township	Delaware	1/1/1972	> 20 years; update in progress
Lansdowne Borough	Delaware	1/1/1972	> 20 years; update in progress
Lower Merion Township	Montgomery	6/16/1998	Plan between 5 and 10 years old
Millbourne Borough	Delaware	1/1/1972	> 20 years; update in progress
Narberth Borough	Montgomery	1/1/1973	> 20 years
Philadelphia	Philadelphia	11/10/1993	Plan between 5 and 10 years old
Radnor Township	Delaware	1/1/1974	> 20 years; update in progress
Upper Darby Township	Delaware	3/1/1975	> 20 years; update in progress
Yeadon Borough	Delaware	1/1/1972	> 20 years; update in progress

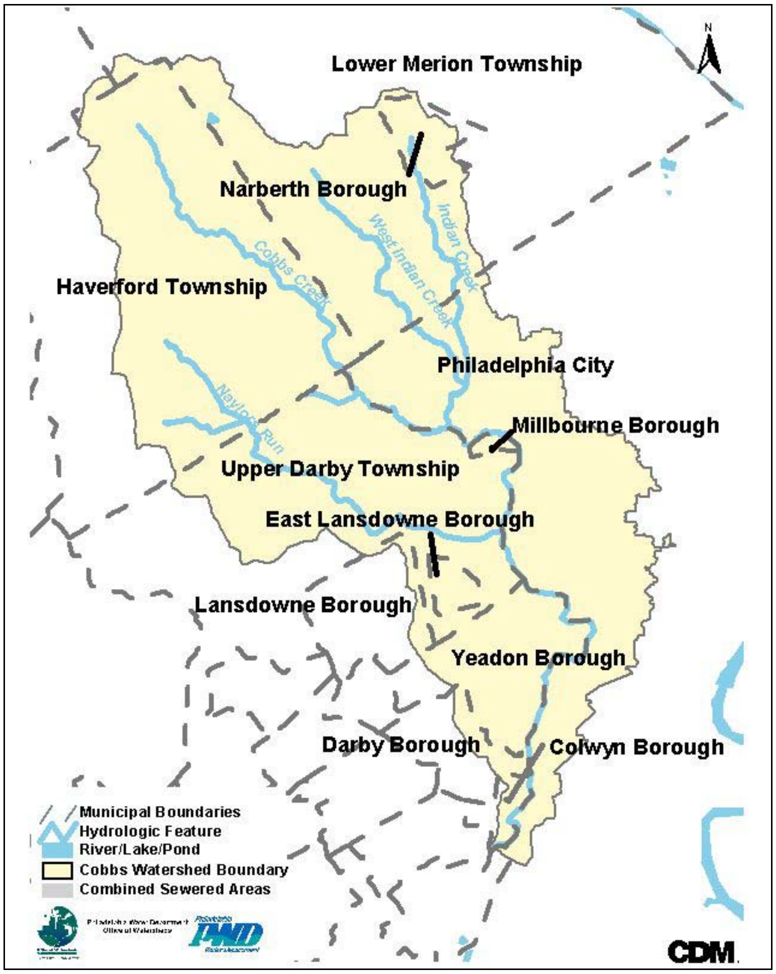


Figure 7-1 Cobbs Watershed Municipalities

Relevant Provisions of Act 537

- All municipalities must develop and implement an official sewage plan that addresses their present and future sewage disposal needs. Local agencies are required to employ both primary and alternate Sewage Enforcement Officers (SEO) responsible for overseeing the daily operation of that agency's OLDS permitting program.

- Local agencies, through their SEO, approve or deny permits for construction of on-lot sewage disposal systems prior to system installation. The SEO is responsible for conducting soil profile testing, percolation testing, OLDS design review, and approving or denying OLDS permit applications.

- Local agencies, through their SEO, must manage the permitting program for individual on-lot disposal systems and community on-lot systems with design flows of 10,000 gallons-per-day or less.

- Municipalities are required to assure the proper operation and maintenance of sewage facilities within their borders.

Municipalities should maintain information on the location, type and operational status of existing sewage facilities, as well as results of sanitary surveys. This information, however, is often incomplete. Septic tank data were included in the U.S. census through 1990, but were believed to be inaccurate and were not included in the 2000 census. County health departments may have information, and assessments have been attempted through voluntary questionnaires submitted by municipalities. These tasks have proven to be difficult but can be completed through perseverance.

Implementation of a Comprehensive Septic Tank Management Program

Each municipality shown in the above table should update its Act 537 plan in the coming 5-year period.

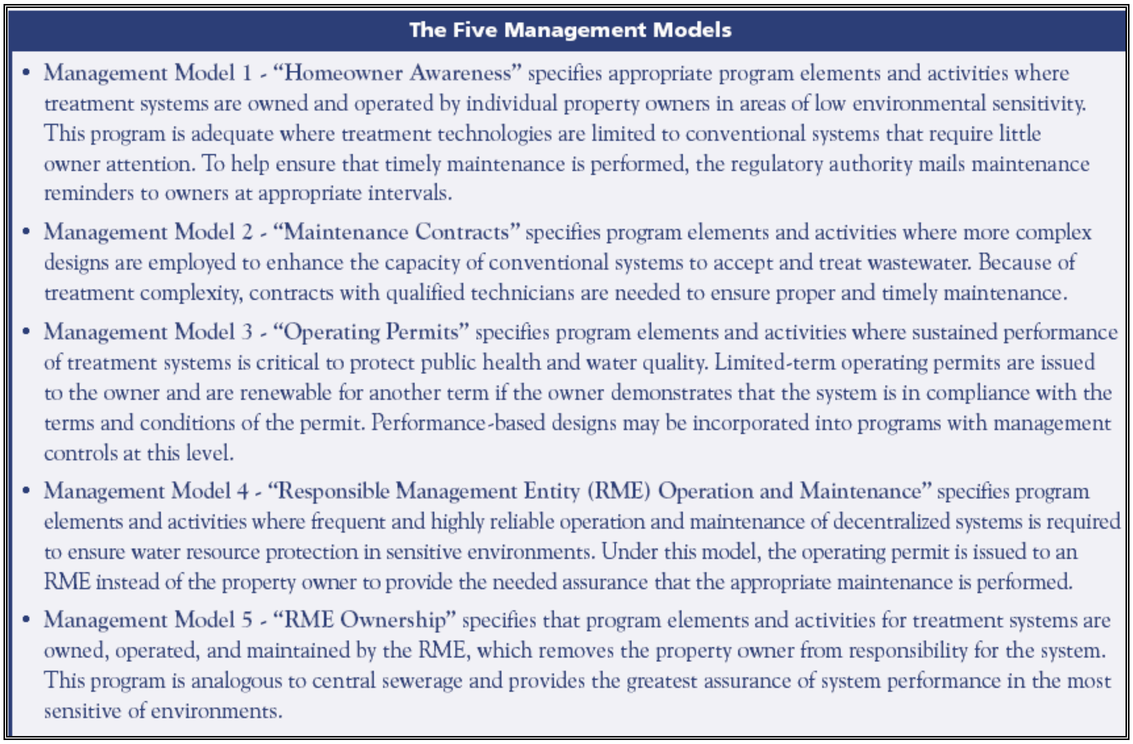
Table 7-2 below presents 1990 census sanitary survey results along with the area within the Cobbs Creek Watershed for Delaware County Municipalities. Implementation of septic system management programs should be actively pursued in municipalities that have a large estimated number of septic systems and a high percentage of their total area within the watershed: Haverford Township, Upper Darby Township, and Yeadon Borough.

Table 7-2 Septic System Data from 1990 Census

Municipality	Area (Acres)	Area in Watershed (Acres)	Percent of Area in Watershed (Acres)	Housing Units with Public Sewer	Housing Units with Septic Systems	Total Housing Units Occupied
Colwyn borough	164	96	58.60%	970	0	924
Darby borough	522	140	26.80%	4027	8	3709
East Lansdowne borough	132	132	100.00%	999	0	961
Haverford township	6406	3873	60.50%	17942	250	17727
Lansdowne borough	753	111	14.70%	5092	11	4917
Lower Merion township	15265	2375	15.60%			
Millbourne borough	44	44	100.00%	405	4	379
Narberth borough	316	268	84.90%			
Philadelphia city	91287	3562	3.90%			
Radnor township	8811	32	0.40%	9568	1013	9838
Upper Darby township	4824	2700	56.00%	33925	137	32746
Yeadon borough	1032	910	88.20%	1973	40	4794

The implementation of comprehensive septic tank management programs in those three municipalities ideally will be consistently designed to provide degrees of protection based on an assessment of the environmental sensitivity of the area.

The EPA has recently issued Voluntary National Guidelines for Management of Onsite and Clustered Wastewater Treatment Systems (EPA 832-B-03-001), covering all aspects of a comprehensive program, from design, inspection, and enforcement to public education and long-term planning. This document presents several different management models to choose from; division of responsibility and ownership between private land owners and public agencies varies between the different models. Municipalities should select that approach which best suits their conditions.



The Five Management Models

- Management Model 1 - "Homeowner Awareness" specifies appropriate program elements and activities where treatment systems are owned and operated by individual property owners in areas of low environmental sensitivity. This program is adequate where treatment technologies are limited to conventional systems that require little owner attention. To help ensure that timely maintenance is performed, the regulatory authority mails maintenance reminders to owners at appropriate intervals.
- Management Model 2 - "Maintenance Contracts" specifies program elements and activities where more complex designs are employed to enhance the capacity of conventional systems to accept and treat wastewater. Because of treatment complexity, contracts with qualified technicians are needed to ensure proper and timely maintenance.
- Management Model 3 - "Operating Permits" specifies program elements and activities where sustained performance of treatment systems is critical to protect public health and water quality. Limited-term operating permits are issued to the owner and are renewable for another term if the owner demonstrates that the system is in compliance with the terms and conditions of the permit. Performance-based designs may be incorporated into programs with management controls at this level.
- Management Model 4 - "Responsible Management Entity (RME) Operation and Maintenance" specifies program elements and activities where frequent and highly reliable operation and maintenance of decentralized systems is required to ensure water resource protection in sensitive environments. Under this model, the operating permit is issued to an RME instead of the property owner to provide the needed assurance that the appropriate maintenance is performed.
- Management Model 5 - "RME Ownership" specifies that program elements and activities for treatment systems are owned, operated, and maintained by the RME, which removes the property owner from responsibility for the system. This program is analogous to central sewerage and provides the greatest assurance of system performance in the most sensitive of environments.

Pet Waste, Litter, and Dumping Ordinances (AR2) Related goals: 5, 6, 8, 9 Related Indicators: 7, 8, 9, 10, 11, 16, 17, 18, 19, 20			
What	Who	Where	When
Adopt and enforce ordinance to require the removal of pet waste by the animal's owner within the municipality; Adopt and enforce ordinance to prohibit littering and dumping within the municipality.	See Table 7-3 (may not identify all municipalities with ordinance)	Entire Watershed	within 5 years; update as needed

Some municipalities in the Cobbs Creek watershed have adopted an ordinance to address removal of pet waste by the animal's owner and an ordinance that prohibits littering and dumping. These ordinances tend to be similar in scope but vary in penalties. Table 7-3 shows the municipalities in the watershed that are known to have adopted pet waste and littering ordinances.

Table 7-3 Pet Waste and Littering Ordinances in the Cobbs Creek Watershed

Municipality	**Pet Waste Ordinance**	**Littering and Dumping Ordinance**
Colwyn Borough		
Darby Borough		
East Lansdowne Borough**		
Haverford Township	X	X
Lansdowne Borough	X	X
Lower Merion Township		X
Millbourne Borough		
Narberth Borough		
Philadelphia		
Radnor Township	X	
Upper Darby Township		
Yeadon Borough		

*** Note: Ordinances for East Lansdowne Borough were not reviewed for this analysis.*

Source: www.ordinance.com, Delaware Valley Regional Planning Commission

Municipalities currently without ordinances are strongly encouraged to adopt them within the next two years. As an example of possible ordinance language, the following excerpts from Haverford Township's pet waste ordinance and Lansdowne Borough's Littering and Dumping Ordinance appear below.

Pet Waste Ordinance	Littering and Dumping Ordinance
Haverford Township All excrement from animal(s) on the owner's property will be the responsibility of the owner of the offending animal to abate, and the owner shall clean the area of excrement on a daily basis. It shall be the duty of the owner of any animal to pick up and remove in its entirety any excrement from said animal from all public and private property. Excrement must not be deposited in a street or at a curbside, but must be removed from the area completely.	Lansdowne Borough The practice of throwing or dumping any discarded matter of any kind in or on any private or public property, vacant or occupied within the Borough of Lansdowne is prohibited. The practice of storing or depositing abandoned or junked vehicles, machinery, etc., in or on any public or private property, vacant or occupied is prohibited. The use or ownership of any unsafe or dangerous building or structure upon any public or private property, vacant or occupied, is prohibited. Driving or permitting the use of a motor vehicle that deposits its contents or other debris on any road within the Borough of Lansdowne is prohibited.

While pet waste and littering ordinances are enacted primarily for aesthetic purposes, reduction of pathogens and debris in stormwater, and thus in Cobbs Creek, can be reduced through their enforcement. Municipalities can assist residents in abiding by ordinances by placing trash cans in areas with higher pedestrian traffic. Plastic bags should be provided with trash cans in areas heavily used by dog owners. Homeowners' associations should also be asked to notify residents of these ordinances and to provide trash cans and plastic bags in those neighborhoods as well.

7.1.2 Public Education and Volunteer Programs

Public Education (AP1) Related Goals: 7, 8, 9, 10 Related Indicators: 16, 17, 18, 19, 20, 21			
What	Who	Where	When
Public Education Plan Educational Program Implementation	Municipalities on the Phase II List (see Table 7-4)	All municipalities in the Cobbs Creek Watershed	Short-term: first 5 years coinciding with the stormwater permit (See Table 7-5)

Public education about watershed management is an integral part of the watershed implementation plan. It is designed to educate citizens on the importance of the watershed to the community, and on ways that individual behavior can impact water quality and the riparian and aquatic environment associated with Cobbs Creek. In accordance with the Cobbs Creek Plan's stated purpose of integrating various existing programs, and to avoid duplication of effort, the recommended implementation plan follows the Stormwater Management Program Protocol ("Protocol") to meet the six Minimum Control Measures required of municipal permittees under Phase II NPDES Stormwater Regulations (found at 40 CFR §§ 122.26 – 123.35). In this way, implementation of these public education measures by municipalities will satisfy federal NPDES permit requirements for municipal separate storm sewer systems ("MS4s"), described in detail at 40 CFR §122.34.

Table 7-4 lists the municipalities that should work together with the City of Philadelphia on Public Education about watershed management issues. Assuming that a single, watershed-wide public education campaign focusing on all three targets (A, B, and C) can be implemented, PWD should, at a minimum, work with Haverford Township, Upper Darby Township, and Lower Merion Township to cover most of the watershed.

Table 7-4 Cobbs Creek Municipalities on Phase I or II Stormwater List

Municipality	County	% of Muni. Area Drained by Watershed	% of Watershed within Muni.
Colwyn Borough	Delaware	55%	1%
Darby Borough	Delaware	17%	1%
E. Lansdowne Borough	Delaware	100%	1%
Haverford Twshp.	Delaware	59%	26%
Lansdowne Borough	Delaware	9%	<1%
Millbourne Borough	Delaware	100%	<1%
Radnor Twshp.	Delaware	1%	<1%
Upper Darby Twshp.	Delaware	50%	18%
Yeadon Borough	Delaware	85%	6%
Lower Merion Twshp.	Montgomery	18%	19%
Narberth Borough	Montgomery	92%	2%
City of Philadelphia	Philadelphia	4%	26%

Public Education Plan

PWD and the primary watershed municipalities should jointly develop a public education plan. The public education plan must target homeowners, business owners, and developers, focusing on connections between their actions, stormwater runoff, and water quality. By the end of Year 1, cooperating municipalities should have a comprehensive plan in place that will help tap into the target audiences' existing communication channels to inform them about improving stormwater quality. During the following permit years, municipalities should monitor the effectiveness of the plan, and update it to ensure information about the target audiences is accurate.

PADEP has made available a template for a public education plan, available on the PADEP website, www.dep.state.pa.us, directLINK "stormwater". The plan should include an approach to collecting information on the three target audience categories. Municipalities should create a comprehensive inventory of the newsletters, newspapers, web sites, meetings, magazines, organizations, associations, etc. used by the target audiences. Cooperation of the municipalities under the Cobbs Creek Watershed Plan in gathering this information should help eliminate redundancy of effort. During the remaining years of the stormwater permit, municipalities are responsible for ensuring that information in the public education plan is accurate and current.

In addition to the PADEP mandated information, other information relevant to watershed management should be included on topics such as:

- Improper Disposal to Storm Drains
- Automobile Maintenance
- Car Washing
- Animal Waste Collection
- Restorative Redevelopment: Public Education Aspects

Public Education Implementation

Once the public education plan is developed, it must be implemented. This means distributing educational materials provided by PADEP that contain messages related to watershed (and stormwater) management. Municipalities can find educational materials needed to implement the educational program on the PADEP website, www.dep.state.pa.us, directLINK "stormwater."

To fulfill NPDES stormwater permit requirements, municipalities should implement two phases of educational outreach. During the first stage, the focus is on raising the awareness of target audiences. In the second stage, municipalities should aim to educate the target audiences about the problems and potential solutions. PADEP presents requirements in the stormwater permit for the "what" and "when" of this minimum measure component, but it does not specify the "how." Municipalities should use their Public Education Plan to determine the most effective means of getting educational materials into the hands of target audiences. Any additional educational activities should show compliance with this Minimum Control Measure. This includes educational activities by watershed groups, and certainly should make use of the existing Cobbs Creek Partnership activities.

In Year 1, municipalities are required to start raising target audience awareness. Raising awareness can be accomplished by use of PADEP materials. PADEP has made available copies of the pamphlet entitled, "When It Rains, It Drains" (available on the PADEP website, www.dep.state.pa.us, directLINK "stormwater)." This document addresses the issue of pollution related to stormwater runoff and activities that citizens can use to improve stormwater quality. It also provides an overview of a typical stormwater management program. Using the information on distribution channels in the Public Education Plan, municipalities should disseminate these pamphlets to all the target audience categories in the community.

In Year 2, municipalities should begin to educate all the target audiences. This includes distributing fact sheets to developers about their responsibilities under the state and federal stormwater regulations. To meet this requirement, municipalities should distribute the Fact Sheets prepared by PADEP, and run a stormwater ad in local newspapers.

In addition to targeting developers, municipalities may distribute posters to schools, community organizations and institutions, and businesses. Topics such as responsible vehicle maintenance, household hazardous waste disposal, and pet waste management are important to stormwater management. PADEP has developed a series of posters that convey messages about these topics.

Another useful measure is storm drain stenciling. While not required by the Protocol, any stenciling done by outside organizations may contribute to meeting permit requirements for this Minimum Control Measure.

Public education directors should check any links to PADEP's stormwater website and update the links if necessary.

In Years 3-5, the implementation continues. This consists mainly of continuing with distribution of posters and fact sheets, and running additional ads in local newspapers.

The schedule for developing and implementing the plan to meet Phase II stormwater requirements is shown in Table 7-5 below.

Table 7-5 Schedule for Implementation of the Public Education Program

PERMIT YEAR		
	Education Plan	**Educational Program**
Year 1	Determine Target Audience Develop Public Education Plan Raise Target Audience Awareness	• Disseminate materials to all target audiences using appropriate distribution channels • Newspaper advertisement • Other components of Plan
Years 2-5	Implement the plan Revise Plan as needed	• Disseminate materials to all target audiences using appropriate distribution channels • Newspaper advertisement • Other components of Plan

Source: PADEP MS4 Stormwater Management Program Protocol, 2003

School-Based Education (AP2) Related Goals: 8, 9 Related Indicators: 17, 18, 21			
What	Who	Where	When
Implement PA Environmental Education Curriculum; engage schoolchildren and watershed protection through resources such as Cobbs Creek Community Environmental Education Center and the John Heinz Wildlife Refuge at Tinicum.	School districts, supported by municipal governments and non-profits	All schools	Short-term (within 5 years)

Besides requirements found in the MS4 Stormwater Management Program Protocol, another important aspect of public education is to reach children through school curricula.

School-based watershed education takes many forms, from lesson plans within the classroom, to hands-on activities outside of the classroom such as field trips to Cobbs and Darby creeks and nearby nature centers, as well conducting actual restoration projects. Teacher training programs, developed to assist teachers in bringing watershed concepts to their students, are critical, as are partnerships with groups like the Cobbs Creek Community Environmental Education Center Inc, and the John Heinz Wildlife Refuge at Tinicum. Being engaged in actual restoration projects, whether through service learning, after school clubs, or as part of lesson plans translates lessons into action.

Sources for lesson plans include the following:

- Incorporate the Pennsylvania Environmental Education Curriculum developed by PADEP into middle school curricula. This curriculum introduces concepts in watersheds, wetlands, stormwater, drinking water, and water and air pollution.
- Use local examples of watershed protection and restoration to enhance the program. The Cobbs Creek Community Environmental Education Center works with schools to provide watershed-based educational opportunities, including the Environmental Scholars Program, Tree Survey Project, Urban Watershed Program, Environmental Clubs, Learning Grove / Trail Development Project, Park Management Program, and Teacher Training Program.

Public Participation and Volunteer Programs (AP3) Related Goals: 4, 6, 7, 8, 9, 10 Related Indicators: 15, 10, 11, 12, 13, 14, 16, 17, 18, 21			
What	Who	Where	When
Public Participation Volunteer Monitoring and Storm Drain Stenciling	Municipalities	All municipalities in the Cobbs Creek Watershed	First 5 years coinciding with the stormwater permit.

Public participation is another facet of implementation that must follow the Stormwater Management Program Protocol (“Protocol”) to meet the six Minimum Control Measures required of municipal permittees under the Phase II NPDES Stormwater Regulations (found at 40 CFR §§ 122.26 – 123.35). The public must participate in issues related to municipal actions to address stormwater impacts on water quality. This includes new planning initiatives, changes to ordinances and other local regulations. This requirement overlaps the public participation aspects of the watershed management plan, and suggests that a unified and coordinated approach between municipalities would be efficient. All municipalities in the watershed (listed in Table 7-4) are required to have a public participation program.

Prior to adoption of any ordinance required under the PADEP Stormwater Protocol, municipalities must provide adequate public notice and opportunities for public review and input, and hold hearings to obtain public feedback. This can be done in conjunction with normal public sessions of the municipal governing body. The notice must be published in a local newspaper of general circulation. Involving citizen groups, watershed organizations and businesses as much as possible will obtain broad support for stormwater management efforts. The current Steering Committee for the Cobbs Creek Watershed Plan is an obvious example of such inclusion, and can help municipalities to meet this requirement.

Although the actual public participation requirements can be met by following guidelines for Act 167 planning, it is recommended that municipalities do more than the minimum. Some options for additional public participation are listed below.

- Develop a Public Involvement and Participation Plan: by the end of Year 1, a municipality may want to have a comprehensive plan in place that will guide your efforts to recruit volunteers and obtain participation at public meetings. This could be part of the Public Education Plan discussed above.

- Produce strategies for recruiting participation from six categories of stakeholders: municipal employees, homeowners, businesses, schools, watershed associations and other volunteer groups and developers.

- Develop a comprehensive stakeholder mailing list.

- Conduct Public Meetings: PADEP suggests using a general stormwater public meeting to kick-off public education and participation efforts. This has already been done for the Cobbs Partnership and Steering Committee, and municipalities are encouraged to make use of this. Invite representatives from all six stakeholder categories. It is important that all stakeholder interests have the opportunity to participate. Meeting agendas should include, but not be limited to, the overview presentation on the watershed management and stormwater program and time for questions from the audience.

An important aspect of public participation is the establishment of volunteer programs. There are many types of volunteer programs that can help manage stormwater and improve a community's water quality. The goal of the volunteer program is to obtain and sustain volunteer support that will aid watershed management efforts. To reach this goal, it is important to develop a program that reflects stakeholders' concerns and interests. Examples of volunteer programs are:

Volunteer Monitoring Program

Municipalities should determine which type of assessment the program will undertake and develop a study design using the manual entitled *Designing Your Monitoring Program: A Technical Handbook for Community-Based Monitoring in Pennsylvania* as the basis for planning and implementing your monitoring program (PADEP, 2001).

Storm Drain Stenciling Program

Municipalities should establish procedures for storm drain stenciling and organize volunteers to carry out the program. PADEP has provided resource materials in a References and Resources CD-ROM on developing and implementing a storm drain stenciling program.

Stream Cleanup and Restoration Activities

Citizen participation in stream cleanups is a good way to get the community involved in keeping the streams free of trash and debris. Stream cleanups can be coordinated with PWD's Waterways Restoration Unit. Other participatory activities can include support of riparian plantings during stream restoration activities.

7.1.3 Municipal Measures

Capacity Management Operation and Maintenance (CMOM) (AM1)
Related Goals: 1, 5, 6
Related Indicators: 7, 9, 11

What	Who	Where	When
Program to manage and maintain sewer systems; plans in place to track SSOs and overflow response plan.	Separate Sewered Municipalities	Separate Sanitary Sewer Areas	Medium term: 5+ years

CMOM programs are recommended for all areas with separate sanitary sewer systems and are an important component of Target A because they help prevent dry weather discharges. Recommendations in this section cover both the dry and wet weather aspects of the program; recommendations that are specific to SSO abatement are included here for completeness and are referred to under Target C. The recommendations in this section are adapted from the "Consensus Recommendation of the SSO Federal Advisory Subcommittee" published in October 1999.

(1) General Standards

- Properly manage, operate and maintain, at all times, all parts of collection system. Perform maintenance and inspections using techniques similar to those recommended for combined sewers in option AM2.
- Provide adequate capacity to convey base flows and peak flows for all parts of the collection system.
- Take all feasible steps to stop, and mitigate the impact of, sanitary sewer overflows in portions of the collection system.
- Provide notification to parties with a reasonable potential for exposure to pollutants associated with the overflow event.
- Develop a written summary of the CMOM program and make it, and the audit under section (5), available to any member of the public upon request.

(2) Management Program

Develop a capacity, management, operation and maintenance (CMOM) program to comply with the above general standards. If any element of this section is not appropriate or applicable for the CMOM program in question, it does not need to address the element, but a written summary must explain why that element is not applicable.

The management program should consist of the following six components.

1. Goals
The program must identify in detail the major goals of the CMOM program consistent with the general standards identified above.

2. Organization
A) Identify administrative and maintenance positions responsible for implementing measures in the CMOM program, including lines of authority by organization chart or similar document; and (B) establish the chain of communication for reporting SSOs from receipt of a complaint or other information to the person responsible for reporting to the NPDES authority.

3. Legal Authority
Include legal authority, through sewer use ordinances, service agreements or other legally binding documents, to:
(A) Control infiltration and connections from inflow sources;
(B) Require that sewers and connections be properly designed and constructed;
(C) Ensure proper installation, testing, and inspection of new and rehabilitated sewers (such as new or rehabilitated collector sewers and new or rehabilitated service laterals);
(D) Address flows from satellite municipal collection systems; and
(E) Implement the general and specific prohibitions of the national pretreatment program that you are subject to under 40 CFR 403.5.

4. Measures and Activities
The CMOM program must address the elements listed below that are appropriate and applicable to the sewer system and identify the person or position in the organization responsible for each element.
(A) Maintenance of facilities
(B) Maintenance of a map of the collection system
(C) Management of information and use of timely, relevant information to establish and prioritize appropriate CMOM activities, and to identify and illustrate trends in overflows.
(D) Routine preventive operation and maintenance activities
(E) Assessment of the current capacity of the collection system and treatment facilities
(F) Identification and prioritization of structural deficiencies and identification and implementation of short-term and long term rehabilitation actions to address each deficiency
(G) Appropriate training on a regular basis.
(H) Equipment and replacement parts inventories including identification of critical replacement parts.

5. Design and Performance Provisions
(A) Requirements and standards for the installation of new sewers, pumps and other appurtenances; and rehabilitation and repair projects.

(B) Procedures and specifications for inspecting and testing the installation of new sewers, pumps, and other appurtenances and for rehabilitation and repair projects.

6. Monitoring, Measurement and Program Modifications
Monitor the implementation and, where appropriate, measure the effectiveness of each element of the CMOM program. Program elements must be updated as appropriate based on monitoring or performance evaluations. The summary of the CMOM program should be modified as appropriate to keep it updated and accurate.

(3) Overflow Response Plan:

An overflow response plan should be developed and implemented that identifies measures to protect public health and the environment including, but not limited to, mechanisms to:

(i) ensure that all overflows are made aware of (to the greatest extent possible);

(ii) ensure that overflows are appropriately responded to, including ensuring that reports of overflows are immediately dispatched to appropriate personnel for investigation and appropriate response;

(iii) ensure appropriate reporting pursuant to 40 CFR 122.42(e).

(iv) ensure appropriate notification to the public, health agencies, and other impacted entities (e.g. water suppliers) pursuant to 40 CFR 122.42(h). The CMOM plan should identify the public health and other officials who will receive immediate notification.

(v) ensure that appropriate personnel are aware of and follow the plan and are appropriately trained; and

(vi) provide emergency operations.

(4) System Evaluation and Capacity assurance plan:

A plan should be prepared and implemented for system evaluation and capacity assurance if peak flow conditions are contributing to an SSO discharge unless either (1) already taken steps to correct the hydraulic deficiency or (2) the discharge meets the criteria of 122.42(g)(2). At a minimum the plan must include:

(i) **Evaluation**: Steps to evaluate those portions of the collection system which are experiencing or contributing to an SSO discharge caused by hydraulic deficiency or to noncompliance at a treatment plant. The evaluation should provide estimates of peak flows (including flows from SSOs that escape from the system) associated with conditions similar to those causing overflow events, provide estimates of the capacity of key system components, identify hydraulic deficiencies, including components of the system with limiting capacity and identify the major sources that contribute to the peak flows associated with overflow events.

(ii) **Capacity Enhancement Measures**: Establish short and long term actions to address each hydraulic deficiency including prioritization, alternative analysis, and a schedule.

(iii) **Plan updates**: The plan should be updated to describe any significant change in proposed actions and/or implementation schedule. The plan should also be updated to reflect available information on the performance of measures that have been implemented.

(5) CMOM Program Audits

As part of the NPDES permit application, an audit should be conducted, appropriate to the size of the system and the number of overflows, and a report submitted of such audit, evaluating the CMOM program and its compliance with this subsection, including its deficiencies and steps to respond to them.

(6) Communications

The permittee should communicate on a regular basis with various interested parties on the implementation and performance of its CMOM program. The communication system should allow interested parties to provide input to the permittee as the CMOM program is developed and implemented.

Inspection and Cleaning of Combined Sewers (AM2)
Related Goals: 6, 7, 10
Related Indicators: 11, 19

What	Who	Where	When
inspection activities routine maintenance, monitoring activities	PWD	Combined Sewered Areas (see Figure 7-2)	First 5 years coinciding with the stormwater permit.

Maintenance of sewers includes activities required to keep the system functioning as it was originally designed and constructed. Any reinvestment in the system, including routine maintenance, capital improvements for repair or rehabilitation, inspection activities, and monitoring activities are generally classified as maintenance.

An inspection program is vital to proper maintenance of a wastewater collection system. Without inspections, a maintenance program is difficult to design, since problems cannot be solved if they are not identified. Sewer inspections identify problems such as blocked, broken, or cracked pipes; tree roots growing into the sewer; sections of pipe that settle or shift so that pipe joints no longer match; and sediment and other material building up and causing pipes to break or collapse. The elements of an inspection program include flow monitoring, manhole inspections, smoke/dye testing, closed circuit television inspection, and private sector inspections. Private sector building inspection activities include inspection of area drains, downspouts, cleanouts, sump discharges and other private sector inflow sources into the system.

In addition to inspection, routine maintenance must also include sewer cleaning, root removal/treatment, cleaning of mainline stoppages, cleaning of house service stoppages, and inspections and servicing of pump stations.

PWD is responsible for implementation of this option in the combined sewer areas of the Cobbs Creek watershed, but municipalities with separate sewers should have similar permanent and active sewer maintenance programs in place under CMOM (see AM1). Figure 7-2 shows the areas where sanitary sewers and combined sewers exist. All municipalities in the watershed are responsible for sewer maintenance.

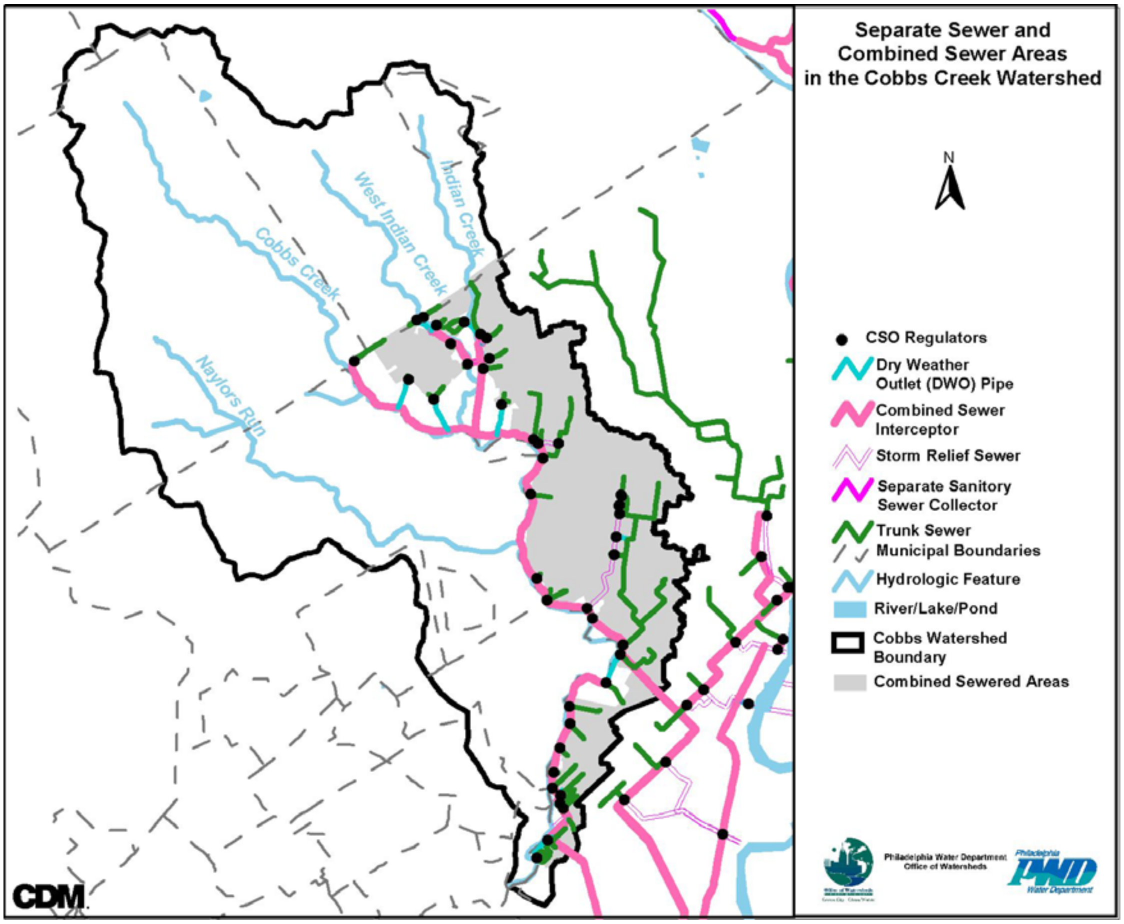


Figure 7-2 Separate Sewer and Combined Sewer Areas in Cobbs Creek

PWD has combined sewer maintenance responsibilities in the Cobbs Creek watershed. CSO regulations (the Nine Minimum Controls discussed in Section 1) have required that PWD carry out improved sewer maintenance. Some of the activities PWD is carrying out include the review and improvement of on-going operation and maintenance programs, and comprehensive inspection and monitoring programs to characterize and report overflows and other conditions in the combined sewer system.

Sanitary Sewer Rehabilitation (AM3) Related Goals:5, 6 Related Indicators:7, 11			
What	Who	Where	When
Perform major repairs or replacement on sections of sewer determined to be in poor condition.	All municipalities with separate sanitary sewer systems	All municipalities with separate sanitary sewer systems	Medium Term

The CMOM and sewer inspection programs discussed in previous sections may identify sections of sewer that are in poor condition and in need of major repair or replacement. This section is adapted from fact sheets provided on the EPA web site: http://www.epa.gov/owm/mtb/rehabl.pdf.

Under the traditional method of sewer relief, a replacement or additional parallel sewer line is constructed by digging along the entire length of the existing pipeline. While these traditional methods of sewer rehabilitation require unearthing and replacing the deficient pipe (the dig-and-replace method), trenchless methods of rehabilitation use the existing pipe as a host for a new pipe or liner. Trenchless sewer rehabilitation techniques offer a method of correcting pipe deficiencies that requires less restoration and causes less disturbance and environmental degradation than the traditional dig and-replace method.

Trenchless Sewer Rehabilitation Methods:

- Pipe Bursting, or In-Line Expansion
- Sliplining
- Cured-In-Place Pipe
- Modified Cross Section Liner

These alternative techniques must be fully understood before they are applied. These four sewer rehabilitation methods are described further in the following sections.

Pipe Bursting or In-Line Expansion

Pipe bursting, or in-line expansion, is a method by which the existing pipe is forced outward and opened by a bursting tool. The Pipebursting™ method, patented by the British Gas Company in 1980, was successfully applied by the gas pipelines industry before its applicability was identified by other underground utility agencies. Over the last two decades, other methods of in-line expansion have been patented as well. During in-line expansion, the existing pipe is used as a guide for inserting the expansion head (part of the bursting tool). The expansion head, typically pulled by a cable rod and winch, increases the area available for the new pipe by pushing the existing pipe radially outward until it cracks. The bursting device pulls the new pipeline behind itself.

Sliplining

Sliplining is a well-established method of trenchless rehabilitation. During the sliplining process, a new liner of smaller diameter is placed inside the existing pipe. The annular space, or area between the existing pipe and the new pipe, is typically grouted to prevent leaks and to provide structural integrity.

Cured-In-Place Pipe

During the cured-in-place pipe (CIPP) renewal process, a flexible fabric liner, coated with a thermosetting resin, is inserted into the existing pipeline and cured to form a new liner. The liner is typically inserted into the existing pipe through an existing manhole. The fabric tube holds the resin in place until the tube is inserted in the pipe and ready to be cured. Commonly manufactured resins include unsaturated polyester, vinyl ester.

Modified Cross Section Lining

The modified cross section lining methods include deformed and reformed methods, sewagelining™, and rolldown. These methods either modify the pipe's cross sectional profile or reduce its cross sectional area so that the liner can be extruded through the existing pipe. The liner is subsequently expanded to conform to the existing pipe's size. Another method of obtaining a close fit between the new lining and existing pipe is to temporarily compress the new liner before it is drawn through the existing pipeline. The sewagelining™ and rolldown processes use chemical and mechanical means, respectively, to reduce the cross-sectional area of the new liner.

External Sewer Rehabilitation Methods (adapted from EPA/600/R-01/034)

External rehabilitation methods are performed from the above ground surface by excavating adjacent to the pipe, or the external region of the pipe is treated from inside the pipe through the wall. Some of the methods used include:

External Point Repairs
Chemical Grouting (Acrylamide Base Gel, Acrylic Base Gel)
Cement Grouting (Cement, Microfine Cement, Compaction)

Internal Sewer Rehabilitation Methods
The basic internal sewer rehabilitation methods include:

Chemical Grouting

Internal grouting is the most commonly used method for sealing leaking joints in structurally sound sewer pipes. Chemical grouts do not stop leaks by filling cracks; they are forced through cracks and joints, and gel with surrounding soil, forming a waterproof collar around leaking pipes. This method is accomplished by sealing off an area with a "packer," air testing the segment, and pressure injecting a chemical grout for all segments which fail the air test. The three major types of chemical grout are: Acrylic, Acrylate, and Urethane.

Continuous Pipe

Insertion of a continuous pipe through the existing pipe (Polyethylene and Polypropylene)

Segmental

Short segments of new pipe are assembled to form a continuous line, and forced into the host pipe. Generally, this method is used on larger sized pipe and forced into the host pipe. (Polyethylene, Polyvinyl Chloride, Reinforced Plastic Mortar, Fiberglass Reinforced Plastic, Ductile Iron, Steel)

Fold and Form Pipe

This is similar to sliplining, except that the liner pipe is deformed in some manner to aid insertion into the existing pipe. Depending on the specific manufacturer, the liner pipe may be made of PVC or HDPE. One method of deforming the liner is to fold it into a "U" shape before insertion into the existing pipe. The pipe is then returned to its original circular shape using heated air or water, or using a rounded shaping device or mandrel. Ideally, there will be no void between the existing pipe and the liner pipe after expansion of the liner pipe with the shaping device. For the "U" shape liner, the resulting pipe liner is seamless and jointless.

Spiral Wound Pipe

This involves winding strips of PVC in a helical pattern to form a continuous liner on the inside of the existing pipe. The liner is then strengthened and supported with grout that is injected into the annular void between the existing pipe and the liner. A modified spiral method is also available that winds the liner pipe into a smaller diameter than the existing pipe, and then by slippage of the seams, the liner expands outward.

Combined Sewer Rehabilitation (AM4) Related Goals: 5, 6, 9, 10 Related Indicators: 7, 8, 9, 10, 11, 19, 20			
What	Who	Where	When
Perform major repairs or replacement on sections of sewer determined to be in poor condition.	PWD	Combined-Sewered Areas	Medium Term

Rehabilitation of combined sewers is conceptually similar to rehabilitation of separate sanitary sewers. Refer to option AM3 for information on specific techniques.

Illicit Discharge, Detection, and Elimination (IDD&E) (AM5)
Related Goals: 5, 6, 8, 9, 10
Related Indicators: 7, 8, 9, 10, 11, 16, 19, 20

What	Who	Where	When
IDD&E Program in conformance with Phase II Stormwater Permits and the LTCP for PWD.	All Municipalities required to do Phase II permit (see Table 7-4) PWD in CSO Areas	All areas with a storm sewer or combined sewer. See Figure 7-2	Five year program associated with stormwater permit. (See Table 7-7)

In accordance with the Cobbs Creek Plan's stated purpose of integrating various existing programs, and to avoid duplication of effort, the recommended implementation plan follows the Stormwater Management Program Protocol ("Protocol") to meets the six minimum control measures required of municipal permittees under the Phase II NPDES Stormwater Regulations (found at 40 CFR §§ 122.26 – 123.35). One of the six minimum controls is an IDD&E program. The IDD&E program can be summarized as consisting of the following steps:

- Develop map of municipal separate storm sewer system outfalls and receiving water bodies
- Prohibit illicit discharges via PADEP-approved ordinance
- Implement an IDD&E Program that includes 1) field screening program and procedures and 2) elimination of illicit discharges
- Conduct public awareness and reporting program (see under Public Education above)

A similar approach to controlling dry weather flows is being followed by PWD under the Long Term Control Plan (LTCP) for CSOs.

Each step is explained in more detail below.

Develop an Outfall Map

The federal regulations define an outfall as "a point source as defined by 40 CFR 122.2 at the point where a municipal separate storm sewer discharges to waters of the United States". A "point source" is defined as "any discernable, confined and discrete conveyance, including but not limited to any pipe, ditch, channel, tunnel, conduit, well, discrete fissure, container, rolling stock, concentrated animal feeding operation, vessel, or other floating craft from which pollutants are or may be discharged."

Many of the outfalls along Cobbs Creek have already been located under the studies performed for the Cobbs Creek Watershed Management Plan. Municipalities should work with PWD to develop a consistent set of outfall maps that meet the specific requirements of the Phase II program.

Illicit Discharge Ordinance

A Model Ordinance is available from PADEP and should be used as is. PADEP discourages changes to the model ordinance, because it has been prepared to meet the MS4 permit requirements. However, some municipalities already have good stormwater ordinances. Municipalities who do not wish to enact the model ordinance in its entirety must get approval from PADEP to ensure that the MS4 permit requirements are met.

The model ordinance must be enacted in the first year of the permit term, except where a municipality commits to a multi-municipal, watershed-based program following this Protocol, in which case the schedule is delayed one year. Subsequent to completion of the Act 167 Plan (or Plan Update), the ordinance must be modified to reflect Plan requirements. Regardless of the timing of the Act 167 Plan (or Plan Update) an ordinance must be enacted within the first two years of the permit term for all municipalities in Cobbs Creek.

IDD&E Program

Following PADEP protocol, the IDD&E Program must consist of the following three elements, which must be implemented according to the schedule shown below.

- Conduct Field Screening
- Identify Source of Illicit Discharges
- Develop and Implement a Strategy to Remove or Correct Illicit Discharges.

Field Screening

Field screening is necessary to identify source(s) of actual illicit discharges. Field screening must start in Year 2 of the permit. PADEP provides a checklist that must be used when conducting field screening. Every outfall in priority areas must be screened two times a year. This activity can be accomplished concurrently with other existing field activities, such as regularly scheduled fire hydrant inspections, road repairs, landscaping activities, other field work conducted during county preparation of the Act 167 stormwater plan, etc.

Using a PADEP supplied Checklist, the staff designated to conduct field screening collect visual data. The screening should be conducted at least 72 hours since the last precipitation event, and at least 48 hours should pass between the first screening at a particular outfall and the second screening at that outfall. If someone conducting the field screening discovers a dry-weather flow, they (or another designated individual with the proper training) must collect a sample of that flow for analysis. Such a discovery triggers the requirements under the other two program elements:

- Identify Source of Illicit Discharges
- Remove or Correct Illicit Discharges

Identify the Source of Illicit Discharges

The following IDD&E Program elements only apply if a dry-weather flow is identified during field screening activities in Years 2, 3, 4, and/or 5. For each illicit discharge that is identified during field screening, the following program elements must be carried out.

- Collect and analyze samples of the dry-weather flow.

If field inspectors identify a dry-weather flow at an outfall during field screening, they should take two grab samples of the flow and analyze the samples for the characteristics and pollutants listed in the Table 7-6 below.

Table 7-6 Dry-Weather Flow Sampling Analysis Requirements

Characteristic/Pollutant	Method
Color	Visual observation
Odor	Visual observation
Turbidity	Visual observation
Sheen/scum	Visual observation
PH	In-field analysis
Total chlorine	In-field analysis
Total copper	In-field analysis
Total phenol	In-field analysis
Detergents/surfactants	In-field analysis
Flow	In-field measurement
Bacteria	Laboratory analysis

- Identify the source of the discharge.

The data obtained from visual, in-field, and laboratory analysis will provide the information necessary to determine the source of the dry-weather flow or floatables. Based on the pollutants contained in the sample, it should be possible to determine if the source is from illegal dumping in a storm drain, a cross-connection, or a leak in a pipe. Potential sources of the dry-weather flow can be located by tracing the flow upstream using storm drain maps and by inspecting upgradient manholes and storm drains. If need be, a more focused test to pinpoint the source can be tried, such as dye testing, smoke testing, and television camera inspection.

Remove or Correct the Illicit Discharge

Once the source has been identified, municipalities need to determine if it is a case of improper dumping or if a property owner has an improper physical connection to the storm sewer system. This will help to select the most appropriate method for correcting or removing the discharge. If it is a case of improper dumping, the only recourse may be to conduct intensified education of residents living in and traveling through that area. If it is a case of an improper physical connection, the appropriate action can be taken to correct the discharge. A plan of action to eliminate elicit connections might include plugging discharge points or disconnecting and reconnecting lines.

If a violation is found, the property owner should be notified of the violation and given a timeframe for removal of the source. After that time has passed, the outfall can be screened to identify the dry weather discharge. The property should be visited a final time to confirm that the property owner removed or corrected the source. The results of all discussions, tests, and screenings should be documented for follow-up purposes. Progress evaluation of the municipal IDD&E program will depend on the ability to tabulate the number of illicit connections corrected and the status of those in the process of being corrected.

All municipalities within Cobbs Creek that have a sanitary sewer system are required to carry out this program. Table 7-4 lists the municipalities, and Figure 7-1 shows the location of the sewered areas.

The PADEP protocol has laid out a very specific time table for completion of this program by the municipalities. The timing is shown in Table 7-7 below.

Table 7-7 Implementation Schedule for IDE&E Program

PERMIT YEAR	*IMPLEMENTATION SCHEDULE PERMIT REQUIREMENTS AND MEASURABLE GOALS*			
	Mapping	**Ordinance**	**Program**	**Education**
Year 2	· Establish priority areas for 25% of system	Implement and enforce	· Screen Priority Areas · Take corrective actions to remove illicit discharges (as needed)	· Distribute educational material (see Public Education and Outreach Minimum Measure)
Years 3-5	· Establish priority areas for 25% of system	Implement and enforce	· Screen Priority Areas · Take corrective actions to remove illicit discharges (as needed)	· Distribute educational material (see Public Education and Outreach Minimum Measure)

Stream Cleanup and Maintenance (AM6) Related Goals: 2, 4, 6, 8, 9 Related Indicators: 3, 4, 5, 6, 10, 11, 15, 16, 17, 19, 20			
What	Who	Where	When
Remove litter and heavy debris. Maintain habitat improvements (fish ladders, FGM, elimination of plunge pools).	PWD Waterways Restoration Unit; Fairmount Park volunteers and other volunteer groups	Portions of Cobbs Creek and tributaries within or along the City boundary; areas outside the City maintained by volunteers only	Begin within 5 years; monthly maintenance schedule to be determined

Keeping streams free of trash is a continuous activity. NLREEP volunteers alone have removed over 2,000 bags of trash from the stream corridor since 1998. Public education should help in reducing trash and debris reaching the streams, however, PWD and municipalities need to put into place a permanent maintenance schedule. PWD has implemented a permanent Waterways Restoration Unit. This team periodically removes trash and large debris from Cobbs Creek on a rotating schedule. For reaches of stream within the City or along the City boundary, the team will focus on removal of litter and heavy debris, and maintenance of in-stream aquatic habitat improvement projects including fish ladders, fluvial geomorphologic restoration projects, and elimination of outfall plunge pools. For reaches of stream outside the City, municipalities should organize periodic stream cleanups using volunteer groups.

Municipalities that have the greatest length of stream within their boundaries include Haverford Township, Upper Darby Township, and Lower Merion Township.

Enhancing Stream Corridor Recreational and Cultural Resources (AO1) Related Goals: 7, 8, 9 Related Indicators: 16, 17, 18, 19, 20, 21			
What	Who	Where	When
Establish and improve trails and greenways using measures recommended in the Darby RCP and the Fairmount Park Trails Master Plan. Protect historic sites listed in the Darby RCP.	Outside Philadelphia: partnership of Department of Conservation and Natural Resources (DCNR), county planning departments, and municipalities. Inside Philadelphia: Fairmount Park Commission.	See Figures 7-3 and 7-4.	Medium term: 5-15 years

Part of Target A addresses the accessibility of Cobbs Creek. Once dry weather water quality and aesthetics have been improved, the recreational value of the Creek will be enhanced, and better accessibility becomes important. A stream accessibility analysis (Section 4, Indicator 18) indicated that much of the headwaters of the Cobbs are inaccessible. The recommended actions focus primarily on improving access to public lands where recreational potential is greatest.

Outside the City of Philadelphia, implementation of the Upper Cobbs Creek Area Greenway is recommended in the Darby Creek Watershed River Conservation Plan. Most of the proposed greenway extension lies in Haverford Township (Figure 7-3). The main recommendations from the RCP are:

- Link existing Fairmount Park green areas northward to Haverford College
- Link the Cobbs greenway to the Darby Creek main-stem through the Merion Golf Club and Haverford State Hospital Site.

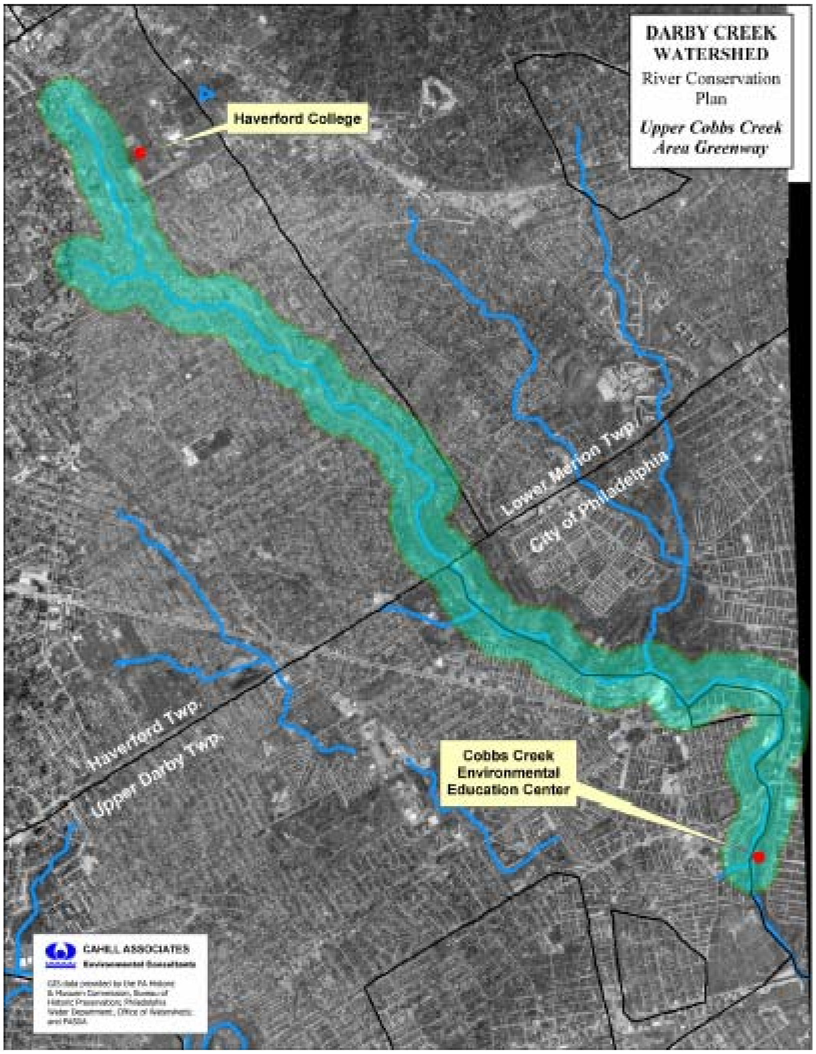


Figure 7-3 Upper Cobbs Creek Area Greenway (Source: Darby RCP)

Fairmount Park's Natural Lands Restoration and Trails Master Plan contains specific recommendations for creating and enhancing trails in the Cobbs section of the Park. These are shown in Table 7-8 and in Figure 7-4.

Table 7-8 Fairmount Park Trails Master Plan Recommendations for Cobbs Creek

- Provide maximum support and development of positive volunteer educational and restoration efforts already in place.
- Eliminate redundant and problematic trails that are contributing to the ecological decline of the natural areas.
- Increase perceived safety by providing better trail sight lines and perimeter lighting.
- Create well-defined trail heads that have good transit and regional connections.
- Provide access points/gateways to adjacent neighborhoods.
- Provide interpretive and educational opportunities for the diverse ecological and cultural settings of the park.
- Provide for adequate parking and controlled access to the trails to eliminate/reduce likelihood of trails as entrance points for motorized vehicles (particularly ATV's and abandoned autos).
- Provide maintenance strategies and restoration solutions for eroded and degraded trails that will continue to be used.

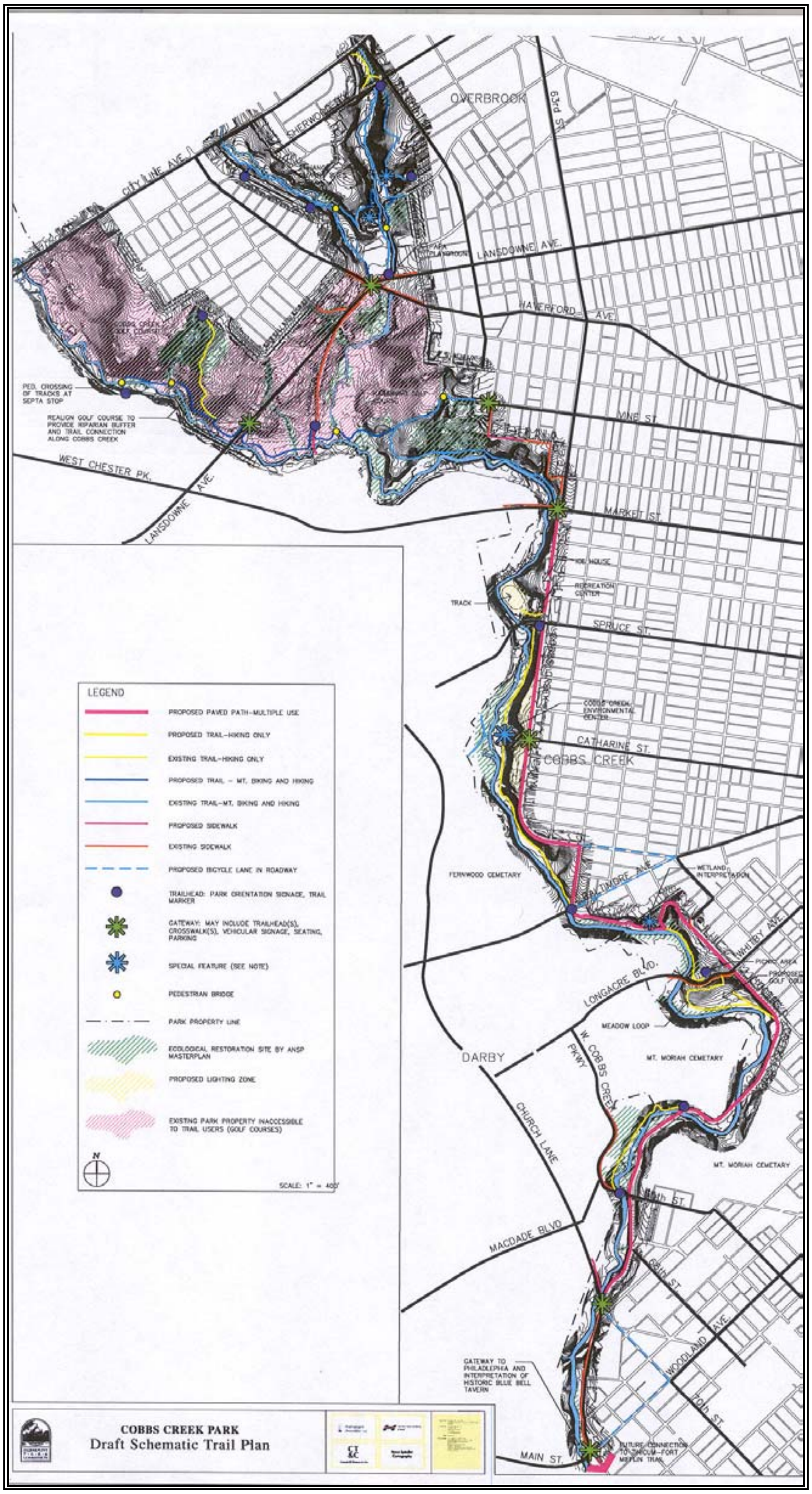


Figure 7-4 Cobbs Creek Schematic Trail Plan (from www.nlreep.org)

7.2 Target B: Healthy Living Resources

Stream and Riparian Corridor Improvement

The Cobbs Creek Watershed Management Plan proposes a comprehensive stream and riparian corridor restoration strategy. Given the historic degradation of the water quality and ecology of Cobbs Creek and its tributaries from urbanization, an interdependent set of corridor improvement actions are recommended. The actions - ranging from conservation of existing open spaces, to stream stabilization actions, to creation of new wetlands and biofiltration areas – together constitute a fully integrated riparian corridor improvement strategy that provides new habitat and water quality improvement. In the Philadelphia portion of the riparian corridor, this approach is intended to complement and expand the Fairmount Park Commission's Natural Lands Restoration and Environmental Education Program (NLREEP).

These riparian corridor improvement actions, when implemented simultaneously, will result in improvements that span the waterway and riparian corridor, from the developed properties along one bank to the developed properties along the opposing bank. Thus, riparian corridor actions improve the ecology of the Cobbs Creek landscape and optimize the ways in which the limited remaining open space can help improve water quality. The long-term benefits of an integrated riparian strategy significantly outweigh the short-term construction disturbances that are needed to implement the Cobbs Creek riparian corridor improvements.

The riparian corridor is defined here as the land area that borders a stream and which directly affects and is affected by the water quality. The riparian corridor typically includes floodplains, shorelines, wetlands, and riparian forest. For the purposes of the Cobbs Creek riparian corridor improvement strategy, the riparian area also includes the stream channel. Thus, the full undeveloped land and waterway area between the existing land development that surrounds the corridor will be considered for ecological improvement and for biofiltration functions that will improve water quality. Listed below are the options recommended for implementation across the corridor, from the lowest point in the landscape (the stream channel) to the highest (upland forest).

Channel Stability and Aquatic Habitat Restoration

BM1	Bed Stabilization and Habitat Restoration
BM2	Bank Stabilization and Habitat Restoration
BM3	Channel Realignment and Relocation
BM4	Plunge Pool Removal
BM5	Improvement of Fish Passage

Lowland Restoration and Enhancement

BM6	Wetland Creation
BM7	Invasive Species Management

Upland Restoration and Enhancement

BM8 Biofiltration
BM9 Reforestation

BMR Monitoring and Reporting

Timeline. The most effective approach to riparian corridor improvement is to perform all the proposed streambed, streambank, wetland, and riparian upland improvements simultaneously along a reach, or stream section. When one section is completed, work shifts downstream, section by section, for the length of the Cobbs Creek corridor. Implementing one set of corridor actions, for example, bed stabilization, without complementary actions, such as bank stabilization, will result in only limited success, because the aquatic and streamside land environments must function interactively to provide optimal stability. For this reason, the riparian corridor improvement strategy is both a short-term and long-term plan. Restoration activities in sections of the Creek that are in greatest need of improvement should be implemented early (targeting stream sections that are causing or contributing to water quality or ecological impairment first). For the Cobbs Creek corridor, it is anticipated that significant improvements in water quality and ecology can be realized by addressing high priority locations early in the planning cycle, with lower priority sections receiving riparian corridor improvement later in the cycle (Figure 7-5 and Table 7-9). It is important to note that the next step in implementing the riparian corridor improvement strategy is to develop a corridor improvement facilities plan, under which integrated designs are prepared for the full range of corridor improvements (e.g., bed and bank stabilization, and wetland creation and enhancement). Also included in this facilities plan are recommended solutions to problems created by channel obstructions such as bridge abutments.

Aside from land management strategies, restoration efforts are generally recommended for implementation beginning in headwater reaches and continuing downstream to avoid undermining any previous efforts. However, restoration projects for the East and West Indian Creeks may occur simultaneously with ongoing efforts upstream of the confluence of East Indian Creek and Cobbs Creek.

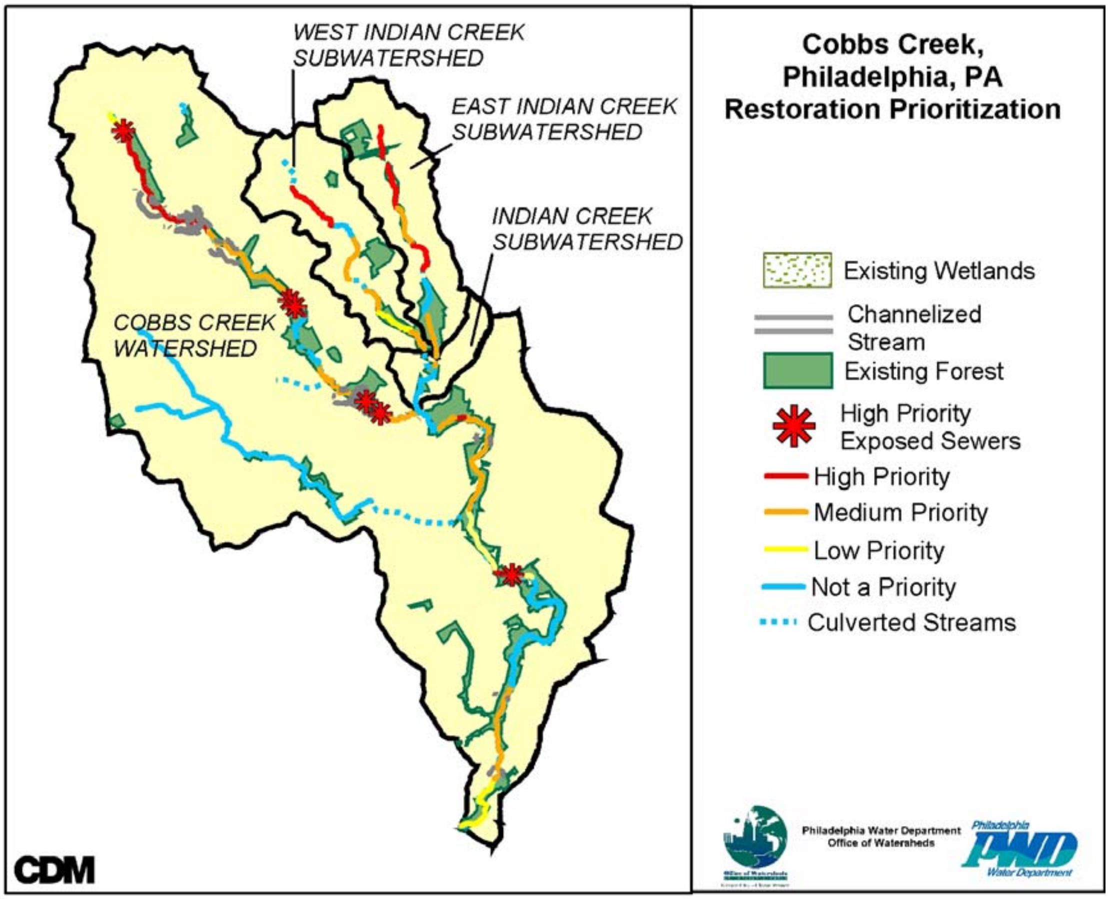


Figure 7-5 Cobbs Creek Watershed Restoration Prioritizations

Table 7-9 Total Miles of Stream by Stream Restoration Priorities

Subwatershed	Priority	Length (miles)
Cobbs	Not a Priority	5.53
Cobbs	Low Priority	3.87
Cobbs	Medium Priority	10.53
Cobbs	High Priority	4.82
East Indian Creek	Not a Priority	1.94
East Indian Creek	Low Priority	0
East Indian Creek	Medium Priority	1.96
East Indian Creek	High Priority	2.37
West Indian Creek	Not a Priority	0.55
West Indian Creek	Low Priority	0.96
West Indian Creek	Medium Priority	2.48
West Indian Creek	High Priority	1.25

7.2.1 Channel Stability and Aquatic Habitat Restoration

The Cobbs Creek watershed is strongly influenced by existing land use and anthropogenic channel changes. Cobbs, East Indian, and West Indian Creeks are all adjusting to increased flows and velocities that have resulted from extremely large amounts of impervious surface and the presence of structures associated with utilities. Changes to channel platform, pattern, and geometry will continue to occur. Cumulative impacts seen today and those that are expected to occur throughout the watershed are bed and bank erosion, channel over-widening, channel down-cutting, the lack or overabundance of sediment, less or no connection to the floodplain, and increased dominance by invasive species. Reach ranking results show that the Cobbs Creek subwatershed is the least stable, followed by West Indian and then East Indian Creeks. Headwater reaches in each subwatershed are more degraded than reaches nearer to the confluences with Cobbs Creek and Darby Creek. Final reach ranks also suggest that land use adversely impacts habitat to a greater degree than it impacts channel stability, while infrastructure is the opposite.

Overall, based on existing conditions, the Cobbs Creek subwatershed contains the greatest amount of degraded channel and has the highest restoration priority. Reaches assigned the highest restoration priority within this subwatershed are those that are severely degraded and/or continue to degrade. In all cases, the highest priority reaches contain infrastructure. Utilities present within these reaches that are of most concern consist of exposed sewer pipes and dams. Reaches both upstream and downstream of these utilities sometimes were included in the prioritization because they are being impacted by these structures or because expected future restoration/retrofit designs may require additional channel length. Multiple consecutive reaches that yielded high final ranking scores, generally those that were greater than the average stability score for the subwatershed, were also assigned a high restoration priority. The least amount of restoration is recommended for the downstream portion of Cobbs Creek.

Results of the reach ranking for the East Indian Creek subwatershed reveal that the downstream portion of the creek is more stable than the upstream portion. Degradation and corresponding higher geometry scores within the upstream portion of the creek can be attributed to a far greater number of disturbances to the channel by landowners. Disturbances such as landscaping, fountains, footbridges, etc. occur less frequently as the East Indian Creek flows downstream. Additionally, as the East Indian Creek flows downstream, land use transitions to less concentrated single family residential development and/or commercial businesses. This change in land use correlates with the width of riparian buffer present and is reflected in the reach habitat scores for the downstream portion of the East Indian Creek. The downstream portion of the East Indian Creek contains the lowest priority reaches, or the most stable reaches, in the entire Cobbs Creek watershed.

Results of the West Indian Creek ranking revealed similar results to those of East Indian Creek. Land use trends for both subwatersheds are alike in that the headwaters are primarily single family residential areas where a large amount of channel disturbances have occurred. Reach ranking reveals that the middle section of the creek are the least stable and show the least amount of natural habitat. West Indian Creek headwater reaches, although some reach ranks suggest this portion of the channel is more stable, are considered the least stable due to anthropogenic changes. Approximately 30% of the total linear feet of channel within this subwatershed have been altered. It follows that the most stable portions of West Indian Creek are the three downstream most reaches, where the riparian corridor is widest and the fewest channel disturbances are present.

Bed Stabilization and Habitat Restoration (BM1) Related Goals: 3 Related Indicators: 3, 4			
What	Who	Where	When
Design structures that provide grade control while diverting flow away from the channel banks. Bed stabilization measures include rock/log vanes with grade control, rock/log cross vanes, and using naturally occurring boulders and bedrock. Incorporate habitat improvements along with the stabilization measures.	Municipalities bordering streams recommended for restoration.	Cobbs Creek (40%) and West Indian Creek (44%) were identified as the areas with the highest percentage of actively degrading creek beds. (See Figure 7-5)	Begin within 5 years; complete restoration program within 10-15 years; monthly maintenance schedule to be determined

Bed conditions in stream channels subjected to urbanized flow often do not support a healthy aquatic ecosystem. High-velocity urbanized flows result in downcutting and widening of the bed over time, and deposition of fine sediments disrupts macroinvertebrate communities that are critical links in the aquatic food chain. Loss of pool and riffle sequences deprives fish of the variety of habitats they need to feed, spawn, and seek shelter from high flows. These channel changes tend to begin downstream and migrate their way upstream over a period of time.

Bed stabilization is recommended for those reaches that are currently degrading through incising or downcutting. Bed stabilization measures include rock/log vanes with grade control, rock/log cross vanes, and using naturally occurring boulders and bedrock. These measures reduce erosion by diverting high flows away from banks and by controlling the grade (slope) of the bed. They also stop downcutting from migrating upstream and restore habitat features that lead to healthy macroinvertebrate and fish communities. Detailed design plans are recommended for those stretches shown in Figure 7-6.

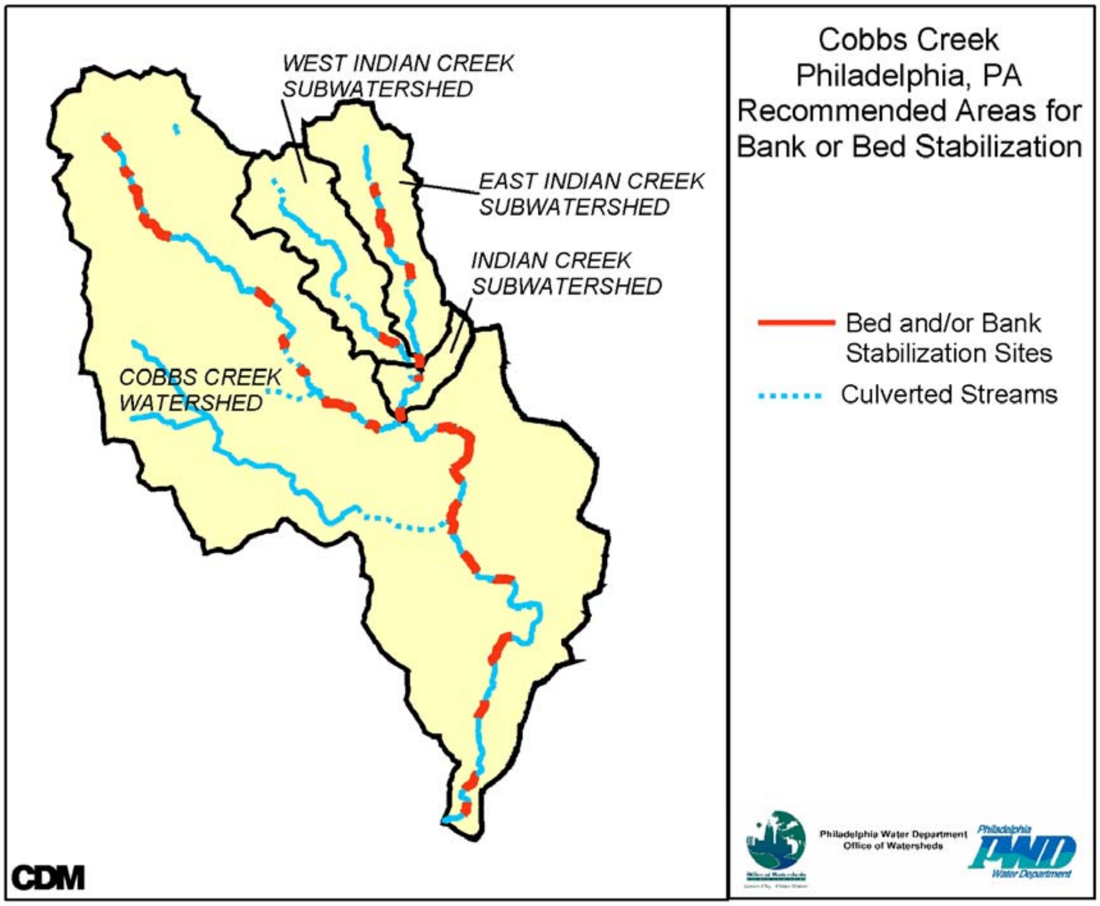


Figure 7-6 Recommended Areas for Bank and/or Bed Stabilization

Bank Stabilization and Habitat Restoration (BM2) Related Goals: 3, 4, 7, 8 Related Indicators: 3, 4, 12, 13, 15, 16, 19			
What	Who	Where	When
Bank stabilization design that may consist of boulder bank and boulder toe stabilization, bioengineering, root wads, plantings, and log and woody structures.	PWD; Fairmount Park NLREEP Municipalities bordering streams recommended for restoration. Municipalities bordering streams recommended for restoration.	Mid-sections of Cobbs Creek are the least stable, highest priority, bank stabilization areas. Channel banks rated as moderate or high should be evaluated further for site specific bank stabilization measures. These methods are best suited to small, local areas of bank erosion in East and West Indian Creek headwaters where discharges are the lowest. (See Figure 7-5)	begin 0-5 years; monthly maintenance schedule to be determined

The fine sediment that is deposited in the beds of many urban streams is often the result of bank erosion upstream. In addition to downcutting the stream bed, high-velocity urban flows result in steep, sometimes vertical banks that disconnect the stream from its historical floodplain. Using natural stabilization measures on banks also provide fish habitat and areas of reduced velocity during storms. A properly restored bank prevents further erosion, reconnects the stream to its floodplain (wetlands and riparian forest as appropriate), and provides fish habitat. It also may remove a hazardous and unsightly condition caused by a collapsing bank.

Bank stabilization measures can vary from small plantings to the installation of boulder walls, based on the severity of the erosion and whether it is localized or continues for some distance along a bank. Boulder structures are used in smaller channels that are eroding and over-widening to the point where property is, or is expected, to be lost. More natural bank stabilization methods such as bioengineering, root wads, plantings, logs, and woody structures are appropriate in areas where the bankfull width is limited and significant additional channel changes are not expected (future increases in the rate of erosion, sediment supply, tree fall, channel widening, and channel migration are not expected). These measures enhance aquatic habitat in addition to providing stabilization. Since 1998, NLREEP has repaired approximately 1020 feet of unstable banks and beds in Cobbs Creek Park, primarily along tributaries to the main stem. Figure 7-5 identifies the 5.9 miles of highest priority where additional stabilization will be recommended within 5 years. The most appropriate measures for each reach will be determined in the detailed design stage.

Channel Realignment and Relocation (BM3)
Related Goals: 3, 7
Related Indicators: 3, 4, 12, 13

What	Who	Where	When
Realignment and relocation for portions of creek channel. Daylighting recommended for two channel sections.	PWD Municipalities bordering streams recommended for restoration.	Five portions of Cobbs Creek, four portions of East Indian Creek and two portions of West Indian Creek that are potential stream realignment and relocation areas. Daylighting: downstream most portion of West Indian Creek and a section upstream of City Line Avenue. (See Figure 7-7)	begin 0-5 years; monthly maintenance schedule to be determined

In the most severely degraded reaches of Cobbs Creek, stabilization of the existing bed and banks may not be possible, or migration of the stream channel may threaten valuable infrastructure. In these areas, realignment and relocation of the stream channel may be necessary. This measure increases stability by creating a new channel along a path that is natural for the stream to follow. The design of bed and bank structures is not constrained by existing conditions. In some cases, the existing channel makes an ideal site for a riparian wetland. Channel realignment and relocation is commonly implemented for portions of a channel rather than for an entire length of channel due to construction and maintenance costs, and the amount of disturbance that occurs to existing natural habitat. Stream channel realignment and relocation is best suited to consecutive severely degraded reaches. Potential realignment and relocation sites totaling 8.0 miles of stream are shown on Figure 7-7.

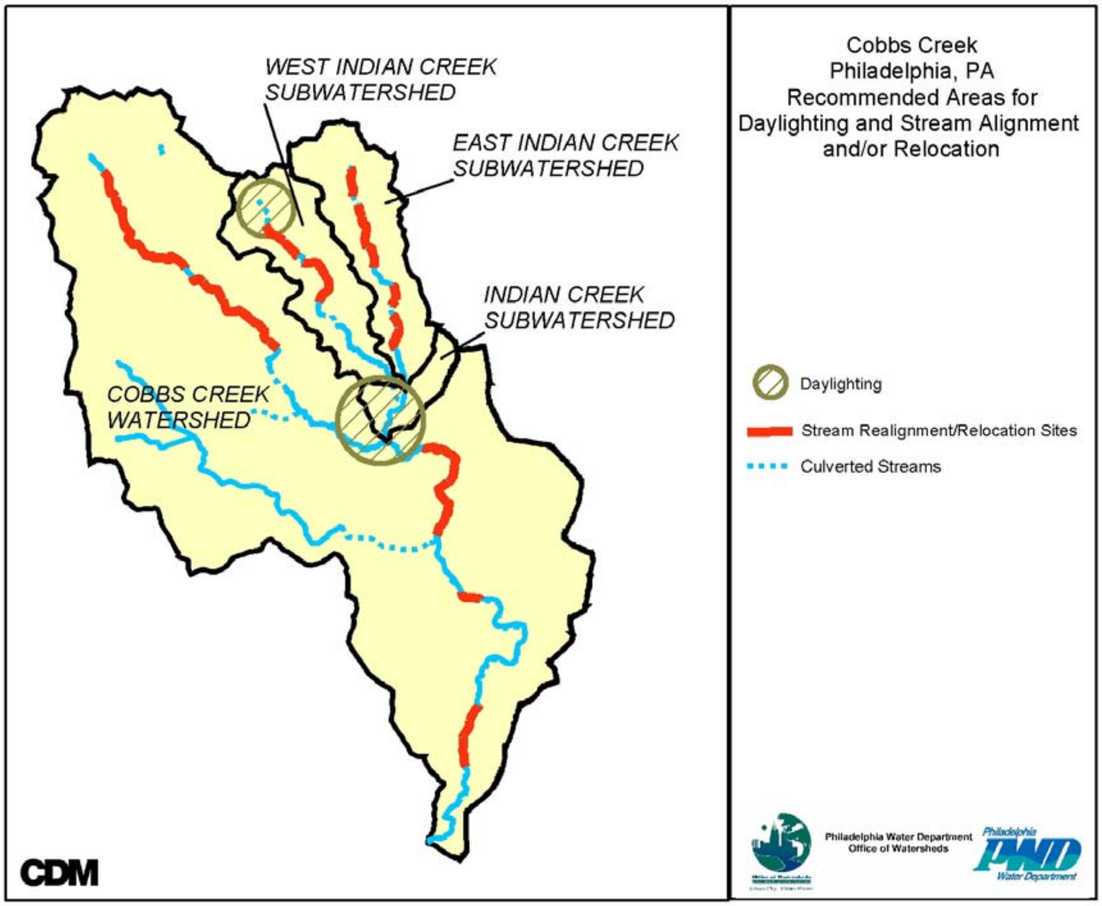


Figure 7-7 Recommended Areas for Stream Realignment and/or Relocation

Plunge Pool Removal (BM4) Related Goals: 3, 4, 9 Related Indicators: 3, 15, 19, 20			
What	Who	Where	When
Remove plunge pools below stormwater and CSO outfalls.	PWD Municipalities bordering streams recommended for restoration.	Outfalls shown in Figure 7-8	begin 0-5 years; monthly maintenance schedule to be determined

When stormwater and combined sewer outfalls discharge directly to the stream channel, they may create deep, poorly mixed pools. Both types of outfalls discharge along the length of the Cobbs and its tributaries (Figure 7-8). Because these pools are typically near the bank and not in the main flow, they can become poorly mixed during low flow. These pools often have increased odors and reduce the aesthetic quality of the stream. DO Biological activity in the sediment and water column can reduce dissolved oxygen to low levels, and this low-DO water can be flushed out and affect downstream areas during wet weather. The depression of DO is a function of both pollutant loads from the outfalls and in stream baseflow, and the physical condition of the channel. When DO is in an acceptable range in the well-mixed portion of the channel but not in nearby plunge pools, elimination of the plunge pools can be expected to eliminate the water quality condition that might affect the aquatic ecosystem.

When possible, outfalls can discharge further up the bank into a wetland or biofiltration area; these areas provide detention, evaporation, cooling, and treatment of pollutant loads in addition to protecting the integrity of the stream channel. Opportunities for creation of these areas will be discussed later in this section. Where the only place for an outfall to discharge is directly into the stream channel, the area may be protected using appropriate bed and bank stabilization features as discussed in previous sections.

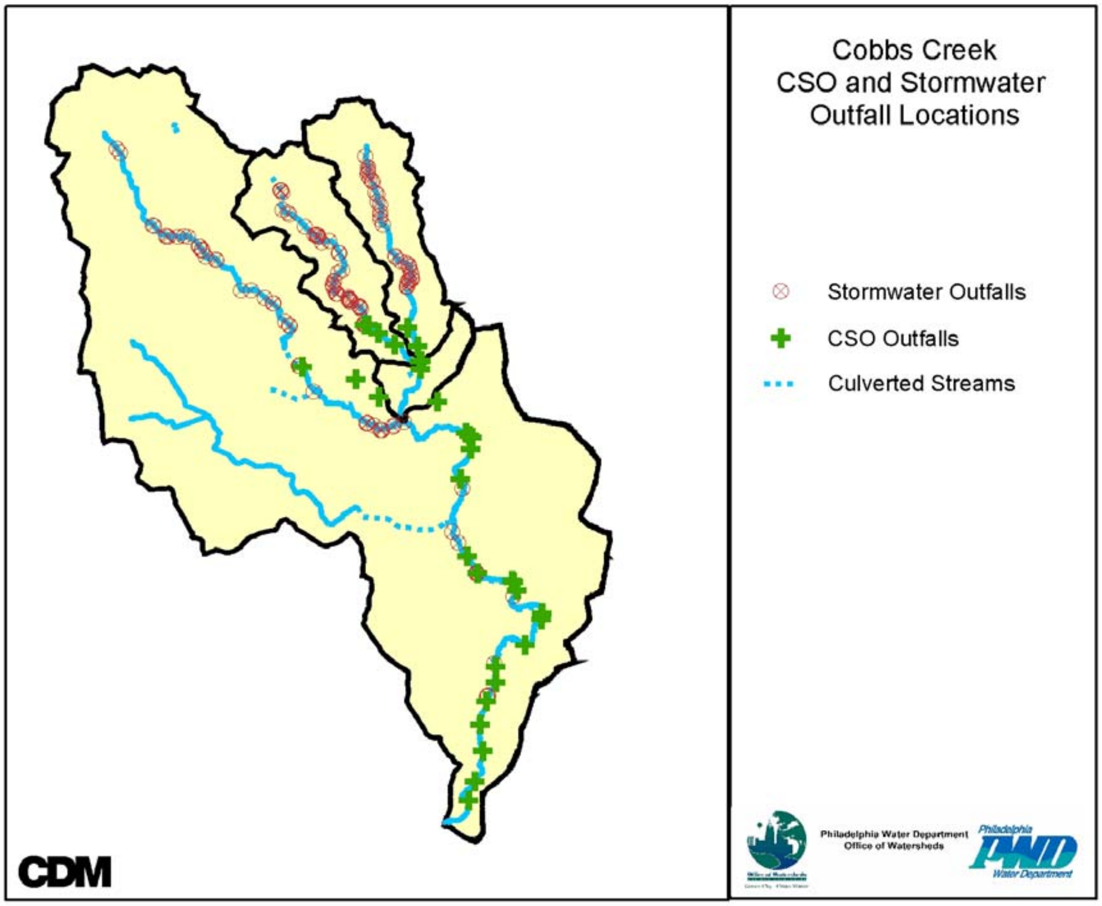


Figure 7-8 Stormwater and CSO Outfalls

Improvement of Fish Passage (BM5) Related Goals: 2, 8, 9, 10 Related Indicators: 3, 5, 6, 16, 19, 20, 21			
What	Who	Where	When
Undertake a detailed study to recommend dam removal, modification, or installation of a fish ladder.	PWD; Fairmount Park NLREEP	Woodland Avenue dam (See Figure 7-9).	Short-term (within 5 years)

For the Cobbs Creek, the State designated aquatic life uses for the non-tidal portion of the creek are Warm Water Fishes (WWF) and Migratory Fishes (MF). The designated recreational water uses also include boating, when surface water flow or impoundment conditions allow; fishing, for recreation and or consumption; water contact sports; and esthetics, for a clean setting to recreational pursuits.

Target A options are designed to ensure that water quality in Cobbs Creek is supportive of fish, and the channel improvements discussed in Target B create suitable aquatic habitat features. In addition to fish that live exclusively in fresh water, creation and enhancement of fish habitat along the Cobbs channel will create an environment suitable for migratory and semi-migratory fish. These anadromous species, such as American shad, spend portions of their life cycles in salt water and portions in fresh water. Currently, a dam at Woodland Avenue excludes migratory fish from most of Cobbs Creek. Historically, migratory fish ranged upstream to just below the current site of Cobbs Creek golf course, where a natural rock ledge (today a low dam) restricts further migration (Figure 7-9). NLREEP has identified ecological benefits to removing the Woodland Ave. dam (Natural Lands Restoration Master Plan); however, the dam is a historic structure and its removal or modification reqires further study. The effects of this dam on the stream channel and upstream sediment will be considered as part of detailed fluvial geomorphological restoration design for the stream corridor.

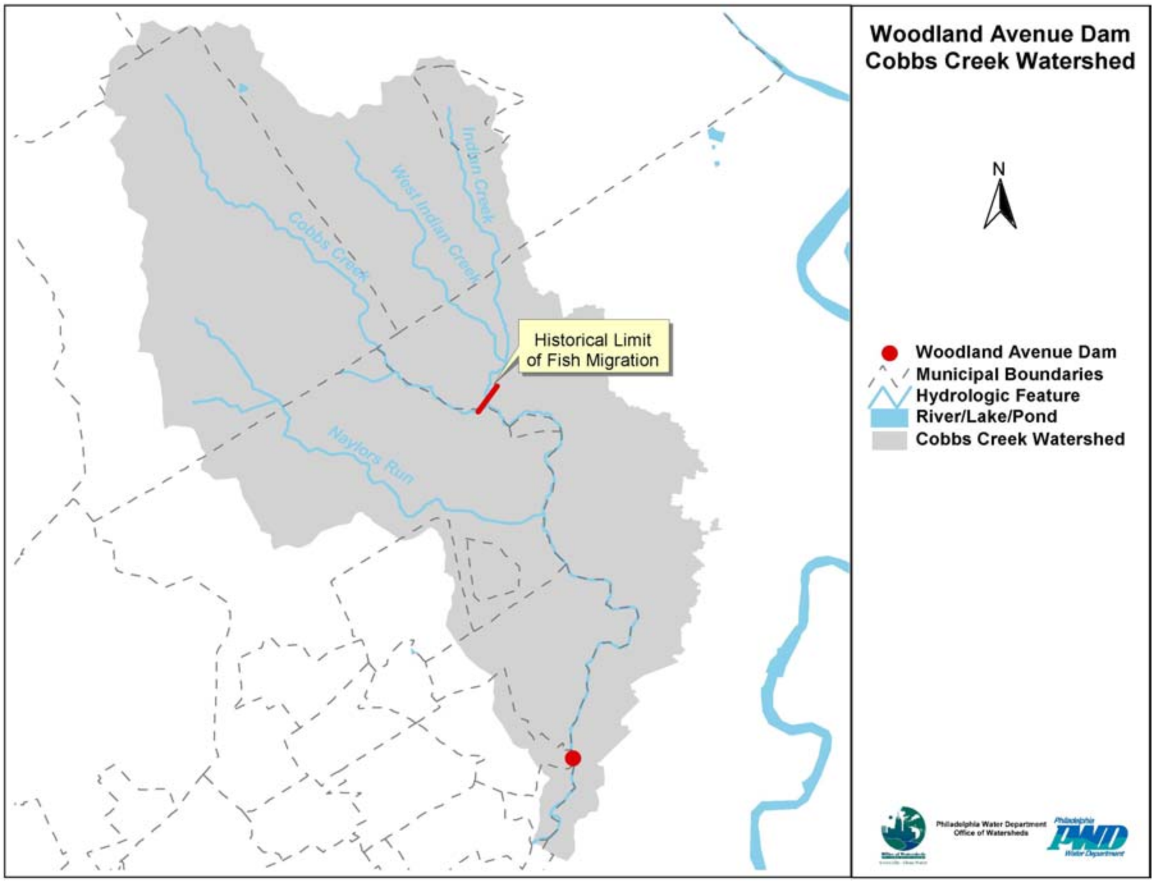


Figure 7-9 Woodland Avenue Dam

7.2.2 Lowland Restoration and Enhancement

One major riparian corridor improvement action, from both an ecological and water quality improvement perspective, is creation and enhancement of wetlands along Cobbs Creek. NLREEP has completed several wetland creation and enhancement projects in Cobbs Creek Park since 1998, including a constructed stormwater treatment wetland at the confluence of Cobbs Creek and Naylors Run. The Cobbs and Indian Creek subwatersheds were field surveyed in 2002/2003 to assess additional wetland creation and improvement opportunities. Existing wetlands were evaluated for their ability to perform important wetland functions (e.g., flood flow alteration, water quality improvement, and habitat). Existing wetlands were then assessed to determine if they were degraded and might be enhanced. Finally, locations where new wetlands could be created were identified. New wetland creation opportunities were classified into two groups:

- Wetlands immediately adjacent to the waterway and which would receive flood flows frequently during the year (< one year storm), and,
- Pocket wetlands that can be created using check dams that are higher in the landscape and that would receive stormwater flows from adjacent subwatershed areas, but would receive flood flows only from major storm

events.

Wetlands Enhancement. Along the Cobbs and Indian Creek subwatersheds, 45 existing wetland areas were identified during the field investigation, and each was evaluated for wetland enhancement potential. Almost one-third of the wetlands exhibited high enhancement potential (Table 7-10), because they had a direct hydrologic relationship with the stream yet showed degraded conditions at present. Half of the wetland areas showed moderate enhancement potential, because their hydrologic relationship with the waterway had been partially compromised or they exhibited somewhat degraded conditions. The potential enhancement sites are designated on Figure 7-10; the site numbers correspond to those in the Comprehensive Watershed Characterization Report (soon to be available on the Partnership website).

Table 7-10 Wetland Enhancement Potential

Wetland Enhancement Potential	
Enhancement Rating	*Wetland Areas*
High	13
Moderate	27
Low	5

In general, priority will be given to wetland creation and enhancement over reforestation of uplands because of the greater water quality benefits provided by wetlands.

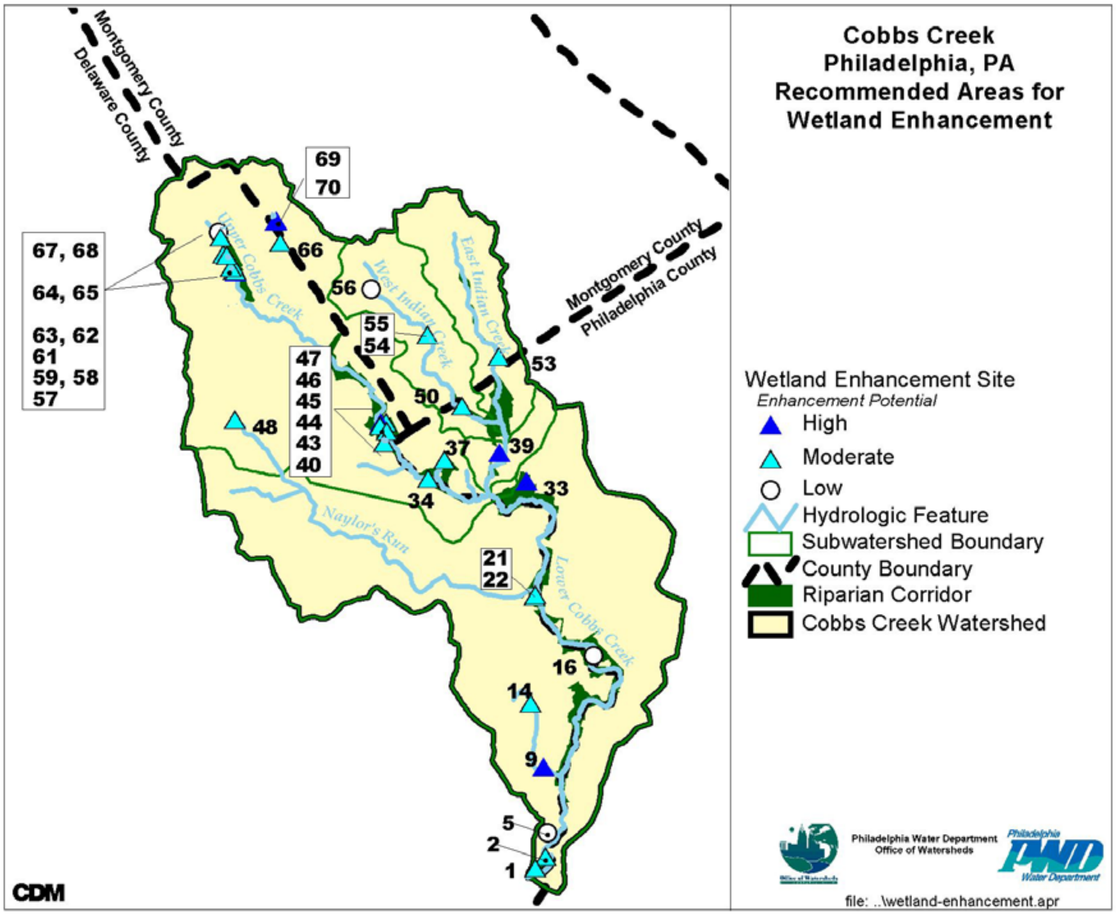


Figure 7-10 Potential Sites for Wetland Enhancement

Wetland Creation. Wetland creation opportunities have been evaluated for the many areas of Cobbs and Indian Creek where stream relocation and realignment are proposed. Because stream relocation and realignment typically involve extensive grading and replanting, new runoff patterns and hydrology can be created that are more similar to original riparian conditions, whereby the riparian corridor received storm runoff sheet flow from the adjacent landscape. In addition, wetland habitats can be created that allow more diverse habitat along Cobbs Creek. Wetlands are rich habitats that rely on saturated soils and vegetation adapted to these conditions. They could be recreated concurrently with channel realignment, bank restoration, and planting of more diverse native vegetation, including hydrophytic species adapted to saturated soil conditions.

Wetlands must have an adequate input of water, either by flooding or runoff, to maintain the soil and vegetation characteristics that are unique to wetlands. Field investigation of wetlands revealed, however, that several factors preclude the creation of extensive areas of new wetland. These include:

- extensive urban and suburban encroachment into the riparian corridor
- competing active recreational uses along the waterway

- steep slopes adjacent to the waterway limiting potential for floodplain hydrology

The wetland field investigation identified only 10 areas (comprising about 10-20 acres) *adjacent to the stream or in the floodplain* as wetland creation locations that would likely experience long-term success. These wetland creation locations are identified in Figure 7-11; the site numbers correspond to those in the Comprehensive Watershed Characterization Report.

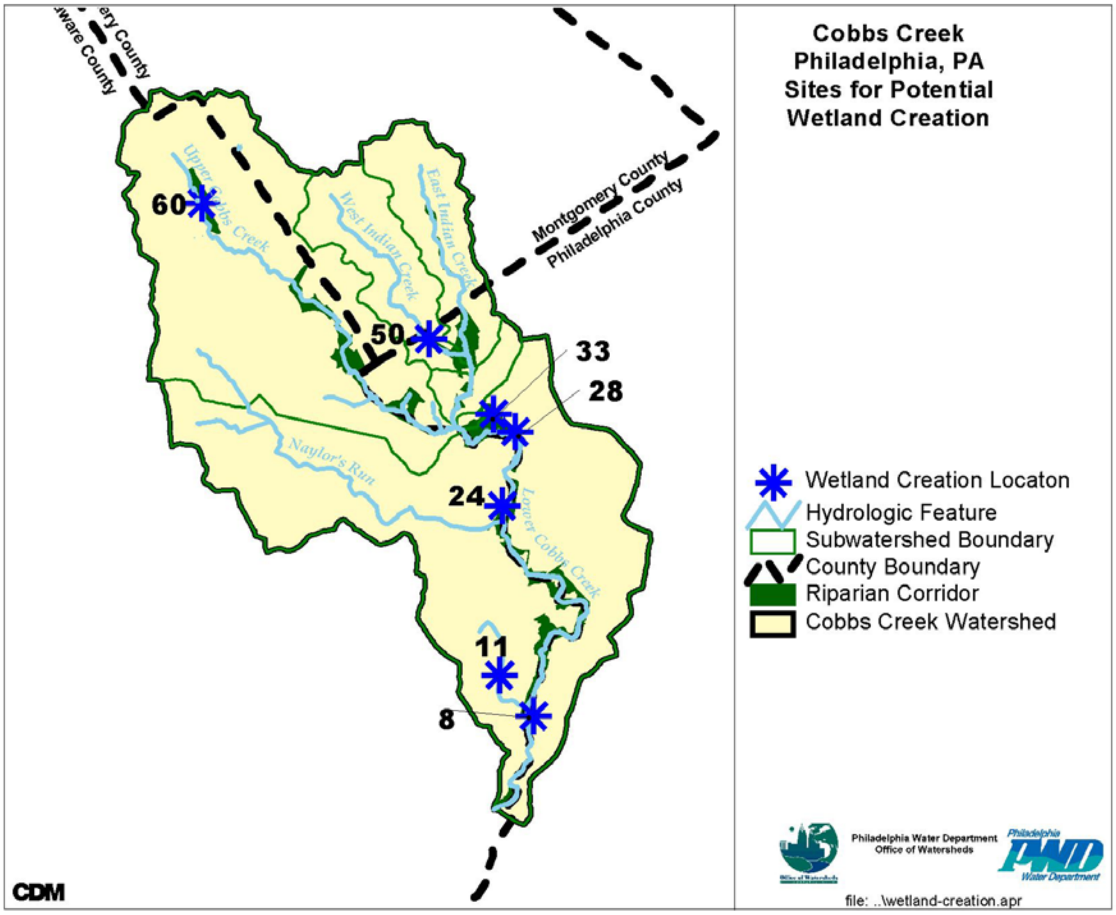


Figure 7-11 Potential Sites for Wetland Creation

However, as noted above, two types of wetland creation are recommended: floodplain wetlands and pocket wetlands. There are numerous opportunities for creation of pocket wetlands throughout the watershed; as stormwater runoff from the adjacent subwatershed is redirected over the riparian landscape, check dams and piping may be used to spread the runoff over the vegetated riparian land surface. Locations for creating pocket wetlands will need to be evaluated in the future as the riparian corridor restoration design is developed during the facilities planning stage. This is because opportunities for creation of pocket wetlands arise from bank restoration, revegetation, and biofiltration actions that will be implemented as part of the integrated riparian corridor improvement strategy for the Cobbs Creek watershed.

Both floodplain wetlands and pocket wetlands offer significant opportunity for water quality and ecological improvement along the Cobbs Creek riparian corridor, and will play a central role as the design of the riparian corridor improvements is developed.

Assuring long term success for wetland creation projects will involve future monitoring to measure integration of the wetland into the riparian landscape and to correct defective conditions, where possible. However, proper design of the wetland to assure adequate input of water (via flooding or runoff), protection from erosion, and maintenance of the diverse planted vegetation is essential to long-term success. Wetland creation projects typically involve monitoring and maintaining the created wetland's hydrology, vegetation (including invasive species), and erosion characteristics for a period of 3 years following creation.

It is estimated that wetlands can remove up to 80% of the total suspended sediments and pollutant loads they receive (Winer, 2000). It is estimated that approximately 50 to 100 acres of wetland creation may be possible in the Cobbs Creek watershed given an intensive creation effort as part of the riparian corridor improvement strategy. If implemented, the area of wetlands created could potentially provide significant improvement of CSO discharges and stormwater runoff from about 5,000 to 10,000 developed acres of the 14,000 acre Cobbs and Indian Creek watersheds (available in the Comprehensive Watershed Characterization report).

Wetland Creation (BM6)
Related Goals: 1, 2, 4, 5, 7, 9, 10
Related Indicators: 1, 2, 3, 4, 7, 8, 9, 15, 19

What	Who	Where	When
Wetland creation and enhancement for flood flow alteration, groundwater recharge, increased habitat, increased plant and animal diversity, and improved water quality.	PWD; Fairmount park NLREEP Municipalities bordering streams recommended for restoration.	Locations available for floodplain wetland creation are limited; areas for pocket wetland creation are extensive, especially where they are adjacent to lands proposed for stream realignment and back restoration. (See Figure 7-11)	Prototype design and evaluation phase in years 1-5; watershed-wide implementation over two 10 year phases, with initial high priority phase.

Further investigation of all potential wetland enhancement and creation opportunities should include the following: identification of landowners, rainfall data collection and evaluation, runoff calculations, soils investigation, water budget, native species investigation, and groundwater/soil saturation monitoring.

The existing historic dam near 67th Street and Race Street, known long ago as Old Mill Pond, has been identified as an area where a floodplain wetland could be created (Figure 7-12). A Philadelphia atlas from 1910 shows that this area has been inundated historically. The existing dam is on top of a natural rock ledge that has prevented fish from migrating further up the Cobbs. Enlargement of the historic dam at this location would recreate extensive floodplain wetlands in a largely undeveloped area, that would provide significant wetland acreage and water quality improvement for stormwater flows from the separate sanitary areas.

Any increase in the height of the dam would result in a gain of intermittently flooded area. This increased area would provide better “wetland treatment” of Cobbs Creek waters, especially during times of stormwater discharge. In the past, consideration has been given to lowering or removing the dam, but such actions would reduce both wetted area and treatment effectiveness. Raising the high water level by ten feet would provide a gain in approximate wetland area of close to 25 acres. The additional storage volume provided at high flow would be approximately 50 million gallons, representing a potential “treatment facility” equivalent value of $100 million to $200 million when compared to the cost of building treatment structures.

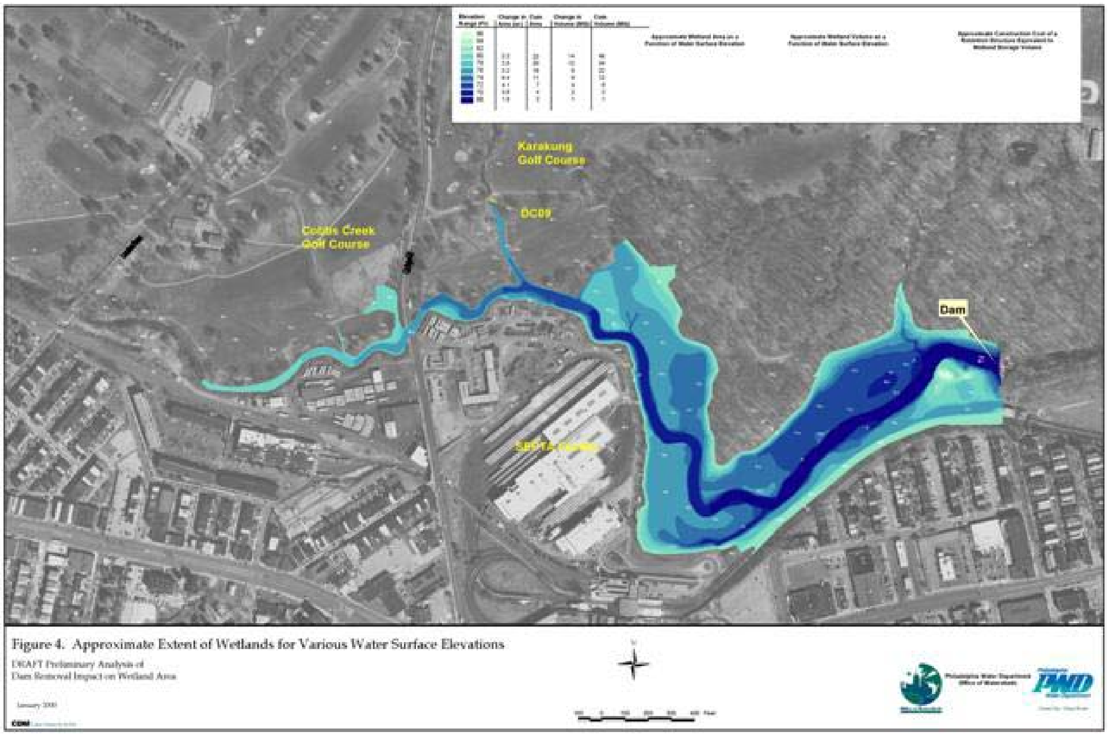


Figure 7-12 Proposed Dam Modification

Invasive Species Management (BM7)
Related Goals: 7
Related Indicators: 12, 13, 14, 19

What	Who	Where	When
Implement an Invasive Species Management Plan (already in effect in Fairmount Park)	PWD; Fairmount Park NLREEP	lowland and upland habitat restoration sites	Within 5 years

A plan to control invasive plant species is necessary when restoring or enhancing wetlands and riparian forests. Invasive species provide little value to native animals that depend on native species for habitat and food. Japanese knotweed (*Polygonum cuspidatum*) is the one prevalent invasive species that was observed during the field reconnaissance. In many areas, knotweed, due to its aggressive nature, has already out-competed native vegetation. Maintaining a healthy riparian plant community along Cobbs Creek, and East and West Indian Creeks will retain biodiversity and support a healthy stream ecosystem.

NLREEP has implemented an invasive species control program in the Fairmount Park portion of the stream corridor. It is recommended that invasive species control be expanded to the remaining natural areas of the corridor. Implementation of an invasive species management plan would assist natural succession within the riparian buffer and decrease further impacts of invasive species.

Planting plans for all restoration efforts should complement the invasive species management plan by recommending appropriate native planting to supplement areas where invasives have been eliminated. Although invasive species management priority areas are considered those that contain 80% or greater invasive species, the most practical approach is to recommend invasive species management be implemented for all riparian restoration sites. Recommended areas where restoration will occur are shown in Figure 7-10 above. An invasive species management plan will require, at a minimum, a three-year commitment to ensure success.

7.2.3 Upland Restoration and Enhancement

Biofiltration (BM8) Related Goals: 1, 4, 6, 9, 10 Related Indicators: 1, 2, 3, 4, 15, 19, 20			
What	Who	Where	When
Biofiltration involves creating sheet flow over the vegetated landscape to slow the rate of runoff, facilitate groundwater recharge, and remove sediment, nutrients, and toxicants from the runoff.	PWD; Fairmount Park NLREEP	Throughout Cobbs, East and West Indian Creek riparian corridors; focus on vegetated landscape	2 10-year implementation phases (high and medium priority)

The goal of the Cobbs Creek riparian corridor improvement strategy is to identify all opportunities along the riparian corridor for natural landscape designs that achieve water quality improvement. For higher landscape positions at the outer edges of the riparian corridor there are extensive opportunities to implement biofiltration to improve runoff. Biofiltration involves creating sheet flow over the vegetated landscape to slow the rate of runoff, facilitate groundwater recharge, and remove sediment, nutrients, and toxicants from the runoff. Typical biofiltration approaches include installation of stormwater swales and check dams along natural drainageways that spread runoff, creation of bioretention plantings and hydrology, and hydrologic features that allow sheet flow to spread over grassed and shrub/scrub fields to achieve water quality improvement. The advantage of biofiltration is that it is compatible with recreational use of the riparian corridor, because flows are very shallow and are usually only present during rainfall events.

Analysis of the existing stormwater management in the Cobbs Creek watershed shows that most stormwater outfalls discharge directly to the waterway. However, if the stormwater was redirected over the vegetated landscape higher in the stream valley, it would follow the natural slope and land contour as it traveled down to the stream. There are over 640 acres of undeveloped land along the Cobbs Creek riparian corridor, mostly in the Upper and Lower Cobbs Creek subwatersheds, but almost none of that land carries runoff sheet flow because the stormwater piping system conveys all flows, from storms large and small, directly to the stream. In order to achieve water quality improvement goals it is important to optimize the ability of this vegetated riparian land to receive overland runoff, rather than piping the runoff directly into the stream.

Under the Natural Lands Restoration Master Plan, NLREEP has constructed a number of stormwater infiltration and biofiltration projects in the Fairmount Park portion of the Cobbs corridor. One example is an excavated basin to capture runoff from a portion of Cobbs Creek golf course.

Biofiltration has an effectiveness range of about 25-60% in removing suspended solids from runoff, and the concept of directing runoff to sheet flow over the vegetated riparian landscape matches fully with the way that such lands function naturally in an undeveloped watershed. Thus, the goal of biofiltration is to restore sheet flow of runoff over the landscape, by using piping and hydraulic controls to spread runoff from smaller storms over the vegetated surface. It is essential that the design for biofiltration provide for high velocity flows from major storms to be bypassed, to avoid erosion.

Reforestation (BM9) Related Goals: 1, 3, 7, 8, 9 Related Indicators: 1, 2, 4, 12, 13, 16, 18, 19			
What	Who	Where	When
Reforestation adjacent to the channel to provide wetland habitat and other associated benefits.	PWD; Fairmount Park NLREEP Municipalities bordering streams recommended for restoration.	Priority reforestation sites: lands adjacent to the creek that are not developed and are currently unforested. Potential reforestation sites are existing ball fields, golf courses, hospital grounds, seminaries, and cemeteries located adjacent to the channel. These should also be evaluated. (See Figure 7-13)	begin 0-5 years; monthly maintenance schedule to be determined

The riparian corridor restoration and enhancement plan being proposed in this section covers the width of the stream corridor from developed edge to developed edge, including both lowland and upland forest. Reforestation that occurs adjacent to the channel will provide wetland habitat and other associated benefits. Although priority reforestation areas consist of floodplains, steep slopes, and wetlands, smaller areas such as public rights-of-way, parks, schools, and neighborhoods also provide reforestation opportunities. Benefits of reforestation are numerous: cooler temperatures, rainfall interception, reduced runoff, reduced sediment load, reduced discharge velocities, increased groundwater recharge, increased species diversity and habitat, and improved air quality and aesthetics. In the Fairmount Park portion of the corridor, NLREEP has planted over 26,000 trees, shrubs, and herbaceous species since 1998.

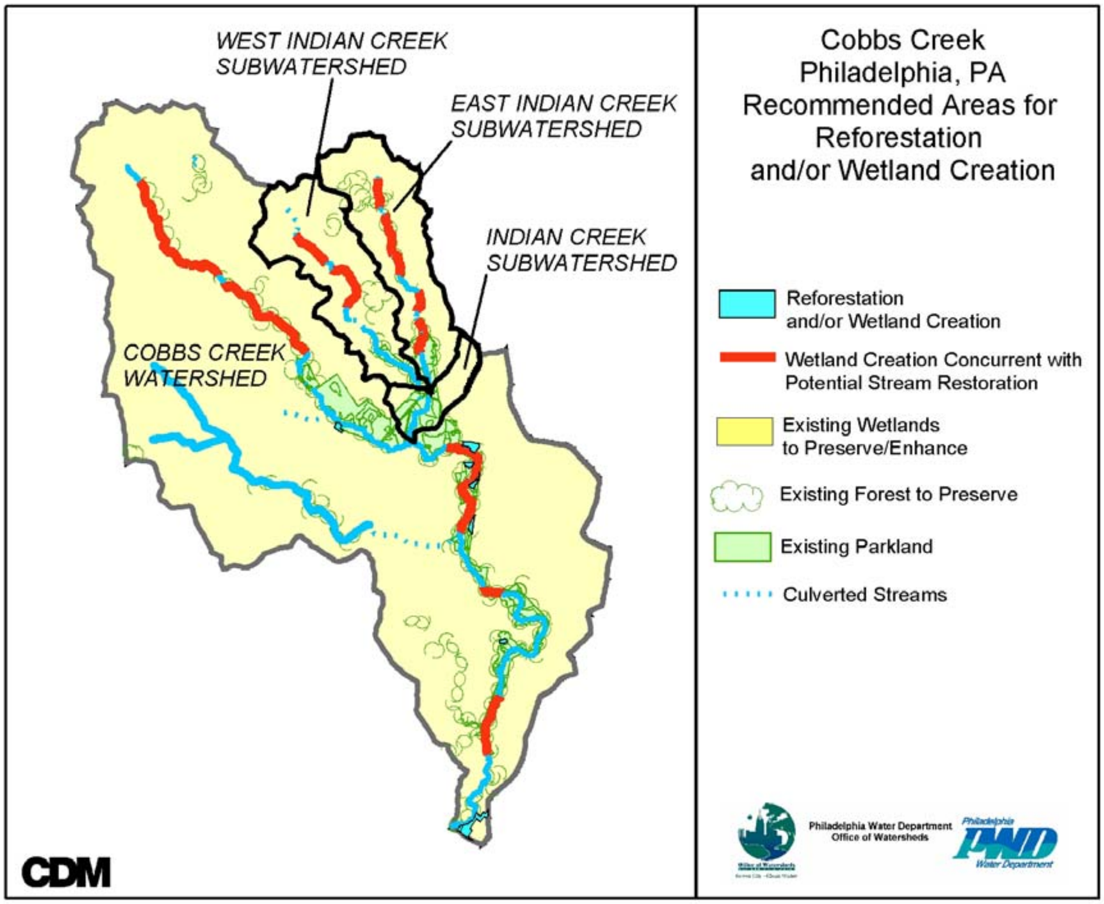


Figure 7-13 Recommended Areas for Reforestation

7.3 Target C: Wet Weather Water Quality and Quantity

Target C must be approached somewhat differently from the first two targets. Full achievement of this target means meeting all water quality standards during wet weather, as well as eliminating all flooding. Full achievement of these goals will be difficult, particularly with regard to wet weather water quality. It would certainly be extremely expensive, and would require a long term effort. The only rational approach to full achievement of Target C goals is through stepped implementation with interim targets for reducing wet weather pollutant loads and stormwater flows. During implementation, monitoring must continue to continuously assess the effectiveness of the program. Based on the extensive modeling analysis carried out for Cobbs Creek to date, an initial goal of a 20-30% reduction in stormwater flows and stormwater/CSO related pollutant loads is challenging but achievable.

In addition to the reduction in discharge volume, an important measure of progress is the percent capture of combined sewage in combined-sewered areas. It is estimated that implementing real time control will increase percent capture to approximately 80% in the middle portion of the Cobbs, and additional BMPs will increase it still further. In addition to capture by regulator structure, the quality of some CSO and stormwater flows will be improved in treatment wetlands before they reach the creek. A more precise assessment of percent capture will be performed during the initial stages of this plan.

It is expected that changes to the approach required to meet Target C, and even to the desired results, will occur as measures are implemented and results are monitored. With permits of 5-year duration for most discharge permits, discharge targets and reduction targets must be set and implementation designed in the first 5 years. Implementation for meeting Target C should occur over the next 5 years, with monitoring for effectiveness taking place for 5 years subsequent to implementation. During the last 5-year period, PWD should also work with the regulatory agencies to review water quality standards and determine whether any adjustments to them may be appropriate based on the results of monitoring.

Regulatory Approaches

Zoning and Land Use Control

CR2 Requiring Better Site Design in Redevelopment

CR3 Stormwater and Floodplain Management
CR4 Industrial Stormwater Pollution Prevention
CR5 Construction Stormwater Pollution Prevention
CR6 Post-construction Stormwater Runoff Management
CR7 Pollution Trading
CR8 Use Review and Attainability Analysis
CR9 Watershed-Based Permitting

Municipal Measures

CM1 Sanitary Sewer Overflow Detection
CM2 Sanitary Sewer Overflow Elimination: Structural Measures
CM3 Reduction of Stormwater Inflow and Infiltration to Sanitary Sewers
CM4 Combined Sewer Overflow (CSO) Control Program
  - Nine Minimum Controls
  - Long Term CSO Control Plan
  - Watershed-Based Planning

CM5 Catch Basin and Storm Inlet Maintenance
CM6 Street Sweeping
CM7 Responsible Landscaping Practices on Public Lands
CM9 *R*esponsible Bridge and Roadway Maintenance

Stormwater Management

Source Control Measures

CS1 Reducing Effective Impervious Cover Through Better Site Design
CS2 Increasing Urban Tree Canopy
CS3 Porous Pavement and Subsurface Storage
CS4 Green Rooftops
CS5 Capturing Roof Runoff in Rain Barrels or Cisterns

Onsite and Regional Stormwater Control Facilities

CS6 Maintaining/Retrofitting Existing Stormwater Structures
CS8 Retrofit of Existing Sewer Inlets with Dry Wells
CS9 Residential Dry Wells, Seepage Trenches, and Water Gardens
CS12 Bioretention Basins and Porous Media Filtration
CS13 Treatment Wetlands: Onsite and Regional

CMR Monitoring and Reporting

Table 7-11 Maximum Feasible Reductions for BMPs with Quantifiable Benefits

	Recommended	DCIA	SW Reduction	CSO Reduction	Pollutant
Target C	Implementation	Reduction	Inf./ET	Captured	Reduction
Municipal Measures					
CM4 Combined Sewer Overflow (CSO) Control Program					
• Real Time Control	15 Sites in PWD's SWDD	N/A	N/A	11%	14%
Structural Stormwater Management Facilities					
Source Control Measures					
CS1 Reducing Impervious Cover through Better Site Design		1%	2%	4%	N/A
CS2 Increasing Tree Canopy Cover	increase from 26% to 31%	5%	1%	not modeled	not modeled
CS3 Porous Pavement and Subsurface Storage	10% of parking lots	1%	0.05%	1%	2%
CS4 Green Rooftops	demonstration projects	N/A	N/A	N/A	N/A
CS5 Capturing Roof Runoff in Rain Barrels or Cisterns	5% of homes	5%	0.5%	2%	2%
Onsite and Regional Stormwater Control Facilities					
CS8 Retrofit of Existing Sewer Inlets with Dry Wells	10% of inlets in combined areas	3%	N/A	0.4%	0.4%
CS9 Residential Dry Wells, Seepage Pits, Water Gardens	10% of residences	14%	0.3%	3%	5%
CS12 Bioretention Basins and Porous Media Filtration	10% of parking lots		0.1%	1%	2%
CS13 Treatment Wetlands: Onsite and Regional		5%	1%	1%	2%
TOTAL		34%	27%		28%

7.3.1 Regulatory Approaches

Encouraging or Promoting Better Site Design in Redevelopment (CR2) Related Goals: 1, 7, 9, 10 Related Indicators: 1, 12, 13, 16, 19, 20			
What	Who	Where	When
Adopt or improve ordinances to encourage developers to use low impact methods for new (“greenfield”) development and redevelopment of urban areas.	See Table 7-14 (may not identify all municipalities with ordinances)	Entire Watershed	within 5 years; update as needed

Environmentally friendly site design, also called low impact development (LID) and conservation site design, encompasses a range of site design elements for developers, and design requirements from municipalities. Some examples of LID design concepts include maintaining stream buffers, designing for open space, reduced street and sidewalk footprints where appropriate, and parking lot designs that reduce runoff and encourage infiltration. Stormwater source controls, infiltration BMPs, and treatment BMPs can be integrated with LID designs. Recommendations for incorporating these features in the Cobbs watershed are found throughout Target C.

LID is intended to reduce the impact of development on natural resources and water resources. Municipal design requirements are intended to preserve or increase open space, protect sensitive natural resources, and limit impervious cover. The environmental *goals* of land development and stormwater ordinances are closely related, although the ordinances themselves and mechanisms for enforcing them may be separate. This section discusses land use-related regulatory approaches to better site design, while the next section discusses regulatory approaches to stormwater management.

It appears that most of the municipalities in the Cobbs Creek watershed encourage several standard low impact development practices through their existing land use ordinances. However, these guidelines tend to focus on clustering housing by allowing higher-density multi-family residential developments with common open spaces. Separate language focusing specifically on the protection of natural resources is recommended. While most municipalities in the watershed have already adopted a steep slope ordinance, Lower Merion Township is currently the only municipality within the watershed with a cluster development ordinance and wetlands protection ordinance in place. Table 7-14 identifies the municipalities located in the watershed that have adopted low impact development ordinances.

Table 7-14 Better Site Design in Existing Ordinances

Municipality	Better Site Design Ordinance (at least one component)
Colwyn Borough	
Darby Borough	
East Lansdowne Borough**	
Haverford Township	X*
Lansdowne Borough	X
Lower Merion Township	X*
Millbourne Borough	
Narberth Borough	
Philadelphia	
Radnor Township	X*
Upper Darby Township	X*
Yeadon Borough	

Notes
** includes a steep slope*
***Ordinances for East Lansdowne Borough were not reviewed for this analysis.*
Source: www.ordinance.com, Delaware Valley Regional Planning Commission

The Delaware Valley Regional Planning Commission (DVRPC) has recently completed the task of reviewing the municipal zoning ordinances of the Delaware Valley's 353 municipalities. Based upon this analysis, DVRPC has created a list of "outstanding sample natural resource and open space protection ordinances." These model ordinances as well as additional information on DVRPC's program are available at:

- DVRPC Natural Resource Protection Information - http://www.dvrpc.org/planning/protectiontools.htm
- Model Ordinances - http://www.dvrpc.org/planning/Protection%20Tools/ordinances.htm

Guidelines for LID in an Urban Setting

Table 7-15 identifies various zoning ordinances that could be adopted by the municipalities in the Cobbs Creek watershed. While some municipalities already incorporate elements of these zoning measures within their existing code, it is recommended that ordinances specific to low impact development be adopted to better facilitate future growth and redevelopment within these municipalities. Model ordinances for each of these examples are available on the DVRPC website at the address listed above.

Table 7-15 Selected Components of Low Impact Development Ordinances

Municipal Zoning Ordinance	Description
Net-Out of Resources / Site Capacity Calculations	Protect wetlands, floodplains, and riparian buffers by removing them from the area considered for new development and redevelopment. In calculating the developable area, environmentally sensitive areas should be excluded. Some local governments allow increased densities in the remaining developable land area to provide an incentive for protecting sensitive environments. Existing trees should be protected if possible; if not, the land owner may contribute to a mitigation fund for each tree cut down.
Wetlands Management Ordinance	Protects environmentally sensitive wetlands areas. This ordinance usually requires wetlands delineation within the municipality and prohibits any type of development in a delineated wetland area.
Cluster Development Ordinance	Allows developers to build at higher densities on one portion of a site in exchange for preserving another portion as open space. Land preservation percentages and densities vary, but the preferred percentage is for at least 50% of the tract to remain as open space. Achieving a landowner's financial objectives may be a function both of partial development and donation of a conservation easement (and its inherent deductibility under the federal tax code).
Planned Residential Development (PRD)	Facilitates residential development in areas designated by the municipality. Provisions are made for higher housing densities, thereby creating larger contiguous common open spaces, and providing for pedestrian access between residential areas.
Steep Slope Ordinance	Regulates development on areas designated as steep slopes. The minimum gradient classified as steep varies by municipality, but according to DVRPC 8% is typical.
Transfer of Development Rights (TDR)	Designates areas of a municipality as "sending" and "receiving" areas. Allows community to preserve open space and natural features while still permitting growth. Development is moved from large tracts of rural land (sending area) to areas designated for higher densities (receiving area).

While the measures above were originally intended for new development, they may be adapted for larger redevelopment projects in urban areas. Older areas often have large areas of vacant and abandoned properties that may be demolished all at once, creating significant open space. Cluster development, for example, could be applied on these larger sites.

In addition to the specific ordinances above, municipalities should require, or provide strong incentives for, innovative site design when urbanized areas are redeveloped.

Effective conservation design techniques to consider include the following:

- Review municipal codes and require smaller footprints for impervious surfaces, such as road and sidewalk widths. Review any stipulation of a minimum size lot that development and stormwater ordinances apply to. In the City of Philadelphia, the ordinance requiring all downspouts to be connected directly to the sewer system is not appropriate in all cases; wherever feasible, infiltration (e.g., using dry wells) should be encouraged over disposal of stormwater to combined or separate storm sewers.

- Depending on the zoning classification, specify a maximum effective impervious cover allowed after construction. Many publications recommend that impervious cover connected directly to the drainage system be limited (see "Reducing Effective Impervious Cover through Conservation Site Design" for specific recommendations). Developers are then free to choose a combination of methods to meet the requirement: an absolute reduction in impervious cover, directing runoff onto depressed landscaped areas, tree credits, and structural BMPs. Consider incentives in the stormwater control calculations to reduce directly connected impervious surfaces.

- For areas experiencing redevelopment, structural stormwater controls may be tied to the impervious area calculations discussed above. Developers have an incentive to reduce impervious area because it may be more cost effective than installing structural stormwater BMPs. Specific recommendations for stormwater ordinances are discussed under option CR3.

- Promote discussions early in the development review process at the sketch plan/conceptual plan level (before developers have spent large sums of money on design and engineering). A number of municipalities around the U.S. have concluded that sketch/conceptual plans are more important in the planning process than preliminary plans because early intervention and change allows greater opportunity to include innovative low impact development designs. Some municipalities have opted to eliminate the final plan and accept the preliminary plan as the final plan as an incentive to developers to participate.

- After the final plan is submitted, require a pre-construction meeting and a site visit to discuss construction issues and pollution prevention.

- Consider incentives in addition to regulations. For example, award density or stormwater control bonuses for reducing impervious cover. Streamline project reviews and waive permit fees when conservation design objectives are met. Tie stormwater fees and/or property taxes to impervious cover and stormwater management practices.

Stormwater and Floodplain Management (CR3) Related Goals: 1, 4, 6, 7, 9, 10 Related Indicators: 1, 2, 12, 13, 15, 19, 20			
What	Who	Where	When
Participate in finalization of the watershed-wide Act 167 plan and model ordinance being developed by Delaware County. Adopt and enforce the model ordinance.	Counties to adopt plan and ordinance first, followed by all municipalities (See Table 7-16)	Entire Watershed	begin within 5 years; update as needed

Table 7-16 identifies the municipalities in the Cobbs Creek watershed that currently have a floodplain protection or stormwater ordinance in place.

Table 7-16 Floodplain and Stormwater Ordinances in the Cobbs Creek Watershed

Municipality	Floodplain Ordinance	Stormwater Ordinance
Colwyn Borough	X	
Darby Borough		
East Lansdowne Borough**		
Haverford Township	X	
Lansdowne Borough		
Lower Merion Township	X	X
Millbourne Borough	X	X
Narberth Borough		
Philadelphia	X	X
Radnor Township	X	X
Upper Darby Township	X	
Yeadon Borough		

*** Note: Ordinances for East Lansdowne Borough were not reviewed for this analysis.*
Source: www.ordinance.com, Delaware Valley Regional Planning Commission

The majority of municipalities in the watershed have adopted ordinances limiting development in the floodplain or designating a floodplain conservation district. The protection offered varies by municipality, but an effective ordinance should place controls on land development within the 100-year floodplain as well as limit development within riparian corridors.

EPA provides a model for a floodplain preservation ordinance at the following website link:

- EPA Model Ordinances

http://www.epa.gov/owow/nps/ordinance/osm1.htm

Led by Delaware County, the four counties in the Cobbs Creek watershed (and the Darby-Cobbs watershed as a whole) are cooperating to develop an official Act 167 Stormwater Management Plan and model ordinance. The model ordinance will specify measures that must be undertaken to promote infiltration, improve water quality, reduce streambank erosion rates, and protect against flooding. These requirements will apply to both new (also called "greenfield") development and redevelopment (including brownfields or former industrial sites), and to both separate-sewered and combined-sewered areas. As of February 2004, the plan and model ordinance were still under development; all counties and municipalities will be invited to provide input before the plan is finalized.

Adoption and implementation of the model ordinance is a critical step that will allow municipalities to begin implementing many of the wet weather management measures mentioned later under Target C. For example, the ordinance will require a specific storage volume to be created on a developed site and will indicate that it must be a BMP capable of water quality treatment. The developer will then consult a stormwater manual designated by the municipality to determine an appropriate BMP and appropriate design criteria.

While many of the state manuals provide excellent guidance for new development, PWD plans to develop a manual with specific guidance for redevelopment projects given local conditions. Some preliminary ideas for this BMP manual are listed below:

<u>Commercial/Industrial Land Uses</u>

1. Use better site design techniques, landscaped areas, and tree credits to decrease impervious cover directly connected to the drainage system.
2. Directly-Connected Parking Lots

- Convert to porous pavement (or other drainage mechanism) and subsurface storage if feasible. If converted, the entire parking lot is no longer considered effective impervious area.
- If porous pavement and storage are not feasible, install a depressed bioretention (and/or porous media filtration) system. If the parking lot area is drained to a bioretention system it is no longer considered effective impervious area.

3. Directly-Connected Rooftops

- If parking lot storage is installed, route rooftop drainage to the storage. The rooftop area will no longer be considered an effective impervious cover if it is drained to the storage.
- If parking lot storage is not feasible, route rooftop drainage to dry wells. If dry wells are not feasible, route rooftop drainage to rain barrels or tanks. In either case, the rooftop is no longer considered an effective impervious area.

3. Other approaches may be proposed and considered on a case-by-case basis.

Residential Land Uses

1. Use better site design techniques, landscaped areas, and tree credits to decrease effective impervious cover.
2. Route roof runoff to dry wells if feasible. If dry wells are not feasible, route rooftop drainage to rain barrels or tanks. In either case, the rooftop is no longer considered an effective impervious area.
3. Other approaches may be proposed and considered on a case-by-case basis.

Industrial Stormwater Pollution Prevention (CR4)
Related Goals: 1, 5, 6, 9, 10
Related Indicators: 1, 2, 3, 4, 7, 8, 9, 10, 19, 20

What	Who	Where	When
Enforcement of NPDES requirements for Industrial Stormwater Management Dissemination of information on spill prevention and pollution prevention plans.	The PADEP is the Designated Authority responsible for issuing, administering, and enforcing NPDES permits Municipalities are responsible for information dissemination.	All sites contributing storm water discharges associated with industrial activity within the watershed	Within 5 years

Industrial stormwater pollution prevention measures can contribute significantly to achieving the watershed plan's wet weather implementation targets. These measures include monitoring and enforcing existing industrial stormwater permit requirements under Phase I of the NPDES program, as well as, Official Industrial Pollution Prevention Plans and Spill Response Actions required by the state. Full implementation of these measures should be monitored and enforced throughout the watershed.

NPDES Industrial Stormwater Permits

All sites contributing storm water discharges associated with industrial activity, defined in federal regulations (40 CFR §§ 122.26(b)(14)(i)-(xi)), are required to be covered under Phase I of the NPDES stormwater program. This includes discharges from any conveyance that is used for collecting and conveying storm water and that is directly related to manufacturing, processing or raw materials storage areas at an industrial plant. This includes, but is not limited to, storm water discharges from industrial plant yards; immediate access roads and rail lines used or traveled by carriers of raw materials, manufactured products, waste material, or by-products used or created by the facility; material handling sites; refuse sites; sites used for the application or disposal of process waste waters; sites used for the storage and maintenance of material handling equipment; sites used for residual treatment, storage, or disposal; shipping and receiving areas; manufacturing buildings; storage areas (including tank farms) for raw materials, and intermediate and final products; and areas where industrial activity has taken place in the past and significant materials remain and are exposed to storm water. The term material handling activities includes storage, loading and unloading, transportation, or conveyance of any raw material, intermediate product, final product, by-product or waste product.

The PADEP is the Designated NPDES Authority responsible for issuing, administering, and enforcing NPDES stormwater permits under the EPA's regulatory provisions set forth in 40 CFR.

Storm water discharges from most industrial facilities are covered under General Permits when they discharge into municipal separate sanitary sewers. General NPDES permits have a fixed term not to exceed 5 years. An operator of a storm water discharge associated with industrial activity which discharges through a large or medium municipal separate storm sewer system shall submit, to the operator of the municipal separate storm sewer system receiving the discharge the following information: the name of the facility; a contact person and phone number; the location of the discharge; a description, including Standard Industrial Classification, which best reflects the principal products or services provided by each facility; and any existing NPDES permit number.

In addition, the operator of a storm water discharge associated with industrial activity covered under a general, group, or individual permit, shall provide the following minimum information (40 CFR § 122.26 (c)(i)):

- A site map showing topography, drainage features, buildings, and areas where materials or activities may contribute pollutants to storm water.
- An estimate of the area of impervious surfaces (including paved areas and building roofs) and the total area drained by each outfall (within a mile radius of the facility) and a narrative description of materials handled or stored as well as measures taken to control pollutants in the runoff.
- A certification that all outfalls that should contain storm water discharges associated with industrial activity have been tested or evaluated for the presence of non-storm water discharges which are not covered by a NPDES permit; tests for such non-storm water discharges may include smoke tests, fluorometric dye tests, analysis of accurate schematics, as well as other appropriate tests. The certification shall include a description of the method used, the date of any testing, and the on-site drainage points that were directly observed during a test;
- Existing information regarding significant leaks or spills of toxic or hazardous pollutants at the facility that have taken place within the three years prior to the submittal of this application;
- Quantitative data based on samples collected during storm events from all outfalls containing a storm water discharge associated with industrial activity for a number of water quality parameters.

Industrial Pretreatment Requirements

Industrial pretreatment requirements are another area where enforcement can result in lower pollutant concentrations in storm water. Under PA Code Title 25 § 94.15, the operator of the sewerage facilities in cases where pollutants contributed by industrial users result in interference or pass through, and the violation is likely to recur, must develop and implement specific local limits for industrial users and other users, as appropriate, that together with appropriate sewerage facility or operational changes, are necessary to ensure renewed or continued compliance with the plant's NPDES permit or sludge use or disposal practices.

Additional Measures

Information on existing pollution prevention plans and spill response requirements should be provided to relevant industries in the watershed as part of the Phase II public education measures.

Industrial Pollution Prevention Plans are one means to prevent spills and accidental releases. Under PA Code Title 25 § 91.34 (Activities Utilizing Pollutants):

- Persons engaged in an activity which includes the impoundment, production, processing, transportation, storage, use, application or disposal of pollutants shall take necessary measures to prevent the substances from directly or indirectly reaching waters of this Commonwealth, through accident, carelessness, maliciousness, hazards of weather or from another cause.
- PADEP may require a person to submit a report or plan setting forth the nature of the activity and the nature of the preventative measures taken. The Department will encourage consideration of the following pollution prevention measures, in descending order of preference, for environmental management of wastes: reuse, recycling, treatment and disposal.

Spill response is another area that can improve wet weather water quality in Cobbs Creek. Spill response requirements are promulgated under PA Code Title 25 and issued under section 5 of The Clean Streams Law (35 P. S. § 691.5).

Under PA Code Title 25 § 91.33 (Incidents Causing or Threatening Pollution):

- If, because of an accident or other activity or incident, a toxic substance or another substance which would endanger downstream users is discharged, it is the responsibility of the person at the time in charge of the substance to immediately notify PADEP by telephone of the location and nature of the danger and, if reasonably possible to do so, to notify known downstream users of the waters.
- In addition to the notices, the person shall immediately take steps necessary to prevent injury to property and downstream users, and within 15 days from the incident, remove from the ground the residual substances to prevent further pollution.

Construction Stormwater Pollution Prevention (CR5) Related Goals: 1, 5, 6, 9, 10 Related Indicators: 1, 2, 3, 4, 7, 8, 9, 10, 19, 20			
What	Who	Where	When
Construction Site Stormwater Program in conformance with Phase II Stormwater Permits • Enact an Ordinance • Review and approve Erosion and Sediment Control Plans • Distribute Educational Materials	All Municipalities required to do Phase II permit (see Table 7-4)	N/A	Five year program associated with stormwater permit (See Table 7-15)

In accordance with the Cobbs Creek Plan's stated purpose of integrating various existing programs, and to avoid duplication of effort, the recommended implementation plan follows the Stormwater Management Program Protocol ("Protocol") to meet the six minimum control measures required of municipal permittees under the Phase II NPDES Stormwater Regulations (found at 40 CFR §§ 122.26 – 123.35). One of the six minimum controls is a Construction Site Stormwater (CSS) Program.

In Pennsylvania, two programs currently exist that address stormwater runoff from construction activities: 1) the Erosion and Sediment Control Program under 25 Pa. Code Chapter 102, and 2) the NPDES Stormwater Construction Permit Program.

The Erosion and Sediment Control Plan submitted by the developer must contain BMPs appropriate to the site and the surrounding area that might be impacted by the construction activities, as well as for post-construction runoff. Construction activity-related BMPs are available to developers and others through the Erosion and Sediment Pollution Control Program Manual, (PADEP ID: 363-2134-008) on PADEP's website, www.dep.state.pa.us, directLINK "stormwater," and available at the County Conservation District (CCD).

The CSS program can be summarized as consisting of the following steps:

- Enact, implement and enforce a stormwater control ordinance using PADEP model language (a model PADEP is available),
- Coordinate the review and approval of Erosion and Sediment Control Plans with the County Conservation District(s) (CCD) or PADEP for any earth disturbance of one acre or more causing runoff or any earth disturbance five acres or more. Make approval of the Erosion and Sediment Control Plan a prerequisite for the formal approval of land development and redevelopment plans or the issuance of building permits, and

- Distribute educational materials to land developers with the applications for building permits and other land development/redevelopment.

Municipalities must have an agreement with their local CCD that addresses these reviews and permitting requirements. This agreement ensures the close coordination between the municipality and the CCD on these important issues affecting water quality. Note that a NPDES Stormwater Construction Permit is required for earth disturbance activities where the construction disturbs five acres or more, or there is a discharge from a site to the MS4 where earth disturbance is one acre or more.

In most cases, the County Conservation District implements these two programs, and PADEP is responsible for implementing and enforcing these programs in cases where the County does not have this responsibility. By requiring review and approval of Erosion and Sediment Control Plans by the CCD or PADEP (and proof of NPDES Stormwater Construction Permits where required), and by coordinating building permit and other land development permits or approvals with the CCD (or PADEP in some cases), municipalities will meet MS4 permit requirements for this component of the Construction Stormwater Runoff Management Minimum Control Measure. Utilizing this existing statewide program, the municipality avoids the need to do a duplicative, independent review of every Erosion and Sediment Control plan.

All municipalities in the watershed are required to fulfill this aspect of the stormwater regulations. Table 7-15 shows the schedule for implementation.

Table 7-15 Implementation Schedule for Construction Stormwater Pollution Prevention

PERMIT YEAR	*IMPLEMENTATION SCHEDULE*	
	Construction Site Stormwater Program	**Developer Education**
Year 1	• Ordinance: enact an ordinance requiring: • the review and approval of Erosion and Sediment Control Plans by the local County Conservation District or PADEP • for any earth disturbance one acre or more with runoff to the MS4, or five acres or more regardless of the planned runoff, and • as a prerequisite for the formal approval of land development plans or the issuance of building permits • Process: Establish an agreement with the local CCD for the review and approval of Erosion and Sediment Control Plans for all earth disturbance activities equal to or greater than one acre with runoff to the MS4 (or five acres or more regardless of the planned runoff) • Standard: Require that the Erosion and Sediment Control Plans be developed in accordance with the requirements of Chapters 102 (erosion and sedimentation) of the PADEP regulations	Meet permit requirements and measurable goals for Year 1 under Public Education and Outreach minimum control measure.
Years 2-5	Implement the ordinance and agreement for review of Erosion and Sediment Control Plans	Meet permit requirements and measurable goals for Year 2 under Public Education and Outreach minimum control measure.

Post-Construction Stormwater Runoff Management (CR6)
Related Goals: 1, 5, 6, 9, 10
Related Indicators: 1, 2, 3, 4, 7, 8, 9, 10, 19, 20

What	Who	Where	When
Post-Construction Stormwater Runoff Management in conformance with Phase II Stormwater Permits • Enact Ordinance • Coordinate Review and Approval of Plans • Ensure BMP Maintenance	All Municipalities required to do Phase II permit (see Table 7-4)	N/A	Five year program associated with stormwater permit. (See Table 7-16)

In accordance with the Cobbs Creek Plan's stated purpose of integrating various existing programs, and to avoid duplication of effort, the recommended implementation plan follows the Stormwater Management Program Protocol ("Protocol") to meets the six minimum control measures required of municipal permittees under the Phase II NPDES Stormwater Regulations (found at 40 CFR §§ 122.26 – 123.35). One of the six minimum controls is a Post-Construction Stormwater Runoff Management Program. The program can be summarized as consisting of the following steps:

- Enact, implement and enforce a stormwater control ordinance using PADEP model language,
- Coordinate the review and approval of post-construction BMPs simultaneously with the review and approval for construction Erosion and Sediment Control Plans as described in the Construction Minimum Control Measure, and
- Ensure long-term operation and maintenance of the BMPs

PADEP links management of post-construction run-off with the Construction Minimum Control Measure component discussed above. Approvals for construction activities will be dependent on how post-construction issues are addressed. For example, if an applicant's plan for a land development or redevelopment project adequately addresses stormwater issues during construction but does not do so for post-construction impacts, then it must not be approved until the post-construction issues are addressed.

Ordinance

Municipalities must enact, implement and enforce a stormwater control ordinance using PADEP model language. The ordinance must address the proper standard for BMPs and operations and maintenance requirements for the BMPs. The ordinance will apply a statewide post-construction requirement until the water quality-based

Act 167 Plan is adopted by the County and implemented by the municipality, at which time the municipality will need to amend it to include those requirements.

The ordinance should require that all development and redevelopment activities with earth disturbance one acre or more with runoff to the MS4 (or five acres or more regardless of the planned runoff), be conducted in accordance with the ordinance. No formal approval of land development plans or issuance of building permits should occur without municipal approval of post-construction stormwater controls. A Model Ordinance is available from PADEP.

Implement Program

The municipalities must commit municipal resources or establish an agreement with the local CCD or other service provider (e.g., municipality's consulting engineer) for coordination of post-construction BMP approvals. There must be a process to review the post-construction controls in conjunction with the review process for construction approval.

Ensure that the post-construction controls will meet state water quality requirements.

The requirements for post-construction controls depend upon the status of the Act 167 Stormwater Management planning in the watershed. Where a water-quality-based Act 167 plan has been completed (or updated), those local watershed requirements apply. Otherwise, statewide requirements must be implemented.

It is the municipalities' responsibility to ensure that the BMPs meet the water quality requirements. However, PADEP will be reviewing post-construction plans for Individual permits, and some County Conservation Districts have the expertise to conduct the reviews under an agreement with the municipality similar to that for the Construction Minimum Control Measure.

Operation and Maintenance of Post-Construction BMPs

It is the municipalities' responsibility to ensure that the post-construction BMPs required and approved pursuant to the program are constructed, operated and maintained. Many BMPs may be "non-structural"; they will require no operation or maintenance. Examples are use of open space and vegetated buffers in development design, minimization of soil disturbance and compaction during construction, and minimization of directly-connected impervious areas. Other BMPs - "structural BMPs" - will require proper operation and maintenance. Examples include wet ponds, grassed swales, infiltration basins and bioretention areas.

Municipalities will need to have a monitoring program that ensures that the post-construction BMPs are constructed, operated and maintained, within the first permit term of 5-years.

The program must have two elements:

- Implementation: ensure installation of the BMPs as designed. Coordinate the monitoring with the CCD, especially where a permit has been issued.

- Operation and Maintenance: some of the structural BMPs will require maintenance over time to be effective. Municipalities must have a system to monitor these BMPs. If any BMPs are not operated or maintained and are ineffective, municipalities must develop a plan to address them. The PADEP Model Ordinance provides legal tools to accomplish this.

All municipalities within the Cobbs Creek Watershed must carry out this program (see Table 7-4). The schedule for full implementation is provided, in accordance with the new Phase II rules, in Table 7-16.

Table 7-16 Post-Construction Stormwater Runoff Management: Implementation Schedule

PERMIT YEAR	*IMPLMENTATION SCHEDULE*	
	Stormwater Management Program	Long Term Operation and Maintenance
Year 1	• Ordinance: Enact an ordinance requiring: • No formal approval of land development plans or issuance of building permits without municipal approval of post-construction stormwater controls • Development and redevelopment activities with earth disturbance of one acre or more with runoff to the MS4, or five acres or more regardless of the planned runoff, be conducted in accordance with the ordinance • Process: Rely on PADEP review of permits where applicable; where no PADEP review of post-construction controls is conducted, use municipal resources, or establish an agreement with the local CCD or other service provider (e.g., municipal engineer), for coordination of post-construction BMP approvals • Standard: Require post-construction structural and non-structural BMPs be designed, constructed and maintained to meet (1) the requirements of the approved Act 167 plan and the municipal ordinance, or until such Act 167 Plan is in place, (2) the PADEP statewide water quality requirements.	• Ensure that stormwater BMPs are built, operated and maintained as designed
Years 2-5	• Implement the ordinance and post-construction BMP approval process	• Ensure that stormwater BMPs are built, operated and maintained as designed

Pollution Trading (CR7) Related Goals: 1, 2, 5, 6, 7, 9, 10 Related Indicators: 1, 7, 8, 9, 10, 11, 12, 13, 14, 16, 19, 20			
What	Who	Where	When
Investigate Opportunities for Pollution Trading; potentially use as part of the framework for distributing BMPs throughout the watershed	All Municipalities	Cobbs Creek Watershed	Long Term, following establishment of TMDLs.

Pollution trading presents an intriguing option to mitigating the impacts of stormwater on Cobbs Creek. Trading could focus on sources of stormwater, TSS, Fecal Coliform, and Cryptosporidium, and could occur between municipalities within the watershed. In Cobbs Creek, only trading between non-point sources is feasible in the absence of point sources, which presents a greater challenge than point source trading. Trading could only occur between municipalities and or private entities responsible for controlling stormwater.

Trading under TMDLs is not yet well established, however, some general guidelines exist. Usually under trading arrangements, the total pollutant reduction must be the same or greater than what would be achieved if no trade occurred. A “buyer” and “seller” would agree to a trade in which the buyer compensates the seller to reduce pollutant loads. Buyers would purchase pollutant reductions at a lower cost than what they would spend to achieve the reductions themselves. Sellers would provide pollutant reductions and receive compensation. Stormwater sources could negotiate trades bilaterally or may trade within the context of an organized program. Sources could negotiate prices or exchange rates for loading reductions themselves, or they may face those established by a market.

To form a tradable allowance market, a few conditions must exist.

- Mitigation measures must show a variety of unit costs, some high, some low. In the case of Cobbs Creek, there are potential cost differences between types of BMPs, and potential cost differences based on the placement of the BMP (either in a CSO area or in a separate storm sewered area).
- All participants are price conscious and seek the lowest cost alternative. This is generally true; however, issues of jurisdiction may impede trading. For example, a municipality may not wish to install a BMP in another municipality.
- An authority exists for the management of stormwater that has determined the ecological limits of Cobbs Creek and can facilitate trading credits. At this time, no such authority exists, however elements of this watershed plan do address this issue through Target C objectives.
- The authority can compute appropriate allowance prices (based on the private and public cost of stormwater management) and can operate as a clearinghouse

for purchase and sale of allowances among participants.

- Runoff is apportioned to each parcel based on “natural” runoff rates, and additional runoff must be controlled, either by use of BMPs, or by buying allowances to cover their storm-water management responsibility. This aspect would be an integral part of any TMDL, which would establish total loads and apportion reductions.

In general, trading will not occur except in the context of a TMDL. Under the TMDL, total loads would be established and apportioned based on ecological impact and assessment of current loads. For Cobbs Creek, TMDLs have not been established, and trading remains a potential, future activity. (Thurston, Goddard, Szlag, Lemberg, 03; USEPA, 1996)

Use Review and Attainability Analysis (CR8)
Related Goals: 5, 6, 7, 9, 10
Related Indicators: 7, 8, 9, 10, 11, 12, 13, 14, 19

What	Who	Where	When
Coordinate water quality standards review and revision with PWD's CSO LTCP	EPA and PADEP in partnership with PWD and other permitted dischargers	Cobbs Creek and tributaries	within 5 years (1 NPDES CSO permit cycle)

The CSO Policy calls for the development of a long-term control plan (LTCP) which includes measures that provide for compliance with the Clean Water Act, including attainment of water quality standards. The CSO Policy provides that "development of the long term plan should be coordinated with the review and appropriate revision of water quality standards (WQS) and implementation procedures on CSO-impacted receiving waters to ensure that the long-term controls will be sufficient to meet water quality standards" (59 FR 18694).

As part of a renewed focus on this commitment, EPA has issued a guidance document, Coordinating CSO Long-Term Planning with Water Quality Standards Reviews (EPA-833-R-01-002). This document lays a strong foundation for integrating water quality standards reviews, implementation of high-priority CSO controls, and development of well-designed and operated LTCPs that support attainment of water quality standards without causing substantial and widespread economic and social impacts. In addition to CSO impacts, many of the processes, procedures and ideas presented can be used to address wet weather issues such as stormwater and other point and nonpoint sources on a watershed basis. An iterative, phased implementation of CSO controls fits well with the watershed approach. Because Cobbs Creek is impacted by a variety of sources, and because some existing water quality criteria may be difficult to meet (e.g., bacteria levels during wet weather), it is an appropriate candidate for designated use review and possible revision.

Depending on the impacts, possible water quality standards revisions could include:

1. Re-evaluating recreational uses and applying criteria for bacteria at the point of contact rather than at the end-of-pipe,
2. Segmenting the water body to preserve recreation in areas where it actually occurs, and
3. Revising the use by creating subclasses to recognize intermittent exceedances of bacteriological criteria.

EPA identifies 11 steps to integrate use review into an LTCP. Steps 1 through 5 address the completion and initiation of an LTCP, steps which have been completed on the Cobbs. Steps 6 through 9 specifically address incorporating use review in the LTCP as discussed in more detail below. Steps 10 and 11 consist of LTCP implementation and compliance monitoring.

Step 6 - Review and accept draft LTCP and evaluate the attainability of water quality standards; implement and, through water quality monitoring, evaluate effectiveness of priority controls (e.g., for sensitive areas) and controls common to all alternatives.

The use review processes begins when watershed communities and the team coordinating LTCP implementation approach the state to discuss possible changes. EPA regulations at 40 CFR 131.10(j) require a Use Attainability Analysis (UAA) whenever a state proposes to reduce the level of protection for a water body. A UAA is a structured scientific assessment of the physical, chemical, biological, and economic factors affecting the attainment of the use. If the State Water Director agrees that a UAA is appropriate, UAA guidance is available from EPA.

If sufficient data are available, the State Water Director evaluates the attainability of the applicable water quality standards. The data collected and analyses conducted by the CSO community may be sufficient to justify a water quality standards revision, or may show that a water quality standards revision is not justified. If the regulating authority agrees that the data and analyses support a water quality standard revision (recognizing the revision may produce more or less stringent standards), this represents a commitment from the regulating authority to proceed with proposing water quality standards revisions. If the data and analyses show that currently applicable water quality standards can be attained, and that revisions to the water quality standards are not justified, the regulatory authority notifies the community and the coordination team.

If sufficient data are not available to evaluate the attainability of the use, the state water director, in consultation with the coordination team, identifies the parameters for which additional information is needed. If the community wishes to pursue a water quality standards review, these additional data should be collected while implementation of the LTCP is initiated.

Step 7 - Propose revisions and revise WQS, if needed.

Once the community has implemented priority CSO controls, the state may determine that a water body has the potential to support improved aquatic life. Under this circumstance, the state would upgrade the aquatic life use for the water body. In other cases, the state may determine that the recreational uses are not fully attained all the time, and may refine the recreational uses to reflect the maximum level of control from a well-designed and operated control program that does not cause substantial and widespread economic and social impact.

EPA's water quality standards regulations at 40 CFR 131.21(b) require that any analyses, including the UAA, used in support of the water quality standard revision be made available for public review and comment at the time the revisions are proposed. Subsequent to public review and comment and appropriate revision, the state submits the revision, supporting analyses and public comments to EPA for review.

Before the revisions in the water quality standards may be used for CWA programs, including TMDLs and NPDES permits, EPA must approve the state-adopted water quality standards revision (see 65 FR 24641, April 27, 2000). Where there has been close coordination and cooperation, the approval process is more likely to proceed expeditiously. EPA is expected to approve a state's new or revised standard within 60 days, or disapprove within 90 days.

Step 8 - Revise LTCP, as appropriate.

If the water quality standards decisions differ from those that the CSO community anticipated, or if the previously implemented controls have not performed as predicted, the community would have to revise the draft LTCP.

Step 9 - Review and approve LTCP, and modify permit.

The NPDES authority coordinates the review of the revisions and, if appropriate, approves the final LTCP, which provides that CSO discharges do not contribute to exceeding of water quality standards or noncompliance with other CWA requirements. The NPDES authority issues a permit or administrative order, or proceeds with revisions to an enforceable order requiring implementation of the approved LTCP.

Watershed-Based National Pollutant Discharge Elimination System (NPDES) Permitting Implementation (CR9) Related Goals: 1, 5, 6, 8, 9, 10 Related Indicators: 2, 7, 8, 9, 10, 11, 16,19, 20			
What	Who	Where	When
Explore approaches to developing NPDES permits for multiple point sources located within the watershed to meet the goals of this integrated watershed management plan.	PADEP	Watershed-wide	Long term

Source: Watershed-Based National Pollutant Discharge Elimination System (NPDES) Permitting Implementation Guidance, December 2003 (EPA 833-B-03-004)

Watershed-Based NPDES Permitting

Watershed-based NPDES permitting is an approach to developing NPDES permits for multiple point sources located within a defined geographic area (watershed boundaries) to meet water quality standards. This approach, aimed at achieving new efficiencies and environmental results, provides a process for considering all stressors within a hydrologically defined drainage basin or other geographic area, rather than addressing individual pollutant sources on a discharge-by-discharge basis. This plan provides the first steps in this process. In the long term, a watershed-based permit in the Cobbs system can provide the regulatory framework for implementation of this integrated watershed management plan.

Watershed-Based NPDES Permitting Related to Other Watershed Management Activities

A truly comprehensive watershed management approach should bring together key programs under the Clean Water Act, such as the NPDES Program, the TMDL Program, the Section 319 Nonpoint Source Program, and Section 404 Wetlands Permitting, as well as the Source Water Assessment Program under the Safe Drinking Water Act. Watershed-based NPDES permitting can be another tool to facilitate comprehensive programmatic integration at a watershed level and ensure that permitting activities tie into existing watershed management efforts.

Developing and Implementing a Watershed-Based NPDES Permitting Approach

EPA's suggested process for developing and implementing a watershed-based NPDES permitting approach consists of the following six steps. This integrated watershed management plan fulfills most requirements of the first three steps.

Step One - Select a Watershed and Determine the Boundaries
Step Two - Identify Stakeholders and Facilitate Their Participation

Step Three - Collect and Analyze Data for Permit Development
Step Four - Develop Watershed-Based Permit Conditions and Documentation
Step Five - Issue Watershed-Based NPDES Permit
Step Six - Measure and Report Progress

Step One - Select a Watershed and Determine the Boundaries

Watershed boundaries will influence the scale and scope of every aspect of the process, particularly stakeholder involvement and data collection. The physical characteristics of the area and the jurisdictional limits affect the process for defining the boundaries of a watershed. The larger the watershed boundaries, the larger the scope of complexities such as multi jurisdictional issues, data collection and management, stakeholder involvement, and funding. Those initiating the process for watershed-based NPDES permitting should keep these factors in mind when defining watershed boundaries. The watershed should be of a manageable size to allow for integration and coordination of water quality program activities with the permitting process. This step is complete for the Cobbs system.

Step Two - Identify Stakeholders and Facilitate Their Participation

Successful watershed management efforts require identifying and involving the key players, or stakeholders, that should participate in the process from the outset because they influence and are affected by watershed decisions. Early and continuous stakeholder involvement can garner stakeholder participation and support on potentially contentious decisions. Stakeholder involvement is particularly important in watershed-based permitting, where sustained voluntary participation of nonpoint sources might be the key to meeting water quality goals, regardless of the watershed-based permit limits reflected in NPDES permits for point sources.

The stakeholder group could serve as the collective decision making body for some aspects of the watershed-based NPDES permitting effort (e.g., goal setting) or as a group that simply provides advice and guidance to the permitting authority. Given the various backgrounds, interests, and areas of expertise among the group, it is important that everyone has a general understanding of the NPDES program and the watershed-based NPDES permitting concept.

The Darby-Cobbs Watershed Partnership provides the foundation of this stakeholder group. In the long term, a more formal group with clearly defined responsibilities may need to be formed. This possibility is discussed in the institutional arrangements section of this plan.

Step Three - Collect and Analyze Data for Permit Development

A watershed-based permit addresses multiple sources within the watershed. This data collection and analysis process will be similar to that used in developing TMDLs for impaired water bodies. Data collection and analysis for watershed-based permitting, however, is further complicated by the fact that the analysis might address not only multiple sources but also multiple pollutants. This section lists questions stakeholders should consider when conducting initial data collection and analysis, and lists potential sources for those data. The water quality data and pollutant loading model results produced as part of this plan form the foundation for step 3.

Step Four - Develop Watershed-Based Permit Conditions and Documentation

In addition to individual monitoring and reporting requirements, watershed-based NPDES permits may contain watershed-wide requirements that could be applied to multiple dischargers in the watershed. For example, permittees might form a monitoring consortium to collect ambient water quality data that supplements end-of-pipe monitoring data required by NPDES permits. Through a monitoring consortium, permittees could generate data that could be used in Clean Water Act section 305(b) water quality reports and other watershed assessments. Depending on the structure of the watershed-based permit(s), watershed-wide requirements might be coordinated across several individual permits or contained in a single permit that applies to multiple sources. EPA has developed guidance on monitoring consortiums that might be helpful to permitting authorities in developing watershed-wide monitoring and reporting requirements (USEPA 1997). Although no mechanism currently exists in Pennsylvania to implement watershed-based permitting, the CCIWMP presents sufficient information to develop permit conditions because there are no point sources other then stormwater discharges in the watershed.

Step Five - Issue Watershed-Based NPDES Permit

The most important factors affecting the process for issuing a watershed-based permit will be the administrative requirements and the type or structure of the permit. Permitting authorities, permittees, and other stakeholders need to be familiar with the specific administrative requirements for permit issuance in their jurisdiction (in accordance with 40 CFR Part 124). Administrative requirements address public notice and comment; public hearings; EPA and state or tribal permit review; actions required for final permit issuance (e.g., approval of the state environmental board); and requirements for modification or for permit appeal after final permit issuance. These requirements vary by jurisdiction.

Watershed-based NPDES permitting approaches will vary from watershed to watershed. As a result, the types of permits developed through a watershed-based permitting process will vary. There is no single model or example of what an NPDES permit developed through watershed-based permitting should look like. Possible watershed-based permitting mechanisms are variations of general and individual point source NPDES permitting approaches.

Step Six - Measure and Report Progress

The ultimate goal of watershed-based permitting is to ensure that receiving water quality is protected through the implementation of an integrated, holistic approach. Progress toward attaining this overall goal can be measured at both the watershed and permit levels. The monitoring and reporting recommendations made in this plan form the foundation for step 6.

Potential Benefits and Challenges of Watershed-Based NPDES Permitting

A number of benefits can be expected from watershed-based permitting. Although the specific benefits will be unique to each project, they will likely include a mix of environmental and administrative benefits such as; integration of water-related programs, targeted and maximized use of resources to achieve greatest environmental results, local cooperative efforts, watershed-wide monitoring plans, and trading and other market-based strategies.

Like the benefits of watershed-based permitting, the challenges of implementing this approach will be unique to each watershed and each permit. Some challenges would be; expanded stakeholder involvement, integrating nonpoint sources, need for more flexible program infrastructure, conflicting jurisdictional requirements, and making an initial investment.

7.3.2 Public Education and Volunteer Programs

Public Education and Volunteer Programs (CP1) Related Goals: Related Indicators:			
What	Who	Where	When
See Public Education and Volunteer Programs under Target A options.	All Municipalities	All Municipalities	Short-term: first 5 years coinciding with the stormwater permit (See Table 7-5)

7.3.3 Municipal Measures

Sanitary Sewer Overflow Detection (CM1) Related Goals: 6, 9, 10 Related Indicators: 10, 11, 19, 20			
What	Who	Where	When
SSO Detection Program	Municipalities with separate sewer systems in Cobbs Creek (see Table 7-4)	See Figure 7-2 (map of separate sewers and responsible authorities)	Permanent ongoing program should be part of each agencies program

Discharges from sanitary sewers to Cobbs Creek during wet weather have been identified as a serious concern. Some of the techniques used for inspection of sewer lines can also be used for identifying potential locations of SSOs. Some of the most effective techniques for identifying the location of SSOs are listed below. (Source: Protocols for Identifying Sanitary Sewer Overflows, American Society of Civil Engineers EPA Cooperative Agreement #CX 826097-01-0, June 2000)

Sewer System Mapping

GIS maps of the sewer system should be developed in all municipalities. These maps serve as the basis for hydraulic modeling, and are key to many of the techniques described below.

Customer and/or Public Complaint

When a basement backup occurs or an SSO occurs in an area exposed to view, it is almost certain that someone will call the sewerage agency and report the incident. The agency should have a plan in place to investigate the reported SSO, find its cause, and take remedial measures to avoid recurrence of the SSO.

Visual Inspections after Overflows

Visual inspections can be used to confirm the occurrence of SSOs at suspected locations. The agency should develop a list of such locations and update it periodically. Immediately following a major storm, an inspection team should be sent to investigate these locations. A visual inspection program can be enhanced by encouraging participation of the public through providing opportunities for the public to become part of the solution.

Scheduled Maintenance Inspection

Municipal sewerage agencies should be performing routine maintenance inspections of their system. While the maintenance crew is performing the inspection, it can also look for signs of SSO. SSOs are most likely to occur pumping stations, manholes, stream crossings, and cleanouts.

GIS-Based Analysis of Past SSOs

GIS analysis can answer questions related to location, condition, trends, patterns, and modeling. Listed below are some typical questions that GIS can answer:

- What exists at a given location?
- Where is the location of an object or outcome with a number of specific characteristics?
- What has changed over a given period?
- What is the spatial distribution of areas with a certain attribute?

Sanitary Sewer Management Systems

A Sanitary Sewer Management System (SSMS) can be used to store, organize and analyze large quantities of data associated with sewer system operation, maintenance, inspection, modeling and rehabilitation. The SSMS may include the following modules:

- Inventory Module
- Flow Module
- Modeling Module
- Inspection Module
- Maintenance Module
- Rehabilitation (CIP) Module
- Mapping Module

Analysis of the data in the SSMS can reveal many problem areas, trends, and patterns. For example, the database can be searched to develop a list of lines with flat slopes or areas where frequent maintenance is needed. Another application of the SSMS is analysis of historical data.

Flow Monitoring

Flow monitoring at strategic locations may be used to identify potential locations of SSOs. Flow monitors can be installed in open channels and pumping stations to obtain the data necessary for proper system evaluation. In conjunction with flow monitoring, rain gauges should also be installed. Many open channel temporary flow meters have both velocity and depth measuring sensors. Municipalities are encouraged to make use of the existing rain gauge network in the Cobbs Creek watershed.

Flow data can be used to determine the average daily flow, the infiltration rate, and the inflow rate. The rain gauge data can be used to determine the recurrence interval or severity of the storm event (for example, 5-year) that caused the inflow. The flow data will also indicate whether a surcharge occurred during the flow monitoring period.

Monitoring of Receiving Stream for Sewage Indicators

This technique may be used for identifying the locations of dry weather SSOs. Samples from a nearby stream are taken at regular intervals along the stream and tested for fecal coliforms. Significant presence of these bacteria could be an indication of sewage leaking from the sewer line into the stream.

Closed Circuit Television (CCTV) Inspection

CCTV inspection has been widely used for inspection of sewer line interiors. The final product of a CCTV inspection is videotape and a field log prepared and narrated by an operator. The videotape provides a visual and audio record of problem areas in the sewer line. Evaluation of the CCTV records help identify structural problems; locate leaking joints and non-structural cracks, blockages, and dropped joints; and identify areas of root intrusion.

Sewer Scanner and Evaluation Technology Surveys (SSET)

The SSET is a new pipeline inspection technology developed in Japan. The equipment consists of a scanner, a CCTV, and a three-axis mechanical gyroscope. The mechanics of placing the SSET in the sewer line are similar to those of CCTV inspection. The images produced by SSET are of higher quality than CCTV images. Interpretation of the results is done in the office by an engineer rather than in the field by a technician. This increases the speed of field operations and reduces the cost.

Surcharge Level Alarms/Remote Monitoring

These devices can be placed at strategic locations in the manholes and pumping stations. Once the flow reaches a certain elevation, the alarm goes off and sends a signal to a control center via a telephone line or SCADA system. The sewerage agency should have a plan in place to respond immediately to such alarms. In addition to taking appropriate action, the responding agency should also record the event in a database.

Dye Tracing

Dyed water testing consists of dye tracing or flooding, and is done to locate possible sources of inflow such as area drains or catch basins suspected of being connected to the sewer line, or sources of rainfall-induced infiltration/inflow which indirectly contribute to the flow in the sewer line through the soil and pipe cracks. Dye testing is normally used to complement smoke testing of suspect areas. The downstream manhole is monitored to see if the dye water injected into an outside source such as a downspout has found its way into the sewer system. Color CCTV may also be used for locating problem areas after the dye enters the pipeline through the surrounding soil. Figure 5-4 is a sample form for recording the results of dye water inspection.

Smoke Testing

The purpose of smoke testing is to locate rainfall-dependent I/I sources which could lead to SSOs during a storm events. Public notification is an important and critical element of any smoke testing program. Specific I/I sources detected by smoke testing includes roof, yard, and area drain connections; catch basins; and broken service lines. The testing procedure consists of pumping non-toxic smoke through a manhole into the sewer pipe for distances up to 600 ft. The smoke will surface through open breaks in the pipe connections. All such sources are photographed and documented.

Aerial Monitoring

Aerial monitoring by helicopter may be used to gain a general understanding of conditions along a sewer line which may lead to an SSO. For example, washout may expose a section of pipe, which would then be at risk of damage and subsequent SSO. Examples of features which may be observed during such monitoring include manholes with broken or missing covers and sewer lines exposed by erosion.

Monitoring of Grease Buildup

A significant cause of SSOs during dry weather is sewer stoppages resulting from grease buildup. Such stoppages occur most frequently in downtown areas where restaurants are major sources of flow in the sewer system. A list of locations of grease buildup should be developed and these locations should be regularly inspected. Grease buildup can be prevented by enforcing grease ordinances, by effective pretreatment programs, and by promoting public education. The grease accumulations can be removed using the many available cleaning techniques, such as bucket machines with brushes, power rodders, and high velocity jet cleaners. Bioaugmentation, which involves the addition of bacteria cultures to sewers to speed up the breakdown of grease deposits, can also be effective.

Pump Station Inspection

Pump station failures can lead to significant SSO problems. Such failures can be avoided by regular inspections. The frequency of inspections may vary from once a day to once a month, depending on the size and criticality of the station, and reliance on monitoring by means such as the SCADA system.

Manhole Inspection

Manhole interiors are inspected for physical soundness for evidence surcharging such as high water marks on manhole walls. The observed defects should be compiled into a database that will be used to estimate the I/I attributable to each manhole and to establish manhole maintenance and rehabilitation program.

Line Lamping

Line lamping is done in conjunction with manhole inspection by inspecting the interior of the sewer lines connected to the manhole using an artificial light and a mirror. Lamping helps identify pipe defects and provides a basis for selecting sewers for television inspection.

Building Inspection

Building inspections are conducted to investigate extraneous flow from connections to sump pumps, foundation drains, downspouts, or leaking laterals. Building inspections should include investigation of the causes of basement backups.

Ground Penetrating Radar

Ground penetrating radar uses the transmission and reflection properties of an electromagnetic wave passing through the soil to determine soil properties and the depth and extent of subsurface objects. The speed and amplitude of the electromagnetic wave are dependent on the moisture content of the soil. This principle can be used to detect leaking joints in the line and voids around the pipe, which may be caused by soils being washed out. In such locations, the signal will be delayed because the speed of the wave will be reduced, and the amplitude of the wave will be attenuated.

Soil Moisture and Temperature Monitoring

When the ground is relatively dry, a larger portion of the rainfall will penetrate the soil, which will result in a decrease of groundwater to sanitary sewers. However, as the soil moisture increases, the amount of infiltration to sewers increases. For this reason, the impact of subsequent storm will be more severe: while the system did not overflow during the first storm, it will do so during the second storm, although the second storm of smaller intensity than the first. By monitoring the soil moisture and temperature, it may be possible to develop a measure for assessing the occurrence of SSOs.

Inspections of Stream Crossings and Parallel Lines

Pipes running alongside or crossing streams are often vulnerable to SSOs. If the sewer is buried under the streambed, the scouring action of the stream bed will eventually expose it, causing the pipe to lose its soil support. The pipe segments may move under the water pressure and joints may open, or the pipe may become exposed as a result of bank erosion. Any such openings admit significant amounts of flow, which may exceed the capacity of the sewer pipe. Stream crossings that include inverted siphons often become clogged with accumulations of silt and debris, which may cause an overflow upstream. The foundations of aerial stream crossing piers are also subject to scouring and may lead to foundation failure of the sewer line.

Sewer pipes that cross or parallel streams should be inspected to ensure that they are not broken or cracked. The manholes on each side of the stream should be checked for excess flow, which would indicate a leaking sewer under the stream. Since these sewers are usually in remote areas, they are vulnerable to vandalism and can overflow undetected for long periods.

All municipalities in the Cobbs Creek watershed should have a routine and effective SSO detection program. Once SSOs are found and the cause determined, proper measures to eliminate the SSO should be taken.

Figure 7-2 shows the areas where separate sanitary sewers exist. All municipalities with separate sanitary sewers are responsible for developing an effective SSO detection program.

Sanitary Sewer Overflow (SSO) Elimination: Structural Measures (CM2)
Related Goals: 6, 9, 10
Related Indicators: 10, 11, 19, 20

What	Who	Where	When
Implement a CMOM program (option AM1). Update and implement official Act 537 Sewage Facilities Plans.	Municipalities with separate sewer systems in Cobbs Creek (see Table 7-4)	See Figure 7-2 (map of separate sewers and responsible authorities)	Short-term (within 5 years of SSO detection)

Discharges to waters of the United States from municipal sanitary sewer collection systems are prohibited, unless authorized by an NPDES permit. Permits authorizing discharges from such systems must contain technology-based effluent limitations, based upon secondary treatment and applicable water quality standards. NPDES permits for municipal wastewater treatment plants should require record-keeping and reporting of overflows that result in a discharge. Permits should also contain requirements for operation and maintenance of the sanitary sewer collection system.

The EPA and PADEP are continuing to address SSO problems with compliance assistance and enforcement in accordance with the Compliance and Enforcement Strategy Addressing Combined Sewer Overflows and Sanitary Sewer Overflows, issued April 27, 2000. In addition to the national policy, Act 537, enacted by the Pennsylvania Legislature in 1966, requires that every municipality in the state develops and maintains an up-to-date sewage facilities plan. The main purpose of a municipality's sewage facilities plan is to ensure that the sewage collection and treatment systems have adequate capacity to convey present and future to sewage flows to a wastewater treatment facility. Official plans contain comprehensive information, including:

- The location of treatment plants, main intercepting lines, pumping stations and force mains, including their size, capacity, point of discharge and drainage basin served (preferably in a GIS format).
- Descriptions of problems with existing sewerage facilities and operation and maintenance requirements
- Planning objectives and needs
- Physical description of planning area
- Evaluation of existing wastewater treatment and conveyance systems
- Evaluation of wastewater conveyance and treatment needs

EPA has developed a comprehensive management framework called Capacity, Management, Operations, and Maintenance (CMOM) to assist municipalities in developing more comprehensive sanitary sewer system management programs. A

CMOM program, as described in option AM1, helps to prevent SSOs. Once a recurring SSO is detected using the methods recommended under option CM1, measures must be taken to eliminate the discharge.

Reduction of Stormwater Inflow and Infiltration (RDII) to Sanitary Sewers (CM3) Related Goals: 6, 9, 10 Related Indicators: 10, 11, 19, 20			
What	Who	Where	When
RDII Reduction Program	Municipalities with separate sewer systems in Cobbs Creek (see Table 7-4)	See Figure 7-2 (map of separate sewers and responsible authorities)	Short-term

Where significant RDII is detected, measures can be taken to seal the sanitary sewer system to reduce inflow of stormwater and groundwater. These measures are discussed in detail under option AM3, sanitary sewer rehabilitation.

Combined Sewer Overflow (CSO) Control Program (CM4) Related Goals: 5, 6, 9, 10 Related Indicators: 7, 8, 9, 10, 11, 19, 20			
What	Who	Where	When
Nine Minimum Controls Long Term Control Plan (LTCP) Capital Projects Watershed Plan Development	Philadelphia Water Department (PWD)	Philadelphia combined sewer system (Figure 7-14)	NMCs complete and ongoing RTC short-term (within 5 years)

The fundamental goal of the Philadelphia Water Department's (PWD) combined sewer overflow (CSO) program is to improve and preserve the water environment in the Philadelphia area and to fulfill PWD's obligations under the Clean Water Act and the Pennsylvania Clean Streams Law by implementing technically viable, cost-effective improvements and operational changes.

The PWD's strategy to attain these goals has three primary phases: aggressive implementation of a comprehensive program for Nine Minimum Controls; planning, design and construction of 17 capital projects that further enhance system performance and reduce CSO volume and frequency; and comprehensive watershed-based planning and analyses that will identify additional, priority actions to further improve water quality in Philadelphia area water bodies.

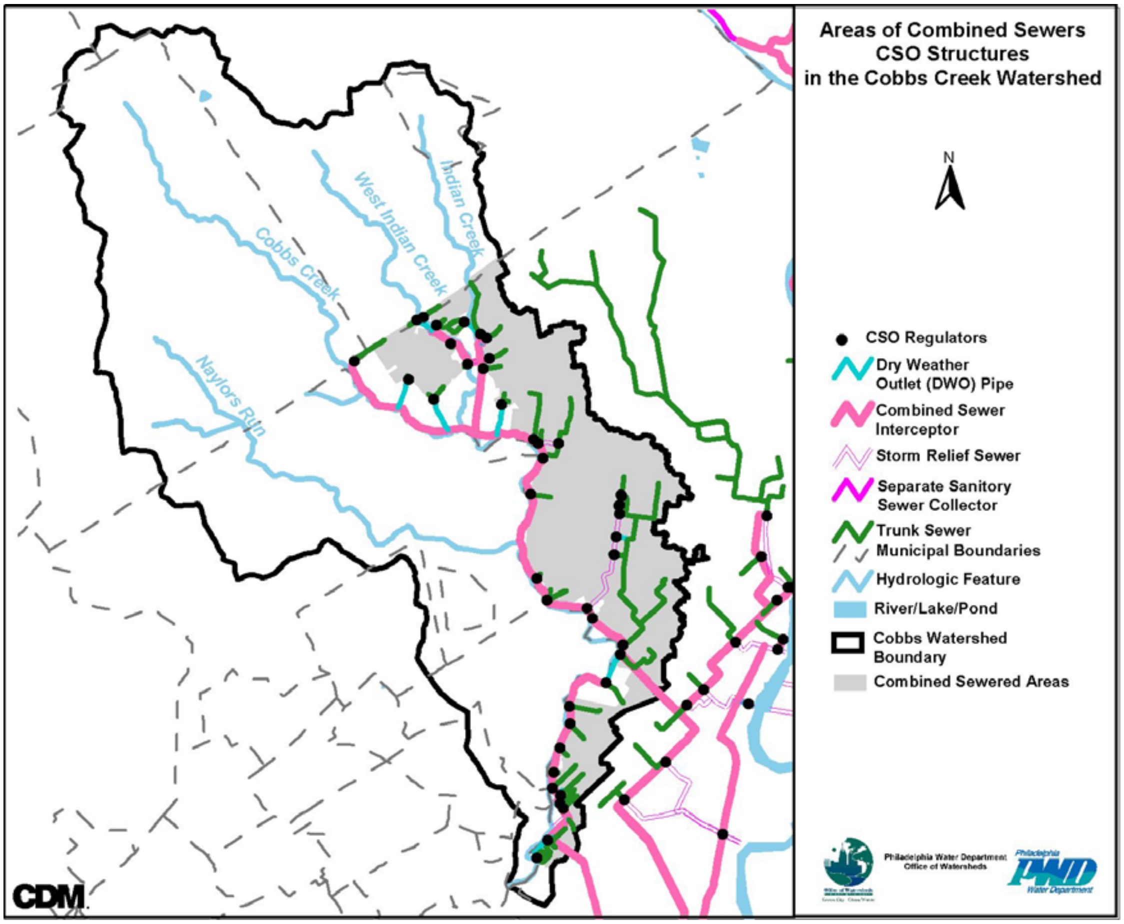


Figure 7-14 Areas of Combined Sewers and CSO Structures

The implementation of each of these control measures is discussed briefly below.

Nine Minimum Controls

In the first phase of the PWD's CSO strategy, and in compliance with its NPDES permits, the PWD submitted CSO Documentation: Implementation of Nine Minimum Controls to the Pennsylvania Department of Environmental Protection on September 27, 1995. The nine minimum controls are low-cost actions or measures that can reduce CSO discharges and their effect on receiving waters, do not require significant engineering studies or major construction, and can be implemented in a relatively short time frame. To provide information needed for the development of the Nine Minimum Controls (NMC) program, the PWD instituted a $6.5 million project to upgrade its comprehensive system flow monitoring network. This program provides information necessary to identify and eliminate dry weather overflows, monitor system performance and operation, and configure and calibrate computer hydraulic models needed to develop the NMCs and long-term CSO control plans. This information provided the basis for the System Hydraulic Characterization Report that was submitted to the PADEP in June 1995 and provided the technical basis for the development of the NMC plan.

Extensive data from the PWD's Geographic Information System (GIS), flow monitoring system, the U.S. Army Corps of Engineer's Storage, Treatment, Overflow, Runoff Model (STORM), and the EXTRAN and RUNOFF blocks of the EPA Stormwater Management Model (SWMM) were used to support each phase of the CSO program. These tools were developed to support concept engineering through implementation and post-construction monitoring. The monitoring system, models, and GIS will serve as the basis for planning improvements and enhancing operation of the sewerage system over the long-term.

Using the above tools, the PWD's NMC program includes comprehensive, aggressive measures to maximize water quality improvements through the following measures:

1. Review and improvement of on-going operation and maintenance programs

CSO Regulator Inspection & Maintenance Program

PWD has committed to demonstrating an improved follow-up response to sites experiencing a dry weather overflow. PWD has instituted a policy of next day follow-up inspection at sites that experience an overflow. PWD will conduct an evaluation of the effectiveness of twice-weekly inspections.

A database has been developed to document the maintenance performed on each CSO site. This system will ensure that proper regulator settings are maintained and system changes are documented. This database can also store scanned plan view and profile view drawings of CSO regulator and hydraulic control point chambers for inclusion in the filed inspection report forms.

Additional components of the O&M program include:

- Pumping Station Maintenance
- Sewer Cleaning Contracts
- Inflow Prevention Program
- Tide Gate Inspection and Maintenance Program
- Emergency Overflow Weir Modification

2. Measures to maximize the use of the collection system for storage

Use of the collection system for storage has long been recognized as a potentially cost-effective means to mitigate the occurrence and impacts of CSOs. PWD has been implementing in-system storage in Philadelphia's combined sewer system for nearly twenty years, using a variety of technologies.

- Reducing tidal inflows at regulators along the Southwest Main Gravity and the Lower Schuylkill West Side interceptors can reduce CSO overflows to Cobbs Creek by increasing available treatment capacity at the SWWPCP.

- A program to install tide gates or other backflow prevention structures at Cobbs Creek regulators to protect these regulators from potential inundation.

- Another approach that can be implemented to gain additional in-system storage is to raise the overflow elevation by physically modifying the overflow structure (e.g. raising an overflow weir). However, this approach must be implemented cautiously, since raising the overflow elevation also raises the hydraulic grade line in the combined trunk sewer during storm flows, and therefore increases the risk of basement and other structural flooding within the upstream sewer system due to backup or surcharge problems.

3. Review and modification of PWD's industrial pretreatment program

(also see the section from Regulatory Approaches: Industrial Pollution Prevention)

- Over the years, PWD has implemented a rigorous industrial pretreatment program. The effectiveness of this program has allowed the City to develop one of the largest and most successful biosolids beneficial reuse programs in the nation. As part of the nine minimum controls effort, the Department is committed to taking actions to encourage industries to better manage their process water discharges to the sewer collection system during wet weather periods.

4. Measures to maximize flow to the wastewater treatment facilities

As a minimum control, maximizing flow to the publicly owned treatment works (POTW) means making simple modifications to the sewer system and treatment plant to enable as much wet weather flow as possible to reach the treatment plant and receive treatment. The secondary capacity of the treatment plant should be maximized, and all flows exceeding the capacity of secondary treatment should receive a minimum of primary treatment (and disinfection, when necessary). The most effective way to determine the ability of the POTW to operate acceptably at incremental increases in wet weather flow, and to estimate the effect of the POTW's compliance with its permit requirement, is to perform stress testing to determine optimum flows, loads, and operations of the plant's unit processes.

5. Measures to detect and eliminate dry weather overflows

Relevant measures are discussed under the municipal measures of Target A.

6. Control of the discharge of solid and floatable materials

Solids are waterborne waste material and debris consisting of sand, gravel, silts, clay, and organic matter. Significant concentrations of solids are not only a visual nuisance, but can affect turbidity, dissolved oxygen, and carry pathogens in the receiving water. In addition, excessive amounts of solids can affect the combined sewer system by decreasing hydraulic capacity, thus increasing the frequency of overflows. Solids can enter the system through domestic and industrial wastewater, and debris washed from streets.

Floatables are waterborne waste material and debris (e.g., plastics, polystyrene, and paper) that float at or below the water surface. Floatables seen in significant quantities are aesthetically undesirable and can cause beach closings, interfere with navigation by fouling propellers and water intake systems, and impact wildlife through entanglement and ingestion.

Floatables and solids control measures consist of non structural and structural technologies.

Non structural technologies include combined sewer system maintenance procedures such as sewer flushing, street sweeping, and catch basin cleaning. Public education, land use planning and zoning, and ordinances are also considered non-structural technologies implemented to reduce solids and floatables entering the combined sewer system. These technologies are discussed under separate subsections and therefore will not be discussed further here.

Structural controls typically consist of abatement devices that would be constructed near the point of discharge. Technologies used for removing solids and floatables from CSOs include: Baffles, Booms, Catch Basin Modifications, Netting Systems, Swirl Concentrators, Screens, and Trash Racks. Modification of storm and combined sewer inlets for solids control, as well as catch basin and storm inlet maintenance are discussed under separate subsections.

Solids and floatables discharged from CSOs may represent a potentially significant impact to Cobbs Creek. PWD currently expends considerable effort to minimize the potential discharge of solids and floatables.

- PWD performs over 50,000 inlet cleanings each year preventing many tons of street surface-related materials from discharging to waterways through CSOs. The significant pipe cleaning and grit removal activities conducted by the department also remove a great deal of material that otherwise might discharge through CSO outlets during wet weather.

- The continued practice of regularly cleaning and maintaining grit pockets at critical locations in the trunk and interceptor system is an important part of the CSO control strategy. Grit buildup reduces the hydraulic capacity of the interceptor both by constricting its cross sectional area, and by increasing its frictional resistance. For example, quarterly cleaning of the 100-foot deep siphon grit pocket located at the Central Schuylkill wastewater pumping station is a major undertaking requiring specialized equipment and the commitment of significant labor resources. This practice has been shown to reduce the hydraulic grade surface at the siphon, increasing the wet weather flow capacity to the SWWPCP. Prior to the institution of this cleaning practice, the grit pit at this location had not been cleaned regularly in over 40 years.

- Inspections have revealed that grit has accumulated in the 30-inch Cobbs Creek Low-Level (CCLL) interceptor to a depth of approximately 12 inches. This project entails the removal of grit and debris along the entire 30-inch interceptor. This project will reduce the frequency and volume of overflows to Cobbs Creek by restoring the conveyance capacity of the 30-inch Cobbs Creek interceptor between the 75th and Gray's Avenue chamber and the SWWPCP low level pumping station. When grit is removed from this interceptor segment, the model indicates that the capacity nearly doubles from 5.9 mgd to 15 mgd. This project results in a 50 MG volume reduction on an average annual basis.

- Operation condition inspections of regulator chamber and backflow prevention devices are conducted for each structure approximately weekly, resulting in more than 10,000 inspections conducted each year. Additionally, comprehensive structural and preventative maintenance inspections are performed annually.

- Floatables will be monitored. If additional floatables control is warranted, then structural technologies will be considered. Structural technologies that would be considered first are catch basin modifications, including further enhancement of inlet grating and submerged outlet installations, netting systems, and static screens. More structurally intensive controls would be considered only if the application of the controls mentioned above proved not to be feasible under specific site requirements.

7. Implementation of programs to prevent generation and discharge of pollutants at the source

Most of the city ordinances related to this minimum control are housekeeping practices that help to prohibit litter and debris from actually being deposited on the streets and within the watershed area. These options are discussed under Target A, including litter ordinances and illegal dumping policies and enforcement. If these pollutants eventually accumulate within the watershed, practices such as street sweeping and regular maintenance of catch basins can help to reduce the amount of pollutants entering the combined system and ultimately, the receiving water.

8. Measures to ensure that the public is informed about the occurrence, location and impacts of CSOs

The Water Department has developed and will continue to develop a series of informational brochures and other materials about its CSO discharges and the potential affect on the receiving waters, in addition to information regarding dry weather flows from its stormwater outfalls. The brochures provide phone contacts for additional information. Also, the opportunity to recruit citizen volunteers to check or adopt CSO outfalls in their watersheds (i.e., notifying the PWD of dry weather overflows, etc.) will be explored through the watershed partnership framework. Brochures and other educational materials discuss the detrimental affects of these overflows and request that the public report these incidences to the department. In addition, the Water Department has enlisted watershed organizations to assist it with this endeavor. The department continued with this focus in 2002 to raise the level of awareness in its citizens about the function of combined and stormwater outfalls through a variety of educational mediums. The watershed partnerships are important for this kind of public/private effort to protect stream water quality. Lastly, the department's Clean Streams Team will investigate the feasibility of installing signs that can withstand nature and vandals at the department's outfalls

A more recent development in 2002/2003 was discussion among the state, PWD and the Delaware Estuary Program, to begin a marina best management practices education program that, in addition to alerting recreational users of the Delaware and Schuylkill Rivers regarding questionable water quality following rain storms, will also provide tips and information to marina operators to ensure their practices are environmentally sound. To complement this effort, the PWD has also been working with other city agencies to devise a "Recreational River Rating System" for the Schuylkill River due to the number of recreational activities that take place on the river year around. This system's educational message will be similar to that of the marina program as the advisories are based upon rainfall, CSOs and upstream influences on water quality.

9. Comprehensive inspection and monitoring programs to characterize and report overflows and other conditions in the combined sewer system.

Monitoring and characterization of CSO impacts from a combined wastewater collection and treatment system are necessary to document existing conditions and to identify water quality benefits achievable by CSO mitigation measures. Tables are compiled annually to represent average annual CSO overflow statistics as required in the NPDES Permit.

Long Term Control Plan Capital Projects

The second phase of the PWD's CSO strategy is focused on technology-based capital improvements to the City's sewerage system that will further increase its ability to store and treat combined sewer flow, reduce inflow to the system, eliminate flooding due to system surcharging, decrease CSO volumes and improve receiving water quality. The recommended capital improvement program is the result of a detailed analysis of a broad range of technology-based control alternatives.

Real Time Control

PWD has been evaluating and implementing computer controlled CSO outfall/regulator gate facilities that use level monitors to control the position of the dry-weather outlet (DWO) gate and tide gate at each location for maximizing the utilization of in-system storage in the combined sewer system. These computer controlled outfall facilities apply real-time control (RTC) mechanisms to maximize in-system storage. The use of RTC allows the capture and delivery to the treatment works of flow at the maximum rate at which it can be treated. This approach is attractive in terms of optimizing the use of the existing sewer system to capture combined wastewater and minimize CSOs.

- PWD is pursuing an opportunity to install an RTC system along the Lower Schuylkill combined sewer system, which takes the flow from the Cobbs Creek High Level (CCHL) interceptor. The modifications affect regulator structure C_17. The C_17 chamber regulates the capture of combined sewage from the largest combined-sewered area in the CCHL system. Due to its location and overflow elevation, C_17 controls the maximum head in the CCHL Cutoff Sewer and the conveyance capacity for the entire CCHL system. The proposed chamber modifications include raising the C_17 diversion dam and increasing its dry weather outlet (DWO) pipe diameter. The locations of C_17, the CCHL Cutoff Sewer and the SWWPCP are displayed on Figure 7-12.

Figure 7-15 Proposed RTC Sites

Cobbs Creek Low Level Interceptor Conveyance Improvements

Inspections have revealed that grit has accumulated in the 30-inch Cobbs Creek Low-Level (CCLL) interceptor to a depth of approximately 12 inches. Grit buildup reduces the hydraulic capacity of the interceptor both by constricting its cross sectional area, and by increasing its frictional resistance. This project entails the removal of grit and debris along the entire 30-inch interceptor. The estimated cost for the project is $440,000.

This project will reduce the frequency and volume of overflows to Cobbs Creek by restoring the conveyance capacity of the 30-inch Cobbs Creek interceptor between the 75th and Gray's Avenue chamber and the SWWPCP low level pumping station. When grit is removed from this interceptor segment, the model indicates that the capacity nearly doubles from 5.9 mgd to 15 mgd. This project results in a 50 MG volume reduction on an average annual basis.

Cobbs Creek Low Level (CCLL) Control Project

Control pipes, located in the CCLL interceptor near Glenmore Avenue, are two 18-inch orifice openings in an interceptor manhole bulkhead. The control pipes were installed to prevent chronic flooding occurring at the 75th and Grays Avenue chamber downstream. The 75th and Grays chamber is a former regulator (C-28), whose outfall to Cobbs Creek was sealed but still contained a 12-inch by 18-inch orifice opening to the interceptor. Grit accumulation has reduced the capacity of this orifice. The orifice opening at the 75th and Gray's chamber was the limiting hydraulic element in the interceptor. The opening restricted flow to the 30-inch interceptor that conveys flow from the 75th and Gray's Avenue chamber to the SWWPCP low level pumping station. The maximum flow through this opening was 11.8 mgd, assuming the 30- inch interceptor downstream of the 75th and Gray's Avenue has been cleaned (Cobbs Creek Low Level Interceptor Conveyance Improvements.) Flow was recently rerouted the flow past the orifice in the 75th and Gray's chamber with a new 30-inch pipe, increasing the capacity to 15 mgd. The hydraulic limit of the 30-inch CCLL interceptor can now be realized. This project was completed at a cost of $200,000. Additionally, the upstream interceptor will be cleaned and lined and a smooth transition between the brick sewer and the new 30-inch RCP bypass will be constructed. The two 18-inch orifices will be reconfigured in order to facilitate cleaning. While these orifices will control flooding problems at the 75th and Grays Avenue, they will not reduce the flow delivered to the interceptor below the interceptor capacity of 15 mgd. The projected cost for this project is $2,500,000.

These projects reduce the frequency and volume of overflows to Cobbs Creek, one of the smaller receiving streams. Interceptor capacity increases from 11.8 to 15 mgd due to the new 30-inch bypass line in conjunction with grit removal in the downstream interceptor (Cobbs Creek Low Level Interceptor Conveyance Improvements). The reduction in overflow volume is 10 MG on an average annual basis.

Watershed-Based Planning and Management

The third component of the City's CSO strategy involves a substantial commitment by the City to watershed planning to identify long term improvements throughout the watershed, including possibly additional CSO controls, which will result in further improvements in water quality and, ultimately, the attainment of water quality standards. The need for this watershed initiative is rooted in the fact that, prior to development of the Watershed Management Plan, insufficient physical, chemical and biological information existed on the nature and causes of water quality impairments, sources of pollution, and appropriate remedial measures. Because of this deficiency, it was impossible to determine what needed to be done for additional CSO control or control of other wet weather sources throughout the watershed. This deficiency, especially with respect to the effects of wet weather discharges and receiving water dynamics, is increasingly recognized nationwide and has led to a broader recognition of the need for watershed-based planning and management to properly define water quality standards and goals. The PWD believes that the National CSO Policy, state and federal permitting and water quality management authorities, cities, environmental groups, and industry, now recognize that effective long-term water quality management can be accomplished only through watershed-based planning. Completion of the Cobbs Creek Integrated Watershed Management Plan represents the realization of this commitment to watershed-based planning.

Catch Basin and Storm Inlet Maintenance (CM5) Related Goals: 4, 6, 8, 9, 10 Related Indicators: 11, 15, 16, 19, 20			
What	Who	Where	When
Regularly inspect catch basins (in combined areas) and storm inlets (in separate areas). Remove sediment as needed.	Sewer Owners (PWD and municipalities)	All inlets throughout watershed	Continue existing programs

Catchbasins and storm inlets that are part of the stormwater collection and conveyance system should be cleaned on a regular basis. Sediments, leaves, grass clippings, pet wastes, litter and other materials commonly accumulate in catchbasins. These materials can contain significant concentrations of nutrients, organics, bacteria, metals, hydrocarbons, and other pollutants. When a storm occurs, runoff entering the basin may dislodge and suspend some of this material. This debris can be conveyed along the storm sewer system and released to a surface water body. Catchbasin clean out should be scheduled for the fall and early spring in order to remove leaves and road salt and sand before the spring rains. In general, this is done with vacuum trucks, with disposal of the debris handled as solid waste.

In separate sewered areas of Cobbs Creek, each municipality is responsible for an effective storm sewer cleaning program. In Philadelphia, PWD has this responsibility.

Street Sweeping (CM6) Related Goals: 4, 6, 8, 9, 10 Related Indicators: 11, 15, 16, 19, 20			
What	Who	Where	When
Evaluate Existing Street Sweeping Programs Implement Enhanced Street Sweeping Practices	All Municipalities	Streets and Parking Lots in Commercial and Dense Residential Areas	Within next 5 years

Street and parking lot cleaning performed on a regular basis in urban and dense residential areas can be an effective measure for minimizing stormwater pollutant, sediment, and floatables loading to receiving waters.

Street sweeping programs had largely fallen out of favor as a pollutant removal practice following the 1983 NURP report. Recent improvements in street sweeper technology, however, have enhanced the ability of modern machines to pick up the fine grained sediment particles that carry a substantial portion of the storm water pollutant load, and have led to a recent reevaluation of their effectiveness. New studies show that conventional mechanical broom and vacuum-assisted wet sweepers reduce non-point pollution by 5 to 30 percent and nutrient content by 0 to 15 percent. However, newer dry vacuum sweepers can reduce non-point pollution by 35 to 80 percent and nutrients by 15 to 40 percent for those areas that can be swept (Runoff Report, 1998). A benefit of high-efficiency street sweeping is that by capturing pollutants before they are made soluble by rainwater, the need for structural storm water control measures might be reduced. Structural controls often require costly added measures, such as adding filters to remove some of these pollutants and requiring regular maintenance to change-out filters. Street sweepers that can show a significant level of sediment removal efficiency may prove to be more cost-effective than certain structural controls, especially in more urbanized areas with greater areas of pavement.

Computer modeling of pollutant removal in the Pacific Northwest suggests that the optimum sweeping frequency appears to be once every week or two (CWP, 1999). More frequent sweeping operations yielded only a small increment in additional removal (Bannerman, 1999; Claytor, 1999).

The following measures should be implemented toward achieving non-point source reductions in wet weather pollutant loads:

- Evaluate existing street and parking lot sweeping practices by municipalities with urban and dense residential areas contributing stormwater runoff to the watershed.
- Implement enhanced street and parking lot sweeping programs in urban and dense residential areas, prioritizing those not served by existing stormwater BMPs designed to reduce stormwater pollutant, sediment, or floatables loading to the receiving waters.

Responsible Landscaping on Public lands (CM7) Related Goals: 1, 6, 7, 8, 9, 10 Related Indicators: 1, 10, 11, 12, 13, 16, 19			
What	Who	Where	When
Incorporate integrated pest management (IPM) to reduce chemical use on public lands. Prevent clippings and cuttings from being transported by stormwater, and dispose of them through composting if possible.	Fairmount Park, municipalities PennDOT for vegetation along state roads	Parks, golf courses, school and institutional grounds, roadside vegetation	Short-term (within 5 years)

Common pesticides such as diazinon and chlorpyrifos (CWP, 1999 and Schueler, 1995) can be harmful to aquatic life even at very low levels. Proper use of these chemicals can be encouraged through public relations campaigns and demonstrated on public lands. Clippings and cuttings carried into the stormwater system and receiving streams can degrade water quality in a variety ways. A related problem exists with the illegal dumping of clippings and cuttings in or near drainage facilities. Recommended controls include:

- Consider an integrated pest management (IPM) program that encourages the use of alternatives to chemical pesticides. An IPM program incorporates preventative practices in combination with non-chemical and chemical pest controls to minimize the use of pesticides and promote natural control of pest species. In those instances when pesticides are required, programs encourage the use of less toxic products such as insecticidal soaps. The development of higher tolerance levels for certain weed species is a central concept of IPM programs for reducing herbicide use. This approach should be balanced with the invasive species control methods discussed under Target B.

- Collect clippings and cuttings on slopes and the bottom of stormwater control facilities and near stormwater inlets. Avoid mowing when significant rain events are predicted. Dispose of material through composting when possible.

Responsible Bridge and Roadway Maintenance (CM9) Related Goals: 1, 7, 9, 10 Related Indicators: 1, 19			
What	Who	Where	When
Incorporate BMPs into regular maintenance and repairs: Road and bridge resurfacing practices Deicing chemicals and practices Existing bridge drains	Bridge and roadway owners (municipalities and PennDOT)	Roadways and bridges (Figure 7-16)	Short-term (within 5 years)

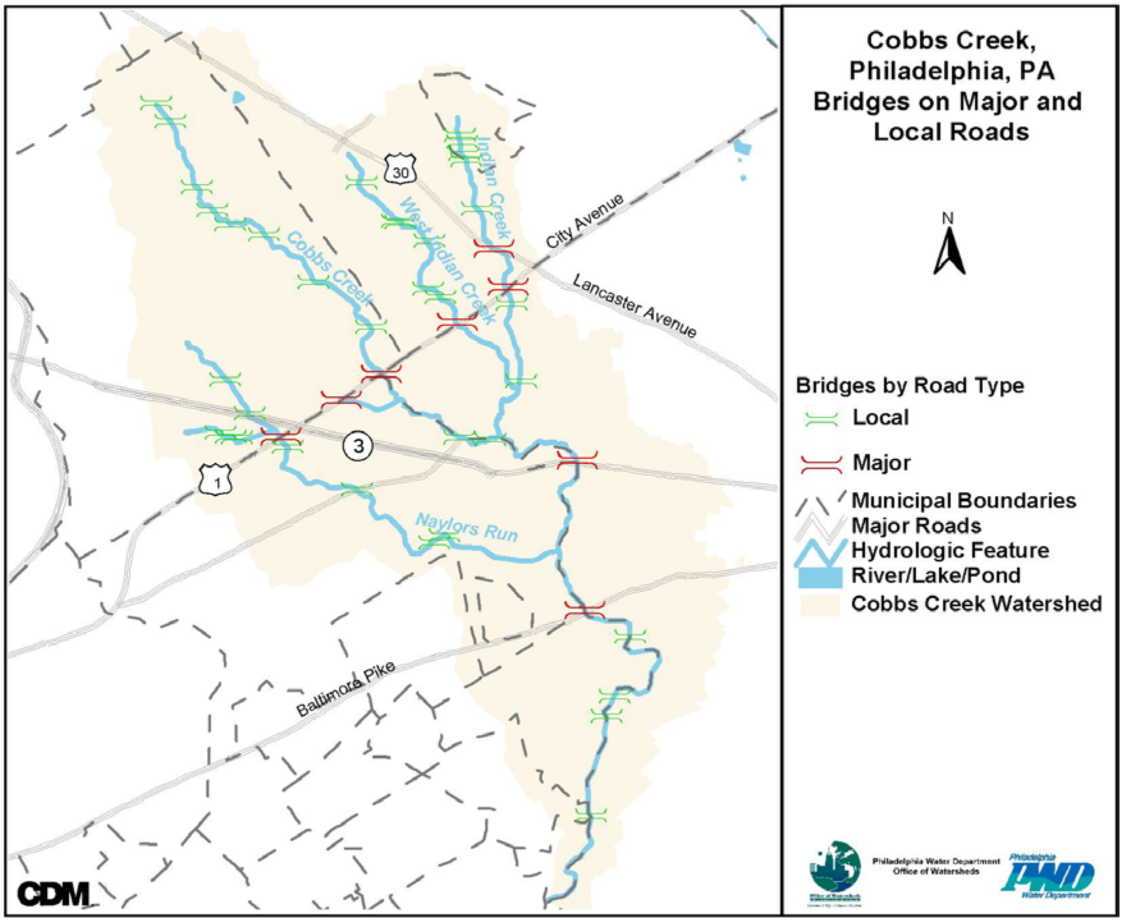


Figure 7-16 Major Roads and Bridges

Sediment and pollutants are generated during daily roadway and bridge use and scheduled repair operations, and these pollutants can impact local water quality by contributing heavy metals, hydrocarbons, sediment and debris to stormwater runoff. The use of road salt is a public safety as well as a water quality issue. Aside from contaminating surface and groundwater, high levels of sodium chloride from road salt can kill roadside vegetation, impair aquatic ecosystems, and corrode infrastructure such as bridges, roads, and stormwater management devices.

Recommended techniques are as follows:

- Consider alterations to road and bridge resurfacing practices near the creeks (Figure 7-16). Perform paving operations only under dry conditions. Cover storm drain inlets and manholes during paving operations, use erosion and sediment control measures, and use pollution prevention materials such as drip pans and absorbent material for all paving machines to limit leaks and spills of paving materials and fluids. Finally, consider employing porous asphalt for shoulder areas to reduce runoff.
- Consider alterations to the way deicing materials are used and applied as summarized in Table 7-17.

Table 7-17 Watershed Protection Techniques for Snow and Snowmelt Conditions

Use of De-icing Compounds

- Consider alternative de-icing compounds such as $CaCl_2$ and calcium magnesium acetate (CMA).
- Designate salt-free areas on roads adjacent to key streams, wetlands, and resource areas.
- Reduce use of de-icing compounds through better driver training, equipment calibration, and careful application.
- Sweep accumulated salt and grit from roads as soon as practical after surface clears.

Storage of De-icing Compounds

- Store compounds on sheltered, impervious pads.
- Locate at least 100 feet away from streams and floodplains.
- Direct internal flow to collection system and route external flow around shelters.

Dump Snow in Pervious Areas Where It Can Infiltrate

- Stockpile snow in flat areas at least 100 feet from stream or floodplain.
- Plant stockpile areas with salt-tolerant ground cover species.
- Remove sediments and debris from dump areas each spring.
- Choose areas with some soil-filtering capacity.

Blow Snow from Curbside to Pervious Areas

Operate Stormwater Ponds on a Seasonal Mode

Use Level Spreaders and Berms to Spread Melt water Over Vegetated Areas

Intensive Street Cleaning in Early Spring can Help Remove Particulates on Road Surfaces

- Consider alterations to existing bridge drains. Scupper drains can cause direct discharges to surface waters and have been found to carry relatively high concentrations of pollutants (CDM, 1993). At a minimum, routinely clean existing drains to avoid sediment and debris buildup, and consider retrofitting with catch basins or redirecting runoff to vegetated areas to provide treatment.

7.3.4 Stormwater Management

Source Control Measures

Reducing Effective Impervious Cover through Better Site Design (CS1)
Related Goals: 1, 7, 9, 10
Related Indicators: 1, 16, 19, 20

What	Who	Where	When
Reduce effective impervious cover by approximately 1% through: Downspout disconnection Pervious landscaping Sidewalk and driveway width reduction Vacant lands management	All municipalities require and/or encourage these measures using regulatory and/or public education options discussed elsewhere in this section.	All areas	Long term: 15+ years

Small changes in site design can lead to a gradual reduction in effective impervious cover that becomes significant over time. When applied consistently, the measures above can result in a 5-10% reduction in areas that are redeveloped. Assuming 10% of the watershed might be redeveloped over the planning horizon, a reduction in effective impervious area of 1% is a reasonable goal. Programs to require or encourage these practices are discussed under the regulatory approaches and public education options.

Downspout disconnection
In highly urbanized areas of the watershed, it is not always possible to direct runoff to pervious areas, and an informal inspection of lower density areas indicates that many properties are already disconnected. However, a further reduction in directly connected roof leaders from just 10% of residences will result in an effective impervious cover reduction of about 5%.

Pervious Landscaping
When repaving parking lots and loading areas, conversion of 10% of the area in half of parking lots to pervious landscaping (a measure required by municipalities including Portland, OR) will decrease watershed effective impervious cover by approximately 0.5%.

Sidewalk and Driveway Width Reduction
Reducing sidewalk and driveway widths by one foot will result in a watershed

effective impervious cover reduction of approximately 1%.

Vacant Lands Management

Vacant and abandoned lands in the City of Philadelphia account for approximately 2% of watershed effective impervious area. These sites are gradually being acquired and demolished by the City. Proper grading of these sites to encourage infiltration, or addition of small, inexpensive BMPs if needed, can eliminate runoff from these sites during all but the largest storms. Similar techniques can be followed for vacant and abandoned lands in the other counties.

Increasing Urban Tree Canopy (CS2) Related Goals: 1, 7, 8, 9, 10 Related Indicators: 1, 4, 13, 16, 17, 18, 19, 20			
What	Who	Where	When
Increase tree canopy in the watershed from 26% to 31%.	Municipalities (through ordinances, education, and incentive programs affecting land owners)	Private property Parking lots Streets Parks (riparian corridors under Target B)	Medium-term (5-15 years)

Tree planting and urban reforestation programs provide hydrologic benefits in addition to quality of life improvements. Leaf surfaces intercept some rainfall that might otherwise fall on impervious surfaces. The rainfall then either evaporates or is conveyed more slowly to the ground along plant stems and trunks. American Forests has assessed tree canopy in the Cobbs watershed at 26% (report "Urban Ecosystem Analysis, Delaware Valley Region" available at www.americanforests.org). American Forests recommends the following levels of tree canopy coverage for urban watersheds:

- 40% overall
- 50% in suburban residential zones
- 25% in urban residential zones
- 15% in central business districts

A goal of increasing tree canopy by 5% of the watershed over the medium term was selected as a feasible implementation level. Several regulatory and incentive-based strategies to achieve these goals include:

- Requirements to protect existing trees on private property, or creation of "tree banks" to offset loss (see regulatory/incentive approaches).
- Tree credits for redevelopers as part of impervious cover requirements or incentives (see regulatory/incentive approaches). The city of Portland, OR has given developers an impervious cover credit equal to 25% of tree canopy over impervious area.
- Parking lot landscaping or shade requirements (see regulatory/incentive approaches).
- Reforestation in parks and along the stream corridor (Target B).
- Increases in the number of trees along public streets and on vacant lots. The City of Philadelphia is taking this approach as part of its Green City Strategy.

Tree canopy over an additional 5% of impervious cover will result in an effective impervious cover reduction of approximately 1.5% over the watershed.

Municipalities with tree related ordinances are shown in Table 7-18.

Table 7-18 Landscape and Tree Related Ordinances

Municipality	Landscaping	Shade Tree/Street Trees	Wooded Lots
Colwyn Borough	X		
Darby Borough	X		
East Lansdowne Borough**			
Haverford Township	X		
Lansdowne Borough	X		
Lower Merion Township	X	X	X
Millbourne Borough	X	X	
Narberth Borough	X	X	
Philadelphia	X		
Radnor Township	X	X	
Upper Darby Township	X		
Yeadon Borough	X		

Forming a tree commission is one way of implementing an urban forestry program in Pennsylvania. The powers and responsibilities of a tree commission are based on state statute and are assumed by local government. By forming and empowering a tree commission, a community can empower and motivate volunteers to run an effective urban forestry program. Tree commissions are either advisory or administrative and may have various responsibilities.

- Advise community leaders and staff on administering the community forest
- Stimulate and organize tree planting and maintenance
- Develop and implement urban forest inventories, management plans, and ordinances
- Lessen liability by arranging to remove hazardous trees and repair damage caused by trees

In Pennsylvania, a tree commission created by municipal ordinance as a decision-making body has exclusive control over a community's shade trees. No tree can be planted or removed within the public right-of-way except under the auspices of the tree commission. This includes public trees that may be planted or removed in conjunction with subdivisions or approved development plans. Tree commissions can be given additional power within a municipality by a council, including:

- Control over all public trees such as trees within community parks
- Review and approval of landscaping proposed in development plans

The formation and empowerment of a tree commission can be a crucial element in developing broad-based support for community trees and ensuring long-term success and continuance of a community forestry program. (For more information, contact the Extension Urban Forestry Program, School of Forest Resources. The Pennsylvania State University, 108 Ferguson, University Park, PA 16802; (814) 863-7941.)

Porous Pavement and Subsurface Storage (CS3) Related Goals: 1, 6, 7, 8, 9, 10 Related Indicators: 1, 10, 11, 16, 19, 20			
What	Who	Where	When
Install porous pavement and subsurface storage in 10-50% of parking lots; coverage to be chosen by municipality to meet a share of watershed-wide reduction targets. Route runoff from nearby impervious cover to storage when possible.	Public and private parking lot owners.	See Figure 7-17.	Long-term: 15+ years

As discussed in Section 5, subsurface storage under parking lots is the best way to create storage and promote infiltration in the highly urbanized environment. Porous pavement is an effective way of directing parking lot runoff to storage, but more conventional inlets or grates are also possibilities. The depth of storage is important. Whenever possible, runoff from nearby impervious areas should be routed into the storage under nearby parking lots. When this is not possible, only a few inches of gravel is needed to store a chosen design storm. Storage designs always include an overflow mechanism for very large storms.

The total parking lot area in the Cobbs watershed is estimated at 120 acres in the combined-sewered portion and 240 acres in the separate-sewered portion (Figure 7-17). Philadelphia has approximately 31% of parking lot area in the watershed. Other municipalities with large parking lot areas are Lower Merion (26%), Upper Darby (23%), and Haverford (12%). Other municipalities have smaller percentages as listed in Figure 7-18.

Because this BMP is believed to be the most important, an ambitious target of retrofitting 10-50% of parking lots over the long term is proposed. Begin with demonstration projects on public land. Over the long term, convert 10%-50% of parking lots watershed-wide to porous pavement with subsurface gravel storage.

The Partnership may choose among a variety of approaches to implementing porous pavement and other structural BMPs. Regulatory and incentive-based approaches were discussed in the low-impact redevelopment section. Distribution of structural BMPs may also be incorporated in a pollution trading program.

- Install demonstration projects in public parking lots.
- Require all parking lots to be retrofit with porous pavement (or other drainage mechanisms) and subsurface storage when they are redone. Private land owners

cannot be expected to bear the entire cost of this approach; municipalities should fund the additional cost of these changes either directly or through tax incentives.

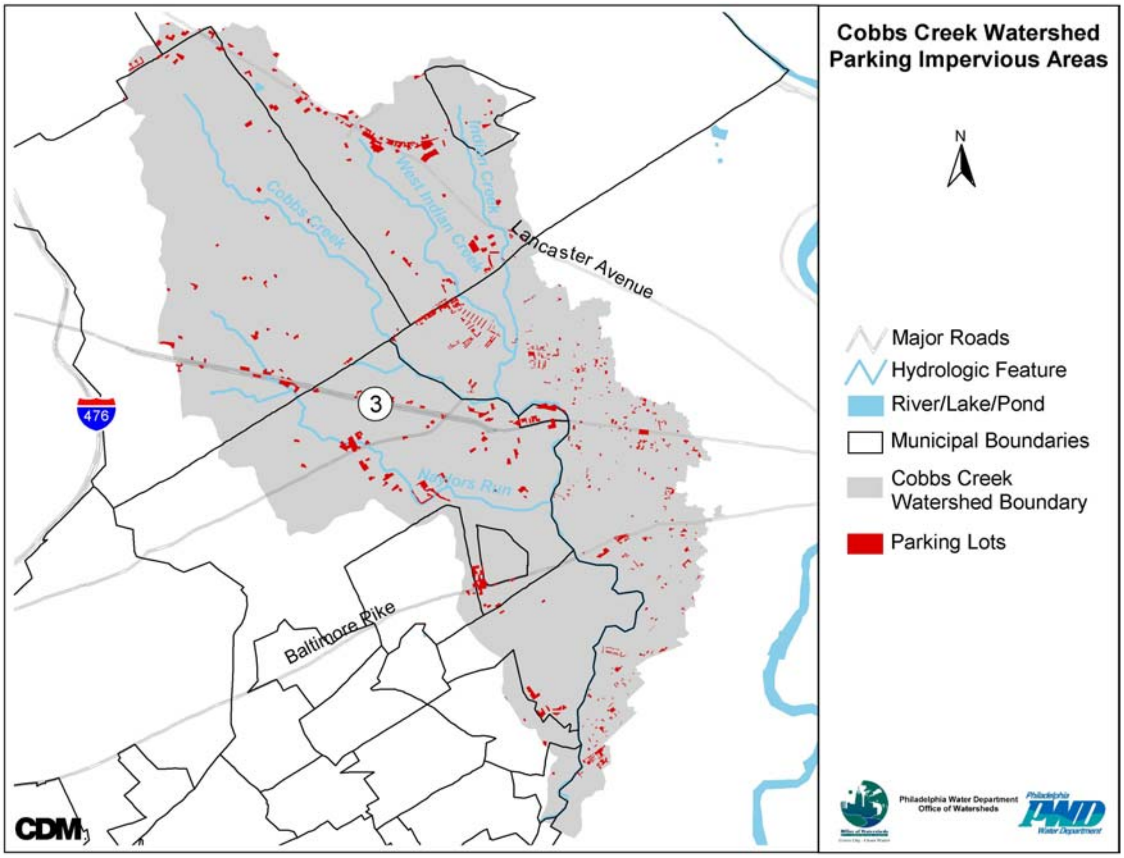


Figure 7-17 Parking Areas in Cobbs Creek Watershed

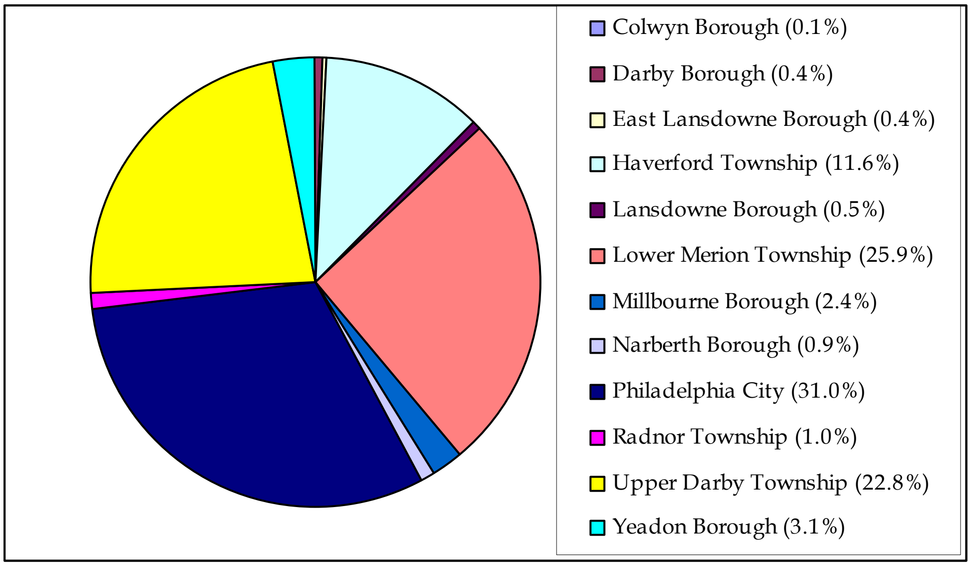


Figure 7-18 Percent of Total Parking Area by Municipality

Green Rooftops (CS4)
Related Goals: 1, 7, 8, 9, 10
Related Indicators: 1, 16, 18, 19, 20

What	Who	Where	When
Green rooftop demonstrations Targeted public information campaign on advantages of green roofs. Feasibility study and green roof implementation plan.	PWD	Appropriate public buildings chosen by PWD	Medium term: 5-15 years

The analyses in Sections 5 and 6 indicate that green rooftops, while highly effective at detaining and evaporating stormwater, are not currently a cost-effective option for the Cobbs. However, there is a potential for them to become more cost-effective in the future. As more successful demonstration projects are implemented in the United States, the materials and construction techniques will become more common and the economies of scale will improve. To facilitate this long-term change locally, this plan recommends that Philadelphia take the lead and implement one or more projects on public buildings in the City. Along with this project, we recommend a feasibility study of the potential for a larger-scale green roof program throughout the watershed. The feasibility study will form the basis for future recommendations when this plan is revised. In addition, we recommend a public relations campaign to change the perceptions of citizens, public officials, and contractors.

Capturing Roof Runoff in Rain Barrels or Cisterns (CS5)
Related Goals: 1, 7, 8, 9
Related Indicators: 1, 16, 18, 19

What	Who	Where	When
Install rain barrels on 5-25% of homes; coverage to be chosen by municipality to meet a share of watershed-wide reduction targets.	Homeowners through municipal incentive and education programs	Homes where dry wells are not feasible	Medium term: 5-15 years

As discussed in Section 5, rain barrels can be an effective stormwater management tool if they are properly designed and maintained. For detention of residential roof runoff, dry wells are the preferred technique because they have a larger capacity, require no maintenance, and allow more infiltration. Rain barrels are recommended as a secondary technique in areas where dry wells are infeasible. Proper design, including an appropriate slow release, is the responsibility of the municipality or nonprofit group leading the rain barrel program. Proper maintenance is accomplished through an intensive public education campaign and series of workshops. An ambitious target is to install rain barrels on 5-25% of homes throughout the watershed in the medium term. Adding barrels to 5% of homes will provide an estimated stormwater runoff reduction of 0.5%, a CSO reduction of 2%, and a pollutant (Total Suspended Solids) reduction of 2%.

Onsite and Regional Facilities

Maintain/Retrofit Existing Stormwater Structures (CS6)
Related Goals: 1, 4, 6, 7, 9, 10
Related Indicators: 4, 11, 15, 19

What	Who	Where	When
Inventory structures Assess potential for increased infiltration	Municipalities	Outside Philadelphia	Short term (within 5 years)

An inventory of existing detention and retention basins in Philadelphia indicates that there are none in the Cobbs portion. Other municipalities are asked to inventory and inspect existing stormwater control structures. Although this is not an explicit requirement of the Act 167 program, it is a reasonable task to include within the Act 167 framework. Older dry and wet detention basins may have been designed to reduce flood peaks but not to facilitate infiltration; this approach helps prevent property damage but may actually increase stream erosion. In some cases, it may be possible to retrofit these older basins to allow infiltration. Specific guidance on retention times and design recommendations will be included in the Act 167 plan.

Retrofitting Existing Sewer Inlets with Dry Wells (CS8) Related Goals: 4, 6, 9 Related Indicators: 11, 15, 19			
What	Who	Where	When
Retrofit 10-40% of existing stormwater catch basins in the combined sewered area to provide storage and allow infiltration	PWD	10-40% of existing inlets in combined-sewered areas	Long-term: 15+ years

As discussed in Section 5, retrofitting existing sewer inlets with dry wells is an expensive but effective measure in combined-sewered areas. Each inlet provides small amounts of storage and detention; distributed over a significant area, these measures reduce the number and duration of overflows.

There are approximately 2000 inlets in the combined-sewered portions of the Cobbs Creek watershed. It is proposed that at least 10% of these be retrofitted with dry wells. This measure will reduce CSO volume by approximately 0.4% and pollutant loads by approximately 0.4%.

During the first permit cycle this plan is in effect, inlets that are being repaired or replaced can be retrofitted at the same time. If, after the first 5 years, the program is not on track to affect the targeted number of inlets in 15 years, existing inlets in good condition may be retrofitted.

Residential Dry Wells, Seepage Trenches, and Water Gardens (CS9)
Related Goals: 1, 4, 6, 7, 8, 9, 10
Related Indicators: 1, 11, 15, 16, 17, 19

What	Who	Where	When
Install dry wells in 10-40% of residential yards; coverage to be chosen by municipality to meet a share of watershed-wide reduction targets. Install water gardens on school grounds	Municipalities School boards	Dry wells throughout watershed Water gardens in school yards with enough space	Long term: 15+ years

Routing residential roof runoff to dry wells is recommended as a priority control for the Cobbs watershed. Dry wells are cost-effective, can potentially affect a large portion of impervious cover, and require virtually no maintenance. They are clearly applicable in the lower-density residential areas but can be installed in some higher density areas; only a small lawn area is necessary. A properly sited and designed dry well will not cause basement flooding. Where soil conditions are insufficient to infiltrate all roof runoff, excess flows can be routed to a combined or sanitary sewer. Because dry wells are a priority control, they are recommended for implementation in the yards of 10%-40% of all homes in the watershed. At the 10% level, this measure could reduce CSO by approximately 3%, stormwater runoff by 0.3%, and pollutant loads (represented by TSS) by 5%.

Water gardens are recommended for implementation on school grounds, where they can both promote infiltration and educate students about stormwater management.

Bioretention Basins and Porous Media Filtration (CS12) Related Goals: 1, 4, 5, 7, 9, 10 Related Indicators: 1, 7, 8, 9, 15, 19, 20			
What	Who	Where	When
Install bioretention and/or sand filters in 10-50% of parking lots; coverage to be chosen by municipality to meet a share of watershed-wide reduction targets.	Public and private parking lot owners.	Everywhere in watershed	Long-term: 15+ Focus on redevelopment

The screening and modeling analyses in Section 5 targeted parking lot runoff for widespread implementation of BMPs. The preferred approach for parking lots is to route runoff to subsurface gravel storage through porous pavement, inlets, or grates. However, there will be cases where that approach is infeasible. The second preferred alternative is to direct parking lot runoff to a bioretention basin and/or a porous media filter. These systems infiltrate smaller storms completely, detain larger storms, and provide effective water quality treatment in separate sewered areas. 10-50% of parking lots are targeted for retrofit with bioretention. At the 10% level, this measure will reduce CSO by an estimated 1.3%, stormwater runoff by 0.1%, and pollutant loads by 2%. Over the long term, it is the goal to retrofit 50% of parking lots with either subsurface storage or bioretention. However, private land owners should not be expected to bear the entire cost of this approach; municipalities should fund the additional cost of these changes either directly or through tax incentives.

Treatment Wetlands: Onsite and Regional (CS13) Related Goals: 1, 5, 6, 7, 9, 10 Related Indicators: 1, 10, 11, 13, 19			
What	Who	Where	When
create and enhance wetlands for treatment	Municipalities	See Figure 7-11 in Target B.	Medium term: 5-15 years

Wetland creation and enhancement has benefits in terms of habitat, water quality, and water quantity. These benefits and proposed sites are discussed extensively under Target B.

Section 8: Cost and Institutional Analysis

8.1 Estimated Cost of Implementation

Planning-level costs have been developed for many of the options being recommended. Because costs are highly dependent on site specific conditions as well as the extent to which implementation occurs, costs are only approximate. These costs are useful, however, in providing order of magnitude funding needs, and also, as a comparison to potential costs associated with more traditional approaches to CSO control such as large scale storage tanks designed to reach the 85% capture goal.

Planning level costs are provided for each of the options discussed under the three Targets. "N/A" means that costs are not applicable because they are relatively small, or the option would be implemented by existing municipal staff. "N/A" can also mean that a cost estimate could not be developed based on existing information.

The combination of structural BMPs and implementation percentages in this section are suggested as a feasible plan that will equal or exceed the 20% discharge reduction target. The exact combination of BMPs implemented in each area of the watershed will be determined by local municipalities or by a government or institutional body to be chosen at a later time.

Order-of-magnitude, planning-level cost estimates are shown in Tables 8-1 through 8-5 for the two components of the plan:

1. A total cost for all options other than real time control and structural stormwater management BMPs.

2. A cost range for real time control and structural stormwater management BMPs. The cost for these measures varies depending on the combination chosen.

Table 8-1 Planning-level Cost Estimates for Target A Options

	Total		Philadelphia		Other Counties	
	Annual Cost	One-Time	Annual Cost	One-Time	Annual Cost	One-Time
Regulatory Approaches						
AR2 On-Lot Disposal (Septic System) Management	$75,000				$75,000	
AR2 Pet Waste, Litter, and Dumping Ordinances[1]						
Public Education and Volunteer Programs	$615,000		$276,000		$340,000	
Municipal Measures						
AM1 Capacity Management Operation and Maintenance (CMOM)[2]						
AM2 Inspection and Cleaning of Combined Sewers	$2,000,000	$21,120,000	$896,000	$8,448,000	$1,104,000	$12,672,000
AM3 Sanitary Sewer Rehabilitation[2]						
AM4 Combined Sewer Rehabilitation[2]						
AM5 Illicit Discharge, Detection, and Elimination (IDD&E)		$22,500,000		$10,125,000		$12,375,000
AM6 Stream Cleanup and Maintenance	$33,000	$31,000	$16,500	$15,000	$16,500	$15,000
AO1 Enhancing Stream Corridor Recreational and Cultural Resources[1]						
AMR Monitoring and Reporting[3]						
Total Cost for Target A Options	$2,723,000	$43,651,000	$1,189,000	$18,588,000	$1,535,000	$25,062,000
Cost per acre for Target A Options	$190	$3,070	$330	$5,220	$140	$2,350

1 - already in place in most locations, or costs difficult to quantify
2 - costs included in option AM2
3 - monitoring and reporting costs not included in this table

Table 8-2 Planning-level Costs for Target B Options

	Total		Philadelphia		Other Counties	
	Annual Cost	One-Time	Annual Cost	One-Time	Annual Cost	One-Time
Channel Stability and Aquatic Habitat Restoration[1]	$33,000	$26,400,000	$16,500	$13,200,000	$16,500	$13,200,000
BM1 Bed Stabilization and Habitat Restoration[2]						
BM2 Bank Stabilization and Habitat Restoration[2]						
BM3 Channel Realignment and Relocation[2]						
BM4 Plunge Pool Removal[2]						
BM5 Improvement of Fish Passage		$130,000		$130,000		
Lowland Restoration and Enhancement						
BM6 Wetland Creation[2]						
BM7 Invasive Species Management[2]						
Upland Restoration and Enhancement						
BM8 Biofiltration[2]						
BM9 Reforestation[3]						
BMR Monitoring and Reporting[4]						
Total Cost for Target B Options	$33,000	$26,530,000	$16,500	$13,330,000	$16,500	$13,200,000
Cost per acre for Target B Options	$2.30	$1,870	$4.60	$3,740	$1.50	$1,240

1 – cost based on restoring high-priority reaches at a cost of $700/lineal ft. If actual cost is lower, medium priority reaches may also be restored
2 – costs included under general “Channel Stability and Aquatic Habitat Restoration” costs
3 – costs included in Target C urban tree canopy costs
4 - monitoring and reporting costs not included in this table

Table 8-3 Planning-level Costs for Nonstructural Target C Options

	Total		Philadelphia		Other Counties	
	Annual Cost	One-Time	Annual Cost	One-Time	Annual Cost	One-Time
Regulatory Approaches						
Zoning and Land Use Control						
CR2 Requiring Better Site Design in Redevelopment[1]		$300,000		$100,000		$200,000
CR3 Stormwater and Floodplain Management[1]		$350,000		$175,000		$175,000
CR4 Industrial Stormwater Pollution Prevention[2]						
CR5 Construction Stormwater Pollution Prevention[2]						
CR6 Post-construction Stormwater Runoff Management[2]						
CR7 Pollution Trading[2]						
CR8 Use Review and Attainability Analysis[2]						
CR9 Watershed-Based Permitting[2]						
Municipal Measures						
CM1 Sanitary Sewer Overflow Detection[3]						
CM2 Sanitary Sewer Overflow Elimination: Structural Measures[3]						
CM3 Reduction of Stormwater Inflow and Infiltration to Sanitary Sewers[3]						
CM4 Combined Sewer Overflow (CSO) Control Program[4]						
CM5 Catch Basin and Storm Inlet Maintenance	$600,000		$269,000		$331,000	
CM6 Street Sweeping	$135,000		$45,000		$90,000	
CM7 Responsible Landscaping Practices on Public Lands[2]						
CM9 Responsible Bridge and Roadway Maintenance[2]						
CMR Monitoring and Reporting[5]						
Stormwater Management						
Source Control Measures						
CS1 Reducing Effective Impervious Cover Through Better Site Design[2]						
CS2 Increasing Urban Tree Canopy	$1,500,000	$15,000,000	$500,000	$5,000,000	$1,000,000	$10,000,000
Onsite and Regional Stormwater Control Facilities						
CS6 Maintaining/Retrofitting Existing Stormwater Structures	$20,000	$100,000	$10,000	$50,000	$10,000	$50,000
Use Review and Attainability Analysis		$300,000		$300,000		
Total Cost for Target C Options	$2,255,000	$16,050,000	$824,000	$5,625,000	$1,431,000	$10,425,000
Cost per acre for Target C Options	$160	$1,130	$230	$1,580	$130	$980

1 - estimated cost for ordinance development
2 - costs difficult to quantify
3 - costs included in option AM2
4 - costs included in AM2 or in Table E-8
5 - monitoring and reporting costs not included in this table

Table 8-4 Range of Costs for Structural Target C Options

Cost	Philadelphia	Other Counties
Lowest	Alternative 1: RTC	Alternative 1: Cost-Effective Stormwater BMPs
	$1,750,000	$5,340,000
Highest	Alternative 5: Focus on Public and Parking BMPs	Alternative 5: Focus on Public and Parking BMPs
	$17,900,000	$42,100,000

Table 8-5 Total Watershed Plan Cost

Total		Philadelphia		Other Counties	
Annual Cost	One-Time	Annual Cost	One-Time	Annual Cost	One-Time
$5,000,000	$93,000,000 - $146,000,000	$2,000,000	$39,000,000 - $55,000,000	$3,000,000	$54,000,000 - $91,000,000
$350/ac	$6,550/ac - $10,280/ac	$560/ac	$10,950/ac - $15,440/ac	$280/ac	$5,080/ac - $8,550/ac

8.2 Distribution of Costs Among Communities

8.2.1 Comparison of Philadelphia to other Watershed Communities

In addition to total estimated costs associated with the CCIWMP, it is useful to express the costs on an annual basis and in the context of acreage and number of households affected. Presenting costs this way allows comparison to existing wastewater infrastructure-related costs supported by users and taxpayers.

Table 8-6 compares projected costs on a per-acre basis and per-household basis in the City of Philadelphia and outside the City of Philadelphia. Philadelphia pays approximately 40% of the total annual cost (line 3) while representing approximately 25% of the watershed area. On a per-acre basis, costs within Philadelphia are approximately double costs outside the City. This difference occurs because of the greater proportion of impervious cover in Philadelphia compared to the remaining aggregated communities; for a given land area, there is more impervious cover and water-related infrastructure requiring management. It is important to note that population density, degree of urbanization, and income vary greatly among the communities outside Philadelphia. An illustrative distribution of costs among municipalities in the watershed is shown in section 8.2.2.

In addition to showing costs per unit area, it is useful to express costs on a per-household basis. Line 7 in Table 8-6 expresses cost per household, assuming only householdes inside the watershed boundaries would be required to pay. This comparison is made because improvements occur, and citizens benefit, primarily within the watershed boundaries. Expressed in this manner, the cost is greater for households outside Philadelphia (line 7, outside parentheses); because of greater population density within the urban watershed, there are more households to distribute the cost among inside the City.

Line 8 of Table 8-6 expresses the per-household cost inside the watershed boundary as a percentage of mean household income (line 8, outside parentheses). Although the per-household cost in Philadelphia is lower, it represents a greater fraction of household income for a median family because of the generally lower mean household income of Philadelphia households when compared with the outside municipalities.

While expressing costs in terms of households inside the watershed boundary allows direct comparison between communities, it is also useful to express costs on the basis of all households within the boundaries of municipalities that intersect the watershed. Currently, most funding and institutional mechanisms occur on a municipal basis. For example, a given township may use a percentage of all water and sewer bills paid to finance improvements related to the CCIWMP, including bills paid by households outside the Cobbs watershed boundary.

The numbers in parentheses on lines 7 through 9 of Table 8-6 present the costs in terms of all residents of municipalities intersecting the watershed. These costs are lowest in Philadelphia because it has the greatest number of households; all households paying sewer bills will pay approximately 0.03% of household income to support the CCIWMP, compared to over 0.1% for the remaining communities. Compared to the other municipalities, Philadelphia has many more households to spread the cost of the CCIWMP over, but ultimately it has many more watersheds that will require management activities. Over time and on a regional basis, watershed management costs are expected to approach 0.3% to 0.5% of MHI within affected communities.

The costs associated with the CCIWMP are generally incremental to existing maintenance and management activities associated with water-related infrastructure. Therefore, it is useful to add the CCIWMP cost to current wastewater charges paid by households to obtain an approximate measure of the total annual cost of watershed and water-related infrastructure management. These costs, shown in the final line of Table 8-6, range from approximately 0.6% to 1.6% of MHI regionally.

Table 8-6 Affordability Impact on Philadelphia and Suburban Communities

		Philadelphia	Suburban Communities *(Combined)*
1	Capital:	$3,770,000	$5,820,000
2	Operating:	$2,000,000	$3,000,000
3	Total Annual Cost Associated with WMP	$5,770,000	$8,820,000
4	Cost per acre in watershed	$1,642	$826
5	2000 Median Household Income	$30,746	$61,962
6	Estimated Annual Sewer User Charge*	$343	$197
7	WMP cost per household in watershed (in entire municipalities)	$146.04 ($9.77)	$185.71 ($87.52)
8	WMP cost as % of MHI in watershed (in entire municipalities)	0.47% (0.03%)	0.30% (0.14%)
9	Existing sewer cost + WMP cost in watershed (entire municipalities)	1.59% (1.15%)	0.62% (0.46%)

* The sewer user charge in Philadelphia includes a stormwater collection and treatment fee. Stormwater-related charges outside Philadelphia were not investigated.

8.2.2 Distribution of Costs Among Communities Outside Philadelphia

Tables 8-7 and 8-8 provide data to assist communities outside Philadelphia in placing projected CCIWMP costs in a local context. Table 8-7 expresses estimated costs for communities per acre and per household inside the watershed boundaries; Table 8-8 presents costs within the boundaries of all municipalities that intersect the watershed. For the purposes of this illustrative example of cost distribution, general, watershed-related costs for communities outside of Philadelphia are apportioned according to the percentage of the watershed area within each municipality's jurisdiction.

These cost tables are but one illustration of a possible cost distribution, and are provided to aid municipalities in deciding what funding and institutional mechanisms may be most appropriate given local conditions.

Table 8-7 Distribution of Costs Among Rate Payers in Cobbs Watershed in Communities Outside Philadelphia

	Colwyn	Darby	East Lansdowne	Haverford	Lansdowne	Lower Merion	Milbourne	Narberth	Radnor	Upper Darby	Yeadon
Municipality area in watershed (ac)	96	140	132	3,873	111	2,375	44	268	32	2,700	910
Area of municipality in watershed (% of municipality total)	59%	27%	100%	60%	15%	16%	100%	85%	0.4%	56%	88%
Households in municipality and watershed	484	1219	939	12185	755	7151	366	1619	141	18357	4277
Annual cost associated with CCIWMP	$79,252	$115,576	$108,971	$3,197,315	$91,635	$1,960,656	$36,324	$221,245	$26,417	$2,228,957	$751,241
Cost per acre (within watershed)	$825.54	$825.54	$825.54	$825.54	$825.54	$825.54	$825.54	$825.54	$825.54	$825.54	$825.54
Cost per household (within watershed)	$163.74	$94.81	$116.05	$262.40	$121.37	$274.18	$99.25	$136.66	$187.36	$121.42	$175.65
Median household income ($/year)	$33,150	$30,938	$44,205	$65,714	$47,017	$86,373	$30,185	$60,408	$74,272	$41,489	$45,450
Cost per household (% of MHI)	0.49%	0.31%	0.26%	0.40%	0.26%	0.32%	0.33%	0.23%	0.25%	0.29%	0.39%

Table 8-8 Distribution of Costs Among all Rate Payers in Communities Outside Philadelphia

	Colwyn	Darby	East Lansdowne	Haverford	Lansdowne	Lower Merion	Milbourne	Narberth	Radnor	Upper Darby	Yeadon
Municipality area (ac)	164	522	132	6,406	753	15,265	44	316	4,824	4,824	1,032
Watershed area in municipality (ac)	96	140	132	3874	111	2376	44	268	32	2701	910
Watershed area in municipality (% of watershed total)	0.7%	1.0%	0.9%	27.3%	0.8%	16.7%	0.3%	1.9%	0.2%	19.0%	6.4%
Households in municipality	857	3,411	939	18,069	4,688	22,845	368	1,895	10,383	32,594	4,730
Annual cost associated with CCIWMP	$79,252	$115,576	$108,971	$3,197,315	$91,635	$1,960,656	$36,324	$221,245	$26,417	$2,228,957	$751,241
Cost per acre (whole municipality)	$483.24	$221.41	$825.54	$499.11	$121.69	$128.44	$825.54	$700.14	$5.48	$462.06	$727.95
Cost per household (whole municipality)	$92.48	$33.88	$116.05	$176.95	$19.55	$85.82	$98.71	$116.75	$2.54	$68.39	$158.82
Median household income ($/year)	$33,150	$30,938	$44,205	$65,714	$47,017	$86,373	$30,185	$60,408	$74,272	$41,489	$45,450
Cost per household (% of MHI)	0.28%	0.11%	0.26%	0.27%	0.04%	0.10%	0.33%	0.19%	0.003%	0.16%	0.35%

8.3 Institutional Analysis

The primary purpose of Section 7 of this plan is to provide recommendations and guidance to stakeholders - primarily state, county and other government agencies, municipalities, non-government organizations, land owners, and individuals - on ways to better manage water resources of Cobbs Creek. Everyone in the watershed communities can contribute in numerous ways to the protection of water resources. Roles of primary stakeholders and participants in the plan are briefly described below, followed by the recommendation that a watershed-wide management organization be created to facilitate implementation.

8.3.1 Description of Roles

Both government and non-government organizations will play a role in the successful implementation of the Cobbs Creek Watershed Management Plan. The primary roles are outlined below.

PADEP Role

Two agencies of the Commonwealth of Pennsylvania are directly and indirectly involved in watershed planning in Cobbs Creek: the Pennsylvania Department of Environmental Protection (PADEP) and PA Department of Conservation and Natural Resources (PADCNR). Achievement of Watershed Plan goals and objectives through local implementation will require continued support through funding and integration of the various existing state level stormwater management and runoff related programs. Particular attention should be paid to the following programs:

- Act 167 Plans
- Phase II Stormwater permits
- Act 537 / CMOM Plans
- Construction Stormwater Pollution Prevention
- Industrial Stormwater Pollution Prevention
- Watershed monitoring and performance reporting
- Exploring Watershed Permitting Opportunities

A critical PADEP role will be activities required under Section 303(d) of the Clean Water Act (PADEP, 2004) and the EPA's Water Quality Planning and Management Regulations (40 CFR Part 130). PADEP will need to actively administer the water quality standards process for portions of Cobbs Creek in the near future. TMDLs should be integrated with the findings of this watershed plan, and the approaches recommended by this plan should be designed to meet the TMDL requirements as they arise. Most of the regulatory approaches will need to define guidelines and limits, including TMDLs, in order to create possibilities for pollution trading. PADEP would also need to support the review and revision of water quality standards and a

Use Attainability Analysis.

PWD Role

PWD, as the primary author of this plan, plays a central role in its implementation, as well as in continued monitoring to chart improvements to water quality and to provide the scientific foundation for eventual TMDLs and for a Use Review and Attainability Analysis. PWD will take a lead role in implementing a variety of the recommendations, including;

- Stream Restoration
- Improvement of Fish Passage
- CSO Control
- Green Rooftop Demonstrations
- Stormwater BMP installation
- Organization of Stakeholder Participation
- Monitoring

Municipal Role

Municipalities can play a key role in the implementation of recommendations through the incorporation of water resources strategies into their land use planning and governance functions. Because of the authorities contained in the Pennsylvania Municipalities Planning Code (MPC), municipalities are one of the two main foci of implementation efforts (PWD being the other). Enabled by the MPC, municipalities are the focal point to address runoff from redeveloped and existing developed lands, to address problems associated with sanitary sewer collection systems, to enhance recreational opportunities, and to protect natural resources from the effects of land disturbance.

The most fundamental roles recommended for municipalities are to consider undertaking a comprehensive review of their existing land use regulations, policies and requirements to identify where they may be unnecessarily causing impacts to water resources; and to undertake the necessary actions needed to eliminate SSOs and sanitary sewer leaks.

The primary actions recommended for municipalities include: encouraging connection of roof leaders to storm sewers, reduction of expansive paved (impervious) parking lot requirements and replacement of asphalt with porous paving surfaces, repair and maintenance of leaking sanitary sewers, instituting a urban tree planting and maintenance program through establishment of a Tree Commission, and the elimination of SSOs.

County Role

The primary role of Delaware County (and to a lesser extent, Montgomery County) is to conduct the necessary comprehensive stormwater management studies to:

- Complete an Act 167 stormwater plan that is consistent with and furthers the achievement of the goals and objectives of this plan.
- Work with municipalities to update Act 537 plans

In addition, the Delaware County Conservation District has several important responsibilities within the watershed, including:

- Chapter 102 Erosion Control: Administers of the State's program to control sediment pollution from earth disturbance activities.
- National Pollution Discharge Elimination System (NPDES): Processes applications and seeks compliance towards stormwater discharge permits for Construction Activities.
- Chapter 105 Waterways and Wetlands General Permitting: Assists applicants with permit information. Processes general permits for work within wetlands and streams.

These are important elements in coordinating Act 167 planning requirements with Phase II of the NPDES Stormwater Program.

Non-Government Organization Role

The Darby-Cobbs Partnership is an important organization within the watershed, and the partnership should continue to work with PWD through the implementation phase. A Tree Commission could be created within the watershed to manage the urban forest program recommendations. In Pennsylvania, a tree commission is created by municipal ordinance as a decision-making body, and once empowered, can have exclusive control over a community’s shade trees.

Land Owners’ Role

Voluntary watershed stewardship by all land owners can contribute significantly toward the protection and restoration of the Cobbs Creek watershed while simultaneously minimizing the need for additional regulatory controls. Recommended roles for land owners include:

- Implementing “watershed stewardship” practices in their landscape and outdoor housekeeping practices.
- Actively working to eliminate litter, trash, and illegal dumping through participation in cleanup activities and through heightened awareness.
- Disconnecting roof leaders and installing rain barrels or dry wells

- Considering pervious solutions for driveways
- Joining and supporting the activities of the watershed partnership.

8.3.2 Possible Organizational Structures

The above outlined roles can be, and often are, carried out within the existing regulatory structure without any real coordination or formal agreement to join and work through a watershed organization. In the absence of a central watershed organization, PWD would commit to implementation of recommended projects and programs within the City, and each of the major municipalities would respond to various regulatory requirements individually. Collectively, these activities would improve water quality and habitat in the watershed; however, there would be significant overlap, duplication of effort, and potential gaps in the implementation. This is far from ideal.

As an alternative, it is preferred that a Cobbs Creek Watershed Organization be created to coordinate activities. A Watershed Organization could be set up with a County or the City of Philadelphia as the primary organization running the program, with other organizations participating through stakeholder meetings. In this case, PWD could assume this role.

Alternatively, a separate, non-profit organization with member organizations bound by formal agreement could be established (perhaps as an expansion of the current Cobbs Creek Partnership). The Organization could be allowed to start modestly, and to grow as the need arises. Thus, the ultimate structure of the Organization and its responsibilities would evolve over time, but participants in the Organization would work together by formally adopting this plan, and providing funds for the completion of the major recommendations. Potential sources of funding could include member assessments, grants, in-kind and cash matches from implementing organizations, and in-kind services from member organizations.

An example of just such an organization was formed for the Rouge River in Michigan. Using the Rouge River Assembly as a guide, the Cobbs Creek Watershed Organization could have some or all of the following characteristics.

- Membership could be open to PWD, all the municipalities, and the two counties in the watershed. All members would either have a permit to discharge storm water into the creek, or are responsible for CSO into the creek.
- Membership could be expanded to include PADEP and EPA in an advisory capacity.
- For the City of Philadelphia, municipalities and the two counties, voting shares and costs could be apportioned based upon land and population in watershed.
- A General Assembly of participants could be set up to meet twice per year to focus on priorities, budget, and assessments.

- An Executive Committee with a representative from each major participating body could be set up to meet 6 times per year to provide management oversight.

- Standing Committees (e.g. Finance, Technical, and Public Involvement) could be established to provide day to day guidance and advice, with members drawn from the member organizations.

- An Organization Committee could be established to consider long term changes for the permanent organization to best meet needs.

Some of the primary functions of the newly formed organization could include:

- Seeking implementation plan approval. This approval includes obtaining signatures from municipalities followed by a letter of support from PADEP. The Organization would encourage PADEP to adopt the Plan as a governing document for the watershed. The existing Watershed Restoration Action Strategy (WRAS) program could provide a framework for implementation of the Plan.

- Instituting a program to hire watershed plan implementation specialists, similar to existing county conservation district specialists. A county would have several specialists, and each specialist would be assigned to several municipalities. The specialists would represent their assigned communities in Organization meetings and other regional meetings. The watershed Organization would apply to the Growing Greener program as a source of funding for these specialists.

- Overseeing the continued implementation of basic, essential services required of all municipalities by stormwater permits (e.g., sewer system maintenance).

- Overseeing continued monitoring, sampling, data analysis, and reporting on both the water quality and biology of the system using the established indicators.

- Providing public participation and public education.

- Exploring innovative solutions to long-term operation and maintenance of stormwater management facilities.

- Requiring that projects applying for state funding (Growing Greener, DCNR) must be reviewed and shown to be consistent with the Plan. The specialists, directed by the Organization, would review all submitted projects and apply a rating scale for consistency with the plan.

- Encouraging the idea of applying for federal funding for regional projects (e.g., stream restoration, regional wetlands); however, most smaller-scale projects would be funded locally. Public funding for major infrastructure projects on private land could be explored.

Appendix A: Glossary of Terms

Adaptive management	Process of continually monitoring progress and adjusting the approach
Bankfull flow	The high flow stage of a fluvial system distinguished by the highest stage elevation a stream can reach before spilling over.
Baseflow	The portion of streamflow contributed by groundwater.
Benthic	Used to describe aquatic organisms living at the bottom of a body of water
Benthic macroinvertebrates	Are mainly aquatic insect larvae that live on the stream bottom. Since they are short-lived and relatively immobile, they reflect the chemical and physical characteristics of a stream and chronic sources of pollution.
BMP -	*Best Management Practice* – Also called a "management option," BMP is a technique, measure, or structural control that addresses one or more objectives (e.g., a detention basin that gets built, an ordinance that gets passed, an educational program that gets implemented).
BOD	Biochemical Oxygen Demand
CCD	County Conservation District(s)
CCHL	Cobbs Creek High-Level Combined Sewer System
CCLL	Cobbs Creek Low-Level Combined Sewer System
CCTV	Closed Circuit Television
Clean Streams Law	
CSO	Combined Sewer Overflow
CSS	Combined Sewer System

CWA	*Clean Water Act* – The Federal Amendment that authorizes the EPA to implement pollution control programs and to set water quality standards for all contaminants in surface waters. "The Act made it unlawful for any person to discharge any pollutant from a point source into navigable waters, unless a permit was obtained under its provisions. It also funded the construction of sewage treatment plants under the construction grants program and recognized the need for planning to address the critical problems posed by nonpoint source pollution." (EPA website)
CWA Section 104(b)(3) Program	Promotes the coordination and acceleration of research, investigations, experiments, training, demonstrations, surveys, and studies relating to the causes, effects, extent, prevention, reduction and elimination of pollution.
CWA Section 208 Wastewater Planning	Intended to encourage and facilitate the development and implementation of area-wide waste treatment management plans.
CWA Section 319(b) Non-point Source Management Program	Designed to address mine drainage, agricultural runoff, construction/urban runoff, hydrologic and habitat modifications, on-lot wastewater systems, and silviculture.
DCIA	Directly Connected Impervious Area
DCVA	Darby Creek Valley Association
DO	Dissolved Oxygen
DRBC	Delaware River Basin Commission
DVRPC	Delaware Valley Regional Planning Commission
DWO	*Dry-Weather Outlet* - connector pipe between a CSO regulator and interceptor sewer.

IDD&E	*Illicit Discharge, Detection, and Elimination* – one of the six minimum control measures required of permittees under the Phase II NPDES Stormwater Regulations. Program steps include developing maps of municipal separate storm sewer system outfalls and receiving waterbodies; prohibiting illicit discharges via PADEP-approved ordinance; implementing an IDD&E Program that includes a field screening program and procedures, and elimination of illicit discharges; conducting public awareness and reporting program. A similar program is being followed by PWD in the Long Term Control Plan (LTCP) for CSOs.
EACs	Environmental Action Committees
Floatables	Waterborne waste material and debris (e.g., plastics, polystyrene, paper) that float at or below the water surface.
ET	*Evapotranspiration* – the sum of water vapor evaporation from the earth's surface and transpiration from plants.
EVAMIX	A multi-criteria evaluation program to help choose objectively between various alternatives
GIS	Geographic Information Systems
Handheld DO	Dissolved oxygen readings taken with a handheld meter.
HIS	Habitat Suitability Indices
IPM	Integrated Pest Management
LID	Low-Impact Development (similar to "better site design" and "conservation site design")
LTCP	*Long-Term CSO Control Plan* – part of the EPA's CSO Control Policy for regulation of CSOs under NPDES that guides municipalities, state, and federal permitting agencies in reaching full compliance with the CWA.
Macro invertebrates	Macroinvertebrates are invertebrate animals that are can be seen without the aid of a microscope.
MPC	Municipalities Planning Code

MS4	Municipal Separate Storm Sewer System
NLREEP	Natural Lands and Restoration and Environmental Education Program (a unit of Philadelphia's Fairmount Park Commission)
NOAA	National Oceanic and Atmospheric Administration
Non-point source pollution	Pollution that comes from a diffuse source such as atmospheric deposition, stormwater runoff from pasture and crop land, and individual on-lot domestic sewage systems discharging through shallow groundwater.
Non-structural BMPs	These BMPs will require no operation or maintenance. Examples are use of open space and vegetated buffers in development design, minimization of soil disturbance and compaction during construction, and minimization of directly-connected impervious areas.
NPDES	National Pollutant Discharge Elimination System
NPDES Phase I	The stormwater management component of the NPDES program, instituted in 1990, which addressed the storm runoff sources most threatening to water quality. Under this phase, sites with larger communities, industrial activity, and construction sites are required to obtain permits for the storm water leaving the site.
NPDES Phase II	Additional stormwater management regulations enacted in 1999, applying to smaller communities and construction sites.
OLDS	On-Lot sewage Disposal Systems
O&M	Operations and Maintenance
OOW	PWD's Office of Watersheds
PA Act 167	Stormwater Management Act
PA Act 537	Sewage Facilities Planning Act
PADCNR	Pennsylvania Department of Conservation and Natural Resources
PADEP	Pennsylvania Department of Environmental Protection

PADEP Greenways Program	An Action Plan for Creating Connections is designed to provide a coordinated and strategic approach to creating connections through the establishment of greenways in the State.
PEC	Pennsylvania Environmental Council
PENNVEST	*Pennsylvania State Revolving Fund Program* - Provides funding for sewer, stormwater, and water projects throughout the Commonwealth.
Point source	Pollution discharged from a single point, defined in the CWA as "any discernable, confined and discrete conveyance, including but not limited to any pipe, ditch, channel, tunnel, conduit, well, discrete fissure, container, rolling stock, concentrated animal feeding operation, vessel, or other floating craft from which pollutants are or may be discharged." (pg20 Section 7)
POTW	Publicly Owned Treatment Works
PRD	Planned Residential Development
PWD	Philadelphia Water Department
QA/QC	Quality Assurance/Quality Control
RBP	Rapid Bioassessment Protocol (developed by the EPA) a standard method to assess aquatic health through fish and macroinvertebrate diversity (EPA Website).
RBP III	Section of the RBP dealing benthic macroinvertebrates.
RCP	PADCNR's Rivers Conservation Program
Riparian corridor	The area of land along the bank or shoreline of a body of water (EPA website).
Riparian woodlands	Woodlands that grow within the riparian corridor.
RTC	*Real Time Control* - a dynamic system of hydraulic controls to provide additional storage and reduce overflows from a combined sewer system
SEO	Sewage Enforcement Officers (designated by PADEP)

Solids	Waterborne waste material and debris consisting of sand, gravel, silts, clay, and organic matter.
Sonde	Shallow depth continuous water quality monitor manufactured by YSI Inc.
SSA	Separate-Sewered Area stormwater runoff
SSET	Sewer Scanner and Evaluation Technology
SSMS	Sanitary Sewer Management System
SSO	Sanitary Sewer Overflow
STORET	USEPA's water quality database (STOrage and RETrieval)
Stormwater Management Program Protocol ("Protocol")	PADEP guidance for implementing the requirements of the NPDES Phase II stormwater regulations
Structural BMPs	These BMPS will require proper operation and maintenance. Examples include wet ponds, grassed swales, infiltration basins and bioretention areas.
SWMM	Storm Water Management Model
TDR	Transfer of Development Rights
TIGER	Topologically Integrated Geographic Encoding and Referencing (U.S. Census database)
TMDL program	*Total Maximum Daily Load program* - EPA/PADEP program for limiting and allocating discharges of a pollutant within a watershed.
Transpiration	The process by which water vapor passes through the membrane or pores of plants to the atmosphere.
TSS	Total Suspended Solids
UA	Urban Areas
UAA	Use Attainability Analysis
USGS	United States Geological Survey

Watershed	The area of land draining to a stream, river, or water body. Watershed boundaries are established where any precipitation falling inside the boundary will drain to that particular watershed water body. Precipitation falling outside the boundary will drain to a different watershed. Watershed boundaries are typically formed on high elevation ridges. The water bodies formed from the watershed drainage are usually at the lowest elevation in the watershed. Watersheds can also be called drainage basins.
WMP	Watershed Management Plan
WQS	Water Quality Standards
WRAS	PADEP's *Watershed Restoration Action Strategy*

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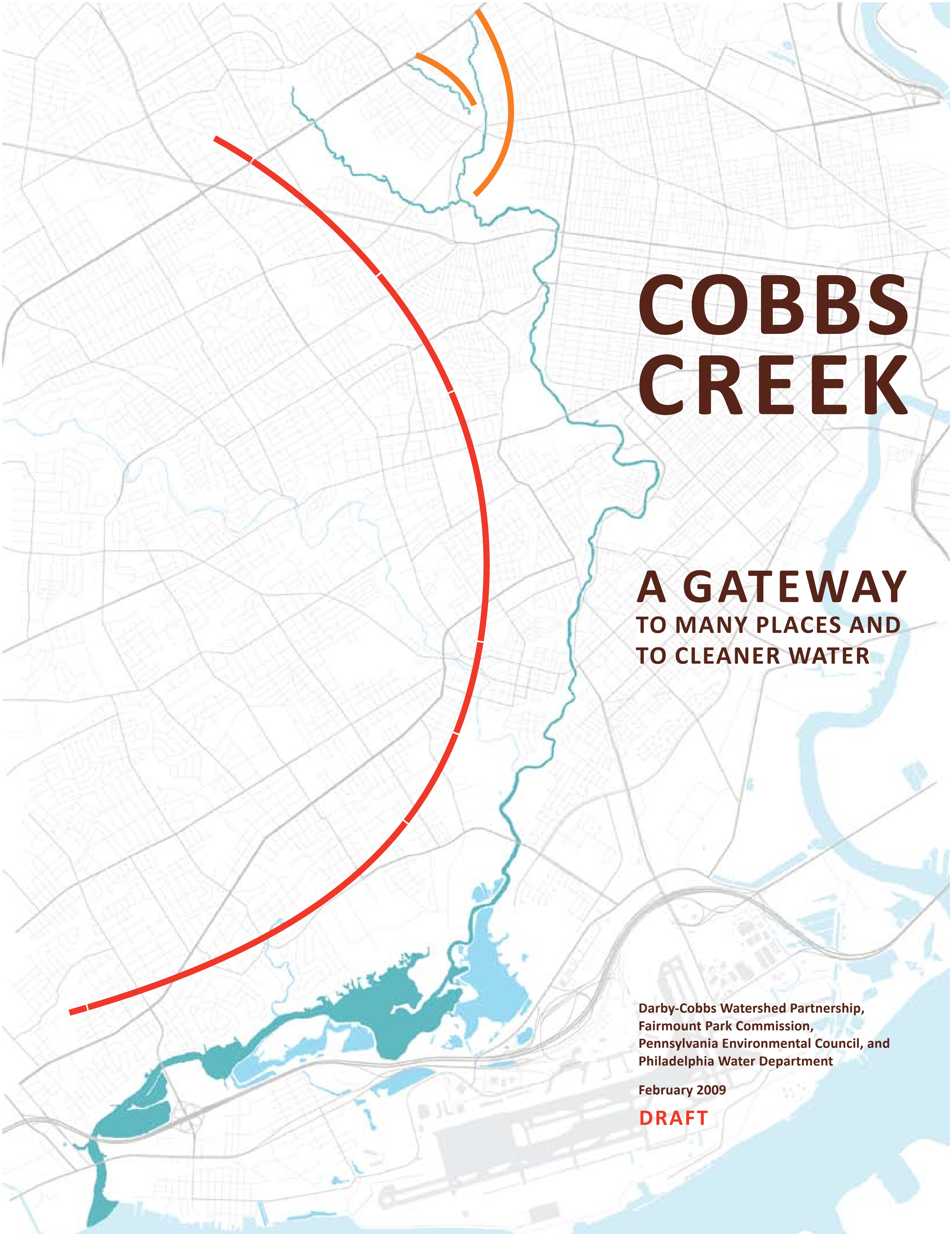


COBBS CREEK

A GATEWAY
TO MANY PLACES AND TO CLEANER WATER

Darby-Cobbs Watershed Partnership,
Fairmount Park Commission,
Pennsylvania Environmental Council, and
Philadelphia Water Department

February 2009

DRAFT

The Darby-Cobbs Watershed Partnership

works to connect residents, businesses, and government as neighbors and stewards of the watershed. The Partnership has been active in developing this vision for the watershed and guiding and supporting subsequent planning activities within the watershed.

The Darby-Cobbs Watershed Partnership members and other organizations that have participated in partnership efforts:

Brother Rousseau Academy
Clean Air Council
Cobbs Creek Community Environmental Education Center
Cobbs Creek Golf Course
Cobbs Creek Recreation Center
Cobbs Creek West Community Association
Colwyn Borough
Darby Borough
Darby Creek Valley Association
Delaware County Anglers
Delaware County Concerned Citizens for Environmental Change
Delaware County Conservation District
Delaware County Environmental Network
Delaware County Intermediate Unit
Delaware County Planning Department
Delaware Valley Earth Force
Delaware Valley Regional Planning Commission
Delco Anglers
Department of Conservation and Recreation’s Southeast Regional Office
East Lansdowne Borough
Fairmount Park Commission
Friends of Cobbs Creek - Southside
Friends Central Middle School
Greater Lansdowne Civic Association
Haddington-Cobbs Creek CDC
Haverford Township
Haverford Township Environmental Advisory Council
Lansdowne Borough
Lansdowne Borough Environmental Committee
Lansdowne Tree Advisory Board
Lower Merion Conservancy
Lower Merion Township
Lower Merion Township Environmental Advisory Council
Men of Cobbs Creek
Merion East Golf Course
Millbourne Borough
Montgomery County Conservation District
Morris Park Restoration Association
Narberth Borough
Natural Resource Conservation Service
Northeast Treatment Center
Office of Congressman Joe Sestak (PA-7)
Operation Weed and Seed of Upper Darby Township
Overbrook Farms Club
PA Cleanways
Partnership CDC
Pennsylvania Department of Environmental Protection
Pennsylvania Environmental Council
Pennsylvania Horticultural Society
Pennsylvania Resources Council
Philadelphia Water Department
Radnor Conservancy
Royal Gardens Association
Saint Joseph’s University
Senior Environmental Corps
SEPTA
Streetz to Creeks, LLC
University of Pennsylvania
Upper Darby School District
Upper Darby Township
Upper Darby Weed and Seed
Ursinus College
Vision Quest
The Wagner Free Institute of Science
Wissahickon Friends Central School
Yeadon Borough

Planning and Design:

WRT

CDM

Cobbs Creek has the potential to be one of the major connective fibers of our region,

providing miles of needed trail links, connecting neighborhoods and amenities, and conveying and cleaning our waters before they reach the Delaware River. This vision has long been held by many who manage, live and play along "the Cobbs" and who over the past decade have collaborated to build this vision.

In 1997, funding from the William Penn Foundation allowed **Fairmount Park** to create a restoration master plan for the Cobbs and to more actively coordinate volunteer and partner activities. During the same period, the **Philadelphia Water Department** initiated the **Darby-Cobbs Watershed Partnership**, a consortium of proactive environmental stakeholders focused on achieving ecological and quality-of-life improvements in the watershed. Since then, Fairmount Park, the Philadelphia Water Department, and their partners have worked to further connect public and private stakeholders to the watershed through planning actions, improvements, and extensive volunteer activities.

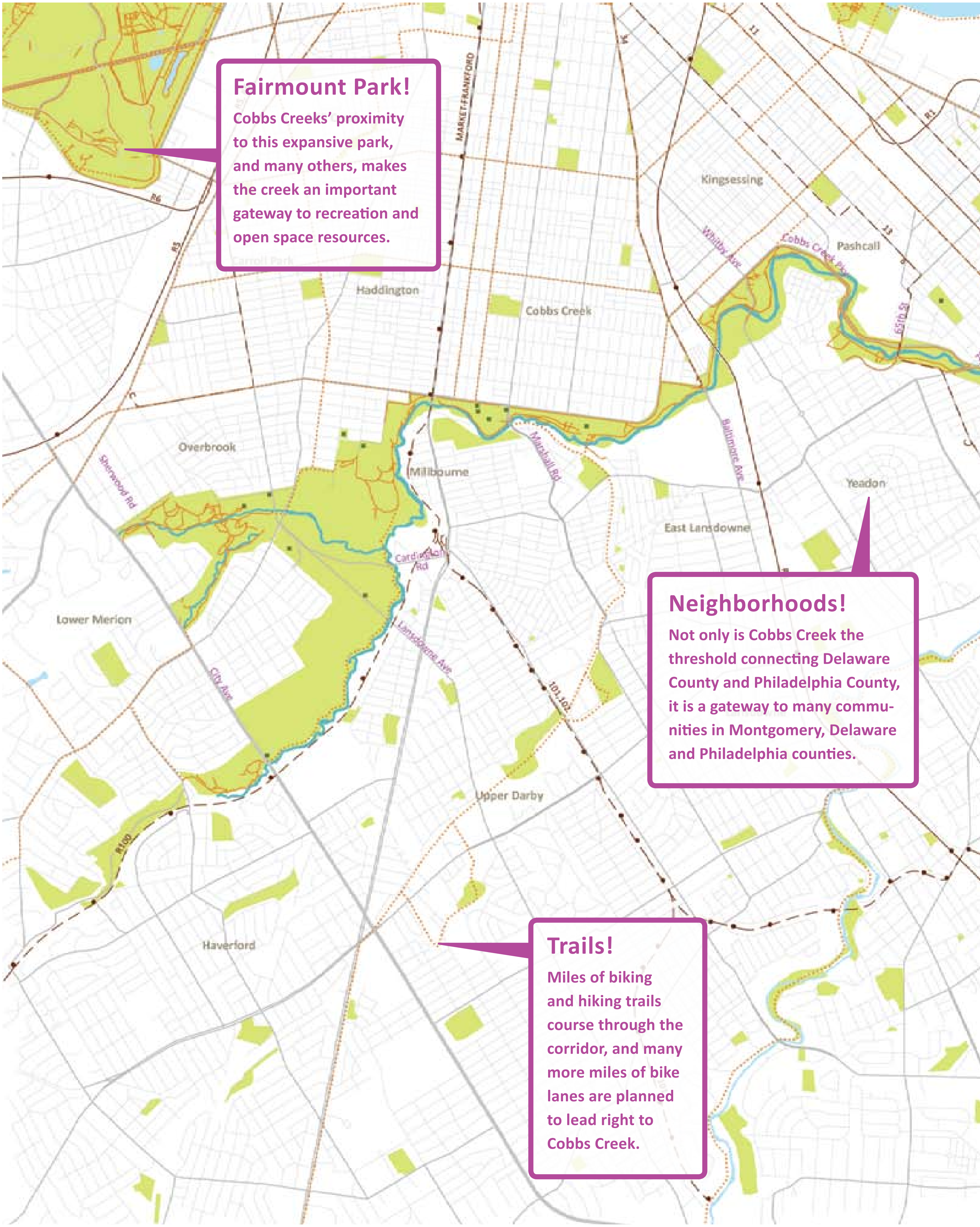
Over 20,000 volunteers are engaged in the management and improvement of the Darby-Cobbs watershed, for a total of almost 50,000 hours! Volunteerism continues to grow, as neighbors and groups come to realize the significance and potential of the creek and its lands. Public funders from the state and federal government such as DCNR and EPA continue to offer support. Knowledgeable partners such as the **Pennsylvania Environmental Council** continue to assist with watershed coordination. Now, ten years after the beginning of significant watershed planning, incipient ideas for Cobbs are being transformed by community participation into an enduring civic vision.

Much has been achieved by the watershed partners and volunteers over the past 10 years to make this vision real:

- A creek restoration and sewer relocation project near Marshall Road;
- 216 acres of restoration, including 1186 shrubs and 4017 trees planted (21 total acres); 9.5 acres of invasive plants removal; 2.4 acres of meadow creation; and 5 acres of stormwater management including wetland creation and stream restoration;
- Development of the Cobbs Creek Community Environmental Education Center; and
- Publicly vetted planning for upcoming trails and restoration projects.

The extensive parkland surrounding Cobbs Creek is public, presenting the opportunity for significant enhancement and public use, but also significant need for maintenance and event planning. The varied terrain and quality of the creek corridor keep people from experiencing or understanding the place in its entirety. It is understood as a composite of places. Its greatest potential can be realized only when it is appreciated as an integrated whole.

This vision statement brings together the many proposed improvements for Cobbs Creek by varied stakeholders, supporting the holistic approach Fairmount Park and the Philadelphia Water Department and their partners have long advocated.



Fairmount Park!

Cobbs Creeks' proximity to this expansive park, and many others, makes the creek an important gateway to recreation and open space resources.

Neighborhoods!

Not only is Cobbs Creek the threshold connecting Delaware County and Philadelphia County, it is a gateway to many communities in Montgomery, Delaware and Philadelphia counties.

Trails!

Miles of biking and hiking trails course through the corridor, and many more miles of bike lanes are planned to lead right to Cobbs Creek.

Recreation!

The Cobbs Creek corridor boasts a multitude of recreational facilities, including playgrounds, recreation centers, park and golf facilities, ice skating rinks, an environmental education center and trails!

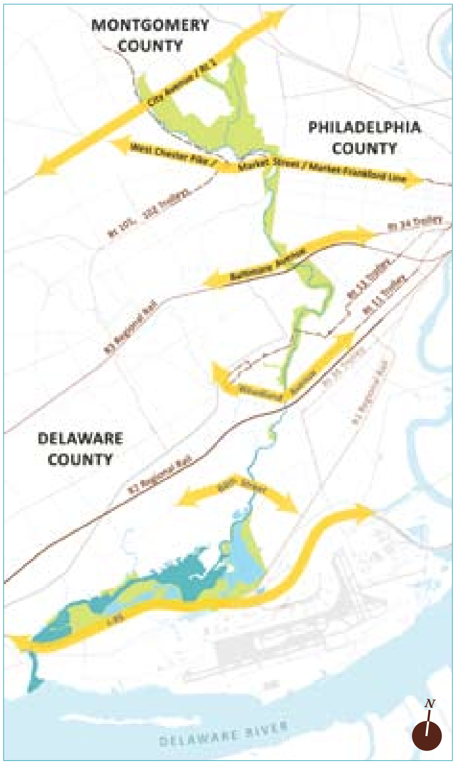
Transit!

Nine rail lines, including regional, subway, and trolley service, cross over or wind along the Cobbs Creek corridor.

Habitat!

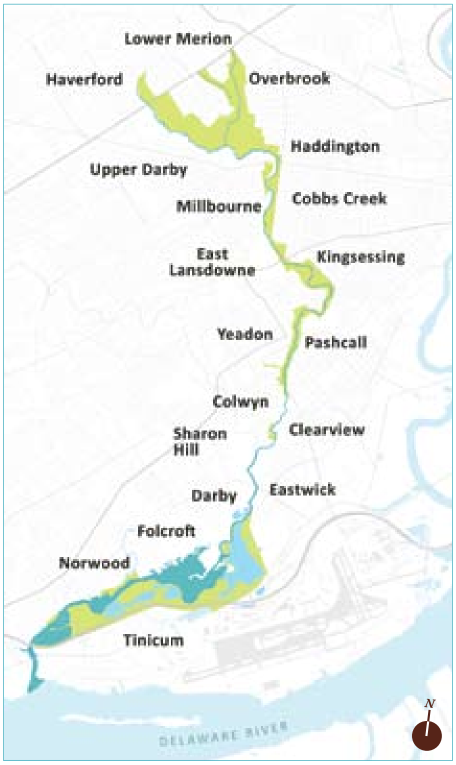
Cobbs Creek flows through the John Heinz National Wildlife Refuge at Tinicum, where marshes support diverse wildlife.

Cobbs Creek: A Gateway to Many Places and to Cleaner Water



A Gateway Across Regions

Cobbs Creek is the border between Philadelphia and Delaware Counties. The northern edge of Indian Creek at City Line Avenue defines the boundary between Montgomery and Philadelphia Counties. Although political borders can sometimes be abstract, Cobbs Creek plays a very real role as the gateway to communities on a regional scale.

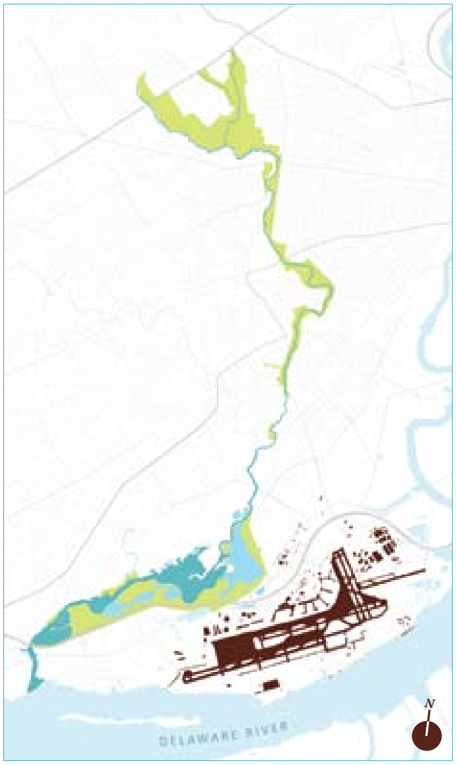


A Gateway to Communities

Cobbs Creek is the thread that unites diverse communities along and across its banks. Through roads, rail and the creek, these communities are stiched together.

A Gateway to Resources

Talk about proximity to cultural and natural resources: parks, including Fairmount Park and a plethora of neighborhood parks; the historic Blue Bell Tavern; the John Heinz National Wildlife Refuge at Tinicum; the Schuylkill and Delaware Rivers — among many others!

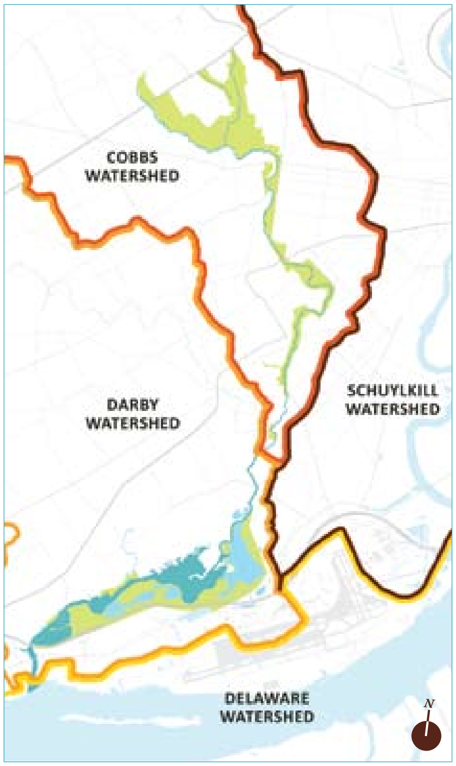


An Aerial Gateway

Viewed from an airplane, Cobbs Creek is a distinctive green ribbon, a connective environment that gracefully frames the approach to Philadelphia's International Airport. It provides a lush counterpoint to the nearby industrial lands of the Schuylkill and Delaware Rivers, enhancing the entry to our region.

A Gateway to Recreation

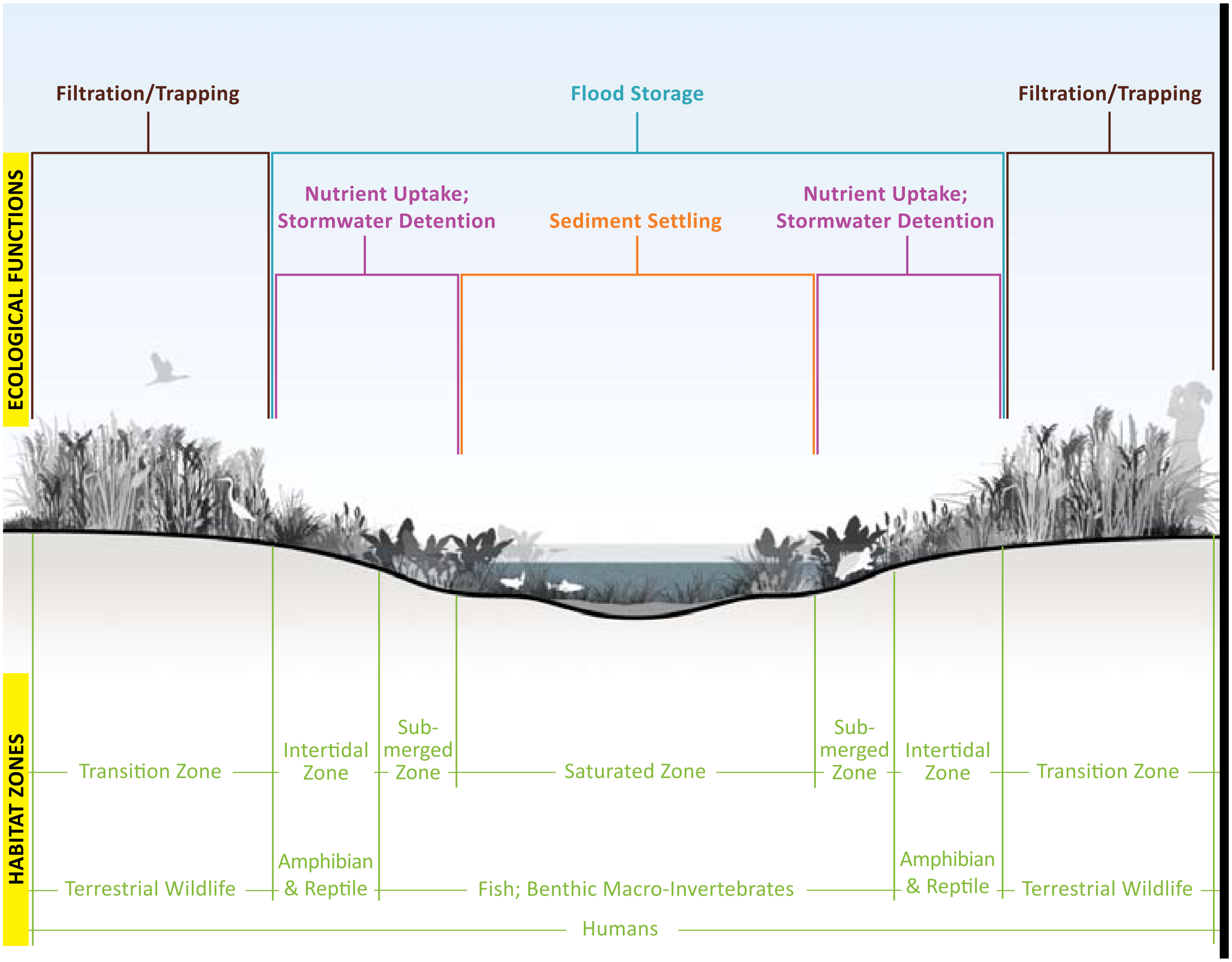
The Cobbs Creek corridor provides essential connective tissue to a network of great and varied recreational opportunities. It raises a series of resources, like golf courses, miles of trails, neighborhood parks, a stable, and acres of open water to kayak in, into a distinctive destination.

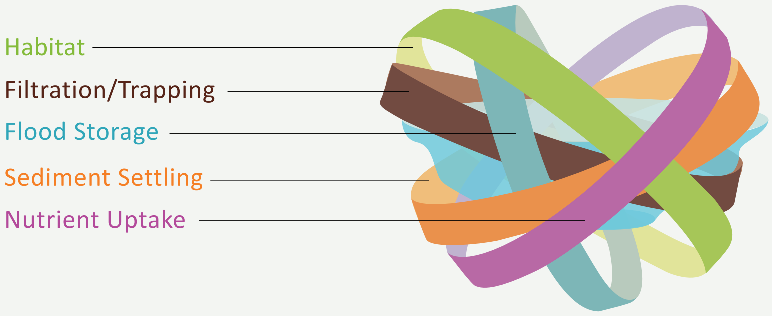


A Gateway to Cleaner Water

Like all of our few remaining creeks, the Cobbs Creek corridor offers us the opportunity to help steady the environmental imbalances caused by urban development. Restoring the natural environment along the stream corridor can improve water quality, habitats and environmental education opportunities.

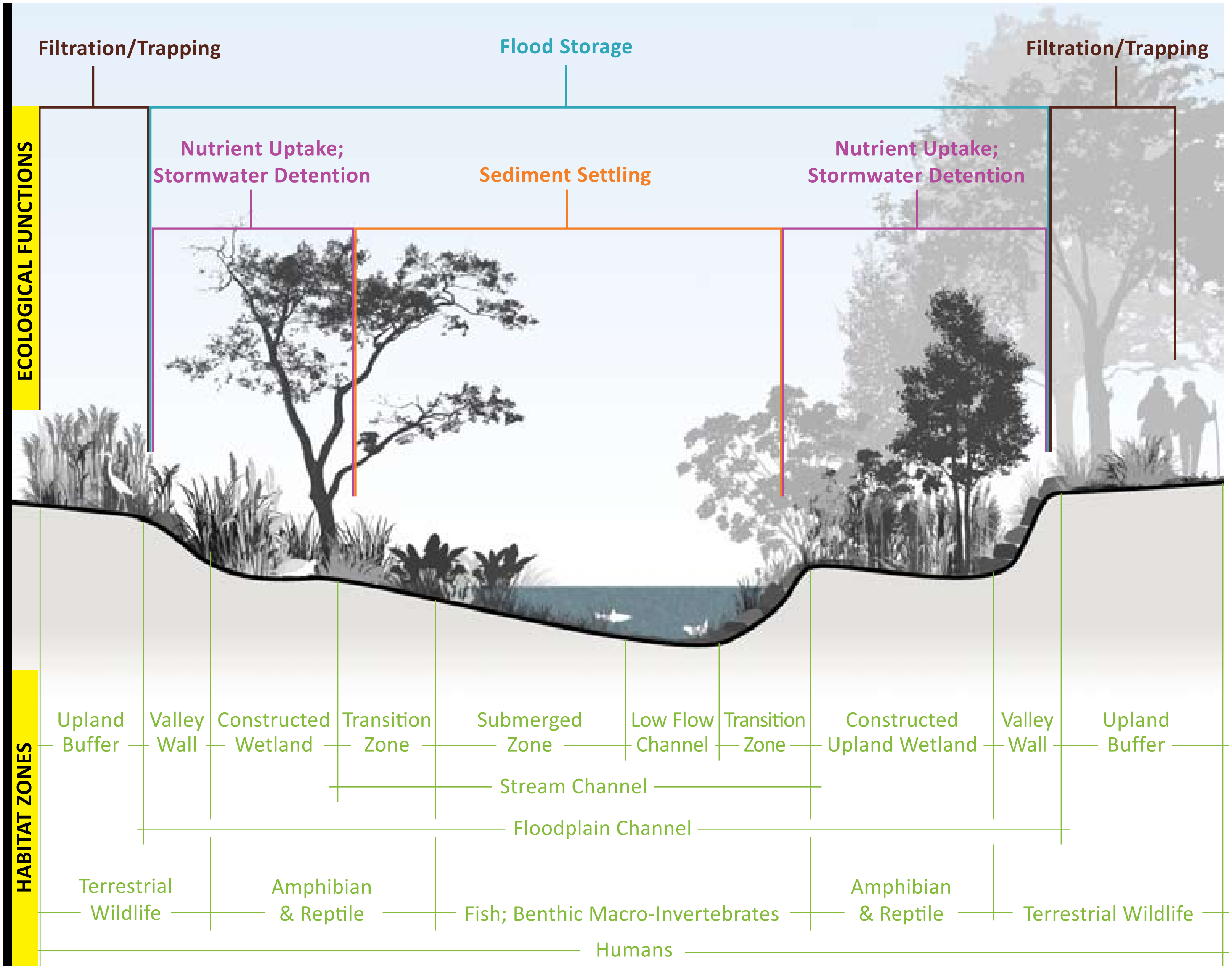
A typical WETLAND performs these kinds of ecological functions...





In a typical wetland, physical, chemical, and ecosystem constituents **cycle continuously** through the wetland.

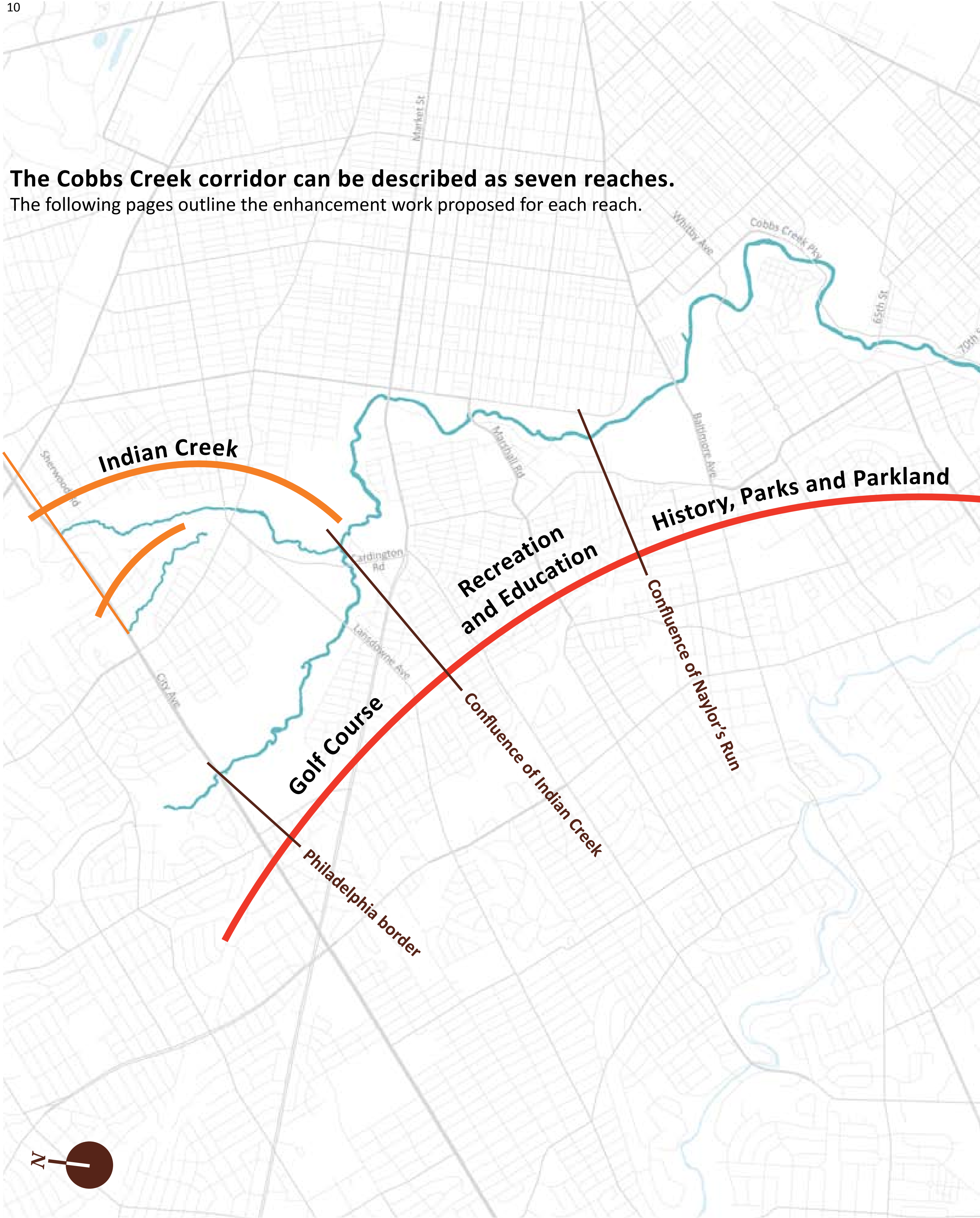
...but an enhanced STREAM CORRIDOR can perform the same functions, too.



The same physical, chemical, and ecological functions can be performed in a riparian corridor, but their spatial organization differs. In a riparian corridor, wetland functions may be more **spread out**, instead of layering over one another. Instead of cycling within a wetland, the functions may be understood as **spiraling** within the entire riparian corridor, with different ecological functions predominating in different areas.

The Cobbs Creek corridor can be described as seven reaches.

The following pages outline the enhancement work proposed for each reach.




Island Ave
84th St
Lower Cobbs
Darby
Tinicum
Woodland Avenue Dam
Confluence of Darby Creek
Confluence of Darby Lake
I-95
Wanamaker Ave
Essington Ave
Confluence of the Delaware River

Indian Creek Reach

The Indian Creek reach of Cobbs Creek represents the convergence of a remarkable number of signature places and recreation opportunities. It also offers some of the most dramatic opportunities for environmental enhancements anywhere in the the city. With 69th Street Terminal at its base, City Line Avenue defining its northern edge and the major streets of Haverford, Lansdowne, and Girard Avenues converging at its center, the site enjoys a remarkable degree of access. Surrounded by Lower Merion, Overbrook and Upper Darby, this reach could be a major community magnet, drawing support and stewardship from all edges.

In its current condition, this reach offers limited positive recreation and environmental education assets. The site does, however, offer a remarkable framework for enhancements. The potential palette of environmental enhancements include stream daylighting at the intersection of the west and east branches of Indian Creek; wetland creation in large, suitable sites; wetland restoration in several locations; and stream channel redefinition and plantings.

The Indian Creek reach offers a remarkable framework for environmental restoration. ***Above:*** *With stream daylighting, the east and west branches of Indian Creek may be brought together near this point.* ***Middle row:*** *This reach includes neighborhood parks, playgrounds, and trails.* ***Below:*** *This site in the upper reach is one of several opportunities for creation of large wetlands.*

A vision of the restoration of the natural watercourse of Indian Creek, upstream of Lansdowne Avenue.

existing conditions

Stream corridor improvements in the Indian Creek reach:

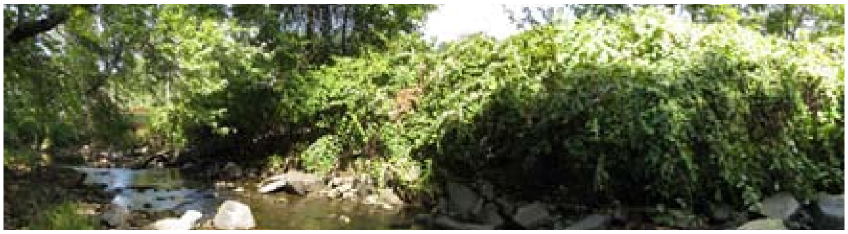
1.4 acres of wetland enhancement
0.5 acre of wetland creation
2.0 acres of stream daylighting

Golf Course Reach

Bordered by the R100 high speed line, with 69th Street Terminal near its base and City Line Avenue near its northern edge, the Golf Course reach is extremely well-connected by transit and roads. The thriving, compact neighborhoods of Parkview and Lower Merion border it and Overbrook neighborhood is close by. Currently, a lack of trails along this reach inhibits pedestrian connectivity between these neighborhoods and to the larger park network. Still, the reach's extensive public golfing facilities draw visitors from within and beyond the area.

In the Golf Course Reach, a pastoral setting and gently sloping banks frame Cobbs Creek. But typical golf course land management practices and application of fertilizers and other chemicals can threaten water quality and promote the spread of invasive vegetation. With stream bank enhancements, in-channel modifications, increased buffers and removal of invasive plants, this reach of the creek could become a true asset that brings many ecological benefits. With trail development, this reach could also provide tremendous educational and recreational benefits.

Top left: *Cloaked by invasives, the stretch near the golf driving range is a hidden jewel.* ***Top right:*** *The City Line Avenue bridge offers a glimpse into the potential and current problems.* ***Above:*** *The City Line Avenue driving range is a low-key, verdant place to spend an afternoon.* ***Below:*** *Managing stormwater from upstream and providing cleaner water will require the creation of more areas for water storage and infiltration.*



existing conditions

Stream corridor improvements in the Golf Course reach:

1.23 acres of wetland enhancement

5.66 acres of wetland creation

2.43 acres of streambank restoration

4.65 acres of in-channel streambank restoration

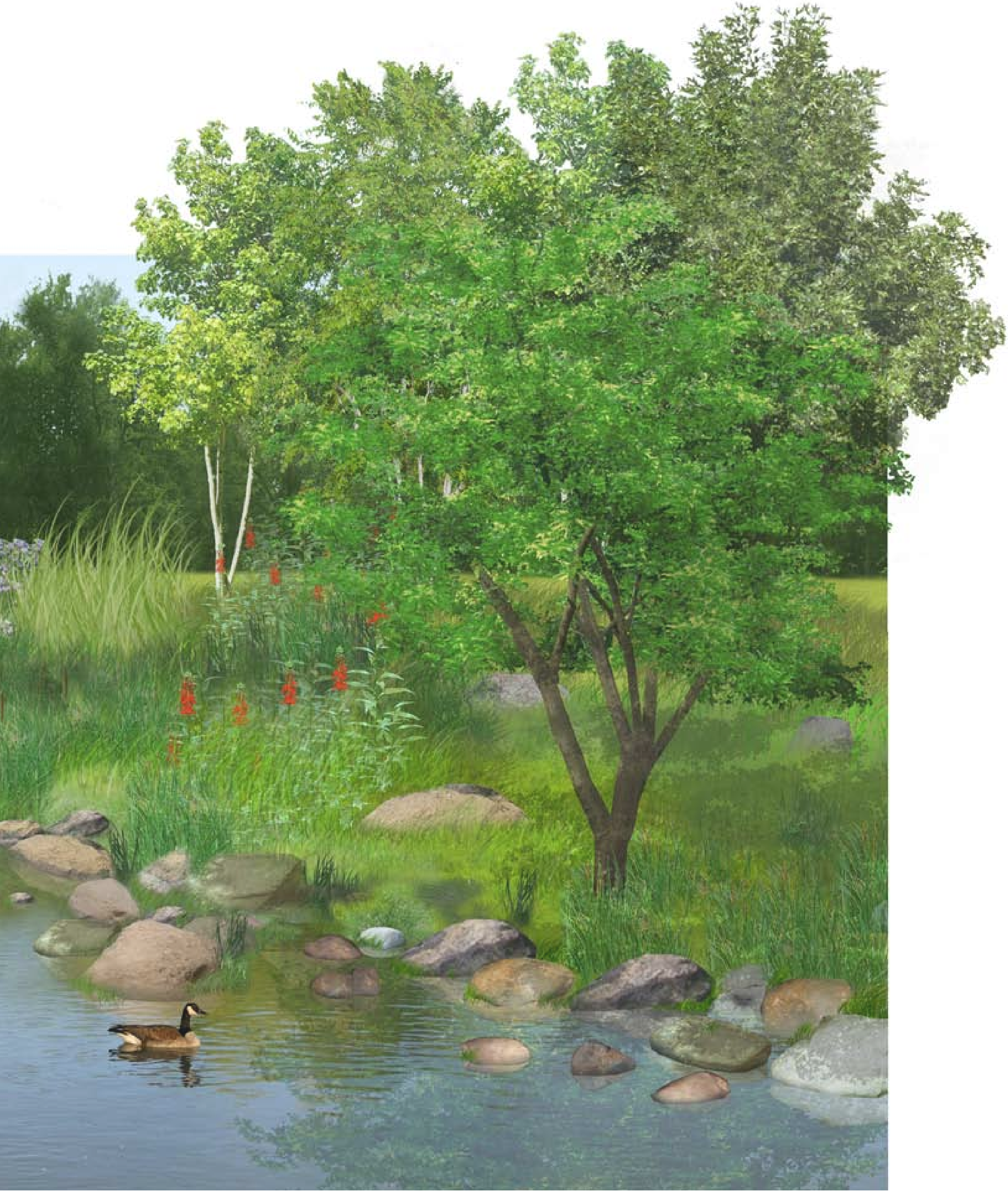
1.30 acres of additional tree canopy cover

1.71 acres of stormwater detention basins

0.19 acre of naturalized stormwater discharge

1.42 acres of new floodplain storage

0.15 acre of improved accessibility using trails



A vision of Cobbs Creek, looking north toward the golf driving range.

Recreation and Education Reach

The Recreation and Education Reach of Cobbs Creek beautifully demonstrates that even narrow corridor segments can provide a plethora of environmental benefits and community amenities. The reach begins at the Cobbs Creek confluence with Indian Creek and ends where it meets Naylor's Run. It is framed by the Cobbs Creek and Millbourne neighborhoods and includes a large range of facilities: an ice skating rink, a pool, a recreation center, and the jewel of the corridor, the Cobbs Creek Environmental Education Center.

The Cobbs Creek Environmental Education Center site's pastoral setting, historic bridge and buildings make it one of the most scenic places in the city. Its beautifully restored wetland and creek segment provide a model for high performing environmental enhancements. The Philadelphia Water Department has demonstrated through its work at the Center site that riparian corridor environmental enhancements can be ecologically high functioning and sustainable. There is still more work needed to bring the rest of this reach up to the standard set by the Cobbs Creek Environmental Education Center segment. Served by the Market-Frankford line, among other public transit routes, this reach is well positioned to become an important destination for education and recreation.

The Recreation and Education Reach provides many opportunities for environmental education and for recreation. ***Above:*** *A dam blocks fish passage in the upper portion of the reach.* ***Middle:*** *Children enjoying free playtime by exploring the Cobbs near the Cobbs Creek Environmental Education Center.* ***Right:*** *A view toward the Cobbs Creek Environmental Education Center building.* ***Bottom:*** *A successful enhancement project that provides a range of environmental and recreational benefits.*

Proposed stream corridor improvements in the Recreation and Education reach:

5.62 acres of wetland enhancement
14.41 acres of wetland creation
5.22 acres of streambank restoration
11.46 acres of in-channel streambank restoration
0.76 acre of additional tree canopy cover
2.60 acres of stormwater detention basins
0.84 acre of naturalized stormwater discharge
2.20 acres of new floodplain storage
2.64 acres of dam removal / new fish passages
0.28 acre of improved accessibility using trails

Stream corridor improvements are already at work in Cobbs Creek!

04/27/00

Years of streambank erosion led to exposure of a sewer pipe within Cobbs Creek near Marshall Road. This type of situation often occurs in streams receiving urban runoff and requires action to prevent damage to the pipe and to stabilize and restore the stream embankment.

10/22/04

In the fall of 2000, the Philadelphia Water Department (PWD) was awarded a PA Department of Conservation and Natural Resources Growing Greener Grant of $150,000 for natural channel restoration and habitat creation in this section of creek. PWD provided additional matching funds and the Marshall Road project has become a model of stream restoration, demonstrating the ecological, recreational and aesthetic value of stream improvement projects.

04/06/06

Design: Biohabitats, Inc.
Construction: Buckley & Company, Inc.

900 linear feet of streambank restoration

$51,000 for clearing and grubbing

170 feet of sewer rehabilitation

3412 cubic yards of excavation

2975 square yards of water course and erosion protection

$11,000 for invasive species management

4 vanes (artificial structures used to direct flows in a stream)

625 cubic yards of constructed riffle

1060 tons of boulder bank stabilization

366 trees planted

277 shrubs planted

492 linear feet of live branch layering

4391 square yards of native seeding and mulching

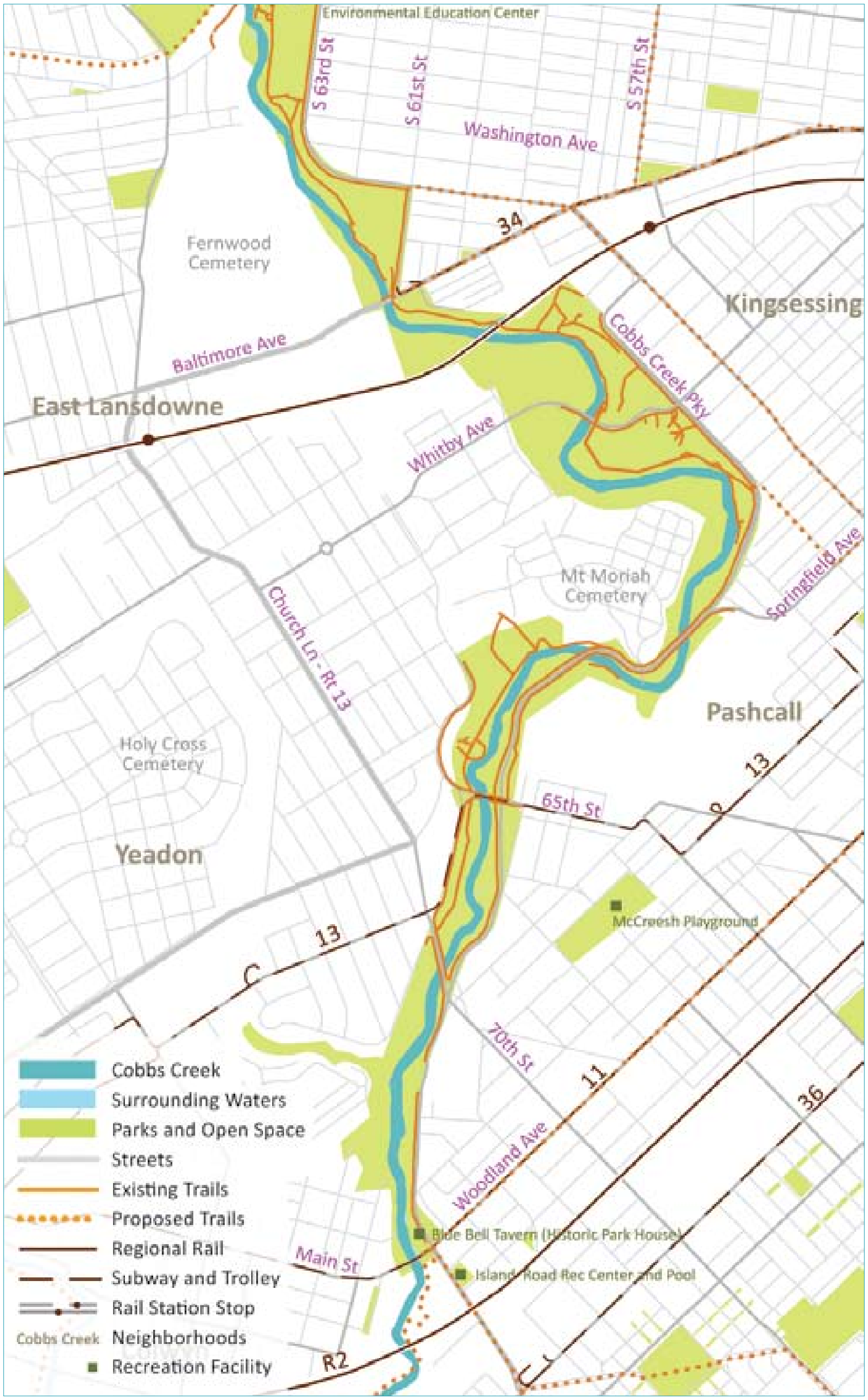
$768,737.80 total cost

09/29/06

History, Parks and Parkway Reach

The History, Parks and Parkway Reach truly imparts a feeling for the pace and setting of past periods. The gentle meanders of the verdant Cobbs Creek Parkway border the east side of the corridor; historic Woodland Avenue brings a visitor to the historic Blue Bell Tavern, the scene of a lethal Revolutionary War skirmish. Mt. Moriah Cemetery, built in the mid -19th Century within the “rural ideal” type, speaks of pastoral landscape style and ambitions of the time. These, and other, threads of the past come together in an area that faces contemporary environmental challenges and opportunities.

Significant opportunities for stream enhancements twine throughout this entire reach. Reconfigured banks can bring wetlands, stormwater storage, revitalized buffers and new trails. The dam near the Blue Bell Tavern currently prevents fish passage but with slight modification could allow for migration. Enhancements to the creek and creek landscape would re-frame the significant assets already in place in this reach, providing a new setting for the historic jewels. This combination of improved environmental, recreational and cultural assets would well serve the city and the densely developed adjacent neighborhoods of East Landsdowne, Yeadon, Kingsessing and Pashcall.



In the History, Parks and Parkway Reach, the strands of the past interweave with contemporary environmental challenges and opportunities. ***Top row, from left:*** *The historic Blue Bell Tavern; the beautiful Cobbs Creek Parkway; one of many quiet park areas.* ***Middle row, from left:*** *The C17 combined sewer outlet; Cobbs Creek near Mt. Moriah Cemetery in early autumn.* ***Bottom row:*** *The well-crafted stone Cobbs Creek Parkway Bridge crossing Cobbs Creek.*

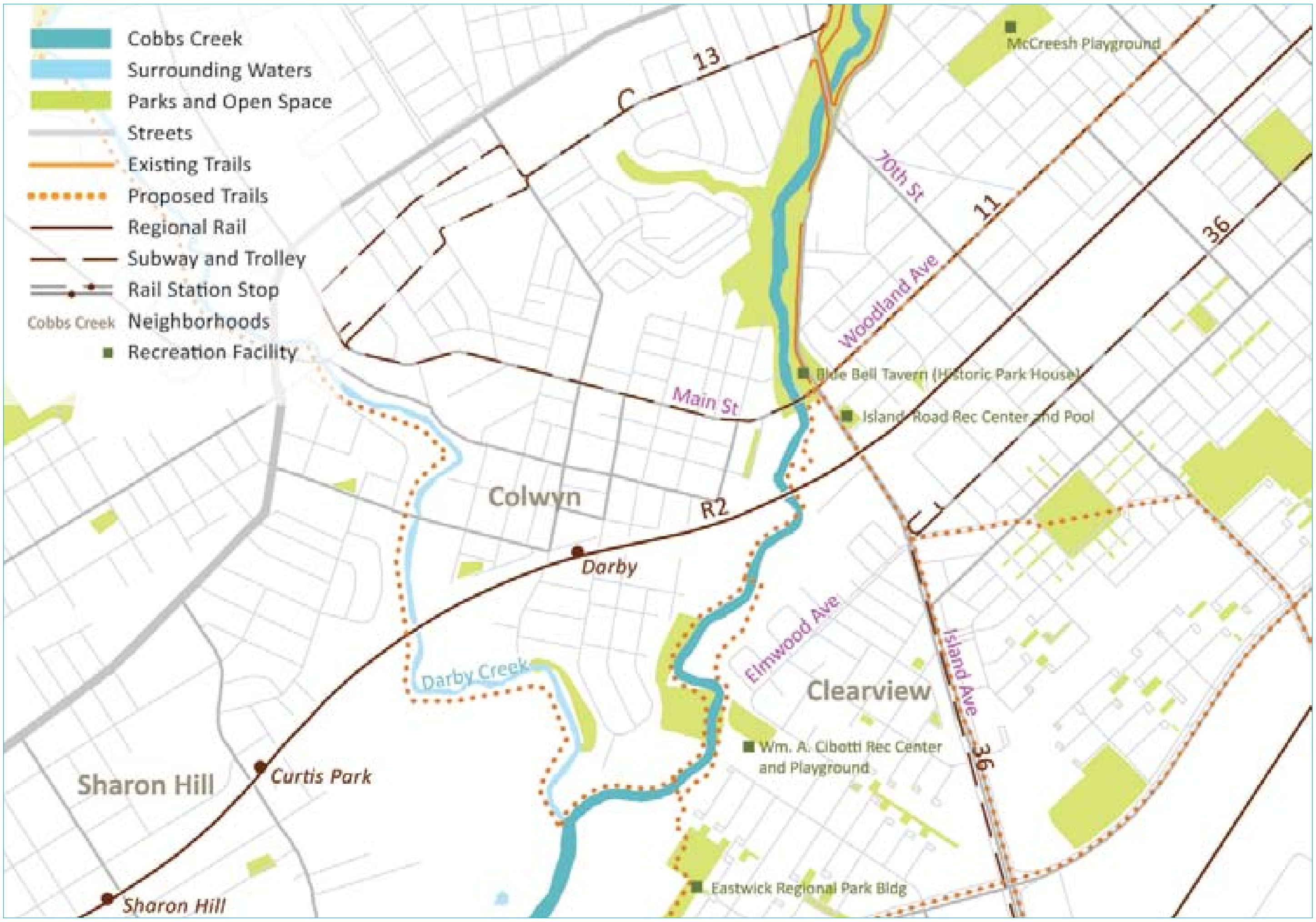
existing conditions

A vision of Cobbs Creek from Whitby Avenue Bridge.

Stream corridor improvements in the History, Parks and Parkland reach:

2.81 acres of wetland enhancement
10.20 acres of wetland creation
4.93 acres of streambank restoration
22.62 acres of in-channel streambank restoration
1.83 acres of additional tree canopy cover
3.53 acres of stormwater detention basins
2.74 acres of naturalized stormwater discharge
4.98 acres of new floodplain storage
2.64 acres of dam removal/ new fish passages
1.10 acres of improved accessibility using trails

Lower Cobbs Reach

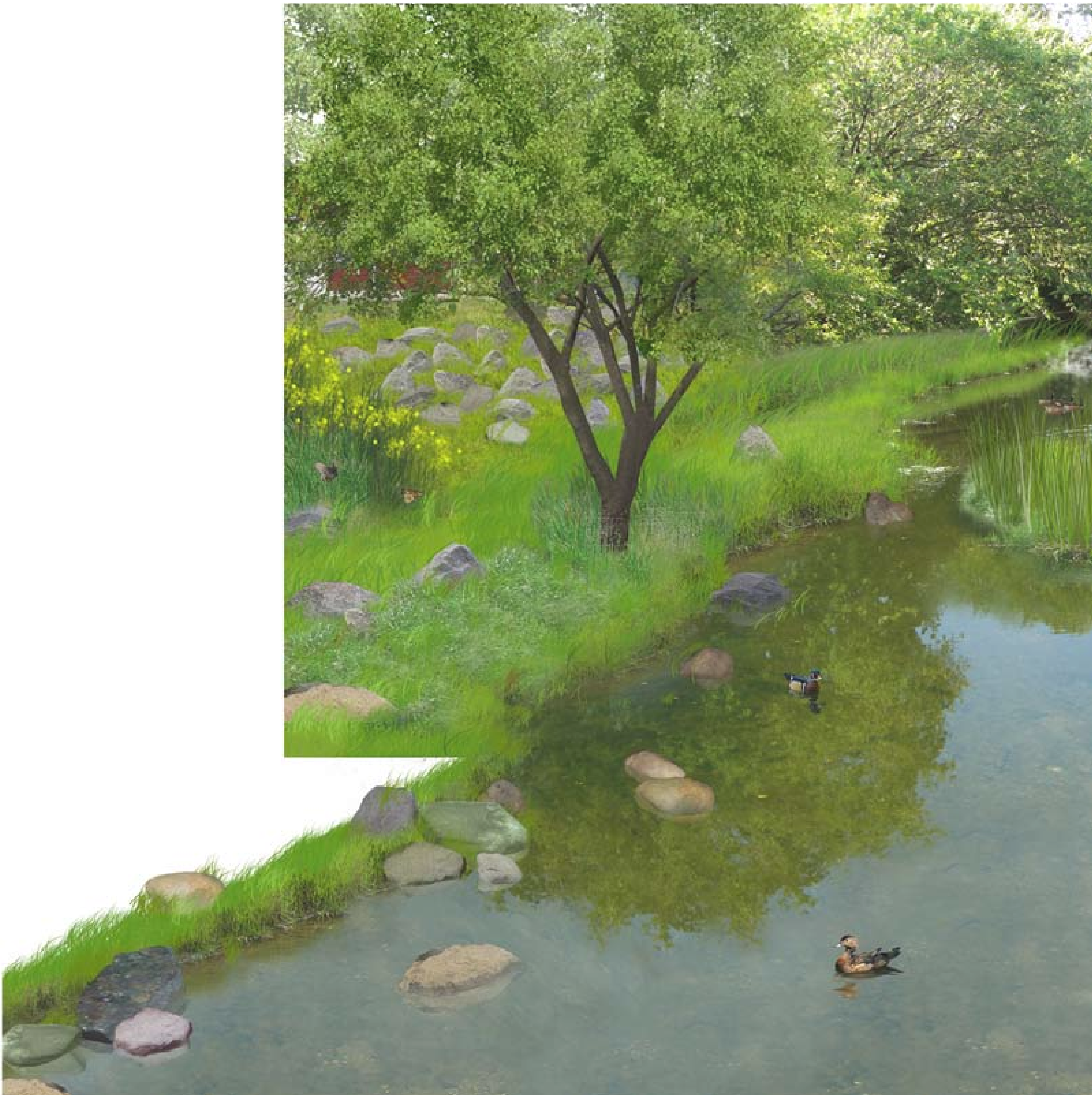


The Lower Cobbs Reach flows through the Colwyn and Clearview neighborhoods, ending at the confluence with Darby Creek. For a short and somewhat narrow reach, it offers green respites, great views and wonderful opportunities for environmental enhancement. Walking from the top of the reach to its end, a visitor would see the historic Blue Bell Tavern, the R2 line, the pastoral views of Saturn Park and the meeting of the the Darby and Cobbs Creeks. In its current state, one would also see stretches of bank erosion, invasive plants and limited tree buffers.

A wide range of improvements such as stream bank restoration, in-channel modifications and buffer enhancements could transform the functioning of this reach and the experiences it provides.

The Lower Cobbs Reach brings its adjacent neighborhoods in close contact with pastoral views and strolls. ***Top:*** *The Lower Cobbs with the Woodland Dam in the background. The photo-simulation on the following page addresses waterway restoration proposals for this area.* ***Lower right:*** *The Greensward of Saturn Park, near the confluence of Darby Creek, behind an Eastwick neighborhood.* ***Lower left:*** *Bank erosion and invasive plants near where Cobbs Creek meets Darby Creek.* ***Middle left:*** *One of the quiet Eastwick neighborhood streets.*

existing conditions



A vision of Cobbs Creek looking toward Woodland Avenue Dam, illustrating a new fish ladder that would promote fish passage.

Darby Reach

The neighborhoods bordering this reach, Sharon Hill, Darby, Clearview and Eastwick, know well the contrasts of their landscape. On one side of the Darby Reach are acres of “tank farm”, or oil tanks, and light industrial uses. On other side is the entry to The John Heinz National Wildlife Refuge at Tinium and the Cusano Environmental Education Center, and well-tended neighborhoods.

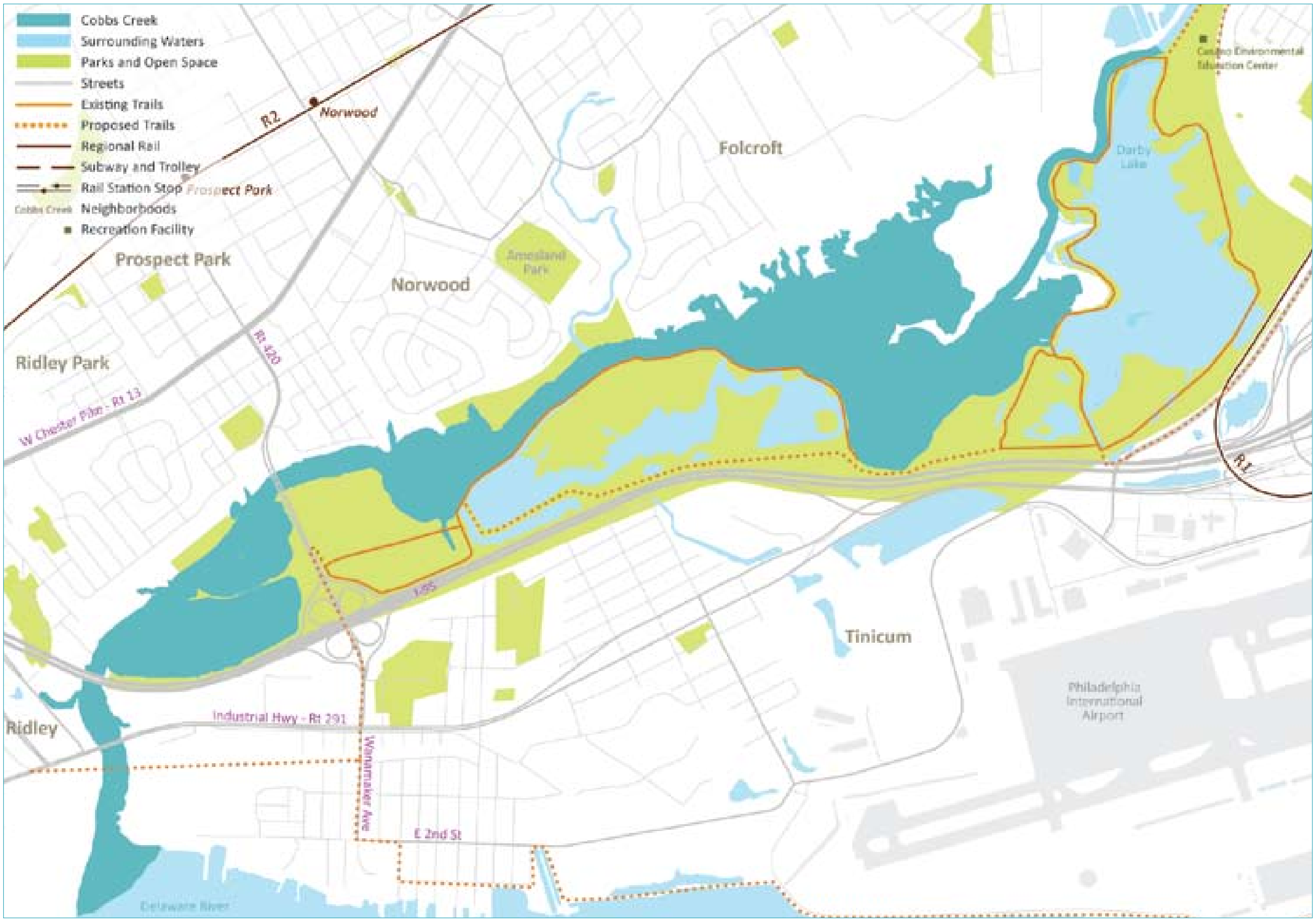
The presence of major circulation infrastructure including Interstate 95, two regional rail lines, trolley and even the airport, brings great opportunity to this area. But land use conflicts have tended to constrict those opportunities. With these conflicts and without a robust open space network to orient toward, some of the neighborhoods have developed frayed edges.

Currently, this reach is not a priority area for environmental restoration because of limited public ownership ouside of the wildlife refuge. With future land use changes, though, this reach will be well positioned for improvements.

The Darby reach is defined by a diverse blend of land uses. ***Below left:*** *The western banks of the Darby Reach are characterized by uses such as petroleum storage and warehousing, in addition to established neighborhoods within Darby (****left****). Opposite these banks is the Cusano Environmental Education Center (****below right****) whose mission is to "demonstrate within an urban setting, the importance of the natural world to the human quality of life and inspire visitors to become responsible stewards of the environment."*

www.phillysolar.com

Tinicum Reach



The first time visitor to the Tinicum Reach is almost always astounded by its vast and beautiful landscape. 1,200 acres of the site represent the largest freshwater tidal wetland in Pennsylvania - and yet, they are only a fraction of the original 6,000 acres of wetland. These wetlands perform amazing work but can cleanse only a portion of the Cobbs and Draby Creek waters that flow past them.

The pollutants those creek waters bring impact the health of plants and animals within the Tinicum Reach, the Delaware and even further. Managing our stormwater within the upper reaches of the Cobbs can bring positive benefits far beyond their boundaries.

With Fairmount Park to the north and the wildlife refuge at its base, with its prominent location within a multimodal circulation network - and someday, with much needed environmental enhancements - Cobbs Creek has the potential to become one of the region's most important riparian corridors. Its restoration could bring enormous benefits in ecological function, recreation, civic identity and quality of life.

Photo: Bill Buchanan, USFWS

Photo: Shari DeAngelo

Photo: Bill Buchanan, USFWS

Photo: Shari DeAngelo

The quality of water flowing from the Cobbs, past the Tinicum Reach, has impacts on the health of the marsh's plants and animals. Seen here are photos taken at John Heinz National Wildlife Refuge at Tinicum.

Cobbs Creek Corridor Enhancements By Reach

Reach:

Length:

Compiled as of November 13, 2008

1 NOTE: The Indian Creek reach is not part of the "Main Stem" study area as designated by the PWD's February 2008 report. The values shown for Indian Creek in the above table are not included in the "Summary of Enhancements" shown at far right.

2 Project area, in acres.

3 Functional value of improvement, in acres.

STANDARD RIPARIAN CORRIDOR RESTORATION ACTIONS
Wetland enhancement
Wetland creation
Streambank restoration
In-channel stream restoration (below streambank)
Addition of tree canopy cover
Stormwater detention basin
Stream daylighting
Naturalize stormwater discharge
Create floodplain storage
Dam removal / create fish passageway
Improve accessibility using trail system

Total Functional Value:

Environmental restoration and improvement projects in the Cobbs Creek corridor might include new and restored wetlands, in-stream and streambank restoration projects, stormwater detention basins, stream daylighting, naturalizing stormwater discharge and increasing floodplain storage, and improving fish habitat and passage.

If these varied projects are to be used as mitigation for lost tidal wetlands or open water, the environmental values they restore must be determined using a functional value analysis. The area of wetlands lost or created (usually expressed in acres) is often used as the standard measure for determining wetland and waterway impacts, and to determine the required mitigation for wetlands and other aquatic resources. The measurement of area impacted or restored has been used in the past because functional assessment methods often have not been developed or calibrated for an area. This area-based comparison method, however, limits the types of projects that can be used to mitigate lost wetlands. Functional assessments are among the best tools available to characterize impact and compensation values, and open up a whole new range of mitigation projects to consider.

In order to assign values to the many possible restoration projects in the Cobbs corridor, and to help permitting authorities decide on the value of restoration and improvement actions, those actions must be organized around the environmental functions that each can provide.

Wetland or stream restoration functions and the values offered through mitigation can be categorized into hydrologic and physical, biological, habitat, and social groups. Each category has one or more measurable criteria that describe the value of the mitigation project. By determining how a wetland functions and the value it provides to the environment, and how those lost wetland

Indian Creek[1]		Golf Course		Recreation and Education		History, Parks and Parkland		Lower Cobbs, Darby, Tinicum
1.86 miles		1.54 miles		2.18 miles		3.52 miles		
AREA[2]	VALUE[3]	AREA[2]	VALUE[3]	AREA[2]	VALUE[3]	AREA[2]	VALUE[3]	
1.40	3.12	1.23	2.39	5.62	8.85	2.81	6.22	Functional evaluation for the Lower Cobbs, Darby and Tinicum reaches are currently under analysis.
0.50	1.52	5.66	22.64	14.41	57.64	10.20	40.80	
0.00	0.00	2.43	3.95	5.22	8.14	4.93	8.20	
0.00	0.00	4.65	7.26	11.46	15.49	22.62	36.23	
0.00	0.00	1.30	1.02	0.76	0.56	1.83	1.38	
0.00	0.00	1.71	3.72	2.60	5.57	3.53	7.16	
2.00	5.63	0.00	0.00	0.00	0.00	0.00	0.00	
0.00	0.00	0.19	0.48	0.84	2.01	2.74	6.75	
0.00	0.00	1.42	3.12	2.20	4.71	4.98	10.31	
0.00	0.00	0.00	0.00	2.73	1.66	2.64	1.32	
0.00	0.00	0.15	0.04	0.28	0.08	1.10	0.31	
	10.27		44.62		104.71		118.68	

and open water functions can be replaced in an urban environment, compensatory mitigation requirements can be identified. Not only does this approach consider lost and restored functions and values, but it also considers the need to enhance valuable functions that may be scarce in the watershed. This functional value system was used to estimate the restoration value, or score, shown in the above table.

The goal of this riparian corridor restoration plan for Cobbs Creek is to illustrate the extensive benefit to the City's environment, its neighborhoods, its fish and wildlife, parks and recreation areas, and the health of our residents that would result from restoration of Cobbs Creek. Impacts to the Cobbs waterway, its water quality, and its wildlife are attendant to a long history of urbanization. This preliminary analysis illustrates the tremendous improvement in the quality of the City's natural environment and quality of life that can be achieved through a comprehensive restoration of the Cobbs Creek waterway.

Summary of Enhancements

TOTAL CREEK LENGTH IN STUDY AREA*

7.24 MILES

TOTAL PROJECT AREA IN STUDY AREA*

122.24 ACRES

TOTAL FUNCTIONAL VALUE IN STUDY AREA*

268.01 ACRES

*THE CURRENT STUDY AREA INCLUDES THE GOLF COURSE, RECREATION AND EDUCATION, AND HISTORY, PARKS AND PARKLAND REACHES.

Related Documents, Related Programs, and Additional Resources

Related Documents

- An **Act 167 Stormwater Management Plan** was completed for the Darby-Cobbs Watershed in 2004 under the leadership of the Delaware County Planning Department's Environmental Planning section. "The Pennsylvania General Assembly enacted Act 167 of 1978, the Pennsylvania Storm Water Management Act. This Act, which is the 'sister' legislation to Act 166, the Floodplain Management Act, recognizes the interrelationship between land development, accelerated runoff, and floodplain management. While Act 166 requires municipalities to regulate development in the floodplain, Act 167 requires municipalities to implement a stormwater management ordinance limiting stormwater runoff from new development."
  http://www.co.delaware.pa.us/planning/environmental/act167.html

- **The 58th Street Connector Greenway** is an initiative that is already underway to create a 1.2-mile recreational trail and green corridor. It will link Bartram's Garden and the Schuylkill River with southwest Philadelphia and Delaware County communities, multiple regional trail networks, and existing recreational facilities along 58th Street and Lindbergh Boulevard. Upon completion, it will be possible to bike, jog, blade, or walk from Center City to Delaware County, or loop around Southwest Philadelphia.
  Pennsylvania Environmental Council
  (and Philadelphia Streets Department)
  www.pecpa.org

- **The Cobbs Creek Connector Trail Feasibility Study** proposes a trail segment in Southwest Philadelphia that would follow the riparian border of the Darby and Cobbs Creeks for about 1.25 miles, connecting existing bicycle and pedestrian trails within the John Heinz National Wildlife Refuge to Cobbs Creek Park at 70th Street, where an existing bike trail continues north. A trail connection along Cobbs Creek would provide access to open space within the stream corridor, while connecting neighborhoods, historic sites, regional trail systems, and schools, businesses and employment centers. The study was submitted to the Clean Air Council in March of 2007.
  Campbell Thomas & Co. Architects
  www.campbellthomas.com

- The **Cobbs Creek Integrated Watershed Management Plan** was created in 2004 by the Philadelphia Water Department and the Darby-Cobbs Watershed Partnership to present "a logical and affordable pathway to restore and protect the beneficial and designated uses of the waters of the Cobbs Creek basin.... The plan recommends appropriate remedial measures, provides a financial commitment to initiate the implementation of the plan, and seeks to provide the impetus for stakeholders of the Darby basin to follow suit." The plan aims to meet regulatory requirements that municipalities are facing, like Stormwater Phase II permitting, Act 167 Stormwater Management Planning, and Combined Sewer Overflow Permitting. The report is available on the Philadelphia Water Department's Office of Watersheds website via a link at the bottom of their home page, under the header "Watershed Planning".
  http://www.phillyriverinfo.org/Watersheds/Darby-Cobbs.aspx

- The **Darby Creek Watershed Conservation Plan** was completed in 2005 by the Darby Creek Valley Association. The summary includes their top ten recommendations to conserve the Darby Creek Watershed, and is available at:
  www.dcnr.state.pa.us/brc/rivers/riversconservation/registry/DarbyCreek.pdf.
  Visit the DCVA website to learn about how this nonprofit organization is dedicated to the protection and enhancement of the Darby Creek watershed.
  www.dcva.org

- **The East Coast Greenway - Pennsylvania Alignment Alternatives Study** "investigates six alternative alignments for the Pennsylvania portion of the East Coast Greenway (ECG) from Bartram's Gardens on the west bank of the Schuylkill River in West Philadelphia to the mouth of Darby Creek in Delaware County."
  Pennsylvania Environmental Council (PEC)
  www.pecpa.org/eastcoastgreenway, and
  www.greenway.org

- The **Fairmount Park Natural Lands Restoration Master Plan** was created from 1998-2001 by Fairmount Park and several local organizations to develop environmental restoration goals, assess park conditions, identify restoration sites, and recommend restoration activities within the Fairmount Park System. The three-volume Master Plans contain recommended restoration activities for 452 high-priority sites in the seven watershed and estuary parks, including Cobbs Creek Park.
  Fairmount Park Commission
  www.fairmountpark.org/Environment.asp

- The **Urban Streams in the Darby-Cobbs Watershed** pamphlet offers a brief yet comprehensive overview of the challenges the Cobbs creek watershed faces, and general recommendations for remedying the health of the watershed, including stormwater management, and restoring and reconnecting with the watershed's floodplain.
  U.S. Army Corps of Engineers
  Philadelphia District
  www.nap.usace.army.mil/Projects/rsm/watershed.html

- The Department of Environmental Protection has created a **Watershed Restoration Action Strategy** (WRAS) for the Darby, Crum, Ridley, Chester and Cobbs Creeks Watersheds, known as Subbasin 03G. The Action Strategy identifies major sources of impairment in Cobbs Creek as habitat alterations, siltation, urban runoff, and municipal point sources. It identifies the highest restoration needs as the restoration of riparian buffers, streambank stabilization, and stormwater runoff controls.
  www.dep.state.pa.us/dep/deputate/watermgt/wc/Subjects/WSNoteBks/WRAS-03G.htm

Related Programs

- Visit the website of the **Center for Watershed Protection** to learn more about watersheds and their importance to water resources. A multitude of documents and resources regarding watersheds, riparian corridors, stream repair, stormwater management and watershed forestry are available for viewing and download here.
  www.cwp.org

- The mission of **Cobbs Creek Community Environmental Education Center** is to preserve the quality of life for residents in the Cobbs Creek area by educating and informing people about issues affecting their environment.
  http://cobbscreekcenter.org

- Visit the website of **Delaware County Planning Department's Environmental Planning section**. They encourage sustainable development practices that "preserve the County's critical natural resources and unique environmental character." They develop plans and offer technical support and assistance to municipalities pursuing environmental protection efforts and recommend improvements.
  www.co.delaware.pa.us/planning/environmental/watershedmanagement.html

- The **Delaware County Conservation District** evaluates problems, implements programs, and advocates for effective solutions dealing with natural resource protection and conservation.
  http://www.delcocd.org

- The **Delaware Valley Regional Planning Commission (DVRPC)** is dedicated to uniting the region's elected officials, planning professionals and the public with a common vision of improving transportation, promoting smart growth, protecting the environment and enhancing the economy. DVRPC most recently awarded $83,000 to the Pennsylvania Environmental Council (PEC) for final design elements for 58th Street Connector Greenway, connecting Schuylkill River with Cobbs Creek. Details on this project are shown at left, under "Related Documents".

- Visit the **Keystone Stream Team** website to read their guidelines on Natural Stream Channel Design (NSCD), and find links to other stream- and watershed-related information. The Keystone Stream Team is a diverse assemblage of members, including watershed groups, technical consultants, and state and federal agencies, and is funded by the Pennsylvania Department of Environmental Protection.
  http://www.keystonestreamteam.org

- The **Watershed Information Center (WIC)**, a web-based library of Philadelphia watershed-related information by the Office of Watersheds, provides information on Philadelphia's seven watersheds and strives to be the "central location for the collection and dissemination of Southeastern Pennsylvania watershed-related information." The site also offers information on its various programs, like ecosystem monitoring and watershed planning, and links to information on combined sewer overflows.
  www.phillyriverinfo.org/

Additional Resources

- Visit **Fairmount Park Commission's Cobbs Creek Park** web page for a brief history on the park, links to area attraction information and for an interactive map.
  www.fairmountpark.org/CobbsCreekPark.asp

- **Real-time water quality data** is available from USGS Gauging Stations within the Darby-Cobbs watershed.
  http://pa.water.usgs.gov/pwd/

- For **general background information** on Cobbs Creek, visit its Wikipedia entry.

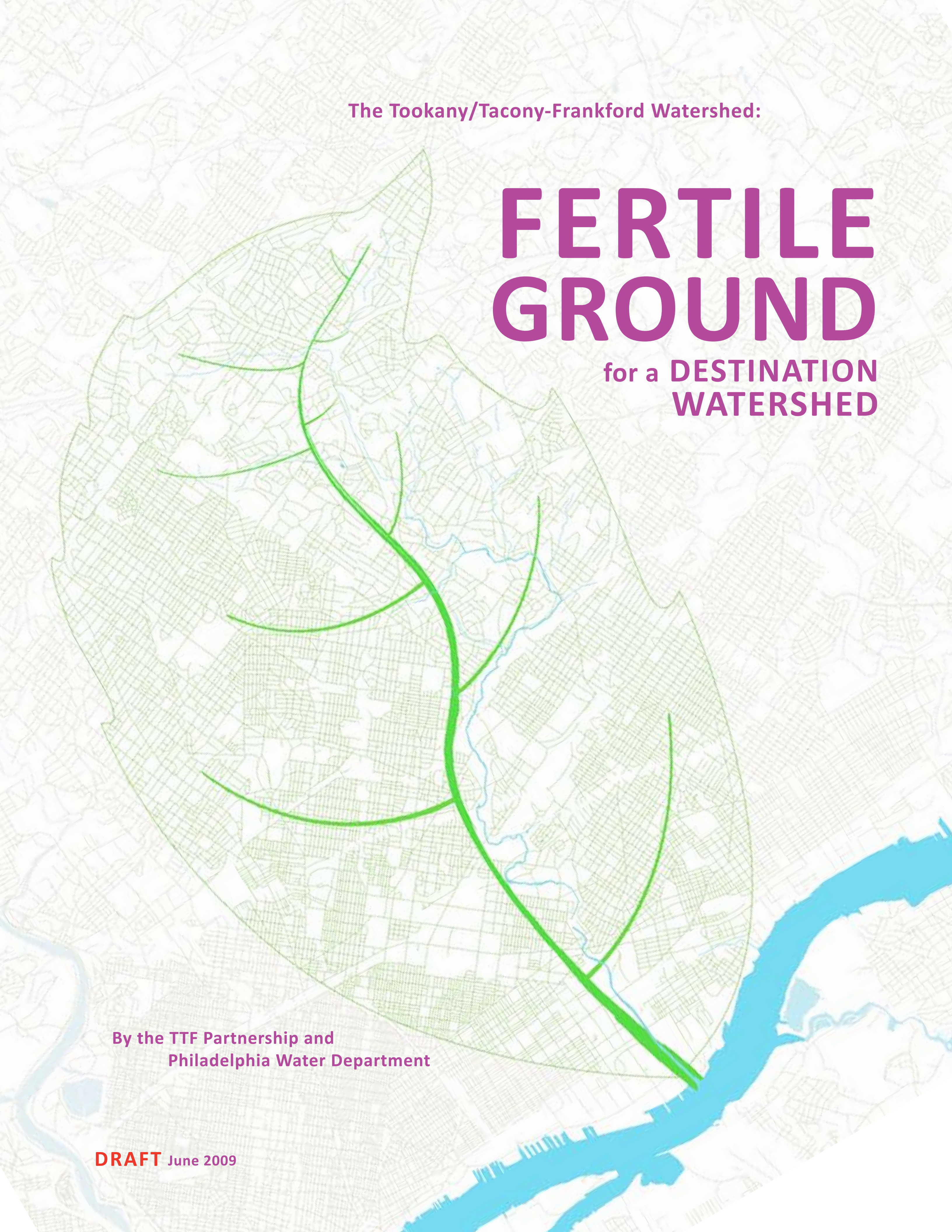
Cobbs Creek: A Gateway to Many Places and to Cleaner Water

February 2009

The Tookany/Tacony-Frankford Watershed:

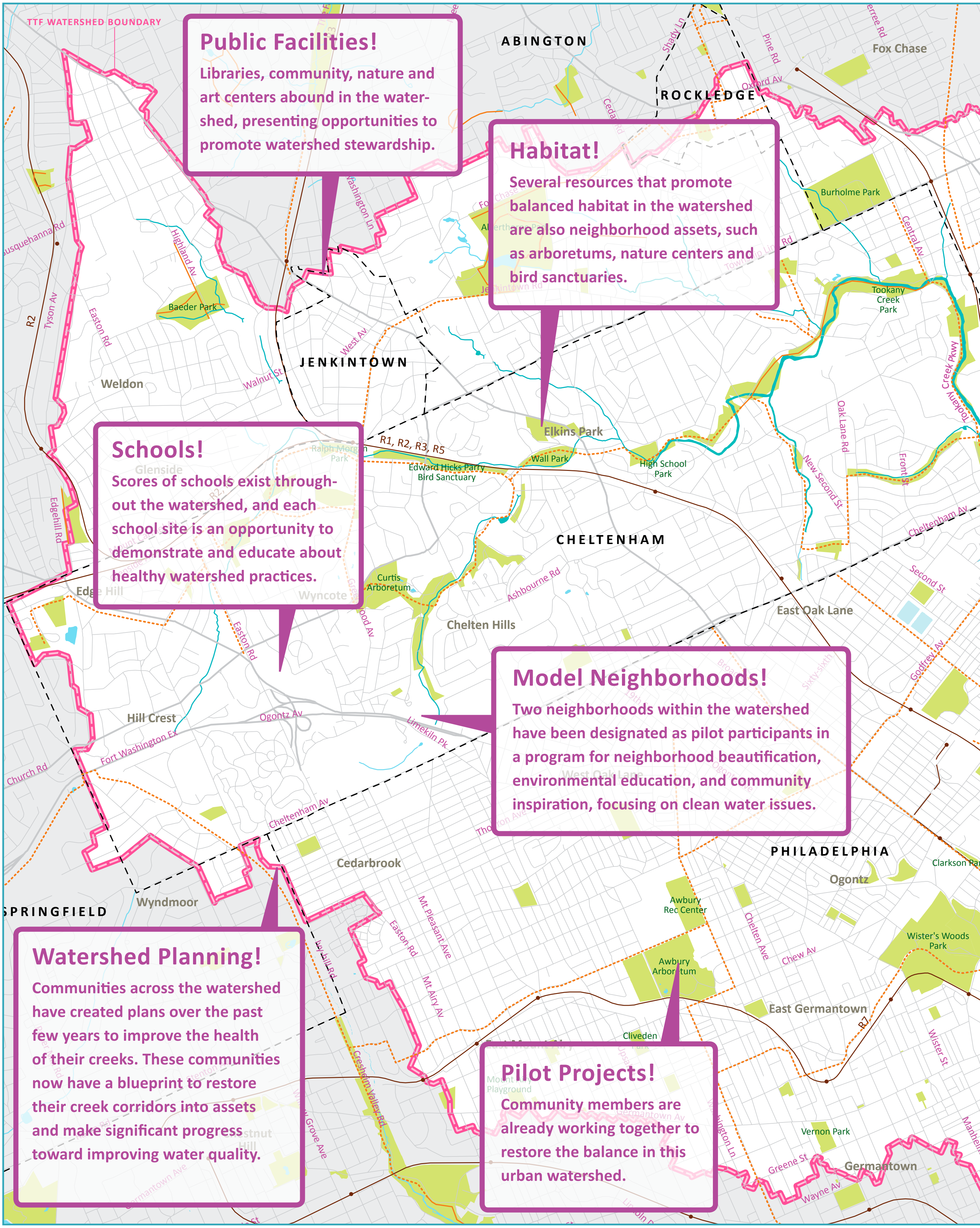
FERTILE GROUND

for a DESTINATION WATERSHED



By the TTF Partnership and
Philadelphia Water Department

DRAFT June 2009



Public Facilities!

Libraries, community, nature and art centers abound in the watershed, presenting opportunities to promote watershed stewardship.

Habitat!

Several resources that promote balanced habitat in the watershed are also neighborhood assets, such as arboretums, nature centers and bird sanctuaries.

Schools!

Scores of schools exist throughout the watershed, and each school site is an opportunity to demonstrate and educate about healthy watershed practices.

Model Neighborhoods!

Two neighborhoods within the watershed have been designated as pilot participants in a program for neighborhood beautification, environmental education, and community inspiration, focusing on clean water issues.

Watershed Planning!

Communities across the watershed have created plans over the past few years to improve the health of their creeks. These communities now have a blueprint to restore their creek corridors into assets and make significant progress toward improving water quality.

Pilot Projects!

Community members are already working together to restore the balance in this urban watershed.

Transit!

Multiple lines, including subway, regional rail, bus and trolley, link many communities within the watershed.

The Delaware!

The TTF watershed drains to the Delaware River. There is potential to tie into waterfront planning happening along the Delaware and to take advantage of the anticipated resources, by planning for open space, trails and greenways connecting back into the watershed.

Trails!

Miles of biking and hiking trails wind along the creeks and through the communities within the watershed. Many more miles of bike lanes and trails are planned.

Parks and Recreation!

Hundreds of acres of parks and fields cover this watershed, including playgrounds, recreation centers, golf courses, sports fields, ice rinks, dog parks, trails and more.

Neighborhoods!

The TTF watershed and its creeks thread together diverse and active communities with rich histories in Philadelphia and Montgomery Counties.

About the TTF Watershed Partnership

The mission of the the TTF Watershed Partnership is to enhance the health and vitality of the Tookany/Tacony-Frankford Creek and its watershed.

The Tookany/Tacony-Frankford Watershed Partnership. Inc. (TTF) acts as the crucial link connecting residents, businesses and government as neighbors and stewards of this impaired, but critically important watershed in the Philadelphia metro region. Through educational programming, community outreach, networking services, and project coordination, TTF facilitates, supports, and initiates efforts to restore the health of the watershed, and to mobilize its communities as watershed stewards.

Launched in 2000 by the Philadelphia Water Department, the Partnership was integral in developing the Tookany/Tacony-Frankford Integrated Watershed Management Plan, a blueprint for restoring this urban creek into a community asset while addressing the mandated requirements of the federal Clean Water Act and the federal Stormwater Permit Program (MS4). In 2005, the Partnership formally incorporated as an independent nonprofit with the recommendations of the Plan as its core vision.

TTF Watershed Partnership Board of Directors:

Abington Township
Arcadia University
Awbury Arboretum
Cheltenham Township
Fairmount Park Commission
Frankford Group Ministry
Friends of High School Park
Heritage Conservancy
Jenkintown Borough
Mayor's Executive Office
Montgomery County Planning Commission
Montgomery County Conservation District
Ogontz Avenue Revitalization Corporation (OARC)
PECO Energy Company
Pennsylvania Environmental Council
Pennsylvania Horticultural Society
Philadelphia City Council
Philadelphia City Planning Commission
Philadelphia Parks Alliance
Philadelphia Water Department
Rockledge Borough
Senior Environmental Corps, Center in the Park
TD Bank

Other TTF Watershed Partnership Partners:

Abington Township Environmental Advisory Council
AE Forum
American Red Cross at Frankford High School
Arcadia University Biology Club
Arcadia University Environmental Club
Awbury Gardens & Landscaping
Awbury Neighbors Association
Cedarbrook Middle School
Chariot Solutions
Cheltenham Township Environmental Advisory Council
Chew & Belfield Neighborhood Club, Inc.
Christopher Swain's TOXTOUR
City Year at Frankford High School
Delaware Valley Earth Force
Delaware Valley Regional Planning Commission
Department of Environmental Protection
Frankford CDC
Friends of Cliveden Park
Friends of Grove Park
Friends of Tacony Creek Park
Glenside Elementary School
Glenside Elementary School Parent-Teacher Organization (PTO)
Green Jenkintown
Maple Point Solar Homes
Montgomery County Conservation District
Mt. Airy USA
NAM Planning & Design, LLC
National Park Service
PA Cleanways
Partnership for the Delaware Estuary, Inc.
Renovo Development Group
Southeastern Pennsylvania First Suburbs Project
Waterview Recreation Center

Municipalities in the TTF Watershed:

Abington Township (Springfield Township)
Cheltenham Township (Springfield Township)
Jenkintown Borough (Springfield Township)
Montgomery County
Philadelphia County
Rockledge Borough (Springfield Township)

Fertile Ground

For A Destination Watershed

There is no metaphor like water itself to describe the cumulative effects of our practices, with every upstream action having an impact downstream. Too often when we seek out respite along our creeks, we find degraded areas filled with trash, silt, weeds and dilapidated structures at the margins. We blame others for dumping trash or our city for not attending to the weeds, but the condition of the creeks is directly related to how we manage stormwater on our own properties and streets. The effects of flooding affect how we can invest and recreate in waterfronts – often thwarting our natural impulses to be next to water.

This document attempts to describe the dynamic, reciprocal relationship between practices throughout a watershed and its waterfront environments. This document also presents a vision for what the Tookany Tacony Frankford watershed could be if we make small changes on our public and private properties. This plan presents a vision of healthy vegetation that supports a diverse range of birds and other animals, where Frankford Creek's water is safe enough to wade in on a hot day and where lasting investments in parks and adjacent development can be realized.

If we can significantly change the amount of stormwater and debris that flood into our creeks, an expansive range of benefits become possible – clean water, places to gather and play, places to invest safely, habitat – the list goes on. The benefits of stormwater management can be immediate and direct as well. Planting trees and installing rain barrels and green roofs saves property owners money and makes buildings and neighborhoods more comfortable and valuable. Wetlands, meadows and woodlands filter our air and water, give respite from compact urban neighborhoods and offer home and food to animals. All of those measures, and other such as pervious pavings, help to replenish the underlying water table, securing our future drinking water.

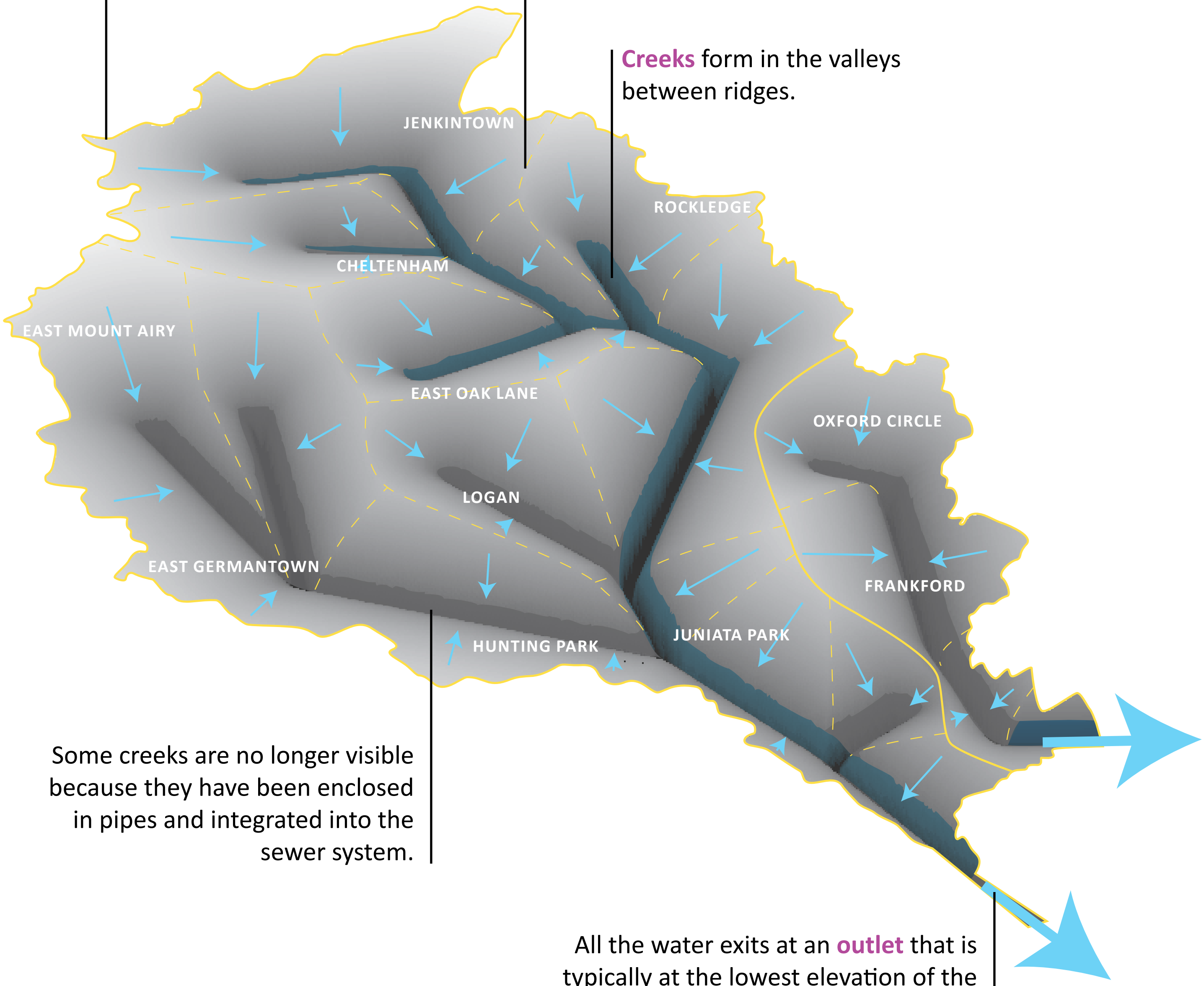
The Tookany Tacony Frankford watershed is an exciting place, full of vibrant neighborhoods and vast potential. Through stormwater investments throughout the watershed and strategic changes along Frankford Creek, we can realize that potential.

What exactly is a watershed?

A watershed is a **drainage basin**, within which all water flows to a single location.

Water flows in opposite directions on each side of a **ridge**.

Creeks form in the valleys between ridges.



Some creeks are no longer visible because they have been enclosed in pipes and integrated into the sewer system.

All the water exits at an **outlet** that is typically at the lowest elevation of the watershed into another body of water.

Fertile Ground

For A Destination Watershed

Laying the groundwork for restoring the Tookany/Tacony-Frankford Creek corridor toward a vision of creek health and community wealth.

FERTILE GROUND FOR STORMWATER INNOVATION

The waters of the TTF watershed and its underground infrastructure stitch together many diverse communities in Montgomery and Philadelphia Counties. Although some communities feel disconnected from their local creek because of limited access or because it has been enclosed by the sewer system, all neighborhoods in this watershed drain to the creek and must share responsibility for its health. It is therefore important for neighborhoods in the watershed to work together to manage stormwater.

The TTF watershed is already home to a number of demonstration projects that exhibit best practices in stormwater management. These projects have become sources of community pride and examples for using green infrastructure to reduce stormwater volume in the city's sanitary system.

FERTILE GROUND FOR DISTINCTIVE RECREATION

The TTF watershed is home to about 357,000 people with a range of income levels and backgrounds, and a variety of community strengths and struggles. One could imagine the creek would serve as a meeting place for relaxation, recreation, inspiration, and community connection.

Because of the area's topography, much of the parkland within the creek corridor is below street level, creating secluded oases within a highly urbanized area. However, the frequent flooding and widespread invasive species reduce the quality of these parks.

A number of core trails exist within the watershed and along the creek, and plans show the intentions of all the municipalities to connect these trails into a cohesive network.

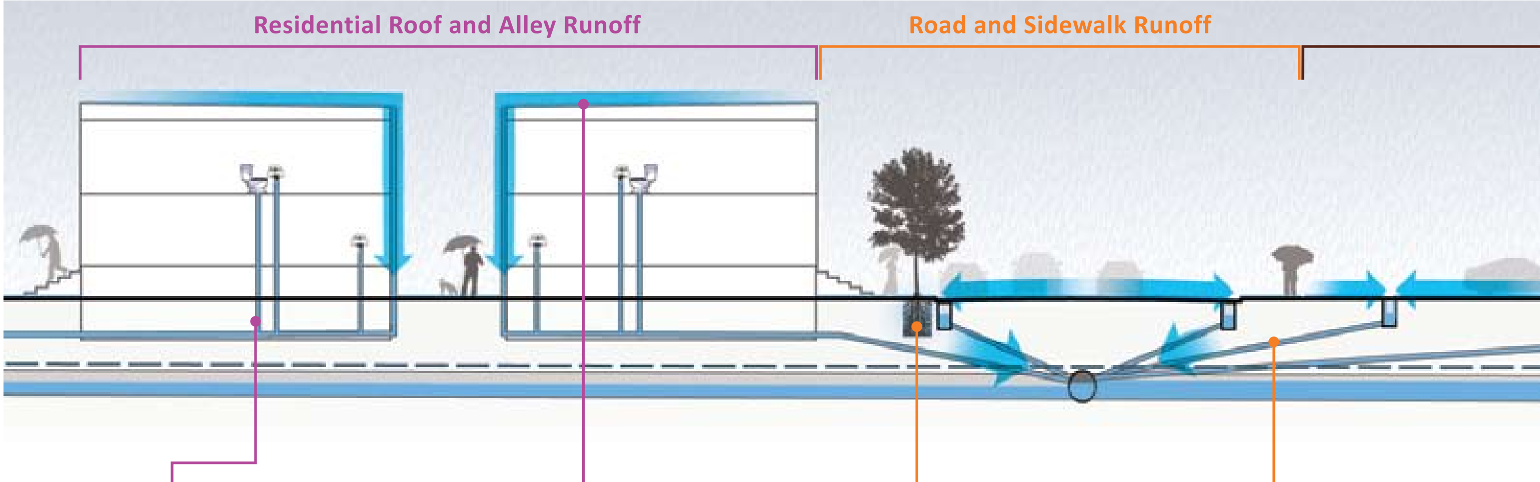
FERTILE GROUND FOR HEALTHY CREEKS

The watershed hosts several creeks, wetlands, and uplands that support diverse communities of wildlife and fish. Like all of our urban creeks, the waters within the TTF watershed have been compromised by intense development.

Today, many areas along and within the creek suffer from frequent flooding, invasive species, litter and illegal dumping that compromises the creek's health, beauty, and habitat value, and this deters residents from enjoying the many benefits healthy creeks offer.

Restoring the creek environment to a more natural state wherever possible and committing to responsible stewardship of the watershed will improve water quality, generate healthier habitats, and create environmental education opportunities.

A TYPICAL urban watershed has negative effects on its creeks:



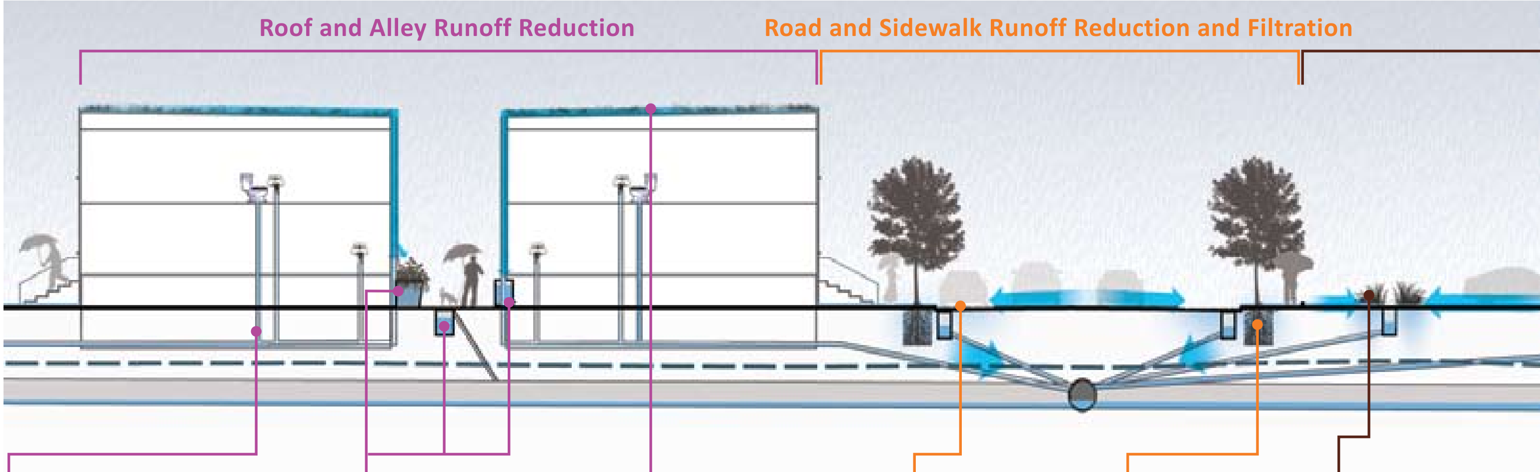
Overuse of water for household and personal needs adds additional stress on the municipal water system.

Roof runoff goes into roof leaders and pipes; it does not absorb into the ground.

Too few street trees to retain stormwater through canopy and root system intercept.

Stormwater drains quickly; does not absorb into the ground.

A more SUSTAINABLE approach to stormwater will positively affect the watershed:



More efficient household water use reduces stress on the municipal water and sewer systems.

Planters, rain barrels and cisterns retain stormwater, provide gardening water.

Green roofs collect and divert runoff from the municipal water system.

Permeable paving in parking lanes reduces road runoff.

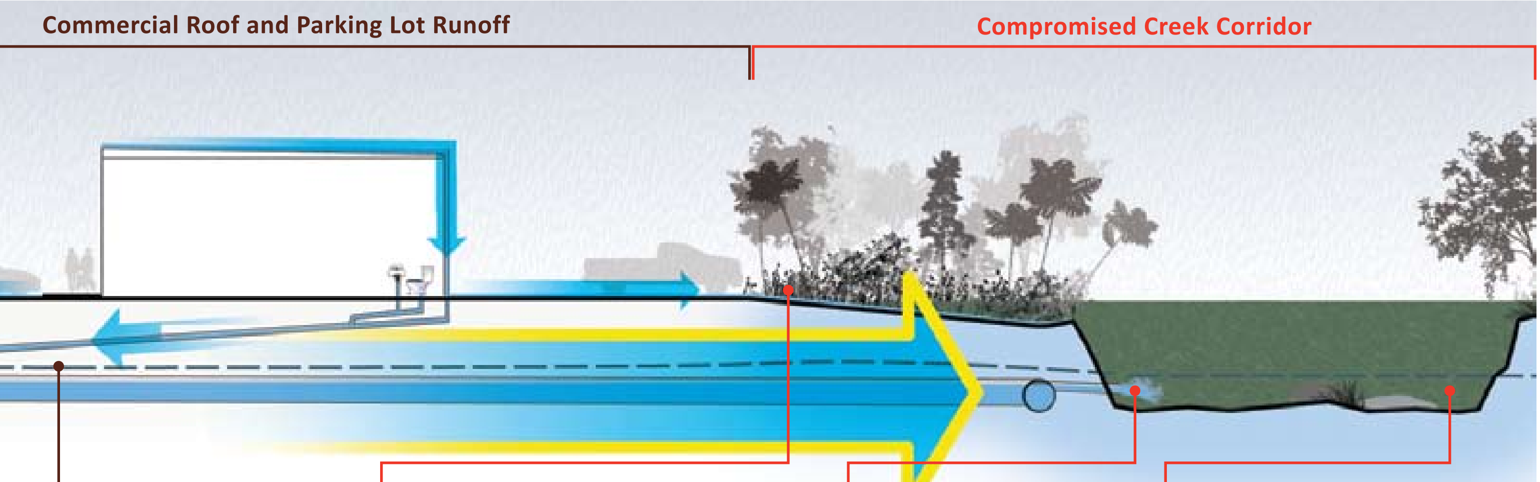
Larger, enhanced street tree networks filter and store runoff.

Groves and swales in parking lots filter and slow runoff.

Fertile Ground

For Stormwater Innovation

Stormwater management is vital to improving creek health in areas near creeks and in areas distant from creeks.

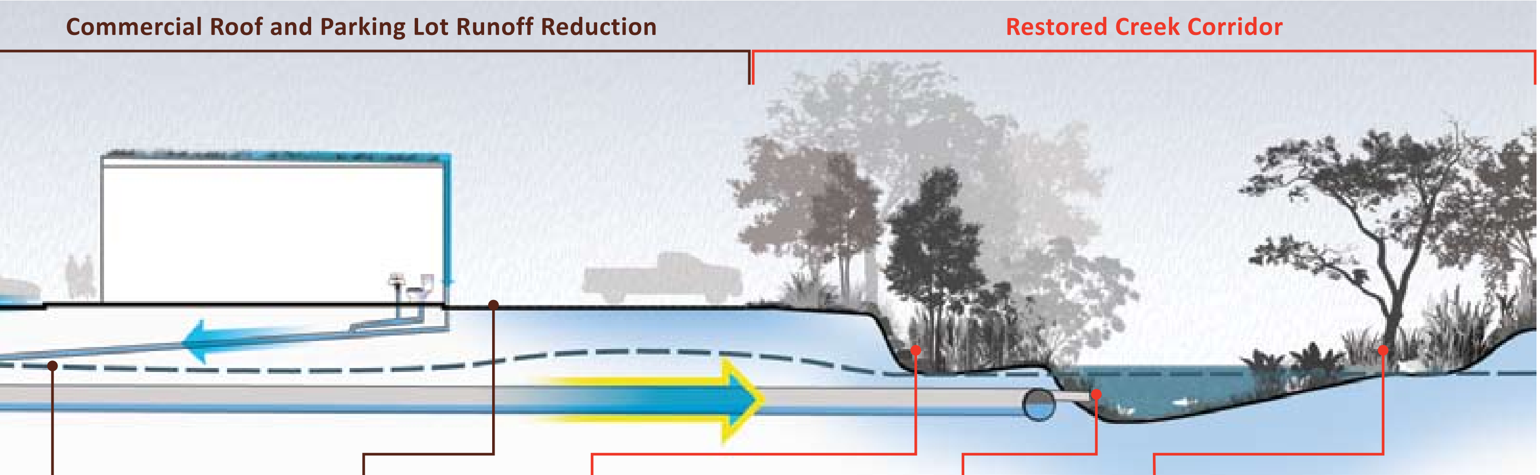


Water table/creek base flow level is lower due to reduced infiltration of stormwater.

Creek banks degrade and lose native plants due to runoff and frequent flooding; become overwhelmed with agressive invasive plants.

Frequent overflows release untreated sewage and unfiltered stormwater into creek.

High flow velocities erode and widen the creek and make it less habitable for fish, wildlife, plants and people.



Water table/creek base flow level is higher, ensuring drinking water supply.

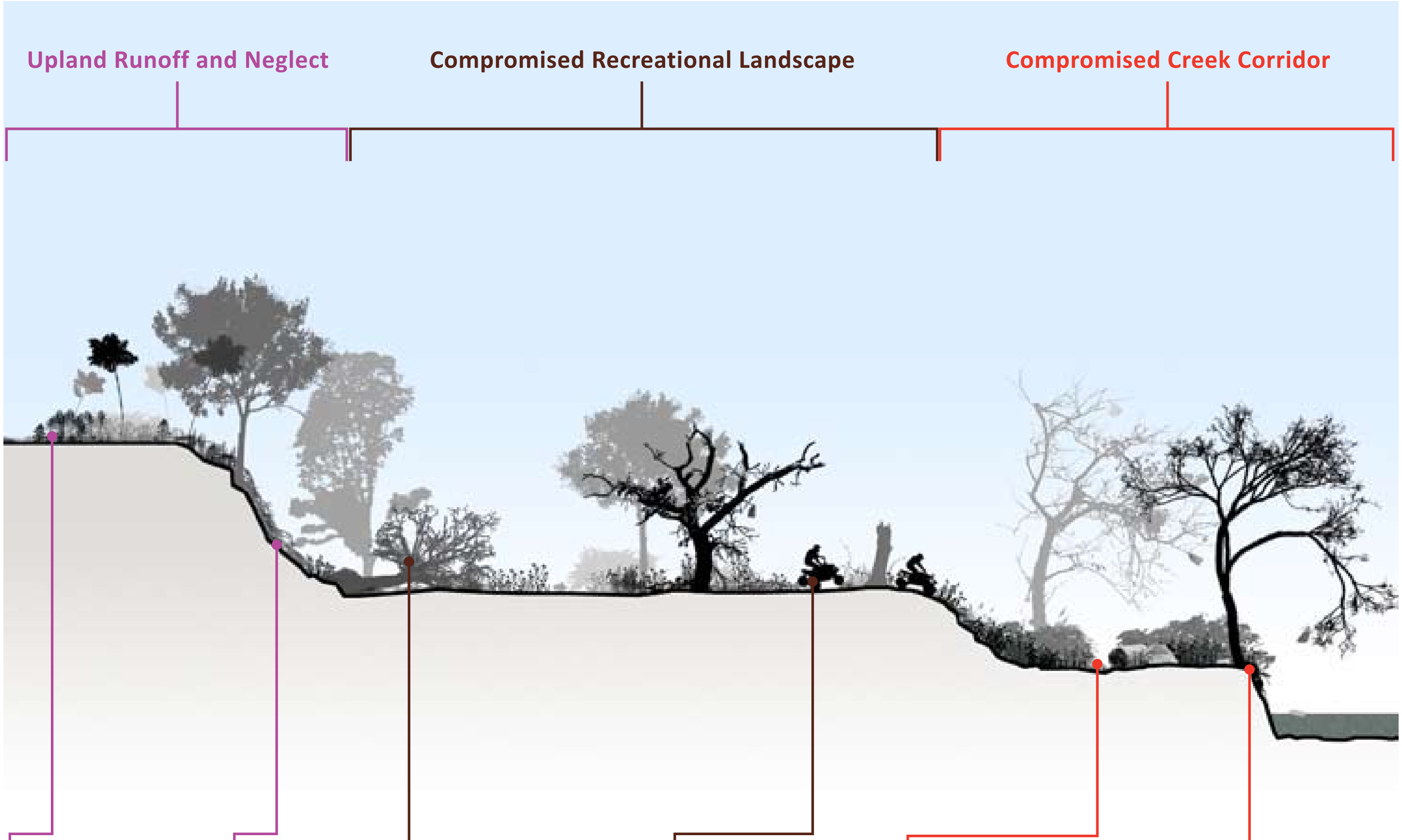
Pervious parking surfaces near the creek reduce runoff.

Reduced runoff and contamination and fewer flood events allow banks to host native plants and wildlife.

Fewer combined sewer overflow events.

Reduced runoff permits slower creek flows, more naturalized channels, and a healthier creek environment.

Frequent flooding degrades landscapes and makes investment in development and maintenance difficult.



Adjacent upland parcels have little investment value.

Slopes are undermined by runoff.

The landscape is unhealthy and suffers from illegal dumping and invasive vegetation.

Neglected public lands encourage illegal recreation.

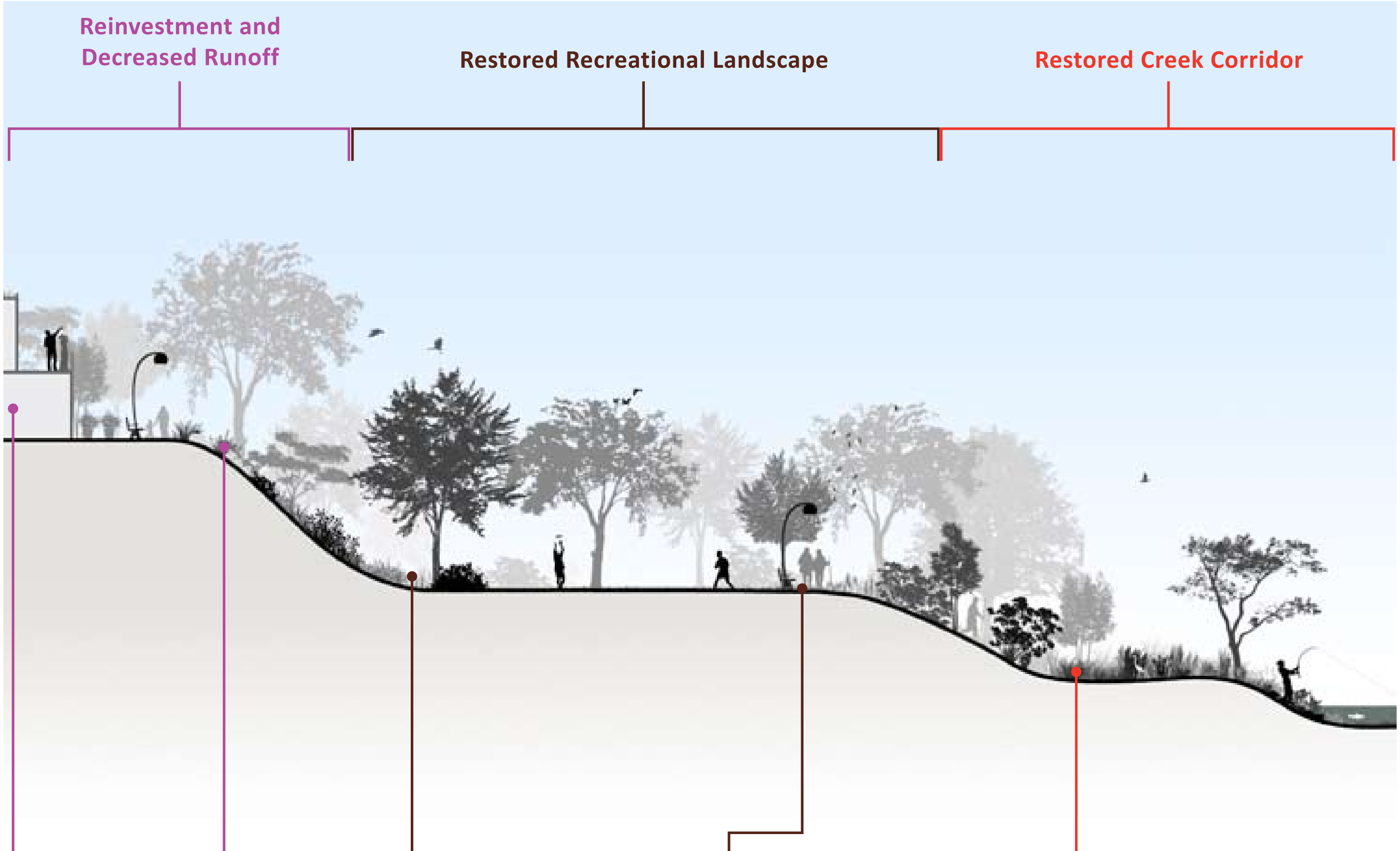
Frequent floods strip floodplains of native vegetation, encourage invasives, deposit debris and compromise the recreational and ecological value of adjacent lands.

Creek banks are steeply eroded.

Fertile Ground
For Distinctive Recreation

Restoration of the floodplain creates spaces for recreation and development sites, enhanced by proximity to the creek.

Watershed-wide stormwater management halts cycles of damage and allows for sustainable investment.



A restored creek landscape can increase its value to the community and encourage nearby investments.

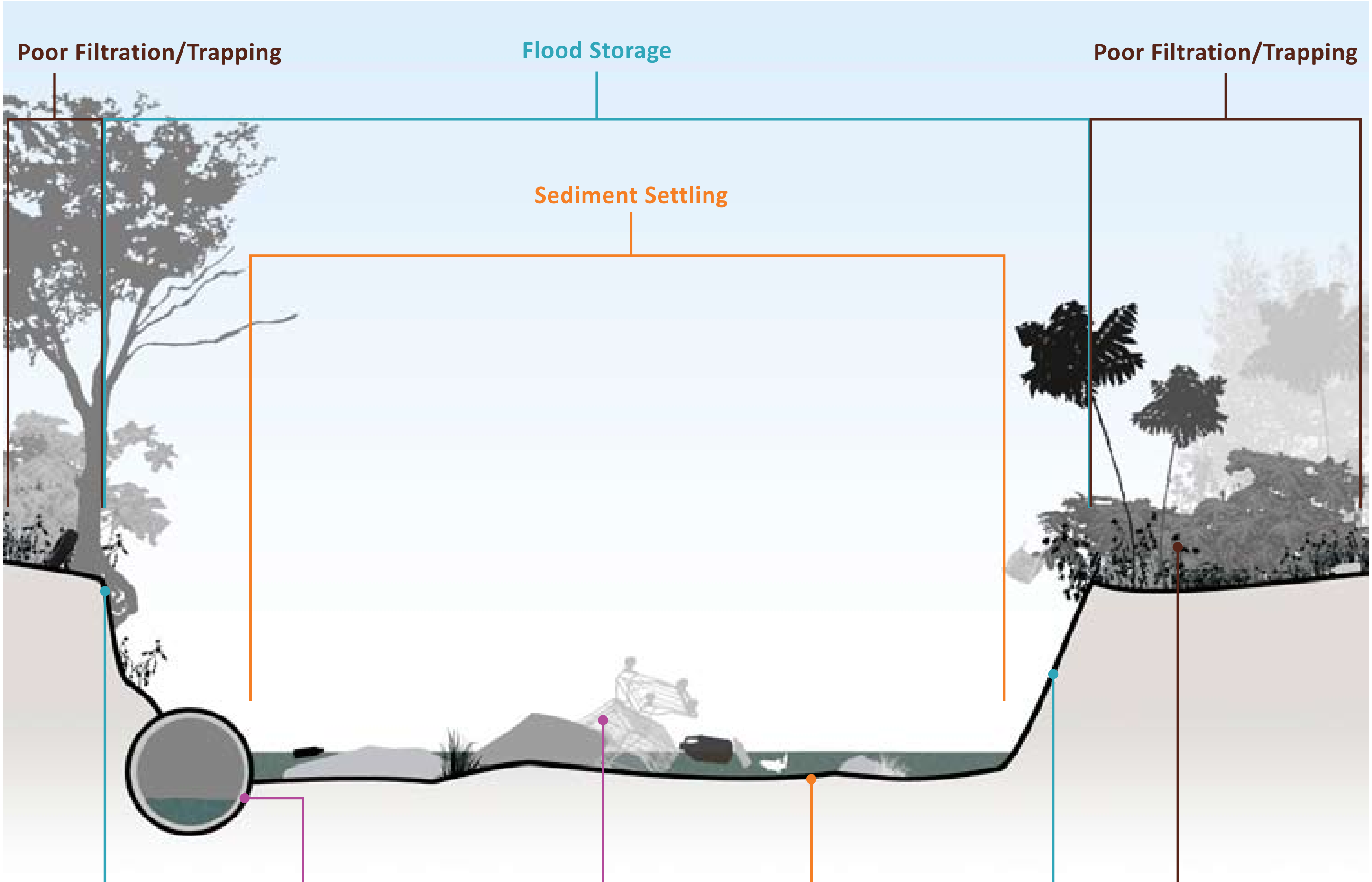
Decreased runoff allows for rehabilitation of upland slopes with native plants.

Reduced flooding and runoff allows for reclaimed parkland that is healthier and more valuable.

Investments in landscape features and park maintenance support diverse and enhanced recreation.

Restored floodplains and creek channels increase flood storage capacity, improve habitat, and encourage community access.

An UNHEALTHY creek corridor cannot perform essential ecological functions.



Flood waters erode creek banks, washing away valuable soil and native vegetation. Banks are left bare or are overcome by aggressive invasive plants.

Bank erosion exposes the sewer system infrastructure, leaving pipes and manholes susceptible to damage.

Trash and debris overwhelm the landscape.

Fast-moving flood waters wash away sediment, which is critical to the health of the creek habitat. Without sediment, fish habitat and food wash away.

Creek banks become steeply eroded after floods, creating a wide, shallow creek during dry weather.

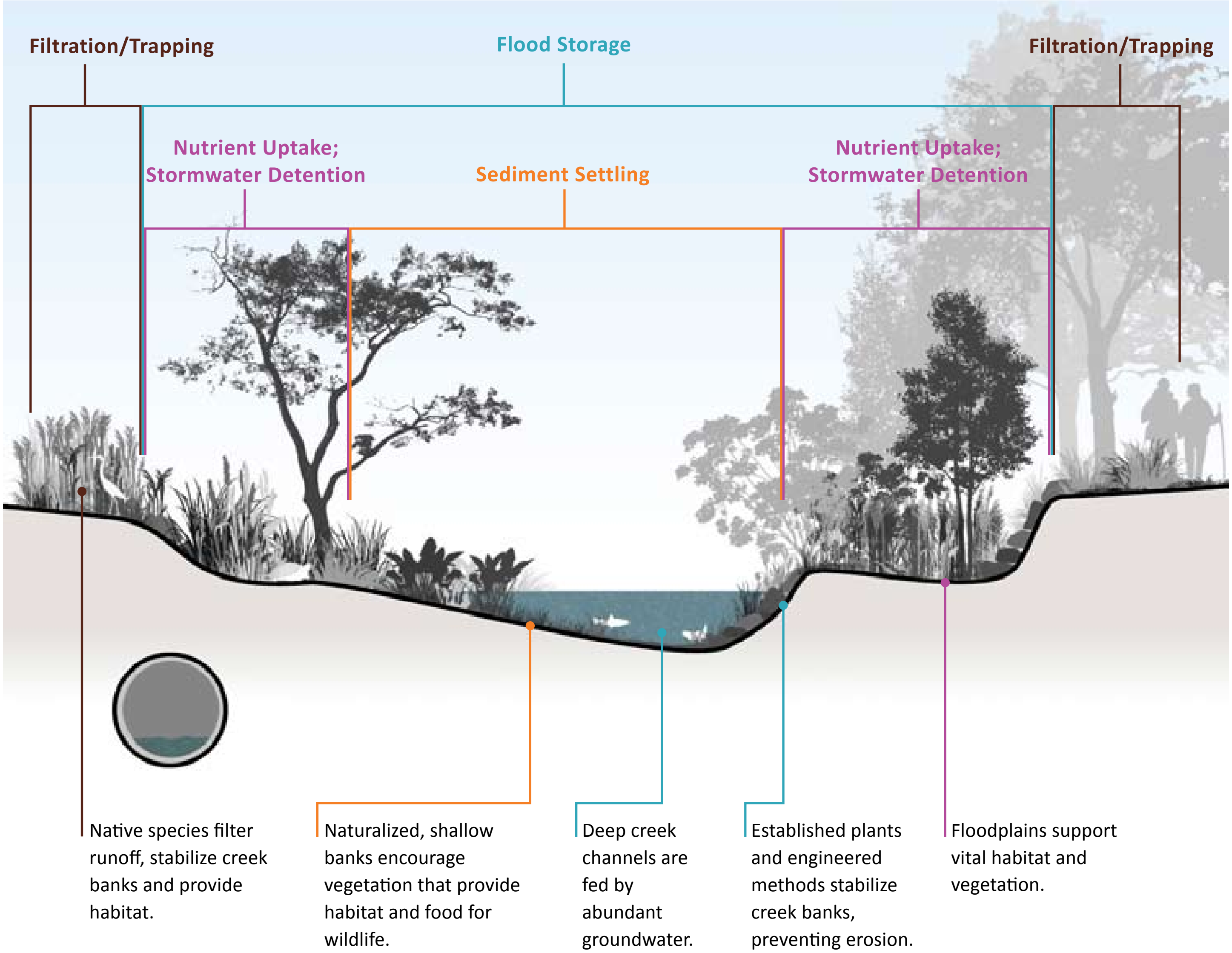
Invasive species overtake compromised creek banks, decreasing its habitat value and increasing maintenance costs.

Fertile Ground

For Healthy Creeks

Creek restoration repairs scoured and littered creek beds, improves water quality and allows native plants and animals to flourish.

A HEALTHY creek corridor performs critical ecological functions.



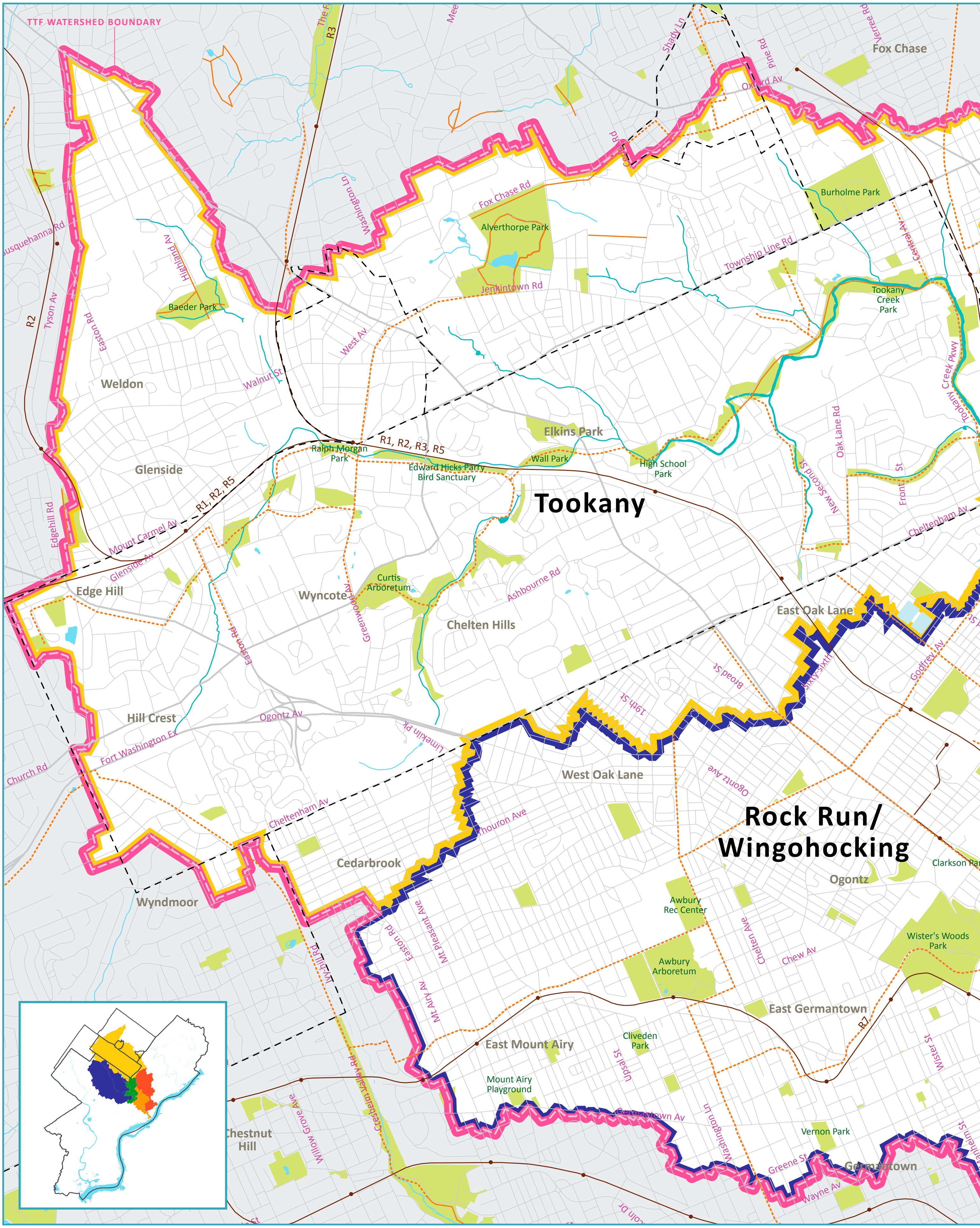
Native species filter runoff, stabilize creek banks and provide habitat.

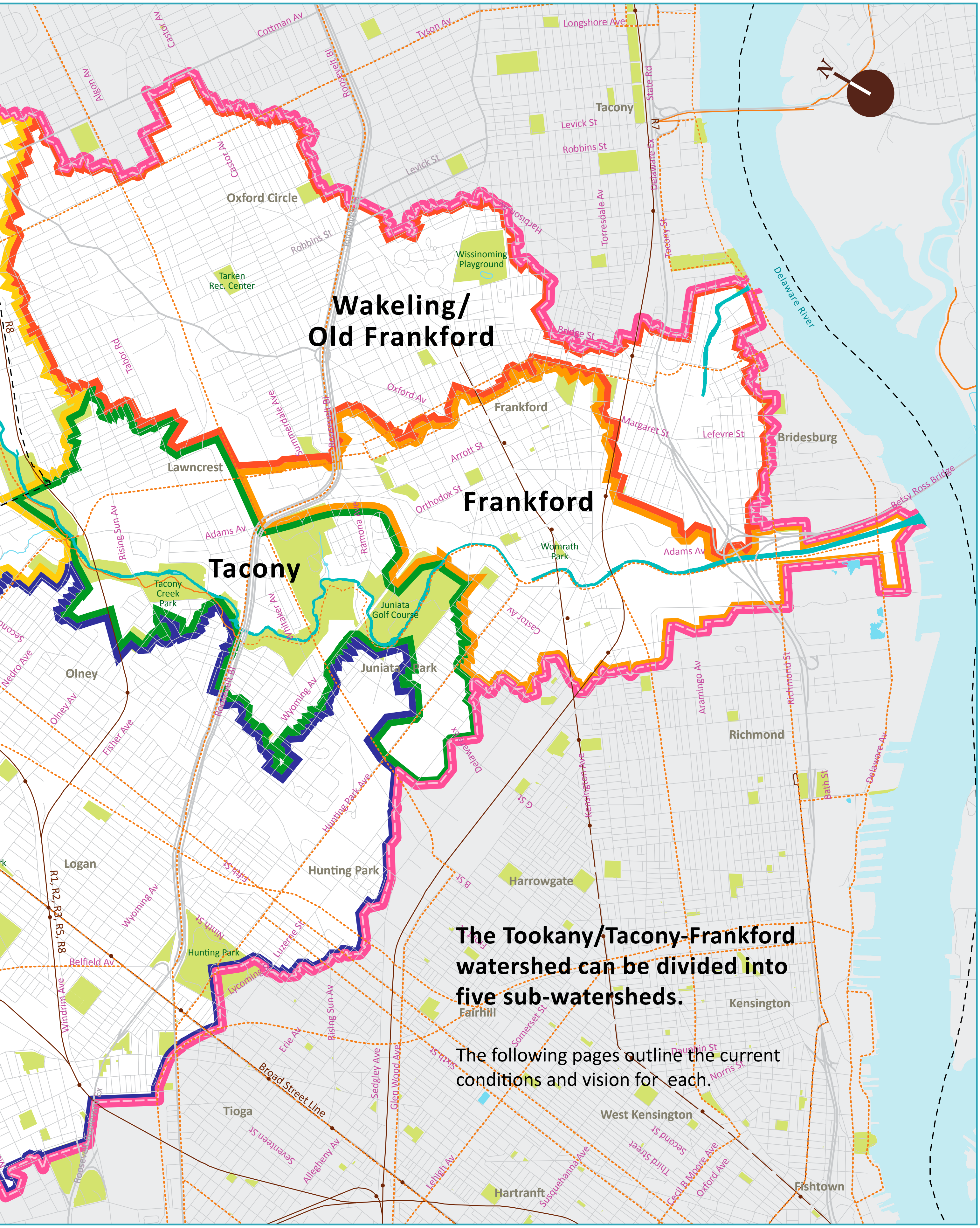
Naturalized, shallow banks encourage vegetation that provide habitat and food for wildlife.

Deep creek channels are fed by abundant groundwater.

Established plants and engineered methods stabilize creek banks, preventing erosion.

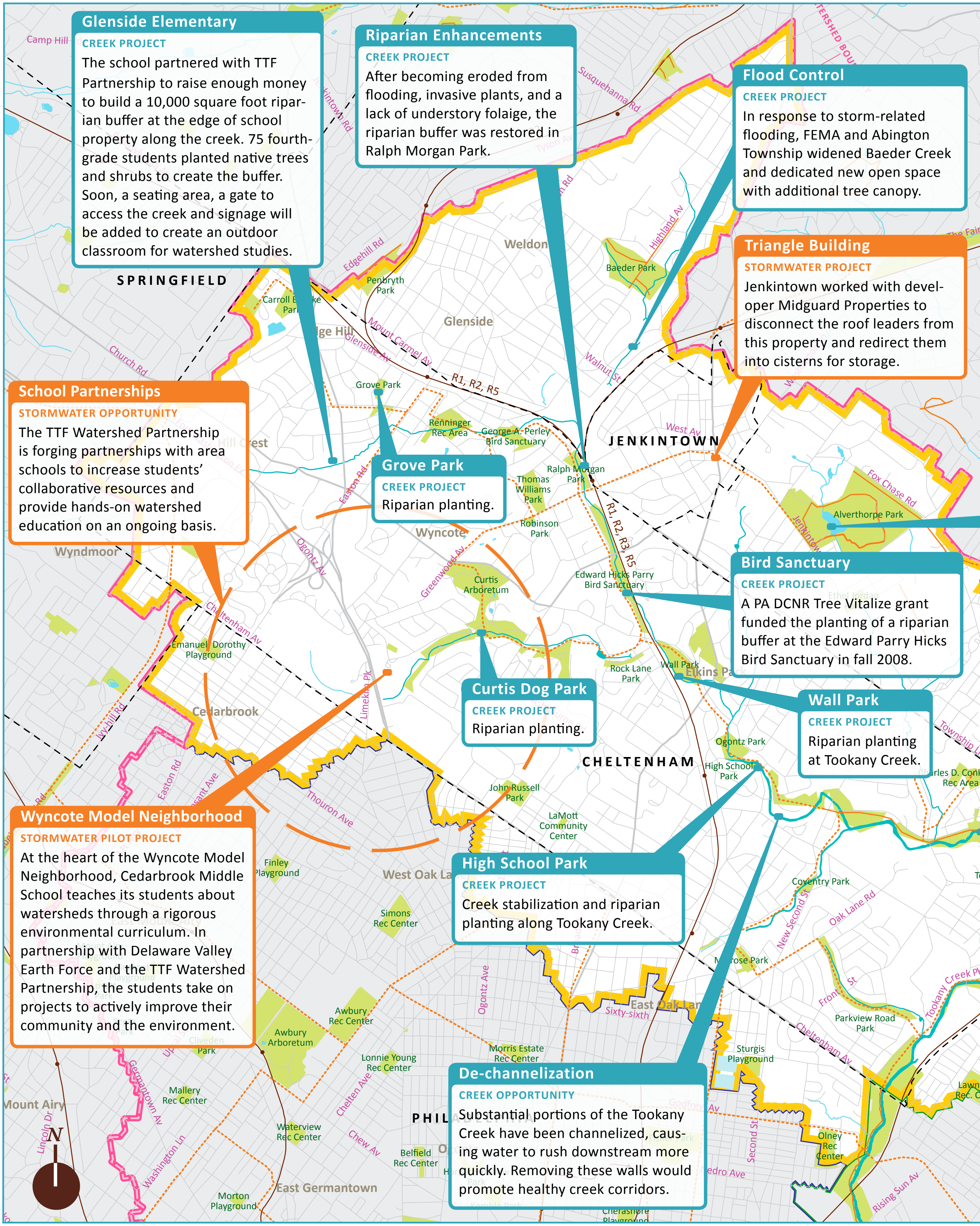
Floodplains support vital habitat and vegetation.


TTF WATERSHED BOUNDARY
Tookany
Rock Run/
Wingohocking
Fox Chase
Weldon
Glenside
Edge Hill
Wyncote
Elkins Park
Chelten Hills
East Oak Lane
West Oak Lane
Hill Crest
Cedarbrook
Wyndmoor
Ogontz
East Germantown
East Mount Airy
Germantown
Chestnut
Hill
Baeder Park
Alverthorpe Park
Burholme Park
Tookany
Creek
Park
Ralph Morgan
Park
Edward Hicks Parry
Bird Sanctuary
Wall Park
High School
Park
Curtis
Arboretum
Awbury
Rec Center
Awbury
Arboretum
Wister's Woods
Park
Cliveden
Park
Mount Airy
Playground
Vernon Park
Clarkson Par
R1, R2, R3, R5
R1, R2, R5
R2
R3
R7
Susquehanna Rd
Tyson Av
Easton Rd
Highland Av
Walnut St
West Av
Washington Ln
Fox Chase Rd
Jenkintown Rd
Township Line Rd
Oxford Av
Pine Rd
Verree Rd
Shady Ln
Central Av
Tookany Creek Pkwy
Oak Lane Rd
New Second St
Front St
Cheltenham Av
Edgehill Rd
Mount Carmel Av
Glenside Av
Greenwood Av
Ashbourne Rd
Broad St
19th St
Sixty-Sixth
Godfrey Av
Limekiln Pk
Ogontz Av
Fort Washington Ex
Church Rd
Thouron Ave
Mt Pleasant Ave
Mt Airy Av
Wyndmoor Rd
Stenton Ave
Chew Av
Upsal St
Germantown Av
Washington Ln
Greene St
Wayne Av
Wister St
Willow Grove Ave
Cresheim Valley Rd



The Tookany/Tacony-Frankford watershed can be divided into five sub-watersheds.

The following pages outline the current conditions and vision for each.



Glenside Elementary

CREEK PROJECT

The school partnered with TTF Partnership to raise enough money to build a 10,000 square foot riparian buffer at the edge of school property along the creek. 75 fourth-grade students planted native trees and shrubs to create the buffer. Soon, a seating area, a gate to access the creek and signage will be added to create an outdoor classroom for watershed studies.

Riparian Enhancements

CREEK PROJECT

After becoming eroded from flooding, invasive plants, and a lack of understory folaige, the riparian buffer was restored in Ralph Morgan Park.

Flood Control

CREEK PROJECT

In response to storm-related flooding, FEMA and Abington Township widened Baeder Creek and dedicated new open space with additional tree canopy.

Triangle Building

STORMWATER PROJECT

Jenkintown worked with developer Midguard Properties to disconnect the roof leaders from this property and redirect them into cisterns for storage.

School Partnerships

STORMWATER OPPORTUNITY

The TTF Watershed Partnership is forging partnerships with area schools to increase students' collaborative resources and provide hands-on watershed education on an ongoing basis.

Grove Park

CREEK PROJECT

Riparian planting.

Bird Sanctuary

CREEK PROJECT

A PA DCNR Tree Vitalize grant funded the planting of a riparian buffer at the Edward Parry Hicks Bird Sanctuary in fall 2008.

Curtis Dog Park

CREEK PROJECT

Riparian planting.

Wall Park

CREEK PROJECT

Riparian planting at Tookany Creek.

Wyncote Model Neighborhood

STORMWATER PILOT PROJECT

At the heart of the Wyncote Model Neighborhood, Cedarbrook Middle School teaches its students about watersheds through a rigorous environmental curriculum. In partnership with Delaware Valley Earth Force and the TTF Watershed Partnership, the students take on projects to actively improve their community and the environment.

High School Park

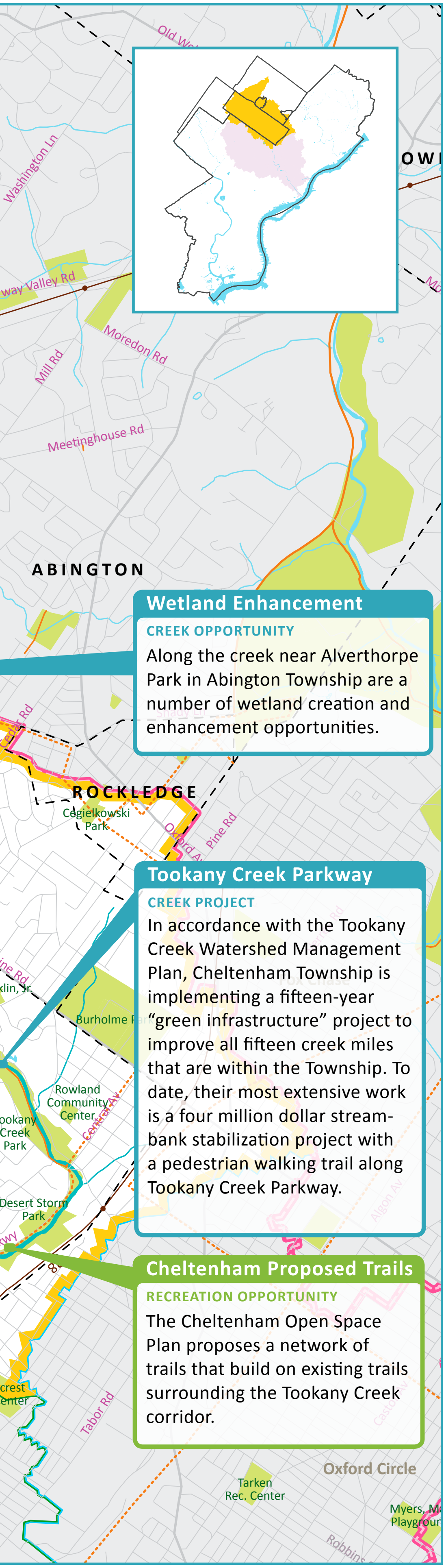
CREEK PROJECT

Creek stabilization and riparian planting along Tookany Creek.

De-channelization

CREEK OPPORTUNITY

Substantial portions of the Tookany Creek have been channelized, causing water to rush downstream more quickly. Removing these walls would promote healthy creek corridors.



Wetland Enhancement

CREEK OPPORTUNITY

Along the creek near Alverthorpe Park in Abington Township are a number of wetland creation and enhancement opportunities.

Tookany Creek Parkway

CREEK PROJECT

In accordance with the Tookany Creek Watershed Management Plan, Cheltenham Township is implementing a fifteen-year “green infrastructure” project to improve all fifteen creek miles that are within the Township. To date, their most extensive work is a four million dollar streambank stabilization project with a pedestrian walking trail along Tookany Creek Parkway.

Cheltenham Proposed Trails

RECREATION OPPORTUNITY

The Cheltenham Open Space Plan proposes a network of trails that build on existing trails surrounding the Tookany Creek corridor.

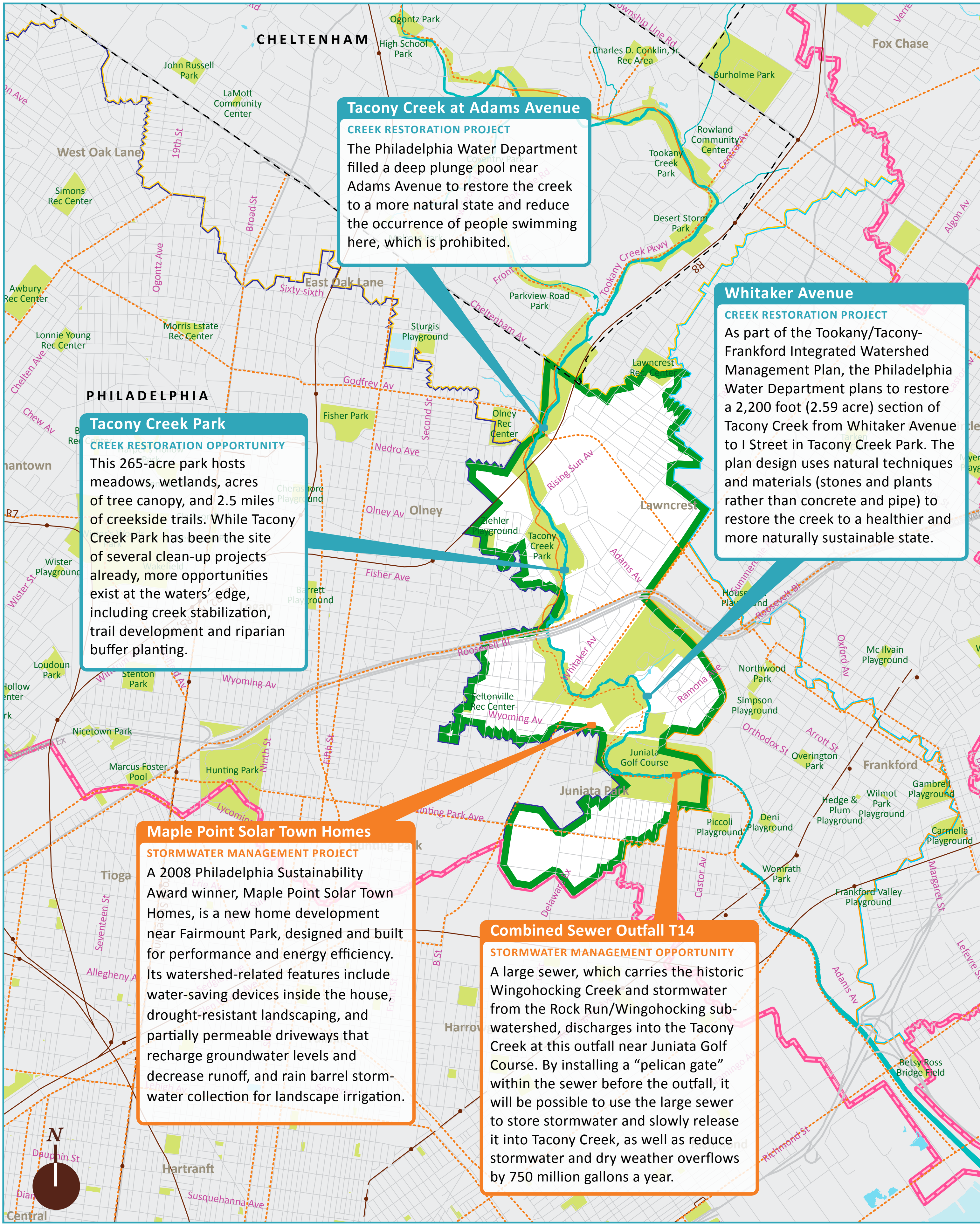
Tookany
sub-watershed

The Tookany sub-watershed exists mostly in Cheltenham and Jenkintown Townships. Tookany Creek flows through a mostly suburban landscape, and, unlike its urban environs downstream, benefits from a lower density of buildings on its banks, as well as open space, trails and greenways. Also, the communities around the creek have sponsored creek enhancements and community programs that focus on watershed health. This sub-watershed also hosts a developing “model neighborhood” described at left.

Despite these measures, the creek suffers the impacts of development, including clear-cutting of its banks, short dumping and litter, invasive species, stormwater surcharges, creek channelization, and incompatible land uses along its banks, like impervious parking lots.

Top: *Tookany Creek at Cedarbrook Middle School, where the creek acts as a classroom and forum for watershed education. Philadelphia Water Department’s T1 interceptor releases overflow just upstream of this site.* ***Middle***: *At Wall Park, there is evidence of the plights of the creek common to this reach: parking lots and surface impermeability at the edge of creek banks, invasive plants, litter and creek channelization (beyond the footbridge).* ***Bottom***: *While de-channelization was not an option at several points along the Tookany in Tookany Creek Park, other bank rehabilitation treatments were employed, including riparian buffers and invasives management. Additionally, the trail at right is a community resource and its upstream expansion is planned.*

Photosim showing potential improvements within the Tookany subwatershed to be developed.



Tacony Creek at Adams Avenue

CREEK RESTORATION PROJECT

The Philadelphia Water Department filled a deep plunge pool near Adams Avenue to restore the creek to a more natural state and reduce the occurrence of people swimming here, which is prohibited.

Whitaker Avenue

CREEK RESTORATION PROJECT

As part of the Tookany/Tacony-Frankford Integrated Watershed Management Plan, the Philadelphia Water Department plans to restore a 2,200 foot (2.59 acre) section of Tacony Creek from Whitaker Avenue to I Street in Tacony Creek Park. The plan design uses natural techniques and materials (stones and plants rather than concrete and pipe) to restore the creek to a healthier and more naturally sustainable state.

Tacony Creek Park

CREEK RESTORATION OPPORTUNITY

This 265-acre park hosts meadows, wetlands, acres of tree canopy, and 2.5 miles of creekside trails. While Tacony Creek Park has been the site of several clean-up projects already, more opportunities exist at the waters' edge, including creek stabilization, trail development and riparian buffer planting.

Maple Point Solar Town Homes

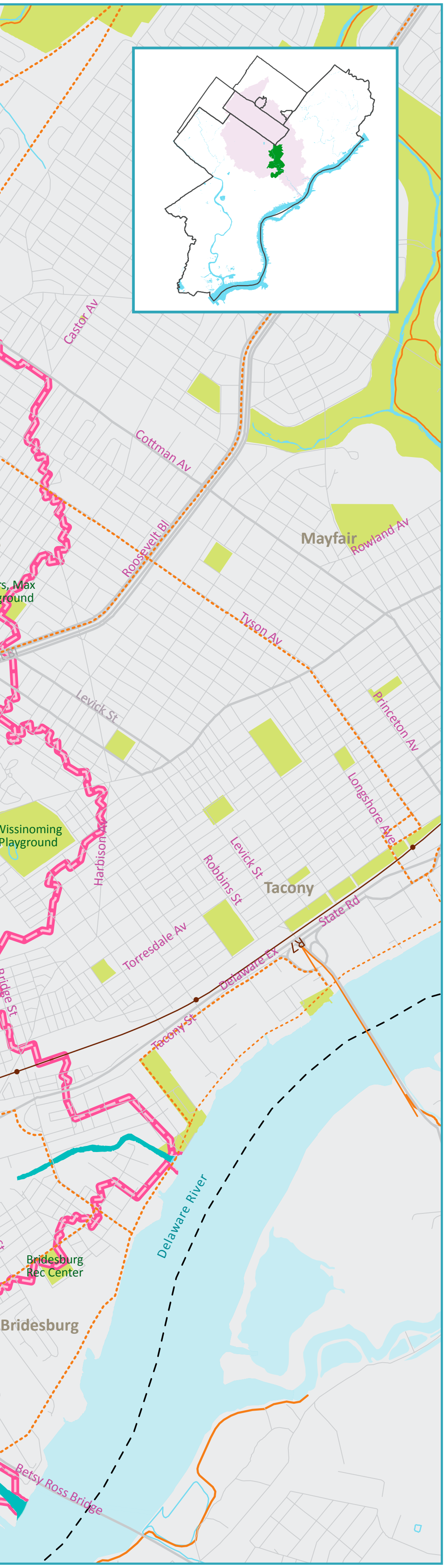
STORMWATER MANAGEMENT PROJECT

A 2008 Philadelphia Sustainability Award winner, Maple Point Solar Town Homes, is a new home development near Fairmount Park, designed and built for performance and energy efficiency. Its watershed-related features include water-saving devices inside the house, drought-resistant landscaping, and partially permeable driveways that recharge groundwater levels and decrease runoff, and rain barrel stormwater collection for landscape irrigation.

Combined Sewer Outfall T14

STORMWATER MANAGEMENT OPPORTUNITY

A large sewer, which carries the historic Wingohocking Creek and stormwater from the Rock Run/Wingohocking sub-watershed, discharges into the Tacony Creek at this outfall near Juniata Golf Course. By installing a "pelican gate" within the sewer before the outfall, it will be possible to use the large sewer to store stormwater and slowly release it into Tacony Creek, as well as reduce stormwater and dry weather overflows by 750 million gallons a year.



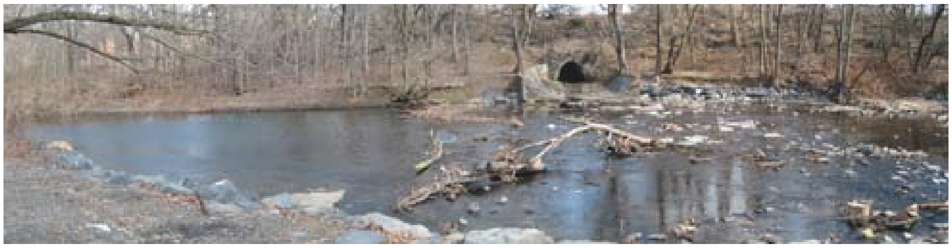
Tacony
sub-watershed

With its northern edge at the Philadelphia border, and its southern edge at the outfall that drains the entire Wingohocking sub-watershed, the Tacony sub-watershed not only performs myriad functions within the larger watershed but also reflects some of its biggest issues. 3 miles of creek banks are enveloped by Tacony Creek Park and other large open spaces like Juniata Golf Course. The functions of these open spaces represent an incredible opportunity to not only restore watershed functions, but also to regenerate valuable community open space and recreational programs for the Olney, Juniata Park and Lawncrest neighborhoods — and beyond.

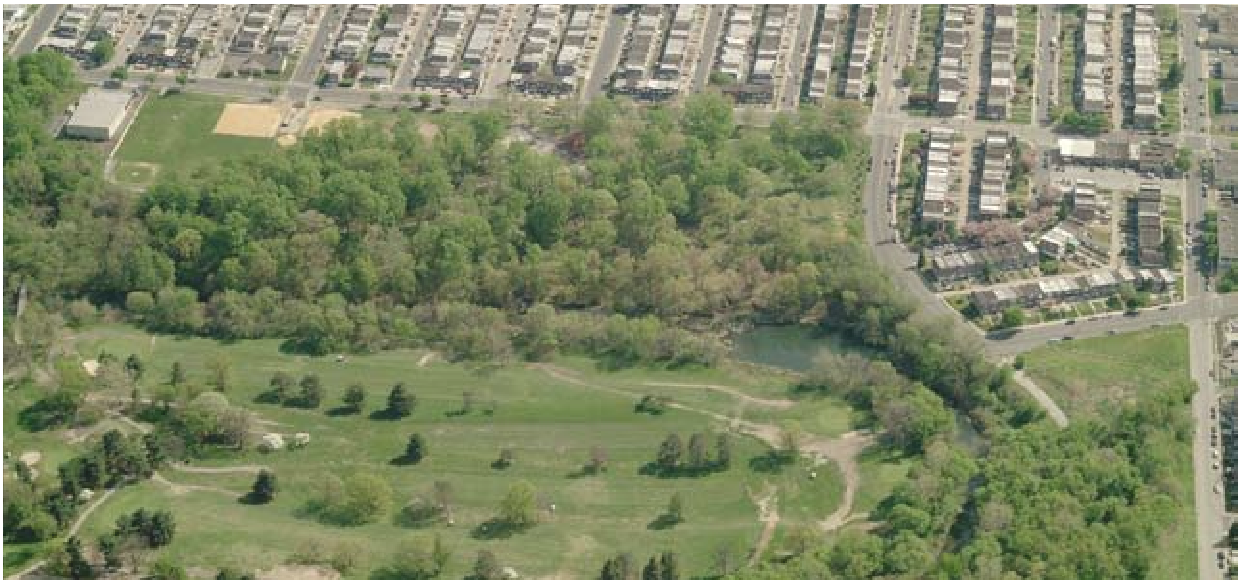
Top*: A trail meanders through a largely unmanaged floodplain landscape in Tacony Creek Park. Utilizing neglected floodplains for open recreational use is a characteristic opportunity within this sub-watershed.*

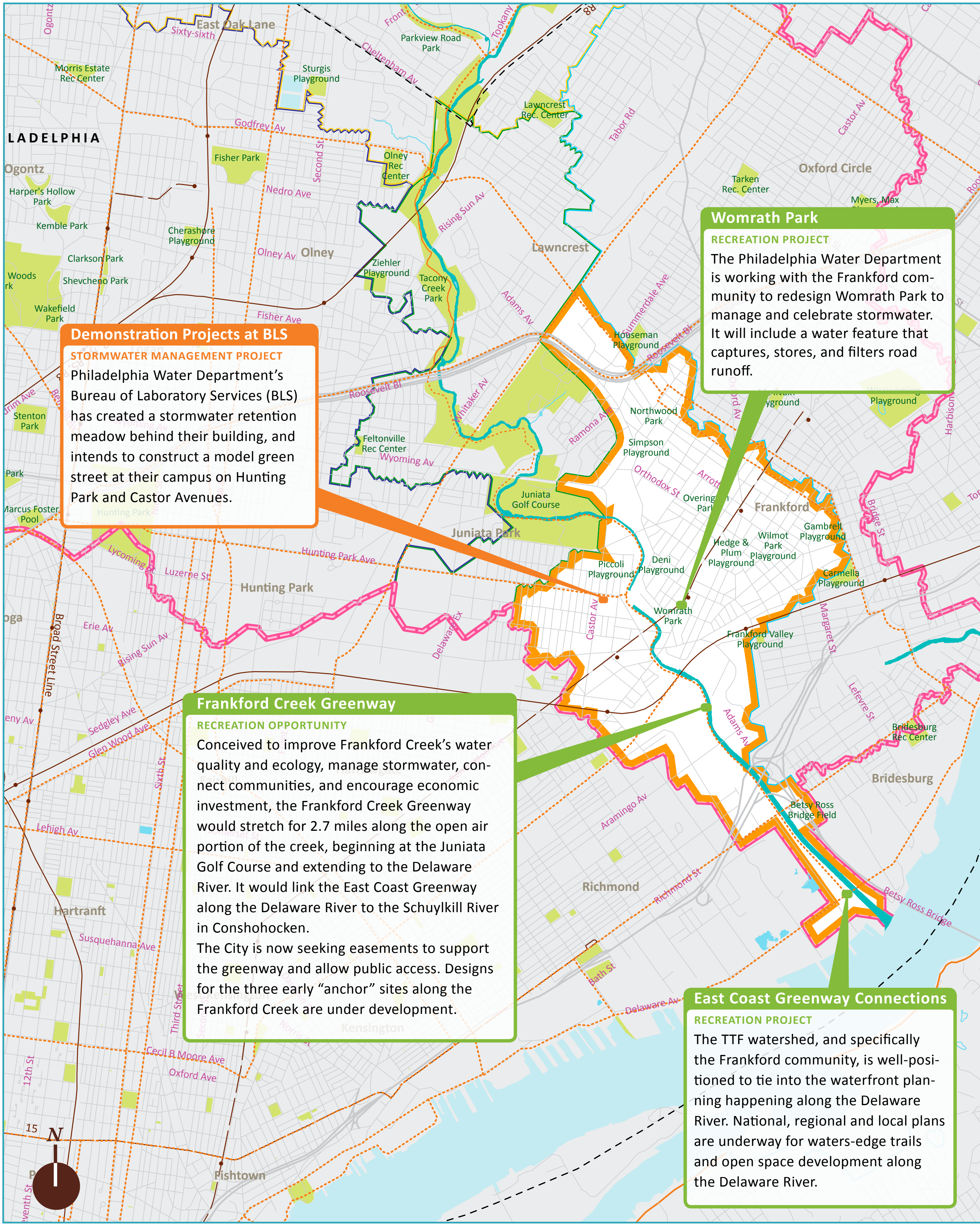
Middle*: The effects of overflow events on the creek are clearly evident at the confluence with the T6 outfall. Forceful water flows during storms have widened the creek creating low base flow, and debris and litter abound. PWD’s Waterways Restoration Team has shored up the banks (foreground) to prevent further erosion. Looking upstream, to the left, reveals the character of the creek before the outfall.*

Bottom*: Just north of Roosevelt Boulevard, the 17-foot wide T8 outfall drains into the creek. Years of overflows have altered the creek’s meander, which now flows under the furthest arch in the bridge instead of through the middle. Major work is needed to restore the integrity of the creek and its surroundings and permit a trail crossing under the bridge.*



The Tacony Creek winds through Juniata Golf Course, and many acres of the course lie within the natural floodplain of the creek. Carefully designed wetlands that can handle the seasonal stormwater floods will reduce downstream impacts, creating a place of both functional and aesthetic value, while upland interventions like green roofs, cisterns, and green streets will reduce overflow events.





Demonstration Projects at BLS

STORMWATER MANAGEMENT PROJECT

Philadelphia Water Department's Bureau of Laboratory Services (BLS) has created a stormwater retention meadow behind their building, and intends to construct a model green street at their campus on Hunting Park and Castor Avenues.

Womrath Park

RECREATION PROJECT

The Philadelphia Water Department is working with the Frankford community to redesign Womrath Park to manage and celebrate stormwater. It will include a water feature that captures, stores, and filters road runoff.

Frankford Creek Greenway

RECREATION OPPORTUNITY

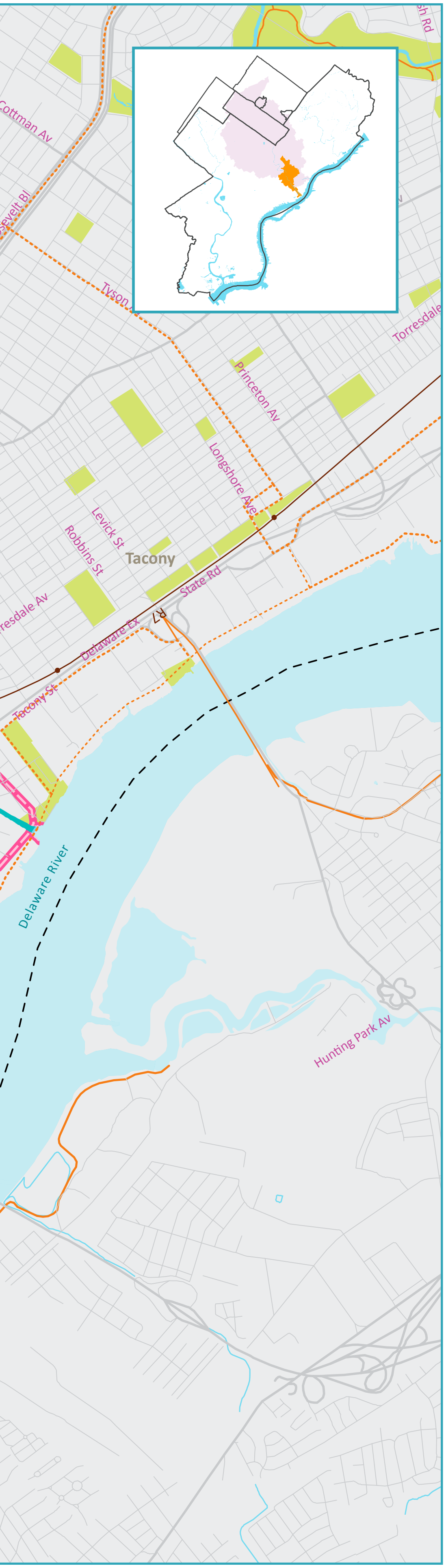
Conceived to improve Frankford Creek's water quality and ecology, manage stormwater, connect communities, and encourage economic investment, the Frankford Creek Greenway would stretch for 2.7 miles along the open air portion of the creek, beginning at the Juniata Golf Course and extending to the Delaware River. It would link the East Coast Greenway along the Delaware River to the Schuylkill River in Conshohocken.

The City is now seeking easements to support the greenway and allow public access. Designs for the three early "anchor" sites along the Frankford Creek are under development.

East Coast Greenway Connections

RECREATION PROJECT

The TTF watershed, and specifically the Frankford community, is well-positioned to tie into the waterfront planning happening along the Delaware River. National, regional and local plans are underway for waters-edge trails and open space development along the Delaware River.



Frankford
sub-watershed

The Frankford sub-watershed hosts a creek channel surrounded by one the most dense urban areas in the watershed. Much of the creek is channelized, and its health has historically been compromised by upstream impacts. It also has a unique characteristic: it includes the creek's confluence with the Delaware River. This confluence, however, is man-made, created as a flood control measure from 1948-1956.

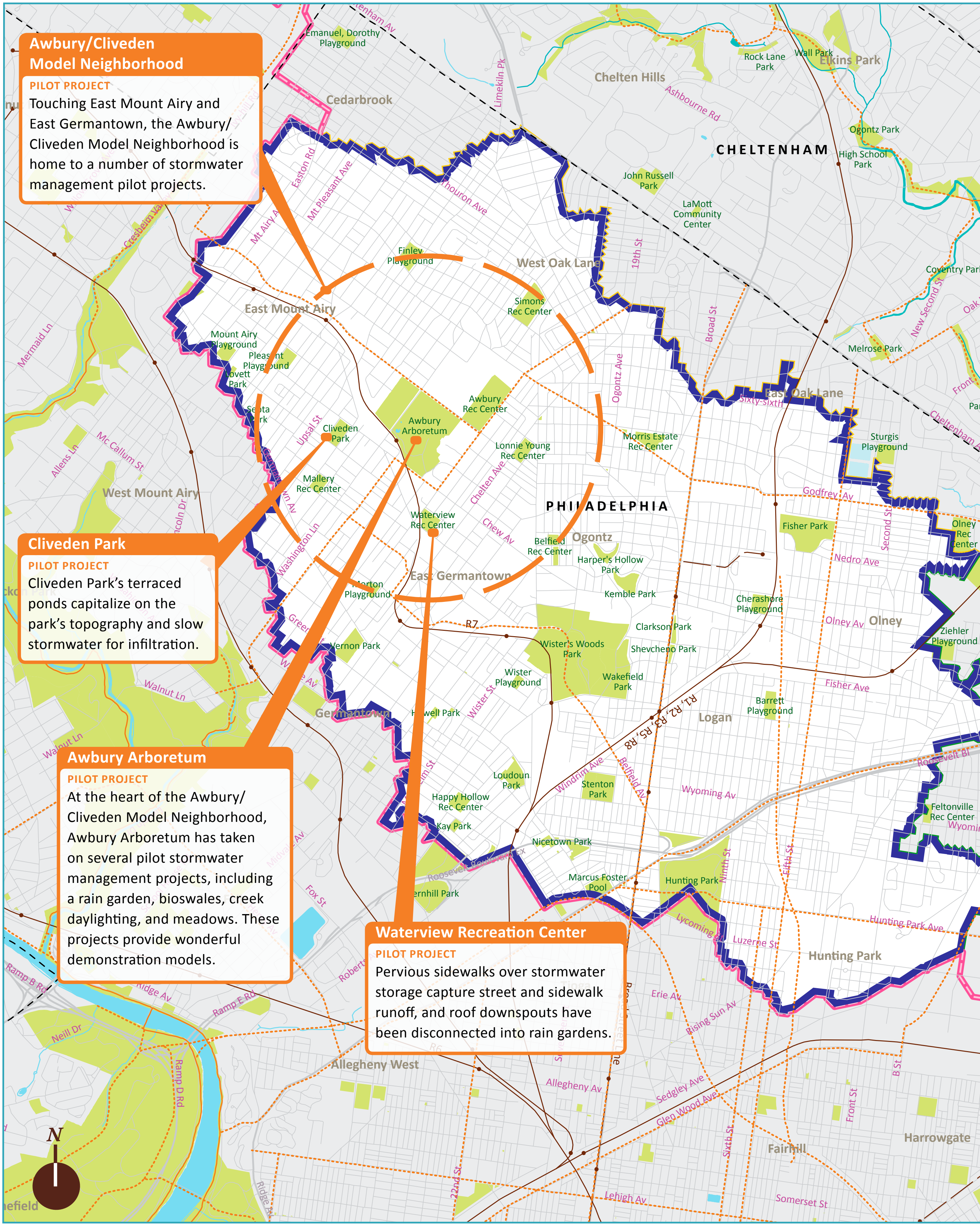
Due to the area's density and the creek's high degree of channelization, opportunities to contribute to the health of the watershed include upland interventions and programs such as green roofs and streets, pervious paving and pocket parks to slow and filter stormwater before entering the creek. There is also the chance to create a greenway along a major portion of the creek, creating much-needed open space and a renewed connection to the creek for the community.

Top left*: Frankford Creek's – and the watershed's – confluence with the Delaware River. The Creek flows into the River just south of the Betsy Ross Bridge fully channelized and through a large industrial area.*

Top right*: Looking upstream at Frankford Creek near the Delaware River, its concrete channelization is revealed, as are the diverse land uses around the creek. They range from light industry to dense residential – all rather impervious – to scrubby fields. Permeable landscapes here could both provide much-needed open space for the community and assist the functions of the watershed.*

Bottom*: Where it is not fully channelized with concrete walls, Frankford Creek is characterized by wide, shallow base flows and severely degraded creek banks due to the erosive forces of floodwaters from further upstream.*

While riparian improvements would be limited in this channelized reach of Frankford Creek, permeability-boosting enhancements to the urban upland, like parks, green roofs, greener streets, pervious paving and even a creek-side greenway would provide much needed open space and vegetation for the community.



Awbury/Cliveden Model Neighborhood

PILOT PROJECT

Touching East Mount Airy and East Germantown, the Awbury/Cliveden Model Neighborhood is home to a number of stormwater management pilot projects.

Cliveden Park

PILOT PROJECT

Cliveden Park's terraced ponds capitalize on the park's topography and slow stormwater for infiltration.

Awbury Arboretum

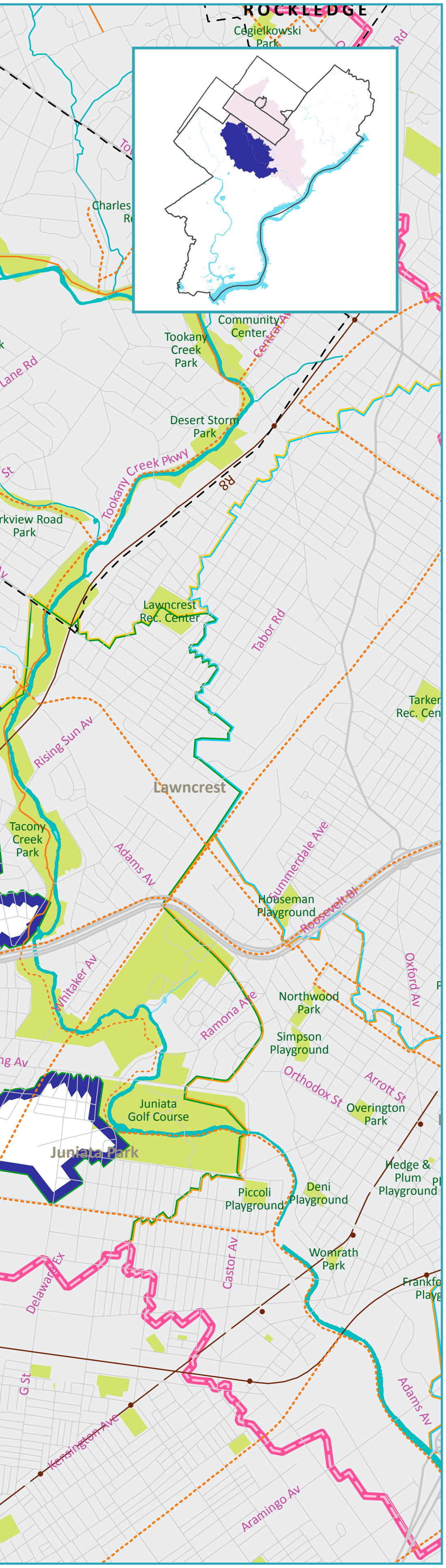
PILOT PROJECT

At the heart of the Awbury/Cliveden Model Neighborhood, Awbury Arboretum has taken on several pilot stormwater management projects, including a rain garden, bioswales, creek daylighting, and meadows. These projects provide wonderful demonstration models.

Waterview Recreation Center

PILOT PROJECT

Pervious sidewalks over stormwater storage capture street and sidewalk runoff, and roof downspouts have been disconnected into rain gardens.



Rock Run/ Wingohocking

sub-watershed

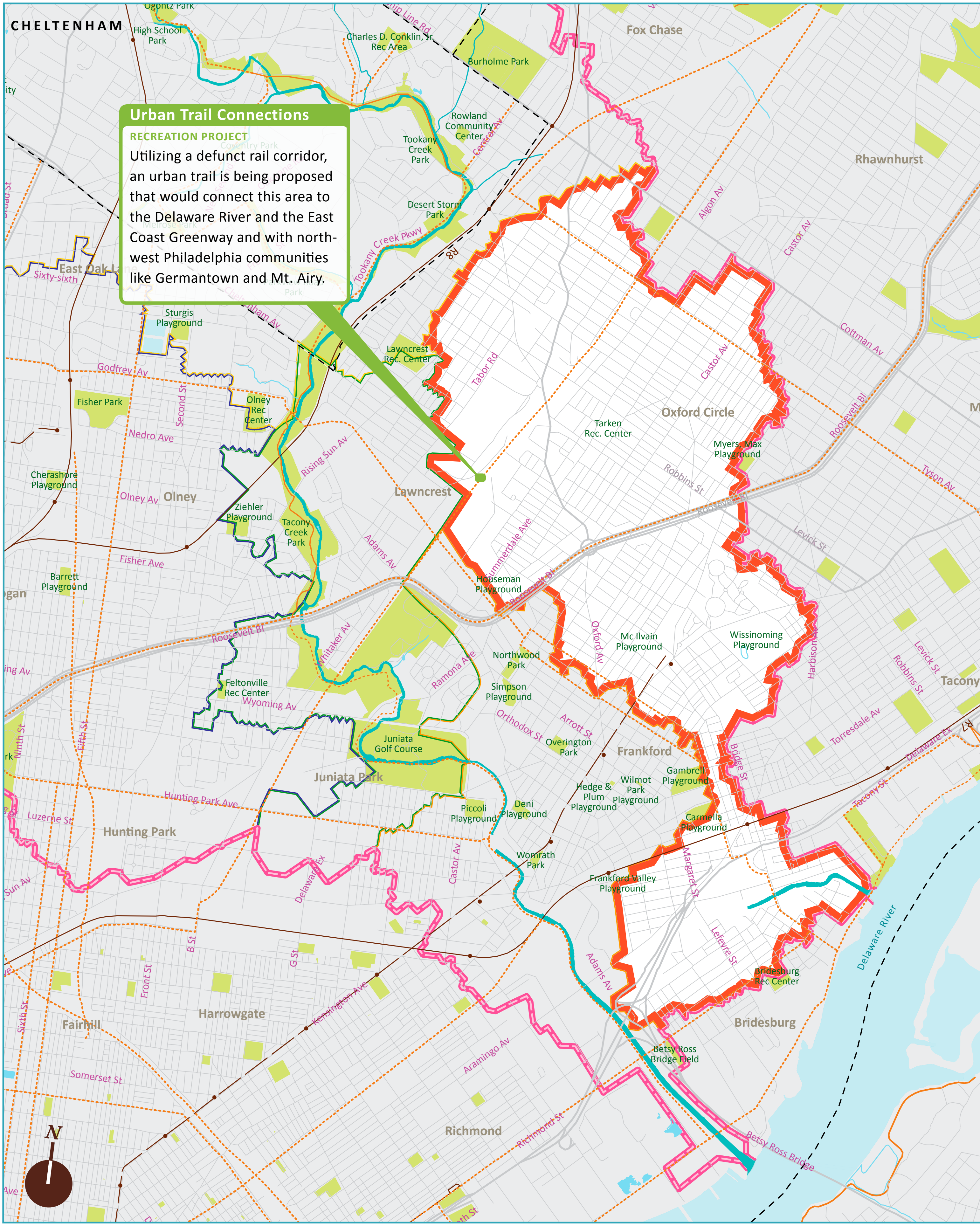
A map of the historic Battle of Germantown in 1777 shows the Wingohocking Creek threading through East Mt. Airy and Germantown. By the 1890s, the historic creek was buried in sewers and streets and houses were built on top of it. It was the largest creek system in the city to be put underground. All of the watershed's piped stormwater (that mixes with wastewater during heavy rains) now drains to a single outfall into the creek near Juniata Golf Course. This sub-watershed exhibits a full gradient of land use, from dense urban neighborhoods near Center City to densely vegetated valleys outside of the city. Parts of this sub-watershed average more tree cover than any other area in Philadelphia. It also boasts plenty of parks, but it still could do better at supporting a healthier watershed by slowing and filtering runoff before it drains away. Steps are being taken to get there: projects and opportunities have been identified in the map shown at left.

*The land use here is diverse, ranging from flat-roofed twin houses with small yards, gardens and mature trees near neighborhood parks (**top left**), to sprawling short-term commercial development with acres of impervious paving (**top right**). Each type of land use has opportunities to positively affect the health of the watershed, from homeowner practices to commercial building guidelines.*

***Bottom left**: Miles of bike trails are planned for this sub-watershed. The green swath running through the photo is a retired rail line near the Juniata Golf Course, which could become a trail that would connect the Tacony Creek with the Schuylkill River.*

***Bottom right**: Using the natural bowl shape of the landscape, this terraced rain garden in Cliveden Park makes an event of rain storms. In warmer months, the three terraced depressions are colonized with plants that slow runoff from the street above.*

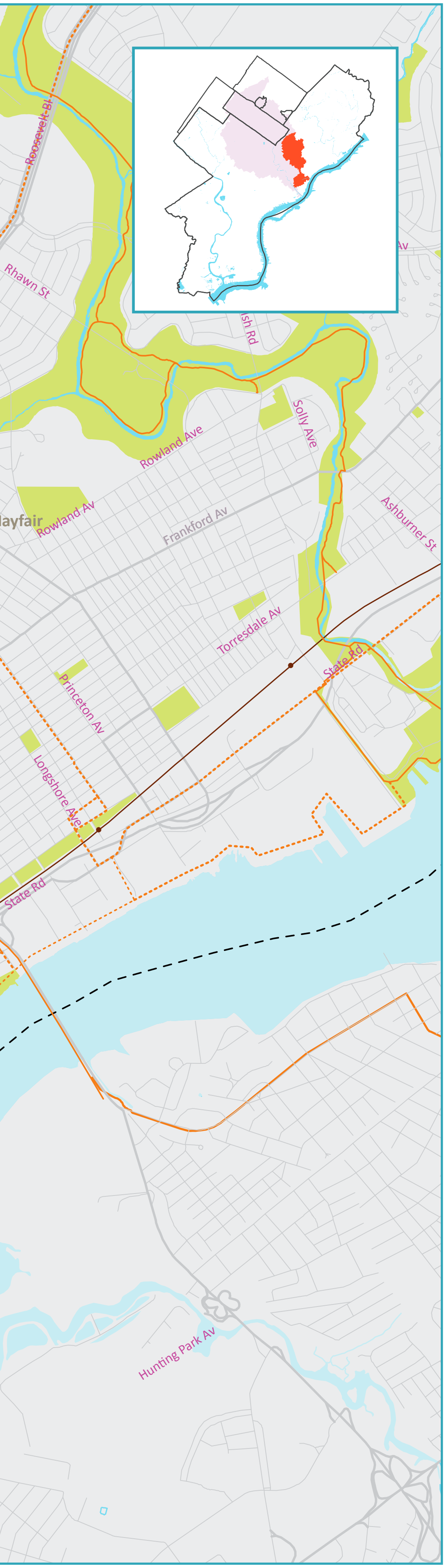
MLK High School becomes a center of activity for environmental education. Stormwater wetlands reveal the original Wingohocking Creek floodplain after rain events. Pervious pavement, street trees and green roofs divert rainfall from the sewers and make for a lush, walkable neighborhood.



Urban Trail Connections

RECREATION PROJECT

Utilizing a defunct rail corridor, an urban trail is being proposed that would connect this area to the Delaware River and the East Coast Greenway and with northwest Philadelphia communities like Germantown and Mt. Airy.



Wakeling/ Old Frankford

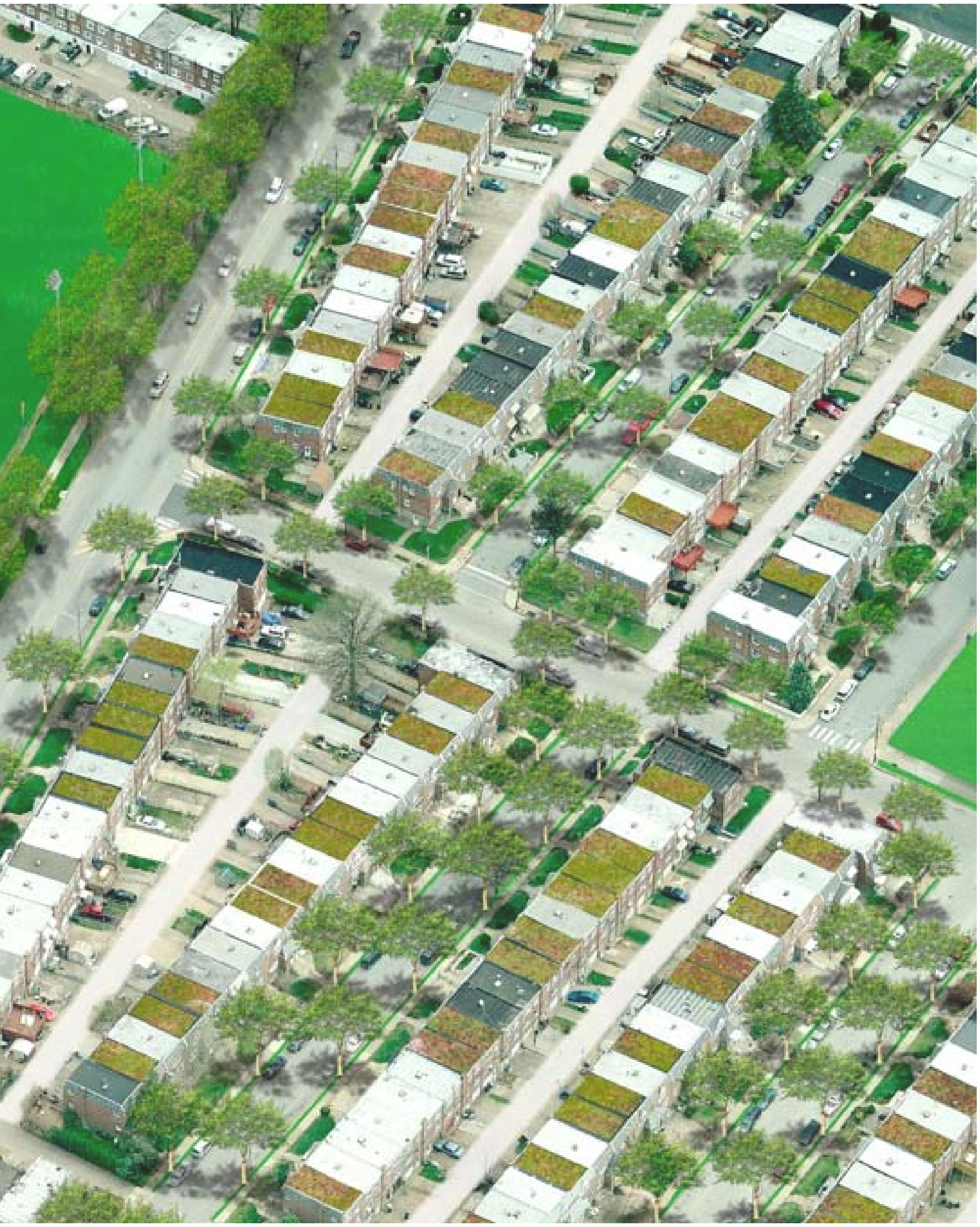
sub-watershed

The Wakeling/Old Frankford sub-watershed, historically connected to the TTF watershed, once contained Wakeling Creek, a tributary to Frankford Creek. This tributary has since been converted into a sewer, and the stormwater that used to slowly absorb into the watershed now drains away quickly over pavement and through sewer mains to the remnant of Frankford Creek where it meets the Delaware River. Today, the acres of impervious surfaces covering this area—buildings, streets and pavement—in addition to too few trees and large open spaces, not only keeps water from infiltrating locally to support a healthy watershed, but also demonstrates the visual impact of poor watershed practices. Here, the focus will need to be on promoting healthier practices, such as green roofs and cisterns, green streets, more pervious cover, less water use and less litter.

Top left*: Sprawling and paved commercial development abuts dense residential neighborhoods near Roosevelt Boulevard. Just behind the Home Depot in the photo, a trail is proposed that would connect the Delaware River—and the East Coast Greenway—with northwest Philadelphia.*

Top right*: The sub-watershed is characterized by dense residential neighborhoods with little access to community parks and open space and not enough tree cover.*

Bottom*: The confluence of the historic Frankford Creek with the Delaware River. Here, the entire TTF watershed used to drain into the Delaware. Now, this channelized remnant is surrounded by acres of paving and mostly industrial uses (and the historic Frankford Arsenal, at right) and drains only the Wakeling sub watershed.*



In dense urban sub-watersheds like the Wakeling/Old Frankford community, efforts to maintain a healthy watershed will focus on upland practices like green roofs, green streets and increased permeability. Community open spaces and parks like Tarken Playground can also manage large amounts of stormwater and further increase their value to the community with stormwater gardens.