WISSAHICKON CREEK WATERSHED
COMPREHENSIVE CHARACTERIZATION REPORT

JANUARY 2007

PREPARED BY THE PHILADELPHIA WATER DEPARTMENT

TABLE OF CONTENTS

Appendices

List of Figures

Page

Section 2

Section 3

Section 4

List of Tables

Page

Section 2

Section 3

Section 4

Section 5

List of Tables

EXECUTIVE SUMMARY

Problems faced by the Wissahickon Creek Watershed stem from many sources. Primarily, the creek suffers from physical disturbance due to urbanization and excess nutrient input from municipal wastewater treatment plants. These effects are evident in the comprehensive assessment of the aquatic habitat, biological communities and water chemistry documented in this report. Healthy aquatic ecosystems cannot thrive in physically unstable habitats or when streamflow is dominated by treated municipal wastewater that does not maintain healthy stream chemistry. This report forms a technical basis for the forthcoming Wissahickon Creek Integrated Watershed Management Plan (WCIWMP), presenting a foundation for planning restoration and enhancement of the creek.

With impervious cover making up over 30% of the land area in many subsheds, stormwater flows have de-stabilized most stream channels of Wissahickon Creek Watershed. Erosion and sedimentation effects are very severe in small tributary streams in the City of Philadelphia, where valleys are generally very steep. Though these Philadelphia tributaries are almost entirely protected within parkland, most either originate as stormwater outfalls or otherwise accept large volumes of urban stormwater. Throughout the watershed, many small ephemeral streams and first order tributaries have been lost to development. Moreover, destabilizing infrastructure features, such as culverts, bridges, channelization, and small dams are omnipresent in Montgomery County. 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 Wissahickon Creek Watershed, also magnifies flow modification by decreasing infiltration and groundwater recharge – establishing a hydrologic pattern of "feast or famine". Presently, baseflow accounts for only 38% of total mean annual flow at the mouth of Wissahickon Creek, and only 32% of the flow at the Fort Washington USGS gauge. Effects of urbanization and physical habitat degradation are evident in biomonitoring data throughout the basin. The Wissahickon Creek Integrated Watershed Management Plan (WCWIMP) in preparation will contain several options for detaining, infiltrating, and treating stormwater to reduce its impact on the stream channel and aquatic habitats. The watershed simply cannot be restored without addressing stormwater impacts.

While all urban watersheds have severe problems with erosion and sedimentation in wet weather, bacterial contamination and other pathogens are also an important concern, particularly in a stream, such as Wissahickon Creek, which contributes to public water supplies and is used extensively for various recreational activities. Of particular concern is the relative proportion of the pathogen load contributed by human vs. wildlife and domestic animal sources. Although bacterial contamination in the Wissahickon Creek Watershed is a problem in wet weather, dry weather bacterial concentrations are generally low, with most sampling locations in compliance with water quality standards.

Though storm events undoubtedly have the greatest influence on physical habitat and erosion related problems in Wissahickon Creek Watershed, dry weather (baseflow) conditions should not be overlooked as sources of impairment. Inputs of municipal treated sewage comprise a large proportion of baseflow in Wissahickon Creek, and nutrient concentrations greatly exceed EPA recommended guidelines for healthy stream ecosystems. Algae were observed to grow to nuisance levels throughout the watershed, and continuous water quality monitoring suggests algae are primarily responsible for dissolved oxygen (DO) and pH fluctuations that may stress natural fish and invertebrate communities. Significant reductions of instream phosphorus concentration are needed to reduce algal density, severity of DO fluctuations, and support a more diverse and healthy aquatic ecosystem overall.

All invertebrate communities sampled in Wissahickon Creek Watershed were characterized as "severely impaired" when compared to unimpaired regional reference sites. Most sites sampled have a very simplified invertebrate community nearly completely dominated by midge fly larvae (chironomids), and a small number of other moderately tolerant invertebrates with generalized food requirements. These invertebrates are tolerant of low DO and frequent disturbance of their habitat. It is unknown whether Wissahickon Creek Watershed has sufficient colonizing sources of more sensitive invertebrates historically extirpated from the Philadelphia region.

Fish communities of Wissahickon Creek Watershed generally exhibited less diversity and specialization than fish communities found at reference sites and nearly all fish found in the watershed are moderately tolerant of pollution. Wissahickon Creek is dominated by moderately tolerant fish with generalized feeding habits and life history strategies, while species that have specialized habitat, food or reproductive needs are largely missing. Fish that require firm, stable, well oxygenated substrates for spawning are also generally not found in the basin. Though the watershed supports a put-and-take trout fishery, there is some evidence that native fish may be adversely affected by high trout densities.

Wissahickon Creek Watershed exemplifies contrasts in history and changing environmental attitudes. While acquisition and protection of the Wissahickon Creek Valley to protect Philadelphia's source water in the 19th century is an example of very progressive forward thinking, most of the remainder of the basin was developed without effective stormwater management. The current unstable physical and ecological state of the Wissahickon Creek Watershed is a result of more than a century of development pressure and the byproducts of urbanization. Correcting these problems will require an enormous commitment on the part of the watershed's residents, but must be done if natural communities are expected to return and flourish. Healthy, stable communities cannot exist without healthy, stable habitats. Philadelphia Water Department and the Wissahickon Watershed Partnership are working to ensure that watershed improvements are cost-effective and based on sound science. We believe this report will serve as a solid foundation for defining reachable goals and developing a roadmap to attaining them in the in the forthcoming Wissahickon Creek Integrated Watershed Management Plan.

1 INTRODUCTION

The Philadelphia Water Department (PWD) has embraced a comprehensive watershed characterization, planning, and management program for the Wissahickon Creek Watershed to meet the regulatory requirements and long-term goals of its stormwater and drinking water source protection programs, as well as to address the implementation of the Wissahickon Creek Total Maximum Daily Load (TMDL) for siltation. 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 aligned to work closely with 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.

The OOW is developing an integrated watershed management plan for five of the City's watersheds including the Cobbs, Tookany/Tacony-Frankford, Wissahickon, Pennypack, and Poquessing. In the summer of 2004, the Cobbs Creek became the first watershed for which an integrated watershed management plan was completed. The Tookany/Tacony-Frankford Watershed plan was completed in the summer of 2005. The Wissahickon Creek Integrated Watershed Management Planning (WCIWMP) effort was kicked off in the fall of 2005.

This Comprehensive Characterization Report (CCR) for the Wissahickon Creek forms the scientific basis for the creation of the Wissahickon Creek Integrated Watershed Management Plan. The Wissahickon CCR characterizes the land use, geology, soils, hydrology, water quality, ecology, and pollutant loads found in the watershed, presenting data collected through the spring of 2006. This report is intended as a compilation of background and technical documents that can be periodically updated as additional field work or data analyses are completed.

2 CHARACTERIZATION OF THE STUDY AREA

2.1 WATERSHED DESCRIPTION

The Wissahickon Creek Watershed (WCW) is located in southeastern Pennsylvania. The headwaters of the Wissahickon Creek originate from just below a parking lot at the Montgomeryville Mall complex in Montgomery Township; the mainstem of the creek flows for approximately 27 miles through nine municipalities before reaching its confluence with the Schuylkill River. Numerous tributaries flow to the Wissahickon Creek; the total number of stream miles contributing to Wissahickon Creek drainage is roughly 114.6 miles. With a total drainage area of 63.68 square miles, this watershed spans portions of fifteen municipalities and the City of Philadelphia, though the combined area of only five of these municipalities make up more than 70% of the drainage area (Table 2-1).

Utilizing orthophotography and topography data from 2004 with two foot accuracy, the hydrology of the stream could be accurately traced in order to give a detailed account of stream mileage (Table 2-2). Hydrologic subwatersheds draining to each tributary (Figure 2-1) were delineated utilizing Arc Hydro software – a data structure that provides the capacity to link hydrologic data to water resources modeling.

Table 2-1 Municipalities within Wissahickon Creek Watershed

Municipality	% of WCW Drainage in Each Municipality
Upper Dublin Township	18.85%
Philadelphia	16.80%
Lower Gwynedd Township	13.01%
Whitemarsh Township	12.90%
Springfield Township	10.12%
Whitpain Township	8.30%
Upper Gwynedd Township	7.87%
Abington Township	5.58%
Montgomery Township	2.43%
Ambler Borough	1.33%
Lansdale Borough	1.11%
North Wales Borough	0.90%
Cheltenham Township	0.42%
Horsham Township	0.18%
Worcester Township	0.14%
Upper Moreland Township	0.05%

Table 2-2 Wissahickon Creek and Tributary Stream Lengths

Hydrologic Feature	Length (mi)
Bells Mill Run	1.2
Cresheim Creek	3.1
Gorgas Run	0.3
Haines-Dittingers Creek	3.3
Hartwell Run	0.7
Hill Crest Run	0.8
Honey Run	1.0
Housten Run	1.3
Kitchens Lane Creek	1.5
Lorraine Run	3.2
Monoshone Creek	1.3
Paper Mill Run	5.8
Pennlyn Creek	2.3
Pine Run	8.5
Prophecy Creek	5.0
Rose Valley Creek	5.7
Sandy Run	8.1
Spring Run	0.7
Stuart Farm Creek	1.2
Sunny Brook Run	3.8
Tannery Run	2.6
Thomas Run	0.8
Trewellyn Creek	7.3
Valley Green Run	0.5
Willow Run East	3.9
Wises Mill Run	1.3
* Wissahickon Creek	39.4
Total	**114.7**

* Wissahickon Creek stream length additionally includes small unnamed tributaries with direct drainage to the mainstem.

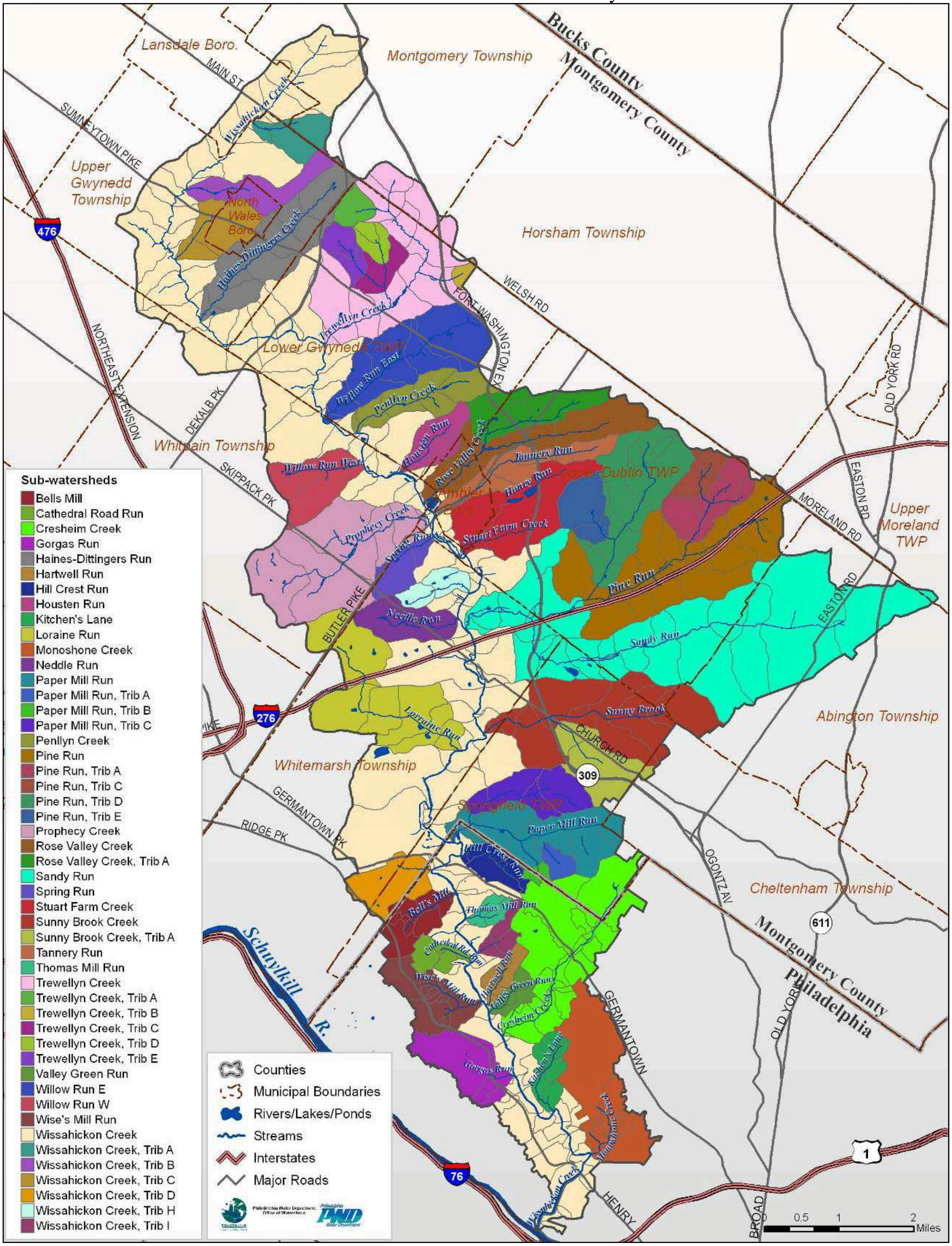


Figure 2-1 Wissahickon Creek Topographic Subsheds Draining to a Survey Point

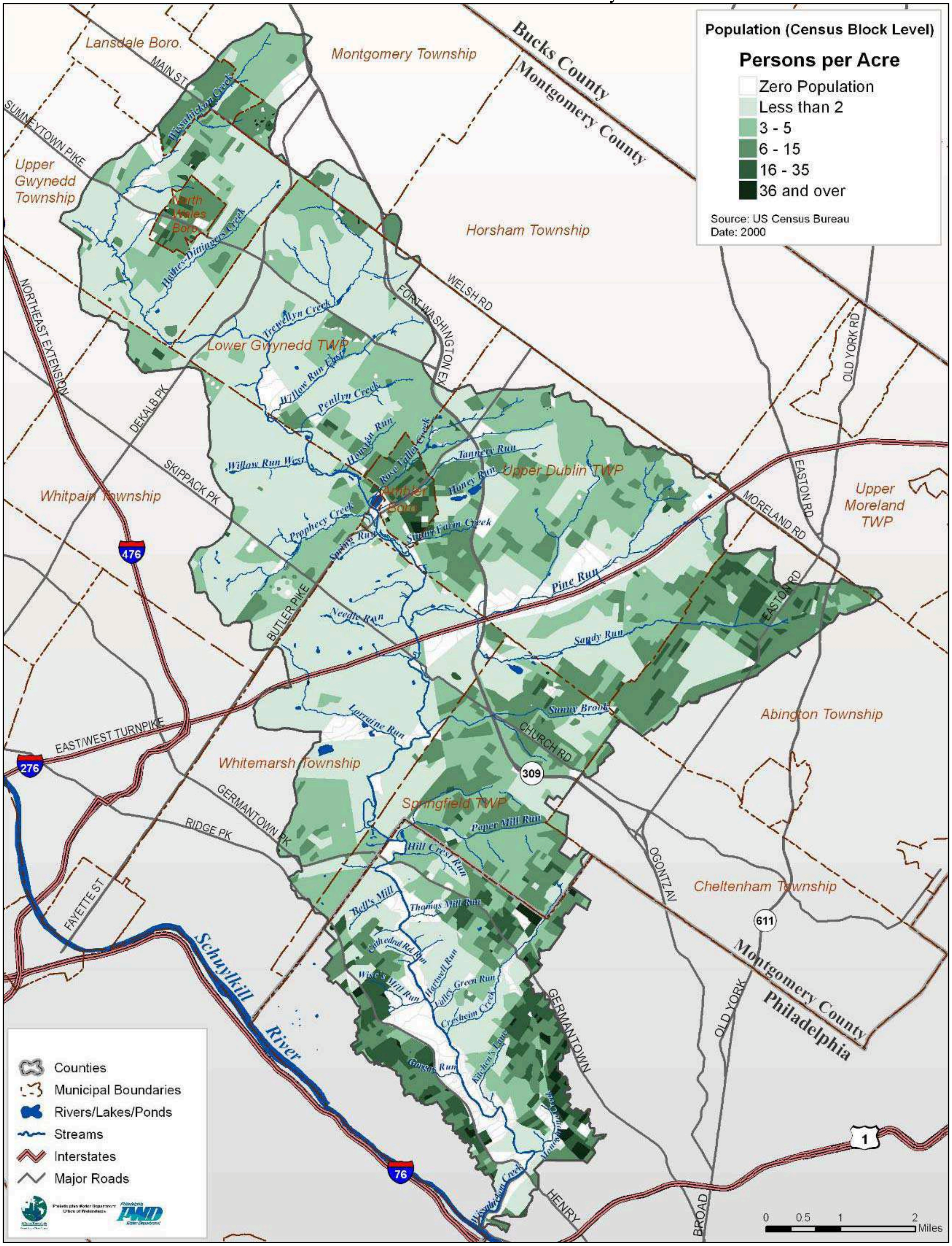
2.2 DEMOGRAPHIC INFORMATION

Population density and other demographic information for this watershed have been gathered from the 1990 and 2000 U.S. Census Surveys (Table 2-3). The population of this area has remained somewhat constant over this time, increasing by only 2.7%. Census data gathered at the county level indicates that the most significant population boom in Montgomery County occurred between the 1950 and 1960 census surveys.

According to the 2000 Census, 157,653 people reside within Wissahickon Creek Watershed. The average population density of the watershed is approximately 3-4 persons per acre (Figure 2-2). The amount of impervious cover in a residential area is closely related to its population density, affecting both the quantity and quality of stormwater runoff.

Table 2-3 Wissahickon Creek Demographic Statistics
Source: 2000 U.S. Census

Municipality	Area within Wissahickon Watershed (ac)	Population in Watershed	Number of Households in Watershed	Number of Housing Units in Watershed
Abington Township	2,291.42	21,804	7,892	8,057
Ambler Borough	541.99	6,426	2,510	2,593
Cheltenham Township	87.17	368	142	144
Horsham Township	73.02	627	342	354
Lansdale Borough	454.24	3,474	1,395	1,432
Lower Gwynedd Township	5,303.90	9,773	3,842	4,012
Montgomery Township	991.44	2,932	1,188	1,201
North Wales Borough	364.91	3,342	1,299	1,324
Springfield Township	4,096.97	19,037	7,273	7,431
Upper Dublin Township	7,680.94	22,819	8,112	8,269
Upper Gwynedd Township	3,206.30	6,290	2,390	2,472
Upper Moreland Township	22.07	112	41	42
Whitemarsh Township	5,258.63	5,361	1,867	1,938
Whitpain Township	3,383.66	5,784	2,320	2,411
Worcester Township	58.95	44	12	13
Montgomery County	**33,815.61**	**108,193.00**	**40,625.00**	**41,693.00**
Philadelphia County	**6,710.71**	**49,460**	**22,411**	**23,627**



Source: US Census Bureau
Date: 2000

Figure 2-2 Wissahickon Creek Watershed Population Density

2.3 EXISTING MUNICIPAL ORDINANCES

Many municipalities of the Wissahickon Creek Watershed experienced extensive land development prior to the initiation of stormwater management controls required by the Pennsylvania Stormwater Management Act of 1978 (Figure 2-3). As noted previously, it appears that the boom in residential development within Montgomery County occurred between 1950 and 1960, two to three decades prior to the existence of stormwater management regulations. According to the Wissahickon Creek River Conservation Plan, "Approximately, 60 percent of the land area in the Watershed was developed prior to the advent of runoff control ordinances that limit impervious area or required detention of excess runoff." (Figure 2-3)

Problems associated with of years of increasing impervious cover and uncontrolled stormwater have been further exacerbated as additional development has taken place – especially as this has taken place in the headwater stream drainage areas, leading to increased flooding and other water quality and quantity issues for the Wissahickon Creek and its tributaries. Ordinances and regulations have been passed in order to help to reduce the impact of future development, but little has been done to address the existing development and its associated issues.

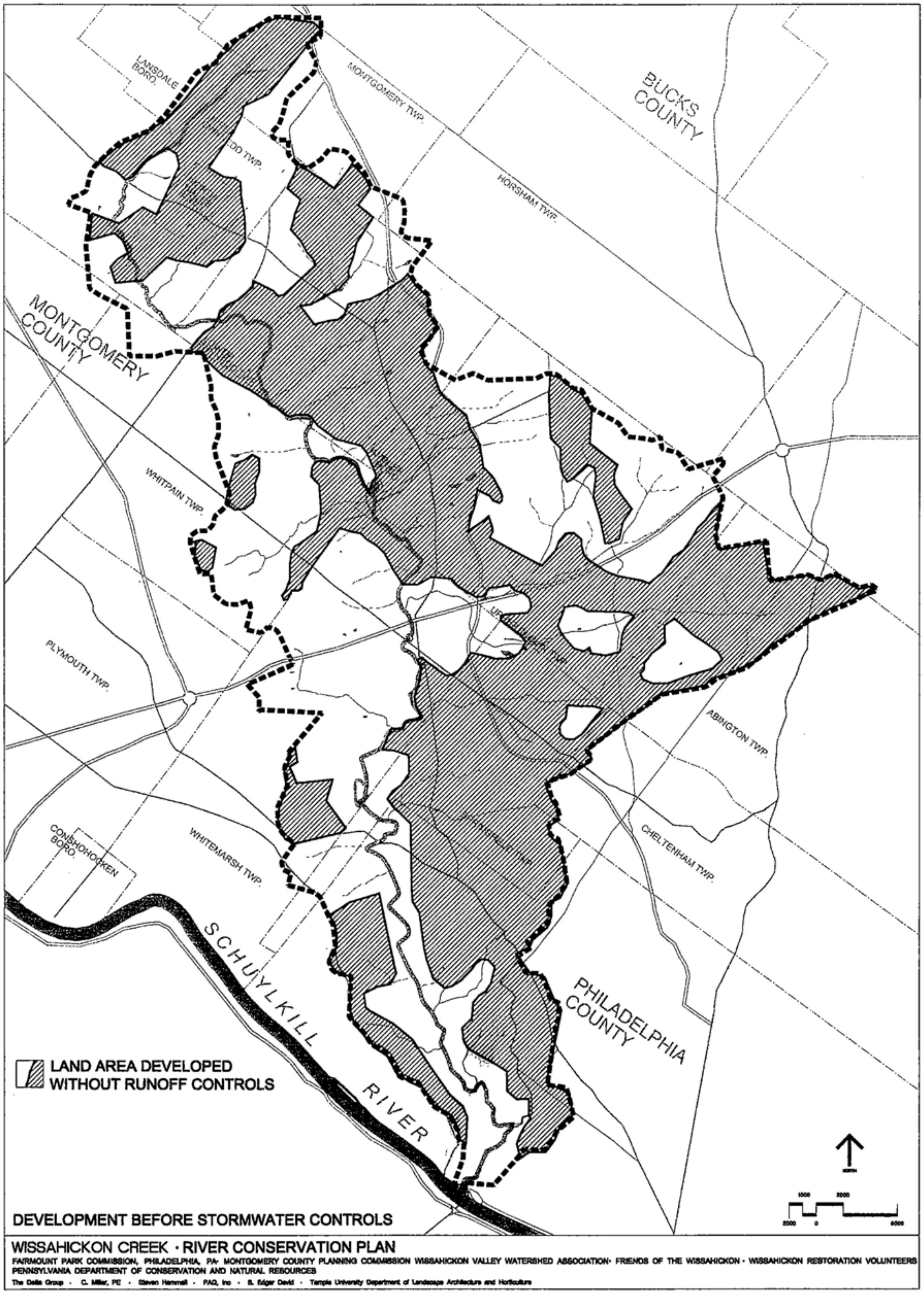


Figure 2-3 Development in the Wissahickon Creek Watershed Prior to Stormwater Management Controls
Source: Wissahickon Creek River Conservation Plan, 2001

2.3.1 CITY OF PHILADELPHIA ORDINANCE §14-1603.2: ENVIRONMENTAL CONTROLS FOR THE WISSAHICKON CREEK WATERSHED

In 1976, as a result of uncontrolled development taking place within the Wissahickon Creek Watershed, the City of Philadelphia enacted a special ordinance that covers only the Wissahickon Creek Watershed portion of the City. This ordinance is aimed at reducing the impact of continued development of this area. It applies to the area generally bounded by Ridge Avenue, Schoolhouse Lane, Germantown Avenue, Mount Airy Avenue, and the Montgomery County boundary.

This ordinance places development controls on environmentally-sensitive sites in the watershed. It applies during and after construction and encompasses all construction site clearing and earth moving within the Wissahickon Creek Watershed in order to promote a regional approach to the protection of the Wissahickon Creek. Special environmental controls are imposed to regulate setbacks from water courses, construction and earth moving activity on slopes, impervious cover, and earth moving plans. The purpose of the ordinance is to prevent additional degradation of the environment by imposing controls to protect the health, safety and general welfare, improving water quality and achieving environmentally sound land development practices within the Wissahickon Creek Watershed.

2.3.2 CITY OF PHILADELPHIA STORMWATER MANAGEMENT REGULATIONS

In January of 2006, the City of Philadelphia updated their stormwater regulations, which complement the existing City-wide stormwater ordinance, §14-1603.1. These updates were largely modeled after the Pennsylvania Act 167 Stormwater Management Plan completed in 2004 for the Darby-Cobbs Watershed portion of Delaware County. The regulations also implement many requirements the City's NPDES Phase I Stormwater Permit.

There are four main components of the City's regulations: water quality, channel protection, flood control, and nonstructural site design. All projects with earth disturbance of more than 15,000 sq. ft. must comply with the water quality and nonstructural site design requirements. All new development projects must comply with all four of the components. Redevelopment projects may be exempt from the channel protection and flood control requirements if they reduce directly connected impervious area by 20% or more, or if they are in areas that drain directly to tidal water bodies. These regulations encourage tree planting, greening, groundwater recharge, and capture and treatment of over 75% of all stormwater initial release of concentrated pollution. Additional information on the City of Philadelphia's new stormwater regulations is available at: www.phillyriverinfo.org.

2.3.3 MONTGOMERY COUNTY MUNICIPAL ORDINANCES AND NPDES PHASE II STORMWATER REGULATIONS

Federal regulations enacted in December 1999 required municipalities in urbanized areas to implement a stormwater management program beginning in March of 2003, to continue over the subsequent five years. (40 CFR §§ 122.26 – 123.35.) These regulations, called National Pollution Discharge Elimination System (NPDES) Phase II Stormwater Regulations, apply to municipal separate storm sewer systems (MS4s), and mandate that MS4s adopt certain local legal requirements through an ordinance, or other regulatory mechanism. 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.

There are six "minimum control measures" (MCMs) communities must implement as part of a municipal stormwater management program. The measures are required by Phase II permits and are incorporated into Philadelphia's Phase I permit.

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 development 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). Many communities choose to regulate smaller construction sites at the local level.
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).

Since 2003, all Montgomery County municipalities within the Wissahickon Creek Watershed have been required to fulfill NPDES Phase II regulations and to adopt a stormwater ordinance. Evaluation of each municipality's stormwater ordinance was beyond the scope of this study.

2.4 FLOODING IN THE WISSAHICKON CREEK WATERSHED

As previously noted, considerable development and suburbanization within the Wissahickon Creek Watershed has led to a number of problems; perhaps the most identifiable to residents is the increased incidence and severity of flooding. The frequency of flooding in the watershed has continued to increase as suburban development has sprawled within the upstream portions of the watershed. Additionally problematic within this watershed area is the prevalence of development within the floodplain, which occurred prior to the enactment of municipal floodplain management ordinances.

2.4.1 MONTGOMERY COUNTY FLOODING

Municipalities of the mid-portion of the Wissahickon Creek Watershed just outside of the City of Philadelphia have experienced devastating flood related losses including both property damage and loss of life. The Sandy Run Creek tributary of the Wissahickon Creek has been host to many of the disastrous effects of flooding over the years. Flooding in September 1996 caused the Sandy Run Creek to overrun its banks and flood homes along Madison Avenue in Abington Township; during this flood, two residents were killed when they became trapped in the basement of their home while the flood waters continued to rise. As a result of the devastating events of that year, FEMA bought out and removed thirteen homes from the Sandy Run Creek floodplain (www.fema.gov).

The Fort Washington Office Park in Upper Dublin Township has experienced significant flood flooding over the years as a large portion of this complex was developed not only within the floodplain – but also the floodway. As a result of the damages and losses of property suffered by businesses leasing space within the office park, the vacancy rate for this office park has been higher than that of other commercial/industrial parks in the region. In less than a decade, the office park has experienced three 100-year inundations and one 500-year inundation (The New Planner). Temple University's Center for Sustainable Communities (CSC) has been working with Upper Dublin Township and other partners to study the office park and make recommendations for improvements that would reduce the impacts of stormwater on the site.

2.4.2 CITY OF PHILADELPHIA FLOODING

Within the City of Philadelphia portion of the watershed, much of the flooding and flood related damage is experienced within the Wissahickon Valley Park area of the Fairmount Park System. In the summer of 2004, several storms ravaged the Wissahickon Creek Watershed; specifically the storms of August 1st and September 28th, which caused severe damage to the parks and trails of the Wissahickon Park area. These two storms washed out two trails, clogged drains and culverts, eroded banks, uprooted trees, dislodged a guiderail along the creekside of forbidden drive between Wises Mill and Valley Green in as well as washing out half of a parking lot and an old stone bridge. The total estimated damages to the park were over $3M.

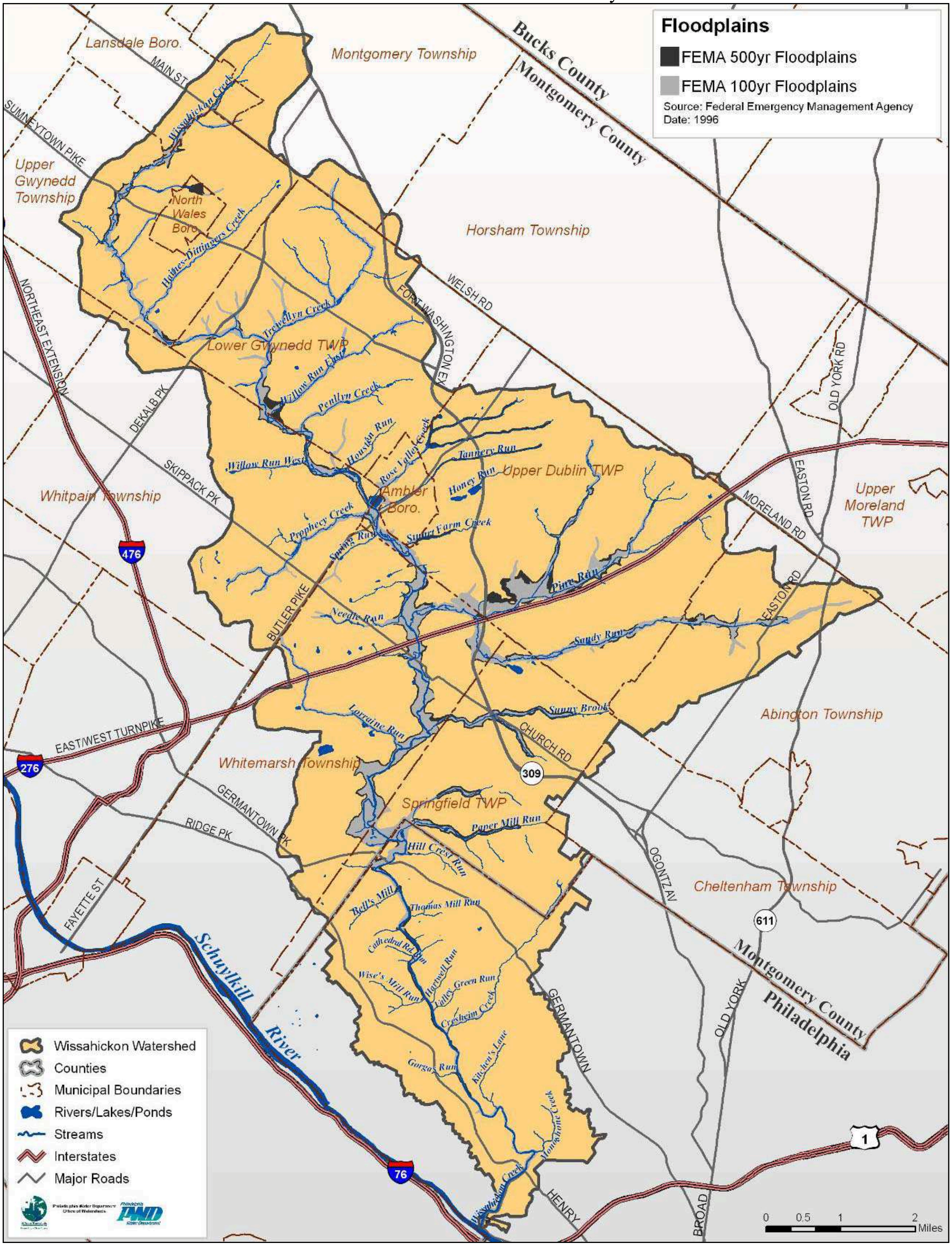
Additional flood related impacts experienced within the City of Philadelphia portion of the watershed include the closing of Lincoln Drive when it becomes inundated with flood water. Numerous times during the course of the year, this major artery into the City is closed after becoming impassible due to rising flood waters.

2.4.3 FUTURE FLOOD RELATED STUDIES

It was beyond the scope of this effort to perform a detailed analysis of existing municipal floodplain and stormwater development ordinances. This analysis has been held aside in hopes that future funding will become available.

Additionally, the CSC has embarked on two flood related studies within the watershed area that shall present partners with information on the issues, recommendations and constraints related to flooding in this area.

- The first study that the CSC has initiated is an updated delineation of the FEMA floodplains for the Sandy Run Creek Watershed.
    - The CSC is additionally considering an expansion of this updated floodplain delineation to the entire Wissahickon Creek Watershed pending municipal commitment to such an initiative and funding availability.
- The second study that the CSC has initiated is called the Fort Washington Area Flooding and Transportation Improvement Study. For more information on either of these initiatives, please visit: http://www.temple.edu/ambler/csc/projects/projects2.htm.



Source: Federal Emergency Management Agency
Date: 1996

Figure 2-4 FEMA Floodplains of the Wissahickon Creek Watershed

2.5 PENNSYLVANIA ACT 167 STORMWATER MANAGEMENT PLANNING

Pennsylvania's Stormwater Management Act (Act 167) of 1978 is administered by Pennsylvania Department of Environmental Protection (PADEP) and is designed to address the inadequate management of accelerated stormwater runoff resulting from development. The Act requires Pennsylvania counties to prepare and adopt stormwater management plans for each watershed located in the county, as designated by the PADEP. The plans are to provide for uniform technical standards and criteria throughout a watershed, for the management of stormwater runoff from new land development and redevelopment sites.

The plan must address a wide range of hydrologic impacts that result from land development on a watershed basis, and include such considerations as tributary timing, flow volume reduction, baseflow 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. This Act recognizes the interrelationship between land development, accelerated runoff, and floodplain management. Act 167 requires municipalities to implement a stormwater management ordinance limiting stormwater runoff from new development.

The types and degree of controls that are prescribed in the stormwater management plan need to be based on the expected development pattern and hydrologic characteristics of each individual watershed. The final product of the Act 167 watershed planning process is a comprehensive and practical implementation plan and stormwater ordinance developed with a firm sensitivity to the overall needs (e.g. financial, legal, political, technical, etc.) of the municipalities in the watershed. Every municipality within the watershed must adopt the ordinance.

In 1997, the Sandy Run subwatershed was separated from the Wissahickon Creek Watershed in order to expedite the stormwater planning process, specifically in response to major flooding experienced within the sub-watershed. The Sandy Run watershed includes portions of Upper Dublin, Abington, Springfield and Whitemarsh Townships. This watershed is currently undergoing an Act 167 Stormwater Management Planning process. It was funded in the spring of 2004 and should be completed by 2007. At this time, there is no timeline in place for the initiation of an Act 167 plan for the entire Wissahickon Creek Watershed.

2.6 PENNSYLVANIA ACT 537 SEWAGE FACILITY MANAGEMENT

Act 537, enacted by the Pennsylvania Legislature in 1966, requires that every municipality in the state develop and maintain an up-to-date sewage facilities plan. Regulations written to implement the Act took effect in 1972. The act requires proper planning for all types of sewage facilities, permitting of individual and community on-lot disposal systems, and uniform standards of design.

The main purpose of the 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.

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

The Montgomery County Official Sewage Facilities Plan was the first attempt at a coordinated document for long-range sewage planning in Montgomery County. It was adopted in 1972 and updated 1978. This plan was adopted by 60 of the 62 county municipalities and served as their official sewage facilities plan. Since that time, many Montgomery County municipalities have written their own official plans and updated them periodically through the planning module and plan revision processes. However, a few municipalities still fall under the jurisdiction of the 1972/1978 Montgomery County Official Sewage Facilities Plan

Presently, all of the municipalities in the watershed have adopted an Act 537 Plan; however, some plans are older than others and each vary in the levels of detail (Figure 2-5).

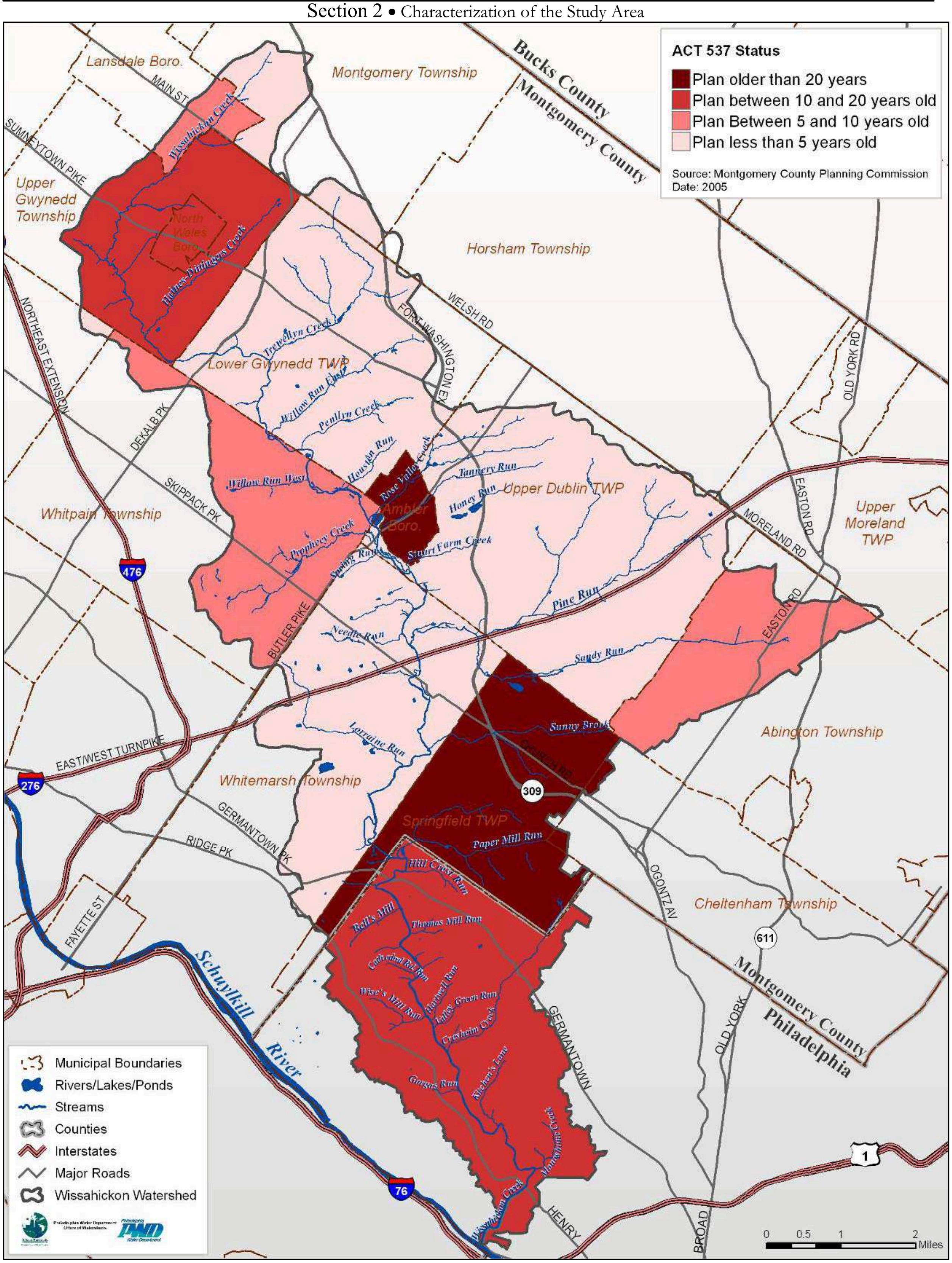


Figure 2-4 Age of Act 537 Municipal Sewage Facilities Plans

2.7 LAND USE IN THE WISSAHICKON CREEK WATERSHED

Land use information for the Wissahickon Creek Watershed was obtained from the Delaware Valley Regional Planning Commission (DVRPC). Over time, the Wissahickon Creek Watershed has experienced continual and extensive urban and suburban land development. More than half of the Wissahickon Creek Watershed is covered by residential development with single family residential making up the bulk of that development. (Table 2-4, Figure 2-6).

Several major arterial roads transect this watershed area, including the Pennsylvania Turnpike (Rt. 276), Fort Washington Expressway (Rt. 309), Dekalb Pike (Rt. 202), Skippack Pike (Rt. 73) and Sumneytown Pike. Large clusters of commercial and industrial uses and associated large parking lots along with higher density residential development are found along these corridors.

A large portion of the riparian corridor of the Wissahickon Creek and its tributaries has remained wooded land, mostly protected through long-term preservation efforts. Additionally, large tracts of privately owned open space such as agricultural land and golf courses remain undeveloped and are dispersed throughout the watershed, perhaps presenting opportunities for future preservation efforts.

Table 2-4 Land Use within the Wissahickon Creek Watershed
Source: DVRPC 2000 Land Use Data

Land Use Category	Percentage
Agriculture	6.2%
Cemetery	0.9%
Commercial	3.3%
Community Services	2.9%
Golf Course	4.0%
Manufacturing: Light Industrial	2.0%
Mining	0.2%
Parking	2.7%
Recreation	2.9%
Residential: Mobile Home	0.0%
Residential: Multi-Family	3.6%
Residential: Row Home	1.2%
Residential: Single-Family Detached	47.2%
Transportation	1.3%
Utility	0.7%
Vacant	3.3%
Water	0.8%
Wooded	16.8%

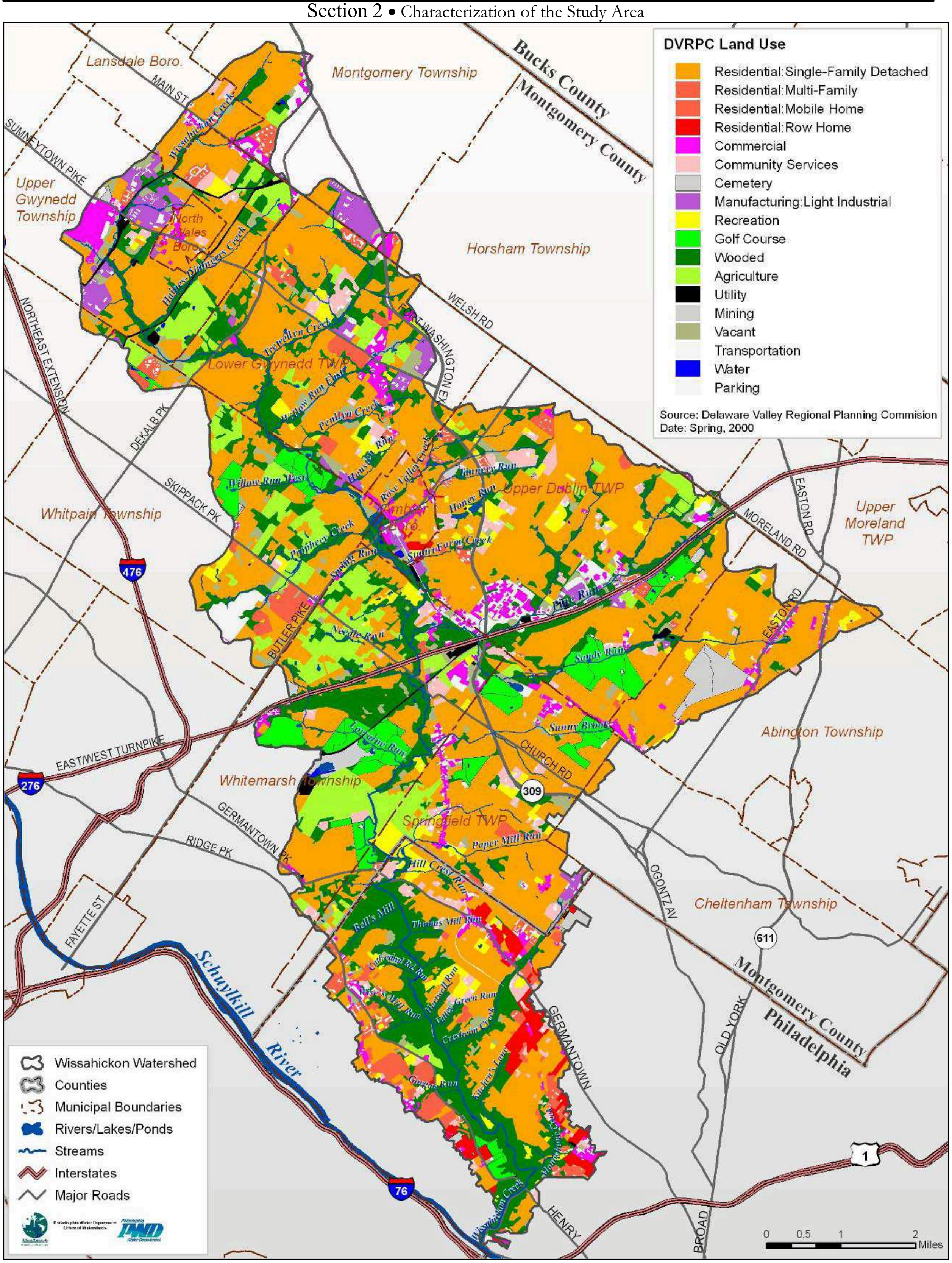


Figure 2-6 Land Use in the Wissahickon Creek Watershed

2.8 WISSAHICKON CREEK WATERSHED OPEN SPACE

The Wissahickon Creek Watershed has over 4,103 acres of preserved open space, much of which is located along the mainstem of the creek (Table 2-8, Figure 2-7). Multiple parties including the counties, municipalities, nonprofit groups and others have worked together to assemble what has become the "Green Ribbon Preserve", 22-mile strip of permanently protected land along the creek connecting the municipalities of Montgomery County with the City of Philadelphia.

2.8.1 MONTGOMERY COUNTY OPEN SPACE

Within the Montgomery County portion of the watershed, a large portion of the Green Ribbon Preserve has been protected through the efforts of the County Planning Commission as well as nonprofit preservation organizations such as the Wissahickon Valley Watershed Association (WVWA). The WVWA now protects more than 600 acres of natural area within Wissahickon Creek Watershed. Additional preserved open space within the county includes the Fort Washington State Park, which occupies 484 acres of land in Whitemarsh Township.

Significant preservation potential exists within a 2,000-acre expanse in the lower portion of the county bordering the City of Philadelphia that includes the Erdenheim Farm, the Morris Arboretum, Chestnut Hill College and three country clubs. This expanse of open space fills in a two-mile gap between Fairmount Park in Philadelphia and Fort Washington State Park in Montgomery County.

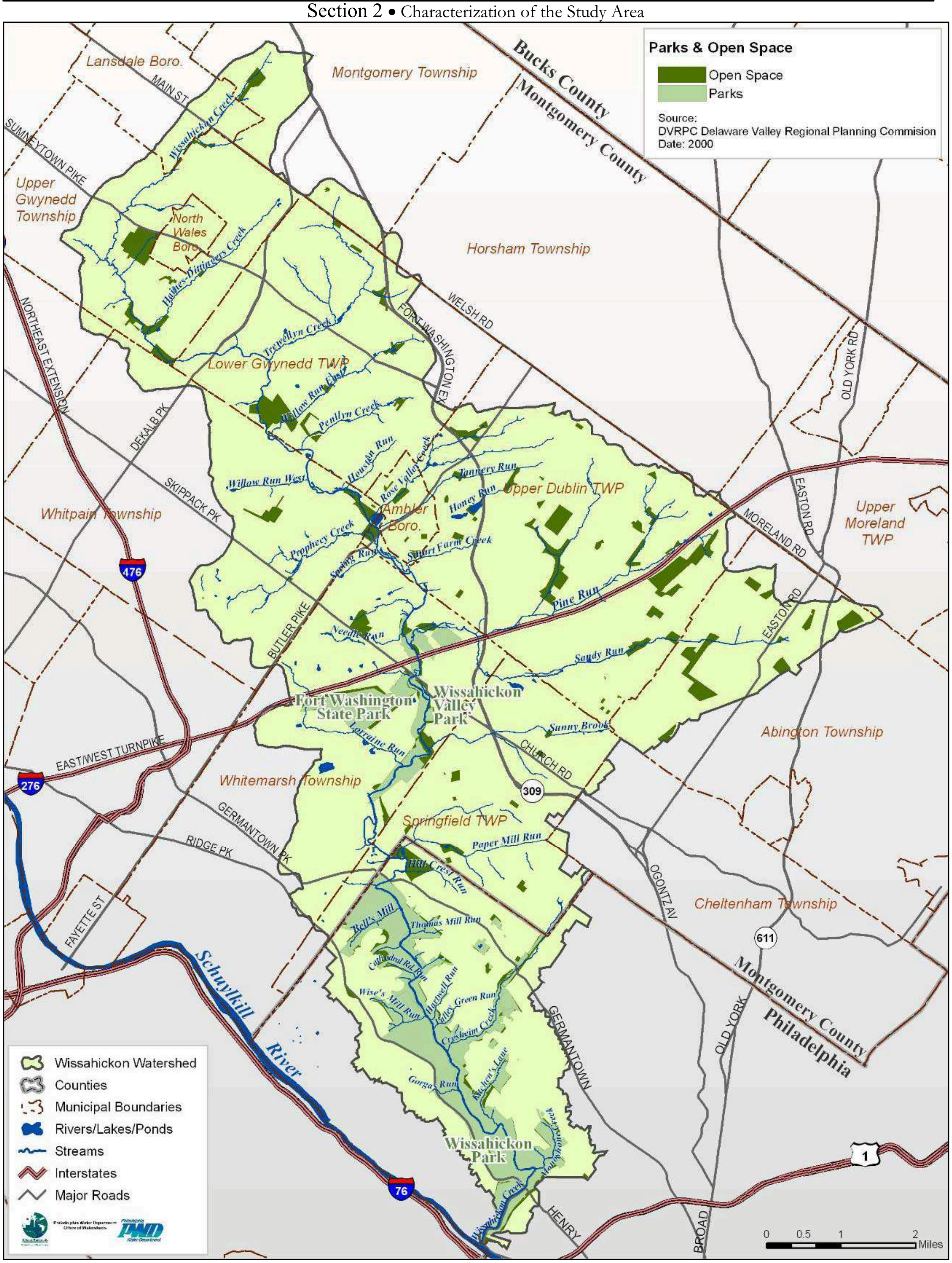
2.8.2 CITY OF PHILADELPHIA OPEN SPACE

Wissahickon Valley Park occupies roughly 1,800 acres of Philadelphia's 9,200-acre Fairmount Park, one of the largest city parks in the world. The Wissahickon Valley Park has a seven-mile length, extending from Chestnut Hill in the north to Manayunk in the southwest. Forbidden Drive, a wide gravel road closed to automobile traffic, parallels the Creek and the Park is crossed by more than 50 miles of trails.

The 2190 acres of preserved land within the Philadelphia portion of the watershed include Fairmount Park land along the Wissahickon Creek mainstem and tributaries as well as numerous neighborhood "pocket parks" within the watershed.

Table 2-5 Municipal Preserved Open Space within Wissahickon Creek Watershed
Source: Delaware Valley Regional Planning Commission (2000)

Municipality	Acres of Open Space within WCW
Abington Township	202
Ambler Borough	29
Lansdale Borough	3.6
Lower Gwynedd Township	186
Montgomery Township	35
North Wales Borough	0.1
Springfield Township	60
Upper Dublin Township	498
Upper Gwynedd Township	195
Whitemarsh Township	631
Whitpain Township	74
Montgomery County	**1913**
Philadelphia	**2190**



Source:
DVRPC Delaware Valley Regional Planning Commision
Date: 2000

Figure 2-7 Preserved Open Space within the Wissahickon Creek Watershed

2.9 IMPERVIOUS COVER AND WATERSHED HEALTH

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). While there are a few isolated regions with less impervious cover, such as Prophecy Creek and other small tributary subwatersheds, Wissahickon Creek Watershed has greater than 26% impervious cover overall, placing it in the "Non-Supporting" category of stream health (Table 2-6 and Table 2-7). Adverse changes in critical stream characteristics are listed, along with the levels of imperviousness typically associated with these changes, in Table 2-7.

Table 2-6 Estimated Total Impervious Cover

Watershed	County	Total Area (ac)	Acres Impervious	Percent Impervious
Wissahickon Creek	Philadelphia	6,710.7	1751.5	26%
Wissahickon Creek	Montgomery	33,815.6	9967.24	29%

Table 2-7 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

Most of the impacts of traditional development on streams and watersheds are directly attributed to the increase of impervious cover, but construction disturbance, non-point source pollution and other changes to the landscape also play an important role (Table 2-8). Figure 2-8 is a conceptual diagram of typical changes to the volume and duration of runoff after development. Figure 2-8 also illustrates the benefits of using various stormwater Best Management Practices (BMPs) and low impervious cover techniques to manage stormwater.

Table 2-8 Impacts of Traditional Development on Watershed Resources
Source: 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 • Embedding 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 from 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

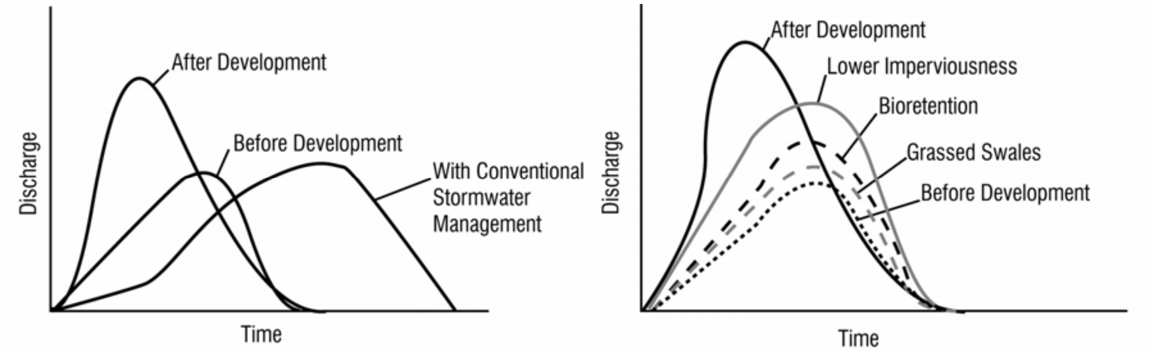
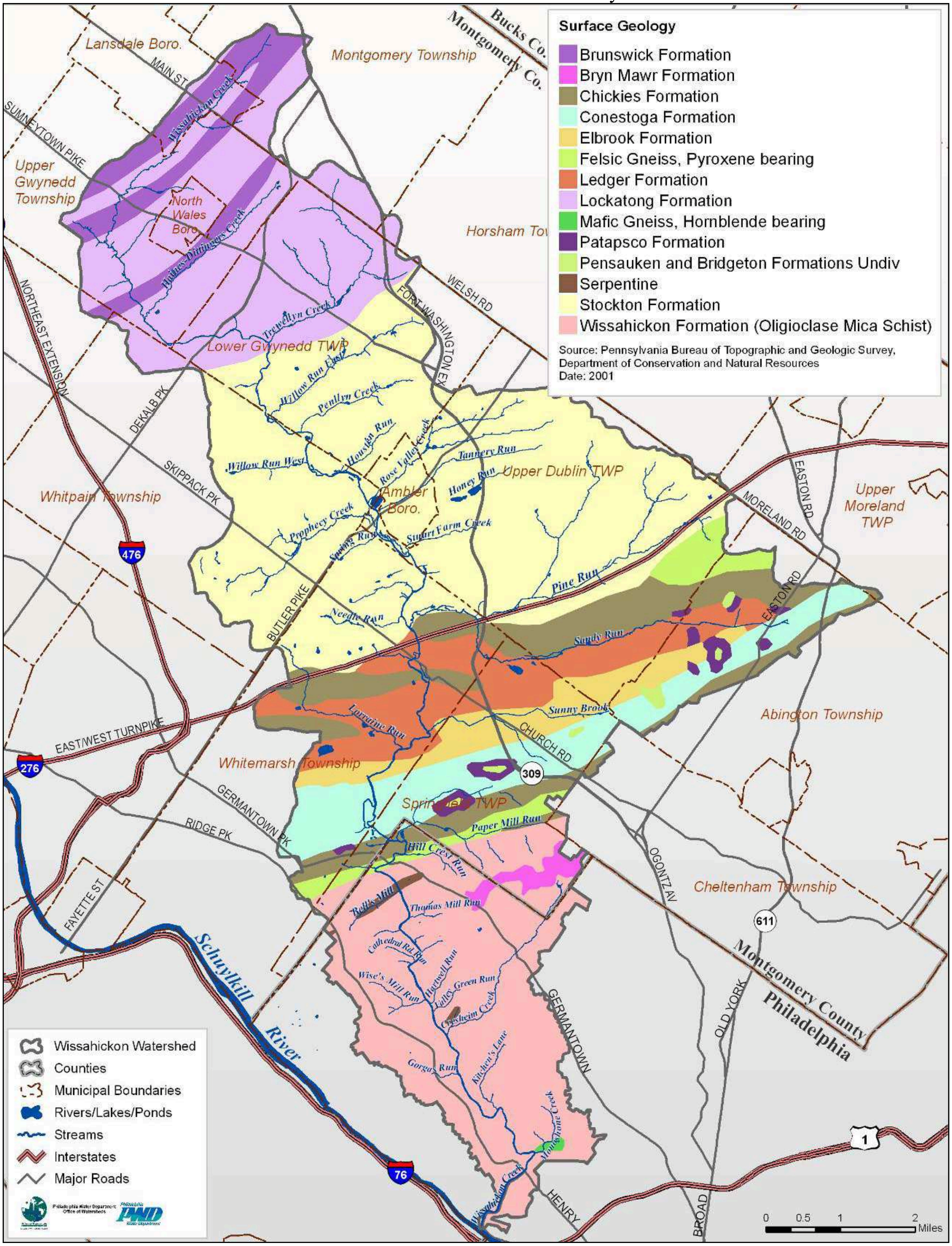


Figure 2-8 Comparison of Volume and Duration of Stormwater Runoff Before and After Land Development, and Reductions in Runoff from BMPs.
Source: Prince George's County Department of Environmental Resources et. al., undated

2.10 Geology and Soils

Geology and soils play a role in the hydrology, water quality, and ecology of a watershed. The northern portion of the Wissahickon Creek Watershed is located within the Gettysburg-Newark Lowlands and Piedmont Lowlands, underlain by various clastic sedimentary rocks. The southern portion of the watershed is within the Piedmont Upland physiographic region, which is underlain by a variety of sedimentary, metamorphic and igneous rocks (Figure 2-8, Table 2-9).



Source: Pennsylvania Bureau of Topographic and Geologic Survey, Department of Conservation and Natural Resources
Date: 2001

Figure 2-9 Wissahickon Creek Watershed Surface Geologic Formations

Table 2-9 Generalized descriptions of Geologic Formations within the Wissahickon Creek Watershed

Source: U.S. Department of Agriculture, Natural Resource Conservation Service, 2005, Montgomery County Open Space Plan, 2005, and Wissahickon Creek River Conservation Plan, 2001

Formation	Description
Brunswick Formation	This formation underlies much of the northwestern half of Montgomery County and is characterized by reddish brown shale, mudstone, and siltstone. The topography of the formation is characterized by rolling hills.
Bryn Mawr Formation	This formation consists of white, yellow, and brown gravel and sand. This is a deeply weathered formation.
Chickies Formation	This formation is created when sandstone is exposed to extreme heat and pressure. Composed of quartzite and quartz schist. This hard, dense rock weathers slowly. This formation has good surface drainage. A narrow band of quartzite extends westward across Bucks County from Morrisville.
Conestoga Formation	Conestoga Limestone is a blue-gray, thin-bedded, argillaceous limestone with intervals of a purer, granular limestone. Some of the basal beds are a coarse limestone conglomerate containing large pebbles and irregular masses of coarse white marble in a gray limestone This formation consists of Ordovician micaceous, medium-gray, impure, shaly limestone, which extends in the relatively wide belt across the county.
Elbrook Formation	The formation consists of blue dolomite and dolomitic limestone, some siliceous and shaly beds that weather to a well drained yellowish-red loam. This formation is moderately resistant to weathering. Solution channels provide a secondary porosity of moderate magnitude; moderate to high permeability. Solution openings which may be found in the substrata create certain structural problems for heavy buildings.
Felsic Gneiss, Pyroxene Bearing	This formation consists of metamorphic rock units that yield small quantities of water due to the smallness of the cracks, joints, and other openings within the rock. This fine - grained granitic gneiss is resistant to weathering but shows good surface drainage.
Ledger Dolomite	Ledger Dolomite is a white to light gray, massive to thick-bedded, granular, rather pure dolomite with a high magnesium content. The dolomite is interbedded with some siliceous beds and laminated limestone. The Ledger contains a few beds of marble with a high calcium content. Limestone and dolomite formations yield good trap rock and calcium rich rock which has been quarried for various industrial and construction uses. (Coorson's Quarry is found in this formation.)
Lockatong Formation	This formation is composed of dark gray to black argillite with occasional zones of limestone and black shale. This formation is part of a larger band, several miles wide, which runs from the Mont Clare area to the Montgomery/Horsham Township border. Resistant to weathering, these rocks form the prominent ridge that runs through central Montgomery County.
Mafic Gneiss	This formation consists of medium to fine grained, dark colored calcic plagioclase, hyperthene, augite, and quartz. It is highly resistant to weathering, but shows good surface drainage.
Pennsauken Formation	This formation consists of sand and gravel yellow to dark reddish brown, mostly comprised of quartz, quartzite, and chert. It is a deeply weathered floodplain formation.
Serpentine	This formation forms barren, rocky outcrops on low hills and ridges. Only small quantities of water are contained in the fractures. The water is hard and mineralized (magnesium bicarbonate).
Stockton Formation	This formation consists of interbedded arkose, arkosic conglomerate, feldspathic sandstone, and red shale and siltstone. It is a primarily coarse sandstone formation, which tends to form ridges resistant to weathering. This rock is a good source of brick, floor tile, and sintered aggregate material.
Wissahickon Schist	This formation is composed of mica schist, gneiss and quartzite. The schists are softer rock and are highly weathered near the surface. This formation consists mostly of metamorphosed sedimentary rocks, but also includes rocks of igneous origin.

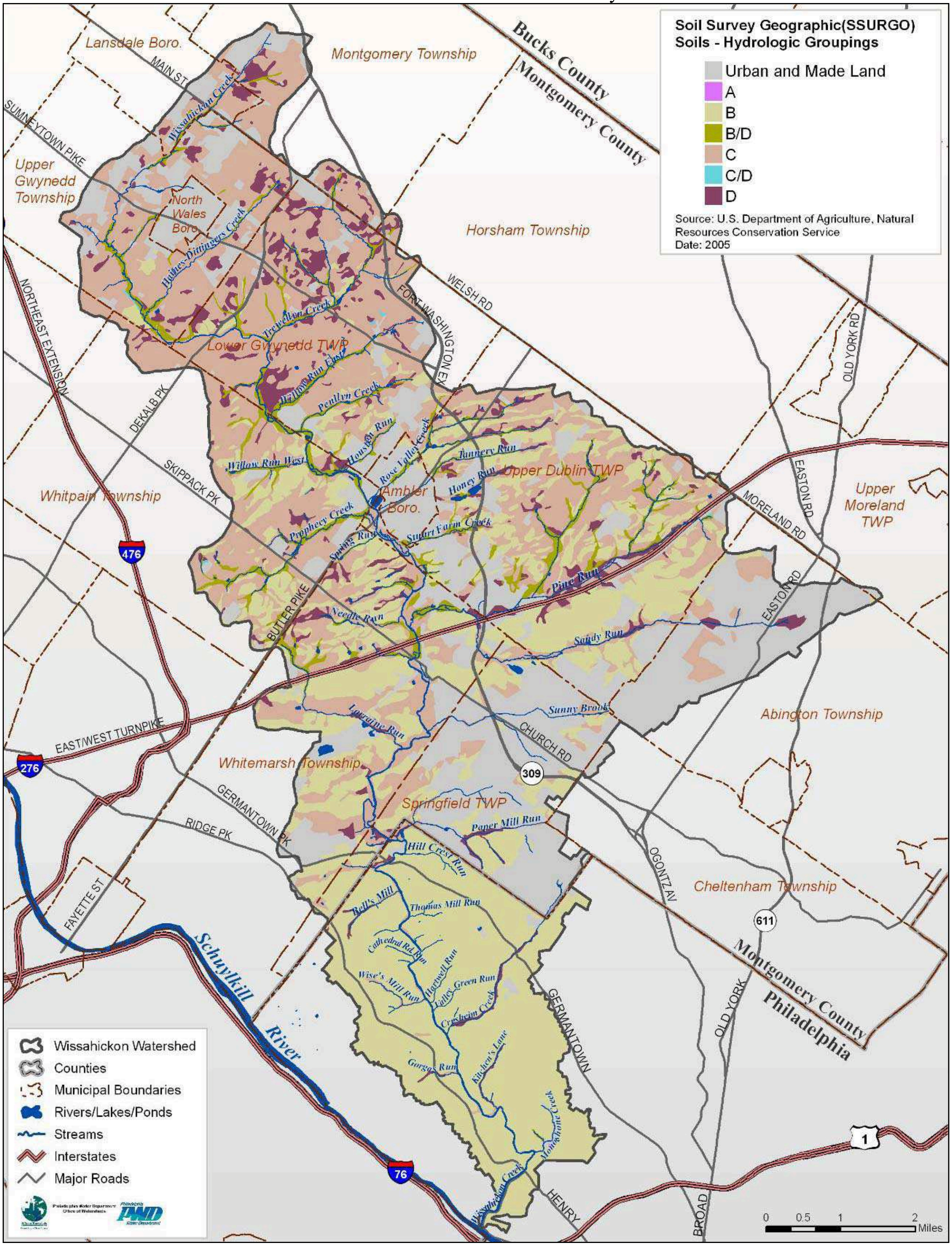


Figure 2-10 Soil Texture Types in the Wissahickon Creek Watershed

The United States Department of Agriculture, Natural Resource Conservation Service (NRCS) has assigned soils to Hydrologic Soil Groups (HSG). The assigned groups are listed in NRCS 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. Most soils in Wissahickon Creek Watershed are categorized as hydrologic category B, with some upstream areas in category C (Figure 2-10). This means that most of the study area has soils that have 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.

3 WATERSHED HYDROLOGY

This section examines the components of the hydrologic cycle for the Wissahickon Creek Watershed. A significant portion of the data used to examine the components of the hydrologic cycle is provided by the Tellus Institute (2004).

3.1 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 important to understand that the natural water cycle components including precipitation, evapotranspiration (ET), infiltration, stream baseflow, and stormwater runoff must be supplemented with an understanding of the many artificial interventions related to urban water, wastewater, and stormwater systems.

For the purposes of this analysis, the water resources system is defined as flow in Wissahickon Creek itself, the surface drainage area contributing flow to the creek, groundwater shallow enough to communicate with the creek, and manmade piping systems within the topographic watershed boundary. 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.

<u>Inflows</u>: *P + OPW + WW/IND Rech + EDR + WW Disch*

<u>Outflows</u>: *RO + SWW + GWW + EDW + BF + OWD + ET*

where:

P is the average precipitation recorded at the Philadelphia gages;

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 plants; 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.

3.1.1 PRECIPITATION

P + OPW + WW/IND Rech + EDR + WW Disch = RO + SWW+ GWW + EDW + BF + OWD + ET

Precipitation data can be obtained from PWD's network of 24 rain gages throughout the City. These data are available in 15-minute increments from the early 1990s to the present. Four of the City gages are located in or near the Wissahickon Creek Watershed, as shown in Figure 3-1. Data from these gages provide precipitation at a high level of spatial and temporal detail within the City of Philadelphia. Monthly and yearly summaries of rain gage data are located in Tables 3-1 and 3-2, respectively. A summary of the yearly rain data to determine the Water Evaluation and Planning (WEAP) system and water budget, completed by the Tellus Institute (2004), is presented in Table 3-3.

Table 3-1 Monthly Summary of Philadelphia Rain Gage Data (1990 – 2005)

Month	Rain Gage				Average
	6	18	19	21	
	(in)	(in)	(in)	(in)	(in)
January	3.4	2.9	3.1	3.3	3.2
February	2.5	2.1	2.1	2.5	2.3
March	4.5	4.1	4.4	4.7	4.4
April	3.4	3.0	3.2	3.4	3.3
May	3.7	3.6	3.7	3.7	3.7
June	3.6	3.5	3.6	4.0	3.7
July	4.7	4.1	4.4	4.7	4.4
August	4.1	3.7	3.8	3.9	3.9
September	4.8	4.3	4.6	5.2	4.7
October	3.5	3.0	3.4	3.6	3.4
November	2.9	2.8	3.0	3.2	3.0
December	4.1	3.7	3.9	4.1	4.0

Table 3-2 Yearly Summary of Philadelphia Rain Gage Data (1990 – 2005)

Year	Rain Gage				Average
	6	18	19	21	
	(in)	(in)	(in)	(in)	(in)
1990	45.4	43.4	43.0	43.4	43.8
1991	44.4	42.9	39.9	45.4	43.2
1992	40.8	42.5	41.2	48.9	43.3
1993	51.2	46.0	51.5	55.8	51.2
1994	46.0	39.0	45.5	46.2	44.2
1995	33.9	32.8	35.5	37.3	34.9
1996	54.8	52.9	56.1	54.2	54.5
1997	41.5	35.4	37.9	39.0	38.5
1998	37.4	32.9	37.0	39.3	36.6
1999	52.4	41.7	46.0	51.1	47.8
2000	45.7	40.0	42.3	44.0	43.0
2001	31.9	29.3	31.2	34.7	31.8
2002	40.3	37.9	39.3	41.9	39.8
2003	50.2	45.0	48.0	48.7	48.0
2004	56.1	48.8	50.0	59.1	53.5
2005	45.1	39.8	44.2	47.7	44.2
Mean	44.8	40.7	43.0	46.0	43.6
Max	56.1	52.9	56.1	59.1	56.1
Min	31.9	29.3	31.2	34.7	31.8
N	16.0	16.0	16.0	16.0	16.0
Std. Dev.	7.0	6.2	6.4	6.9	6.6

Table 3-3 WEAP Water Budget Precipitation Summary (Tellus Institute, 2004)

Month	Year	Precipitation (in)
January	2000	3.03
February	2000	2.36
March	2000	6.08
April	2000	3.29
May	2000	4.32
June	2000	4.78
July	2000	3.46
August	2000	3.66
September	2000	6.07
October	2000	1.25
November	2000	2.58
December	1999	2.97
Total		43.9

Average temperatures during the winter months are above the freezing point during the day and below the freezing point at night (Table 3-4). Snow and snowmelt events occur, but it is rare for a snow pack to accumulate and last through the season.

Table 3-4 Average Monthly Temperature and Potential Evaporation

Month	Average Temperature High (°F)	Average Temperature Low (°F)	Potential Evaporation (in/month)
January	39.2	24.4	2.1*
February	42.1	26.1	2.1*
March	50.9	33.1	2.1
April	63.0	42.6	4.5
May	73.2	52.9	5.4
June	81.9	61.7	6.3
July	86.4	67.5	6.6
August	84.6	66.2	5.7
September	77.4	58.6	4.2
October	66.6	46.9	2.7
November	55.0	37.6	2.1
December	43.5	28.6	2.1*

** estimated*

Additional precipitation data is available in portions of the watershed outside the City of Philadelphia. This information was not collected for the current study.

Precipitation data used for the EPA mandated Wissahickon Total Maximum Daily Load (TMDL) for Siltation, was obtained from a National Climatic Data Center (NCDC) weather station located 15 miles northwest of the watershed (Table 3-5). The period of record encompassed April 1, 1993 through March 31, 2001. Daily average temperature data from this station was also used for input into the Siltation TMDL model (EPA, 2003).

Table 3-5 TMDL Precipitation Summary

Year	Rainfall (in)
4/93-12/93	43.2
1994	49.3
1995	45.8
1996	59.2
1997	38.4
1998	44.1
1999	47.1
2000	45.5
1/01-3/01	10.6
Mean	47.9
Max	59.2
Min	38.4
N	8
Std. Dev.	6.3

Figure 3-1 City Rain Gages In and Around Wissahickon Creek Watershed

3.1.2 OUTSIDE POTABLE WATER

P + OPW + WW/IND Rech + EDR + WW Disch = RO + SWW+ GWW + EDW + BF + OWD + ET

Raw water is drawn from Schuylkill and Delaware Rivers into the drinking water distribution system for the Philadelphia portion of Wissahickon Creek Watershed. Schuylkill River water is withdrawn approximately ½ miles south of the Wissahickon Creek's confluence with the Schuylkill River at the Queen Lane Water Treatment Plant (WTP). The Queen Lane WTP services Northwestern Philadelphia, areas bounded by the Schuylkill River on the west, Broad Street on the east and Market Street to the South. The intake also services areas south of Market Street, east of the Schuylkill River and north and west of the Delaware River is supplemented by drinking water provided by the Baxter Water Treatment Plant, which draws water from the Delaware River. For the outside communities, water is supplied by the Ambler Spring Water Company, Aqua America (formerly Philadelphia Suburban), The North Wales Water Authority and the North Penn Water Authority.

The Ambler Spring Water Company operates nine deep wells, with a territory that comprises approximately 6.5 square miles, including Ambler and North Wales Boroughs and portions of Lower Gwynedd, Upper Dublin, Whitemarsh and Whitpain Townships. There are approximately 5700 water customers in the Ambler Borough service area. The North Penn Water Authority and the North Wales Water Authority withdraw water from the Delaware River in Bucks County and transport it to Montgomery County. The North Penn Water Authority serves both Worcester Township and Lansdale Borough in the Wissahickon Creek Watershed. Only a small portion of Worcester Township exists within Wissahickon Creek Watershed limits. The North Wales Water Authority serves North Wales Borough along with portions of Montgomery, Upper Gwynedd, Lower Gwynedd, Whitpain and Upper Dublin Townships. Determining to what extent the over 300,000 Montgomery County Aqua America customers are reliant upon water withdrawn from sources within as opposed to outside Montgomery County was beyond the scope of the current study.

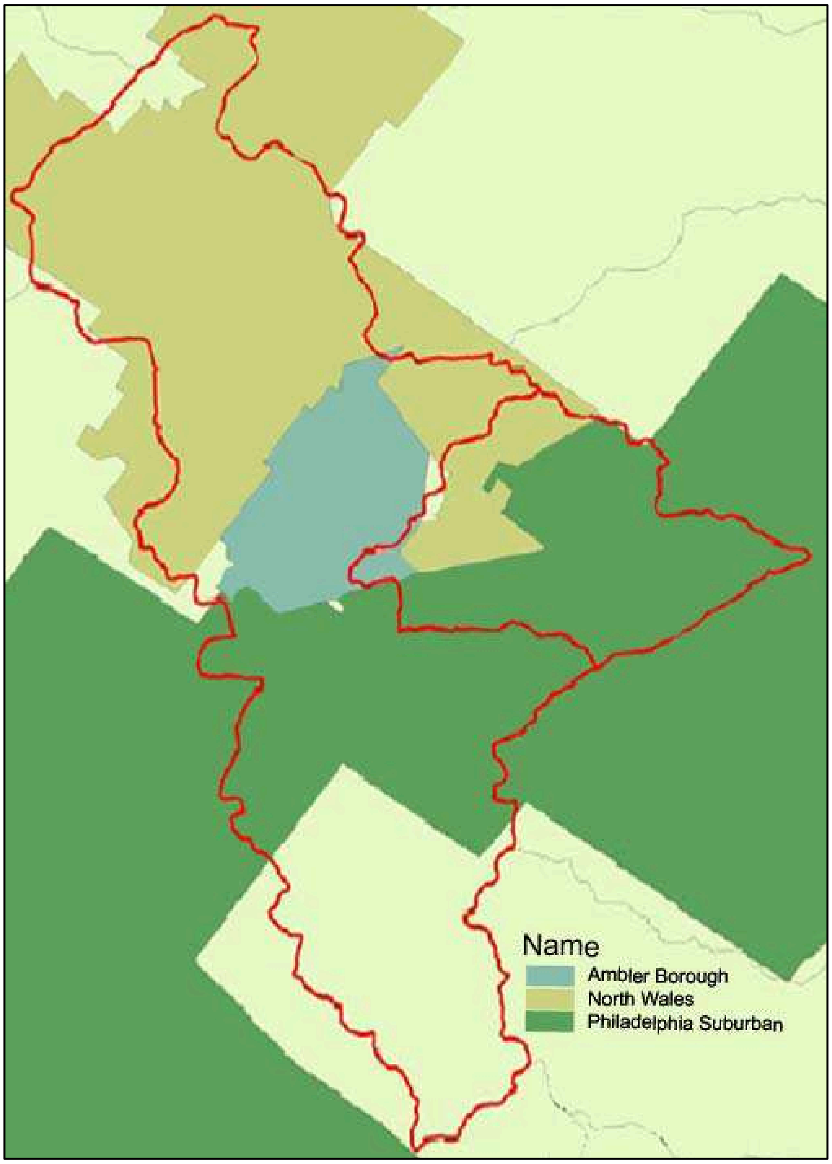


Figure 3-2 Potable Water Service Areas (Philadelphia Suburban is Currently Aqua America)
Source: Tellus Institute, 2004

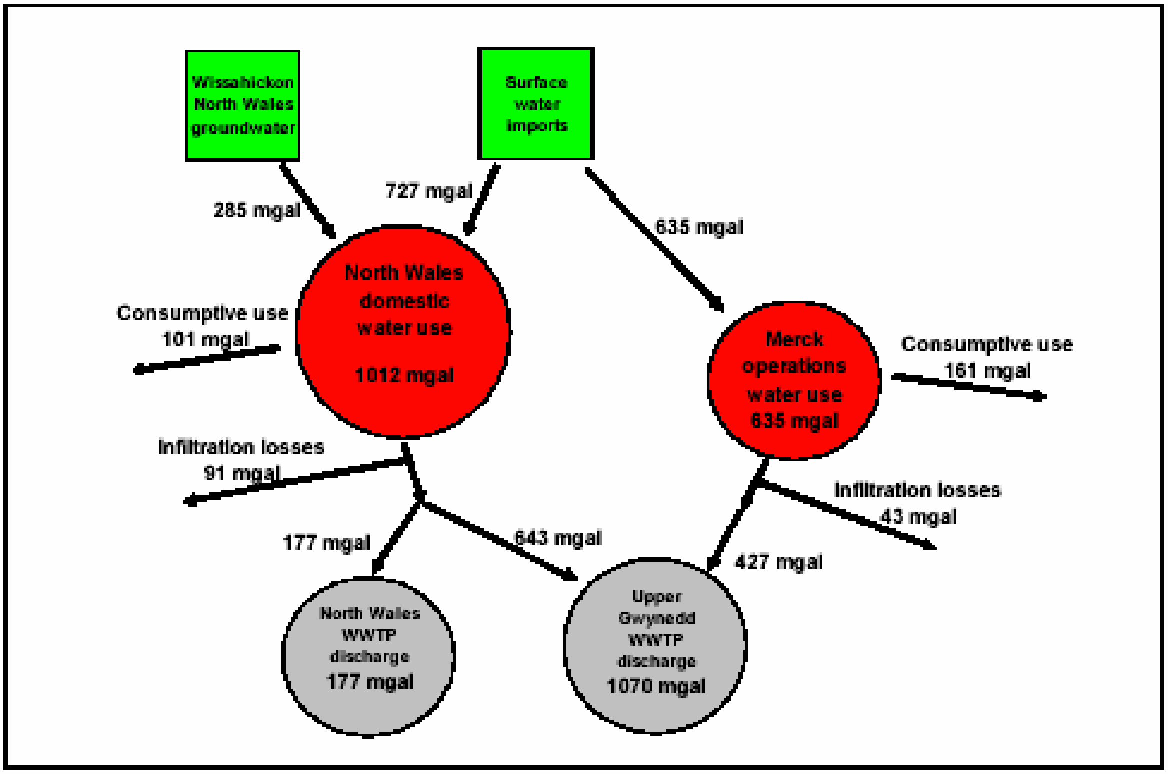


Figure 3-3 Flow Diagram for North Wales Service Area
Source: Tellus Institute, 2004

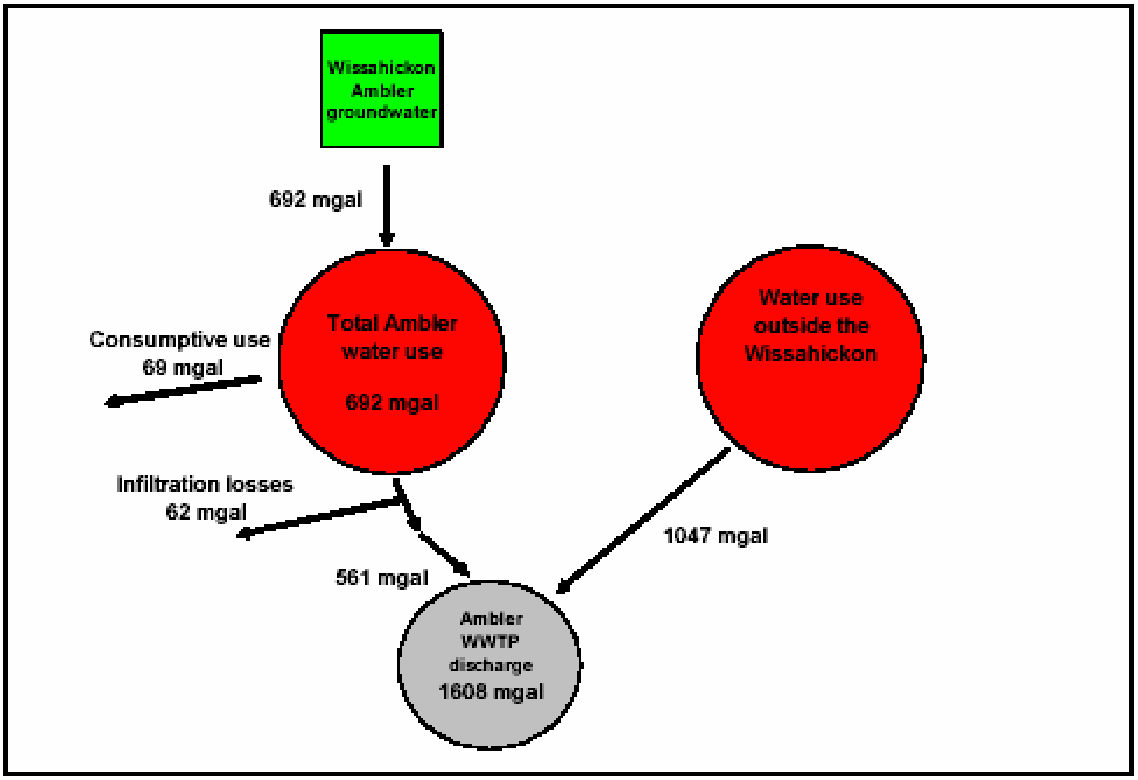


Figure 3-4 Flow Diagram for Ambler Service Area
Source: Tellus Institute, 2004

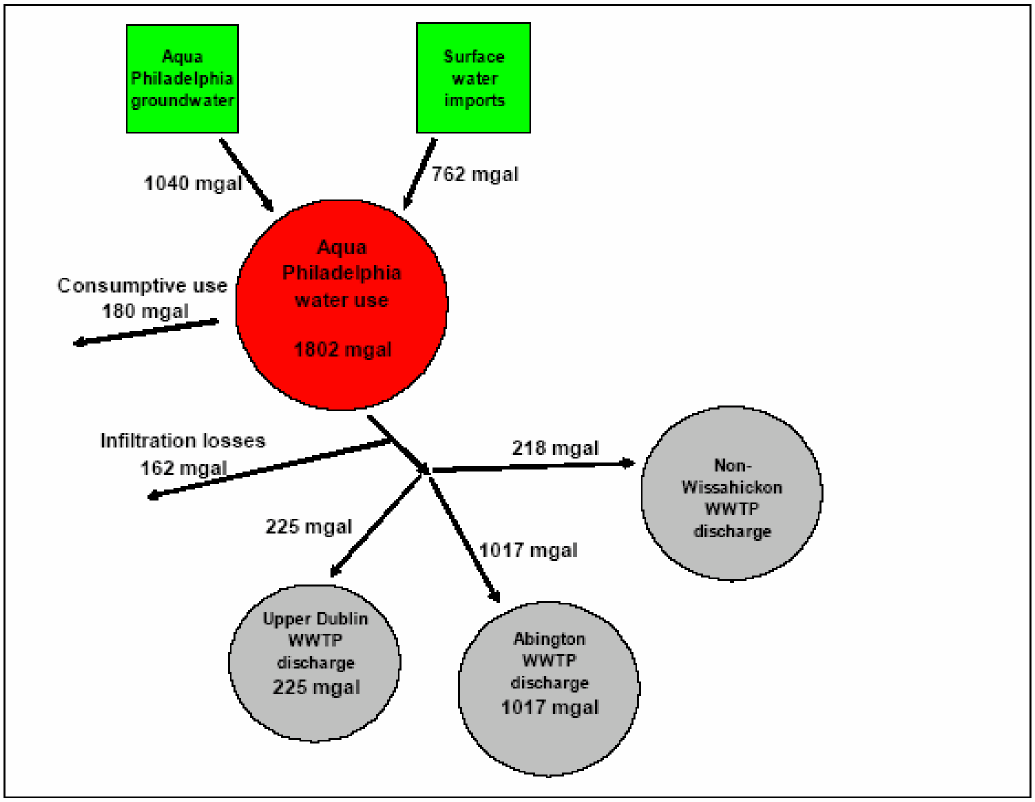


Figure 3-5 Flow Diagram for Water in the Aqua Philadelphia (currently Aqua America) Service Area
Source: Tellus Institute, 2004

3.1.3 WASTEWATER AND INDUSTRIAL RECHARGE TO GROUNDWATER

P + OPW + WW/IND Rech + EDR + WW Disch = RO + SWW+ GWW + EDW + BF + OWD + ET

The Tellus Institute (2004) assumed that 10% of wastewater might be lost to groundwater before reaching a treatment plant. Using this assumption, they obtained a watershed-wide estimate of 362 MG per year, or 0.325 inches per year over the entire watershed.

3.1.4 ESTIMATED DOMESTIC RECHARGE

P + OPW + WW/IND Rech + EDR + WW Disch = RO + SWW+ GWW + EDW + BF + OWD + ET

The total number of households in unsewered areas within the City of Philadelphia was determined from the 2000 U.S. Census and an average of 2.5 people was assumed to each household (an assumption typically used in wastewater planning). Based on this information and an estimate of 50 gallons of sewage per person per day discharged to septic systems, this component represents a potential 43,125 gallons of recharge per day in the Wissahickon Creek Watershed. These flows may also be expressed as approximately 0.09 inches per year over the Philadelphia portion of the Wissahickon Creek Watershed.

Septic tank inputs to groundwater were not assessed outside the City of Philadelphia.

3.1.5 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 five major municipal wastewater treatment plants discharging to Wissahickon Creek (Figure 3-6). These discharges were estimated from Discharge Monitoring Reports (DMRs) by EPA (2004b) through May 2001 and by PWD between June 2001 and 2005 (Table 3-6).

Two operations, Coorson's Quarry dewatering operations, and Merck remediation activities, transfer groundwater directly to the stream. These operations are discussed in more detail in the groundwater withdrawals (GWW) section.

Table 3-6 Permitted and Actual Flows Reported in DMRs (MGD)

Parameters	Units	Service Area/ Water User	Period of Record	Limit	Min	Mean	Max	Standard Deviation
Discharge	MGD	North Wales	1/98-4/01	0.835	0.217	0.482	0.917	NR
Discharge	MGD	North Wales	1/03-5/05	0.835	0.19	0.603	2.98	0.374
Discharge	MGD	Upper Gwynedd	9/90-5/02	4.5	1.67	2.6	4.7	NR
Discharge	MGD	Upper Gwynedd	6/02-8/03	4.5	1.74	3.22	8.97	1.13
Discharge	MGD	Ambler	1/89-5/01	6.5	2.75	4.21	8.1	NR
Discharge	MGD	Abington	1/89-5/01	3.91	1.97	3.18	5.49	NR
Discharge	MGD	Abington	1/03-8/05	3.91	0.142	3.37	7.32	0.752
Discharge	MGD	Upper Dublin	1/98-5/01	1	0.498	0.644	0.945	NR
Discharge	MGD	Upper Dublin	1/03-5/05	1	0.72	0.918	1.23	0.152

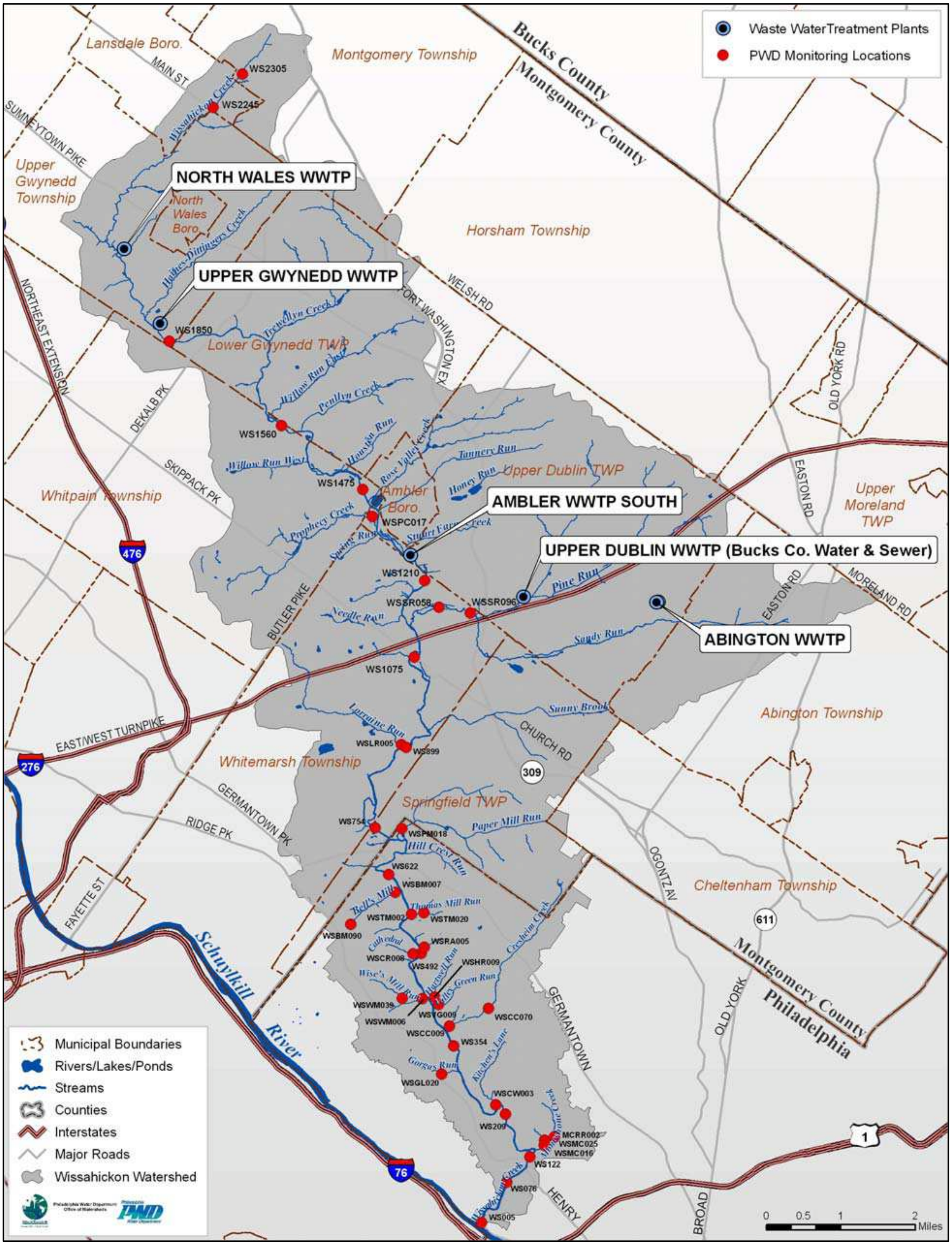


Figure 3-6 Major Municipal Wastewater Treatment Plants Discharging to Wissahickon Creek

Discharges chosen to represent the five facilities in subsequent calculations are identified in Table 3-7. For Ambler, Abington, and North Wales, a mean discharge was determined for the period of record studied. For Upper Gwynedd and Upper Dublin, mean discharge for the 2003-2005 period was chosen. Permitted and actual discharges for these plants have increased relative to the 1998-2001 period.

Table 3-7 Representative Wastewater Treatment Plant Discharge (MGD)

Service Area/ Water User	North Wales	Upper Gwynedd	Ambler	Abington	Upper Dublin
Mean Discharge	0.533	3.220	4.210	3.216	0.918

3.1.6 RUNOFF

P + OPW + WW/IND Rech + EDR + WW Disch = RO + SWW+ GWW + EDW + BF + OWD + ET

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 (Sloto, 1996). This baseflow separation technique uses an empirically defined relationship between drainage area and duration of surface runoff to aid in determining ground water baseflow. The following excerpt explains this method:

> "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 gages in this analysis were listed in Table 3-5.
>
> "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."

3.1.6.1 SUMMARY STATISTICS

During the USGS/PWD cooperative program in the 1970s, the USGS established streamflow gaging stations at four locations in Wissahickon Creek Watershed. These locations are presented in Figure 3-1. Table 3-8 contains summary information at each of the gaging stations for their respective periods of record. An historical rating curve is shown in Figure 3-8.

Table 3-8 USGS Gages and Periods of Record and Data Used for Baseflow Separation

Gage	Name	Period of Record	Period of Record (yrs)	Drainage Area (sq. mi.)	N (days)	2N* (days)
01473900	Wissahickon Creek at Fort Washington	9/1/1961 to 9/1968, 6/2000 to Present	13	40.8	2.10	5
01473950	Wissahickon Creek at Bells Mill Rd, Phila., PA	10/1/1965 to 9/30/1981	16	53.6	2.22	5
01473980	Wissahickon Creek at Livezey Lane, Phila., PA	10/1/1965 to 11/3/1970	5	59.2	2.26	5
01474000	Wissahickon Creek at Philadelphia	10/1/1965 to Present	40	64	2.30	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.

The results of the hydrograph decomposition exercise are summarized in Tables 3-9 and 3-10.

Table 3-9 Runoff Statistics For Wissahickon Gages Compared to Other Area Streams.

	Runoff (in/yr)			
	Mean	Max	Min	St. Dev.
Fort Washington 01473900	9.5	21.5	3.4	5.4
Bells Mill Rd 01473950	9.7	17.5	4.9	3.9
Livezey Lane 01473980	6.9	8.7	6.0	1.2
Mouth at Philadelphia 01474000	10.4	22.3	5.1	3.9
French Creek 01475127	7.4	15.4	2.9	3.1
Cobbs Creek 01475550	10.7	15.6	5.2	2.7
Darby Creek D/S 01475510	8.9	15.6	3.6	2.9
Frankford Creek 01467087	11.4	20.3	6.2	3.5

Table 3-10 Runoff as a Percentage of Annual Total Flow for Wissahickon Gages Compared to Other Area Streams.

	Runoff (% of Annual Total Flow)			
	Mean	Max	Min	St.Dev.
Fort Washington 01473900	68%	78%	62%	6%
Bells Mill Rd 01473950	64%	78%	50%	8%
Livezey Lane 01473980	68%	77%	60%	9%
Mouth at Philadelphia 01474000	61%	76%	51%	6%
French Creek 01475127	36%	47%	25%	5%
Cobbs Creek 01475550	58%	84%	46%	10%
Darby Creek D/S 01475510	38%	46%	25%	6%
Frankford Creek 01467087	62%	74%	51%	6%

The results of the hydrograph decomposition exercise suggest differences in degree of urbanization for watersheds in southeastern Pennsylvania. For convenience, the flows in Table 3-9 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 3-9 shows streamflow statistics for French Creek as representative of a minimally impaired stream. On a unit-area basis, runoff in Wissahickon Creek Watershed is slightly greater than in the Darby watershed, a suburban watershed, but less than runoff in the Cobbs and Frankford systems, two highly urbanized streams in the Philadelphia area.

Expressing runoff as a percent of total measured flow produces a potentially misleading result. Results from regional streams are on the order of 30-40% for undeveloped and suburban watersheds (e.g., French and Darby Creeks) and on the order of 60% for urban streams (Table 3-10). Results in Wissahickon Creek Watershed range from 64% to 68%, indicative of a highly urbanized stream. However, this percentage is misleading due to the fact that a considerable portion of Wissahickon Creek flow is lost to groundwater just north of the county border. This loss does not increase the absolute quantity of runoff but does increase runoff expressed as a percent of total flow. This situation is discussed in more detail in section 3.1.8, Groundwater Withdrawals.

The estimated stormwater runoff discharges by outfall within the City of Philadelphia were estimated using a calibrated hydrologic model (CDM, 2006). This model is a lumped-parameter numerical simulation using algorithms in the USEPA Storm Water Management Model (SWMM). Results are presented in Table 3-11. A summary of runoff from parkland and outfalls is presented in Table 3-12.

Table 3-11 Philadelphia Stormwater Outfall Runoff

Outfall	Drainage Area (acres)	Runoff (in./yr)	
		1/90-12/05	4/93-3/01
W-083-01	62.75	8.0	7.7
W-083-02	106.06	9.5	9.3
W-083-03	4.94	10.6	10.4
W-083-04	12.21	12.1	11.9
W-076-01	90.28	6.2	6.0
W-076-02	38.27	6.4	6.1
W-076-08	5.94	12.6	12.4
W-076-11	10.59	7.6	7.3
W-076-12	47.51	10.2	10.0
W-077-01	46.18	9.2	8.9
W-077-02	239.02	10.3	10.0
W-086-01	270.33	15.0	14.8
W-086-02	76.68	12.9	12.6
W-086-03	35.27	13.4	13.2
W-086-04	31.62	19.0	18.8
W-086-05	47.73	11.9	11.7
W-086-06	85.34	11.8	11.6
W-086-07	23.64	17.4	17.2
W-067-01	392.26	12.4	12.2
W-067-02	41.29	15.1	14.9
W-067-03	29.52	13.6	13.3
W-076-07	47.99	9.5	9.3
W-076-14	67.56	10.6	10.4
W-095-01	99.75	11.5	11.3
W-095-03	51.27	12.5	12.4
W-068-01	15.98	12.4	12.2
W-068-02	10.68	15.8	15.7
W-068-03	4.07	13.2	13.0
W-068-06	23.25	10.6	10.3
W-068-08E	25.91	9.7	9.4
W-068-08W	33.78	10.1	9.8
W-060-04	12.66	4.9	4.8
W-060-08	16.30	6.3	6.4
W-060-09	17.02	4.7	4.7
W-060-10	163.18	6.3	6.3
W-060-11	39.24	4.4	4.3
W-068-04	627.70	5.3	5.3
W-068-05	76.35	5.8	5.7
W-095-02	6.07	9.3	9.1
W-095-04	6.82	15.6	15.4
W-095-05	20.67	15.0	14.8
W-076-09	62.76	10.2	10.0
W-076-10	46.03	11.0	10.7
W-075-01	154.31	14.7	14.5
W-075-02	9.88	8.4	8.2
W-076-04	9.02	8.6	8.4

Outfall	Drainage Area (acres)	Runoff (in./yr) 1/90-12/05	Runoff (in./yr) 4/93-3/01
W-076-05	3.82	10.6	10.4
W-076-06	9.62	11.7	11.5
W-076-13	91.98	13.4	13.2
W-076-X	9.47	1.9	1.7
W-052-01	12.40	11.5	11.3
W-052-02	15.49	13.1	12.8
W-060-01	111.14	12.8	12.5
W-060-02	25.49	14.2	14.0
W-060-03	63.18	14.1	13.8
W-060-05	96.75	8.7	8.4
W-060-06	2.58	16.8	16.7
W-060-07	22.02	12.7	12.4
W-067-04	23.84	14.0	13.9
W-067-05	10.05	14.2	14.1
W-067-06	41.54	11.0	10.8
W-068-07	24.87	9.6	9.4
W-076-03	9.21	11.8	11.7
W-085-01	83.94	12.5	12.3
W-085-02	57.43	11.6	11.4

Table 3-12 Philadelphia Runoff

Philadelphia	Runoff (in./yr) 1/90-12/05	Runoff (in./yr) 4/93-3/01
Outfalls	10.2	10.4
Natural Drainage	5.9	6.2

Figure 3-7 provides some idea of trends in unit-area runoff from year to year. Although there is considerable variability between years, flows at the four gages follow the same patterns. The most recent data suggest that the downstream gage, 01474000, records a higher amount of runoff per area when compared with the upstream gage.

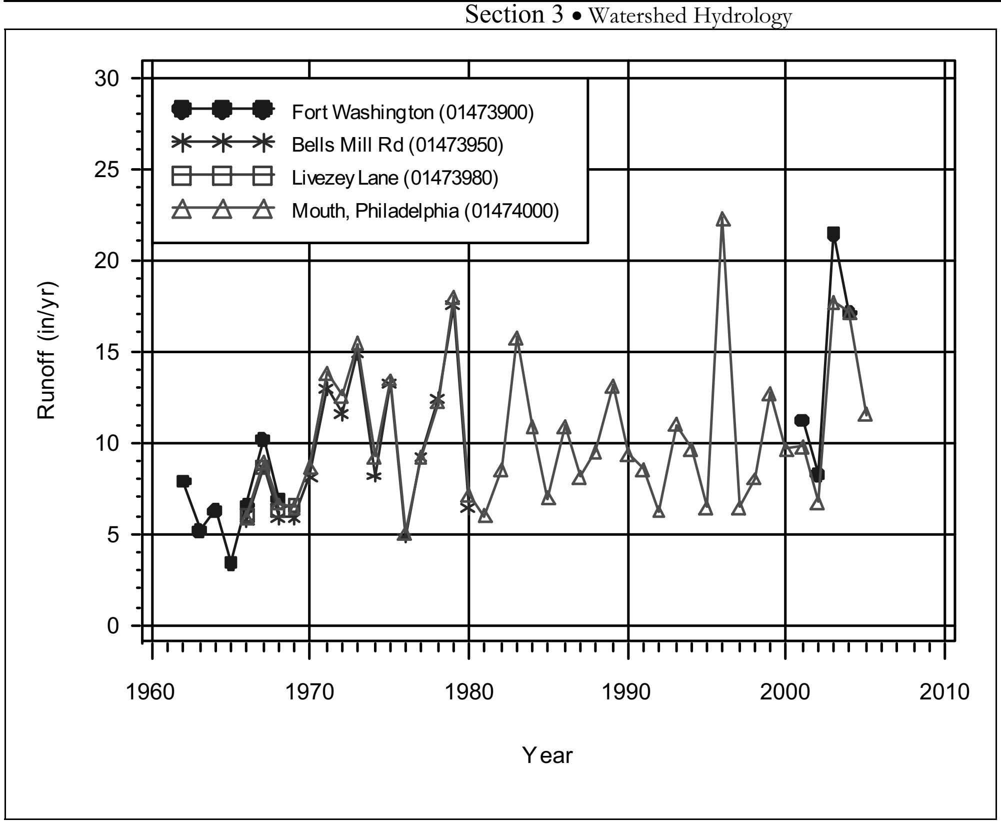


Figure 3-7 Runoff Trends at Four USGS Stations

Table 3-13 Summary of Runoff by County

	Montgomery County Portion	Wissahickon Mouth
Drainage Area (sq.mi.)	50.3	63.3
Runoff (in/yr)	10.1	10.4

3.1.7 SURFACE WATER WITHDRAWALS

P + OPW + WW/IND Rech + EDR + WW Disch = RO + SWW+ GWW + EDW + BF + OWD + ET

Withdrawals of surface water from Wissahickon Creek are believed to be negligible. However, about 13-30%, or an average of about 24%, of water discharged by Wissahickon Creek is drawn into Philadelphia's Queen Lane Water Treatment Plant intake, on the Schuylkill River approximately 1200 ft downstream of the confluence with Wissahickon Creek (PWD, 1998).

3.1.8 GROUNDWATER WITHDRAWALS

P + OPW + WW/IND Rech + EDR + WW Disch = RO + SWW+ GWW + EDW + BF + OWD + ET

The Delaware River Basin Commission (DRBC) regulates large water withdrawals in Montgomery County. Any proposed surface or groundwater withdrawal in the basin exceeding 100,000 GPD (gallons per day) is subject to review by the DRBC Board. In 1980, the DRBC responded to concerns about potential overuse of groundwater in and around Montgomery County and established the Southeastern Pennsylvania Groundwater Protected Area (GWPA). Since then all proposed groundwater withdrawals that exceed 10,000 GPD are subject to review as well. In 1998, the regulations were amended to include maximum withdrawal limits for each sub-basin within the GWPA, as well as provisions for mitigation programs when a new proposed withdrawal forces the total for the sub-basin to exceed 75 percent of the maximum. Subbasins that exceed 75 percent of the maximum withdrawal limit are classified as "potentially stressed." The Wissahickon Creek has been identified as potentially stressed.

Tellus Institute (2004) provided an estimate of groundwater withdrawals for industrial or domestic use in 2000 (Table 3-14). These estimates do not include groundwater transferred directly to surface water by the Coorson's Quarry and Merck operations, as discussed below.

Table 3-14 Groundwater Withdrawals (Tellus Institute, 2004).

Service Area	Water Use	Self-supplied groundwater (MGD)
Ambler Borough	Domestic	1.232
	Industrial Process	0.049
	Other	0.613
North Wales	Domestic	1.077

Coorson's Quarry EPA (2003c) estimated Coorson's Quarry average discharge at 12.5 cfs. The Tellus Institute (2004) estimated average discharge in 2000 as 14.0 cfs. This flow is discharged to Lorraine Run.

A PWD analysis indicates that baseflow in Lorraine Run was only 8 cfs during a PWD monitoring period of 2/12/04 to 7/10/05. This suggests that actual discharge from the quarry may be lower at present than assumed in the EPA and Tellus analyses. Another possible explanation is a partial loss of flow to groundwater in Lorraine Run.

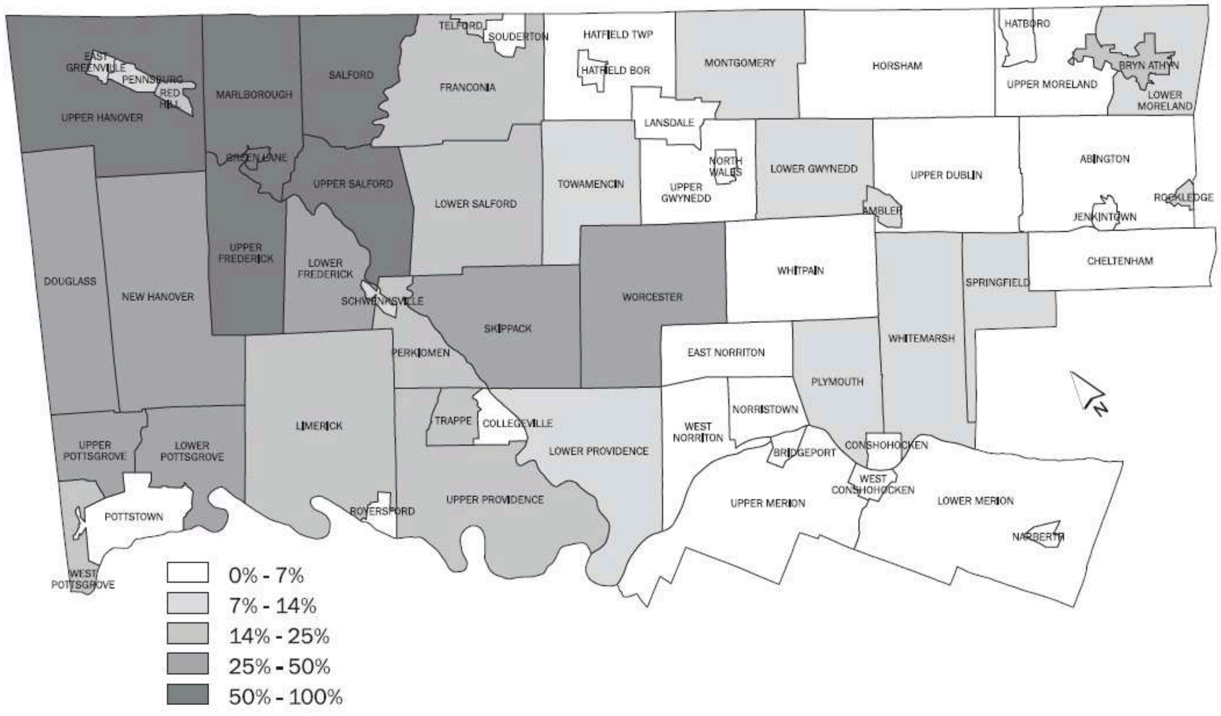
EPA (2003c) found a similar discrepancy between the reported quarry discharge into Lorraine Run and measured flows in Wissahickon Creek during drought conditions. "...background flows (streamflow without discharge contributions) for Wissahickon Creek were estimated for 7Q10 flow conditions by subtracting average discharge flows recorded during the critical summer period of 2002 (combined flow of 14.9 cfs) from the 7Q10 at the mouth (16.3 cfs). A preliminary estimate of the background flow is thus 1.4 cfs in Wissahickon Creek. After discharges were removed from consideration for 7Q10 flows, the remaining 1.4 cfs flow did not account for flows from Coorson's Quarry (historical average of 12.5 cfs). Under drought conditions, much of Wissahickon Creek flow is therefore considered lost to groundwater before reaching the mouth."

A portion of the quarry discharge may represent an inter-basin transfer, indicating that the aquifer pumped may be outside the area that would naturally contribute baseflow to Wissahickon Creek. The relative size of this component was not quantified.

3.1.9 ESTIMATED DOMESTIC WITHDRAWALS

P + OPW + WW/IND Rech + EDR + WW Disch = RO + SWW+ GWW + EDW + BF + OWD + ET

According to the 2005 Montgomery County Water Resources Plan, roughly 98,000 Montgomery County residents receive their water from private wells. The most concentrated population of private well users is in the western and central portion of the county. Based on the information provided in Figure 3-8, the municipalities of the Wissahickon Creek Watershed have between 0% and 14% of their population served by private wells.



Source: U.S. Census 2000 data, Pennsylvania DEP Annual Water Supply Reports.

Figure 3-8 Estimated Montgomery County Domestic Groundwater Withdrawals

3.1.10 BASEFLOW

P + OPW + WW/IND Rech + EDR + WW Disch = RO + SWW+ GWW + EDW + BF + OWD + ET

The recharge and discharge areas of shallow groundwater systems generally correspond to the surface watershed area. This implies that infiltration entering the groundwater aquifer eventually flows to the surface to be discharged as stream baseflow. Given that infiltration is difficult to measure, infiltration was determined at stream gages through baseflow separation techniques on streamflow. The infiltration component is then directly balanced by the baseflow component if baseflow is assumed to equal infiltration. In the tables below, estimated point source discharges are subtracted from baseflow to give an estimate of dry weather flow due to the groundwater component alone.

Unit-area baseflow is greater at the downstream gage than at the upstream gages, but it is less than baseflow in French or Darby Creeks (Table 3-15). The Darby and Wissahickon Creek Watersheds have a similar suburban character. Expressing baseflow as a percentage of total flow, the same pattern is evident (Table 3-16). It is interesting to note that although Wissahickon Creek Watershed is less impervious than Cobbs or Frankford Creek Watersheds, it has less mean baseflow on both an area-weighted and percentage basis. A possible explanation for this phenomenon can be attributed to the "losing stream" trend, discussed below.

Table 3-15 Baseflow Statistics

	Baseflow (in/yr)			
	Mean	Max	Min	St.Dev.
Fort Washington 01473900	4.7	11.1	1.4	3.1
Bells Mill Rd 01473950	5.8	10.4	1.7	2.8
Livezey Lane 01473980	3.5	5.9	1.9	1.9
Mouth at Philadelphia 01474000	6.9	12.9	2.2	2.7
French Creek 01475127	12.9	20.8	5.8	3.8
Cobbs Creek 01475550	8.1	16.1	1.8	3.6
Darby Creek D/S 01475510	14.5	21.4	7.6	4.0
Frankford Creek 01467087	7.1	13	4.5	2.2

Table 3-16 Baseflow Statistics as a Percentage of Total Flow

	Baseflow (% of Annual Total Flow)			
	Mean	Max	Min	St.Dev.
Fort Washington 01473900	32%	38%	22%	6%
Bells Mill Rd 01473950	36%	50%	22%	8%
Livezey Lane 01473980	32%	40%	23%	9%
Mouth at Philadelphia 01474000	39%	49%	24%	6%
French Creek 01475127	64%	75%	53%	5%
Cobbs Creek 01475550	42%	54%	16%	10%
Darby Creek D/S 01475510	62%	75%	54%	6%
Frankford Creek 01467087	38%	49%	26%	6%

Although there was considerable interannual variation and periods of record did not completely overlap, baseflows measured at the four gages generally followed the same patterns (Figure 3-9).

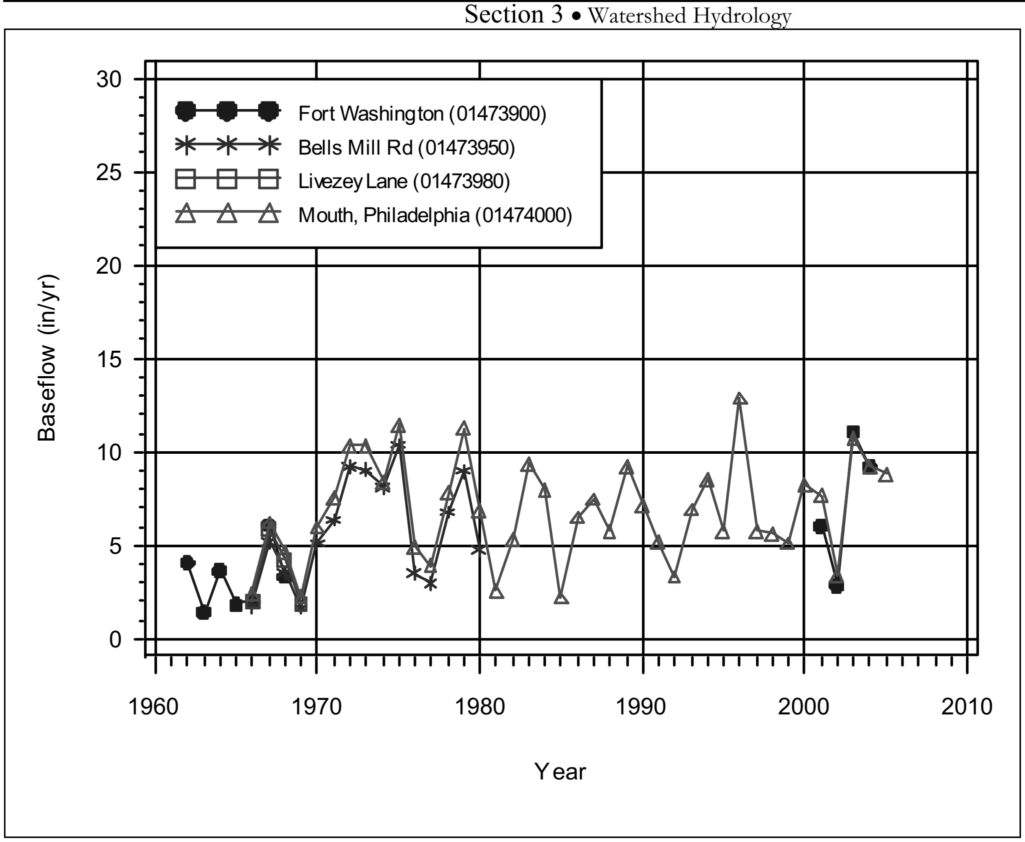


Figure 3-9 Baseflow Trends with Point Sources Removed

EPA (2003c) concluded that Wissahickon Creek is a "losing stream" under low flow conditions, meaning that streamflow is lost to groundwater.

The Regional Science Research Institute (1973) also concluded that a portion of Wissahickon Creek may lose surface water to groundwater:

> "A rather unusual situation prevails for Wissahickon Creek, in that peak discharges tend to decrease in a downstream direction from Fort Washington to Bell's Mill – even though drainage area increases by 30%....Of 22 floods which occurred during 1966-70, peak discharge was lower at Bell's Mill than at Fort Washington for all but three. This pattern does not strictly hold for the rare floods, having recurrence intervals of 5 years or more; but even then the downstream increase in discharge is considerably less than would normally be expected.
>
> "The primary explanation for this situation appears to be the fact that, between Fort Washington and Bells Mill, Wissahickon Creek crosses a zone which is underlain by limestone. This limestone belt...roughly separates the two portions of the watershed which are associated with the piedmont lowland and piedmont upland physiographic sections. Limestone is noted for forming subterranean channels which can provide storage for surface waters. Such channels may even form drainage paths leading out of the basin entirely.
>
> "It is significant that total direct runoff associated with major storms increases by only about 10% from Fort Washington to Bell's Mill; the expected increase would be approximately the same as the percent increment in drainage area (30%). Annual

> runoff, pertaining to non-storm as well as storm periods, also increases by less than would normally be expected...."

Table 3-17 is adapted from this report.

Table 3-17 Annual Runoff at Three USGS Stations 1935-1970 (Regional Science Research Institute, 1973)

USGS Station	Drainage Area (sq.mi.)	Annual Average Discharge (1935-1970) (cfs)	(cfs/sq.mi.)	(in)
Fort Washington	40.8	54.7	1.34	18.2
Bells Mill	53.6	68.3	1.27	17.3
Watershed Mouth	64.0	83.8	1.31	17.8

3.1.11 OUTSIDE WASTEWATER DISCHARGES

P + OPW + WW/IND Rech + EDR + WW Disch = RO + SWW+ GWW + EDW + BF + OWD + ET

Wastewater in the City of Philadelphia is exported to PWD's Southwest Water Pollution Control Plant. The Tellus Institute (2004) estimated these flows at approximately 218 MG in 2000, or 0.196 inches per year over the entire watershed.

3.1.12 EVAPOTRANSPIRATION

P + OPW + WW/IND Rech + EDR + WW Disch = RO + SWW+ GWW + EDW + BF + OWD + ET

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. A site in New Castle County, Delaware has recorded daily evaporation data from 1956 through 1994. Average daily evaporation rates from this site were developed and are listed in Table 3-4 (City of Philadelphia Combined Sewer Overflow Program: System Hydraulic Characterization).

The Tellus Institute estimated evapotranspiration equal to 22.7 billion gallons in 2000, representing 46% of precipitation in Wissahickon Creek Watershed. In a water budget analysis for the nearby, but less developed, French Creek basin, Sloto estimated evapotranspiration to be 57% of precipitation. The estimate was determined by taking the difference between the precipitation, streamflow, and groundwater storage terms calculated in that study (Tellus Institute, 2004; Sloto, 2004).

3.2 WISSAHICKON CREEK WATER CYCLE SUMMARY

This section summarizes key components of watershed hydrology used as a basis for pollutant load estimates and as a baseline for evaluation of stormwater management practices. Estimations of runoff, baseflow and other water cycle components are similar to a study of the water budget for Wissahickon Creek Watershed (Sloto, 2005).

Table 3-18 Average Annual Streamflow Components

Components of Streamflow	Montgomery County Portion	Wissahickon Mouth
Drainage Area (sq. mi.)	53.5	64.0
Runoff (in/yr)	10.1	10.4
Baseflow (Groundwater) (in/yr)	6.1	6.9
Municipal Wastewater Effluent (in/yr)	4.8	4.0
Coorson's Quarry (in/yr)	2.0	1.7

Table 3-19 Average Annual Discharge from Municipal and Industrial Sources (expressed over watershed drainage area)

Discharger	Average Discharge (in/yr)
North Wales	0.2
Upper Gwynedd	1.1
Ambler	1.4
Abington	1.1
Upper Dublin	0.3
Coorson's Quarry	1.7

3.2.1 ADDITIONAL ANALYSIS OF TOTAL FLOW

Figure 3-10 provides some idea of trends in unit-area total flow from year to year. Although there is considerable variability between years, flows at the four gages follow the same patterns. The long term trend at the longest continuously operating gage, 01474000, shows that total flow per area has been increasing.

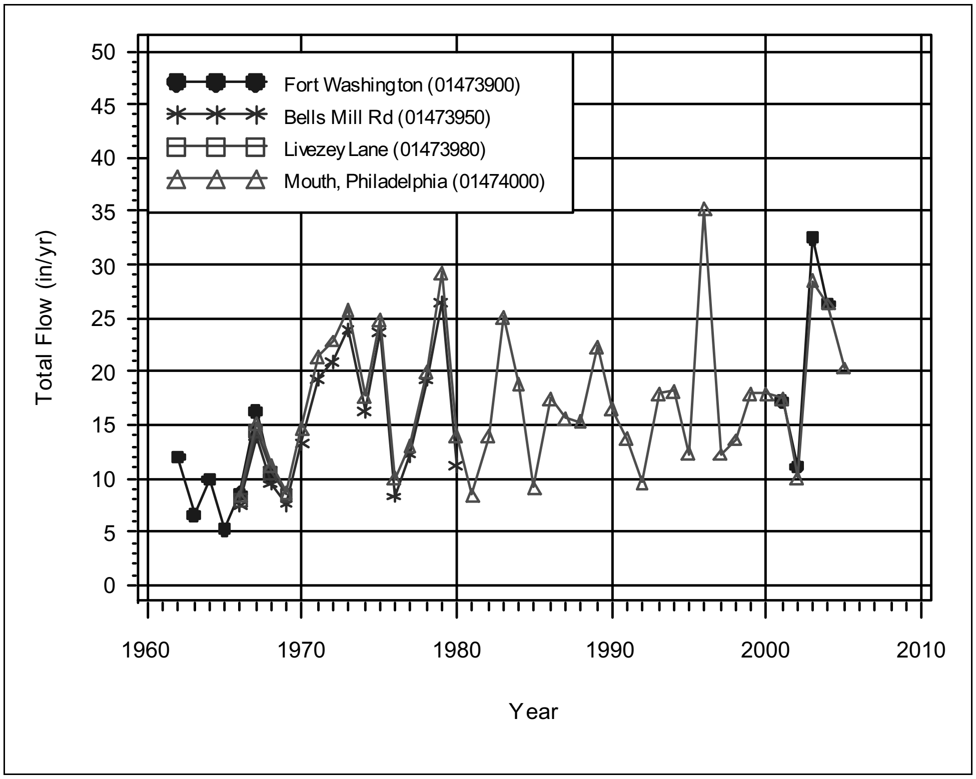


Figure 3-10 Total Streamflow Trends

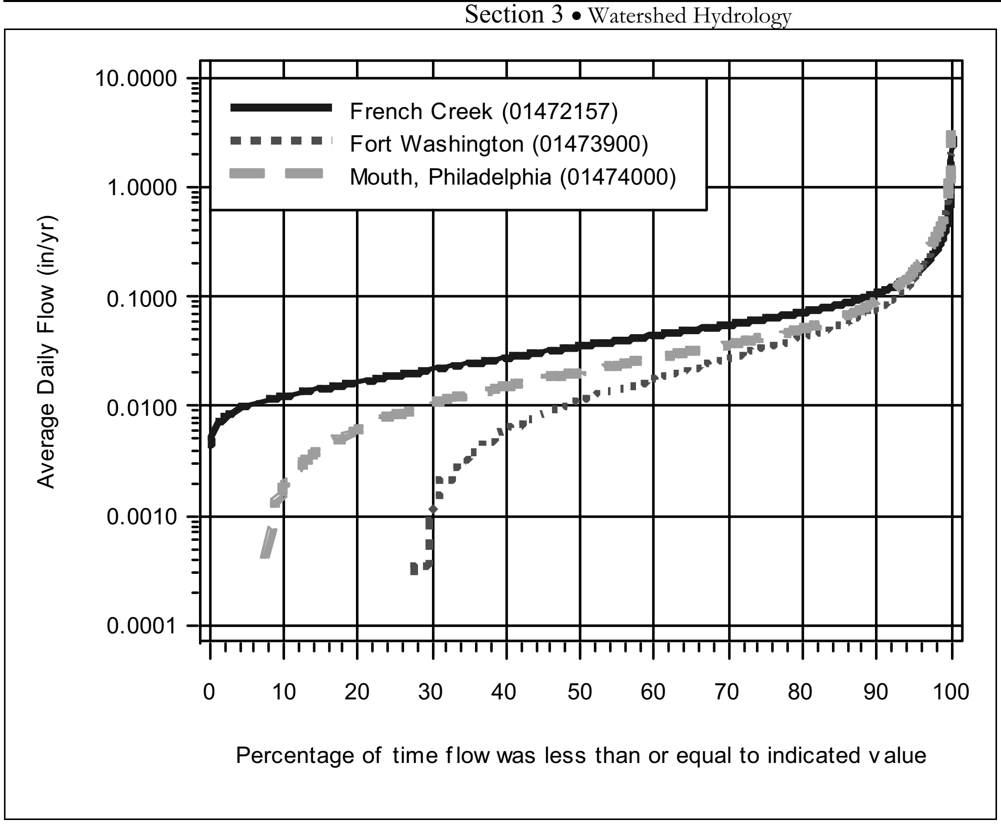


Figure 3-11 Cumulative Distribution of Total Flow with Point Sources Removed

3.2.2 CUMULATIVE DISTRIBUTION

The cumulative distribution of average daily flow at the mouth of Wissahickon Creek in Philadelphia shows the percent of daily flow observations, excluding point sources (horizontal axis) that are equal to or less than a given value (on the vertical axis). For example, average daily flow at the mouth of Wissahickon Creek was less than 0.1 in/yr on about 90% of days observed (Figure 3-11). Excluding point sources, Wissahickon Creek experiences greater extremes of flow than French Creek, a watershed of similar size. On approximately 94% of days, flow in Wissahickon Creek is less than flow at French Creek on a unit-area basis. On the wettest 6% of days, flow in Wissahickon Creek at both gages is greater than flow at French Creek on a unit-area basis. Flow at the mouth is greater than flow at the Fort Washington on these same days. These observations strengthen the evidence that downstream reaches of the creek (within Philadelphia) are more influenced by stormwater runoff than upstream reaches. On the driest 27% of days there is no natural (groundwater-derived) baseflow at the upstream gage, Fort Washington. At the downstream gage 8% of the days have no natural baseflow. During these periods the creek is dominated by point source flows discharging into the creek. A possible explanation for the relative increase in baseflow is a transfer of groundwater to surface water by Coorson's Quarry via Lorraine Run.

4 WATER QUALITY

4.1 BACKGROUND

This section identifies potential water quality problems in the watershed and the analysis tools used to define the problems and locations. Several criteria were relevant to the analysis, many of which provided specific numeric standards with which to comply. Others referred to as narrative standards were less specific, but nonetheless relevant.

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 2000).

Also, PADEP's general water quality criteria state:

> "(a) Water may not contain substances attributable to point or nonpoint 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." (PADEP Chapter 93 § 93.6.).

Pennsylvania Code Title 25, Chapter 93.4: Statewide Water Uses.

(a) Statewide water uses. Except when otherwise specified in law or regulation, the uses set forth in Table 4-1 apply to all surface waters. These uses shall be protected in accordance with this chapter, Chapter 96 (relating to water quality standards implementation) and other applicable State and Federal laws and regulations.

Table 4-1 Statewide Water Uses

Symbol	*Use*
	Aquatic Life
WWF	Warm Water 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

Water quality standards are established for each stream. These are based on, in part, aquatic life habitat, human health requirements, and recreation use. Threshold chemical and biological characteristics and other stream conditions are required to be maintained for each water quality designation. The state has an ongoing program to assess water quality by identifying streams that do not meet these standards – designated as "impaired."

Protected use categories for streams include aquatic life, water supply, recreation, and special protection. The criteria for water quality under each category vary; streams are designated in one of several subcategories. Streams with a designation of WWF (Warm Water Fishes) are able to support fish species, flora, and fauna that are indigenous to a warm-water habitat. Similarly, streams designated CWF (Cold Water Fishes) support life found in and around a cold-water habitat. Streams that are designated TSF (Trout Stocking Fishes) are intermediate quality streams that support stocked trout, as well as other wildlife and plant life that are indigenous to a warm water habitat. Migratory fish (MF) streams are protected for the passage and propagation of fish that ascend to flowing waters to complete their life cycle. Streams designated as special protection waters with an EV (Exceptional Value) or an HQ (High Quality) designation are of the best quality.

Pennsylvania Code Title 25, Chapter 96.3: Water Quality Protection Requirements.

(a) Existing and designated surface water uses shall be protected.
(b) Antidegradation requirements in §§ 93.4a—93.4d and 105.1, 105.15, 105.17, 105.18a, 105.20a and 105.451 shall apply to surface waters.
(c) To protect existing and designated surface water uses, the water quality criteria described in Chapter 93 (relating to water quality standards), including the criteria in §§ 93.7 and 93.8a(b) (relating to specific water quality criteria; and toxic substances) shall be achieved in all surface waters at least 99% of the time, unless otherwise specified in this title. The general water quality criteria in § 93.6 (relating to general water quality criteria) shall be achieved in surface waters at all times at design conditions.
(d) As an exception to subsection (c), the water quality criteria for total dissolved solids, nitrite-nitrate nitrogen, phenolics, chloride, sulfate and fluoride established for the protection of potable water supply shall be met at least 99% of the time at the point of all existing or planned surface potable water supply withdrawals unless otherwise specified in this title.

(e) When a water quality criterion described in Chapter 93, including the criteria in §§ 93.7 and 93.8a (b), cannot be attained at least 99% of the time due to natural quality, as determined by the Department under § 93.7(d) based on water quality observations in that waterbody or at one or more reference stations of similar physical characteristics to the surface water, the natural quality that is achieved at least 99% of the time shall be the applicable water quality criterion for protection of fish and aquatic life.
(f) When the minimum flow of a stream segment is determined or estimated to be zero, applicable water quality criteria shall be achieved at least 99% of the time at the first downstream point where the stream is capable of supporting existing or designated uses.
(g) Functions and values of wetlands shall be protected pursuant to Chapters 93 and 105 (relating to water quality standards; and dam safety and waterway management).

The Wissahickon Creek is classified as a TSF under the 1997 Pennsylvania Water Quality criteria. The Wissahickon has been identified on Pennsylvania's 1996, 1998, and 2002 Section 303(d) lists as an impaired waterbody, with segments failing to attain this aquatic life use.

Ten stream segments in the Wissahickon Creek Watershed have been included in Pennsylvania's 303(d) list due to nutrient impairments (figure 4-1). These include five segments of the Wissahickon Creek mainstem as well as five tributaries. Excessive nutrient loading to a waterbody can be detrimental to the biological system; potentially fostering an unhealthy and expanded growth in the production of nuisance algae. This leads to decreased DO levels in the stream. Sources of nutrients have been identified as municipal point sources and urban runoff/storm sewers.

Twenty one stream segments in the Wissahickon Creek Watershed have been included on Pennsylvania's 303(d) list due to siltation impairments (figure 4-2). These include the entire (six segments) of mainstem Wissahickon Creek and fifteen tributary segments. Siltation reduces the habitat complexity through the filling of pools and interstitial spaces between gravel and sand. Excess sediment can clog an organism's gill surfaces, which decrease its respiratory capacity. This pollutant also impacts visual predators by negatively impacting their ability to hunt and feed in a more turbid environment. Sources of siltation impairments include urban runoff/storm sewers and habitat modification.

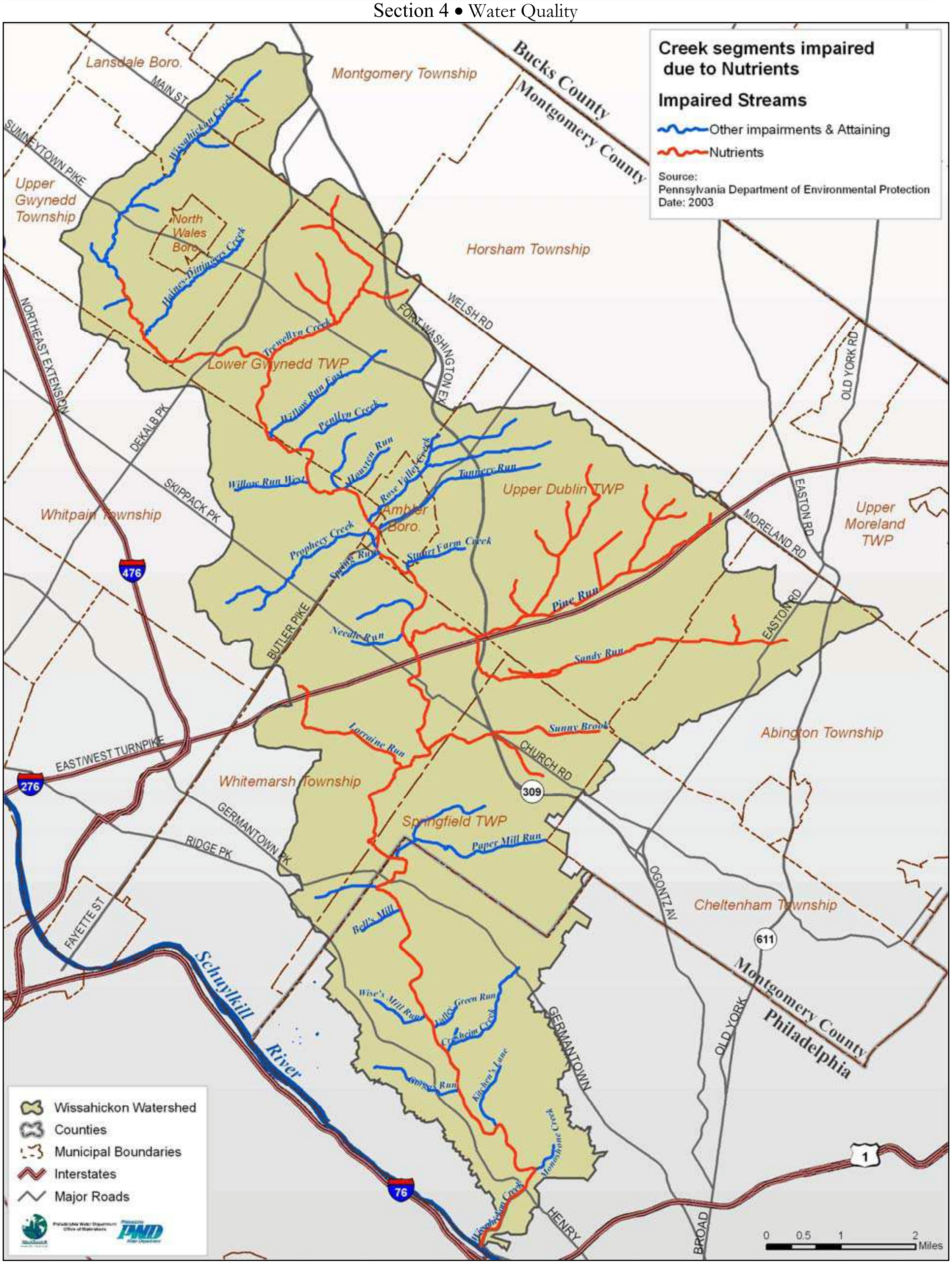


Figure 4-1 Wissahickon Creek Segments Designated as Impaired in Pennsylvania's 303(d) List Due to Nutrients

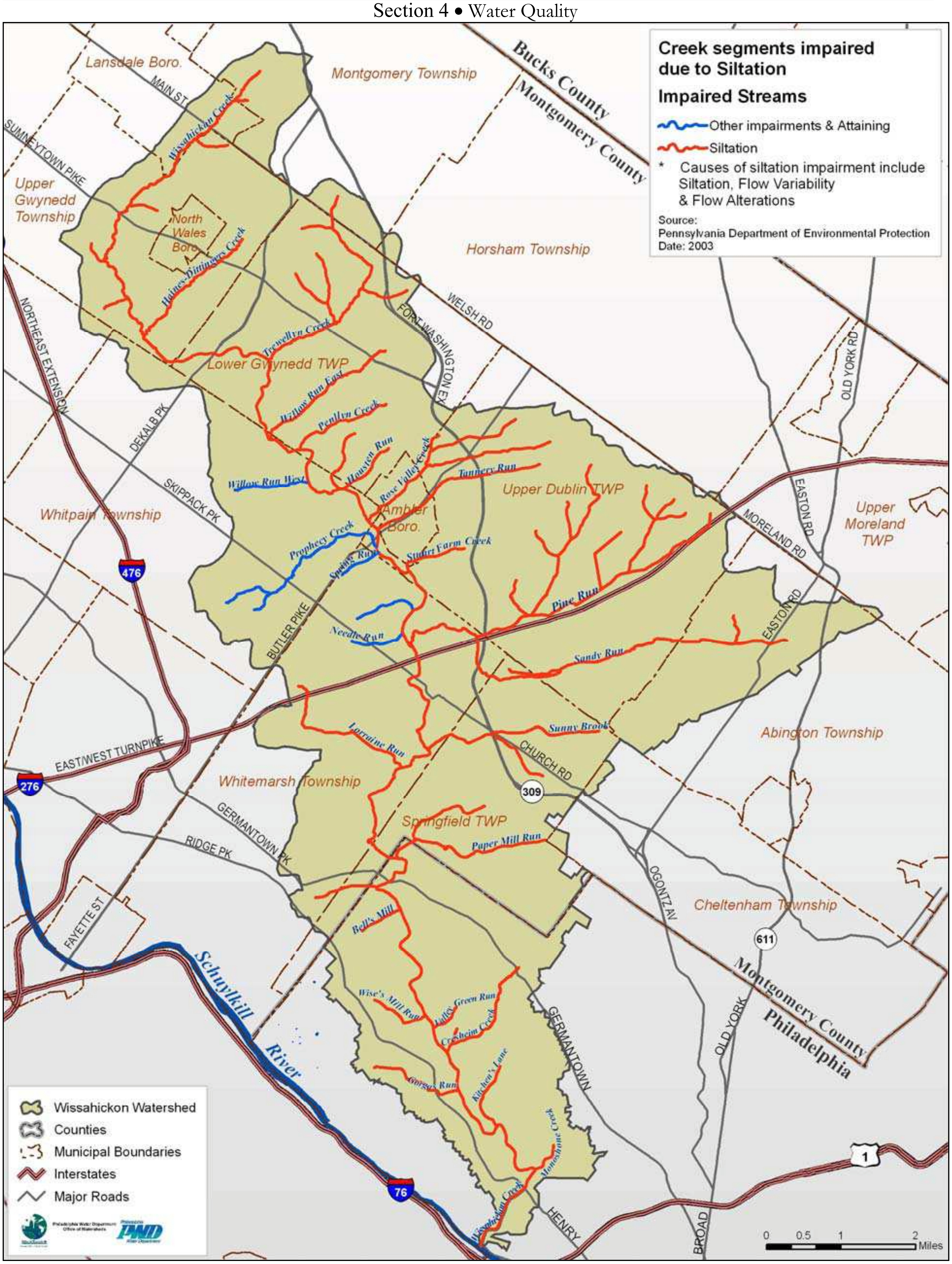


Figure 4-2 Wissahickon Creek Segments Designated as Impaired in Pennsylvania's 303(d) List Due to Siltation

Pennsylvania Code Title 25, Chapter 96.4: Total Maximum Daily Loads (TMDLs) and Water Quality Based Effluent Limitations (WQBELs)

(a) The Department will identify surface waters or portions thereof that require the development of TMDLs, prioritize these surface waters for TMDL development, and then develop TMDLs for these waters.

(b) The Department will develop WQBELs for point source discharges using applicable procedures described in this chapter when the Department determines that water quality protection requirements specified in § 96.3 (relating to water quality protection requirements) are or would be violated after the imposition of applicable technology based limitations required under sections 301(b), 306, 307 or other sections of the Federal Clean Water Act (33 U.S.C.A. §§ 1311(b), 1316 and 1317) and The Clean Streams Law (35 P. S. §§ 691.1—691.1001) to the point source.

(c) TMDLs and WQBELs shall be developed to meet the requirements of § 96.3.

(d) WLAs developed in accordance with this chapter shall serve as the basis for the determination of WQBELs for point source discharges regulated under Chapter 92 (relating to National Pollutant Discharge Elimination System permitting, monitoring and compliance). When LAs are developed in accordance with this chapter, they shall serve as the basis for the development of nonpoint source restoration plans.

(e) In developing TMDLs and WQBELs, the Department will:
   a. As appropriate, consider relevant design factors, including, but not limited to: water quality criteria duration, flow duration and frequency, natural seasonal variability in water temperature, the natural variability of pH and hardness, the physical characteristics of a watershed, reserve factors, factors of safety and pollutant contributions from other sources.
   b. Treat all pollutants as conservative unless it finds based on scientifically valid information that the substance is not conservative and adequate information is available to characterize the substance's fate or transformation, or both.

In accordance with the federal Clean Water Act, TMDL restrictions are imposed on waterways that do not meet water quality standards. It involves assessing the health of a waterway and developing a strategy for impaired waterways to meet the state's water quality standards. A TMDL establishes the maximum amount of a pollutant that a body of water can assimilate

In 2003, the U.S. Environmental Protection Agency (EPA) Region III established Total Maximum Daily Loads (TMDLs) for nutrients and siltation in the Wissahickon Creek Watershed. In 2006, the US EPA initiated a reevaluation of the Wissahickon Creek Nutrient TMDL.

4.2 WATER QUALITY CRITERIA AND REFERENCE VALUES

An analysis was conducted on the water quality data collected in the Wissahickon Creek Watershed. Using the data collected from discrete wet and dry weather sampling, comparisons were made to PADEP 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 listed in Table 4-2.

A color coding system was used to indicate problems (red) and potential problems (yellow). Problems were identified if more than 10% of samples exceeded the applied water quality standard or criterion. Potential problems were identified if between 2% and 10% of samples exceeded the standard or criterion.

Table 4-2 Water Quality Standards and Reference Values

Parameter	Criterion	Water Quality Criterion or Reference Value	Source
Alkalinity	Minimum	20 mg/L	PADEP
Aluminum	Aquatic Life Acute Exposure Standard	750 μg/L	PADEP
Aluminum	Aquatic Life Chronic Exposure Standard	87 μg/L (pH 6.5-9.0)	53FR33178
Chlorophyll-*a*	Reference reach frequency distribution approach for Ecoregion IX, subregion 64, 75th percentile	3 μg/L, (Spectrophotometric) ***	EPA 822-B-00-019
Dissolved Cadmium	Aquatic Life Acute Exposure Standard	0.0043 mg/L *	PADEP
	Aquatic Life Chronic Exposure Standard	0.0022 mg/L *	PADEP
	Human Health Standard	10 mg/L	PADEP
Dissolved Chromium	Aquatic Life Acute Exposure Standard	15 mg/L	PADEP
	Aquatic Life Chronic Exposure Standard	10 mg/L	PADEP
Dissolved Copper****	Aquatic Life Acute Exposure Standard	0.013 mg/L *	PADEP
	Aquatic Life Chronic Exposure Standard	0.0090 mg/L *	PADEP
	Human Health Standard	1000 mg/L	PADEP
Dissolved Iron	Maximum	0.3 mg/L	PADEP
Dissolved Lead	Aquatic Life Acute Exposure Standard	0.065 mg/L *	PADEP
	Aquatic Life Chronic Exposure Standard	0.025 mg/L *	PADEP
	Human Health Standard	50 mg/L	PADEP
Dissolved Zinc	Aquatic Life Acute Exposure Standard	0.120 mg/L *	PADEP
	Aquatic Life Chronic Exposure Standard	0.120 mg/L *	PADEP
	Human Health Standard	5000 mg/L	PADEP
Dissolved Oxygen	Average Min (August 1 to February 14)	5 mg/L	PADEP
	Instantaneous Min (August 1 to February 14)	4 mg/L	PADEP
	Average Min (February 15 to July 31)	6 mg/L	PADEP
	Instantaneous Min (February 15 to July 31)	5 mg/L	PADEP
Fecal Coliform	Maximum	200/100mL (Swimming season) or 2000/100mL (Non-swimming season)	PADEP
Fluoride	Maximum	2.0 mg/L	PADEP
Iron	Maximum	1.5 mg/L	PADEP
Manganese	Maximum	1.0 mg/L	PADEP
NH_3-N	Maximum	pH and temperature dependent	PADEP
NO_{2-3}-N	Nitrates – Human Health Consumption for water + organisms	2.9 mg/L ***	EPA 822-B-00-019
NO_2 + NO_3	Maximum (Public Water Supply Intake)	10 mg/L	PADEP
Periphyton Chl-*a*		Ecoregion IX – 20.35 mg/m2	USEPA 1986 (Gold book)
pH	Acceptable Range	6.0 - 9.0	PADEP
Phenolics	Maximum	0.005 mg/L	PADEP
TDS	Maximum	750 mg/L	PA DEP
Temperature		Varies w/ season. **	PADEP
TKN	Maximum	0.675 mg/L ***	EPA 822-B-00-021
TN	Maximum	4.91 mg/L ***	EPA 822-B-00-020
TP	Maximum	140 μg/L ***	EPA 822-B-00-022
TSS	Maximum	25 mg/L	Other US states

Parameter	Criterion	Water Quality Criterion or Reference Value	Source
Turbidity	Maximum	8.05 NTU ***	EPA 822-B-00-023

* - Water quality standard requires hardness correction; value listed is water quality standard calculated at 100 mg/L $CaCO_3$ hardness

** - Additionally, discharge of heated wastes may not result in a change of more than 2°F during a 1-hour period.

*** - Ecoregion IX, subregion 64 seasonal median

**** - All locations except site WS1850 have permitted exemptions of state dissolved copper standards due to a Water Effects Ratio.

4.3 REVIEW OF EXISTING DATA AND GIS CONSOLIDATION OF HISTORICAL MONITORING LOCATIONS

As part of the data review for the Wissahickon Creek Watershed Comprehensive Characterization Report, a desktop GIS analysis was conducted using existing ESRI shapefiles of monitoring locations provided by various primary sources, including Penn State University's PASDA web based GIS data repository, USEPA's STORET (STOrage and RETrieval) system, as well as GIS, web, and print-based materials provided by the United States Geologic Survey (USGS), Pennsylvania Department of Environmental Protection (PADEP), National Institute for Environmental Renewal (NIER), Academy of Natural Sciences of Philadelphia (ANSP), and Fairmount Park Commission (FPC). A data inventory conducted by PWD as part of the 2002 Source Water Assessment Program (SWAP) was invaluable in conducting the analysis.

After all water quality sampling location information for Wissahickon Creek Watershed was compiled, more than 100 distinct GIS point features were identified. The primary focus of the GIS sampling location analysis was to consolidate all water quality samples collected at a given sampling location, despite differences in documentation or other sources of error (*e.g.*, imprecise instruments and/or techniques used to determine geographic coordinates, errors encountered in conversion between different geographic projections, distance estimates from landmarks, interpretation of sampling location descriptions). There was considerable overlap between some GIS data sources, and these data varied with respect to accuracy of spatial information. In some cases, incongruities within data sets or documented problems with sampling procedures necessitated further investigation or resulted in outright rejection of data.

Despite these difficulties, GIS analysis and consolidation of historical water quality and quantity data resulted in identification of a sizable body of historical information from which a meaningful comparison to present day conditions could be made, if at a limited number of sites. It is hoped that the consolidated water quality sampling database and site information will be available for distribution along with the WCWCCR. A web-based data dissemination system is also under development at the time of writing.

4.3.1 PWD – USGS COOPERATIVE PROGRAM

In the early 1970s, the Philadelphia Water Department began a study in cooperation with the U.S. Geological Survey (USGS) entitled, "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. By 1970, the USGS had already established three stream gaging stations in Wissahickon Creek Watershed (gage 01474000 at Ridge Avenue, gage 01473950 at Bells Mill Road, and gage 01473980 at Livezey Lane). Between 1959 and 1967, ten additional stations were established in Wissahickon Creek and its tributaries.

Four stations were instrumented with water level sensors and rated for discharge, while other stations were used only briefly to collect a small number of water quality samples. While only two of the thirteen original gages remain operational today, the water quality monitoring program has recently been revitalized and the two USGS gages at Ridge Avenue and Fort Washington are being fitted with continuous water quality monitoring equipment.

PWD and USGS conducted monthly water quality sampling from 1971 to 1980 at Ridge Avenue (gage 01474000) and Bells Mill Road (gage 01473900). This dataset provided the best opportunity to make a meaningful comparison of historical water quality to present-day conditions. These monthly "snapshot" water quality samples were not intentionally directed at dry or wet weather, so they were subsequently classified as wet or dry using discharge and other components of the dataset associated with wet weather (*e.g.*, decreased conductivity, increased turbidity and TSS). Locations of the historical monitoring stations from the PWD/USGS Cooperative Program and periods of activity are shown in Figure 4-3 and table 4-3, respectively.

Figure 4-3 Locations of the Historical Monitoring Stations from the PWD/USGS Cooperative Program

Table 4-3 Periods of Activity of Historical Monitoring Stations from the PWD/USGS Cooperative Program

PWD Site	Gage number	Flow Data Period of record	Daily Streamflow records	WQ Samples	Number Samples
WS005	01474000	1965-present	14245	1959-present	146
WS209	01473990	N/A	N/A	1999	3
WS354	01473980	1965-1970	1855	1967-1970	18
WS622	01473950	1965-1981	5844	1967-1979	50
WS1075	01473900	1961-present	4352	1962-present	73
WS1475	01473895	N/A	N/A	1972-1976	15
WS2245*	01473808, 01473809	N/A	N/A	N/A	N/A
WS2305*	01473807, 01473806	N/A	N/A	N/A	N/A
WSSR058**	01473850, 01473860, 01473890	N/A	N/A	N/A	N/A

*Four USGS gages were operated for a short period of time upstream of site WS2245. No data were available for these gages

**Three USGS gages were operated for a short period of time on Sandy Run and Pine Run. No data were available for these gages.

Comparison of historical data at sites where a sufficient number of samples were available to the 2005 dataset revealed significant differences in nitrate, orthophosphate and total phosphorus (table 4-4). While significant, most of these differences are minor when one considers that concentrations are so drastically different from natural conditions that effects on the natural communities are probably minimal. For example, historical dry weather mean TP and PO_4 concentrations were 3.04 and 4.22, respectively. Though present day mean values are lower, the difference may not be particularly meaningful, as concentrations are at least an order of magnitude greater than the concentrations that might be expected to limit growth of algal periphyton.

Table 4-4 Significant Difference between 2005 Water Quality Data and Historic Water Quality Data

Parameter	Wet/Dry	Comparison	Test	U-value	p-value	Valid n Group 1	Valid n Group 2	Mean Group 1	Mean Group 2
NO3	Dry	City of Philadelphia 2005 data vs historic data	Mann Whitney U-test	2517.5	0.00	52	192	4.83	3.79
NO3	Dry	Upstream City of Philadelphia 2005 data vs historic data	Mann Whitney U-test	577.5	0.04	55	29	7.83	5.96
NO3	Wet	City of Philadelphia 2005 data vs historic data	Mann Whitney U-test	2141.5	0.00	59	103	3.43	2.66
NO3	Wet	Upstream City of Philadelphia 2005 data vs historic data	Mann Whitney U-test	398.0	0.03	107	12	3.42	4.56
PO4	Dry	City of Philadelphia 2005 data vs historic data	Mann Whitney U-test	184.0	0.00	52	38	0.60	5.00
PO4	Dry	Upstream City of Philadelphia 2005 data vs historic data	Mann Whitney U-test	217.0	0.01	55	14	1.31	2.10
PO4	Wet	City of Philadelphia 2005 data vs historic data	Mann Whitney U-test	2.0	0.00	59	19	0.48	3.12
TP	Dry	City of Philadelphia 2005 data vs historic data	Mann Whitney U-test	489.5	0.00	40	190	0.71	3.08
TP	Dry	Upstream City of Philadelphia 2005 data vs historic data	Mann Whitney U-test	131.5	0.02	44	11	1.48	2.30
TP	Wet	City of Philadelphia 2005 data vs historic data	Mann Whitney U-test	635.0	0.00	35	96	0.64	2.15
TP	Wet	Upstream City of Philadelphia 2005 data vs historic data	Mann Whitney U-test	212.5	0.01	64	12	0.89	1.22

4.4 WATER QUALITY SAMPLING 1990-PRESENT

While the PWD-USGS cooperative program samples effectively documented water quality conditions at two locations over an entire decade, spatially distributed data were not available for this time period. Data collection efforts carried out in the late 1990s addressed this lack of spatial dispersion of sampling sites, with extensive sampling by the Pennsylvania Department of Environmental Protection (PADEP), National Institute for Environmental Renewal (NIER), Academy of Natural Sciences of Philadelphia (ANS), and PWD.

PADEP water pollution biologists collected invertebrates and conducted habitat analysis in Wissahickon Creek Watershed in 1997 as part of the unassessed waters program and shared results of additional water quality and biological investigations conducted in Wissahickon Creek Watershed in 1989, 1993, 1996, 1997, 1998, and 2002, including a stream periphyton survey at ten sites in 1998 (Table 4-5). Nutrient and Siltation TMDLs were established for Wissahickon Creek Watershed by Tetra Tech of Fairfax, VA under contract to USEPA. Additional sampling required for TMDL development included low flow water quality sampling conducted by NIER, low-flow dye testing time of travel analysis conducted by PADEP, and cursory FGM and substrate assessments by ANS.

Table 4-5 PADEP Stream Periphyton Survey in Wissahickon Creek, 1998

Title	Author	Date	Scope	Sites
Aquatic Biology Investigation of Wissahickon Creek	M. Boyer	3/15/89	Watershed-wide	14
Aquatic Biology Investigation of Wissahickon Creek	M. Boyer	6/26/97	Watershed-wide	14
Aquatic Biology Investigation of Wissahickon Creek	S. Schubert	2/6/96	Watershed-wide	4
Aquatic Biology Investigation of Sandy Run	M. Boyer	7/21/93	Sandy Run	4
Biological Investigation UNT Wissahickon Creek	M. Boyer	6/22/93	Lorraine Run	3
Periphyton Standing Crop and Diatom Assemblages in Wissahickon Creek Watershed (1998)	A. Everett	2/19/02	Watershed-wide	10
2002 Diel Oxygen Study of Wissahickon Creek Watershed	PADEP	7/2002	Watershed-wide	8

PWD conducted baseline assessments of Wissahickon Creek and Monoshone Creek watersheds in 2000 and 2001, respectively. Water quality samples were collected from 15 sites in Wissahickon Creek Watershed and 5 sites in Monoshone Creek watershed, along with habitat and macroinvertebrate assessments and fish collections from a limited number of sites.

Finally, students and faculty from Chestnut Hill College and volunteers from the Center in the Park and Senior Environmental Corps (SEC) have collected water quality data from Monoshone Creek periodically since 1999, and this partnership is expected to continue as SEC is preparing to institute a water quality monitoring program for the Saylor Grove Stormwater Treatment Wetland Project in the Monoshone watershed.

4.5 SAMPLING BACKGROUND

The Philadelphia Water Department (PWD) has carried out an extensive sampling and monitoring program to characterize conditions in Wissahickon Creek 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.

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

Wissahickon Creek Watershed, stormwater outfalls and wastewater treatment facilities are classified as point sources and are regulated by NPDES.

Regulation of stormwater outfalls under the NPDES program requires operators of medium and large municipal separate storm sewer systems or MS4s, 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 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. Wissahickon Creek is listed by the PADEP as impaired for nutrients and sediment, requiring Total Maximum Daily Loads (TMDLs) for both pollutants.

Wissahickon Creek and its tributaries are designated trout stock fisheries (TSF). The entire mainstem of the watershed and tributaries, with the exception of Prophecy Creek, Spring Run and Needle Run, 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 Wissahickon Creek Watershed.

PWD's Office of Watersheds (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.

4.6 SUMMARY OF PHYSICAL AND CHEMICAL MONITORING

The 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 Wissahickon Creek Watershed. The program includes hydrologic, water quality, biological, habitat, and fluvial geomorphological components.

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.

Sampling and monitoring programs have been performed recently by PWD, PADEP, and USGS (tables 4-6 and 4-7). A river mile-based naming convention is followed for sampling and monitoring sites located along waterways in the watershed. The naming convention includes two to four letters and three or more numbers which denote the watershed, stream, and distance from the mouth of the stream. For example, site WSMC016 is named as follows:

- "WS" indicates the Wissahickon Creek.
- "MC" indicates Monoshone Creek, a tributary to Wissahickon Creek.
- "016" places the site 0.16 miles upstream of the confluence of Monoshone Creek and Wissahickon Creek.

Table 4-6. Summary of Physical and Biological Sampling and Monitoring

Site Name	Stream Name	USGS Gage Number	Physical		Biology				
			USGS Daily Flow	USGS Water Quality	PWD			PADEP	
					RBP III*	RBP V**	Habitat	RBP	Habitat
WS005	Wissahickon Creek	01474000	1965-present	1959-present	Mar-05		Mar-05	1997	1997
WS076	Wissahickon Creek								
WS122	Wissahickon Creek				Mar-05		Mar-05		
WS209	Wissahickon Creek	01473990		1999	Mar-05	Jun-05	Mar-05		
WS354	Wissahickon Creek	01473980	1965-1970	1967-1970	Mar-05	Jun-05	Mar-05		
WS492	Wissahickon Creek				Mar-05		Mar-05		
WS622	Wissahickon Creek	01473950	1965-1981	1967-1979		Jun-05			
WS754	Wissahickon Creek								
WS899	Wissahickon Creek				Mar-05	Jun-05	Mar-05		
WS1075	Wissahickon Creek	01473900	1961-present	1962-present	Mar-05	Jun-05	Mar-05		
WS1210	Wissahickon Creek				Mar-05	Jun-05	Mar-05		
WS1475	Wissahickon Creek	01473895		1972-1976	Mar-05	Jun-05	Mar-05	1997	1997
WS1560	Wissahickon Creek				Mar-05		Mar-05		
WS1850	Wissahickon Creek				Mar-05	Jun-05	Mar-05		
WS2245	Wissahickon Creek	01473808 01473809	N/A	N/A	Mar-05		Mar-05		
WS2305	Wissahickon Creek	01473807 01473806	N/A	N/A	Mar-05		Mar-05		
WSWM039	Wises Mill Run				Mar-05		Mar-05		
WSWM006	Wises Mill Run							1997	1997
WMUT003	Unnamed Tributary To Wises Mill				Mar-05		Mar-05		
WSVG009	Valley Green Run				Mar-05		Mar-05		
WSTM002	Thomas Mill Run				Mar-05		Mar-05		
WSTM020	Thomas Mill Run				Mar-05		Mar-05		
WSSR058	Sandy Run	01473850 01473860 01473890	N/A	N/A					
WSSR096	Sandy Run				Mar-05	Jun-05	Mar-05	1997	1997
WSRA005	Rex Avenue				Mar-05		Mar-05		
WSPC017	Prophecy Creek				Mar-05	Jun-05	Mar-05		
WSPM018	Papermill Run				Mar-05		Mar-05	1997	1997

Site Name	Stream Name	USGS Gage Number	Physical		Biology				
			USGS Daily Flow	USGS Water Quality	PWD			PADEP	
					RBP III*	RBP V**	Habitat	RBP	Habitat
WSMC016	Monoshone Creek							1997	1997
WSMC025	Monoshone Creek				Mar-05		Mar-05		
WSLR005	Lorraine Run				Mar-05		Mar-05	1997	1997
WSHR009	Hartwell Run				Mar-05		Mar-05		
WSGL020	Gorgas Lane Run				Mar-05		Mar-05	1997	1997
WSCC070	Cresheim Creek				Mar-05		Mar-05	1997	1997
WSCC009	Cresheim Creek				Mar-05		Mar-05		
WSCR008	Cathedral Run				Mar-05		Mar-05		
WSCW003	Carpenters Woods				Mar-05		Mar-05		
WSBM007	Bells Mill Run				Mar-05		Mar-05		
WSBM090	Bells Mill Run				Mar-05		Mar-05		

* EPA Rapid Bioassessment Protocol III Benthic Macroinvertebrates

** EPA Rapid Bioassessment Protocol V Ichthyofaunal (Fish)

4.6.1. WATER QUALITY SAMPLING AND MONITORING

In order to comply with the State-regulated stormwater permit obligations, water quality sampling was conducted during 2005. A range of water quality samples were collected at 8 mainstem sites and 8 tributary sites in the watershed. The sites are shown on Figure 4-4 and listed in Tables 4-6 and 4-7. 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 4-8. Water quality in each reach and section of the watershed is characterized in this section.

The sampling and analysis program was designed in part to meet regulatory needs within an allotted time period, while also providing both spatial and temporal data. Historical data collected from various state and federal agencies was also incorporated into the analysis design in attempt to identify historical changes in water quality.

Table 4-7 Summary of Water Quality Sampling Locations

SITE	ASSESSMENT		
	Discrete	Continuous	Wet Weather
WS076	X	X	X
WS122	X		
WS354	X	X	
WS492	X		
WS754	X	X	X
WS1075	X	X	X
WS1210	X	X	
WS1850	X	X	X
WSWM006		X	X
WSSR058	X		
MCRR002		X	X
WSPC017	X		
WSMC016		X	X
WSCR008		X	X
WSBM007		X	X
WSBM090		X	X

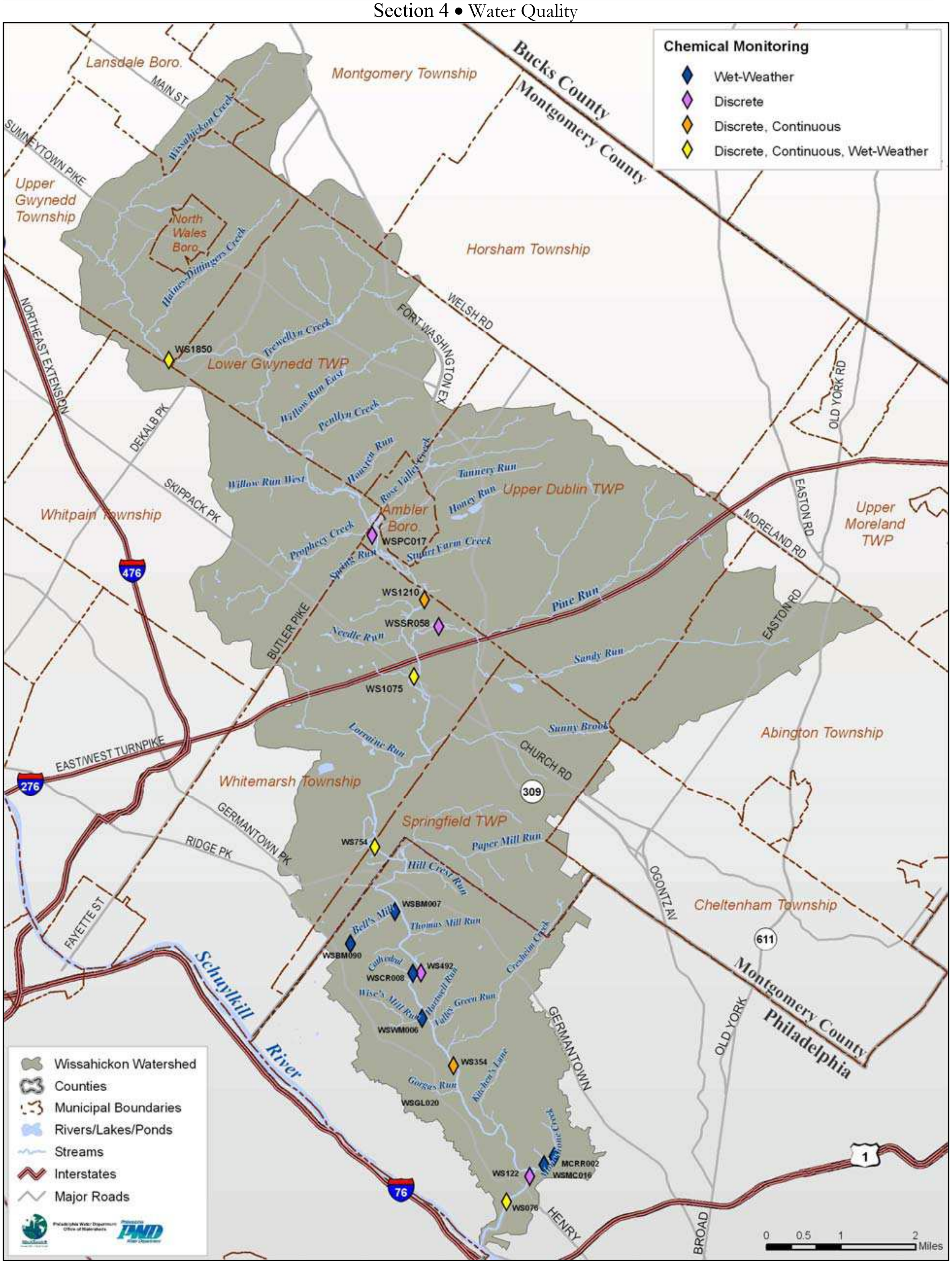


Figure 4-4 Water Quality Sampling Sites in Wissahickon Creek Watershed, 2005

Table 4-8 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-*α*	µg/L	X	X	
Fecal Coliform	CFU/100mls	X	X	
E. coli	CFU/100mls	X	X	
Miscellaneous				
Phenolics	mg/L	X	X	

4.6.2. DISCRETE INTERVAL SAMPLING

Bureau of Laboratory Services staff collected surface water grab samples at ten (n=10) locations within Wissahickon Creek Watershed for chemical and microbial analysis (Figure 4-5). Each site along the stream was sampled once during the course of a few hours, to allow for travel time sample processing/preservation. 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 (SOP) "Field Procedures for Grab Sampling".

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 1/13/05, 1/20/05, 1/27/05, and 2/3/05; "spring" samples collected 4/21/05, 4/28/05, 5/5/05, and 5/12/05; "summer" samples collected 8/4/05, 8/11/05, 8/18/05 and 9/8/05. A total of 120 discrete samples, comprising 4920 chemical and microbial analytes, were collected and recorded during the 2005 assessment of Wissahickon Creek Watershed. To add statistical power, additional discrete water quality samples from PWD's wet-weather chemical sampling program were included in analyses when appropriate. Discrete sampling was conducted on a weekly basis and was not specifically designed to target wet or dry weather flow conditions. Ten sampling events occurred during dry weather.

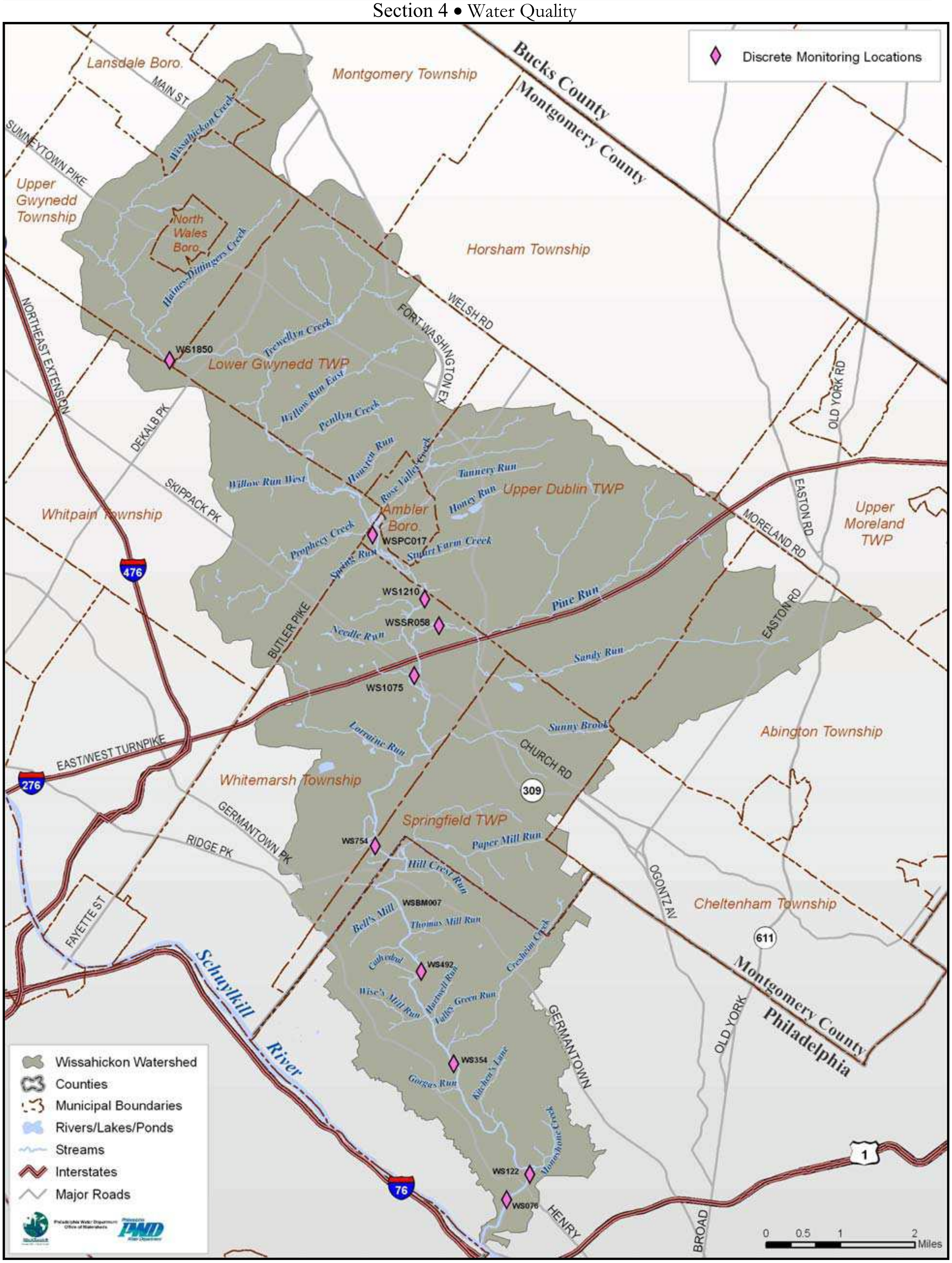


Figure 4-5 Discrete Water Quality Sampling Sites in Wissahickon Creek Watershed, 2005

4.6.3 CONTINUOUS 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 from 3/9/2005 to 11/21/2005 at six (n=6) sites within Wissahickon Creek Watershed in order to collect DO, pH, temperature, conductivity and depth data (Figure 4-6).

Sondes continuously monitored conditions and discretized the data in 15 min increments for a total of 1234 days. The instrument measures parameters using voltage and diffusion-based probes rather than physically collecting samples. 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.

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 4-9) (See Appendix B). All pH and temperature data were acceptable.

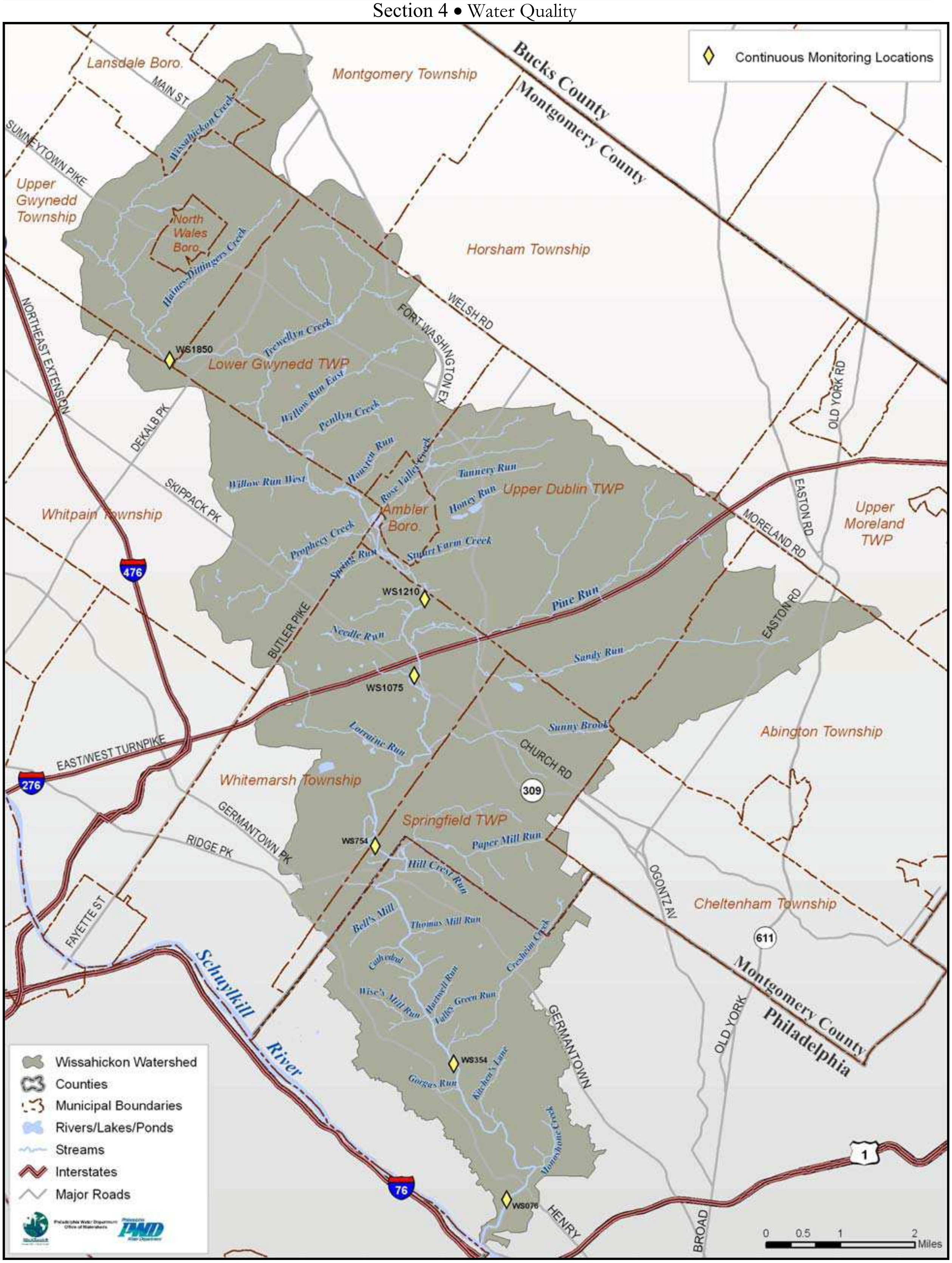


Figure 4-6 Continuous Water Quality Sampling Sites in Wissahickon Creek Watershed, 2005

Table 4-9 Total Sonde Hours and Flagged DO Data

Site	Flagged Hours	Quality Hours	Total Hours	Quality
WS076	904	4967	5871	84.6%
WS1075	68	5799	5867	98.8%
WS1210	506	5151	5658	91.0%
WS1850	63	5193	5256	98.8%
WS354	938	4543	5481	82.9%
WS754	229	5375	5605	95.9%
Total	2708	31029	33737	92.0%

4.6.4 WET WEATHER EVENT SAMPLING

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 from 4 mainstem and 4 tributary sites during runoff producing rain events in 2005. Samples were collected from 4 mainstem locations during three wet weather events that took place 7/8/05, 10/8/05 and 11/16/05. Additionally, samples were collected from Monoshone Creek on 5/20/05 and 7/8/05; Bells Mill on 9/15/05, 9/26/05 and 10/8/05; Cathedral Run on 11/10/05 and 11/15/05; and Wises Mill on 11/16/05. Wet weather data collection in tributary sites is on-going. The data allow characterization of water quality responses to stormwater runoff and wet weather sanitary sewer overflows (SSOs).

The automated sampler system obviated the need for BLS team members to manually collect grab samples, thereby greatly increasing sampling efficiency. Automated samplers were equipped with vented instream pressure transducers that allowed sampling to commence beginning with an increase in stage. While in the testing phase of automated sampler installation, it was determined that diel fluctuations in flow volume from the various dischargers regularly caused stream stage to increase as much as 0.6 in during dry weather, but these fluctuations were unpredictable and it was not feasible to create sampling algorithms that would compensate for these changes. Wet weather event sampling was initiated based upon a 0.1 ft increase in stream stage over a one hour interval, after which the Isco computer-controlled peristaltic pump and distribution system collected the first 4 grab samples at 40 minute intervals and the remaining samples at 1 hr. intervals. Though the protocol for initiating the start of a sampling event, an increase of 0.1 ft, was the same as used previously in stormwater/CSO only systems, actual rain event initiation was assumed to be less accurate than wet weather monitoring in stream systems that do not have dry weather discharges. These differences should be considered when comparing wet weather chemistry data between basins.

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 40 minute and 1 hour intervals were found to be generally satisfactory in collecting representative samples over the course of a storm event.

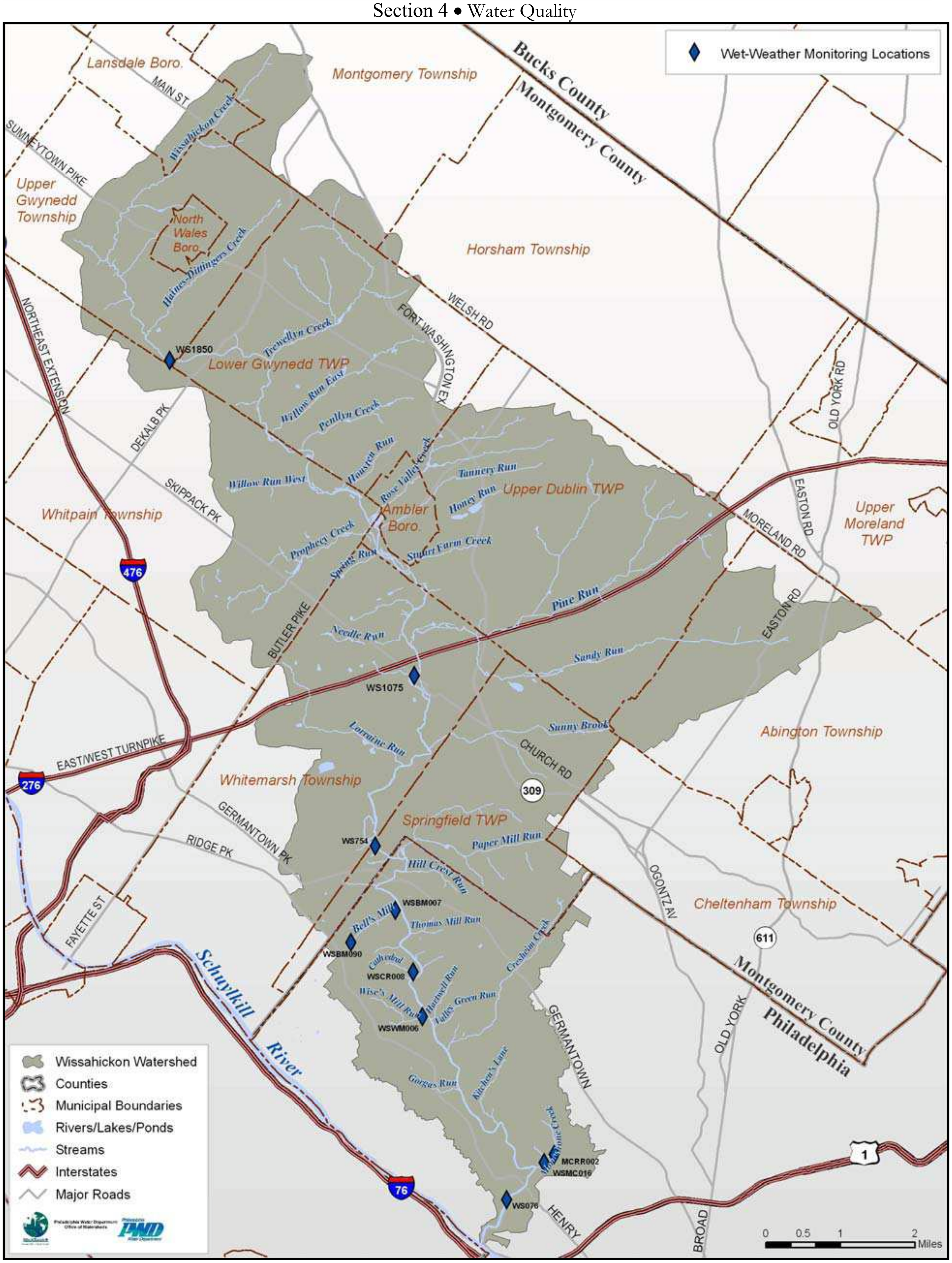


Figure 4-7 Wet Weather Water Quality Sampling Sites in Wissahickon Creek Watershed, 2005

4.6.5 BIOTIC LIGAND MODEL (BLM) ANALYSIS

The Biotic Ligand Model is a toxicity prediction tool that addresses the major constituents of water that may compete for ligand bonding sites of fish gills and respiratory apparatus of invertebrates. The model is built from empirical studies of the interactions of 12 separate water quality parameters on the toxicity of various toxic metals. Generally, these water quality parameters function to bind, chelate or form organic complexes with toxic metals thereby reducing toxicity. Biotic Ligand Model Version 2.1.2 for Microsoft Windows (Hydroqual 2005) was used to address toxicity effects of Zn and Cu only as other toxic constituents (*e.g.*, Cd and Cr) were rarely or never measured above reporting limits.

4.6.6 SEDIMENT LOAD DATA COLLECTION METHODS

In conjunction with Section D (*Sediment Total Maximum Daily Load (TMDL) for Wissahickon Creek*) of the City's stormwater permit, PWD has initiated a monitoring plan that addresses the adverse impacts to in-stream habitats as a result of transport of sediment and/or stream-bank erosion. Baseline data from 13 perennial tributaries that originate in the City will be monitored to define their contribution of sediment loading.

There are two elements to the monitoring program. The first estimates the sediment load originating from streambanks. The second estimates the total sediment load being carried by the stream. Data collection is on-going for both studies.

4.6.6.1 STREAMBANK EROSION RATES

Streambank erosion rates were first predicted using Bank Erosion Hazard Index and Near Bank Stress assessments and then directly measured with bank pins.

BEHI/NBS Assessments

PWD employed the Bank Erosion Hazard Index (BEHI) and Near Bank Stress (NBS) as defined by Rosgen (1996) to predict erosion rates and classify the erosion potential of the tributaries. Three hundred and sixty eight reaches in 13 tributaries have been assessed using BEHI and NBS criteria. Reaches were assessed based on visual inspection of obvious signs of erosion.

BEHI and NBS scores were grouped as very low, low, moderate, high or very high. Predicted streambank erosion rates were calculated based on a relationship between these scores and measured streambank erosion rates (Rosgen 1996). The predicted rate is multiplied by the bank height and length as well as a conversion factor to get a sediment load in tons/year.

Bank Pins

Bank pins were installed in Bells Mill, Cathedral Run, Wises Mill and Monoshone Creek in October and November 2005. Nine bank pin sites were chosen in each of the tributaries listed with the exception of Monoshone. Only four bank pin sites were chosen in Monoshone because much of the tributary is channelized. Bank pins were installed in reaches with varying BEHI and NBS scores in order to validate and calibrate the prediction model. Three of the 9 sites were in reaches deemed to be stable and therefore without a BEHI/NBS score. Additional bank pin sites in these tributaries and others are planned for the future.

Bank pins were installed where the bank curvature was greatest. At least one bank pin was put in below bankfull height and they were spaced no closer than 1ft. The number of bank pins at a site was dependant on bank height and ranged from one to three.

Bank Profile Measurements

Bank profiles were measured and recorded on field sheets as defined by Wildland Hydrology (2001). The profile was measured prior to and after wet weather events of different intensities. Measurements will continue at these sites and additional bank pin sites as they are added.

Measurements were made using a survey rod, a Keson pocket rod and two levels. The survey rod was placed on the edge of the toe pin and held perpendicular to the stream bed plane using a spirit level. The distance from the bank to the edge of the survey rod closest to the bank was measured by placing the pocket rod against the bank directly above each bank pin and recorded on the field data sheet. The pocket rod was leveled horizontally (perpendicular to the survey rod) with a spirit level.

4.6.6.2 TOTAL SUSPENDED SEDIMENT LOAD

Total suspended sediment load carried by the stream was estimated using stage discharge rating curves and total suspended sediment discharge rating curves. Four tributaries (Monoshone Creek, Wises Mill, Cathedral Run, and Bells Mill) were selected, based on visual inspection of obvious signs of erosion, in order to estimate sediment loads and calibrate methods used in other tributaries.

Stage Data

Stage data from Bells Mill, Cathedral Run, Wises Mill and Monoshone were recorded near the Wissahickon confluence downstream of all storm water outfalls. Stage was measured every six minutes by either an ultrasonic downlooking water level sensor or a pressure transducer and recorded on a Sigma 620 datalogger/control unit (Hach, formerly Sigma). PWD staff periodically downloaded and analyzed stage data for errors.

Dates of ultrasonic downlooker installation in Bells Mill, Cathedral Run and Wises Mill were May 2005, September 2005 and August 2005 respectively. Pressure transducers were installed in Monoshone in July 2005 and Bells Mill in November 2005. Stage data will continue to be recorded at these sites and additional sites will be added.

Stage Discharge Rating Curves

Staff gages were installed in Monoshone, Wises Mill and Bells Mill concurrent with ultrasonic downlooker or pressure transducer installation. Staff gages are located next to the stage recording device in culverts with concrete floors to ensure that the cross section will not change over time.

Discharge rating curves were established in Monoshone, Wises Mill and Bells Mill following a modified version of USGS protocol (Buchanan and Somers 1969). Discharge was measured in a cross section close to the staff gage using a SonTek Flowtraker Handheld ADV and plotted against stage. Due to lack of a suitable monitoring location, discharge in Cathedral Run was calculated using Manning's equation rather than being calculated from a site specific rating curve.

Total Suspended Sediment Discharge Rating Curve

Total suspended sediment samples were collected from Monoshone Creek (5/20/2005 and 7/8/2005), Wises Mill (11/16/2005), Cathedral Run (11/10/2005 and 11/16/2005) and Bells Mill (9/15/2005, 9/26/2005 and 10/8/2005). Samples were collected using an Isco automated sampler and followed methods described in wet weather monitoring. Water level is recorded during the sample period allowing a sediment discharge rating curve to be established. Additional sample collections are planned for these 4 tributaries as well as other tributaries.

4.7 WATER CHEMISTRY RESULTS

4.7.1 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. 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. Wissahickon Creek Watershed is designated a trout stocking fishery (TSF). This designation is used for streams that cannot necessarily support naturally reproducing salmonid populations, but are appropriate for a put-and-take fishery (*i.e.*, stocking trout to provide recreational opportunities).

PADEP DO criteria for trout stocking fishery streams vary seasonally, and are more stringent in spring and early summer to ensure survival and maintenance of stocked trout. Water quality regulations for TSF streams require that minimum DO concentration not fall below 5.0 mg/L from February 15 through July31, and 4.0 mg/L from August 1 through February 14. Daily average DO concentration must remain at or above 6.0 mg/L from February 15 through July31, and 5.0 mg/L from August 1 through February 14. As colder stream water has a greater capacity for dissolved oxygen and metabolic activity slows down in colder water, Philadelphia's streams rarely experience DO problems in winter. Violations of DO criteria can occur in spring and summer when water temperatures are higher and biological activity increases. Furthermore, nutrient enriched streams with excessive algal growth often experience severe diel fluctuations in DO that may result in violations of daily minimum criteria, and in a few cases, violation of the daily average requirement. Despite colder water temperatures, DO violations may be more common in early spring at some sites because canopy cover is reduced prior to leaf out and algal growth rates are very high.

Continuous water quality monitoring instruments (YSI Model 6600 and 600XLM Sondes) were deployed periodically at 6 sites throughout Wissahickon Creek Watershed from 2004 to 2006 collect data in 15-minute intervals (Table 4-9). A total of 1234 days of DO data have been collected from these monitoring locations thus far. 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 A Sonde QC protocol). Intervals during which probe failure occurred are summarized in Appendix B. Quality of recovered data was excellent, owing to procedures for cleaning and replacing sondes that were developed and refined over the course of four years of study in the nearby Tookany-Tacony/Frankford Watershed.

However, 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 constantly be in motion. While it was not always possible to situate instruments in ideal locations due to conditions found in urban areas (*e.g.*, severe flows, infrastructure effects, debris accumulation, vandalism, etc.), low- flow velocity measurements and channel geometry measurements indicated highly turbulent flow conditions at all mainstem sonde sites.

Table 4-10 Reynolds Numbers for Sonde Sites in Wissahickon Creek Based on Discharge Measurements on February 8, 2006

Attributes	**WS354**	**WS754**	**WS1075**	**WS1210**	**WS1850**
mean depth (m)	0.402657	0.400812	0.230588	0.254924	0.322028
width (m)	12.4968	13.04544	12.192	17.3736	6.096
mean velocity (m/s)	0.341681	0.322783	0.40325	0.179222	0.10607
Kinematic viscosity	1.01E-06	1.01E-06	1.01E-06	1.01E-06	1.01E-06
Reynolds	128352.5	121038.4	88972.77	44076.95	30678.89

DO concentration in Wissahickon Creek Watershed was found to be highly variable, both seasonally and spatially, but in general, DO was controlled by temperature, biological community metabolism and inputs of treated municipal sewage and untreated stormwater. DO violations were generally restricted to the warmer months. Most serious effects occurred at site WS1850, where daily minima were violated on 119 of 210 days (56%), but severe DO suppression was also observed at sites WS1075 and WS1210, where violations occurred on 40% and 28% of days observed, respectively (Table 4-11, Appendix C). Downstream sites in the City of Philadelphia showed only moderate fluctuation due to biological activity, perhaps due to increased dilution, canopy cover, or reaeration at dams. Effects of stream metabolism on DO concentration are addressed in section 4.8 (Stream Metabolism).

Table 4-11 Sonde Data Meeting Standards by Site, 2005

Sampling Site	Parameter	Sonde DO	Sonde Temperature	Sonde pH	Sonde pH	Sonde pH	Sampling Site	Parameter	Sonde DO Daily Average	Sonde DO Daily Min	Sonde pH Daily Max	Sonde pH Daily Min
	Standard	Minimum	Maximum	Maximum	Minimum	Min/Max Total		Standard	Minimum Average	Minimum	Maximum	Minimum
WS076	No. Obs	16780	19232	18854	18854	18854	WS076	Days	225	225	260	260
	Number Exc.	1	5700	156	0	156		No. Exceed	0	7	13	0
	Percent Exc.	0.01	29.64	0.83	0	0.83		% Exceed	0	3	5	0
WS354	No. Obs	15329	17580	16745	16745	16745	WS354	Days	204	204	235	235
	Number Exc.	0	4990	385	0	385		No. Exceed	0	3	8	0
	Percent Exc.	0	28.38	2.3	0	2.3		% Exceed	0	1	3	0
WS754	No. Obs	17493	18016	18016	18016	18016	WS754	Days	240	240	250	250
	Number Exc.	1	5010	302	0	302		No. Exceed	1	16	13	0
	Percent Exc.	0.01	27.81	1.68	0	1.68		% Exceed	0	7	5	0
WS1075	No. Obs	18943	19215	19215	19215	19215	WS1075	Days	261	261	264	264
	Number Exc.	537	5668	0	0	0		No. Exceed	21	111	0	0
	Percent Exc.	2.83	29.5	0	0	0		% Exceed	8	43	0	0
WS1210	No. Obs	16287	18074	18074	18074	18074	WS1210	Days	231	231	251	251
	Number Exc.	257	5683	69	0	69		No. Exceed	9	63	6	0
	Percent Exc.	1.58	31.44	0.38	0	0.38		% Exceed	4	27	2	0
WS1850	No. Obs	16982	17234	17234	17234	17234	WS1850	Days	235	235	237	237
	Number Exc.	1418	9675	0	0	0		No. Exceed	20	135	0	0
	Percent Exc.	8.35	56.14	0	0	0		% Exceed	9	57	0	0
WSCR008	No. Obs	1137	1137	1137	1137		WSCR008	Days	13	13	13	13
	Number Exc.	0	171	0	0			No. Exceed	0	0	0	0
	Percent Exc.	0	15.04	0	0			% Exceed	0	0	0	0
WSWM006	No. Obs	1140	1140	1140	1140		WSWM006	Days	13	13	13	13
	Number Exc.	0	117	0	0			No. Exceed	0	0	0	0
	Percent Exc.	0	10.26	0	0			% Exceed	0	0	0	0

4.7.2 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) (Eaton *et al.* 2005). 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 Wissahickon Creek 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 water quality criteria despite re-aeration due to atmospheric diffusion and instream production of DO.

Wissahickon Creek Watershed is affected by municipal wastewater treatment plants and other permitted discharges that introduce BOD to the stream. These discharges were believed to be the most important sources of BOD loading to Wissahickon Creek Watershed. Elevated BOD_5 is a good indicator of the presence of organic material in stream water that may exert oxygen demand independently of natural stream metabolism. The nutrient TMDL for Wissahickon Creek Watershed published in 2003 addresses DO problems primarily through BOD and Ammonia limits for dischargers, but this program was being re-evaluated by EPA as of August 2006.

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 where point source discharges of BOD are regulated and there are no other major sources of organic enrichment (87% of dry weather samples and 83% of wet weather samples had BOD_5 concentration below reporting limits).

As BOD_5 concentration data were affected by a large number of imprecise values and only 19% of samples were collected in wet weather, it was not possible to evaluate differences between sites or evaluate weather effects. BOD_5 was never measurable downstream of site WS1075 and was usually greatest downstream of point source discharge at site WS1850.

4.7.3 PH

Water quality criteria established by PADEP regulate pH to a range of 6.0 to 9.0 in Pennsylvania's freshwater streams (25 PA Code § 93). 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 PADEP.

pH fluctuations generally occur most often at highly productive sites with abundant periphytic algae (Figure 4-8), primarily due to the relationship between algae and dissolved inorganic carbon (DIC). Pronounced diurnal fluctuations in pH were observed at most sites along with DO fluctuations, yet pH maximum violations were more frequent at downstream sites in the City of Philadelphia where DO fluctuations were less pronounced. Minimum pH standards were never violated (Table 4-12). Algal densities and stream metabolism effects on stream pH are discussed further in section 4.8.2 (Relation of Algal Activity to stream pH).

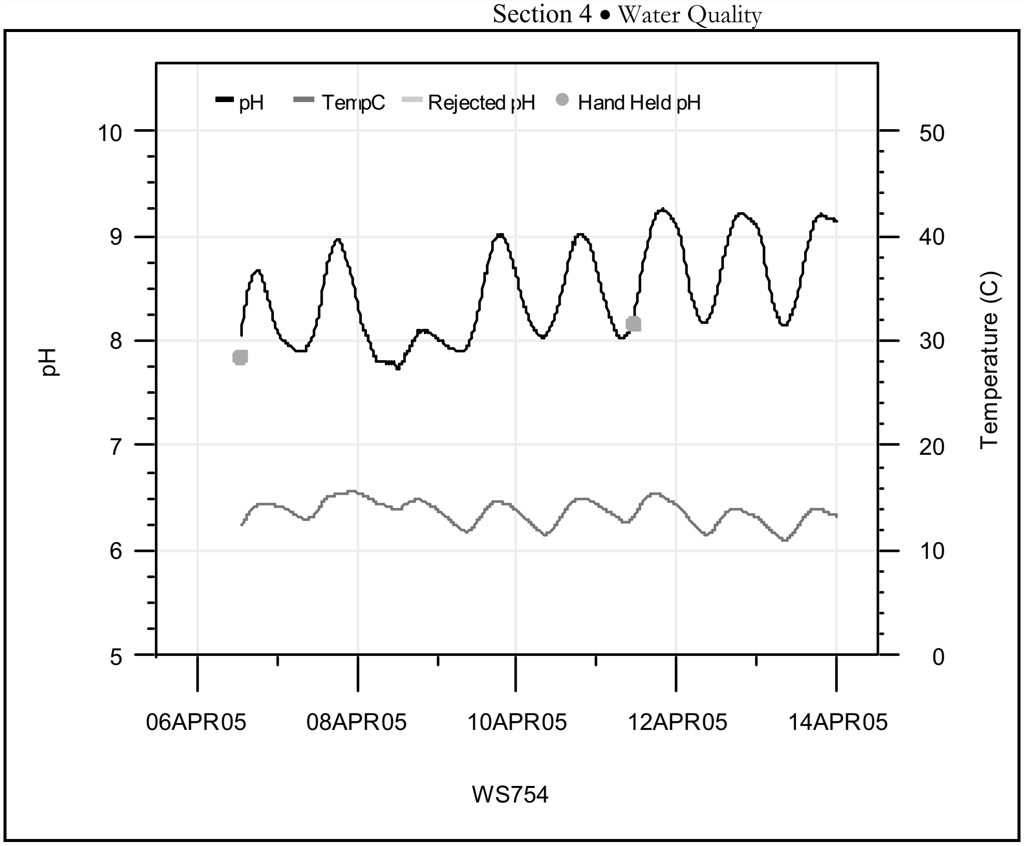


Figure 4-8 pH Fluctuations at Site WS754, April 2005

Table 4-12 Sonde Minimum pH Values Exceeding Standard by Site, 2005

Sampling Site	No. Obs	Number Exc.	Percent Exc.
WS076	18854	0	0.00
WS354	16745	0	0.00
WS754	18016	0	0.00
WS1075	19215	0	0.00
WS1210	18074	0	0.00
WS1850	17234	0	0.00

Wissahickon Creek Watershed is not known to be directly affected by anthropogenic inputs of acids or bases (*e.g.*, acid mine drainage, certain industrial discharges) that would tend to change stream pH independently of the natural bicarbonate buffer system. Accordingly, the WCIWMP will not specifically address pH as a separate problem independent of stream eutrophication. Furthermore, as pH problems in Wissahickon Creek 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.

4.7.4 MICROBIAL AND PATHOGENIC PARAMETERS OF CONCERN

4.7.4.1 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. PADEP 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 2000 CFU/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 (25 PA Code § 93.7). 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, PADEP, 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 the Philadelphia regional 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 various watershed management plans, fecal coliform bacteria analysis has been separated into dry and wet weather components. Wet weather events are based on characterizing a storm event at various locations along the river continuum in its entirety (*i.e.*, rising limb, peak discharge, and descending limb). Wet weather was defined as a 10% increase in flow and a minimum rainfall of 0.05 inches in a 24 hour period (*e.g.*, Assuming a baseflow of 100 CFS, a flow of 110 CFS and at least 0.05 inches of rainfall is considered wet weather.)

Dry Weather Fecal Coliform Bacteria

The geometric mean of 65 fecal coliform bacteria concentration samples collected from Wissahickon Watershed in dry weather during the non-swimming season from 2004-2005 did not exceed 2000 CFU/100mL (Table 4-13). Only 3 of the 65 samples collected from sites WS076, WS754 and WS1075, exceeded the state criterion (estimated fecal coliform concentrations 2500, 2200 and 2300 CFU/100mL, respectively). Similarly, dry weather geometric mean fecal coliform concentration did not exceed water quality criteria of 200 CFU/100mL during the swimming season, with the exception of two mainstem sites and one tributary site (WS1075, WS1210 and WSSR058, respectively)(Table 4-14). In addition, a decrease in dry weather fecal coliform concentrations can be seen in both swimming and non-swimming season when data from 2004-2005 is compared to historical data from 1970-1998 ($t_{0.05(2);118} = -6.52$, $p<0.001$ and $t_{0.05(2);85} = -4.86$, $p<0.001$, respectively) (Table 4-15)

Table 4-13 Fecal Coliform Concentration (CFU/100mL) Dry Weather Non-swimming Season (1 Oct. - 30 Apr.)

Site	Valid N	Mean	Geometric Mean	Median	Minimum	Maximum	Std. Dev.
WS005	10	44	30	40	10	100	34
WS076	10	402	101	80	10	2500	776
WS122	4	60	41	55	10	120	50
WS354	4	68	47	50	20	150	62
WS492	4	60	40	30	20	160	67
WS754	10	362	150	165	20	2200	658
WS1075	7	434	168	140	40	2300	825
WS1210	5	194	138	110	60	550	203
WS1850	7	126	83	70	10	270	100
WSPC017	2	30	28	30	20	40	14
WSSR058	2	160	139	160	80	240	113

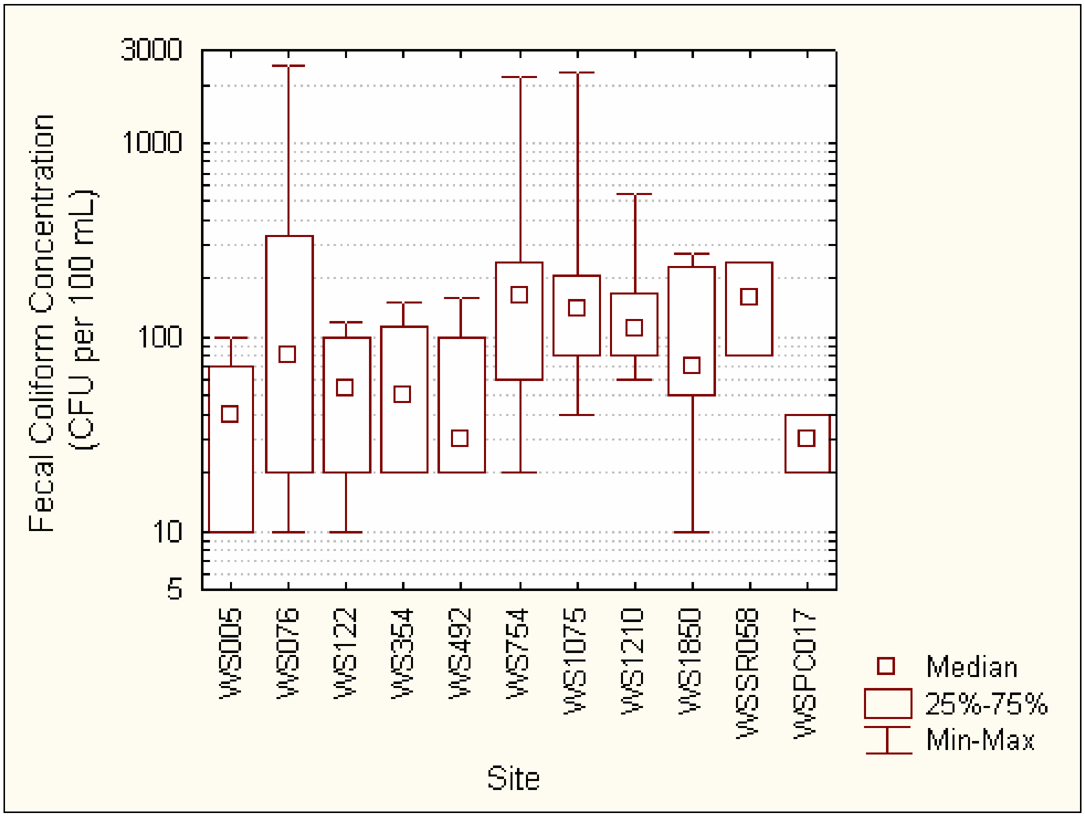


Figure 4-9 Fecal Coliform Concentration (CFU/100mL) Dry Weather Non-swimming Season (1 Oct. - 30 Apr.)

Table 4-14 Fecal Coliform Concentration (CFU/100mL) Dry Weather Swimming Season (1 May - 30 Sept.)

Site	Valid N	Mean	Geometric Mean	Median	Minimum	Maximum	Std. Dev.
WS005	7	114	90	110	30	260	81
WS076	9	210	151	130	50	690	209
WS122	6	165	104	105	40	550	195
WS354	6	210	188	195	100	430	116
WS492	6	110	89	65	50	230	82
WS754	9	229	178	210	60	670	185
WS1075	10	303	277	285	120	500	129
WS1210	6	548	429	340	260	1600	521
WS1850	9	164	157	170	80	220	47
WSPC017	5	158	88	140	10	400	153
WSSR058	5	512	293	220	120	1700	674

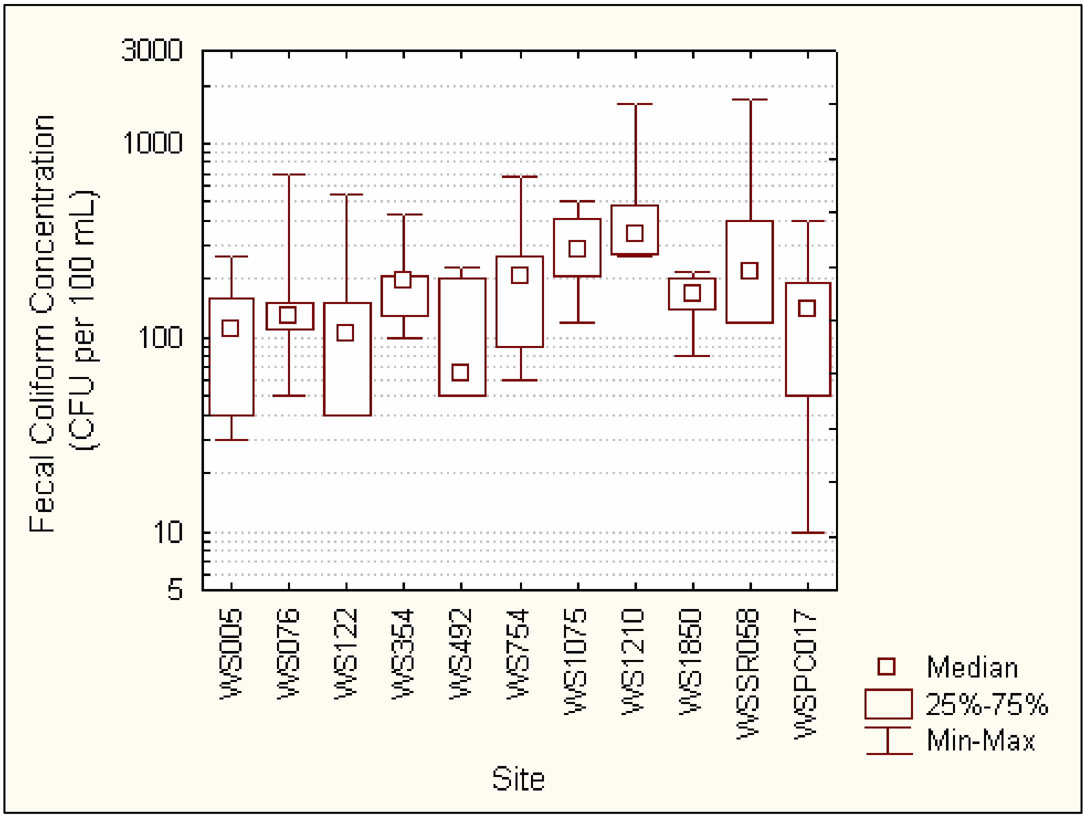


Figure 4-10 Fecal Coliform Concentration (CFU/100mL) Dry Weather Swimming Season (1 May - 30 Sept.)

Table 4-15 Historic (1970-1998) and 2005 Fecal Coliform Concentrations (CFU/100mL) During Dry Weather (Swimming and Non-swimming Seasons)

Sampling Period	Season	Valid N	Mean	Geometric Mean	Median	Minimum	Maximum	Std. Dev.
2005	Swimming	78	241	165	170	10	1700	272
2005	Non Swimming	65	217	78	80	10	2500	489
1970-1998	Swimming	42	2119	587	569	59	51000	7847
1970-1998	Non Swimming	22	603	367	598	20	1800	467

Spatial and temporal variability of fecal coliform concentrations was also compared by performing a two-way analysis of variance (ANOVA). Location (*i.e.*, Montgomery County and Philadelphia County) and season (*i.e.*, swimming vs. non-swimming) served as the categorical predictors and fecal coliform concentration was considered the dependent variable. Collectively, there was no significant difference in mean fecal coliform bacteria concentrations among upstream and downstream sites ($F_{0.05(1),1,139}=3.50, p>0.05$), season ($F_{0.05(1),1,139}=0.06, p>0.05$) or interactions among season and location ($F_{0.05(1),1,139}=0.05, p>0.05$).

Unlike previous watersheds that have been intensely monitored by PWD, dry weather fecal coliform concentrations during swimming and non-swimming periods are significantly lower. Moreover, the minimal effect of spatial variability on fecal coliform concentrations and the significant decrease in concentrations from historical data implies that current management strategies to reduce point source discharges and/or infrastructure failures are functioning properly during dry weather. 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). Evidently, 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.

Wet Weather Fecal Coliform Bacteria

Wet weather fecal coliform concentration of 111 samples collected during the swimming season (*i.e.*, 5/1 - 9/30) and 128 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 4-16, Figure 4-11). All sites, including tributaries (*i.e.*, WSBM007 and WSMC016), had geometric mean fecal coliform concentrations at least eighteen times the state criterion during the swimming season. Spatial variability (*i.e.*, upstream vs. downstream) of fecal coliform concentration was compared by performing a one-way analysis of variance (ANOVA). Results suggest that the mean concentration of fecal coliform during wet weather did not significantly differ from upstream, downstream and tributary sites during the swimming season ($F_{0.05,(1),1,105} = 0.62, p>0.05$).

Table 4-16 Fecal Coliform Concentration (CFU/100mL) Wet Weather, Swimming Season (1 May - 30 Sept.)

Site	Valid N	Mean	Geometric Mean	Median	Minimum	Maximum	Std. Dev.
WS076	21	14120	8127	9000	120	42000	11916
WS754	15	19510	10540	15000	250	74000	19570
WS1075	12	29367	18465	24000	1300	94000	25774
WS1850	18	20484	9801	17000	130	52000	16291
WSMC016	24	16096	6902	8350	390	82000	20019
WSBM007	21	24093	3693	5500	10	243000	52689

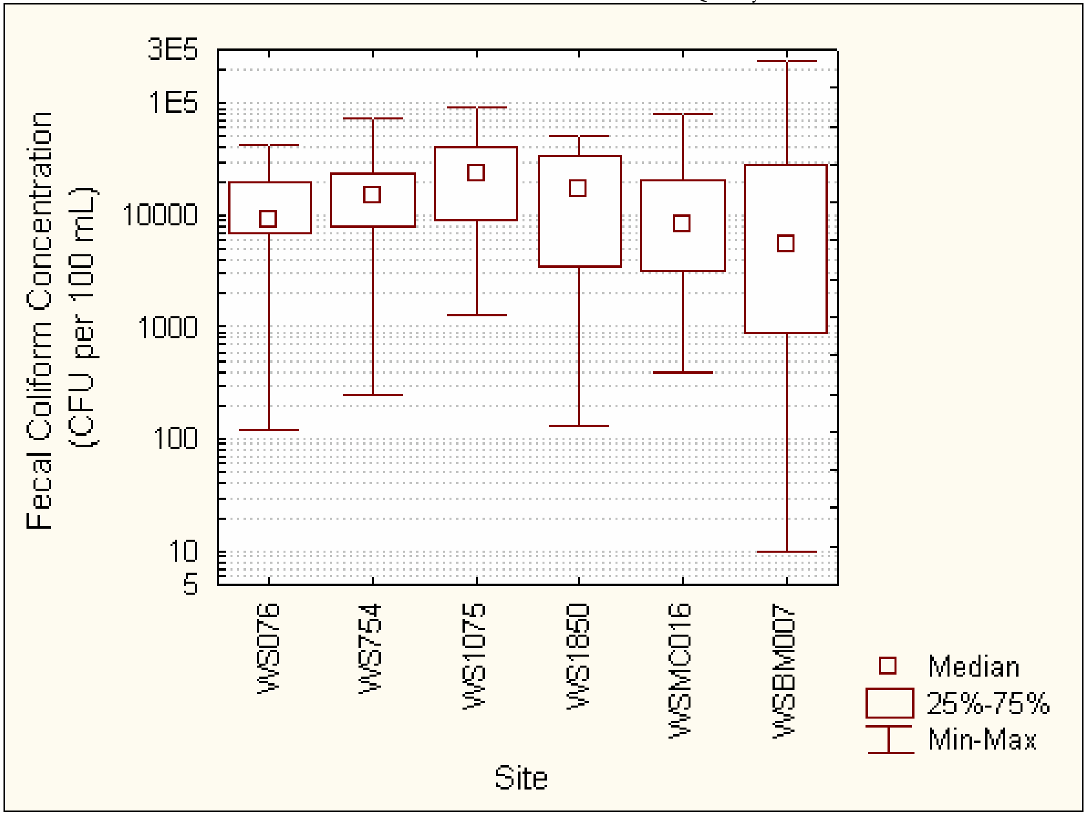


Figure 4-11 Fecal Coliform Bacteria Concentrations of Samples Collected from 6 Sites in Wissahickon Creek Watershed in Wet Weather During the Swimming Season, 2005.

Similarly, geometric mean fecal coliform concentrations during the non-swimming season exceeded 2,000 CFU/100mL at all sites along the Wissahickon Creek mainstem and its associated tributaries (Table 4-17, Figure 4-12). ANOVA results suggest significant differences in mean fecal coliform concentrations among sites ($F_{0.05(1),6,\ 121}$=2.81, p<0.05) and an *a priori* test (Student- Newman-Keuls) revealed that fecal coliform concentrations at upstream sites (WS1850 and WS1075) were significantly greater than both downstream sites (WS754 and WS076, *p*=0.05 and *p*=0.03, respectively) and tributary sites (WSCR008 and WSWM006, *p*=.004 and *p*=0.01, respectively). At this time, there is no definitive explanation for the elevated concentrations of fecal coliform in the upstream reaches in wet conditions during the non-swimming period. Regardless, fecal coliform concentrations at all locations were well above the state criterion of 2000 CFU/100mL, and therefore, the problem should be addressed as a watershed-wide issue and not as a targeted study. Future wet weather events collected during the 2006 monitoring season will elucidate the spatial and temporal trends and will be posted as an addendum to the current report. As previously stated, plans to initiate a bacteria source tracking program (BST) will also be informative in distinguishing the origin of pathogens during wet weather events.

In addition to the 2005 sampling period, a comparison of historical data collected by USGS and PADEP during 1970-1998 was performed. However, it must be noted that the sampling program conducted by PWD specifically targeted wet weather events in their entirety. Sampling methods and equipment (*i.e.*, automated samplers) were more conducive to characterize fecal coliform concentrations at all points along the hydrograph and were more suitable to collect periods of peak fecal coliform concentrations. Regardless, geometric means of historical wet weather samples (n=38) and samples collected in 2005 (n=239) both exceeded the state criteria for swimming and non-swimming seasons (2520 CFU/100 mL and 6976 CFU/100 mL, respectively). Moreover, the elevated concentrations of fecal coliform were omnipresent at all monitoring locations during the historical assessments, similar to the findings of the 2005 study.

Table 4-17 Fecal Coliform Concentration (CFU/100mL) Wet Weather, Non-swimming Season (1 Oct. - 30 Apr.).

Site	Valid N	Mean	Geometric Mean	Median	Minimum	Maximum	Std. Dev.
WS076	28	21697	6164	5050	40	234000	43818
WS754	27	17617	3853	3100	40	151000	32913
WS1075	17	34299	17616	24000	80	97000	29811
WS1850	17	55096	27870	40000	40	179000	47715
WSBM007	9	25081	7579	13000	700	85000	33163
WSCR008	20	17256	2177	3850	30	73000	25389
WSWM006	10	11612	2356	3450	60	57000	19181

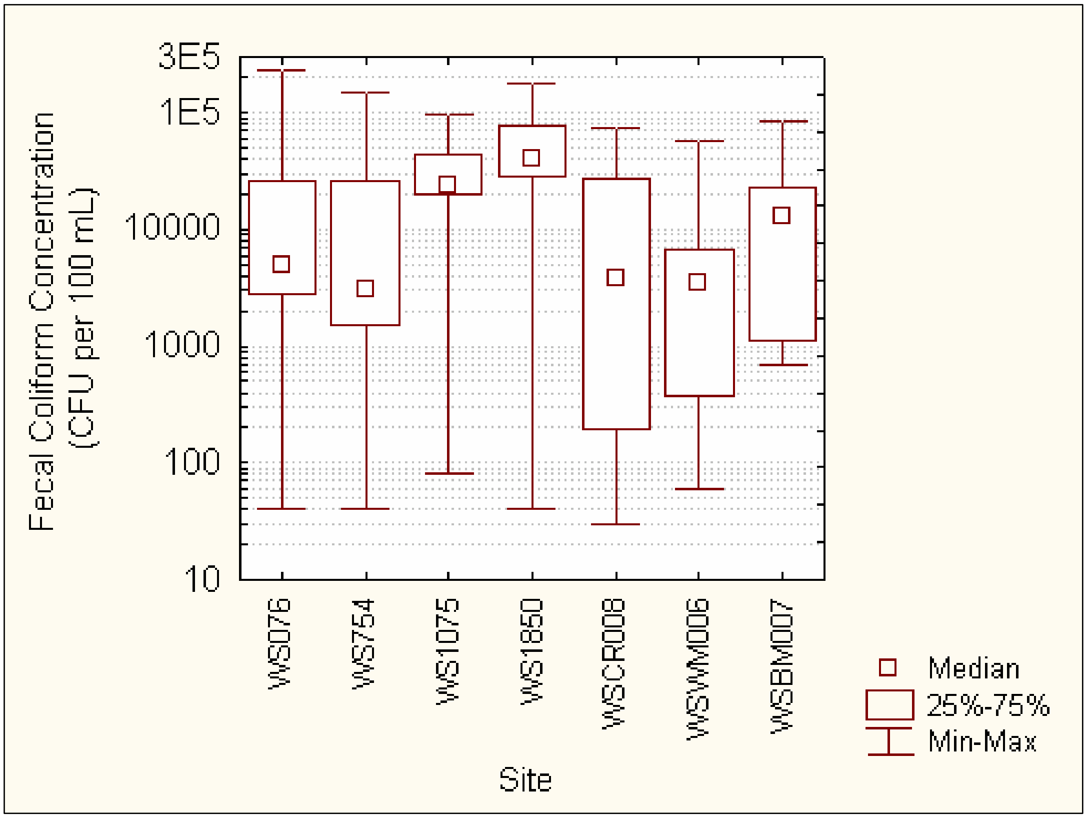


Figure 4-12 Fecal Coliform Bacteria Concentrations of Samples Collected from 7 Sites in Wissahickon Creek Watershed in Wet Weather During the Non-swimming Season, 2005.

4.7.4.2 *CRYPTOSPORIDIUM*

Cryptosporidium parvum is a pathogenic protozoan that lives in the intestines of humans and animals. It is commonly spread by the feces of an infected host entering surface water through agricultural runoff or waste water treatment plant discharges. During storm events, correlations can be observed between *Cryptosporidium* and flow, turbidity, fecal coliform, and total coliform data

(Crockett 2000). During dry weather conditions, *Cryptosporidium* concentrations are observed in direct relationship to flow and inversely related to water temperature. *Cryptosporidium* concentrations are lowest during the warmer months of June through October. Aside from flow and temperature, no correlations have been identified between *Cryptosporidium* and other water quality parameters during dry weather conditions (Rosen *et al.* 2006).

The dormant oocyst stage of the pathogen's life cycle is extremely resistant to conventional water treatment methods, but can be removed effectively with various filtration techniques, such as bag or cartridge filtration, membrane filtration, second stage filtration, and slow sand filtration. Alternately, cysts can be inactivated by chlorine dioxide, ozone, or UV treatment.

Cryptosporidium can cause an infection of the intestines called cryptosporidosis. The disease causes diarrhea and dehydration, and can be serious or even deadly in some susceptible populations, such as children, the elderly and individuals with compromised immune systems. This pathogen is federally regulated by the *Interim Enhanced Surface Water Treatment Rule* (IESWTR) for water systems serving 10,000 persons or more and the *Long Term 1 Enhanced Surface Water Treatment Rule* (LT1) for water systems serving fewer than 10,000 persons (USEPA 2002). These rules require 2-log removal (99%) of *Cryptosporidium* oocysts.

While LT1ESWTR requirements were sufficient for addressing most water utilities, *Long Term 2 Enhanced Surface Water Treatment Rule* (LT2ESWTR, often abbreviated LT2) criteria were subsequently developed to acknowledge and address utilities with exceptionally high levels of *Cryptosporidium* in their source waters (USEPA 2006). Under LT2ESWTR criteria, systems are required to conduct surface water monitoring to characterize *Cryptosporidium* occurrence. Based on the results of these source water assessments, each system is given a bin classification with associated reduction requirements if *Cryptosporidium* is found to exceed 0.075 cyst/L (Table 4-18). The required log reduction can be achieved through a combination of demonstrating actual reduction and the implementation of various "microbial toolbox" options to receive credits towards compliance. Some "microbial toolbox" options include the implementation of a Watershed Control Program to reduce upstream *Cryptosporidium* contributions, meeting treatment requirements through pre-filtration, demonstrating filter performance, adding additional filtration, or through advanced treatment (inactivation) using chlorine dioxide, ozone, or UV.

Table 4-18 Classification Categories of Source Water Assessments to Characterize *Cryptosporidium* Occurrence

Source Water Bin	Action Bin
MRAA or Mean Source Water *Cryprosporidium*/L	Action Required
<0.075	No Action
0.075 to 1.0	1 additional log treatment from toolbox (Table 2)
1.0 to 3.0	2 additional log treatment (1 log inactivation membranes required plus 1 toolbox)
> 3.0	2.5 additional log treatment (1 log inactivation membranes required plus 1 toolbox)

The *Pennsylvania Safe Drinking Water Act, adopted in 1971 and amended frequently thereafter* mirrors the above mentioned federal rules (Chapter 109 PA Code ref).

PWD collects samples from drinking water intakes on a monthly basis to test for *Cryptosporidium*. Additionally, PWD is leading a *Cryptosporidium* Source Tracking Program with Lehigh University to identify the sources of *Cryptosporidium* in Wissahickon Creek Watershed. Surface water is sampled twice per month at the mouth of the Wissahickon (WS076) and at the boundary of Philadelphia and Montgomery counties (WS754) and once per month from an upstream waste water plant discharge.

Samples collected at the mouth of the Wissahickon (WS076) provide an indication of the potential impact of *Cryptosporidium* from the Wissahickon on the Schuylkill River. Sensitive uses in the Schuylkill River include PWD's Queen Lane and Belmont Water Treatment Plant intakes as well as aquatic contact recreation activities. The Queen Lane Water Treatment Plant (QLWTP) intake is a particular concern, as dye testing suggests that Wissahickon Creek flow can make up as much as 30% of the flow to this plant during certain flow conditions. Samples collected at WS754 provide an indication of the contribution of upstream communities outside of the City to the *Cryptosporidium* observed in the Wissahickon within the City. Samples collected from the upstream waste water discharge provide some indication of how WWTPs may contribute to *Cryptosporidium* loadings in the watershed and may also help to isolate the influence of human sources.

Fecal samples collected from various host sources (deer, geese, horse, cow, pig, etc.) and at various locations within the watershed assist in identifying the sources of the oocysts observed in water samples and provide further indication of what sources may have the greatest impact on oocyst concentrations in the watershed.

Cryptosporidium has been found at each of the 3 sampling locations. Sources identified to date include human, skunk, deer, goose, and snake. Sample collection will continue through December of 2006, after which the data will be validated and conclusions will be made.

In conjunction with the sampling conducted under the *Cryptosporidium* Source Tracking Program, duplicate samples are collected at each location and then sent to a third party laboratory (Clancy Environmental, Inc., St. Albans, Vermont) for oocyst enumeration and infectivity analysis. Of the 41 samples so far analyzed, only 1 sample has been identified as infectious (Table 4-19).

Table 4-19 *Cryptosporidium* Samples Collected in Wissahickon Creek Watershed and at Queen Lane Water Treatment Plant for Enumeration and Infectivity Analysis (Through 6/5/06)

	WS076	WS754	WWTP
Number of samples	19	17	5
Total number of oocysts counted	24	16	7
Number of samples with positive detections	7	7	3
number of infectious oocysts detected	1	0	0

4.7.4.3 GIARDIA

Giardia lamblia is a pathogenic protozoan that lives in the intestines of humans and animals. It is commonly spread by the feces of the infected host entering surface water. The pathogen is federally regulated under the *Surface Water Treatment Rule*, which requires 3-log removal (99.9%) and inactivation of *Giardia* cysts. Pennsylvania regulations include the *Pennsylvania Safe Drinking Water Act*, which has the same requirements. *Giardia* can cause an intestinal infection called Giardiasis, which has symptoms and risks for certain segments of the population similar to cryptosporidosis

Giardia is analyzed together with *Cryptosporidium* from the monthly samples collected at PWD's Water Treatment Plant intakes as well as from the samples collected under PWD's Source Tracking Project. Initial results indicate a potentially significant contribution of *Giardia* from WWTPs and an association between the presence of *Giardia* and the presence of *Cryptosporidium* at all sampling points

Table 4-20 Geosmin Samples Collected and Enumerated from Wissahickon Creek Watershed and at Queen Lane Water Treatment Plant (Through 6/5/06)

	WS076	WS754	WWTP
Number of samples	19	17	5
Total number of *Giardia* organisms counted	66	37	920
Number of samples with positive detections	7	10	3

4.7.5 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 water quality criteria for Wissahickon Creek Watershed are based on the trout stocking fishery (TSF) designation, and reflect the fact that the watershed is not expected to have appropriate conditions to support self-propagating populations of coldwater fish (*e.g.*, trout species), but can support stocked fish as part of a put-and-take fishery.

Maximum temperature criteria for trout stocking fisheries are considerably more stringent than those for warm water fisheries during the critical spring and summer periods, usually several degrees cooler than those specified for warm water streams. Trout Stock fisheries, however, may be allowed to warm to the same extent as warm water fishery streams (*i.e.*, up to 87ºF, or 30.5ºC), if for a only a brief 15 day period in late summer considered the warmest part of the year (August 16 through 30). Warm water fisheries may have water temperature up to 87ºF (30.5ºC) throughout July and August.

Stream temperatures in Wissahickon Creek Watershed were generally similar across sites. With the exception of site WS1850, many potential violations of daily maximum temperature occurred early in the year, but rarely in summer (Appendix D Continuous Dissolved Oxygen Figures). As stream temperatures are most strongly related to ambient air temperature (Bartholow 1989), it is recognized that patterns observed in the 2004/2005 dataset are not necessarily representative of other years. Stream temperatures for a given time period exhibit a great deal of interannual variation and exceedences of water temperature criteria may occur at random due to climatic factors. Water temperature was, however, consistently higher at site WS1850 than at other sites and potential violations of water quality criteria occurred throughout the year at this site. This observation is probably due to baseflow suppression (*i.e.*, reduced groundwater recharge) causing minimal dilution of municipal treated wastes at this location. Furthermore, relationships between weather events, streamflow, air temperature, and stream temperature were not simple. Stormwater demonstrated the ability to warm or cool the stream, depending on season and the preexisting temperature states of the stream, air and landscape (Appendix D Continuous Dissolved Oxygen Figures).

According to 25 PA Code §93.7, "heated wastes" can neither cause stream temperature to exceed the maximum temperature criterion for a given time period, nor can they result in an increase of 2ºF (~1.1ºC) over one hour. Continuous water quality monitoring results suggest that temperatures in Wissahickon Creek Watershed frequently exceeded maximum and rate-of-change water quality criteria (Table 4-21). However, increases of 2ºF over a one hour period have been observed to be common throughout southeast PA due to natural temperature fluctuations, especially in low gradient streams, reservoirs and ponds.

According to PADEP Division of Water Quality standards, municipal treated waste and stormwater are not usually considered heated wastes, and exceedences of water quality criteria due to these sources and natural fluctuations are generally not enforced. The PADEP does, however, reserve the right to make determinations on a case by case basis and impose temperature limitations on any discharge that has been demonstrated to be (or is expected to be) causing a problem. Of particular concern are Exceptional Value (EV) waters and wild reproducing brown trout streams.

Flow modifications have probably reduced the influence of groundwater on baseflow water temperature in Wissahickon Creek Watershed. Dam construction and riparian buffer removal have also probably resulted in enhanced solar heating of stream water; however, temperature did not appreciably increase in a downstream direction within the City of Philadelphia despite numerous dam impoundments. One explanation for this could be the shape of the Wissahickon Valley and nearly contiguous mature forest canopy buffer along both streambanks in Fairmount Park.

Table 4-21 Sonde Temperature Measurements Exceeding Maximum Standards by Site, 2005

Sampling Site	No. Obs	Number Exc.	Percent Exc.
WS076	19232	5700	29.64
WS354	17580	4990	28.38
WS754	18016	5010	27.81
WS1075	19215	5668	29.50
WS1210	18074	5683	31.44
WS1850	17234	9675	56.14

4.7.6 OTHER PHYSICOCHEMICAL PARAMETERS

4.7.6.1 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. PADEP has identified the cause of impairment in Wissahickon Creek to be "siltation" in 21 stream segments. Six of these segments are mainstem Wissahickon and 15 segments are tributaries. Most of the segments have "urban runoff/storm sewers" listed as the source of siltation. Three exceptions list habitat modification, municipal and other non-point sources and surface mining as sources.

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, Ongley 1996, Ferguson 1986); errors related to sampling technique should preclude computation of sediment transport during severe storm events that mobilize large streambed particles. TSS concentration was significantly greater in wet weather than in dry weather ($U_{0.05(2)124,305} = 5570$, $p<0.001$).

TSS and turbidity concentrations were measured from surface water grab samples collected prior to wet weather events and from samples collected by automated samplers (Teledyne Isco Inc.) during wet weather events. A total of 260 samples were collected from eight sites along mainstem Wissahickon Creek throughout 2005 (WS076, WS122, WS354, WS492, WS754, WS1075, WS1210 and WS1850), and 169 samples were collected from tributary sites. Data collected from tributaries outside of the City (Sandy Run and Prophecy Creek) were not included in the statistical analysis due to differences in geology and land use.

TSS concentration in mainstem Wissahickon was found to be significantly positively correlated to turbidity (Log transformed) ($r_{(243)}=0.92$, $p<0.001$). The minimum and maximum TSS concentrations observed were 1.07 and 487.3 mg/L, respectively. Minimum and maximum turbidity concentrations observed were 0.661 and 227 NTU, respectively.

TSS and turbidity were more closely correlated in mainstem samples than in the tributaries, however, the latter correlation was still significant (Log transformed) ($r_{(58)}=0.80$, $p<0.001$). Because of their relatively smaller drainage areas, tributary sites must experience generally more concentrated local rainfall in order to result in greater flow magnitude. The more ephemeral nature of these events constrained the range of flows in the data set. Minimum and maximum TSS concentrations of samples collected from tributary sites were smaller than those observed in mainstem sites, at 1.31 and 211.8 mg/L, respectively. The minimum and maximum turbidity concentrations of samples collected from tributary sites were 0.245 and 69.5 NTU respectively. Strong correlations between TSS and Turbidity support the future use of turbidity as an indicator of TSS concentration with the caveat that extrapolation is less reliable outside of the measured range.

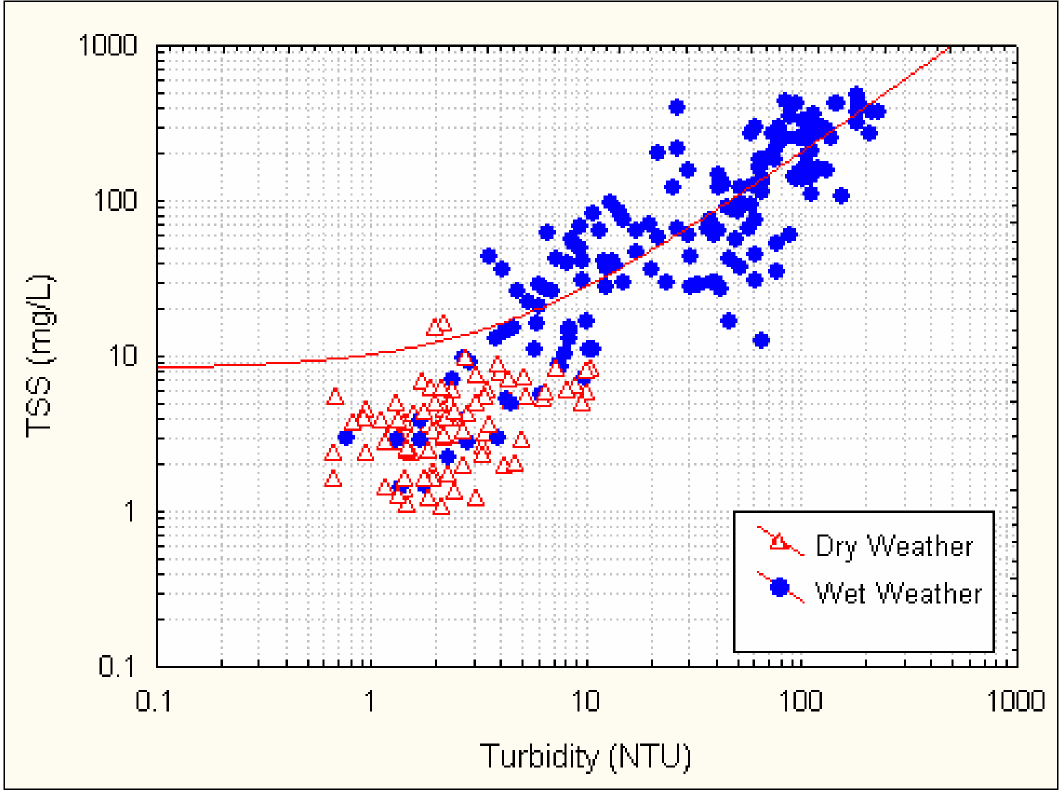


Figure 4-13 Scatterplot of Paired TSS and Turbidity Samples Collected from 8 Mainstem Sites in Wissahickon Creek Watershed, 2005

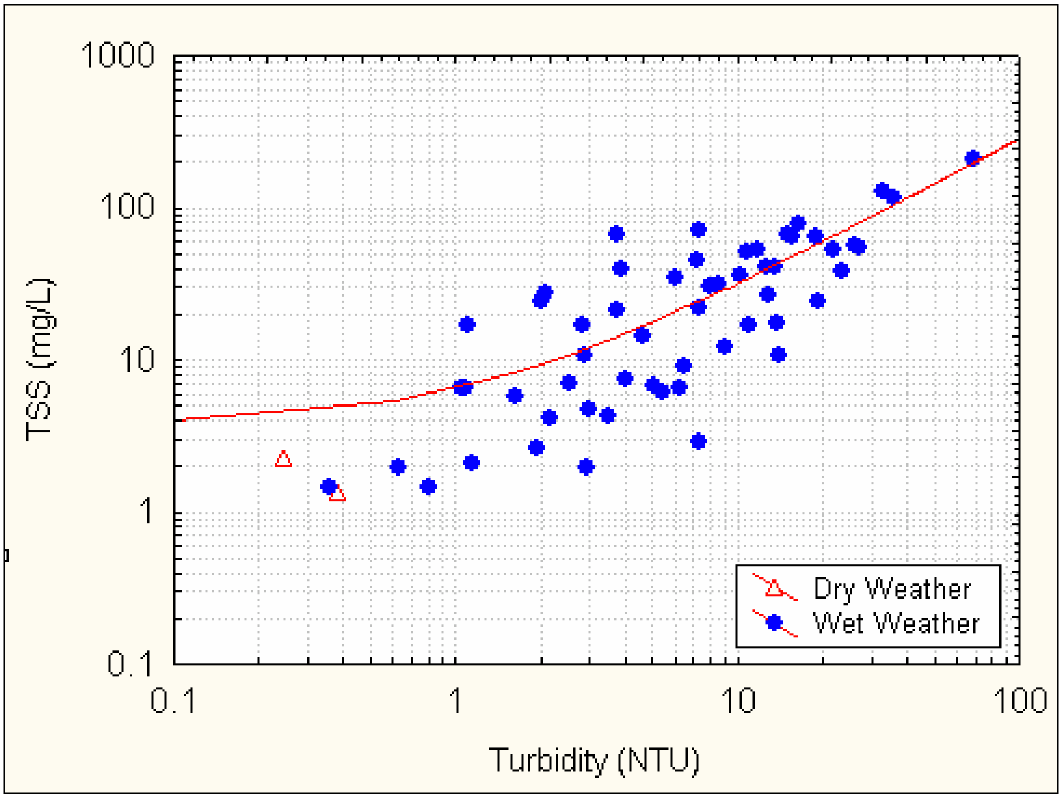


Figure 4-14 Scatterplot of Paired TSS and Turbidity Samples Collected from 4 Tributary Sites in Wissahickon Creek Watershed , 2005

Using the relationship between TSS and turbidity in mainstem Wissahickon described in this section, TSS concentration was extrapolated from continuous sonde turbidity data. The extrapolated data were plotted against corresponding streamflow data collected by USGS. Data were collected in 15 minute increments producing a large data set. Only a subset of this data was plotted. The dates 3/23/05 through 4/6/05 include three wet weather events and are appropriate to show the relationship between TSS and flow. Log transformed TSS and streamflow were found to be significantly positively correlated at site WS076 ($r_{(1340)} = 0.88$, $p<0.001$) and WS1075 ($r_{(1347)} = 0.93$, $p<0.001$). Maximum TSS concentration and streamflow recorded at WS076 were 3378.7 mg/L and 6640 NTU and at WS1075 were 2289.3 mg/L and 5690 NTU.

Though a significant correlation exists, it is not always the case that peak TSS and peak streamflow will occur simultaneously. Plots of TSS vs streamflow often exhibit hysteretic loops (*i.e.*, tracing the samples synchronously, one may find that the data points do not follow a straight line, but rather resemble a clockwise or counterclockwise loop). Hysteretic loops occur because the timing of peak TSS is dependant on its source and antecedent wet weather event conditions. TSS that is predominantly channel supplied will generally peak prior to streamflow, creating a clockwise hysteretic loop. Alternatively, there will be a lag time for peak TSS if it originates from runoff and streambank erosion (Van Sickle and Breschta 1983, Klein 1984). Two storms occurring in succession may produce very dissimilar patterns as the first storm can leave the stream in a variety of potential states, particularly with regard to in-channel sediment availability.

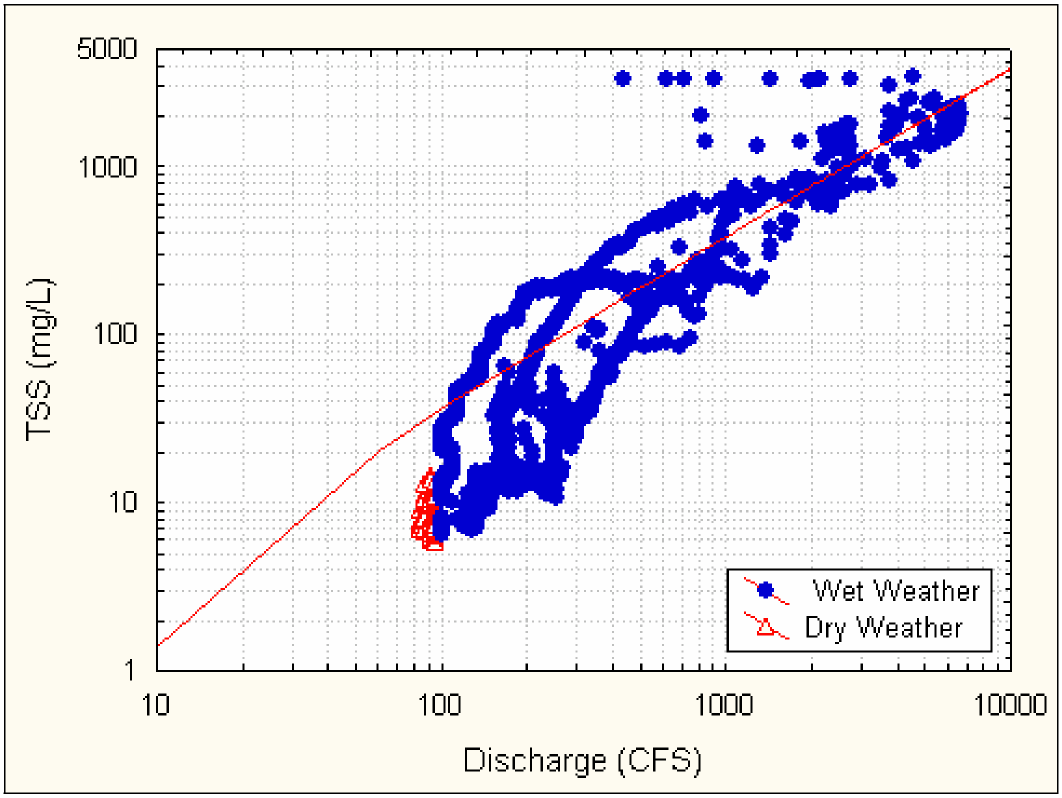


Figure 4-15 Scatterplot of Paired Streamflow and TSS Samples From Site WS076 (3/23/05 - 4/6/05)

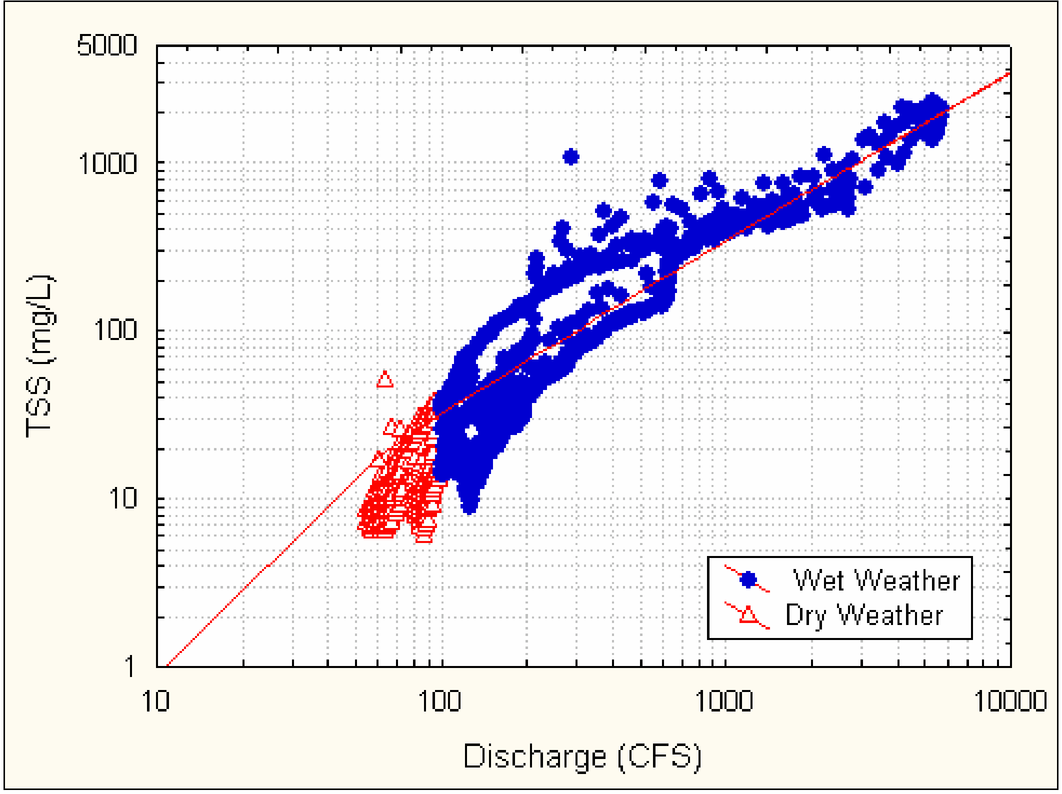


Figure 4-16 Scatterplot of Paired Streamflow and TSS Samples From Site WS1075 (3/23/05 - 4/6/05)

4.7.6.2 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 also clog gills and feeding apparatus of fish, benthic invertebrates, and microorganisms. Furthermore, feeding efficiency of visual predators may be reduced in consistently turbid waters.

PADEP has not established numeric water quality criteria for turbidity, though General Water Quality Criteria (25 PA Code §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 WCIWMP will use 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 (US EPA 2000). Turbidity was determined to be a problem in all sites based on continuous Sonde data. Discrete data were similar, as turbidity was determined to be a problem during wet weather and a potential problem during dry weather in the watershed overall. During wet weather, 186 out of 310 total samples were above the reference value. While there were differences in the proportion of samples above the reference value among sites, turbidity was determined to be a problem or a potential problem during both dry and wet weather in all sites with a sufficient number of discrete samples.

4.7.6.3 CONDUCTIVITY AND TOTAL DISSOLVED SOLIDS (TDS)

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) (Eaton *et al.* 2005). 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 ungaged 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, PADEP water quality 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.

4.7.6.4 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. Hardness is important in the calculation of water quality criteria for toxic metals (25 PA Code § 16), as toxicity of most metals is inversely proportional to hardness concentration. Groundwater in Wissahickon Creek Watershed is naturally moderately hard to hard, so streams usually have greater hardness in dry weather than in wet weather. Domestic drinking water supplies may also be somewhat naturally hard, with pH and sulfate levels that allow municipal water suppliers in Montgomery County to forego addition of corrosion inhibitors. It has been hypothesized that elevated dissolved metals (*e.g.*, lead and copper) concentrations in municipal wastewater effluents may be primarily due to corrosion in potable water distribution systems.

Two wet weather samples collected from Radium Run, a small spring-fed tributary to Monoshone Creek Wissahickon Creek Watershed had hardness concentration below the 20mg/L water quality criterion, but this probably reflects natural stormwater conditions. 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 water quality criteria below reporting limits for the ICP-MS technique (*i.e.*, less than 1μg/L). These samples are discussed in greater detail in section 4.7.7.

4.7.6.5 IRON AND MANGANESE

Iron (Fe) and Manganese (Mn) are generally not toxic in natural streams, but certain conditions (*e.g.*, very low pH due to acid mine drainage) can result in increased toxicity of Fe and Mn. The typical mechanism of Fe toxicity in fish is asphyxiation due to accumulation of metal on gill surfaces

(Dalzell and MacFarlane 1999) though Fe[II] toxicity is not unknown. Dissolved Fe and total recoverable Mn are also regulated in waters of the Commonwealth of Pennsylvania for public water supply (PWS) protection (25 PA Code §93.7) 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 life and relatively abundant in the soils and surface geology of Wissahickon Creek Watershed.

Iron is a particularly abundant element (at approximately 5% of the Earth's crust it is second only to Aluminum in abundance among metals) and was detected in 356 of 360 samples collected from Wissahickon Creek Watershed. Manganese was less abundant but detectable in 299 of 307 samples. Presence of these metals in surface water samples may be naturally 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). Blooms of iron fixing bacteria were observed in some areas of the watershed.

Mn criteria were never exceeded in 307 samples, but violations of total recoverable Fe water quality criteria were frequent in wet weather (Appendix E Water Quality Results and Comparison to Standards). However, Fe may not be toxic to aquatic life at the concentrations observed, as pH levels were typically neutral and conditions in Wissahickon Creek Watershed do not favor accumulation of Fe on gill surfaces (Gerhardt 1994). Nevertheless, Fe cannot be ruled out as a potential cause of observed impairments in aquatic communities. Unlike toxic metals (*e.g.*, lead, cadmium and copper), Fe and Mn are not regulated by 25 PA Code § 16 - Water Quality Criteria for Toxic Substances.

4.7.7 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 25 PA Code § 16.24 - Toxic Metals 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 (Eaton *et al.* 2005). 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 general. Water quality sampling data from the Philadelphia metropolitan area suggests that urban streams without point sources of treated municipal waste typically experience increases in toxic metal concentrations due to stormwater and soil erosion. Metals in stormwater runoff may consist of predominantly large inert inorganic particulates, such as ores and minerals, or metals adsorbed to soil particles or complexed with other constituents such that the ratio of dissolved metal to total recoverable metal decreases with increasing total metal concentration. This relationship is consistent among many toxic metal constituents in urban streams studied by PWD (PWD 2004).

However, Wissahickon Creek Watershed is also affected by point sources of toxic metals. Point and non-point sources may differ significantly with respect to the ratio of dissolved vs. total recoverable metal. Dry weather point source inputs tended to have a very high dissolved to total metal ratio that remained consistent over a range of total metals concentration. The predominant factor in dry weather dissolved metals concentration was due to dilution effects of stream discharge. Individual facilities and groups of facilities discharging to the watershed have received exemptions to PA water quality criteria in NPDES permits based on Water Effects Ratio (WER) studies. These studies are addressed as appropriate in subsequent sections.

As dissolved metals concentrations in the smaller tributaries to Wissahickon Creek Watershed were usually small or undetectable in both dry and wet weather, the potential for heavy metal toxicity in these tributaries is believed to be low, at least for water column organisms. 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. For example, Borgmann and Norwood (1997) found *Hyalella azteca* (Amphipoda: Hyalellidae) demonstrated increased sensitivity to sediment pore water Zn, but no observable increase in toxicity with increases in sediment pore water Cu concentration.

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 water quality criteria are based on hardness (as $CaCO_3$), to reflect inverse relationships between hardness and toxicity that exist for most metals (Figure 4-17). This relationship becomes especially important in streams where stormwater tends to dilute the ionic content of water while increasing concentrations of toxic metals. Point source influenced Philadelphia streams tend to experience decreased conductivity and hardness during storm events.

While hardness-based 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), a draft of which was presented by EPA in 2003 (Di Toro *et al.* 2001)

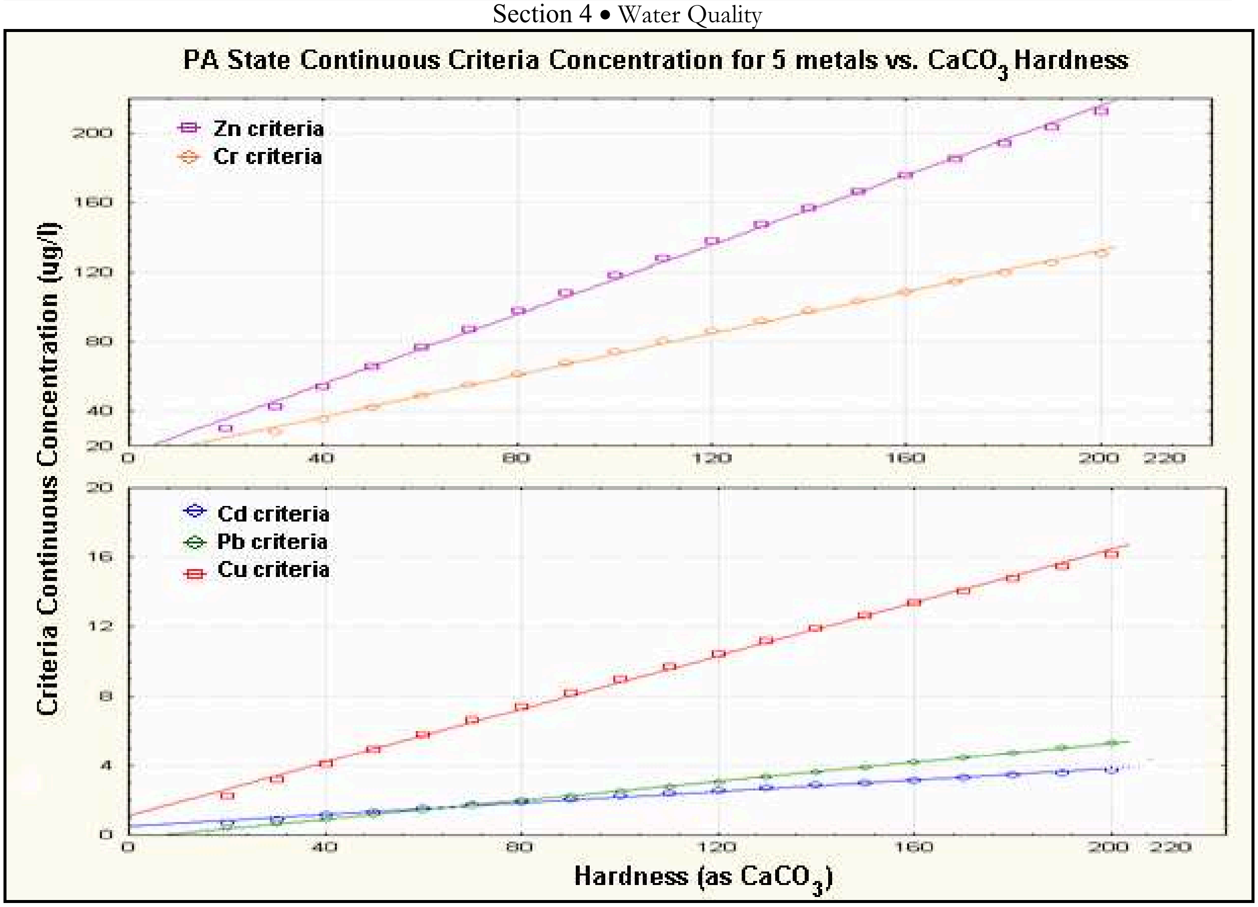


Figure 4-17 PADEP Hardness-based Criteria Continuous Concentrations for 5 Toxic Metals.

4.7.7.1 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. As described in section 4.3 (Water Quality Sampling and Monitoring Protocols), the 2005 Wissahickon water quality database contains results from numerous sampling programs with varying objectives. Considering only the sites from which a valid number of samples were collected, water column Al concentrations were significantly higher in wet weather than in dry weather ($U_{0.05(2)110,213}=3317, p<0.001$). Examination of paired dissolved and total recoverable Al concentrations from discrete interval grab samples collected from Wissahickon Creek Watershed showed that while total recoverable Al concentrations may often have exceeded 100 µg/L in wet weather, dissolved Al was rarely present in similar concentrations (Figure 4-18). The strong positive correlation between Al and TSS also suggested that Al was usually present in particulate form, such as clays, during storm events (Figure 4-19).

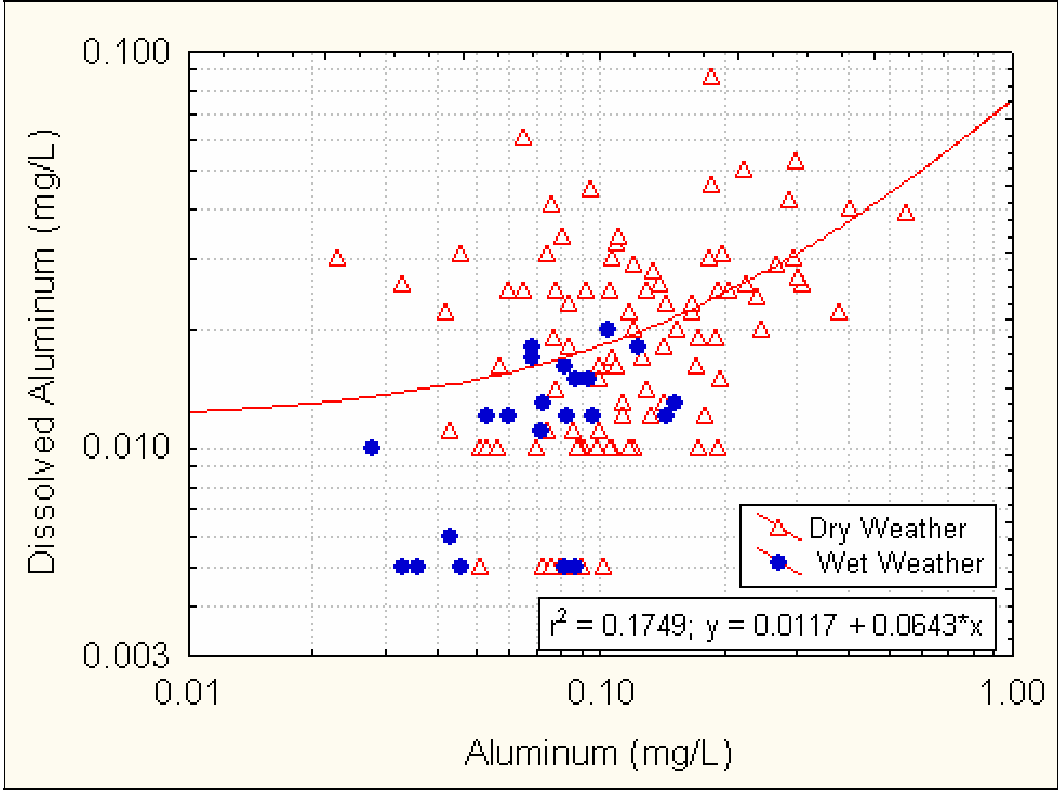


Figure 4-18 Scatterplot of Paired Total Recoverable Aluminum and Dissolved Aluminum Samples Collected at 8 Mainstem and 2 Tributary Sites in Wissahickon Creek Watershed, 2005

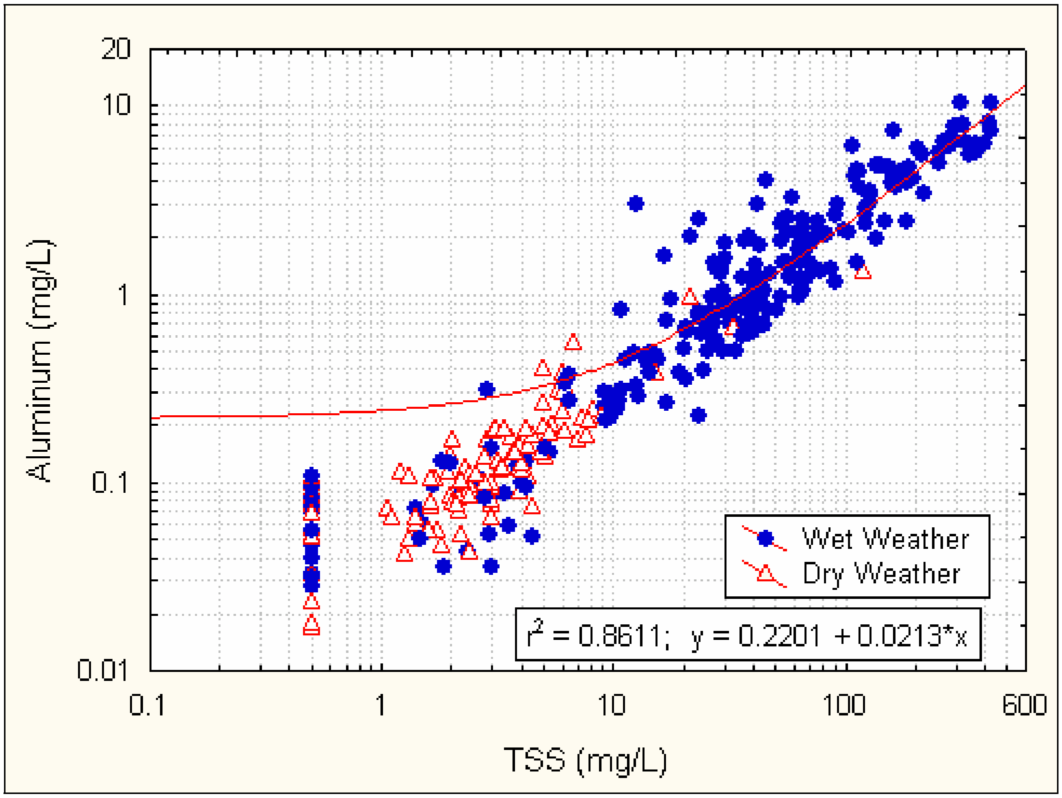


Figure 4-19 Scatterplot of Paired TSS and Total Recoverable Aluminum Samples Collected from 8 Mainstem and 6 Tributary Sites in Wissahickon Creek Watershed, 2005

Wet-weather targeted sampling events are more likely to capture greater concentrations of wet weather constituents that correlate with flow than discrete interval samples, especially in flashy urban streams. Tributary sites WSMC016, MCRR002, WSBM007, and WSBM090 did not have a sufficient number of dry weather samples to compare the effects of wet weather on total or dissolved metals, but it is assumed that dry weather concentrations are generally much smaller and that only a small fraction of the metal is present as the dissolved fraction.

Al was detected in 321 of 323 samples from Wissahickon Creek Watershed (Table 4-22); violations of PADEP water quality criteria were observed in 2% and 60% of samples collected in dry weather and wet weather, respectively. However, a much greater proportion of wet weather samples were collected from smaller tributaries which are not affected by point source discharge. Wet weather suspended solids loads consist of a mixture of urban/suburban stormwater, eroded upland soils, streambank particles, and in mainstem Wissahickon Creek downstream of WS1850, municipal treated waste. It is thus impossible to determine individual Al contributions of these sources.

Al found in natural streams may be predominantly mica and clays, which are inert under normal stream conditions. Dissolved Al had a much poorer correlation with TSS than total recoverable Al. (Figures 4-18 and 4-19). As of September 2005, the wet weather sampling procedure has been modified to so that grab samples are taken for dissolved metals analysis while replacing collection bottles. This additional sampling effort is being directed at analyzing these total/dissolved metals relationships for stormwater-impacted tributaries within the City of Philadelphia.

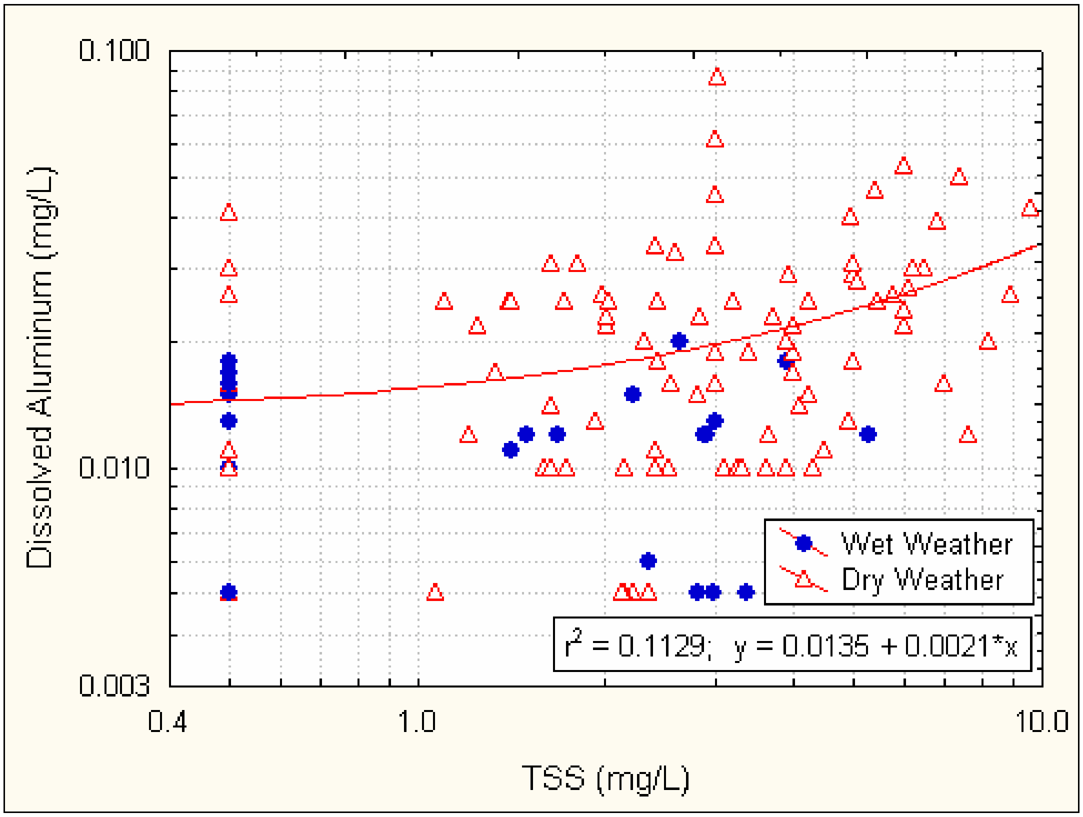


Figure 4-20 Scatterplot of Paired TSS and Dissolved Aluminum Samples Collected from 8 Mainstem and 2 Tributary Sites in Wissahickon Creek Watershed, 2005

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 recognized that total recoverable Al in stream samples may be due to clay particles and documented many high quality waters that exceed water quality standards for total recoverable Al (USEPA 1988, 53FR33178). As Wissahickon Creek 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 in Wissahickon Creek Watershed to Al toxicity.

Table 4-22 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	110	1	213	1
Dissolved Aluminum	94	31	22	7
Total Cadmium	110	110	233	233
Dissolved Cadmium	94	94	22	22
Total Chromium	102	94	219	93
Dissolved Chromium	94	78	22	21
Total Copper	99	0	223	0
Dissolved Copper	90	0	22	0
Total Lead	110	97	233	69
Total Zinc	100	13	233	16
Dissolved Zinc	84	0	22	0

4.7.7.2 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 PADEP water quality criteria are based on dissolved concentrations. Cd was never detected in 334 water samples, so it is unlikely that Cd toxicity is responsible for observed biological impairment in Wissahickon Creek Watershed.

Though concentrations were always below reporting limits, water quality criteria for Cd reflect the fact that this metal may be toxic in very small concentrations. Water quality criteria for Cd are calculated based on hardness and Cd concentrations less than 1µg/L may be a violation of water quality criteria in very soft water. Dissolved Cd was not detected in any of the 116 samples (table 4-22); there were no violations of state water quality criteria. Hardness would have to drop below 34 mg/L in dry weather and below 26.5 mg/L in wet weather in order to drop water quality criterion below the reporting limit. Hardness never dropped below 103 mg/L; there were no potential water quality violations.

4.7.7.3 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 water quality 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, water quality 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 only detected in 17 of 116 samples (table 4-22), and there were no violations of water quality criteria

4.7.7.4 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 copper pipes, 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, water quality criteria are based on dissolved Cu concentration, which is a better predictor of Cu toxicity than total recoverable metal concentration.

Dissolved concentrations of Cu 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 surface water grab sample. However, point sources such as industrial or municipal wastewater may have a much greater relative proportion of dissolved Cu. Wissahickon Creek Watershed appears to be affected by a point source discharge or discharges with very high relative proportion of dissolved Cu to total Cu. The suspected source is corrosion of copper pipes and plumbing materials in the water distribution system(s).

Individual dischargers and groups of dischargers have submitted Water Effects Ratio (WER) studies to PADEP in applications for exemptions to specific water quality criteria for Cu. When approved, these exemptions established water effect ratios (WER), or "multipliers" that modified the water quality criterion to account for properties of the effluent and receiving waters that affect toxicity of the pollutant. PWD was unable to compile accurate information regarding existing WERs in order to evaluate results of stream samples for dissolved Cu, specifically the extent to which WERs exempt downstream violations of WQ criteria. As of January 2007, PADEP was revising policy related to these limits and no additional information was available.

Cu and dissolved Cu were always detectable above reporting limits in Wissahickon Creek Watershed. Basic statistics for Total Cu and Dissolved Cu appear in Table 4-22. Water samples should be filtered within 15 minutes for dissolved metals analysis (Eaton *et al.* 2005), but it was not possible to use this recommended technique for dissolved metals samples collected with automated Isco samplers. Dissolved metals samples are predominantly from the discrete interval (weekly) sampling program. As of May 2006, 116 paired dissolved and total copper results were available, but the limited number of samples from wet periods precluded statistical analysis of weather effects.

As described in section 4.4.7.1 Aluminum, additional paired dissolved/total Cu samples are being obtained from wet weather sampling events in Philadelphia tributaries. This increased sampling intensity should address the question of whether dissolved/total Cu ratios in stormwater tributaries are similar to mainstem Wissahickon Creek, or more like other stormwater systems studied by PWD in which there was no strong relationship between dissolved and total recoverable Cu in wet weather samples.

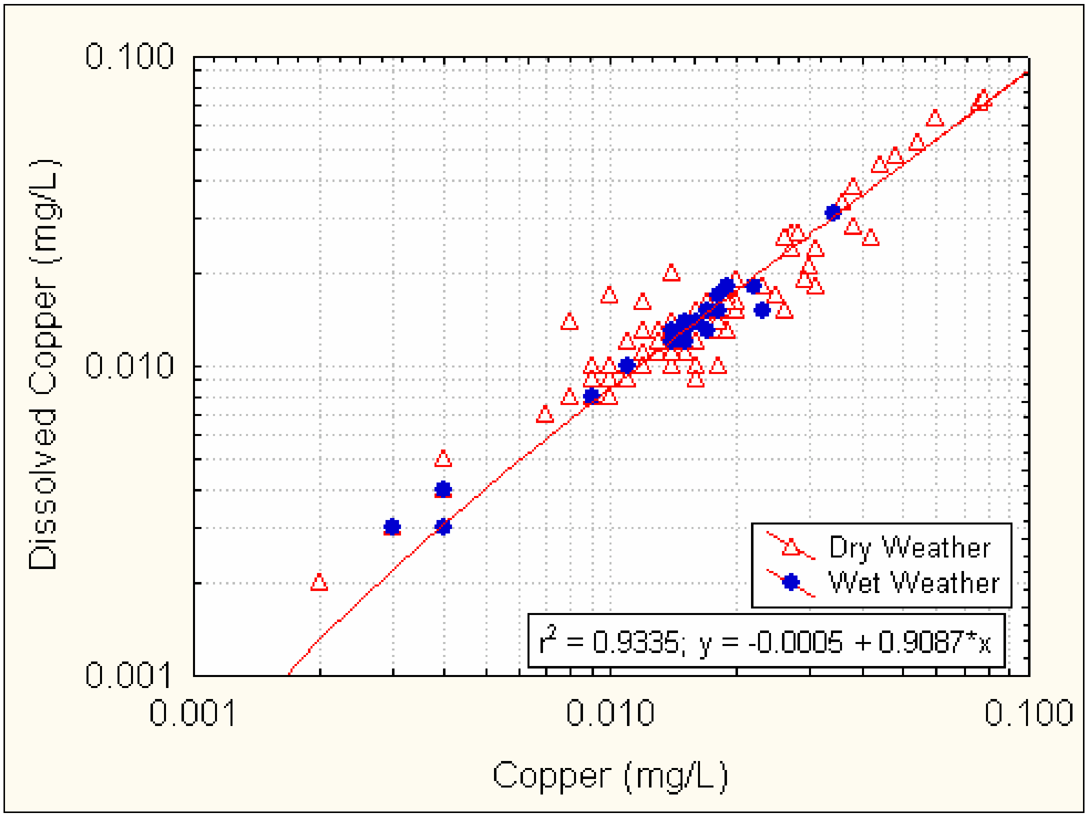


Figure 4-21 Scatterplot of Paired Total Recoverable Copper and Dissolved Copper Samples Collected from 8 Mainstem and 2 Tributary Sites in Wissahickon Creek Watershed, 2005

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 packs. 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, Warnick and Bell 1969) and the obvious disparity between Wissahickon Creek Watershed sites and reference sites with respect to number and abundance of mayfly and other sensitive taxa may be attributable to heavy metal pollution. Sediment metals concentrations and reference site chemistry data are needed before any conclusions can be drawn.

4.7.7.4.1 BIOTIC LIGAND MODEL ANALYSIS OF DISSOLVED COPPER

Cu toxicity was also investigated using the Biotic Ligand Model (BLM) (DiToro *et al.* 2001) as many water chemistry parameters can affect Cu toxicity. Other ions and organic molecules tend to compete with gill ligand bonding sites for available Cu. Figures 4-22 and 4-23 illustrate the effect of pH and temperature on Cu bioavailability and toxicity. BLM data were used to address the question of whether Cu toxicity could be affecting the biology of Wissahickon Creek Watershed. EPA is in the process of developing new water quality recommendations for Cu integrating the BLM with appropriate margins of safety for protecting aquatic life, but it is unlikely that these recommendations will be adopted into state water quality criteria due to the relatively large number of samples and parameters that must be analyzed to supply the BLM input data.

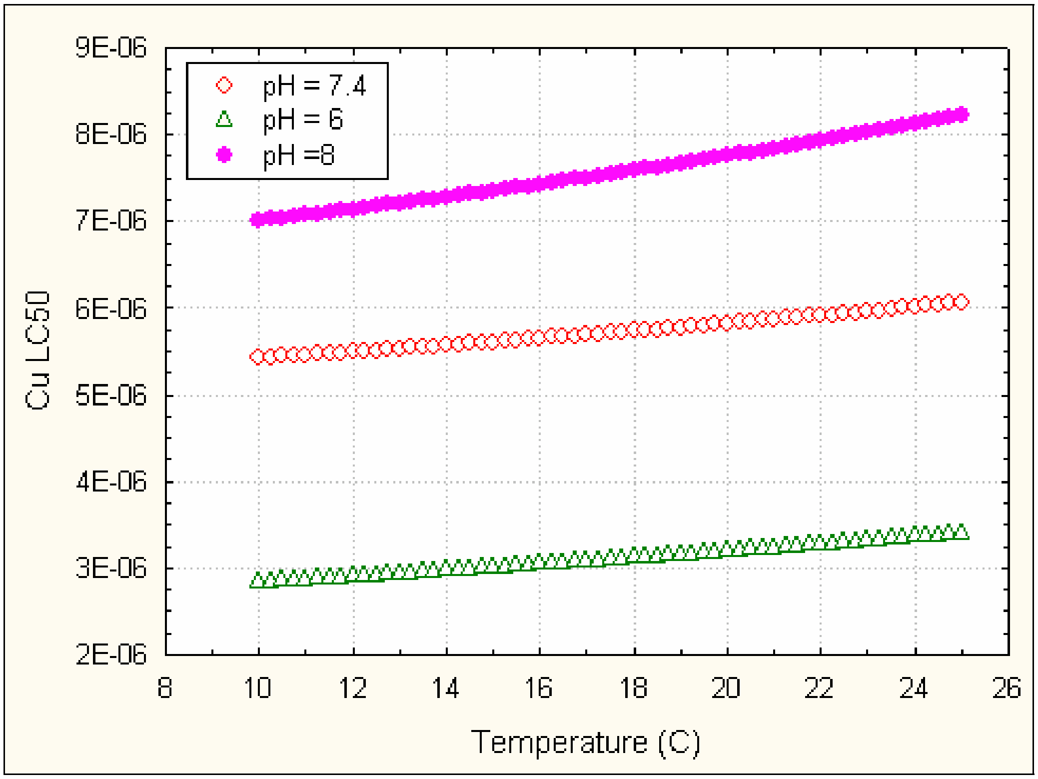


Figure 4-22 Effects of pH and Temperature on Copper Toxicity to Fathead Minnows

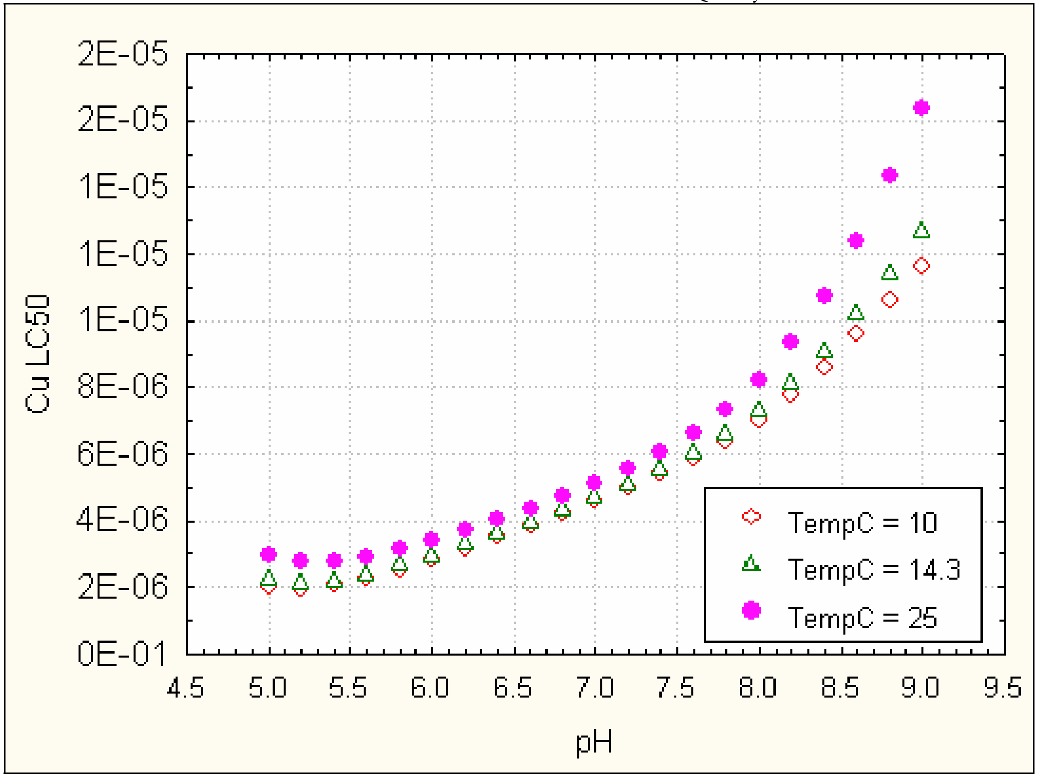


Figure 4-23 Effects of pH and Temperature on Copper Toxicity to Fathead Minnows

The BLM was used to estimate the LC_{50} (lethal concentration for 50% of test organisms) of dissolved copper to fathead minnows (*Pimephales promelas*), and three cladoceran microcrustaceans (*Ceriodaphnia dubia*, *Daphnia magna*, and *Daphnia pulex*). Each model input case consisted of water quality data from a single sample from Wissahickon Creek Watershed, though some parameters were estimated due to lack of availability in the 2005 data set. Parameters for which estimates were used included: dissolved organic carbon (DOC), percent of DOC contributed by humic acids, chloride, and sulfate. DOC competes for Cu with gill ligand sites and is positively correlated to the LC_{50} of Cu, therefore a conservative estimate of 4.8 mg/L from 30+ years of PWD/USGS data at site WS005 was used. 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). Actual instream DOC content is probably greater in zones where dissolved Cu concentration is elevated, reducing the risk of toxicity.

Chloride and sulfate model input values (44mg/L and 55mg/L, respectively) were means from site WS005, including historical data and other miscellaneous samples from the basin in PWD databases. As with DOC, these values are conservative and probably smaller than the concentrations expected at upstream locations where point source discharges contribute a greater proportion of flow, especially during low flow conditions.

When comparing dissolved Cu concentrations from Wissahickon Creek Watershed to predicted LC_{50}, the predicted LC_{50} concentration was reduced by an order of magnitude (margin of safety). With this margin of safety, 0, 90, 96, and 86 out of 114 samples had dissolved Cu concentration above the LC_{50} /10 for *P. promelas*, *D. magna*, *D. pulex*, and *C. dubia* respectively. None were above the LC_{50} concentration without a margin of safety. This model generally corroborates the various WER studies submitted to PADEP on behalf of wastewater dischargers showing low Cu toxicity in stream water and whole effluent. Discharges appeared to be generally rich enough in competing substances to substantially reduce bioavailability (and toxicity) of Cu.

4.7.7.5 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 65ug/L, respectively, at 100mg/L $CaCO_3$ hardness) (25 PA Code § 16.24). Dissolved Pb was rarely detected in Wissahickon samples from 2005, except at site WS1850, where dissolved Pb was detected in 9 of 14 samples.

Dissolved lead concentration of these samples never exceeded 2µg/L, and, like dissolved Cu, was assumed to be related to corrosion of plumbing materials in water distribution infrastructure. Furthermore, historical data showed no samples above detection limits in wet or dry weather, and no violations of water quality criteria were found (Table 5-5). When compared to discontinued total recoverable metals criteria, 118 of 294 samples would have been violations.

4.7.7.6 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 Wissahickon Creek Watershed; only 29 of 333 individual total recoverable Zn samples were below reporting limits (Table 4-24), and dissolved zinc was always present.

Dissolved zinc concentrations mirrored total recoverable concentrations in a manner similar to Cu and Mn. This effect was observed in both dry and wet weather, suggesting point sources. Contamination was suspected in several sets of samples collected in 2005 where dissolved concentrations were somewhat greater than total recoverable concentrations (Figure 4-22). Dates and sample information for these sample dates are summarized in Appendix F Water Quality Sampling Results with Potential Contamination.

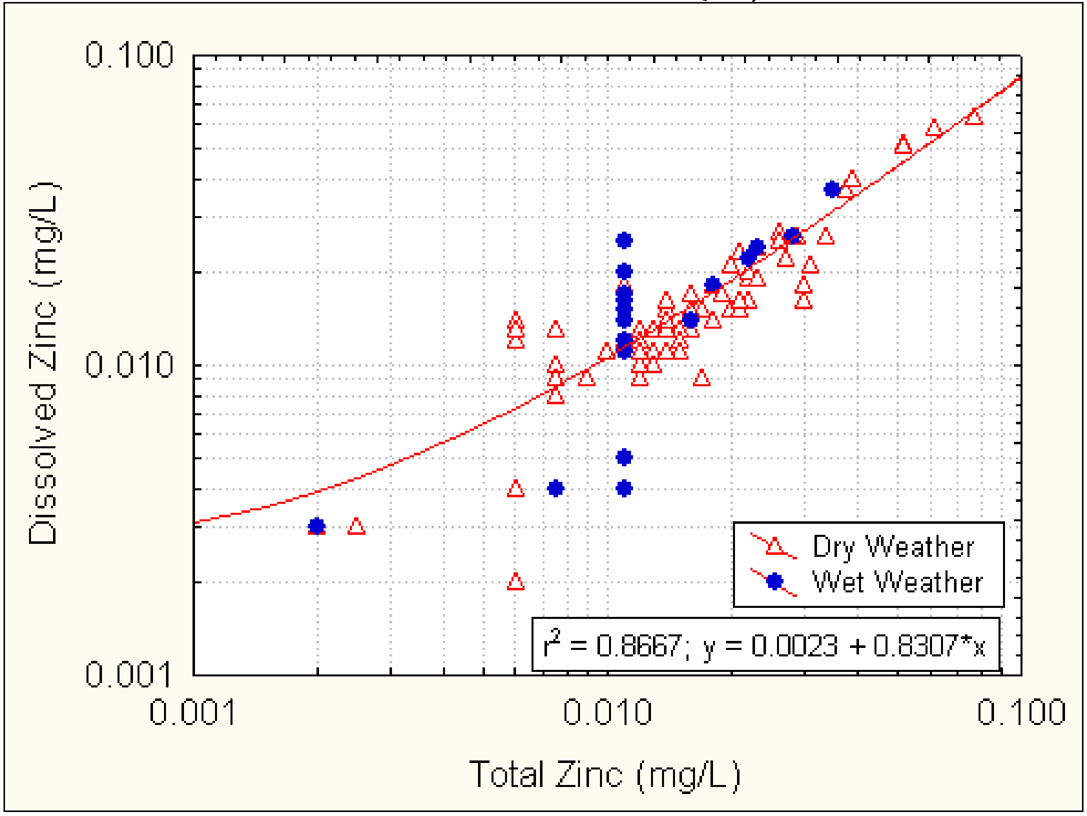


Figure 4-24 Scatterplot of Paired Total Recoverable Zinc and Dissolved Zinc Samples Collected from 8 Mainstem and 2 Tributary Sites in Wissahickon Creek Watershed, 2005

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, but airborne zinc particles in dust are another potential source.

The BLM was used to estimate the toxicity of dissolved Zn to fathead minnows (*Pimephales promelas*), rainbow trout (*Oncorhynchus mykiss*), and a cladoceran water flea (*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 LC_{50} concentrations generated by the model and the resulting concentration was compared with dissolved zinc data collected in 2005 from Wissahickon Creek Watershed. Even with this safety margin, no observed dissolved zinc concentrations exceeded the calculated LC_{50} for the studied organisms.

4.7.8 NUTRIENTS

4.7.8.1 PHOSPHORUS

Phosphorus (P) concentrations are often correlated with algal density and are used as a primary indicator of cultural eutrophication of water bodies. Phosphorus is generally so plentiful in

Wissahickon Creek that N:P ratio analysis suggests it does not limit algal growth in mainstem sites. Total Phosphorus (TP) concentration includes some smaller fraction of P that is considered to be bioavailable. Bioavailable P (BAP) includes soluble reactive P (SRP) and, depending on other factors, some portion of particulate inorganic P. Orthophosphate (OPO_4) was used primarily in nutrient analysis because this form is considered bioavailable, or readily usable by stream producers.

Wissahickon Creek Watershed has been listed by PADEP as impaired due to nutrients, and water quality criteria for TP and OPO_4 were being revised through the TMDL process at the time of writing. Numerous water quality standards or reference values for P have been proposed for various types of water bodies (Dodds and Welch 2000, Dodds and Oakes 2004, USEPA 2000). For the WCIWMP, TP concentrations will be evaluated against reference stream data using a frequency distribution approach recommended by USEPA (2000). Data were compiled for reference reaches in EPA Ecoregion IX, subregion 64 (75th percentile of observed data=140µg/L) (USEPA 2000). This reference value is considerably greater than the mesotrophic/eutrophic boundary for TP suggested by Dodds *et al.* (1998) (*i.e.*, 75µg/L).

Readily available dissolved orthophosphate (OPO_4) concentration was greater than 0.1 mg/L in 120 of 138 total samples collected in dry weather, and in 212 of 309 wet weather samples. Overall, mean OPO_4 concentration was significantly greater in dry weather than wet weather throughout the watershed ($U_{0.05(2)137,309}=10930, p<0.001$), indicating that TP generally originates from point sources and is diluted during wet weather events. Log transformed OPO_4 concentration was significantly negatively correlated with log transformed discharge in mainstem sites ($r_{(446)}=-0.63, p<0.001$) (Figure 4-25).

Dry weather OPO_4 concentrations were significantly greater than wet weather concentrations in grouped mainstem sites ($U_{0.05(2)107,166}=5032, p<0.001$) and grouped tributary sites ($U_{0.05(2)30,143}=1701$, $p=0.038$), however it should be noted that approximately half the tributary samples are from a large tributary (*i.e.*, Sandy Run) that is also affected by point source discharge. Average dry weather OPO_4 concentration in Sandy Run was similar to mainstem values and was greater than other tributary sites by almost an order of magnitude. No point sources of P exist downstream of site WS1075, and P concentrations appear to generally decrease along the stream gradient due to dilution and assimilation by producers. Mean OPO_4 concentration of samples collected from grouped upstream mainstem sites outside the City of Philadelphia was greater than that of grouped downstream site samples ($U_{0.05(2)111,162}=6876, p<0.001$). Furthermore, all samples with OPO_4 concentration in excess of 1.25 mg/L were collected from sites WS1075, WS1210, WS1850 and WSSR058.

Comparison of 2005 data to historic data (1968 – 1999) suggests a very large decrease in OPO_4 concentration has occurred within the watershed over the past 4 decades, both inside and outside the City. The decrease was evident during both dry and wet weather. Historic USGS data (1968) show OPO_4 concentrations as high as 22.1 mg/L at site WS076, but the data exhibit obvious reductions concomitant with construction and upgrading of municipal waste treatment facilities in the 1970s and 1980s. Unfortunately, the evidence at hand still suggests that P concentrations continue to greatly exceed the levels needed to prevent nuisance algae effects. Some algal taxa have the ability to store intercellular reserves of inorganic nutrients such as P ("luxury consumption") when concentrations exceed immediate demands Furthermore, intercellular P ratios from 2005 algae samples analyzed by Penn State University were heavily skewed from typical ratios (Carrick and Godwin 2006). This topic is addressed in greater detail in Section 4.5.4 Nutrient Limitation Effects on Primary Production.

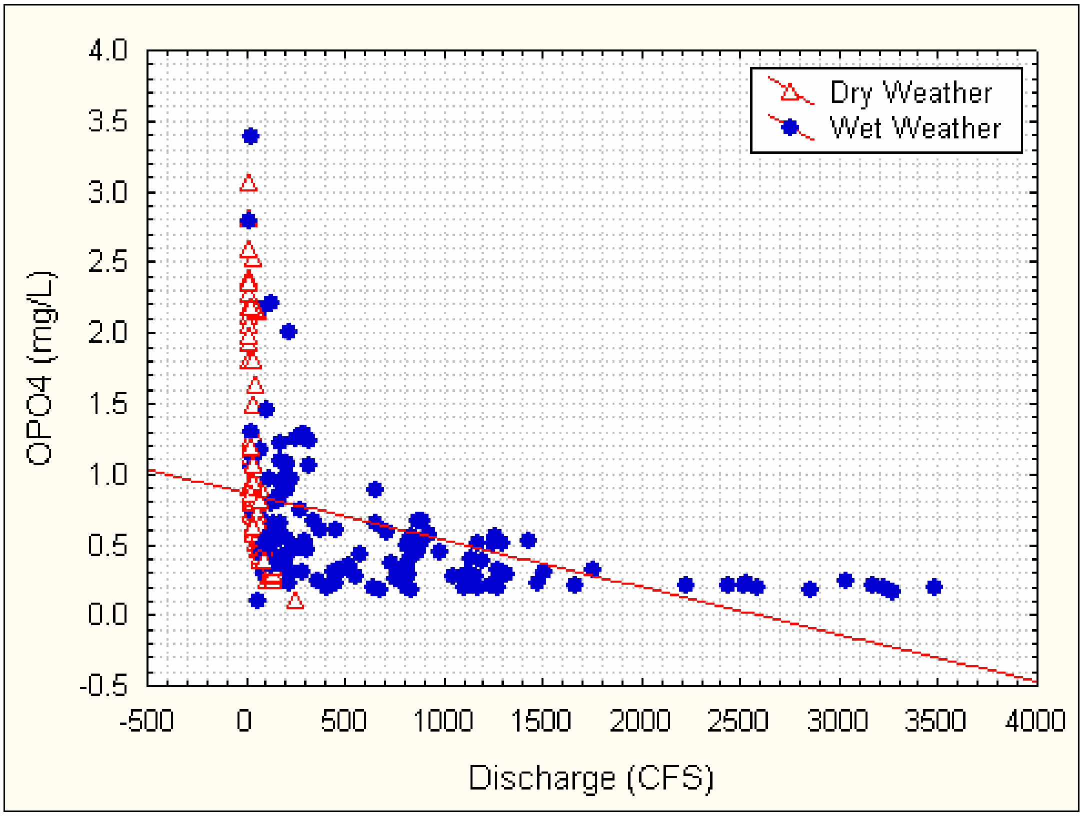


Figure 4-25 Scatterplot of Paired Streamflow and PO4 Samples Collected from 9 Mainstem Sites in Wissahickon Creek Watershed, 2005

4.7.8.2 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. PADEP water quality criteria for NH_3 reflect the relationship between stream pH, temperature, and ammonia dissociation. Ammonia toxicity is inversely related to hydrogen ion [H+] concentration (*e.g.*, 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 considered potentially toxic.

NH_3 concentration was above the detection limit of 0.1 mg/L in 111 of 309 wet weather samples, and only 25 of 137 dry weather samples. Due to the large number of samples with NH_3 concentration below reporting limits, half the reporting limit was substituted for these samples. Once this correction was made, mean NH_3 concentration was significantly higher in wet weather than in dry weather ($U_{0.05(2)137,309}=16792$, $p<0.001$). Most of the samples with elevated NH_3 concentration during wet weather were collected from tributary sites. Ammonia may be introduced to streams through breakdown of natural organic material, stables and livestock operations, stormwater runoff, and in some cases from more serious anthropogenic sources such as defective laterals, crossed/illicit connections, and sanitary sewer overflows (SSOs). PWD has established intensive field infrastructure trackdown, infrared photography, sewer camera monitoring, and dye testing programs to identify and correct these problems where and when they occur.

There were no observed violations of Ammonia water quality criteria in Wissahickon Creek Watershed in the 2005 sample dataset. However, the NH_3 sampling regime was not ideal for identifying possible violations of water quality standards as discrete interval grab samples were collected in the morning, while daily pH maxima were typically reached in afternoon/early evening hours. In order to explore whether these circumstances had the potential to obscure violations, daily maximum pH recorded at each site was subsequently used to calculate toxicity levels and compared to measured NH_3 concentrations. Using the maximum pH values and adjusting for lower temperature, only 3 samples had the potential to violate water quality criteria.

4.7.8.3 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 47 of 305 wet weather samples collected from Wissahickon Creek Watershed; most of these observations were samples taken at tributaries.

NO_2 concentrations were greater than reporting limits relatively more frequently in dry weather (24 of 131 samples) than in wet weather (47 of 305 samples). Contribution of NO_2 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. Once this adjustment was made, Mann-Whitney U test analysis showed no significant difference in NO_2 concentration in samples collected during dry weather than in samples collected during wet weather ($U_{0.05(2)131,305}=19348$, $p=0.42$).

4.7.8.4 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), inputs of groundwater with elevated NO_3 concentration, 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.

PADEP has established a limit of 10mg/L for oxidized inorganic nitrogen species ($NO_3 + NO_2$) (25 PA Code § 93.7). This limit is based on public water supply use (PWS) and intended to prevent methemoglobinemia, or "blue baby syndrome", not to prevent eutrophication of natural water bodies. As described in 25 PA Code § 96.3, this standard applies only at the point of existing or planned water supply intakes.

Waters of the Commonwealth that have been determined to be impaired due to excess nutrients may have Waste Load Allocations (WLA) determined through the Total Maximum Daily Load (TMDL) process. Wissahickon Creek Watershed has been listed as impaired due to nutrient enrichment, but the evidence at hand at the time of writing suggests that P reductions will be the regulatory mechanism for reducing nuisance algal densities. For the WCWCCR, $NO_2 + NO_3$ concentrations were evaluated against reference stream data using a frequency distribution approach recommended by USEPA (2000). Data were compiled for reference reaches in EPA Ecoregion IX, subregion 64 (75th percentile of observed data=2.9 mg/L) (US EPA 2000). Groundwater in and around Wissahickon Creek Watershed is generally higher in Nitrate (median NO_3 concentration of groundwater samples from monitoring wells in PADEP groundwater monitoring network zone 65 = 2.70 mg/L, PADEP 1998) than in the reference streams used to compile this data (USEPA 2000). The reference value used for the WCIWMP is also considerably greater than the mesotrophic/eutrophic boundary for Total N suggested by Dodds *et al.* (1998) (*i.e.*, 1.5 mg/L TN).

The reference value of 2.9 mg/L was exceeded in 247 of 450 samples from Wissahickon Creek Watershed. Nitrogen enrichment was greatest upstream in dry weather where and when point sources were minimally diluted; twenty four samples from sites WS1075, WS1210, WS1850 and WSSR058 exceeded 10mg/L. NO_3 concentrations typically decreased in wet weather. Mean dry weather NO_3 concentration in the Wissahickon Creek Watershed was significantly greater than mean wet weather concentration ($U_{0.05(2)138,310}=7053$, $p<0.001$). Furthermore, NO_3 was significantly negatively correlated with discharge in mainstem sites (Log transformed $r_{(448)} = -0.77$, $p<0.001$, Figure 4-24. This relationship demonstrates dilution by stormwater. Nutrient dynamics and relationships to autotrophic community production are addressed in greater detail in section 4.8 - Stream Metabolism.

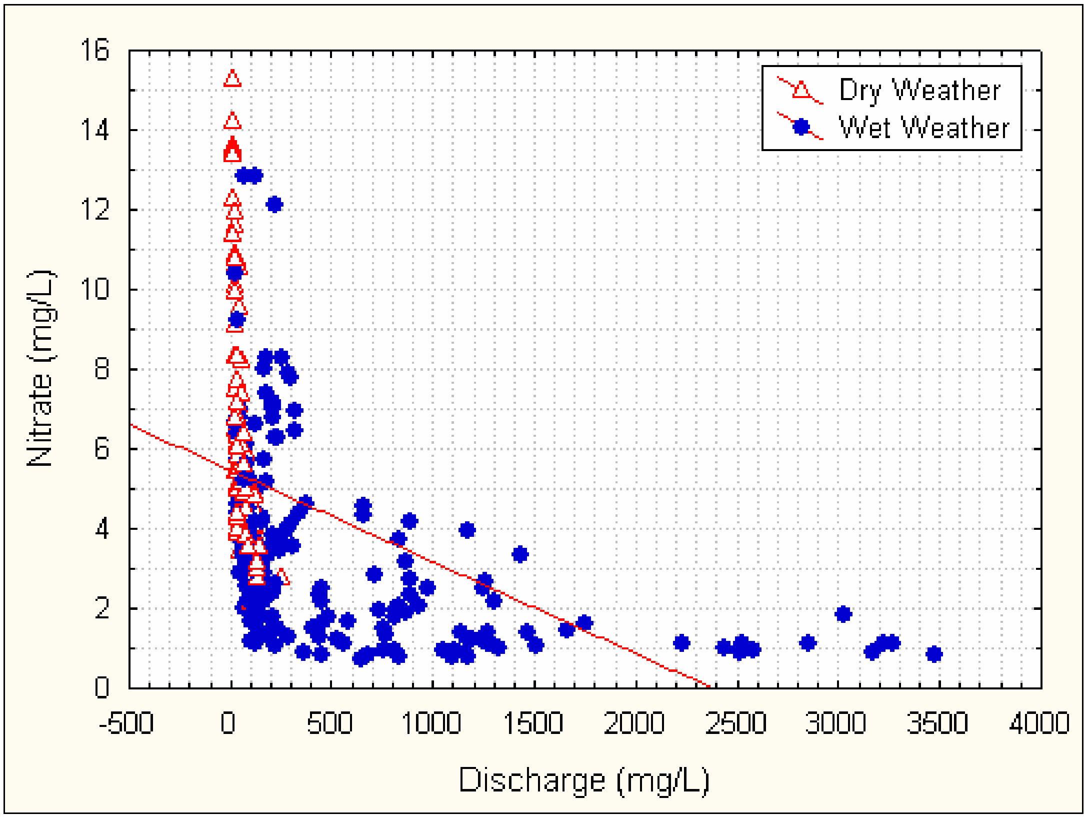


Figure 4-26 Scatterplot of Paired Streamflow and Nitrate Samples Collected from 9 Mainstem Sites in Wissahickon Creek Watershed, 2005

4.7.8.5 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 suggested the most important source of organic N in Wissahickon Creek Watershed is natural and anthropogenic organic material washed into the stream during storm events. However, sewage inputs from failed septic systems and defective laterals are another possible source, as are SSO discharges where and when they occur. Organic N concentration was significantly greater in wet weather than in dry weather ($U_{0.05(2)125,238}=9670, p<0.001$). Log transformed organic N was also significantly positively correlated with log transformed fecal coliform bacteria concentration, $r_{(407)}=0.59, p<0.001$ (Figure 4-27), suggesting that fecal material (whether from domestic animals, wildlife or human waste) is a component of the organic load.

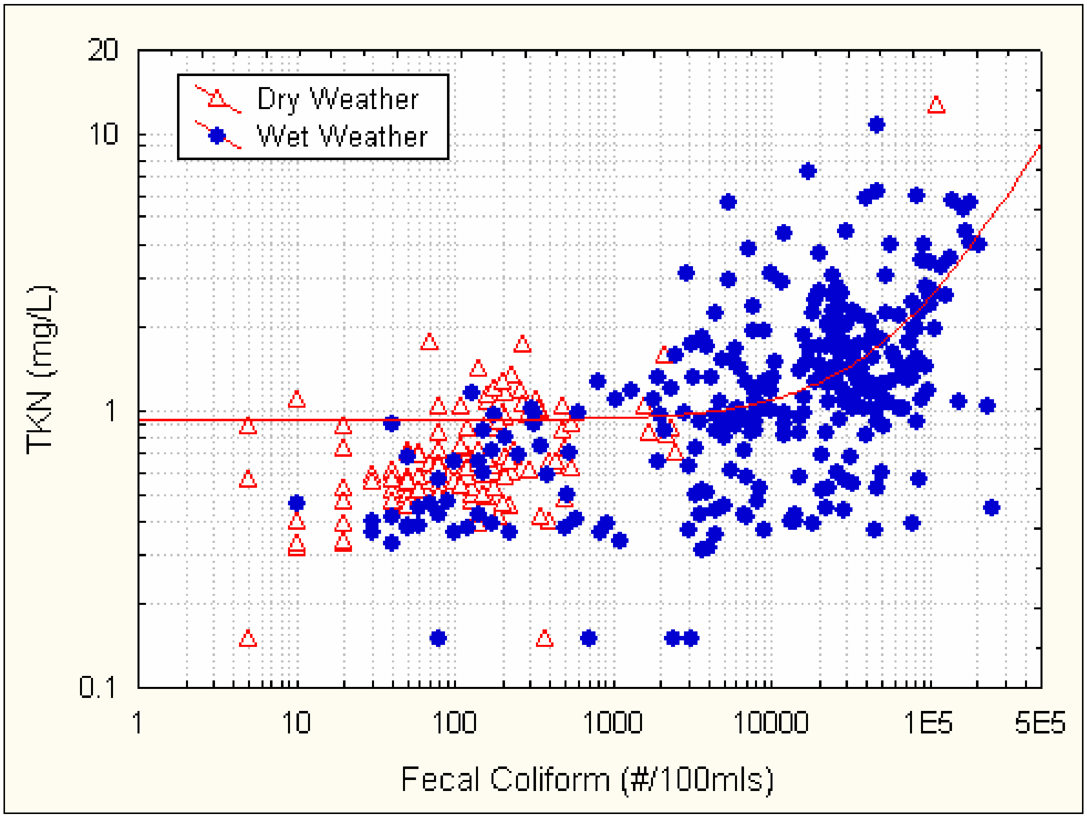


Figure 4-27 Scatterplot of Paired Fecal Coliform and TKN Samples Collected from 8 Mainstem and 8 Tributary Sites in Wissahickon Creek Watershed, 2005

4.8 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 shallow mid-order streams with less than complete tree canopy. Periphyton communities may strongly influence water column dissolved oxygen, pH, and inorganic carbon speciation.

Continuous water quality data indicated that most sites in Wissahickon Creek Watershed experience pronounced diurnal fluctuations in DO and pH, though DO fluctuations were generally more severe upstream and pH fluctuations were slightly more severe downstream. These fluctuations were observed to be reduced in magnitude following storm events (Figure 4-28). Fluctuations in DO resulted in violations of state water quality daily minimum standards, frequently so at sites WS1850, WS1210, and WS1075.

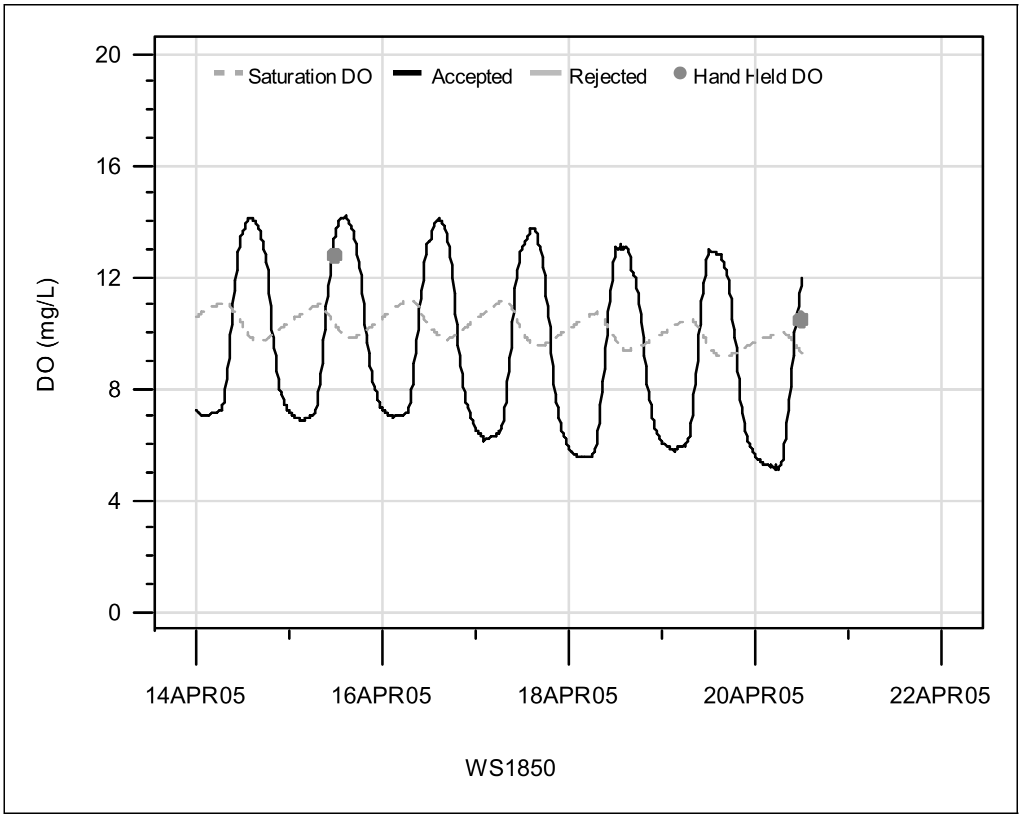


Figure 4-28 Example Plot of Severe Dissolved Oxygen Fluctuations at Site WS1850

As Wissahickon Creek 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. Also supporting this conclusion are observed reductions in the magnitude of fluctuations during and immediately after storm events (Figure 4-29), indicating scouring away and rapid recolonization of attached algae.

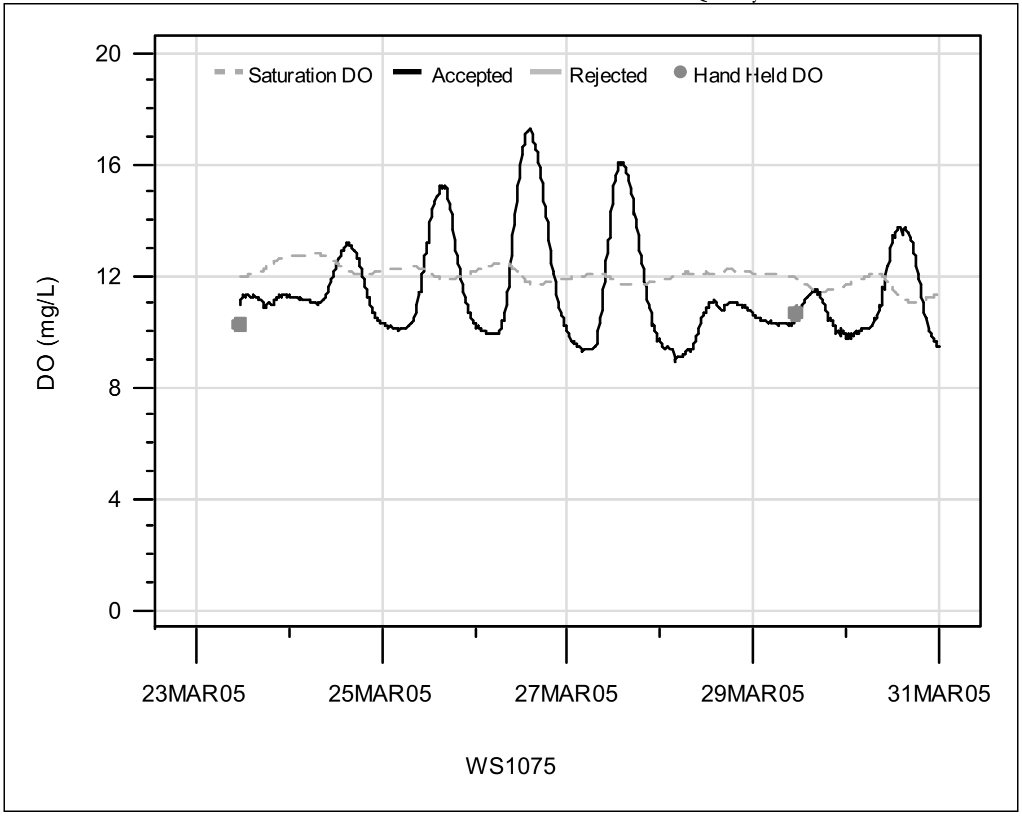


Figure 4-29 Example Plot of Continuous Dissolved Oxygen Concentration at Site WS1075 Showing Changes Due to Rainfall. (Storm Events Occurred 3/23 and 3/29)

Nutrients, substrate particle size, current velocity, and the frequency of scouring disturbances are likely the most important factors shaping algal communities in Wissahickon Creek Watershed. Differences in algal community structure between sites, physignomy of algal mats, and temporal variations in nuisance algal blooms are likely the result of different light and canopy conditions, temperature, substrate size and relative stability; and disturbance regimes (Triska *et al.* 1983, Hill and Knight 1988, Everett 1998).

4.8.1 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 pronounced 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 spring and 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 in Wissahickon Creek Watershed experienced pronounced diurnal fluctuations in dissolved oxygen (DO) concentration. When biological activity was high, DO concentrations were observed to violate state regulated (seasonally variable) TSF minima of 4.0 and 5.0 mg/L. Violation of these standards was generally limited to segments between sites WS1850 and WS754, as sites

WS354 and WS076 experienced violations on only 2% and 3% of days observed, respectively (Table 4-9, Appendix C Continuous Dissolved Oxygen Plots). Dry weather dissolved oxygen suppression tended to occur at night and was likely caused by respiration of algae and heterotrophic organisms, as well as microbial decomposition of organic constituents in the absence of photosynthetic oxygen production.

Following storm events, amplitude of daily DO fluctuations was reduced, more so than could be explained by dilution of BOD_5 alone (mean BOD_5 was slightly greater at sites WS1850 and WS1210, and greater in dry weather than in wet weather, while all samples within the City of Philadelphia were below reporting limits). Scouring and flushing effects of high flows reduced periphyton and phytoplankton algal biomass, and oxygen produced through photosynthesis and consumed through respiration was reduced (*i.e.*, amplitude of diel fluctuations was damped). Peak DO concentrations and range of diurnal fluctuations subsequently returned to pre-flow conditions rather quickly, often in 3 days. This phenomenon was assumed to be due to accrual of algal biomass following scouring events.

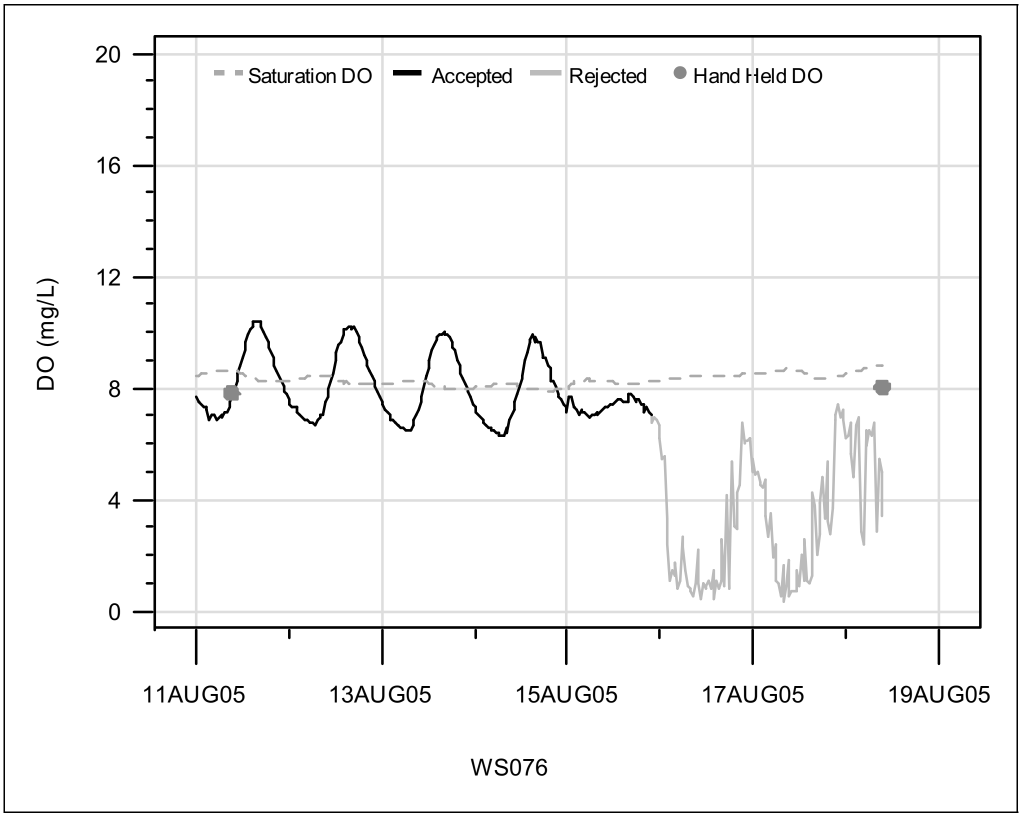


Figure 4-30 Continuous Plot of Dissolved Oxygen Concentration at Site WS076 Showing DO Probe Failure.

Algal biomass at site WS076 was significantly greater than at sites further upstream. However, WS076 demonstrated some of the smallest fluctuations in DO, suggesting that the relationship between biomass and primary production is not straightforward. It was hypothesized that algae, nitrogenous wastes, BOD and SOD account for the greater fluctuations in DO at sites WS1075, WS1210 and WS1850 in dry weather. Further confounding the interpretation of these data is the fact that sonde placement and light effects were difficult to measure. Microclimate conditions surrounding the DO probe membranes may partially explain the difference in DO fluctuations observed between sites.

4.8.2 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. 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.

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 Wissahickon Creek Watershed is chiefly determined by this metabolic activity; the watershed is not heavily influenced by anthropogenic inputs, such as acid mine drainage.

Comparison of diurnal fluctuations of pH at sites in Wissahickon Creek Watershed found that WS076 had a slightly greater variability between daytime and nighttime pH. This finding may perhaps be attributed to the greater benthic algae biomass found at this site.

4.8.3 GEOSMIN/MIB

Geosmin and 2-methylisoborneol (MIB) are two organic molecules produced by a diverse group of algae and microorganisms such as blue-green algae, bacteria, brown algae, and actinomycetes that may be present in soil and surface waters. The biological role of these odorous molecules is unknown. Algae cells producing geosmin and MIB can contribute earthy, musty tastes and odors to drinking water that persist despite conventional treatment. As taste and odor (along with clarity) are the qualitative attributes of water that contribute most strongly to a consumer's perception of the suitability of water for drinking, the impact of taste and odor episodes caused by geosmin and MIB can lead to diminished confidence in the general quality of water produced by the supplier. For this reason, Water suppliers must expend significant resources removing these from raw water influents by addition of Powdered Activated Carbon (PAC) to the filtration process, or in some extreme cases, even explore other sources of raw water. The human nose can detect levels greater than 10 ng/L, or parts per trillion. Beyond this threshold, these parameters begin to noticeably affect the taste and odor of treated drinking water.

Another impact of taste and odor producing compounds relates to recreational opportunities in Wissahickon Creek Watershed. Effects of geosmin on the taste of fish are well documented in the fish farming industry as well as in fish taken from algae-impaired streams and lakes (Klausen *et al.* 2005, Schrader & Blevins 1993). Anecdotal accounts and angler reports in the local media suggest that most anglers that intend to harvest their catch do so within the first few days of the opening of trout season, as the fish become unfit for consumption following longer exposure in Philadelphia area streams impacted by municipal treated sewage (Stark, K. "Creeks mix in the foul with the fish". *Philadelphia Inquirer*, 4/13/1993).

Taste and odor episodes associated with geosmin and MIB are seasonal in nature and associated with algal growth, sunlight exposure, and water temperature. The majority of episodes occur during the spring months, especially March through May, probably due to increases in water temperature and metabolic activity combined with increased daylight and lack of tree canopy shade. During the taste and odor episode of spring 2006, PWD customer service documentation corroborated the results of water quality sampling, identifying geosmin as the principal cause of customer taste and odor complaints. PWD used over 400 tons of PAC at a cost of over $200,000. Since 2004, sampling has been extended from water quality intakes to environmental sources to determine the sources of these parameters in order to prioritize sources and investigate factors which influence releases of these compounds. It is hoped that these ongoing studies will inform management decisions and reduce the severity and length of subsequent episodes.

Intensive sampling was conducted in spring 2006 throughout Wissahickon Creek Watershed as well as in the Schuylkill River and the Manayunk Canal to identify major sources of geosmin, large concentrations of which were being observed at PWD's QLWTP intake. Samples were conducted weekly from 3/14/06 through 5/9/06, and sampling locations were changed based on results of the previous week's sampling. This dynamic "track down" sampling program was intended to identify the greatest sources of geosmin loading to the WTP. In other words, the purpose of the study was to prioritize sources, considering not only the concentration of geosmin/MIB in a sample but also the flow rate contribution from each source.

Initial sampling along the Wissahickon Creek mainstem and in the Schuylkill River indicated the most significant contribution of geosmin to PWD's QLWTP to be from Wissahickon Creek, and while autochthonous production within the mainstem was observed to be an important contribution, the most significant source within Wissahickon Creek Watershed was determined to be Lorraine Run, a tributary to Wissahickon Creek in Whitemarsh Twp. Further sampling identified ponds on the property of the Philadelphia Cricket Club as the most significant single source of geosmin that impacts QLWTP. The next step in addressing this problem is to develop recommendations for reducing geosmin at the golf course. It is hoped that the Wissahickon Watershed partnership can develop a management plan with the golf course to reduce its geosmin contribution before next spring.

While MIB can contribute to taste and odor problems along with geosmin, MIB was not found in problematic concentrations during the taste and odor episode observed at QLWTP in spring 2006. While a small number of stream and intake samples had MIB concentration greater than the human odor detection threshold, additions of PAC used to address geosmin effects were probably sufficient to control MIB when present.

4.8.4 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 limit 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.*, Faulkner *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-mesotrophic 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).

Even once one assumes that phosphorus is the limiting nutrient of concern and reductions of instream P concentration should be implemented to control nuisance growths of algae, management decisions and criteria setting are complicated by uncertainty in the relationships between nutrient concentrations and the levels of algal growth associated with them. Setting goals for algal growth is usually accomplished by establishing a target level of algal growth, expressed as chlorophyll-*a* per unit area of stream substrate. Several chlorophyll-*a* target values (both mean and maximum) have been proposed for streams by various authors (Dodds and Welch 2000, Dodds and Oakes 2004, Biggs 2000, Brightbill and Koerkle 2003).

However, the most appropriate target values for periphyton chlorophyll-*a* and corresponding phosphorus concentrations expected to achieve them in Wissahickon Creek Watershed probably can be taken from a series of local studies of Nutrients and TMDL endpoints conducted by H.J. Carrick and C. Godwin of Penn State University (Carrick 2004, Carrick and Godwin 2005, Carrick and Godwin 2006). The researchers applied 3 established chlorophyll-*a* to phosphorus regressions to Wissahickon Creek Watershed data and estimated target P concentrations that might be expected to achieve different periphytic algal densities (*i.e.*, 50 and 100 mg/m^2). Two of these regressions were originally derived by Dodds, *et al.* (2002) for assumed periphyton N:P ratio 15:1 and 4:1 (Table 3). The target TP concentration of 205 µg/L is perhaps most appropriate as a long term management goal for the watershed. While Wissahickon algae presently exhibit extremely skewed intercellular C:N:P concentrations, periphyton communities will likely revert to near Redfield N:P ratios (or at least more natural ratios) as reductions in P are implemented.

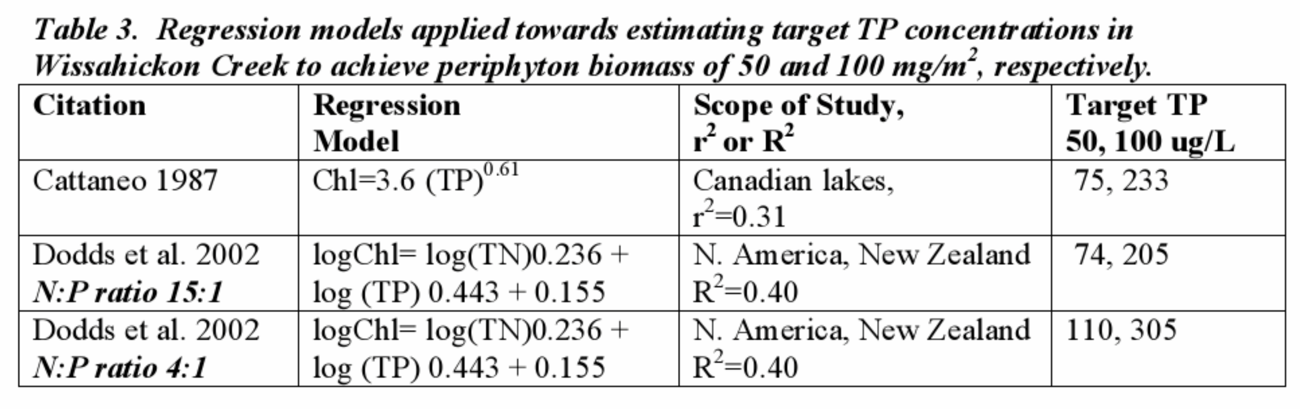


Table 3. Regression models applied towards estimating target TP concentrations in Wissahickon Creek to achieve periphyton biomass of 50 and 100 mg/m^2, respectively.

Citation	**Regression Model**	**Scope of Study, r^2 or R^2**	**Target TP 50, 100 ug/L**
Cattaneo 1987	Chl=3.6 $(TP)^{0.61}$	Canadian lakes, r^2=0.31	75, 233
Dodds et al. 2002 ***N:P ratio 15:1***	logChl= log(TN)0.236 + log (TP) 0.443 + 0.155	N. America, New Zealand R^2=0.40	74, 205
Dodds et al. 2002 ***N:P ratio 4:1***	logChl= log(TN)0.236 + log (TP) 0.443 + 0.155	N. America, New Zealand R^2=0.40	110, 305

4.8.8.6 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 have 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 (atomic ratio) 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 for Wissahickon Creek Watershed was focused on steady state (*i.e.*, dry weather) conditions because these are the conditions under which dissolved oxygen suppression effects are greatest and also when nutrient limitation is most likely to affect periphyton communities.

Combining the above frameworks, most samples collected from sites in mainstem Wissahickon in dry weather were not determined to be limited by either nitrogen or phosphorus (*i.e.*, N:P ratio was between 10:1 and 20:1). Of 44 samples collected within Philadelphia during dry weather, 16 were considered phosphorus limited and none were considered nitrogen limited. Outside of the City 6 out of 55 sites are considered phosphorus limited and 5 are nitrogen limited. Using the mesotrophic-eutrophic boundary 75 µg/L for TP and 1500 µg/L for TN (Dodds 1998) all samples were considered eutrophic with respect to both macronutrients. The average orthophosphate value in the City of Philadelphia was significantly lower ($t_{0.05(2);97}$=-5.86, p<0.001) than the average orthophosphate value outside the City, as most dry weather Orthophosphate originated from point sources outside the City. Average total nitrogen (NO_3, NO_2 and NH_3) values were lower within the City as well ($t_{0.05(2);97}=-5.98$, $p<0.001$).

In contrast to mainstem Wissahickon, almost all sites in tributaries were determined to be phosphorus limited. Sixteen out of 33 orthophosphate samples were below the detection limit of 0.1 mg/L. Excluding Sandy Run, six out of 22 samples were considered eutrophic for phosphorus (as orthophosphate) while 19 samples had nitrogen concentration above the threshold considered eutrophic. Sandy Run is an exception to the general phosphorus limitation in the tributaries. Ten out of 11 samples from Sandy Run were not limited by nitrogen or phosphorus and all samples were eutrophic with respect to both nitrogen and phosphorus. Downstream of the confluence of Sandy Run and Wissahickon Creek, average orthophosphate values are not significantly different than values upstream ($t_{0.05(2);24}=0.307$, $p=0.71$) because orthophosphate in Sandy Run also originates from point source discharges and there is little dilution effect, despite drainage area increasing by approximately $10mi^2$.

The next major tributary downstream of Sandy Run is Lorraine Run, which receives a significant amount of dry weather groundwater flow from a quarry dewatering pumping operation (*i.e.*, Coorson's Quarry). This limestone groundwater generally has much smaller concentrations of nutrients and serves to dilute nutrient concentrations in mainstem Wissahickon Creek. Average orthophosphate values downstream of the confluence of Lorraine Run and Wissahickon were significantly lower than those values upstream of the confluence ($t_{0.05(2);27}=2.88$, $p=0.001$).

Based on data collected in 2005, the average C:N:P ratio in periphyton tissue collected from seven mainstem sites and 2 tributary sites was actually 8:1:1, much lower than the Redfield Ratio (Carrick and Godwin 2006), suggesting periphyton is not limited by either phosphorus or nitrogen. Furthermore, the extreme deviation in cellular P from the Redfield ratio suggests luxury consumption is taking place, at least with respect to P.

4.8.2.2 FLOW EFFECTS ON STREAM NUTRIENT CONCENTRATIONS

Stream nutrient concentrations in Wissahickon Creek Watershed 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 6.00, and 2.85mg/L, 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 organic constituents in stormwater runoff and possibly SSO discharges. Nitrate (NO_3) and ammonium ions NH_4^+ forms are generally bioavailable, but other forms are not available for algal growth. Log transformed total organic nitrogen concentration (TON; calculated as TKN minus NH_3) showed a significant positive correlation with log transformed fecal coliform concentration, suggesting that sewage is a primary source of organic loading to the watershed ($r_{(409)}=0.60$, $p<0.001$)

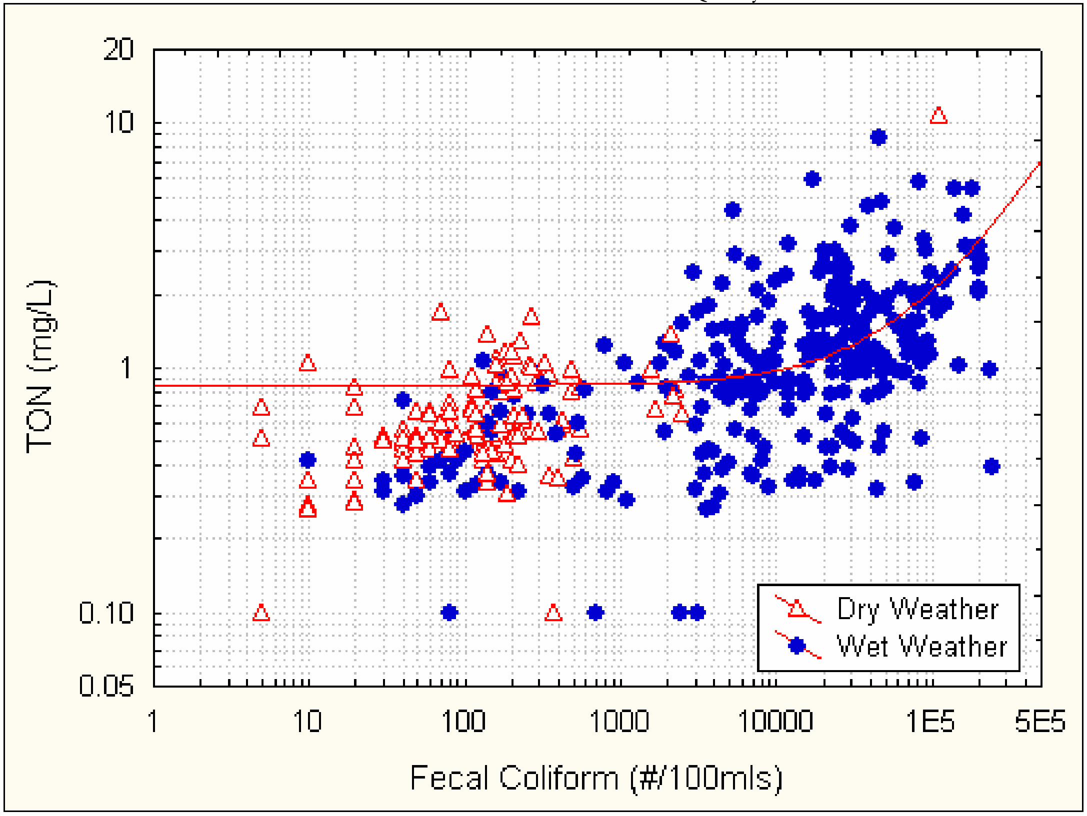


Figure 4-31 Scatterplot of Paired Fecal Coliform and TON Samples Collected from 8 Mainstem and 8 Tributary Sites in Wissahickon Creek Watershed, 2005

P concentrations followed a pattern similar to NO_3, with concentrations generally greater in samples collected during dry weather than samples collected in wet weather. Higher PO_4 concentration in dry weather (mean = 0.85 mg/L) is indicative of loads originating from point sources which are periodically diluted in wet weather events.

4.9 PROBLEM SUMMARY

4.9.1 RECREATION

Table 4-23 Summary of Fecal Coliform Recreation Criteria Exceedances

Season	Site	No. Obs.	No. Exceed	% Exceed
Non Swimming	WS076	38	24	***63***
	WS354	6	0	0
	WS754	37	18	***49***
	WS1075	24	17	***71***
	WS1210	6	0	0
	WS1850	24	16	***67***
Swimming	WS076	29	22	***76***
	WS354	6	3	***50***
	WS754	23	19	***83***
	WS1075	21	19	***90***
	WS1210	6	6	***100***
	WS1850	26	17	***65***

Parameter is not a problem **Potential problem** ***Problem***

4.9.2 AQUATIC LIFE

Table 4-24 Summary of Aquatic Life Acute Criteria Exceedances

Parameter	Criteria	Dry			Wet		
		No. Obs.	No. Exceed	% Exceed	No. Obs	No. Exceed	% Exceed
Al	Acute Maximum	110	2	2	212	127	***60***
Dissolved Cu	Acute Maximum	90	11	***12***	22	1	**5**
DO (continuous observations)	Minimum	76091	1716	**2**	28000	498	2
Dissolved Fe	Maximum	94	0	0	22	0	0

Parameter is not a problem **Potential problem** ***Problem***

Table 4-25 Aquatic Life Acute Criteria Exceedances by Site

Parameter	Site	Dry			Wet		
		No. Obs.	No. Exceed	% Exceed	No. Obs.	No. Exceed	% Exceed
Al	WS076	12	0	0	33	25	***76***
	WS754	12	0	0	26	22	***85***
	WS1075	13	0	0	18	16	***89***
	WS1850	13	0	0	23	22	***96***
	WSBM007	2	0	0	19	11	***58***
	WSBM090	3	1	33	31	13	***42***
	MCRR002	2	1	50	27	7	***26***
	WSMC016	1	0	0	19	11	***58***
Dissolved Cu	WS1850	11	11	***100***	1	1	100
DO (continuous samples)	WS1075	13593	386	**3**	5350	151	**3**
	WS1850	12065	1099	**9**	4917	319	**6**

Parameter is not a problem   **Potential problem**   ***Problem***   Insufficient Data

Table 4-26 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 4-26 Summary of Aquatic Life Chronic Criteria Exceedances

Parameter	Criteria	Dry			Wet		
		No. Obs.	No. Exceed	% Exceed	No. Obs	No. Exceed	% Exceed
Al	Chronic Maximum	110	75	***68***	212	188	***89***
Dissolved Cd	Chronic Maximum	94	0	0	22	0	0
Dissolved Cr	Chronic Maximum	94	0	0	22	0	0
Dissolved Cu	Chronic Maximum	90	11	***12***	22	1	**5**
Dissolved Zn	Chronic Maximum	84	0	0	22	0	0
DO (continuous observations)	Minimum Daily Average	848	20	**2**	574	31	**5**

Parameter is not a problem   **Potential problem**   ***Problem***   Insufficient Data

Table 4-27 Summary of Aquatic Life Chronic Criteria Exceedances by Site

Parameter	Criteria	Dry			Wet		
		No. Obs.	No. Exceed	% Exceed	No. Obs.	No. Exceed	% Exceed
Al	WS076	12	5	***42***	33	31	***94***
	WS122	10	6	***60***	2	0	0
	WS354	10	8	***80***	2	0	0
	WS492	10	7	***70***	2	1	50
	WS754	12	12	***100***	26	26	***100***
	WS1075	13	13	***100***	18	17	***94***
	WS1210	11	11	***100***	1	1	100
	WS1850	13	6	***46***	23	22	***96***
	WSPC017	4	0	0	4	1	25
	WSSR058	7	4	***57***	5	1	***20***
	MCRR002	2	1	50	27	22	***82***
	WSMC016	1	0	0	19	17	***58***
	WSBM007	2	0	0	19	18	***90***
	WSBM090	3	2	67	31	31	***100***
Dissolved Cu	WS1850	11	11	***100***	1	1	100
DO (continuous samples)	WS1075	151	8	**5**	110	13	***12***
	WS1210	138	3	**2**	93	6	**6**
	WS1850	136	9	**7**	99	11	***11***

Parameter is not a problem **Potential problem** ***Problem*** Insufficient Data

4.9.3 STREAM TROPHIC STATUS

Table 4-28 Summary of Stream Trophic Criteria Exceedances

Parameter	Criteria	Dry			Wet		
		No. Obs.	No. Exceed	% Exceed	No. Obs	No. Exceed	% Exceed
Chlorophyll-*a*	Maximum	86	40	***47***	10	1	***10***
pH (continuous observations)	Range	79877	859	1	30538	53	0
Temperature (continuous observations)	Maximum	80987	27185	***34***	30641	9829	***32***
TKN	Maximum	123	52	***42***	281	211	***75***
TP	Maximum	98	91	***93***	195	156	***80***
TSS	Maximum	123	2	2	303	177	***58***
Turbidity	Maximum	157	8	**5**	308	184	***60***

Parameter is not a problem **Potential problem** ***Problem*** Insufficient Data

Table 4-29 Summary of Stream Trophic Criteria Exceedances by Site

Parameter	Site	Dry			Wet		
		No. Obs.	No. Exceed	% Exceed	No. Obs.	No. Exceed	% Exceed
Chl-*a*	WS076	9	5	***56***	0	0	0
	WS122	9	6	***67***	0	0	0
	WS354	9	6	***67***	0	0	0
	WS492	9	4	***44***	1	0	0
	WS754	10	3	***30***	1	0	0
	WS1075	9	5	***56***	1	0	0
	WS1210	10	5	***50***	0	0	0
	WS1850	10	3	***30***	1	0	0
TKN	WS076	14	2	***14***	39	36	***92***
	WS354	10	1	***10***	2	0	0
	WS492	10	3	***30***	2	0	0
	WS754	14	7	***50***	31	29	***94***
	WS1075	14	11	***79***	29	28	***97***
	WS1210	11	9	***82***	1	0	0
	WS1850	15	14	***93***	35	35	***100***
	WSSR058	7	3	***43***	5	1	***20***
	WSMC016	1	0	0	20	11	***55***
	MCRR002	2	1	50	31	21	***67***
	WSBM007	2	0	0	21	10	***48***
	WSBM090	3	1	33	32	25	***78***
	WSCR008	2	0	0	17	11	***65***
	WSWM006	1	0	0	9	4	***44***
TP	WS076	10	10	***100***	29	29	***100***
	WS122	10	10	***100***	2	2	100
	WS354	10	10	***100***	2	2	100
	WS492	10	10	***100***	2	2	100
	WS754	10	10	***100***	23	23	***100***
	WS1075	10	10	***100***	14	14	***100***
	WS1210	11	11	***100***	1	1	100
	WS1850	11	11	***100***	25	25	***100***
	WSSR058	7	7	***100***	5	5	***100***
	WSMC016	1	0	0	20	13	***65***
	WSMC025	1	0	0	0	0	100
	MCRR002	2	1	50	26	15	***58***
	WSBM007	0	0	0	19	9	***47***
	WSBM090	0	0	0	23	16	***70***
TSS	WS076	14	0	0	49	31	***63***
	WS754	14	0	0	41	33	***80***
	WS1075	15	0	0	29	26	***90***
	WS1850	14	0	0	35	31	***89***
	WSMC016	1	0	0	20	11	***55***
	MCRR002	2	1	50	32	12	***38***
	WSBM007	2	0	0	21	11	***52***
	WSBM090	3	1	33	32	19	***59***
	WSCR008	2	0	0	18	1	**6**
	WSWM006	1	0	0	9	2	***22***

Parameter	Site	Dry			Wet		
		No. Obs.	No. Exceed	% Exceed	No. Obs.	No. Exceed	% Exceed
Turbidity	WS076	23	2	**9**	49	31	***63***
	WS122	10	1	***10***	2	0	0
	WS354	10	1	***10***	2	0	0
	WS492	10	1	***10***	2	0	0
	WS754	24	2	**8**	42	33	***79***
	WS1075	15	0	0	29	26	***90***
	WS1850	13	0	0	35	31	***89***
	WSMC016	1	0	0	20	14	***70***
	MCRR002	2	1	50	32	17	***53***
	WSBM007	2	0	0	21	6	***29***
	WSBM090	3	0	0	32	22	***69***
	WSCR008	2	0	0	17	1	**6**
	WSWM006	1	0	0	9	2	***22***
pH continuous observations)	WS354	11943	332	**3**	4802	53	1
	WS754	13158	302	**2**	4858	0	0
Temperature (continuous observations)	WS076	14165	4131	***29***	5067	1569	***31***
	WS354	12718	3665	***29***	4862	1325	***27***
	WS754	13158	3788	***29***	4858	1222	***25***
	WS1075	13865	4006	***29***	5350	1662	***31***
	WS1210	12928	4075	***32***	5146	1608	***31***
	WS1850	12290	7382	***60***	4944	2293	***46***
	WSWM006	933	69	**7**	207	48	***23***
	WSCR008	930	69	**7**	207	102	***49***

Parameter is not a problem **Potential problem** ***Problem*** Insufficient Data

4.9.4 PROBLEM PARAMETER SUMMARY

Problem parameters are those constituents for which more than 10% of the samples exceeded the standard watershed-wide. Parameters where the standards (or reference values) were exceeded over 2% of the time for all samples throughout the Wissahickon Creek Watershed are listed as potential problems. A minimum of 10% of samples at one sampling location must have exceeded the standard for a parameter to be considered a problem.

In Table 4-30, the problem and potential problem parameters are listed by category. They are also categorized as either wet or dry weather problems, if applicable. Toxic metals were categorized further to address separate chronic vs. acute criteria.

Table 4-30 Summary of Problem and Potential Problem Parameters

Parameter	Standard	Dry	Wet	Chronic
Recreation				
Fecal Coliform	Maximum Swimming Season	***WS076, WS354, WS754, WS1075, WS1210, WS1850,***	***WS076, WS754, WS1075, WS1850***	
Fecal Coliform	Maximum Non-swimming season	***WS076, WS754, WS1075***	***WS076, WS754, WS1075, WS1850***	
Acute				
Al	Acute Maximum	***WSBM090, MCRR002***	***WS076, WS754, WS1075, WS1850, WSBM007, WSBM090, WSMC016, MCRR002***	
Dissolved Cu	Acute Maximum	***WS1850***	***WS1850***	
DO (continuous samples)	Minimum	**WS1075, WS1210, WS1850**	**WS1075, WS1850**	
Chronic				
Al	Chronic Maximum			***WS076, WS354, WS754, WS1075, WS1210, WS1850***
Dissolved Cu	Chronic Maximum			***WS1075, WS1210, WS1850***
DO (continuous samples)	Average Minimum			**WS1075, WS1210, WS1850**
Other Parameters based on reference values				
Chl-*a*	Maximum	***WS076, WS354, WS754, WS1075, WS1210, WS1850***		
NO3	Maximum	***WS1075, WS1210, WS1850***	***WS1075, WS1850***	
pH	Range	**WS354, WS754**		
TKN	Maximum	***WS076, WS354, WS754, WS1075, WS1210, WS1850***	***WS076, WS754, WS1075, WS1850***	
TP	Maximum	***WS076, WS354, WS754, WS1075, WS1210, WS1850***	***WS076, WS354, WS754, WS1075, WS1210, WS1850,***	
TSS	Maximum		***WS076, WS754, WS1075, WS1850***	
Turbidity	Maximum	***WS076, WS354, WS754***	***WS076, WS754, WS1075, WS1850***	
Total Nitrogen	Maximum	***WS076, WS354, WS754, WS1075, WS1210, WS1850***	***WS076, WS354, WS754, WS1075, WS1210, WS1850***	
Temperature	Maximum	***WS076, WS354, WS754, WS1075, WS1210, WS1850***	***WS076, WS754, WS1210, WS1850***	

🟩 Parameter is not a problem   🟨 **Potential problem**   🟥 ***Problem***   Insufficient Data

5 BIOLOGICAL CHARACTERIZATION

5.1 SUMMARY OF HISTORICAL AND EXISTING INFORMATION

As described in Section 2, much of the suburban development within the Wissahickon Creek Watershed occurred prior to wide-scale adoption of effective stormwater controls and protection of wetlands and riparian corridors, causing widespread degradation of natural habitats and ecosystems. Development practices, especially the creation of impervious surfaces, have reduced infiltration of stormwater, accelerated erosion and sedimentation throughout the basin, and had a deleterious effect on natural communities. Furthermore, nearly all the first order streams (springs, ephemeral streams, and small streams without tributaries) in the watershed were buried or encapsulated in storm sewers to facilitate development. These first order streams are an important link in aquatic food webs and critical to sustaining populations of certain sensitive macroinvertebrates.

Several large municipal wastewater treatment plants were constructed or upgraded in Wissahickon Creek Watershed in the 1960s and 1970s. As described in Section 3, the total currently permitted discharge of these wastewater plants is 12.097 MGD (18.75 CFS). Though they are modern plants that remain in compliance with most regulations, the sheer volume of treated waste relative to natural baseflow taxes the watershed's ability to assimilate these wastes, leading to eutrophication and dissolved oxygen stress in aquatic communities.

5.1.2 NLREEP MASTER PLAN

There is scant historical information about aquatic life in Wissahickon Creek Watershed prior to industrialization and suburban development. In 2001, the Academy of Natural Sciences of Philadelphia (ANSP) submitted a report to the Fairmount Park Commission's Natural Lands Restoration and Environmental Education Program (NLREEP) that summarized a comprehensive review of historical biological data from sampling efforts conducted by the Pennsylvania Fish and Boat Commission (PFBC), Pennsylvania Department of Environmental Protection (PADEP), and historical records of collections by ANSP fisheries biologist Dr. Richard Horwitz. In addition to being the most complete review of historical biological information available, the ANSP report also documented original macroinvertebrate and fish sampling data from collection efforts in 1998 and 2000.

ANSP (2001) cited the abundance of modern historical fish sampling records as the primary reason for reduced sampling effort in Wissahickon Creek as part of the NLREEP assessment program. Seven sites were sampled, and while the qualitative information from this collection effort allowed comparisons to present day conditions, the electrofishing procedures were not thorough enough to account for all species that might have been present. Furthermore, the methods employed were not appropriate for quantitative metrics or estimating biomass. Conversely, methods for macroinvertebrate collection used at 11 tributary sites throughout the watershed were very thorough and quantitative. Unfortunately, only aggregate macroinvertebrate data were presented and the report lacks documentation of the actual taxa collected (with the exception of craneflies, which were collected in the adult stage in a more widespread study that also considered terrestrial and semi-aquatic species).

5.1.1 PADEP UNASSESSED WATERS PROGRAM AND 1998 PERIPHYTON STUDY

In 1997, PADEP collected macroinvertebrates and surveyed habitats as part of the Unassessed Waters Program, listing Wissahickon Creek Watershed as impaired due to nutrients, siltation, habitat alterations, flow variability and flow alterations (PADEP, 2004 Integrated List of Waters). The first two listings, nutrients and siltation, resulted in TMDL programs being developed for the watershed. PADEP also conducted biological assessments of the watershed in 1989, 1993, 1996, 1997, and 2002. Everett (1998) conducted a study of periphyton communities in Wissahickon Creek watershed, sampling seven locations in Wissahickon Creek and three tributary sites.

5.1.3 PWD 2001 BASELINE ASSESSMENT OF THE WISSAHICKON CREEK WATERSHED

In 2001, the Philadelphia Water Department collected benthic macroinvertebrates and fish from 15 and 6 sites, respectively, within Wissahickon Creek Watershed and its tributaries (Butler *et al.* 2001). Methods and locations were similar to the 2005 sampling effort, allowing rough comparisons to be made.

5.1.4 TMDL ENDPOINT ESTIMATES FOR AN URBAN-SUBURBAN STREAM BASED UPON IN-STREAM PERIPHYTON BIOMASS

Carrick and Godwin (2005) sampled periphyton from the same 10 locations that were sampled by PADEP in 1998 (Everett 1998). Periphyton biomass, cellular chemistry, and diatom community composition data were compiled, and the researchers applied Phosphorus-algal biomass regression equations (Cattaneo 1987, Dodds *et al.* 2002) to estimate P endpoints for TMDL development.

5.1.5 SUMMARY OF HISTORIC BIOLOGICAL INFORMATION

Results of all historical studies have been consistent and clear; 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.). Moreover, impairment of Wissahickon Creek Watershed was not found to be limited to fish and macroinvertebrates. Two separate studies of periphyton communities found Wissahickon Creek to be heavily affected by excessive accumulations of filamentous algae (macroalgae) and periphyton scums.

The 2005 PWD study, however, is the first to integrate extensive physical habitat and chemical information. When assessing an urban stream system that has been impaired for many years, particularly one that lies at the center of a region with widespread impairment, it may be difficult to determine whether observed effects are the result of antecedent or ongoing impairments. Water quality has improved slightly over the past 30 years, but the stream generally remains impaired.

5.1.6 BIOLOGICAL MONITORING BACKGROUND INFORMATION

Though Wissahickon Creek Watershed fish and benthic macroinvertebrate sampling 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 Wissahickon Creek 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 Wissahickon Creek 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, occurs 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 re-colonization of Wissahickon Creek Watershed by rare or extirpated macroinvertebrate taxa is by aerial dispersal of 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 and population dynamics of local populations representing potential colonists), and
4.) Miscellaneous factors, such as natural and anthropogenic mechanisms of passive dispersal.

Wissahickon Creek Watershed is at the center of a region of widespread impairment due to urbanization (Figure 5-1). Some areas of the watershed, tributaries in particular, 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.

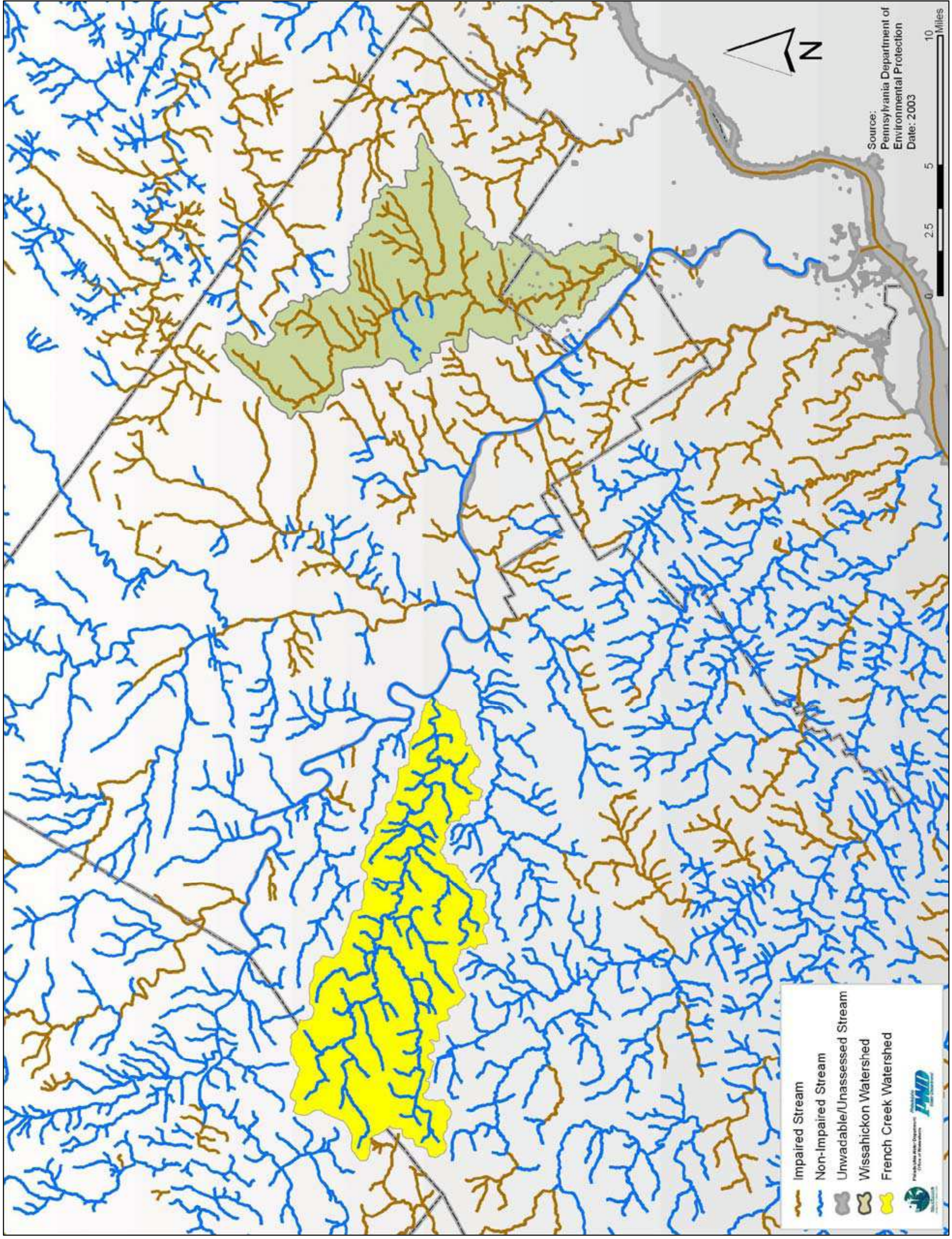


Figure 5-1 Southeastern PA Stream Segments in Wissahickon Creek Watershed, French Creek Watershed, and the Surrounding Region Showing Attainment Status from PADEP 2004 List of Waters (formerly 303d list)

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. Wissahickon Creek Watershed is unique among Philadelphia's major watersheds as the confluence with the next largest river system is on the non-tidal Schuylkill River. Wissahickon Creek does not have an unimpeded access to the Delaware estuary for upstream migration of migratory fish. Furthermore, physical impediments to upstream migration (*i.e.*, dams) probably prevent recolonization of Wissahickon Creek Watershed via the Schuylkill River for most taxa, though American Eels (*Anguilla rostrata*) are a noteworthy exception. There are no records of migratory fish ascending the Wissahickon Creek, probably because the Wissahickon is a tributary to a non-tidal zone of the Schuylkill River and this area was historically a series of steep bedrock ledges. These bedrock features were eliminated when Lincoln Drive was constructed (R. Horowitz, pers. comm.).

Wissahickon Creek differs from other major Philadelphia streams in that its confluence with a major river is within the Wissahickon Formation of the lower Piedmont, a geologic feature characterized by hard-wearing mica schists, while all other major Philadelphia streams' confluences with the Delaware Estuary are located in the softer, sandy alluvial deposits of the Coastal Plain geologic region.

Wissahickon Creek Watershed is actively stocked with trout by the Pennsylvania Fish and Boat Commission (PAFBC) in two zones. The downstream-most zone is approximately 5.5 miles in length and located almost entirely in Fairmount Park in the City of Philadelphia, while the other zone extends from Stenton Avenue upstream to Lafayette Avenue, and is nearly entirely bordered by Fort Washington State Park. Trout are usually stocked four times over the season, and the largest allotment of stocked trout is generally stocked a week prior to the opening day of trout season (the second Saturday in April). Approximately 2/3 of the fish in each stocking are allocated to the downstream zone and 1/3 in the upstream zone.

The Seasonal timing of stocking, number of fish stocked, and relative species composition of individual stocking events are based on site characteristics and PFBC experience regarding angler use patterns and catch rates. Stocking densities also take into account social factors such as number of anglers and accessibility concerns. Anecdotal angler accounts and information from the Pennsylvania Fish and Boat commission suggests that the trout fishery is heavily impacted by objectionable odors which taint fish flesh over time, decreasing angler satisfaction and harvest rates (Stark, K. "Creeks mix in the foul with the fish". *Philadelphia Inquirer*, 4/13/1993; M. Kauffman, pers. comm.). Odor-causing molecules are introduced to the stream from treated sewage and also produced in the stream by blue green algae. More information on instream production of taste and odor causing molecules is included in Section 4.8.3 Geosmin/MIB.

Wissahickon Creek watershed supports warmwater game fish such as smallmouth bass (*Micropterus dolomieu*) and panfish, so angling activity is thus a potential source of releases of non-indigenous fish or other bait items (*e.g.*, non-native minnows and earthworms). Furthermore, Wissahickon Creek's proximity to an urban center and popularity as a recreational destination increases the likelihood of other releases of non-native aquatic life, such as pet fish and reptiles. Most of the common native and established introduced warmwater fish species of southeast Pennsylvania are present, if not abundant, in Wissahickon Creek Watershed, and most of these species are tolerant or moderately tolerant of water pollution. Rare and intolerant native species are generally not found in the basin.

Intolerant and non-game native fish species that do not presently occur in the watershed are unlikely to become established or re-established within the watershed other than by stocking, and PWD supports the efforts of ANSP and FPC to reintroduce species such as margined madtom (*Noturus insignis*) and native minnows for which habitat in Wissahickon Creek Watershed is appropriate. However, all restoration efforts should be well documented within the watershed stakeholder community so that progress can be tracked and results of subsequent ecological investigations are not jeopardized.

Sites in Wissahickon Creek 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 development and impervious cover in portions of Wissahickon Creek 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 5.1 Habitat Assessment. Wissahickon Creek Watershed is only linked to the non-tidal Schuylkill River, while the reference sites have better connectivity and some are classified high quality trout stocking fisheries.

5.2 BENTHIC MACROINVERTEBRATE ASSESSMENT

5.2.1 MONITORING LOCATIONS

During 2/23/05 to 3/17/05, the Philadelphia Water Department conducted Rapid Bioassessment Protocols (RBP III) at thirty (n=30) locations within Wissahickon Creek Watershed (Figure 5-2). Surveys were conducted at 11 mainstem locations and 19 tributary locations. Sixteen of the 19 tributary sites were located within Philadelphia County. There were a disproportionate number of assessment sites within Philadelphia because of the need to establish baseline conditions for future BMPs.

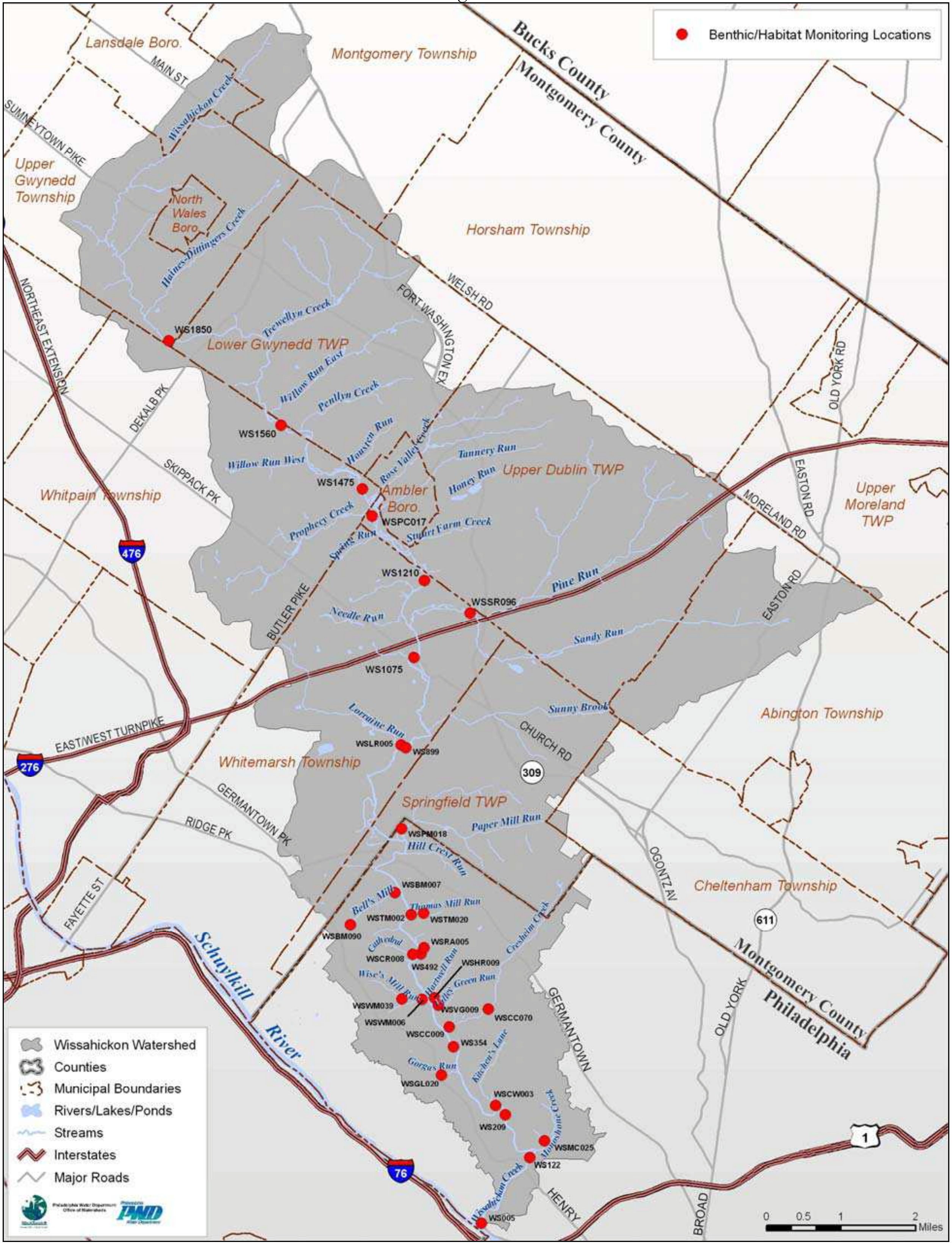


Figure 5-2 Benthic Macroinvertebrate Assessment Sites in Wissahickon Creek Watershed, 2005

5.2.2 FIELD STANDARD OPERATING PROCEDURES

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.

5.2.3 LABORATORY STANDARD OPERATING PROCEDURES

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.

5.2.4 DATA ANALYSES

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 5-1**).

Table 5-1 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%
Percent Contribution of Dominant Taxon (a)	<10	11-16	17-22	>22
Percent 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 at Seven Stars Road (4th order), French Creek at Coventryville Road (3rd order) and Rock Run, a tributary of French Creek (2nd order). Using the following chart, benthic quality of each site was established to identify spatial trends of impairment along the river continuum (Table 5-2).

Table 5-2 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.

5.2.5 RESULTS

5.2.5.1 WATERSHED OVERVIEW

A total of 4,442 individuals from 35 taxa were identified during the 2005 macroinvertebrate survey. The average taxa richness of the watershed was 7.13. Overall, moderately tolerant (96.56%) and generalist feeding taxa (94.92%) dominated the watershed. The average Hilsenhoff Biotic Index (HBI) of all assessment sites was 5.92. Pollution sensitive Ephemeroptera, Plecoptera, and Trichoptera (EPT) taxa were absent or rare throughout the watershed. Modified EPT taxa are Ephemeroptera, Plecoptera, and Trichoptera (EPT) taxa with a Hilsenhoff score of four or less.

Chironomidae (midges) dominated the benthic assemblage of the watershed (percent contribution ranged from 50.0% to 99.1%). Net-spinning caddisflies (Hydropsychidae), isopods, amphipods, tipulids, gastropods, riffle beetles, *Corbicula*, water pennies, planaria and oligochaetes were also present throughout the watershed but in very low abundance. Benthic macroinvertebrate communities of the Wissahickon Creek Watershed were thoroughly dominated by midges, which indicate that a stressor (or stressors) was limiting the ability of other taxa to survive. Of particular concern was the lack of representation by other tolerant invertebrate taxa, such as hydropsychid caddisflies, which are often abundant in moderately polluted waters. It is unknown whether the general absence of this group was a real phenomenon or the result of the inefficiency of sampling apparatus used in 2005.

Feeding measures comprise functional feeding groups and provide information on the balance of feeding strategies in the benthic community (Barbour *et al.* 1999). The trophic composition of macroinvertebrate communities within the watershed was skewed toward generalist feeding gatherers and filterers (94.92%). The unbalanced feeding structure suggests the watershed has an overabundance of fine particulate organic matter (FPOM). The limitation in food sources limits the ability of specialized feeders to flourish. For example, shredders were found to be very uncommon, which may be a response to lack of leaf pack stability and scouring effects of storm flows. In natural streams, it is not uncommon for leaf packs to persist throughout the year as leaves with higher tannin content are more slowly decomposed. Scrapers and predators were also very rare in Wissahickon Creek Watershed. In general, these more specialized feeding groups are more sensitive to perturbation than generalist feeders.

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 (96.56%) dominated the macroinvertebrates collected in Wissahickon Creek Watershed. Sensitive taxa were poorly represented (2.30 %), and their rarity suggests a response to watershed wide perturbation, such as water quality degradation. Other potential explanations for the rarity of sensitive taxa are the relative isolation of Wissahickon Creek Watershed within an urban region without nearby sources of potential colonizers and the changes in seasonal baseflow and temperature that tend to accompany urbanization.

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). The mean HBI score for Wissahickon Creek Watershed was 5.92. The dominance of moderately tolerant individuals and general lack of pollution sensitive taxa contributed to the elevated HBI. In comparison, the mean HBI score of the reference sites used was 3.15. A difference in HBI score between the reference site and assessment site that is greater than 0.71 is an indicator of impairment. When compared to the reference condition, the Wissahickon mean HBI had a difference of 2.77, which suggests severe impairment. Overall, the combination of low taxa richness, elevated HBI scores, lack of EPT taxa, and lack of specialized feeders characterized the watershed as severely impaired.

5.2.5.2 MAINSTEM ASSESSMENT SITES

Eleven mainstem Wissahickon sites (WS005, WS122, WS209, WS354, WS492, WS899, WS1075, WS1210, WS1475, WS1560, and WS1850) were assessed during the 2005 macroinvertebrate survey. All mainstem sites received a total metric score of zero (0) out of a possible 30. All sites were designated as "severely impaired". Sites were characterized by low taxa richness (n=4 to n=11), low or absent modified EPT taxa, and elevated Hilsenhoff Biotic Index score (5.79 to 6.07). Chironomids (50.0% -94.69%) and generalist feeders (72.95% to 100%) dominated all assessment sites. Specialized feeders were absent or found in low abundance. Moderately tolerant individuals (79.53% to 99.12%) dominated the benthic assemblage at all mainstem sites. While spatial trends were not very distinct, benthic macroinvertebrate communities sampled at sites WS1075, WS1210, WS1475, and WS1560 generally had slightly better attributes (*e.g.*, modest increase in taxa richness, EPT taxa collected at two sites, slight decrease in the proportional abundance of dominant taxa) compared to downstream sampling locations. But this observed difference was probably more reflective of poor sampling efficiency than actual differences, as described below.

Table 5-3 Benthic Macroinvertebrate Assessment Results from 11 Mainstem Sites in Wissahickon Creek Watershed, 2005

2005 Wissahickon Creek Watershed Assessment	Taxa Richness	Modified EPT Taxa	Hilsenhoff Biotic Index (modified)	Percent Dominant Taxon	Percent Modified Mayflies	Biological Quality (%)	Biological Assessment
WS005[a]	6	0	5.90	80.17 (Chironomidae)	0	0	Severely Impaired
WS122[a]	4	0	5.92	92.00 (Chironomidae)	0	0	Severely Impaired
WS209[a]	5	0	6.00	90.20 (Chironomidae)	0	0	Severely Impaired
WS354[a]	6	0	5.86	87.88 (Chironomidae)	0	0	Severely Impaired
WS492[a]	6	0	6.00	94.69 (Chironomidae)	0	0	Severely Impaired
WS899[a]	5	0	5.99	92.00 (Chironomidae)	0	0	Severely Impaired
WS1075[a]	8	0	5.80	68.00 (Chironomidae)	0	0	Severely Impaired
WS1210[a]	9	0	5.93	67.96 (Chironomidae)	0	0	Severely Impaired
WS1475[a]	9	1	5.79	65.42 (Chironomidae)	0	0	Severely Impaired
WS1560[a]	11	1	5.80	50.00 (Chironomidae)	0	0	Severely Impaired
WS1850[b]	7	0	6.07	68.27 (Chironomidae)	0	0	Severely Impaired
*FC472	22	9	2.59	25.00 (*Serratella*)	27.68		
*FC1310	21	9	3.63	18.63 (*Prosimulium*)	11.8		

*Reference site used for metric comparison

[a] FC472 used as reference

[b] FC1310 used as reference

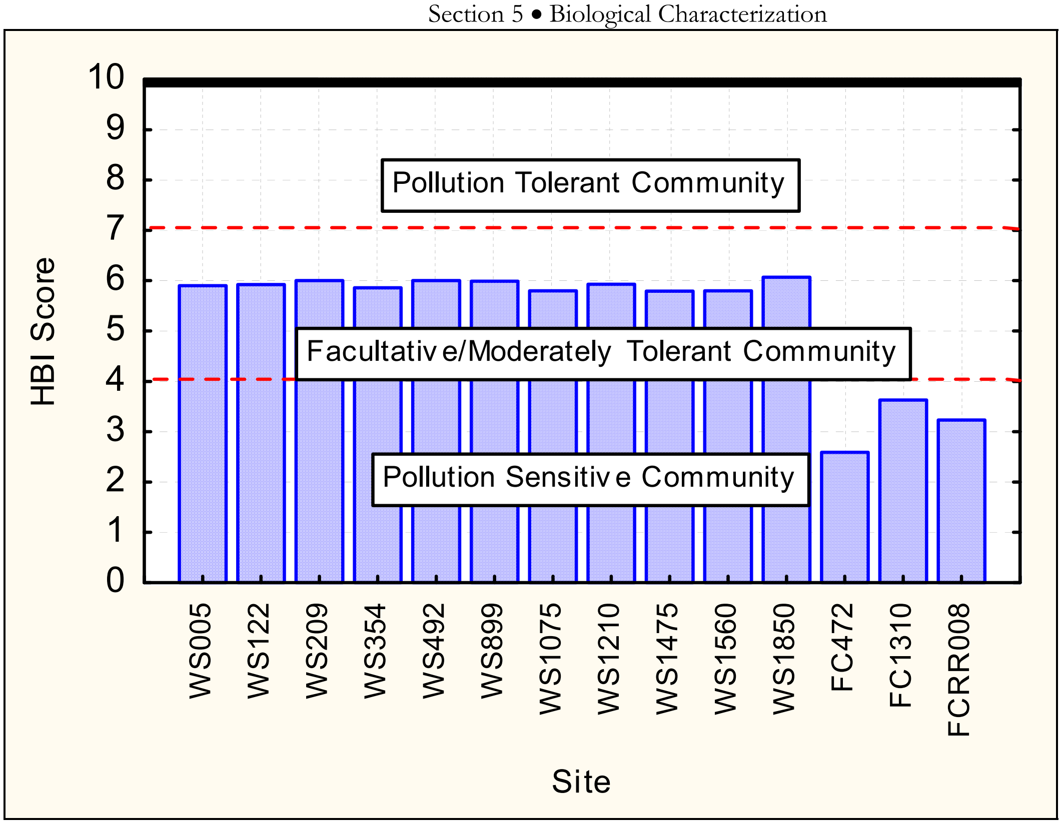


Figure 5-3 Hilsenhoff Biotic Index of Benthic Macroinvertebrate Communities at 11 Mainstem Sites in Wissahickon Creek Watershed and French Creek Reference Sites, 2005

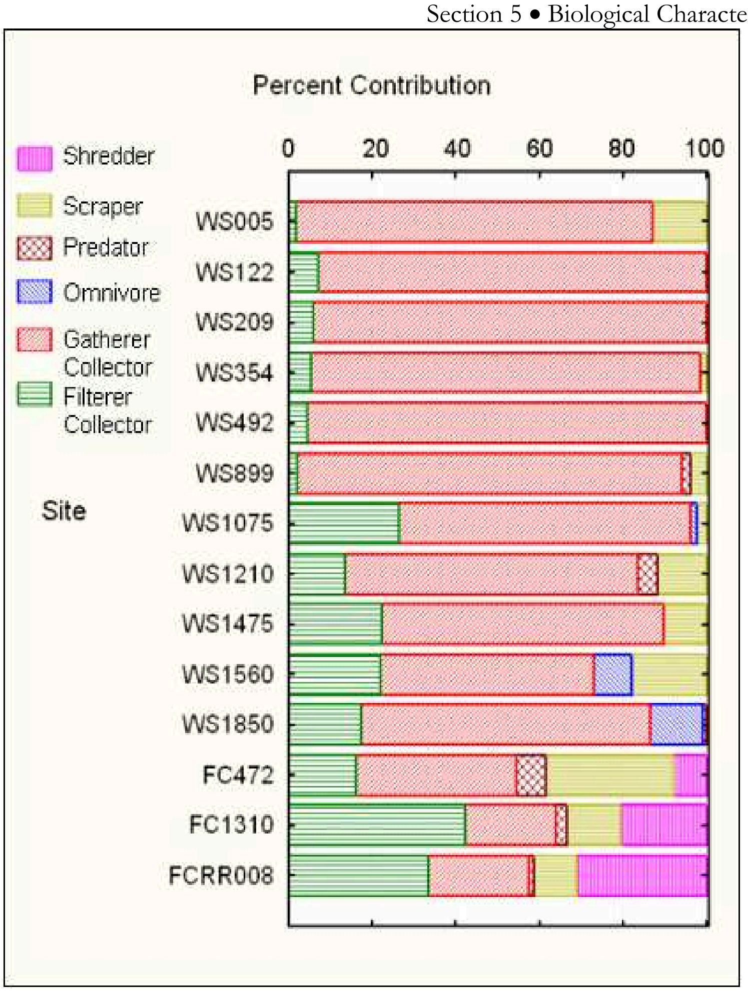


Figure 5-4 Benthic Macroinvertebrate Community Trophic Composition at 11 Mainstem Sites in Wissahickon Creek Watershed and French Creek Reference Sites, 2005

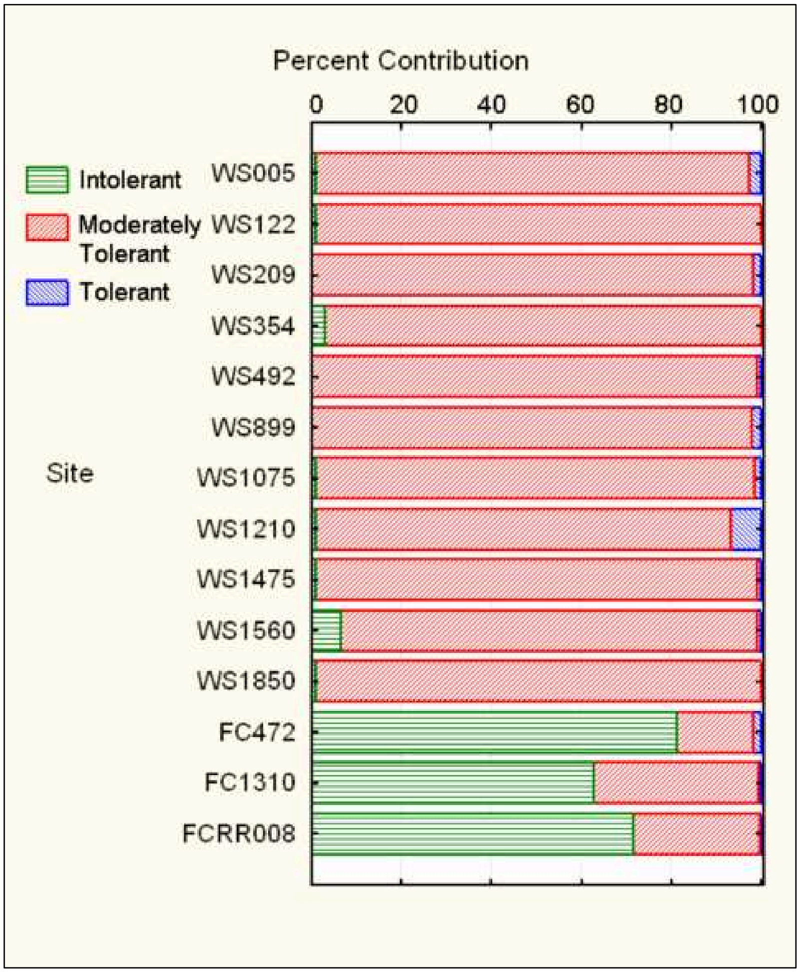


Figure 5-5 Tolerance Designations of Benthic Macroinvertebrate Communities at 11 Mainstem Sites in Wissahickon Creek Watershed and French Creek Reference Sites, 2005

Results of the 2005 benthic macroinvertebrate sampling in Wissahickon Creek Watershed may not accurately depict the quality of the macroinvertebrate community found at the mainstem assessment sites. Biologists noted heavy growth of brown algal periphyton at all mainstem assessment sites while collecting macroinvertebrates. Periphyton was more prominent at assessment sites in Philadelphia County. The periphyton was later identified by BLS biologists as principally *Navicula* sp., in a matrix of organic detritus and inorganic sediment particles. Periphyton scum disturbed from stream substrates clogged the kicknet (500µm mesh), reducing the number of benthic organisms that could be collected in the kicknet. Biologists observed turbid water bypassing the net because the heavy periphyton growth would not allow water to flow through the kicknet. The reduced sampling efficiency may have skewed results or rare taxa may have been overlooked at some sites. While the collection method was semi-quantitative at best, it should be noted that in many cases multiple subsamples, or “plugs” had to be sorted in order to obtain 100 individuals.

Five mainstem assessment sites were resampled on March 7, 2006 and March 8, 2006. These additional samples were collected due to concerns about results being inaccurate due to the kicknet mesh size. A kicknet with 1,000 µm mesh was used to explore whether sampling results from 2005 were skewed due to periphyton clogging the kicknet. Periphyton was present at the time the 2006 samples were collected, but biologists noted that algal mats were not as dense as those observed during sampling in 2005.

Results of the 2006 benthic macroinvertebrate sampling were similar to 2005 results except for taxa richness and abundance (qualitative). Taxa richness increased at all five sites, and none of the five 2006 samples required more than one subsample to count 100 or more individuals. The most pronounced differences were observed at site WS122-Lincoln Drive, where taxa richness increased from four taxa in 2005 to 14 taxa in 2006. All other metrics were scored the same as 2005 results. Despite the increased taxa richness observed at some sites (and increased sampling efficiency), all assessment sites were still designated as "severely impaired" when compared to reference conditions. The increase in taxa richness at each sampling station supported the conclusion that low taxa richness observed during the 2005 macroinvertebrate survey was likely due to mesh size of the kicknet and that differences in the 2005 and 2006 datasets do not necessarily indicate a change in water quality.

Table 5-4 Metric Comparison of 2005 and 2006 Benthic Macroinvertebrate Assessment Sites in Wissahickon Creek Watershed

Wissahickon Creek Watershed Assessment	2005 Taxa Richness	2006 Taxa Richness	2005 Modified EPT Taxa	2006 Modified EPT Taxa	2005 Hilsenhoff Biotic Index (modified)	2006 Hilsenhoff Biotic Index (modified)	2005 Percent Dominant Taxon	2006 Percent Dominant Taxon	2005 Percent Modified Mayflies	2006Percent Modified Mayflies
WS122	4	14	0	1	5.92	5.94	92.00 (Chironomidae)	79.33 (Chironomidae)	0	0
WS354	6	9	0	0	5.86	5.92	87.88 (Chironomidae)	89.85 (Chironomidae)	0	0
WS492	6	10	0	0	6.00	6.06	94.69 (Chironomidae)	80.16 (Chironomidae)	0	0
WS1210	9	12	0	1	5.93	5.96	67.96 (Chironomidae)	43.79 (Cheumatopsyche)	0	0
WS1850	7	8	0	0	6.07	5.90	68.27 (Chironomidae)	66.07 (Chironomidae)	0	0

In 2001, PWD conducted a similar macroinvertebrate survey of Wissahickon Creek Watershed, sampling stations. Most of the metrics were similar between the 2001 and 2005 surveys. Taxa richness was generally greater in the 2001 assessment data. While it is possible that benthic macroinvertebrate communities experienced additional degradation between 2001 and 2005, differences in taxa richness were most likely due to differences in kicknet mesh size. A kicknet with 1000μm mesh was used in 2001, and a kicknet with 500μm mesh was used in 2005. As stated earlier, the kicknet used for the 2005 survey was quickly clogged with periphyton. The differences observed were in all likelihood due to net clogging and macroinvertebrates not being sampled efficiently in the 2005 assessments.

5.2.5.3 TRIBUTARY ASSESSMENT SITES

Macroinvertebrate communities from tributary sites (*i.e.*, sites WSWM039, WMUT003, WSBM007, WSBM090, WSCC009, WSCC070, WSCR008, WSCW003, WSGL020, WSHR009, WSMC025, WSPM018, WSRA005, WSTM002, WSTM020, WSVG009, WSLR005, WSPC017, and WSSR096) generally had slightly better attributes than mainstem sites, particularly with regard to the presence of sensitive taxa, albeit in very low densities. Sites WSPC017 and WSBM090, in particular, had slightly higher taxa richness than the other tributary assessment sites (n=14 and n=11 respectively). These sites also had a number of EPT taxa and other sensitive taxa present. Nevertheless, all tributary assessment sites received total metric scores of zero or two out of a possible 30 and all tributary sites were designated as "severely impaired". Sites were characterized by low taxa richness (n=2 to n=14), low or absent modified EPT taxa and elevated Hilsenhoff Biotic Index scores (5.43 to 6.21). Chironomids (58.47% -99.10%) and generalist feeders (85.83% to 100%) dominated all assessment sites. Specialized feeders were absent or found in low abundance. Moderately tolerant individuals (79.53% to 100.0%) dominated benthic assemblages at all tributary sites.

Table 5-5 Benthic Macroinvertebrate Assessment Results from 19 Tributary Sites in Wissahickon Creek Watershed, 2005

2005 Wissahickon Creek Watershed Assessment	Taxa Richness	Modified EPT Taxa	Hilsenhoff Biotic Index (modified)	Percent Dominant Taxon	Percent Modified Mayflies	Biological Quality (%)	Biological Assessment
WSWM039[b]	2	0	5.98	99.10 (Chironomidae)	0	0	Severely Impaired
WMUT003[b]	3	0	6	79.49 (Chironomidae)	0	0	Severely Impaired
WSBM007[b]	6	0	5.98	88.98 (Chironomidae)	0	0	Severely Impaired
WSBM090[b]	11	2	5.79	73.25 (Chironomidae)	0	6.67	Severely Impaired
WSCC009[b]	9	2	5.83	88.99 (Chironomidae)	0	0	Severely Impaired
WSCC070[b]	6	0	5.97	93.04 (Chironomidae)	0	0	Severely Impaired
WSCR008[b]	7	0	6	85.33 (Chironomidae)	0	0	Severely Impaired
WSCW003[b]	9	2	5.91	83.59 (Chironomidae)	0	0	Severely Impaired
WSGL020[b]	7	0	6.03	92.67 (Chironomidae)	0	0	Severely Impaired
WSHR009[b]	8	1	5.97	86.11 (Chironomidae)	0	0	Severely Impaired
WSMC025[a]	6	0	6.21	75.47 (Chironomidae)	0	0	Severely Impaired
WSPM018[a]	7	0	5.99	95.28 (Chironomidae)	0	0	Severely Impaired
WSRA005[b]	4	0	5.99	88.76 (Chironomidae)	0	0	Severely Impaired
WSTM002[b]	6	1	5.95	77.55 (Chironomidae)	0	0	Severely Impaired
WSTM020[b]	9	2	5.68	58.47 (Chironomidae)	0	0	Severely Impaired
WSVG009[b]	7	0	5.99	95.98 (Chironomidae)	0	0	Severely Impaired
WSLR005[b]	8	0	5.98	89.43 (Chironomidae)	0	0	Severely Impaired
WSPC017[a]	14	2	5.43	68.50 (Chironomidae)	0	6.67	Severely Impaired
WSSR096[a]	9	0	5.96	63.96 (Chironomidae)	0	0	Severely Impaired
FC1310*	21	9	3.63	18.63 (*Prosimulium*)	11.8		
FCRR008*	16	7	3.23	30.35 (*Prosimulium*)	9.34		

*Reference site used for metric comparison

[a] FC1310 used as reference

[b] FCRR008 used as reference

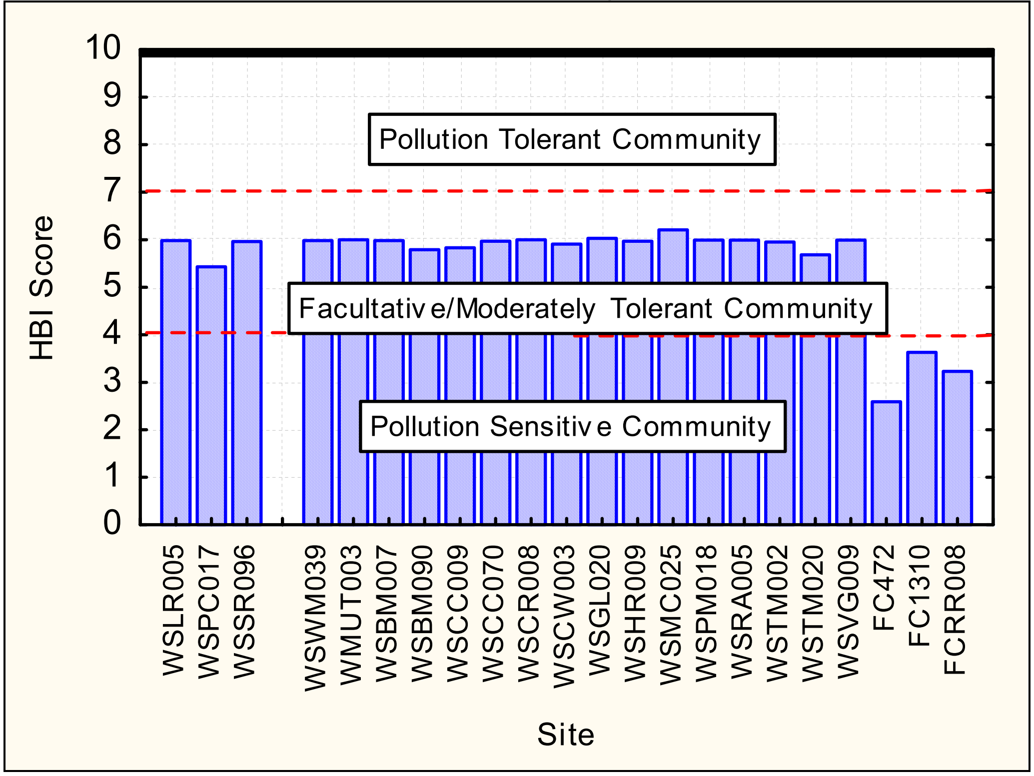


Figure 5-6 Hilsenhoff Biotic Index of Benthic Macroinvertebrate Communities at 19 Tributary Sites in Wissahickon Creek Watershed and French Creek Reference Sites, 2005

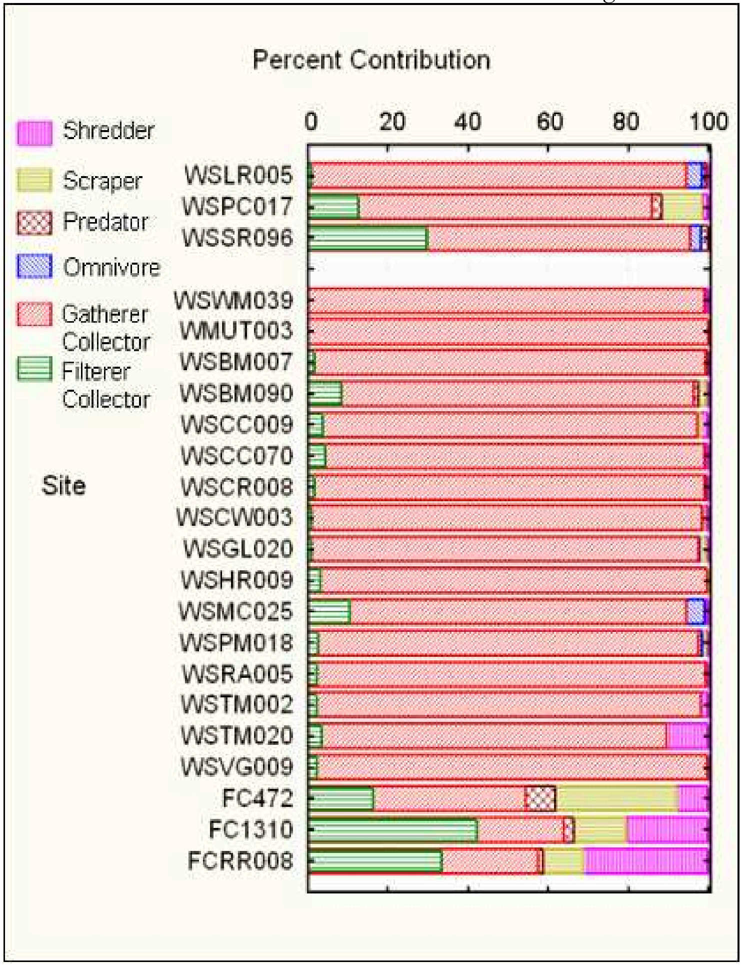


Figure 5-7 Benthic Macroinvertebrate Community Trophic Composition at 19 Tributary Sites in Wissahickon Creek Watershed and French Creek Reference Sites, 2005

Figure 5-8 Tolerance Designations of Benthic Macroinvertebrate Communities at 19 Tributary Sites in Wissahickon Creek Watershed and French Creek Reference Sites, 2005

Three assessment sites (WSTM002, WSTM020, and WSCW003) in Philadelphia and one site in Montgomery County (WSPC017) had *Amphinemura* (Plecoptera: Nemouridae) present in the subsample. Although this pollution-sensitive stonefly was collected at these locations, the sites were still designated as "severely impaired" because of low taxa richness and the dominance of chironomids. *Amphinemura* was present in low densities at all three sites. Other sensitive macroinvertebrate taxa collected from tributary sites in 2005 included *Rhyacophila* (Trichoptera: Rhyacophilidae) at site WSBM090; *Glossosoma* (Trichoptera: Glossosomatidae) at site WSCC009, *Dolophilodes* (Trichoptera: Philopotamidae at site WSBM090, WSHR009, WSCW003 and WSCC009, *Prosimulium* (Diptera: Simuliidae) at site WSPC017, *Ancyronyx* (Coleoptera: Elmidae) at site WSSR096 and WSPC017, *Prostoia* (Plecoptera: Nemouridae) at site WSPC017 and *Diplectrona* (Trichoptera: Hydropsychidae) at site WSTM020.

The only main stem sites where sensitive taxa were collected in 2005 were WS005, where the riffle beetle *Macronychus* (Coleoptera: Elmidae) was collected, and WS1850 where a single *Prosimulium* (Diptera: Simuliidae) blackfly larva was found. The moderately sensitive cranefly *Antocha* (Diptera: Tipulidae) was also found at sites WS122, WS354, and WS1075, and the water penny beetle larva *Psephenus* (Coleoptera: Psephenidae) was collected from sites WS1210 and WS1560. Sensitive taxa collected in mainstem sites resampled in 2006 included *Boyeria* (Odonata: Aeshnidae) at site WS354, *Dolophilodes* (Trichoptera: Philopotamidae) at site WS315, *Nehalennia* (Odonata: Coenagrionidae) at site WS1560, and *Prosimulium* (Diptera: Simuliidae) at site WS1210.

The presence of sensitive macroinvertebrate taxa suggests that water quality and habitat may be adequate to support sensitive macroinvertebrate populations in some, or perhaps most tributaries. Sensitive macroinvertebrate populations may be limited by baseflow suppression, habitat degradation, or storm water quality and/or quantity. These few individuals collected may represent remnants of larger populations that once existed in these locations, or perhaps even new colonists. As populations dwindle in size, it becomes more difficult for adult insects to find mates and "genetic bottleneck" effects may become problematic. PWD plans to conduct in-situ bioassays to determine whether these sensitive organisms can survive in Philadelphia's stormwater-influenced tributaries.

5.3 ICHTHYOFAUNAL ASSESSMENT

5.3.1 MONITORING LOCATIONS

Between 6/1/05 and 6/17/05, PWD biologists conducted fish assessments at ten (n=10) locations within Wissahickon Creek Watershed (Figure 5-9). Surveys were conducted at eight mainstem locations and two tributary locations.

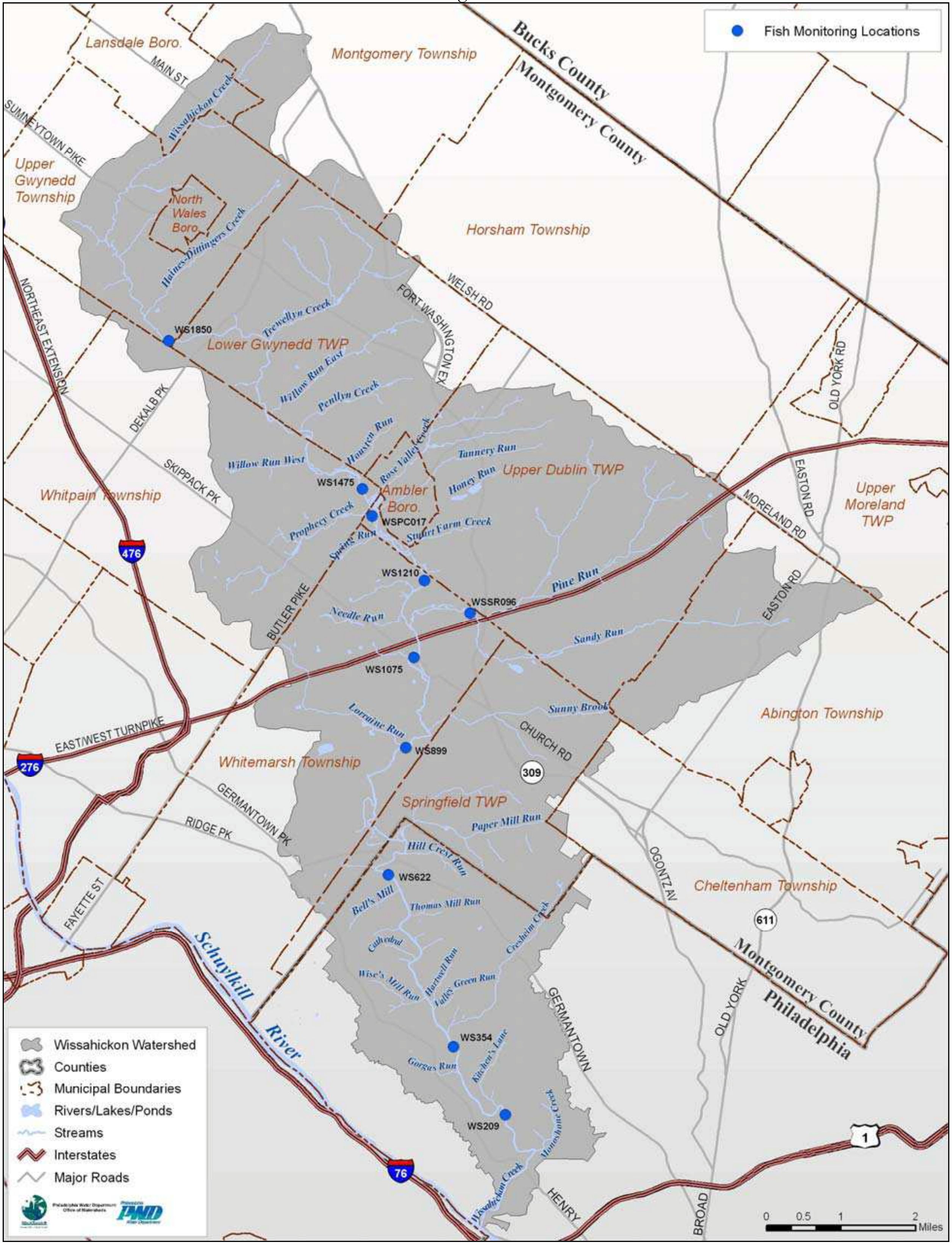


Figure 5-9 Fish Monitoring Sites in the Wissahickon Creek Watershed, 2004

5.3.2 FIELD STANDARD OPERATING PROCEDURES

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 each reach to ensure maximum likelihood population and biomass estimates.

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 log-log 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.

5.3.4 DATA ANALYSES

5.3.4.1 FISH IBI METRICS

The health of fish communities in Wissahickon Creek 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 5-6 and 5-7 describe the various indices and scoring criteria used for the IBI metrics in Wissahickon Creek Watershed. Additional metrics used in the analysis are displayed in Table 5-8.

Table 5-6 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	<3%	3-15%	>15%
5. Number Of Sensitive Species	>67%	33-67%	<33%
6. Percent Generalists	<20%	20-45%	>45%
7. Percent Insectivores	>50%	25-50%	<25%
8. Percent Top Carnivores	>5%	1-5%	<1%
9. Proportion of diseased/anomalies	0%	0-1%	>1%
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 5-7 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 5-8 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

5.3.4.2 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.

5.3.4.3 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).

5.3.4.4 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):

$$MIwb = 0.5*\ln N + 0.5*\ln B + H_N + H_B \qquad \text{(eq. 2)}$$

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

5.3.5. RESULTS

5.3.5.1. WATERSHED OVERVIEW

During the 2005 Wissahickon Creek Watershed fish assessment, PWD surveyed 10 sites and collected a total of 5932 fish representing 27 species in 8 families (Table 5-9). Spottail shiner (*Notropis hudsonius)* and white sucker (*Catostomus commersonii),* two taxa tolerant to moderately tolerant of poor stream conditions, were most abundant and comprised less than half (41.5%) of all fish collected. Other common species included common shiner (*Luxilus cornutus*), redbreast sunfish (*Lepomis auritus*), longnose dace (*Rhinichthys cataractae*), and blacknose dace (*Rhinichthys atratulus*). Of 27 species collected in the watershed, the six aforementioned species comprised 79% of the entire fish assemblage. Similarly, three species made up greater than 80% of the total fish biomass, with white sucker contributing 66% of the biomass.

White sucker, redbreast sunfish, and green sunfish (*Lepomis cyanellus*) were found at all sites in the watershed while goldfish (*Carassius auratus*), brown bullhead (*Ameiurus nebulosus*), creek chub (*Semotilus atromaculatus*), and largemouth bass (*Micropterus salmoides*) were each only found at one site on the mainstem Wissahickon Creek. Of particular concern was the presence of longnose dace, satinfin shiner (*Cyprinella analostana*), and smallmouth bass (*Micropterus dolomieui*) at all sampling locations except WS1850, which is directly downstream of a point source discharge of treated municipal waste. This site (WS1850) also displayed low fish diversity, highest percentage of white suckers (27%), greatest percentage of generalist feeders (93%), and high percentage of individual fish with deformities, eroded fins, lesions, and other anomalies; this resulted in the worst Index of Biotic Integrity score (16 – poor) in the entire Wissahickon Creek Watershed. The presence of stocked brown trout (*Salmo trutta*) and rainbow trout (*Oncorhynchus mykiss*) were spatially documented in the lower and middle portions of the watershed up to site WS1210 at Morris Road, Whitemarsh Township, Montgomery County (river mile 12.10). The abundance of trout was greatest in the lower watershed and decreased in an upstream direction.

Three species collected during a study in 1960 (Wurtz *et al.* 1965) were absent in PWD's 2001 and 2005 fish assessment; bluntnose minnow (*Pimephales notatus*), creek chubsucker (*Erimyzon oblongus*), and margined madtom (*Noturus insignis*). The overall fish diversity in Wissahickon Creek Watershed was almost the same from 2001 to 2005. The only differences included; mummichog (*Fundulus heteroclitus*) collected in 2001 but not in 2005; brown bullhead and goldfish collected in 2005 but not in 2001. There was a slight shift in dominant species, with common shiner most abundant in 2001 (n=1130) and spottail shiner (n=1403) most abundant in 2005. The six most common fish (spottail shiner, common shiner, white sucker, redbreast sunfish, blacknose dace, and longnose dace) were identical from 2001 to 2005. There were significantly more trout collected in 2005 (n=181) than in 2001 (n=41), however, several more sites were added in 2005.

Trophic composition evaluates quality of the energy base and foraging dynamics of a fish assemblage. However, interpreting results of biological indexing methods that evaluate certain attributes of a fish community, such as the relative abundance of top predators, or proportion of intolerant species, can be difficult in a watershed that is heavily stocked with trout. It is important to consider stocked fish when examining the trophic composition of the fish community. While an increase in top predators in an urban stream usually would be viewed as a positive development, top predators are not expected to be overwhelmingly dominant in balanced ecosystems. Data from some Wissahickon sites suggests that at very high predator densities, abundance and diversity of forage fish may be reduced.

As applied to urban streams, the trophic composition of a fish assemblage is an effective means of evaluating the shift towards more generalized foraging that typically occurs with increased degradation of the physicochemical habitat (Barbour *et al.* 1999). For example, generalist feeders (52%) dominated the Wissahickon Creek Watershed fish assemblage, with 43% insectivores and 5% top carnivores (or 2% top carnivores if stocked trout are excluded). 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 extremely low percentage of insectivores in the two upstream-most sites illustrates this point. Trophic composition was fair compared to reference sites, which have more insectivores than generalists. Though community composition varied between sites, the fish assemblage in Wissahickon Creek Watershed was skewed towards a moderately pollution tolerant, generalist feeding community. The trophic composition displayed little variation from 2001 to 2005, with only a 6% increase in percentage of insectivores and 7% decrease in generalists.

Table 5-9 List of Fish Species Collected from 8 Mainstem and 2 Tributary Sites in Wissahickon Creek Watershed, 2005

Common Name	Scientific Name	Family	Total
spottail shiner	*Notropis hudsonius*	Cyprinidae	1402
white sucker	*Catostomus commersonii*	Catostomatidae	1060
common shiner	*Luxilus cornutus*	Cyprinidae	886
longnose dace	*Rhinichthys cataractae*	Cyprinidae	587
redbreast sunfish	*Lepomis auritus*	Centrarchidae	510
blacknose dace	*Rhinichthys atratulus*	Cyprinidae	235
tessellated darter	*Etheostoma olmstedi*	Percidae	203
brown trout	*Salmo trutta*	Salmonidae	147
satinfin shiner	*Cyprinella analostana*	Cyprinidae	142
green sunfish	*Lepomis cyanellus*	Centrarchidae	122
smallmouth bass	*Micropterus dolomieui*	Centrarchidae	103
spotfin shiner	*Cyprinella spiloptera*	Cyprinidae	87
banded killifish	*Fundulus diaphanus*	Fundulidae	87
pumpkinseed sunfish	*Lepomis gibbosus*	Centrarchidae	69
yellow bullhead	*Ameiurus natalis*	Ictaluridae	68
swallowtail shiner	*Notropis procne*	Cyprinidae	36
rainbow trout	*Oncorhynchus mykiss*	Salmonidae	34
creek chub	*Semotilus atromaculatus*	Cyprinidae	33
fathead minnow	*Pimephales promelas*	Cyprinidae	27
American eel	*Anguilla rostrata*	Anguillidae	25
golden shiner	*Notemigonus crysoleucas*	Cyprinidae	20
bluegill sunfish	*Lepomis macrochirus*	Centrarchidae	18
rock bass	*Ambloplites rupestris*	Centrarchidae	9
brown bullhead	*Ameiurus nebulosus*	Ictaluridae	4
green x pumpkinseed sunfish hybrid	*Lepomis cyanellus* x *Lepomis gibbosus*	Centrarchidae	4
common carp	*Cyprinus carpio*	Cyprinidae	3
green x redbreast sunfish hybrid	*Lepomis cyanellus* x *Lepomis auritus*	Centrarchidae	3
largemouth bass	*Micropterus salmoides*	Centrarchidae	3
satinfin x spotfin shiner hybrid	*Cyprinella analostana* x *Cyprinella spiloptera*	Cyprinidae	3
goldfish	*Carassius auratus*	Cyprinidae	1
green x bluegill sunfish hybrid	*Lepomis cyanellus* x *Lepomis macrochirus*	Centrarchidae	1

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, Wissahickon Creek Watershed was found to be lacking intolerant taxa (not including stocked trout) and therefore illustrates a high level of chemical and physical disturbances. Since trout do not reproduce in Wissahickon Creek and their populations are maintained solely by the state stocking program, we excluded trout when calculating metrics which are intended to be measures of stream health (*i.e.*, Index of Biotic Integrity, number of individuals with deformities, lesions and tumors, percent white sucker, diversity indices, and Modified Index of well being). Nevertheless, stocked trout are a component of the fish community at many sites, and trout have thus been included in most "raw" descriptions of fish assessment results (*i.e.*, number of species, biomass, Catch per unit effort, density, standing crop) for completeness. Figures have been specifically prepared to allow evaluation of the influence of stocked trout.

Presence of trout (and dominance of trout at some sites) in the summer months when our survey was conducted implies that sufficient water quality exists in various locations. More importantly, we documented dispersal of trout into areas that are not stocked, suggesting suitable stream conditions upstream of the “Approved Trout Waters” section of the creek. Approximately 66% of the Wissahickon fish assemblage was moderately tolerant of poor stream quality. Tolerant fish were found to dominate the uppermost stations, whereas the downstream stations had mostly moderately tolerant individuals.

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 community processes and functions (Karr *et al.* 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). Mean IBI score for Wissahickon Creek Watershed was 27 (out of 50), placing it in the “poor” category for biotic integrity. 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 sites in the lower and middle sections of the watershed received a "fair" IBI score, while the upper watershed scored “poor” (Figure 5-10), signifying unhealthy stream conditions. Similar spatial trends revealed that Modified Index of Well-Being values, which are measures of diversity and abundance, were greatest in the lower monitoring stations and worst in the upper portion of the watershed. Another metric used to assess stream health (percentage of fish with disease, tumors, fin damage, or anomalies) revealed the same results with heavily impacted fish (25%) in the middle and upper portions and comparable to reference conditions in the lower watershed (Figure 5-12). Overall, monitoring stations in the downstream portion of the watershed had higher biological integrity, thus environmental quality, than upstream stations.

Figure 5-10 Fish IBI Score from 8 Mainstem and 2 Tributary Sites in Wissahickon Creek Watershed, 2005

5.3.5.2 INDIVIDUAL SITE RESULTS

<u>WS209</u>

A total of 188 fish represented by eight species yielded a biomass of 19.5 kg during 55 minutes of electrofishing. This site had the lowest diversity (*i.e.*, species richness) and second lowest abundance (*i.e.*, number of fish) in the watershed. Based on a stream surface area of 1674 m^2, a density of 0.11 fish per m^2 and a standing crop of 11.7 grams per m^2 were calculated. These values signified the second lowest density and fourth lowest standing crop in the watershed. Similarly, this site had the second smallest catch per unit effort (CPUE) at 3.38 fish per minute of electrofishing. Of the eight species collected at WS209, brown and rainbow trout (which are heavily stocked) comprised 45% of all fish collected and almost 70% of the total biomass. This site had the greatest abundance and biomass of trout in the watershed. When the warmwater predators (smallmouth bass and American eel) were combined with both trout species, this site was overwhelmed with the number (66%) and biomass (92%) of predators. The resulting trophic structure of WS209 was highly skewed, with the highest percentage of top carnivores and lowest percentage of generalist feeders in Wissahickon Creek Watershed.

This fact suggests that direct predation likely explains the overall low abundance and diversity at this site, as well as poor representation of cyprinids (*i.e.*, minnows, shiners, dace). If stocked trout are excluded from the trophic structure analysis, it appears that there are still considerable numbers of native and introduced top carnivore species at site WS209 (Figure 5-11). The fact that site WS209 still had a highly skewed trophic structure once trout are excluded was probably due to the severely reduced number of small forage fish. If these species increased in number, the trophic composition of site WS209 would probably be more similar to a natural stream. Furthermore, while no intolerant fish were found occurring naturally in Wissahickon Creek Watershed, site WS209 had the highest percentage of intolerant taxa and second lowest percentage of tolerant taxa when stocked trout are included (Figure 5-13).

Despite the low diversity and abundance, WS209 was one of three sites that received an Index of Biotic Integrity (IBI) score of 32 out of 50, representing a "fair" quality fish assemblage and therefore, fair environmental health (Figure 5-10). Since the IBI utilizes multiple biological metrics, several other characteristics of the fish community account for the fair score: the presence of two benthic insectivorous species; two water column species; low percentage of white suckers; low percentage of generalist feeders; high percentage of top carnivores; low percentage of dominant species, and low percentage of individuals with disease or anomalies. In fact, the percentage of individual fish with deformities and anomalies was second best among Wissahickon Creek Watershed sites and corroborated the IBI designation (Figure 5-12). In summary, although WS209 scored poorly for fish abundance metrics (due to high density of stocked trout), the high values for trophic structure, fish condition, and community composition metrics elevated the overall IBI score.

<u>WS354</u>

In 1775 m^2 of stream surface area, a total of 1031 individuals of 14 species were collected during 70 minutes of electrofishing. This site had the second highest abundance of fish (n=1031); second greatest total biomass (33.8 kg); third highest density (0.58 fish/m^2) and CPUE (14.4 fish/minute); and below average standing crop (19 grams/m^2) for the watershed. Two benthic insectivorous species as well as three water column species were collected. Spottail shiner (*N. hudsonius)*, a moderately tolerant species, was dominant and comprised 61% of all fish collected but only 6.5% of the biomass. Of the 14 species collected, five species accounted for 88% of the fish assemblage. Brown trout contributed most to overall biomass (28%), followed closely by white sucker (26%), and redbreast sunfish (11%). WS354 had the highest percentage of insectivores (67%) in the watershed, due to high density of spottail shiners, with 24% generalist feeders and 9 % top carnivores (3.7 % top carnivores excluding stocked trout). With or without stocked trout, site WS354 had the most well-balanced trophic structure in Wissahickon Creek Watershed and closely resembled reference stream trophic conditions (Figure 5-11). This site also had the greatest percentage of moderately tolerant taxa (86%) and the least amount of pollution tolerant taxa (8.6%) in the entire watershed (Figure 5-13).

The well balanced community structure of insect feeding, moderately tolerant species, combined with a high abundance and diversity of fish, exemplifies a stream reach with adequate environmental quality. Along with sites WS209 and WS1075, site WS354 received an IBI score of 32 out of 50, which is typical of a fish assemblage with "fair" biotic integrity. Other positive biologic characteristics included the second lowest percentage of white suckers (5.5%); the minimum percentage of individuals with disease, tumors, fin damage, or other anomalies (1.3%); and the second highest Modified Index of Well-Being value (11.2) in the watershed.

<u>WS622</u>

WS622 was the upstream-most sampling location in the City of Philadelphia and many attributes of the fish community were similar to site WS209. For example, site WS622 contained the lowest number of individuals (*i.e.*, abundance) in the watershed with 182 fish of 9 species, resulting in the minimum density (0.08 fish/m^2) and catch per unit effort (3.17 fish/minutes electrofishing) in Wissahickon Creek Watershed. Despite the low abundance, this site had the second greatest abundance of American eel, brown trout, green sunfish, rainbow trout and third greatest abundance of smallmouth bass in the watershed. The abundance of native and introduced top predators mentioned above, combined with the relative paucity of forage fish species, produced an unbalanced trophic structure with the lowest percentage of insectivores (4.9%), second highest percentage of top carnivores (26.4%), and third highest percentage of generalist feeders (68.7%) in the watershed. When trout were excluded from the analysis, the trophic structure was more balanced (Figure 5-11), but probably still skewed due to the low abundance of cyprinids.

Tolerance designations were 56.6% tolerant, 29.7% moderately tolerant and 13.7 % intolerant (includes trout). With trout excluded, the assemblage was composed of 34% tolerant and 66% moderately tolerant fish.(Figure 5-13) Site WS622 received a low IBI score (22 out of 50), characteristic of a fish assemblage with "poor" biotic integrity. Similarly, the Modified Index of Well-Being (9.57) and Shannon Diversity Index (1.72) values further supported the IBI classification. Although WS622 had several low scores, it should be noted that this site had fewer individual fish with disease and anomalies than all upstream monitoring locations (Figure 5-12).

WS899

A total of 1506 fish representing 15 species were collected in 1613 m^2 of stream surface area in 82 minutes of electrofishing. This site had the maximum total biomass (138 kg), standing crop (85.8 g/m^2), number of individuals (n=1506), and catch per unit effort (18.33 fish/minute), as well as second highest density (0.93 fish/m^2), in the watershed. These relatively high abundance and diversity values, indicative of the quality of the fish assemblage, produced a Modified Index of Well-Being value of 10.61 and Shannon Diversity Index value of 1.92. More longnose dace, redbreast sunfish, swallowtail shiner, tessellated darter, and white sucker were found here than at any other site in the watershed. Though diverse and abundant, the fish assemblage at WS899 was nearly devoid of pollution sensitive taxa and top carnivores. Of the 15 species found here, three species composed 72% of all individuals collected and 95% of the total biomass. Also, this site had the greatest number of white suckers in the watershed which is symptomatic of degraded stream conditions.

The trophic composition also displayed unbalanced characteristics with less than one- percent top carnivores, 37% generalist feeders, and 62% insectivores (Figure 5-11). In addition, approximately 8.5% of all fish had some type of disease, tumors, fin damage, or other anomalies (Figure 5-12). Furthermore, one unusual longnose dace specimen was found to have a second pair of pelvic fins. Regardless of this unevenness and prevalence of anomalies, WS899 was only one of three mainstem sites with more insectivores than generalist feeders, which helped elevate the IBI score. With positive scores for abundance, diversity, and trophic structure, this monitoring location received an IBI score of 30 out of 50 and was designated a "fair" quality fish assemblage.

WS1075

White sucker, common shiner, spottail shiner, and longnose dace comprised 70% of the 340 individual fish collected at this location. There were two benthic insectivorous species, four water column species, and seven cyprinid species found in 1693 m^2 of stream surface area. Of the 14 species documented here, 4 species accounted for 86% of the total biomass. This site had the second lowest total biomass (11.7 kg) and subsequently the minimum standing crop (6.9 g/m^2) in Wissahickon Creek Watershed. Catch per unit effort (8.4 fish/minute) was close to average, while density (0.2 fish/ m^2) was well below average. The trophic structure was relatively well balanced with 61.5% insectivores, 35.9% generalist feeders, and 2.7% top carnivores (less than 1% top carnivores with stocked trout excluded, Figure 5-11). However, this site had the greatest percentage of individual fish with deformities, eroded fins, lesions, and other anomalies (DELTA), with more than 25% of the assemblage affected (Figure 5-12 fish delta bar chart) . This is an excellent measure of the sub-acute effects of chemical pollution and aesthetic value of non-game fish (Barbour *et al.* 1999).

The Modified Index of Well-Being (9.66) was below average but the Shannon Diversity Index (2.04) was above average. Since there were 14 species collected at a site with low abundance, the Shannon Diversity Index is high. Despite the high prevalence of DELTA and a high percentage of white suckers, this site was one of three that received a "fair" IBI score of 32 out of 50 due to good rankings for total number of fish species, number of water column species, and very high percentage of insectivores. This IBI score represented a fish community reflective of fair environmental quality.

WS1210

This sampling location marked a sharp decline in the quality of the fish assemblage in Wissahickon Creek Watershed. Here we observed a transition in the trophic structure from an insectivore-dominated community, to generalist feeders (52%), with the numbers of insectivores decreasing while generalist feeders increased (Figure 5-11). Likewise, the percentage of pollution tolerant individuals increased (45%) while moderately tolerant (55%) individuals decreased (Figure 5-13 fish tolerance bar chart). The high percentage of white sucker (26%) is indicative of degradation since they show increased distribution or abundance despite the historical disturbances and they shift from incidental to dominant in disturbed sites (Barbour *et al.* 1999). Of the 18 species documented at this site, white sucker, common shiner, spottail shiner, and longnose dace comprised approximately 73% of all fish collected. White sucker, yellow bullhead, and redbreast sunfish encompassed over 85% of total fish biomass (~32 kg). This site had the third highest total biomass (32 kg) and second highest catch per unit effort (15 fish per minute) in the watershed.

The high diversity and number of cyprinid species produced the greatest Shannon Diversity Index score (2.19) in the watershed, however, lower abundance values yielded an average Modified Index of Well-Being score (10.24). The lack of intolerant species, high percentage of white suckers, skewed generalist feeding community, and high percentage of individual fish with deformities, eroded fins, lesions, and other anomalies resulted in a “poor” IBI score of 28 out of 50, suggesting poor stream conditions.

WS1475

A total of 201 fish represented by 10 species yielded a biomass of 10.6 kg during 55 minutes of electrofishing. This site had the second lowest percentage of insectivores (8%) and second highest percentage of generalist (83%) feeder fish taxa in the watershed. Based on a stream surface area of 1189 m^2, a density of 0.17 fish per m^2 and a standing crop of 8.9 grams per m^2 were calculated. These values signified the third lowest density, second lowest standing crop, and the minimum total biomass in the watershed. Similarly, this site had low catch per unit effort (CPUE) at 3.7 fish per minute of electrofishing. Of the 10 species collected at WS1475, white sucker, redbreast sunfish, and green sunfish comprised 80% of all fish collected and over 80% of the total biomass. The resulting trophic structure of WS1475 was highly skewed, with the second highest percentage of generalist feeders (83%) and second lowest percentage of insectivores (8%) in Wissahickon Creek Watershed (Figure 5-11). Generalist feeders become dominant with increased stream degradation. All species collected at this sampling location were tolerant (49%) or moderately tolerant (51%) of stream pollution (Figure 5-13).

Taking into account the aforementioned problems, as well as the high percentage of DELTA, WS1475 received an IBI score of 20 (out of 50), placing it into the "poor" classification for biotic integrity. The IBI score for this site was second worst in the watershed. The Modified Index of

Well-Being (9.62) and Shannon Diversity Index (1.70), measures of abundance and diversity, represented some of the lowest scores in Wissahickon Creek.

WS1850

The fish assemblage at WS1850 contained only nine species, two of which were represented by only a single individual. White sucker, common shiner, and blacknose dace contributed almost 80% of all fish collected at this location and 77% of total fish biomass. Species richness typically decreases with increased degradation. However, one might also expect to find reduced species richness as upstream drainage area decreases and very few species in shallow headwater streams. This site was also devoid of pollution intolerant taxa and only contained one water column species and one benthic insectivorous species. With 93% generalist feeders, this was one of the most highly skewed trophic structures in all of Philadelphia's watersheds surveyed by PWD (Figure 5-11). 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 extremely low percentage of insectivores in the two upstream-most sites illustrates this point.

This was the only site in Wissahickon Creek Watershed with a greater percentage of pollution tolerant individuals than moderately tolerant (Figure 5-13 fish tolerance bar chart). Also, WS1850 had a large percentage (13%) of individuals with disease, tumors, fin damage, or other anomalies (Figure 5-12) and the greatest percentage of white suckers in Wissahickon Creek Watershed. This is symptomatic of an impacted assemblage downstream of point source pollution or in areas where toxic chemicals are concentrated (Barbour *et al.* 1999). The Modified Index of Well-Being (10.48) was average, while the Shannon Diversity Index (1.62) was second worst in the watershed. This site received the worst IBI score (16 out of 50) in the watershed, as well as one of the worst scores in a Philadelphia area stream (based on PWD data from 2000-2005) (Figure 5-10). Low species richness and trophic composition metrics combined with poor abundance and condition metrics reflect a stream with severely degraded quality.

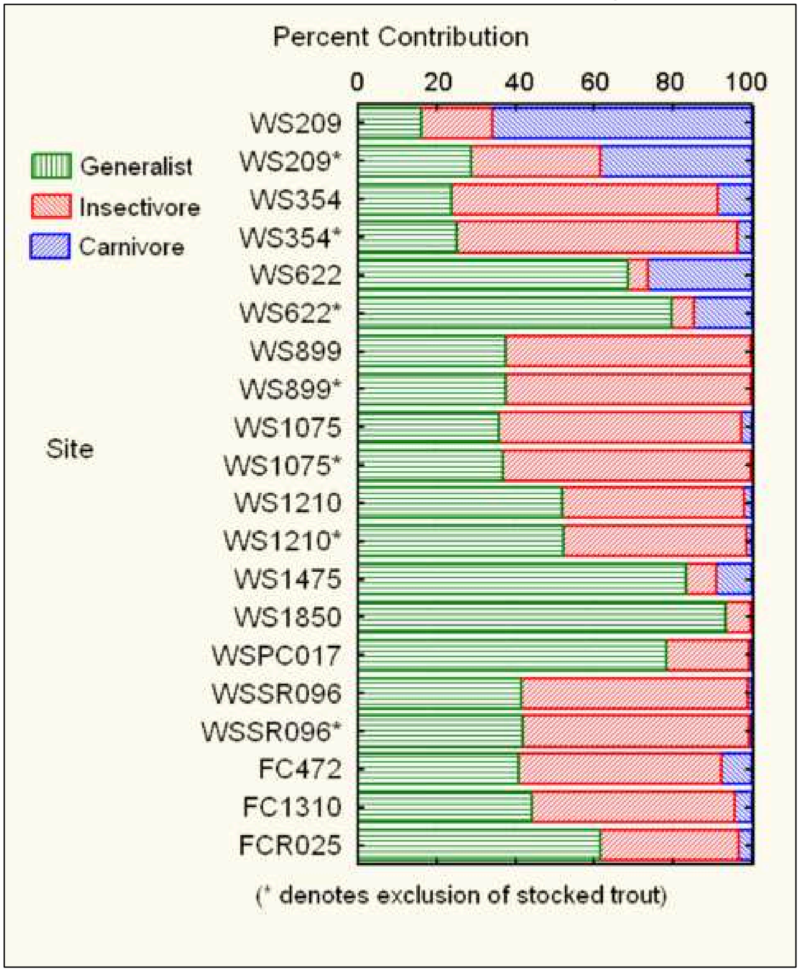


Figure 5-11 Community Trophic Composition of Fish Collected from 8 Mainstem and 2 Tributary Sites in Wissahickon Creek Watershed and French Creek Reference Sites, 2005

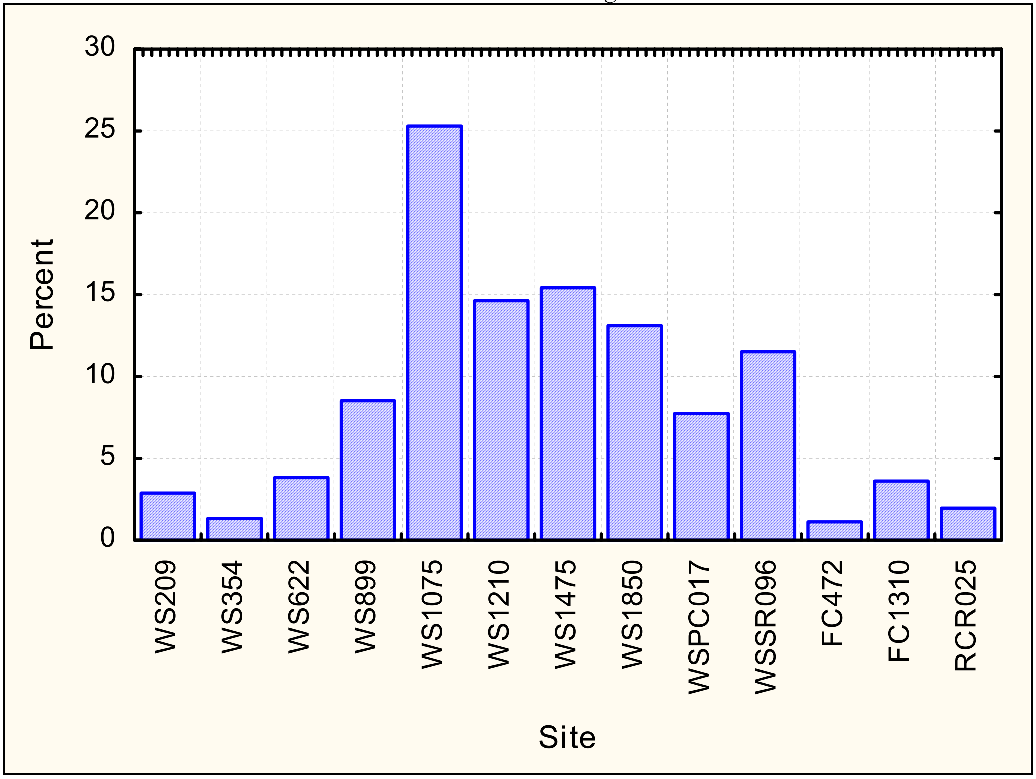


Figure 5-12 Percentage of Fish with Disease, Tumors, Fin Damage or Anomalies Collected from 8 Mainstem and 2 Tributary Sites in Wissahickon Creek Watershed and French Creek Reference Sites, 2005

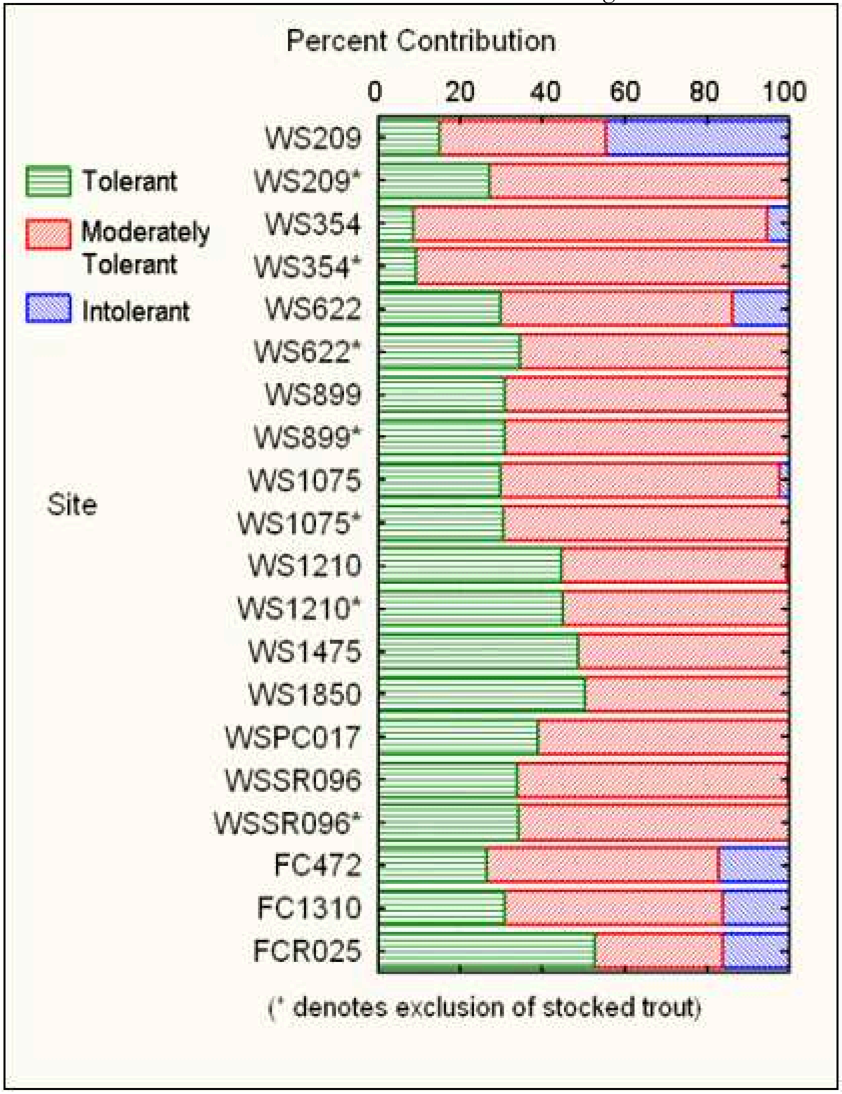


Figure 5-13 Tolerance Designations of Fish Collected from 8 Mainstem and 2 Tributary Sites in Wissahickon Creek Watershed and French Creek Reference Sites, 2005

5.4 PERIPHYTON

5.4.1 MONITORING LOCATIONS

Periphyton communities were sampled from sites WS122, WS354, WS1075, and WS1850, chiefly to assess the role of periphyton regulating stream metabolism (Section 4.8). Surveys were conducted at mainstem locations only, and 2 sites were located within Philadelphia County. Sites were chosen based on proximity to continuous water quality monitoring stations, but some cases adjustments were made in order to situate the periphyton sampling locations in areas with sufficient depth and substrates and to attempt to control for differences in canopy cover.

The intensity of PWD's 2005 periphyton monitoring in Wissahickon Creek Watershed was curtailed because of a periphyton study being conducted concurrently by Penn State University with assistance from PADEP (Carrick and Godwin 2006). PWD's sampling program was thus limited to surface water chlorophyll-*a* (n=98) from grab samples and estimates of periphyton chlorophyll-*a* at four sites in spring and summer (24 periphyton samples total).

Table 5-10 C, N, P, and Chl-*a* Concentrations from Wissahickon Creek Periphyton Assemblage Study, Carrick and Godwin 2006

PWD site	River Mile	C (g/m^2)	N (g/m^2)	P (g/m^2)	Chl-α (mg/m^2)
WS076	0.1	11.6	1.99	1.99	252.5
WS622	6.1	26.8	2.58	1.76	74.3
WS1075	10.6	45.4	5.37	4.33	297.8
WSSR096	11	74.8	8.68	6.77	210
WS1210	12	10.1	2.08	2.2	98.9
WWV*	12.7	5.3	0.93	1.03	85
TGH**	16	14.2	1.81	1.73	276.3
WS1850	16.9	17.5	2.59	2.45	204.6
WS2245	19.3	45.6	6.04	3.96	313.9

*site located upstream of Ambler WWTP; no equivalent PWD site

**site located on Trewellyn Creek; no equivalent PWD site

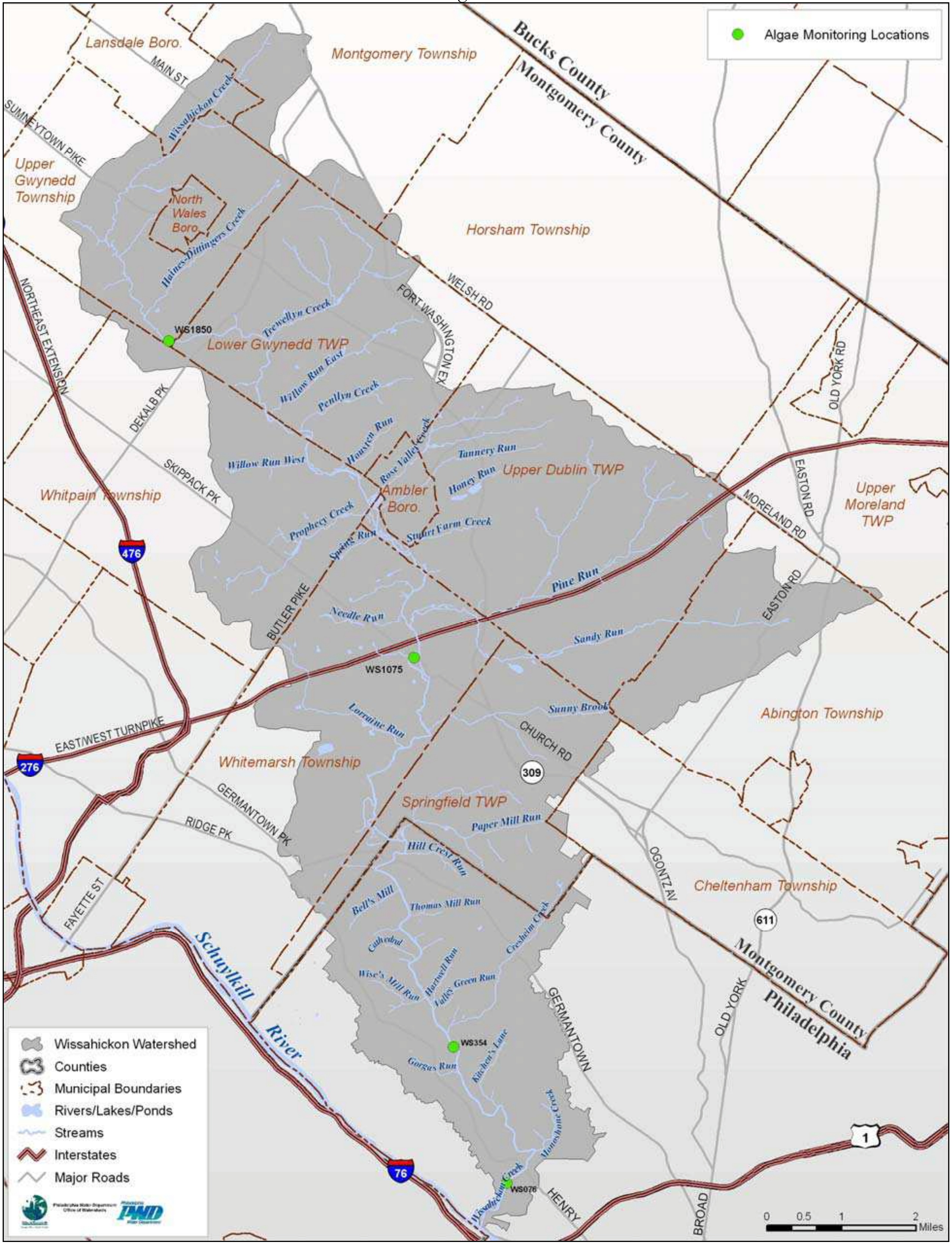


Figure 5-14 Periphyton Monitoring Locations in Wissahickon Creek Watershed, 2005

5.4.2 FIELD STANDARD OPERATING PROCEDURES

Periphyton was collected from natural substrate particles in shallow (~20cm) run habitats. Substrate particles were chosen by walking transects at random until appropriate depth of flow was reached. Biologists then walked heel to toe and selected the first substrate particle that was encountered by reaching down at the very tip of the wading shoe. Very large and very small substrate particles were rejected, as were substrate particles that appeared to have been recently moved. Manmade substrate particles such as bricks, concrete and other debris were also rejected.

Substrate particles were placed in white plastic lab trays in the same orientation they had been found and large debris such as gravel, leaves, large macroinvertebrates, and built up decaying organic matter were removed. Substrate particles collected from Wissahickon Creek Watershed were observed to have noticeably fewer hydropsychid caddisflies, scuds (amphipods) and mayflies than other sites monitored by PWD. At most other sites surveyed by PWD, substrate particles (particularly sides and undersides of rocks) typically contain several caddisfly nets that are removed as part of the periphyton sampling procedure. If the substrate particle had extensive coverage of macroalgae, the filaments were trimmed to the profile of the substrate particle as viewed from above.

Three replicate samples were collected at each site. Depending on the size of the substrate particles collected, 1 to 3 particles were used for each replicate sample at each site. Each member of the three person sampling team was assigned a different replicate letter, "A", "B", or "C", and sample containers were pre-labeled with site and replicate information. Periphyton was removed from the upper surface of each substrate particle using firm bristle toothbrushes that had one half the brush length trimmed away (Figure 5-15). Substrate particles were irrigated with stream water and scraped until the surface became noticeably rough and not slimy. All substrate particles for each replicate sample were composited into 250mL Nalgene sample bottles by rinsing the plastic tray with stream water. Samples were stored on ice in a darkened cooler and exposure to sunlight was minimized throughout the sample handling procedure.

Figure 5-15 Algae Sampling in Wissahickon Creek Watershed, 2005

All substrate particles used for a given replicate were wrapped with aluminum foil, which was folded, trimmed, and/or notched, as appropriate, to carefully match the surface of the substrate particle that was scraped to collect periphyton (Figure 5-16). All substrate particle foil molds for each replicate were stored in a pre-labeled Ziploc bag.

Figure 5-16 Cutting Foil for Algae Sampling in Wissahickon Creek Watershed, 2005

5.4.3 SUBSTRATE PARTICLE SURFACE AREA DETERMINATION WITH DESKTOP IMAGE ANALYSIS

Foil molds were scanned and digitized using a Microtek Scanmaker 4900 scanner. The scanner was modified with a dense black light-absorbing background to increase contrast in the resulting images, which were saved as 8 bit (256 levels of greyscale) TIFF files. Surface area was measured using Scion Image version 4.0.3.2. Differences in color between the foil and background were used to select and count the number of foil pixels, which was converted to square meters based on a calibration to the scanned image. For replicates in which more than one substrate particle was scraped to obtain the periphyton sample, the total surface area of all substrate particles sampled for each replicate was calculated by summing the individual areas of each particle used for the sample.

5.4.4 LABORATORY STANDARD OPERATING PROCEDURES

Periphyton samples were brought to the Bureau of Laboratory Services and processed in the Wastewater Laboratory using a modified version of EPA Method 445.0. Each replicate sample was homogenized using a laboratory blender (Waring, Inc.). The sample was transferred to a large beaker and the blender was rinsed with deionized water multiple times. Deionized water was added to the sample to make volume up to 1L for ease of filtration and to simplify volumetric calculation of algal density. 5ml aliquots of this diluted sample were vacuum filtered through a 0.45 µm glass fiber filter (Whatman, Inc.) to concentrate algae. As many as three 5mL aliquots were filtered through the filters to ensure that enough material was collected by the filter. A laboratory vacuum manifold was used to process multiple samples simultaneously. The total volume filtered was recorded on a data sheet and the sample label. Filters were individually wrapped in aluminum foil and stored for up to 21 days in a laboratory freezer at -20°C.

Filters were placed in a test tube with 90% acetone extraction solution and homogenized using a counter-rotating tissue grinder (Omni EZ Connect Homogenizer model TH115), and the chlorophyll *a* pigments were extracted from the phytoplankton in 90% acetone overnight in a refrigerator at 4°C. A volume of 5ml of extract was placed in a cuvette and analyzed by the fluorometer before and after acidification to 0.003 N HCl with 0.1 N HCl to convert chlorophyll *a* to pheophytin *a*. A ratio of the chlorophyll *a* to pheophytin *a* is used to determine the initial chlorophyll *a* concentration.

5.4.5 DATA ANALYSES

Periphyton chlorophyll *a* was determined with a volumetric calculation based on the amount of diluted sample that was filtered onto the glassfiber filter and results were expressed as mg/m^3 using the appropriate conversion factors.

5.4.6 RESULTS

Periphytic algae grew to nuisance densities in Wissahickon Creek Watershed and caused severe fluctuations in dissolved oxygen concentration and moderate fluctuations in pH (sections 4.5.1 and 4.5.2). These fluctuations resulted in frequent violations of PADEP water quality criteria and may have been partially responsible for the biological impairment that was observed throughout the watershed (sections 5.2.5 and 5.3.5). In 2005, PWD biologists were unable to effectively sample benthic macroinvertebrates from many sites in the watershed using standard protocols because the sampling apparatus ($1m^2$ kicknet, 500µm mesh size) became clogged with algae (section 5.2.2). Algae caused objectionable odors in drinking water from the City of Philadelphia's Queen Lane Water Treatment Plant, requiring the addition of 400 tons of activated carbon at a cost of approximately $200,000 (section 4.5.3). Algal mats and odors also have been identified as detracting from the aesthetic value of a popular urban park (ANSP 2001), and decreased the quality of the trout fishery.

On four occasions, algal periphyton samples were examined under magnification for basic identification of taxa associated with algal mats or "scums" that were present in the stream. Physiognomy of these mats exhibited considerable variation. In early spring, mainstem Wissahickon Creek was found to have extensive coverage of pennate diatoms (*Navicula* sp., Figure 5-17), along with associated mucilage and decaying organic matter. On some occasions, this periphyton layer appeared to be very loosely attached and subject to releasing from the substrate and creating floating mats of brown algae and decomposing organic matter (Figures 5-18 and 5-19). This phenomenon may be related to self-shading (*i.e.*, as the mat becomes thicker and more opaque, less and less sunlight is available for cells near the lower surfaces of the mat and these lower cells die and decompose), or entrainment of gas bubbles in the algal-detrital matrix.

Figure 5-17 ***Navicula*** **sp. Micrograph (400X), Wissahickon Creek Watershed, 2005**

Figure 5-18 “Patchy” Stream Bottom Appearance Resulting from Brown Algal Scum Releasing from Substrate, Wissahickon Creek Watershed, 2005

Figure 5-19 Close-up of Brown Algal Scum Released from Stream Substrate, Wissahickon Creek, 2005

Other generalized algal assemblages observed were filamentous green and blue-green algae combined with pennate diatoms, and very extensive mats of branched filamentous green macroalgae (*Cladophora* sp., Figures 5-20 and 5-21). Aquatic mosses were also locally abundant at some sites. Furthermore, algal mats and dense accumulations of macroalgae were observed in some tributary streams, (Figure 5-22), suggesting that algae may reach nuisance densities even where nutrient concentrations are generally much smaller than in the wastewater effluent-influenced main channel.

Figure 5-20 *Cladophora* **sp. Micrograph (400X), Wissahickon Creek Watershed, 2005**

Figure 5-21 Dense Growth of Filamentous Green Algae, Wissahickon Creek Watershed, 2005

Figure 5-22 Dense Accumulation of Filamentous Macroalgae, Bells Mill Tributary, 2006

Periphytic algal communities and diatoms in particular, have been used as indicators of water quality (Stevenson and Pan 1999, Lowe 1974, Charles *et al.* 2006). However, as most water chemistry parameters (*e.g.*, nutrients, BOD, etc.) within Wissahickon Creek Watershed have been fully characterized through extensive sampling, using periphyton communities to infer an ecological condition was given a low priority. Several periphyton subsamples were preserved for taxonomic identification by the phycology branch of ANS, but these analyses have not been completed. Taxonomic identification of samples from the PADEP/PSU study is ongoing, and the researchers intend to present autecological characteristics of the algal assemblages alongside chemical data.

Mean periphyton Chlorophyll-*a* concentrations ranged from 100 mg/sq. meter at site WS354 to 285 mg/sq. meter at site WS076 (Figure 5-23). Although temporal patterns were indistinct, ANOVA results show that chl-*a* concentrations were significantly different between sites ($F_{0.05(2);3\ 24}=5.43$, $p<0.05$) and a *post hoc* test (Student- Newman-Keuls) revealed that periphyton chlorophyll-*a* was significantly greater at site WS076 than sites WS354, WS1075 and WS1850 ($p<0.05$ for all sites). This result probably reflects differences in canopy coverage or other habitat-related factors rather than a water quality effect, as all sites were considered to be highly eutrophic with respect to nutrient concentration (Section 4.4.8).

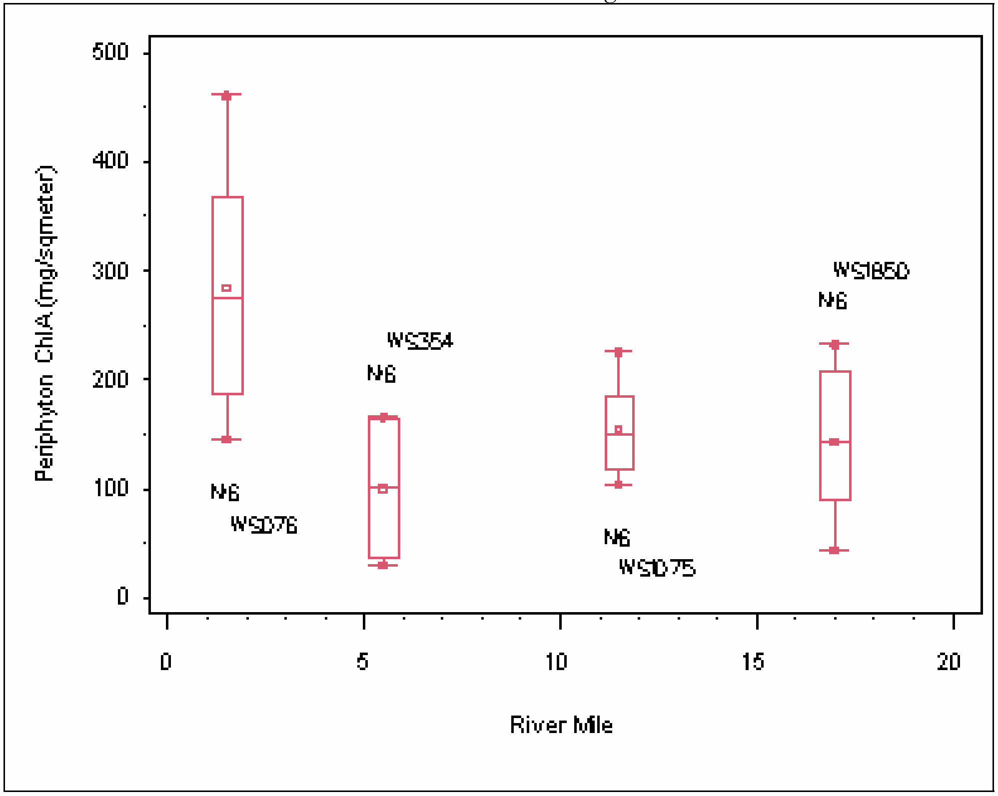


Figure 5-23 Periphyton biomass (as Chl-*a*) at 4 locations in Wissahickon Creek Watershed, 2005

Substrate size and stability probably governed the biomass of periphyton on individual rocks randomly sampled for periphyton analysis, as many sites were observed to have obvious differences in algal mat thickness or extent of macroalgae coverage. In some locations, nearly every stable substrate particle (approximately the size of a small boulder, or 10in/256mm) in sufficient depth of flow was covered with filamentous green algae, while smaller particles generally appeared scoured and cleaner (Figure 5-24).

Figure 5-24 Example of Periphyton Biomass-Substrate Size Effects Observed in Wissahickon Creek Watershed, 2005

Though storm events may tend to scour and remove algal biomass, nutrient conditions favored rapid re-establishment of pre-disturbance algal densities, as evidenced by observed patterns of diel dissolved oxygen fluctuations (Section 4.8, Figure 4-29).

Suspended water column chlorophyll-*a* grab samples were collected at 10 Wissahickon Creek Watershed sites on multiple occasions as part of the 2005 seasonal discrete interval sampling program (Figure 5-25). Water column (*i.e.*, suspended) chl-*a* concentrations were typically below 5 μg/L at all sites, though downstream concentrations at site WS076 tended to be slightly larger and more variable, which is likely due to increased residence time and the influence of impoundments created by abandoned mill dams (Section 6.5). Phytoplankton blooms were visible in these impoundments, but chlorophyll-*a* concentrations were nevertheless relatively small. By way of comparison, large river and lakes may be dominated by phytoplankton communities (potamoplankton) and reach concentrations of 250 μg/L (Reynolds 1988). Streams in Wissahickon Creek Watershed are relatively small and shallow, and the ratio of water column chlorophyll-*a* to periphyton chlorophyll-*a* indicates that attached algal communities are the dominant primary producers.

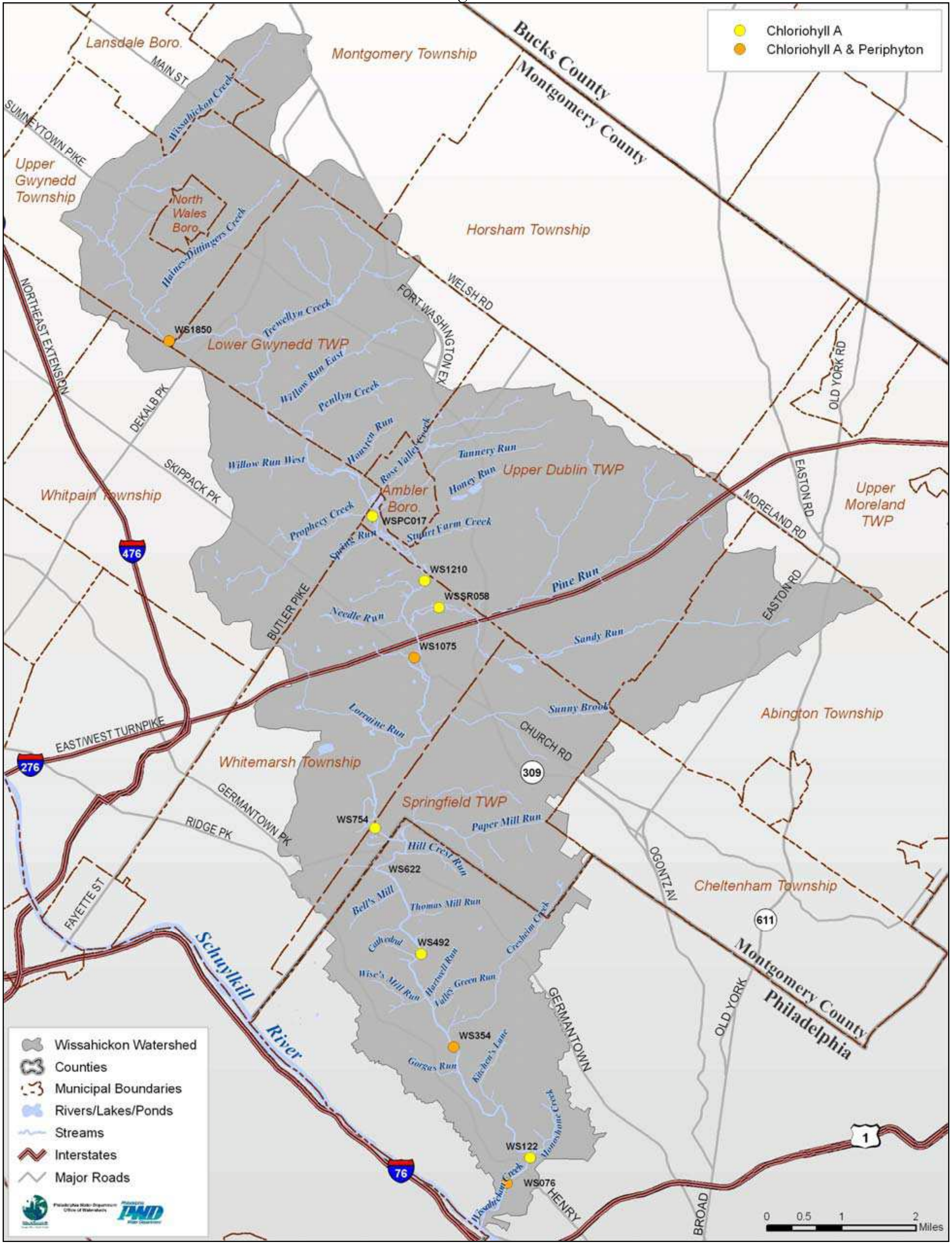


Figure 5-25 Discrete Water Quality Sampling Sites and Periphyton Sampling Sites

5.5 SUMMARY OF BIOLOGY BY SITE

WS005/WS076/WS122/WS209:

Sites WS005, WS076, WS122, and WS209 are grouped here for convenience, as they represent the downstream-most sites for the various monitoring activities that were conducted in Wissahickon Creek Watershed. With the exception of site WS209, all these sites were located downstream of Monoshone Creek, the last major tributary to mainstem Wissahickon Creek (the fish assessment site had to be moved upstream of Walnut Lane in order to find appropriate habitat heterogeneity and ensure pools were entirely accessible by wading). Upstream drainage area is approximately 55 square miles and 30% percent impervious surfaces, so it is not surprising that the stream channel was overwidened in these segments.

Despite the fact that Fairmount Park is the only adjoining land use, EPA RBP Habitat scores varied widely between sites WS005, WS122, and WS209, generally decreasing in a downstream direction (Section 6.2.1). This is in part due to narrowing of the directly adjacent riparian corridor, as Lincoln Drive is located in close proximity to the left bank and a recreational path follows the right bank. Reduced canopy cover may thus partially explain the larger periphyton biomass measured at site WS076.

Results of 2005 fish and macroinvertebrate sampling showed poor correlation with habitat quality, particularly within mainstem sites in City of Philadelphia. Habitat quality may not be a strong predictor of ecological health at these sites due to water quality problems, temperature, algal growth, and dam impoundments. Site WS076 also had very desirable riffle characteristics, yet was found to have a very small number of longnose dace (*Rhinichthys cataractae*). Top-down (*i.e.*, predation) factors may partially explain this phenomenon, as stocked trout may use riffles of adequate depth as feeding stations.

With the exception of typical urban wet weather sediment and fecal coliform bacteria, water quality standards violations were generally not considered to be a problem at site WS076 (Section 4.9), but all mainstem sites were noted to have extremely high nutrient concentrations and algal growth. Furthermore, there may be other contaminants present in treated sewage and urban stormwater that can stress aquatic communities.

Both fish and macroinvertebrate assessments in these downstream-most Philadelphia sites were marked by very small abundance, taxa richness, and biomass. Site WS209 had the second smallest number of individual fish collected of all 2005 assessment sites, of which 45% of the individuals and 70% of the biomass were made up by non-native stocked trout (Section 5.3.5.2). Despite the very small overall abundance, the fish assemblage was given very good scores for other fish community metrics, such as trophic structure, fish condition, and other community attributes and the Fish IBI (a multi-metric assessment technique) score was among the highest in the watershed.

A healthy natural stream system the size of Wissahickon Creek Watershed generally demonstrates an increase in fish community taxa richness from upstream to downstream (ANS 2001,Volume III), and the number of individuals or total biomass collected in a 100m segment might be expected to increase with the size of sampling area. Yet Wissahickon Creek Watershed exhibited the exact opposite condition. Fish species richness at site WS209 was lowest in the watershed. Likewise, six subsamples had to be sorted in order to obtain at least 100 individuals in the macroinvertebrate assessment (this sampling procedure was not originally intended for use as a quantitative metric, and sampling notes indicated that sampling was adversely affected by a combination of heavy periphyton growth and small mesh size in the sampling apparatus).

Of these three lower Wissahickon sites, only WS122 was resampled in 2006 with larger mesh size sampling apparatus. This sample exhibited the greatest increase in taxa richness among all sites resampled. A number of the invertebrates collected in 2006 were not collected at sites WS005, WS122, or WS209 in 2005, suggesting some drift or recolonization from upstream may have taken place. However, none of the taxa collected were sensitive to pollution, and modified EPT taxa, such as the flathead mayfly *Stenonema* sp., collected historically from this site, were not collected in 2006.

WS354

Site WS354 was located downstream of Livezy Dam, and was bounded on both banks by extensive bedrock outcrops. EPA RBP Habitat quality was rated highest among Philadelphia sites and second among mainstem Wissahickon Creek sites. No dissolved oxygen violations were observed at this site and the site should probably be assumed to have suitable dissolved oxygen conditions due to very turbulent flow and reaeration that takes place as water spills over the dam and through the large riffle and bedrock constriction downstream. Algal activity resulted in a small number of pH violations, but the incidence of pH violations within Wissahickon Creek Watershed overall was observed to be poorly correlated with DO fluctuations and greater at downstream sites. This probably reflects a difference in buffering capacity at the upper watershed sites which are more heavily influenced by carbonate geology and subject to inputs of inorganic ion-rich treated sewage in much greater concentrations relative to baseflow.

Site WS354 fish sampling data contrasted with sites WS209 and WS622, as 1031 individuals were collected, compared to 188 and 182 individuals at sites WS209 and site WS622, respectively. 19 species of fish were collected, among them were 7 cyprinid species, and 10 insectivorous species. The trophic distribution of the fish assemblage was also very different from sites WS209 and WS622, with stocked trout (and other top predators) only making up a small proportion of the overall fish assemblage. The only major differences in habitat attributes between site WS354 and the other two Philadelphia sites were better instream cover and a greater percentage of pools at site WS354.

As stocked trout (and other top predators) were present at all three sites, the more completely balanced trophic structure at WS354 suggests that while "top down" predation effects may be present, they were not the sole factor influencing fish communities in this area. Relative insect biomass and production data might be helpful in explaining ecological relationships among trophic levels in these managed "put and take" fisheries. Of primary concern is whether the stocking density may be adversely affecting native fish communities or whether other factors were responsible for the unbalanced trophic structure and poor representation of native species (insectivores and cyprinids in particular) observed at some lower Wissahickon sites but not at others.

WS622

As described previously, site WS622 was similar to site WS209 and contrasted with site WS354 due to an unusual dearth of forage fish species, cyprinids in particular. For example, it was very unusual that common shiners (*Luxilis cornutus*) and spottail shiners (*Notropis hudsonius*) would be so abundant downstream, but not a single individual of either species was collected at site WS622. Similar to WS209, riffle conditions appeared to be suitable for longnose dace, but abundance and biomass were seemingly reduced compared to other sites with suitable riffle conditions. Site WS622 was also notable for being the largest site assessed, both in terms of surface area and volume. Given the aforementioned low abundance and biomass, it was not surprising that this site had the smallest fish density (individuals/surface area) and biomass/volume of all sites assessed.

It is likely that upstream migration of most native fish is limited due to the three large dams located between site WS354 and site WS622. The presence of these impediments does not fully explain the lack of cyprinid species, many of which were abundant upstream. American eels (*Anguilla rostrata*) were collected at this site (in fact, throughout the watershed) despite 5 major obstructions and numerous small and partial obstructions between this site and the confluence with the Schuylkill River.

While EPA RBP habitat was designated "supporting" and many habitat attributes rated as suboptimal or optimal at site WS622, the site may have had some deficiencies related to substrate composition. This site was located within a band of distinct transverse bedrock outcrops crossing the stream and it was not possible to discern the sizes of substrate particles or separate bedrock from boulders because of turbid conditions (the site was sampled for fish one day following a rain event and a second rain event occurred during the sampling procedure). When the cross sectional analysis was conducted the following week, the site was found to be composed almost entirely of bedrock, lacking in fine gravels and cobbles.

Bedrock substrates are stable, and can provide good ambush cover for predators (especially when deeply folded or fractured like the features in site WS622), but they lack the interstitial spaces that are found under and between loose substrate particles and favored as habitat by many types of invertebrates. Bedrock substrates are therefore not usually suitable substrates for secondary production and it was perhaps not unusual to find a smaller number of invertebrates and unbalanced trophic structure in biological communities, overall, at this site. The percentage of generalist feeders, and relative abundance of white suckers (*Catostomus commersonii*) more than doubled from site WS354 to site WS622, despite the fact that biomass and abundance decreased sharply overall. Generalists such as white suckers are more capable of subsisting on a suboptimal food base than more specialized feeders.

WS754, WS899

Sites WS754 and WS899 are notable not only for being the downstream-most sampling locations outside the City of Philadelphia, but also due to changes in land use, geology and riparian corridor management conditions. Over 94% of the Riparian area within the City of Philadelphia is managed as parkland, with complete tree canopy coverage on steep valleys cutting through the Wissahickon formation. The area north of Philadelphia to site WS899 is only partially protected by parkland in Fort Washington State Park. Landform slope, underlying geology, and floodplain morphology change dramatically from site WS622 to sites WS754 and WS899. Furthermore, as described in section 6.4, approximately 60% of the mainstem river miles between the City Line and site WS899 were found to be lacking a forested riparian corridor on at least one bank and 30% were lacking riparian buffer on both banks (Heritage Conservancy 2001).

Lack of forested canopy cover has many implications for aquatic communities, such as increased light penetration and primary production, as well as increased water temperature. Overhanging vegetation is an important habitat feature, providing cover and a source of food (terrestrial insects). Temperature effects were difficult to address because the pumping operation at Highway Materials (Coorson's Quarry), a contribution of cooler groundwater, is also located in the vicinity. It may be possible that without the quarry discharge, stream temperatures would be greater along mainstem Wissahickon Creek.

Decreased slope and the presence of several dams appeared to create a sedimentation problem, as many segments of mainstem Wissahickon Creek in this vicinity were observed to have smaller substrate particles and other depositional features. It was deemed infeasible to sample algal periphyton at the WS754 continuous monitoring location because this segment of stream was affected by extensive deposits of fine silt along with brown algae and decaying organic material. Suitable sampling conditions could not be found within reasonable proximity to the Sonde's location. Sedimentation was also observed to be a serious problem in the man-made "oxbow", or diversion, of Wissahickon Creek located within the Whitemarsh Country Club.

Decreased slope, increased sedimentation, and other physical attributes might also partially explain trends in biological data, as tessellated darters (*Etheostoma olmstedi*) were most abundant at this site. These small perch are strongly associated with slower velocity runs and shallow pools with sandy to gravelly substrates, and were not found in large numbers downstream. The trend of increased relative abundance and biomass of white suckers in an upstream direction continued, as relative biomass more than doubled from site WS622 to WS899. Though total fish biomass was greatest at site WS899 by a considerable margin, white suckers contributed 88% of the total biomass, suggesting a very poor food base and/or unstable habitat conditions at this site.

Trends in macroinvertebrate data were similar, and appeared to be correlated with habitat conditions. During the macroinvertebrate assessment, most substrate particles at site WS899 and sites downstream were found to be covered with diatoms (brown algae) and organic scum, while aquatic moss and filamentous green algae were more prominent upstream. Site WS899 and all sites downstream all exhibited near complete dominance by chironomids, while upstream samples were noted to have greater abundance of hydropsychid caddisflies and more evenness in general.

Site WS899 was also the location in which two noteworthy biological specimens were collected. As biologists concluded the first pass of the fish assessment, a juvenile Eastern red-bellied turtle (*Pseudemys rubriventris*) was found captured on the upstream side of the downstream-most block net. While locally abundant in some areas, red-bellied turtles are considered threatened in Pennsylvania, and their decline has been attributed to habitat destruction and competition from non-native turtle species, such as red-eared sliders. The turtle was photographed, measured, and released unharmed; PAFBC and DCNR were notified. The other unusual specimen collected at site WS899 was a longnose dace with two pairs of pelvic fins. This type of deformity probably indicates a problem during the fish's early development.

WS1075

As mentioned in the description of site WS899, above, site WS1075 and all other monitoring sites upstream tended to have less coverage of fine brown algal scum and proportionally more aquatic moss and macroalgae. While both types of algal growth were associated with severe fluctuations in instream DO concentration, the latter type of algal community did not impair the collection of benthic macroinvertebrates to the degree that the algal periphyton present at downstream sites did. As a result, the macroinvertebrate community sampled at site WS1075 and other sites upstream in 2005 generally had better evenness and were less dominated by chironomids.

As described in section 5.2.5.2, above, observed differences in macroinvertebrate community structure are believed to be related to the influence of algae clogging the sampling apparatus. Observed increases in macroinvertebrate taxa richness and evenness in the 2006 samples strongly support this theory. Longnose dace were more abundant at site WS1075 than any other site, a pattern that is probably related to the good riffle characteristics at this site.

The most noteworthy finding at site WS1075 was the fact that nearly 25% of all fish collected at this site were affected by deformities/parasites or other anomalies. The incidence of these types of anomalies is positively correlated with water pollution, such as treated or untreated sewage. Anomalies were relatively rare in the downstream Philadelphia sites, with incidence rates comparable to reference site conditions. The incidence of anomalies increased successively at each site in an upstream direction until peaking at site WS1075, then remained relatively constant for the remainder of upstream sites.

One possible explanation for the greater incidence of anomalies at site WS1075 is its position in the watershed. While all other upstream sites were exposed to treated sewage, WS1075 was located just downstream of the confluence with Sandy Run, a large tributary with numerous NPDES permitted dischargers, including two municipal wastewater treatment plants. Site WS1075 is thus the upstream-most sampling location that aggregates waste from all the upstream municipal wastewater dischargers, with minimal dilution. Sandy Run also has a large proportion of its drainage area made up of commercial and industrial land use, especially in the vicinity of the Rt. 309 and PA turnpike industrial corridors.

Furthermore, if one considers not only the volume of discharge but the timing of exposure, WS1075 may be in an even more disadvantageous position. Due to the diurnal pattern in sewer usage and time of travel, WS1075 may be exposed to more concentrated sewage for a longer period of time than other sites which are subject only to flows from a single source.

WS1210

Site WS1210 was one of only two sites in Montgomery County where benthic macroinvertebrates were resampled in 2006 with different (*i.e.*, larger mesh) sampling apparatus. Some changes were noted when comparing 2006 and 2005 data, primarily that the relative abundance and percent dominance of chironomids decreased even more noticeably. Site WS1210 was the only site where the benthic macroinvertebrate community was found to be not dominated by chironomids. The group that replaced chironomids at this site, hydropsychid caddisflies, are not necessarily more sensitive, but may be considered more valuable prey items due to their larger size.

Site WS1210 was bounded at its upper extent by Morris Rd, which crosses the creek upstream of the Germantown Academy Preparatory School. The constriction at this bridge was observed to have caused a large deposit of sediment in a channel bar at the upstream extent of the fish sampling site, with the majority of flow following the right bank.

This site was also the upstream-most mainstem site in which trout were collected. Furthermore, the large size of one of five trout specimens collected at this site, (rainbow trout, 38.5cm TL, mass 601.8g), suggested that the fish had overwintered in Wissahickon Creek Watershed. This fish was considerably larger than the cohort of stocked fish, which were approximately 29cm and 200g on average. Of course, fish are quite mobile, so it is not reasonable to draw conclusions about habitat or water quality of this particular site in light of the fact that an overwintering fish was found here (this site is also only approximately 0.5 mi from the upstream extent of the trout stocking zone). It is, however, a positive sign that water quality is suitable for some salmonid fish to overwinter in the watershed despite the fact that they cannot reproduce successfully.

WS1475

Site WS1475 was another example of a site where habitat conditions probably strongly influenced results of bioassessment activities. The site was located within a zone of exposed bedrock, and bedrock was confirmed to be the primary or secondary substrate component at 18 of 20 habitat cross sections that were assessed during the fish assessment. The bedrock creek bed was relatively flat and did not offer much cover or epifaunal substrate. Furthermore, the fracture patterns in this rock resulted in thin, plate-like substrate particles, which may not be ideal habitat for small fish or macroinvertebrates.

Habitat conditions at site WS1475 were very similar to site WS622, and the fish communities present at both sites were also very similar, if one disregards the number of stocked trout at the latter site. This was perhaps unusual given the difference in drainage area. This relationship probably reflects the fact that most common fish are able to survive in mid-order streams with varying habitat and trophic conditions.

WS1850

Site WS1850 might be described as having the worst water quality in Wissahickon Creek Watershed, due primarily to the relatively concentrated amounts of treated sewage that were being discharged upstream of the site. There was very little baseflow to dilute treated waste at this site and nutrient concentrations were greatest in the watershed. Conductivity was also elevated, creating a problem for the fish sampling apparatus. This site had consistently higher water temperatures than other sites instrumented with continuous data logging monitoring equipment, and the greatest incidence of days with instantaneous minimum dissolved oxygen violations. Furthermore, because the primary discharger has not formally applied for an exception to the “Chapter 16: Water Quality Toxics Management Strategy” water quality criteria, this was the only site that experienced frequent violations of dissolved Cu water quality standards.

Yet despite the very poor water quality, WS1850 showed signs of degradation that were consistent with most other sites. The relative incidence of fish deformities, anomalies, disease and tumors, as well as percent dominance by the dominant fish and macroinvertebrate taxa (white suckers and chironomids, respectively) were not drastically different from, and in some cases, better than other upstream sites receiving treated wastes. This can probably be explained by the fact that all sites were so degraded that additional pollution did not affect the results as severely. The communities that are able to survive under conditions found throughout Wissahickon Creek Watershed are primarily tolerant generalists. Another mitigating factor may be the habitat at site WS1850, which was rated best in the watershed.

WSPC017

Site WSPC017 received good scores for most assessment activities and was determined to be the best site assessed in the Wissahickon Creek Watershed based on a number of positive attributes. This is not surprising, as this stream had the smallest proportion of impervious cover in the watershed and in many locations appeared to still have adequate access to its floodplain for flow attenuation. Biologists noted generally small substrate size and areas of sedimentation in a few locations while conducting the habitat and fish assessments, but the fish assessment site was also noted for its sinuosity and microhabitat heterogeneity.

This was the only site in which many uncommon fish taxa were well represented, and many metrics (*e.g.*, number of cyprinid species, taxa richness, density, and percentage of dominant species) compared favorably with FCR025 (Rock Run) reference conditions. This site also had benthic macroinvertebrate taxa richness comparable to the 2nd order reference site, and was the only tributary site outside Philadelphia in which stoneflies (*Amphinemura* sp.) and water penny beetle larvae (*Psephenus* sp.) were collected. Positive attributes aside, WSPC017 did show signs of biological impairment, such as a fish community dominated by generalists. A site of this site should have a much larger proportion of insectivorous fish. Site WSPC017 also had an elevated number of fish with anomalies and three combinations of sunfish hybridization. The incidences of these effects are generally correlated with increased degradation of water quality.

Comparison with tributaries within the City of Philadelphia was complicated due to differences in slope and drainage area. Prophecy Creek generally has a milder slope than most Philadelphia tributary sites studied, while at the same time having a greater drainage area. These factors probably contribute to the fact that Prophecy Creek has a resident fish community while Philadelphia tributaries generally do not (Philadelphia tributaries are generally too steep, with unpredictable or insufficient baseflow). Though Prophecy Creek appeared to have stable baseflow, riffles were generally shallow and riffle velocities were very low. Unsuitable riffle conditions probably explain the good representation of tessellated darters and absence of longnose dace at this site.

WSSR096

The Sandy Run assessment site was found to be aptly named. Gravel and sand were found to be the dominant substrate components at nearly every cross section location. This site was relatively deep, but riffle conditions were above average, and longnose dace were very abundant at this site. Turbid water conditions and wastewater treatment plant discharge are probably the factors that explain the relative paucity of tessellated darters and centrarchids, respectively.

This site was the only tributary site in which a trout was collected. Similar to site WS1210, the size of the brown trout collected at this site (38.5cm TL, mass 601.8g), suggested that the fish had overwintered in Wissahickon Creek Watershed. Again, it is not reasonable to draw conclusions about habitat or water quality of this particular site in light of the fact that an overwintering fish was found here (this site is also only approximately 0.5 mi from the upstream extent of the trout stocking zone). It is, however, a positive sign that water quality (in at least some parts of the watershed) is suitable for some salmonid fish to overwinter.

6 PHYSICAL CHARACTERIZATION

6.1 INTRODUCTION

Habitat and water quality are the two most important factors determining the types of living things that may be found occupying a given aquatic habitat. Unfortunately, aquatic habitats are subject to severe destabilization and destruction due to land development and increases in the human population. Assessing habitat for a watershed, a stream, or even a small segment of stream in a meaningful way can be difficult, as habitat attributes that are more suitable for one species or group of species may be less suitable for another species, different life stages of the same organism may require different habitat conditions, and habitats can change rapidly following a disturbance. Habitats also change seasonally due to climate and biological growth, particularly in temperate climates. Furthermore, some habitat attributes may be compensatory, in that a deficiency in one attribute can be partially compensated for by one or more unrelated factors. For the purpose of the Physical Characterization of the Wissahickon Creek Watershed, it was assumed that the habitat conditions that existed in the watershed prior to urbanization represent the most desirable conditions, where the greatest diversity of natural native communities can flourish.

The most severe destabilizing force affecting aquatic habitats is the modification of natural flow patterns, volume, and timing that accompanies land development. Impervious surfaces, such as roads, roofs and driveways, shed water allowing for very little infiltration. The type of drainage that is common in the City of Philadelphia, that of roof downspouts, parking areas and streets directly connected to a storm sewer system, has the greatest capacity to change flow patterns. A conceptual diagram of the change in hydrograph with increased impervious surface is depicted in Figure 6-1. The negative impacts of this flow modification are twofold – more water volume and velocity during rain events, and diminished baseflow during dry weather. While the severe erosion that has been observed in small stormwater tributaries in Wissahickon Creek Watershed may be more obvious (Figure 6-2), the effect of diminished baseflow may also be important in explaining the extirpation of sensitive taxa from the watershed.

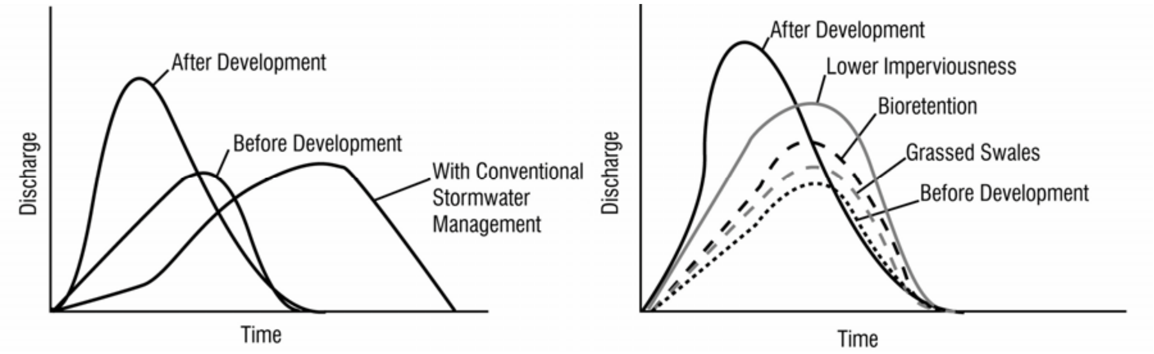


Figure 6-1 Comparison of Volume and Duration of Stormwater Runoff Before and After Land Development, and Reductions in Runoff from BMPs
Source: Prince George's County Department of Environmental Resources et. al., undated

Other anthropogenic factors lead to destabilization of natural stream flow patterns and habitat destruction. Human activity has indirectly altered the stream channels through changes in flow volume and timing, but also directly through construction of infrastructure such as dams, culverts, and channelization of stream channels and floodplains. Dams can block upstream migration of fish and invertebrates, disrupt sediment transport, and alter natural microhabitat (*i.e.*, pool, riffle, run) sequences by creating impoundments of stagnant water that may have suitable conditions for algal blooms, oxygen depletion, and nutrient release from stream substrates (Figure 6-3). Culverts constrain flow, causing high velocities, headcutting, and scour at nickpoints and sediment deposition in channel bars downstream. Channelization may be effective at reducing erosion on a small area, but often exacerbates erosion problems downstream.

Figure 6-2 Severe Erosion Downstream of Summit Ave, Wise's Mill Run

Figure 6-3 Magargee Dam Impoundment Showing Phytoplankton Bloom

Wissahickon Creek Watershed is listed by PADEP as being impaired due to siltation caused by urban runoff from storm sewers. Deposition of fine sediment can be especially detrimental to aquatic macroinvertebrates that depend on interstitial spaces under and between rocks and fish that spawn over gravel and coarse sandy substrates. A TMDL for sediment was established for Wissahickon Creek Watershed in 2001. A brief description of the field methods and modeling efforts currently being employed to address compliance with the Wissahickon Creek Sediment TMDL is included in section 4.6.6.

Habitat conditions in Wissahickon Creek Watershed were assessed with a variety of techniques. Some assessment methods were evaluated with comparison to unimpaired reference streams (French Creek and Rock Run, in Chester County, PA), selected for good habitat conditions. TMDL development was accomplished by comparison to Ironworks Creek, an unimpaired tributary to Neshaminy Creek with similar land use patterns (USEPA 2003). Still other habitat metrics were based on models or comparison to literature datasets.

6.2 HISTORICAL INFORMATION

6.2.1 WISSAHICKON CREEK WATERSHED RIVERS CONSERVATION PLAN

The Pennsylvania Department of Conservation and Natural Resources developed the River Conservation Planning Program in an effort to provide funding and technical assistance for the local creation of River Conservation Plans. The Wissahickon Creek River Conservation Plan (December 1999) was jointly funded by the PA DCNR and a grant from the William Penn Foundation. The Montgomery County Planning Commission, together with Fairmount Park Commission, sponsored the plan. The plan aims to identify natural and cultural resources within the watershed, identify sources of degradation and recommend restoration techniques as well as other action items to conserve the landscape.

Stronger regulations and ordinances were recommended as part of the restoration implementation tools. One of the strongest recommendations was a push for more stringent stormwater management controls. Most of the development in Wissahickon Creek Watershed took place prior to stormwater management plans. Adopted in September 2005 and effective as of January 1st, 2006, Philadelphia Water Department's revised Stormwater Regulations provide more stringent controls for managing runoff from development occurring throughout Philadelphia. The Regulations are applicable to both new and redevelopment projects disturbing over 15,000 ft^2 of earth. Specific stormwater requirements beyond Flood Control for Wissahickon Creek Watershed development projects now include Water Quality and Channel Protection components. The Water Quality criterion requires infiltration of the first inch of rainfall from all directly connected impervious area (DCIA). Should infiltration not be feasible, in part or in whole, then the stormwater must be treated before being released to the storm sewer. The Channel Protection criterion requires slow release of the 1-year, 24-hour storm, a depth of 2.6 inches over the DCIA.

The Wissahickon Creek River Conservation Plan aims to be followed by a 10 year comprehensive plan which focuses on subwatersheds. Detailed plans for three subwatersheds are provided along with recommendations for use in future subwatershed plans.

6.2.2 ENVIRONMENTAL STUDY OF THE WISSAHICKON WATERSHED WITHIN THE CITY OF PHILADELPHIA (COUGHLIN, ET AL. 1973)

Problems associated with urban sprawl and stormwater management may seem to be fairly new concepts, but these effects and potential solutions were hot topics of discussion for urban planners in the early 1970s (McHarg 1969). A local example of this pioneering work is the Environmental Study of the Wissahickon Creek Watershed within the City of Philadelphia (Coughlin *et al.* 1973), a report submitted to the City of Philadelphia by the Regional Science Research Institute. This study documented, among other environmental impairments, the effect of urbanized flows on small stream channels.

Clearly influenced by early geomorphologists such as Luna Leopold, the study related changing patterns in hydrology to systemic changes in the structure and function of stream channels in the City of Philadelphia. Rates of stream channel enlargement and predictive models of degradation under various build–out scenarios were also presented. This study was intended to provide the City of Philadelphia's Planning Commission with a tool to address development of remaining vacant land and redevelopment of larger parcels deemed prone to sub-division. One of the study directors, Thomas R. Hammer, also published aspects of this research in journal articles (*e.g.*, Hammer 1972) and as his doctoral thesis at the University of Pennsylvania.

The report predicted that bankfull cross section area measured in nine tributaries to Wissahickon Creek would increase by an order of magnitude proportional to an increase in urbanization in the watershed. Cross sections surveyed in 2004 that were located close to 1973 cross sections were compared to see if this prediction held true (Table 6-1). It does not seem that the cross section area increased in the manner which was predicted. This may be due to the fact that small channels show high variability in cross sectional area (Hammer 1972). Furthermore, site selection may partially explain differences between predictions and present conditions. Coughlin, *et al.* (1973) chose cross sections very carefully based on characteristics of quasi-equilibrium, whereas 2004 cross sections were chosen for other characteristics.

Although bankfull cross section area was not shown to increase in the manner predicted, the entire stream channel is obviously enlarged. Booth (1990) describes another type of channel enlargement termed channel incision. Channel incision is a rapid deepening of the channel which produces a larger channel than would be expected from discharge. Incised channels still have defined bankfull channels within them. Streams that have the ability to transport greater sediment than they are supplied and that have a high gradient are prone to incision. It appears that this is the type of channel enlargement taking place in the Wissahickon tributaries.

6.2.3 NLREEP ANSP STREAM QUALITY INDEX

As part of a grant from the William Penn Foundation to restore natural areas within the Fairmount Park system, the Academy of Natural Sciences of Philadelphia (ANSP) created Natural Lands Restoration Master Plans for the Fairmount Park System (ANSP 1999). In an effort to appraise the current status of stream channels as well as guide future restoration projects, ANSP developed an assessment program comprised of two levels, "screening" and "detailed".

The screening level assessment culminated in a Stream Quality Index (SQI) score. SQI was based on geomorphology, aquatic habitat, and riparian condition. Stream morphology data include observed bed morphology, planform, bar type, floodplain morphology, and channel cross sectional area. Aquatic habitat assessment was comprised of both the physical habitat as well as benthic macroinvertebrate community attributes. Finally, riparian condition was based on vegetation type and condition, width of vegetated corridor, and level of human disturbance. The three components were combined to yield a final SQI score. When this assessment was conducted on the tributaries of the Wissahickon Creek within the City of Philadelphia, it was found that with the exception of portions of Monoshone and Gorgas Lane, all received either moderately impaired or impaired SQI scores. Portions of Monoshone Creek and most of the Gorgas Lane Tributary received a severely impaired designation.

In addition to Stream Quality Index, ANS completed a detailed analysis of selected stream reaches. Detailed analysis was completed for Wises Mill, Bells Mill, Cresheim Creek, Wissahickon tributary #26, and Kitchens Lane (Carpenters Woods). In each stream reach designated for detailed analysis, the longitudinal profile and five cross sections were surveyed. These cross sections, along with 14 others from streams within Fairmount Park, were compared to 16 reference reaches in Chester County, PA and Cecil County, MD. Results showed that urbanization had significantly changed the morphology of the stream segments.

6.3 EPA HABITAT ASSESSMENT

6.3.1 FIELD STANDARD OPERATING PROCEDURES

Immediately following benthic macroinvertebrate sampling procedures, habitat assessments were completed at thirty sites (n=30) (Figure 6-4) 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.

Figure 6-4 Physical Habitat Monitoring Sites in Wissahickon Creek Watershed, 2005

6.3.2 DATA ANALYSES

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 6-1 lists the various parameters addressed during habitat assessments.

Table 6-1 Habitat Assessment Criteria Used at Benthic Macroinvertebrate 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 were assessed separately.

6.3.3 RESULTS

6.3.3.1 WATERSHED OVERVIEW

Mainstem Wissahickon Creek sites exhibited very little spatial variability in EPA Habitat assessment scores, and there were generally no longitudinal patterns (Figure 6-5). Mainstem sites located within relatively wide parcels of protected parklands generally had greater scores than sites located on privately owned property or where protected lands adjacent to the creek were narrow or made up of transportation or commercial land uses. For example, site WS1850, which was located in a parcel of land preserved by the Wissahickon Valley Watershed Association, received the highest EPA Habitat assessment score in the watershed. Protected sites in the City of Philadelphia's Fairmount Park as well as the Fort Washington State Park generally received good scores. Though site WS005 was technically located in Fairmount Park, land uses associated with Ridge Avenue transportation and Schuylkill River adjacent Commercial/Industrial corridors restricted the width of the stream riparian zone and this site received the lowest score for a mainstem site within the watershed.

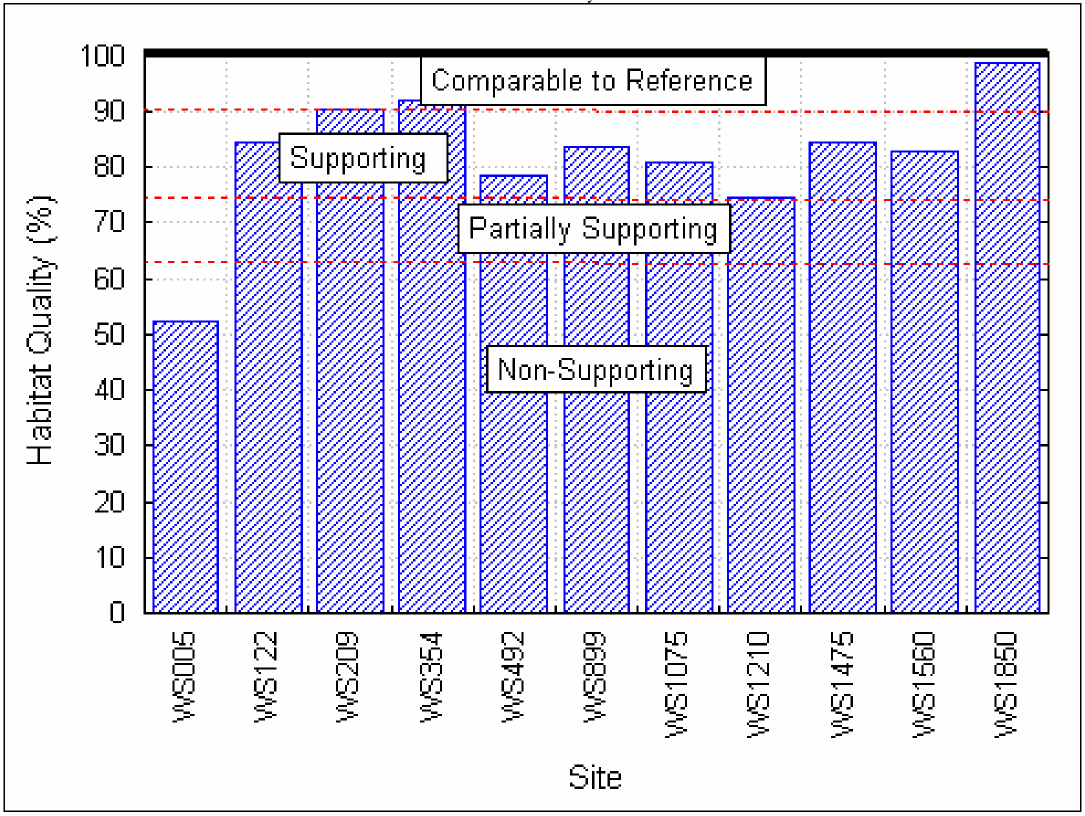


Figure 6-5 EPA Habitat Score for 11 Mainstem Sites in Wissahickon Creek Watershed, 2005.

Tributary sites exhibited much greater spatial variability in EPA Habitat assessment scores than mainstem sites, and scores were also lower overall (Figure 6-6). Throughout 2005 and 2006, PWD collected data to develop a program to comply with the Wissahickon Creek Watershed Sediment TMDL, so all tributaries within the City of Philadelphia, and in some cases, multiple sites on the same tributary, were included in benthic macroinvertebrate and physical habitat assessments. This level of detail contrasted strongly with Montgomery County, where only 3 tributary sites were assessed.

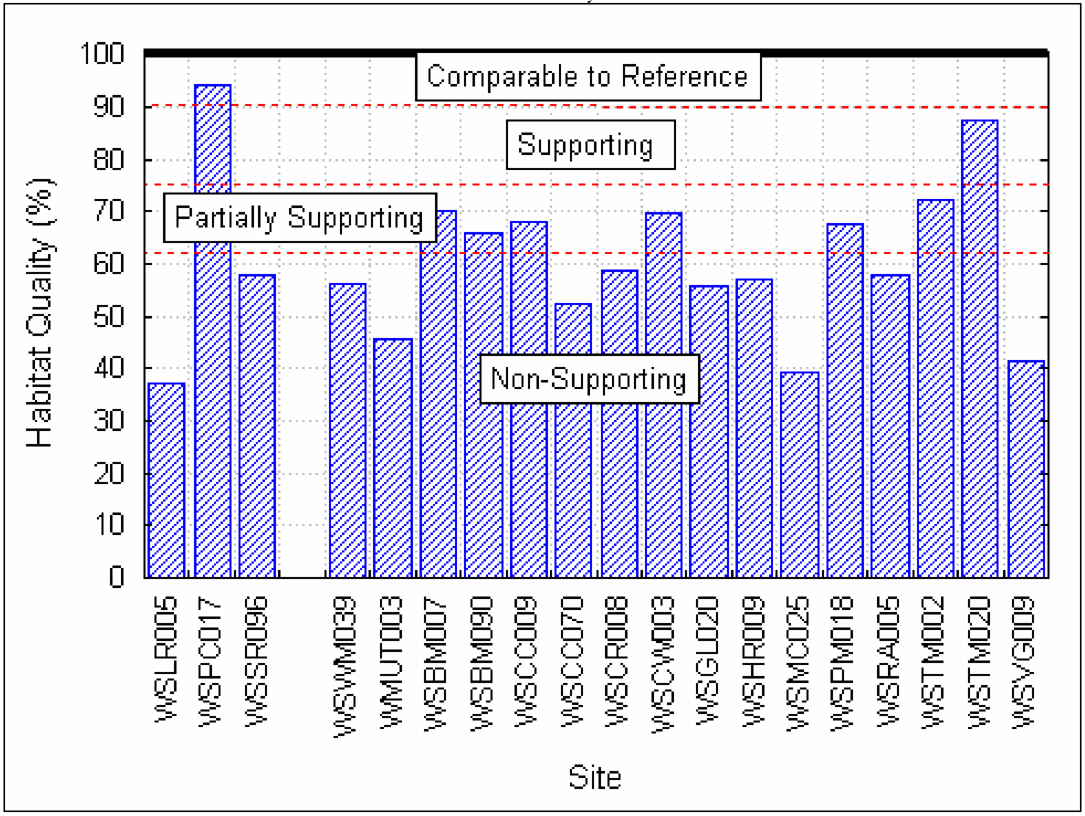


Figure 6-6 EPA Habitat Score for 19 Tributary Sites in Wissahickon Creek Watershed, 2005

Furthermore, there were important differences in the tributary sites chosen for analysis. Many tributary sites in the City of Philadelphia had slopes in excess of 2%, and might be considered “B”, or even “G” stream types in the Rosgen classification system (Rosgen 1996), while other sites, including all Montgomery County sites, were less steep and would be classified as “C”, or “F” stream types. The EPA Habitat assessment procedure provides two separate assessment methods – one for “low gradient” streams and one for “high gradient” streams. PWD practice has been to use the entire list of metrics for the “low gradient” stream assessment procedure, but modified the protocol to include the three additional metrics from the “high gradient” stream method as well. Some truly high gradient streams probably received low scores for “low gradient” stream metrics, such as pool variability and sinuosity. Low gradient streams, in turn, probably received lower scores for high gradient stream metrics such as frequency of riffles.

WS005

The mean habitat score at WS005 was 107.0. When compared to the reference at FC472, the habitat was designated as “non-supporting”. Most condition categories were scored as marginal. The vegetative protection and riparian zone were greatly reduced at this location and there was decreased bank stability. Both banks have been either channelized or armored with gabions or rip-rap. Field observations included severe erosion on both banks and dense algal periphyton growth.

WS122

WS122 received a mean habitat score of 173.0 and habitat was deemed as “supporting”. There was very little sediment deposition at the sampling station. Riffles (60%) and boulders (40%) dominated the stream morphology. Most habitat attributes were scored as sub-optimal. The left bank of the creek was moderately unstable with marginal vegetative protection and riparian zone. The right bank is adjacent to Wissahickon Park and is well preserved.

WS209

The site at WS209 received a mean habitat score of 185.0 and had a 90.24% comparison to the reference condition ("comparable to reference"). The inorganic substrate and stream morphology types at the sampling site were evenly distributed. All four velocity depth regimes were present, and the site had little to no stream channel alteration. Both stream banks were relatively stable, and there was a well-established riparian zone. Heavy algal growth was observed at the time of benthic macroinvertebrate sampling.

WS354

The mean habitat score at WS354 was 188.0. The habitat at the site was designated as "comparable to reference". Most condition categories were scored as high sub-optimal or low optimal. There was an even distribution of stream morphology types and inorganic substrate. The site offered good epifaunal substrate/available cover and has an even mix of pool types. Both banks were stable and the riparian zone was extensive. Thick algal mats were noted when sampling.

WS492

The site at WS492 received a mean habitat score of 160.5 and had a 78.29% comparison to the reference condition ("supporting designation"). Most condition categories were scored as suboptimal. The riparian zone on the left bank of the site was excellent. The right bank scored as suboptimal because of a large area that is mowed for recreational uses. The right bank of the site was also moderately unstable and had many raw areas due to erosion. Heavy algal growth was observed at the time of benthic sampling.

WS899

WS899 had a mean habitat score of 171.5. The habitat was deemed to be "supporting". Habitat attributes were rated as suboptimal and optimal. Stream morphology was primarily run (40%) and pool (40%) and the inorganic substrate was mostly cobble (30%) and gravel (35%). All four velocity/depth regimes were present, and there was little to no channel alteration. There was an extensive riparian zone and the stream banks were moderately stable with good vegetative protection.

WS1075

Assessment site WS1075 received a mean habitat score of 165.5. The habitat was designated as "supporting". Most habitat attributes were scored as suboptimal. The stream morphology of the site was dominated by run (55%) with very few riffles (15%). There was an even distribution of inorganic substrate types. WS1075 is also located within Fort Washington State Park and has a very large riparian zone. The right bank was moderately unstable due to erosion.

WS1210

The mean habitat score at WS1210 was 152.5, which was a 74.4% comparison to the reference at FC472 ("supporting" designation). The stream morphology was 50% run and there was an even inorganic substrate distribution. The riparian zone of the site was greatly reduced due to the parking lot of Germantown Academy on the left bank and athletic fields on the right bank. The right bank was severely eroded and moderately unstable.

WS1475

WS1475 had a mean habitat score of 173.0. The habitat designation of the site was "supporting". Most habitat condition categories were rated as suboptimal. Bedrock (35%) and boulder (25%)

dominated the inorganic substrate of the site. The stream morphology was evenly distributed. The stream channel had no alteration and there was very little sinuosity.

WS1560

Assessment site WS1560 received a mean habitat score of 170.0. The habitat was designated as “supporting”. Most habitat attributes were scored as suboptimal and optimal with the exception of pool substrate, pool variability and epifaunal substrate/ available cover. The inorganic substrate was mostly bedrock (35%) and boulder (25%). Pools only comprised 10% of the stream morphology. Pool substrate was mostly bedrock and all pools were shallow.

WS1850

The mean habitat score at WS1850 was 209.5, which was a 98.6% comparison to the reference at FC1310 (“comparable to reference” designation). Most habitat attributes were scored as optimal. The site had even distributions of stream morphology types and inorganic substrate. The site had an extensive riparian buffer with a large flood plain. Biologists noted heavy sewage odor at the time of macroinvertebrate sampling.

WSPC017

WSPC017 had a mean habitat score of 200.5. The habitat designation of the site was “comparable to reference”. All habitat condition categories were rated as optimal or suboptimal. The inorganic substrate of the site was mostly cobble (35%), gravel (35%) and sand (20%). Stream morphology was evenly distributed. The stream channel had no alteration and there was good sinuosity.

WSCC009

Assessment site WSCC009 received a mean habitat score of 163.5. The habitat was designated as “partially supporting”. Most condition categories were scored as suboptimal or marginal. Riparian vegetative zone width, vegetative protection and channel alteration all scored as optimal because of the site’s location within Fairmount Park. Pools were poorly represented and the inorganic substrate was mostly boulder (30%) and cobble (30%).

WSCC070

The mean habitat score at WSCC070 was 126.0, which was a 52.6% comparison to the reference at FCRR008 (“non-supporting” designation). The stream morphology was dominated by riffles (60%). Most habitat attributes were scored as marginal or suboptimal. Riparian vegetative zone width scored as optimal because of the protection of Fairmount Park. The right bank had extensive erosion and was very unstable. The assessment site was severely damaged by heavy storm flows in the fall of 2004.

WSCW003

WSCW003 had a mean habitat score of 167.0. The habitat designation of the site was “partially supporting”. Most condition categories were scored as suboptimal or marginal. Riparian vegetative zone width and channel alteration all scored as optimal because of the site’s location within Fairmount Park. There was an even distribution of substrate types, and riffle (45%) dominated the stream morphology.

WSMC025

Assessment site WSMC025 received a mean habitat score of 83.5. The habitat was designated as “non-supporting”. Most habitat attributes were scored as marginal or suboptimal. Pools were absent at the assessment location. There was extensive channel alteration (dams, channelization) and a reduced riparian zone. The vegetative protection was decreased on both banks with moderate stability only due to rip rap.

WSWM039
The mean habitat score at WSWM039 was 134.5, which was a 56.2% comparison to the reference at FCRR008 ("non-supporting" designation). Most condition categories were scored as marginal. The left bank had extensive erosion with obvious disruption to bank vegetation. Riffles dominated the stream morphology and boulder (35%) and cobble (25%) were the dominant substrate.

WSCR008
WSCW003 had a mean habitat score of 141.0. The habitat designation of the site was "non-supporting". Most condition categories were scored as marginal or suboptimal. The bank stability and vegetative protection in the assessment area was greatly reduced. Both banks had extensive erosion and reduced vegetative protection. Riffles composed 60% of the stream morphology and boulder (40%) dominated the substrate.

WSTM002
The mean habitat score at WSTM002 was 173.5, which was a 72.4% comparison to the reference at FCRR008 ("partially-supporting" designation). The substrate of the sampling location was primarily boulder (40%). The lower portion of Thomas Mill Run is high gradient and the stream morphology is 70% riffle. Most habitat attributes were scored as suboptimal or marginal. Riparian vegetative zone width was scored as optimal because of the surrounding parkland in Wissahickon Park.

WSTM020
WSTM020 had a mean habitat score of 210.0. The habitat designation of the site was "supporting". Most condition categories were scored as optimal or suboptimal. Riparian vegetative zone width, vegetative protection, bank stability and channel alteration all scored as optimal because of the site's location within Fairmount Park. Similar to the assessment site on the lower portion of Thomas Mill Run, boulder (40%) dominated the substrate and riffle (60%) dominated the stream morphology.

WSRA005
Site WSRA005 received a mean habitat score of 139.0. The habitat was designated as "non-supporting". Most habitat attributes were scored as marginal or suboptimal. Pools (20%) and run (10%) were poorly represented at the assessment location. Boulder (35%) dominated the inorganic substrate and there was moderate sediment deposition. Bank stability and vegetative protection were reduced on both banks.

WSHR009
The mean habitat score at WSHR009 was 136.5, which was a 57.0% comparison to the reference at FCRR008 ("non-supporting" designation). Most habitat attributes were scored as marginal. Stream morphology was mostly riffle and substrate was dominated by boulder (30%) and cobble (30%). Pools were almost absent and channel flow filled only about 50% of the available channel. The left bank was severely eroded with very poor vegetative protection. The riparian zone of the site was optimal which indicate erosion is primarily caused by storm water.

WSBM007
The mean habitat score at WSBM007 was 168.5, which was a 70.3% comparison to the reference at FCRR008 ("partially-supporting" designation). Most habitat conditions were scored as suboptimal. The banks were moderately stable with decent vegetative protection. The riparian zone on the left

bank was reduced by a parking lot. Though the stream has not been altered (*e.g.*, channelized), the stream channel was not sinuous. Bells Mill is one of several Philadelphia tributaries with slope greater than 2%, which might be considered a threshold above which it becomes increasingly inappropriate to consider lateral sinuosity the principal mechanism for increasing habitat heterogeneity and attenuation of flood flows. The original EPA Habitat assessment procedure addresses this problem by providing two separate sets of criteria, one for high gradient streams, and one for low gradient streams.

WSBM090

WSBM090 had a mean habitat score of 157.5. The habitat designation of the site was "partially-supporting". The average stream depth at this location was only about 0.15 meters. The substrate had an even distribution and the stream morphology was dominated by shallow riffles (60%). Habitat scores varied between optimal and poor. There was an extensive riparian buffer with no channel alteration. Pools were greatly reduced and there was moderate sediment deposition.

WSPM018

Site WSPM018 received a mean habitat score of 143.5. The habitat was designated as "partially-supporting". Most habitat attributes were scored as marginal or suboptimal. The substrate had an even distribution and the stream morphology was dominated by shallow runs (50%). The stream is channelized downstream of the sampling area. Both banks were moderately unstable with suboptimal vegetative protection.

WSSR096

The mean habitat score at WSSR096 was 123.0, which was a 57.9% comparison to the reference at FC1310 ("non-supporting" designation). Most habitat attributes were scored as marginal or suboptimal. Both banks were moderately unstable. The right bank had poor vegetative protection and a greatly reduced riparian zone (parking area). The substrate of the site was dominated by sand (40%) and the stream morphology was primarily run (45%).

WSLR005

WSLR005 had a mean habitat score of 89.0. The habitat designation of the site was "non-supporting". Most habitat attributes were scored as marginal or poor. Epifaunal substrate, pool variability, pool substrate, and sediment deposition were all scored poor. The right bank of the site had severe erosion with little to no vegetative protection. The riparian zone on both banks was also reduced. The stream morphology was predominantly run (85%) and the substrate was mostly clay (60%). The flow of Lorraine Run is dominated by quarry discharge that has high levels of suspended solids.

WSGL020

Assessment site WSGL020 received a mean habitat score of 133.5. The habitat was designated as "non-supporting". Most habitat condition categories were scored as marginal. The substrate was evenly distributed and pools (10%) were poorly represented. The right bank was severely eroded with very poor vegetative protection. The riparian zone of the site was optimal which would indicate erosion is primarily from elevated levels of storm water.

WSVG009

The mean habitat score at WSVG009 was 99.0, which was a 41.3% comparison to the reference at FCRR008 ("non-supporting" designation). Most habitat attributes were scored as poor or marginal. Pools were almost absent at the site and there was heavy sediment deposition. Silt comprised 30%

of the substrate. Riffle (50%) and run (45%) dominated the stream morphology types. The right bank was severely eroded with very poor vegetative protection. A park access road paralleled the creek on the right. The road and high storm water levels both contribute the heavy erosion at the site.

WSUT003

WSUT003 had a mean habitat score of 109.5. The habitat designation of the site was "non-supporting". Most habitat attributes were scored as marginal or poor. The left bank of the site was severely eroded with no vegetative protection the length of the site. Wises Mill Road borders the left bank of the creek, which decreases the riparian zone width to less than six meters. The right bank of the creek also had severe erosion with decreased vegetative protection. The riparian zone on the right side of the creek was optimal. The habitat at this location is severely impaired due to heavy storm water flows.

6.3.3.2 PRINCIPAL COMPONENTS ANALYSIS (PCA) OF EPA HABITAT DATA

Principal Components Analysis (PCA) in Statistica (Statsoft 1998) was used to reduce the number of variables needed to explain the variation between scores for thirteen different habitat attributes among Wissahickon Creek Watershed and Reference sites assessed with EPA habitat assessment procedures. The first factor extracted accounted for 61.2% 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 H). The second factor extracted accounted for 12.8% of the variance, for a cumulative total of 74% variance explained. Only frequency of riffles (a "high gradient" stream metric, perhaps not equally appropriate for all sites) had a high loading score for factor two (Appendix H). Wissahickon sites and three reference sites were distributed widely across PCA axis one in the ordination plot, with highest-rated Wissahickon sites grouped closely between French Creek and Rock Run reference sites (Figure 6-7). Tributary sites were more strongly dispersed than mainstem sites on both axes.

Overall, the placement of sites along axis 1 correlated closely with total habitat scores and relative comparability to the reference sites (Figure 6-7), while PCA axis 2 was not particularly useful. The only habitat attribute with a strong loading score for axis two was riffle frequency. This was due to extensive internal correlation between variables within the data set. In fact, of 78 possible pairwise comparisons between EPA habitat variables, 69 were significantly positively correlated. When the high gradient stream metric "Frequency of Riffles" was excluded, 64 of 66 possible pairings were significantly correlated. There were no examples of widespread correlations among other habitat variables that would be expected to be independent and randomly distributed, such as drainage area, water quality variables, or other physical habitat data. This unusual finding suggests either that sites are overwhelmingly uniform with regard to various independent measures of impairment considered in the EPA Habitat assessment procedure or perhaps a subjective bias in the assessments.

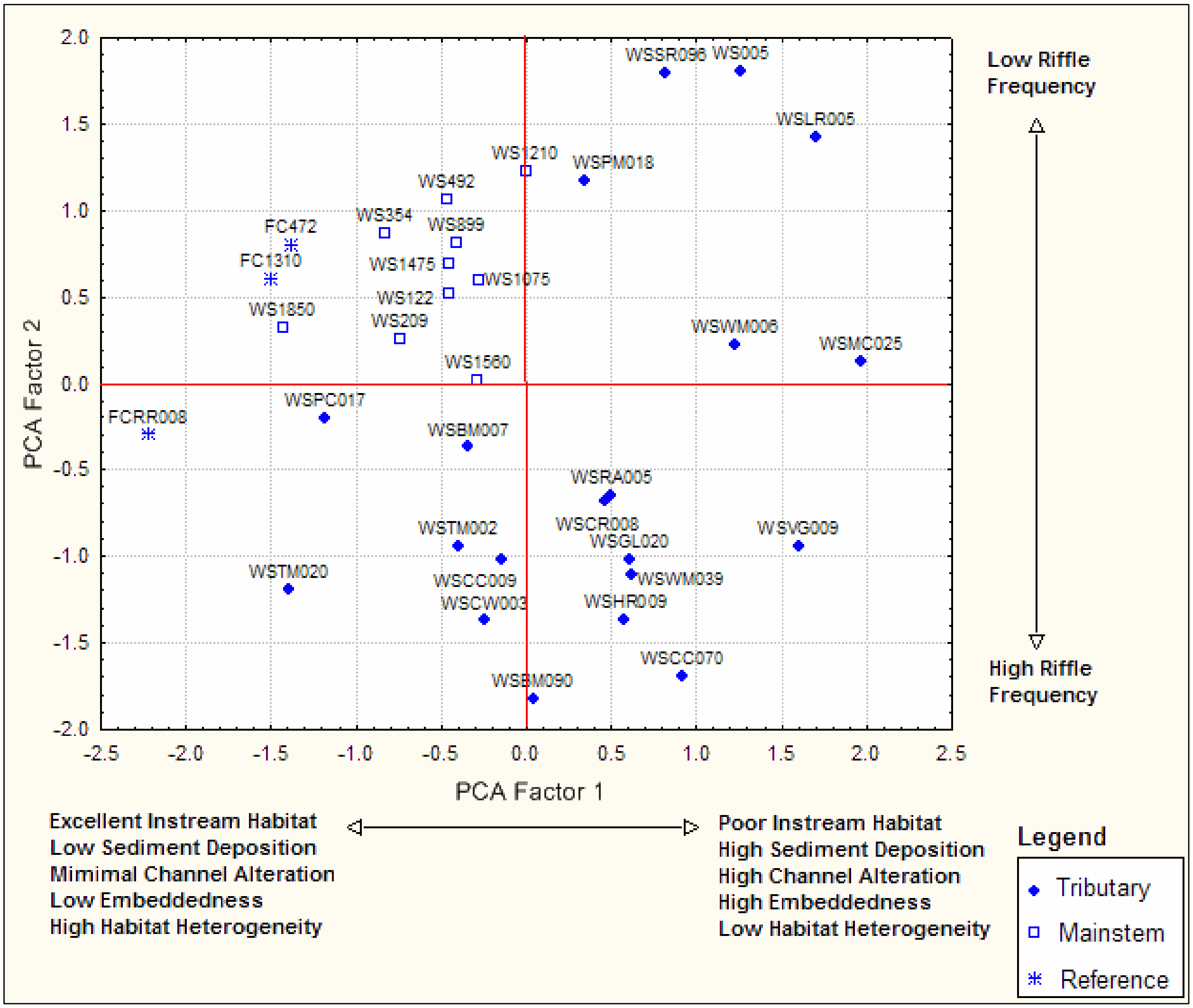


Figure 6-7 PCA Ordination Plot of Habitat Scores for Mainstem, Tributary and Reference Stream Conditions

6.3.4 FISH HABITAT SUITABILITY INDICES (HSI)

6.3.4.1 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. Because fish assessments were conducted in June, conditions that were modeled may not reflect actual conditions during (and up to) sampling. The decision to use continuous data from the entire growing season in model input reflects the philosophy that these models are being applied to evaluate habitat at the site in general, not necessarily to evaluate only those conditions present during sampling. For instance, many stream segments were cooler during the fish assessment than in late August. Fish may move from one site to another to find suitable conditions, so comparison of model output to observed fish biomass and abundance data involves a level of uncertainty.

Clearly, no species exists in a vacuum; aside from habitat variables, other ecological and environmental interactions can strongly influence biological communities. HSI models 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.

6.3.4.2 MODEL INPUTS

Most types of data required by HSI models were available for all sites within Wissahickon Creek 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 models 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 6.3.5. A list of all HSI input variables for the nine HSI models applied to Wissahickon Creek Watershed appears in Table 6-2.

Table 6-2 Habitat Suitability Index (HSI) Variable Matrix

HSI Model Variable Matrix	Variable	Blacknose Dace	Common shiner	Creek Chub	Fallfish	Longnose Dace	Redbreast Sunfish	Smallmouth Bass	Rainbow trout	Brown trout
Total number of HSI variables		16*	9	20	6	6	10	13*	4**	14**
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			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			X
pH fluctuation classification				X						
Minimum dissolved oxygen concentration				X			X	X		X
Minimum dissolved oxygen conc. during spring				X						
Nitrate concentration										X
Percent instream cover during average summer flow	general stream characteristics			X		X	X	X	X	
Instream cover classification					X					
Percent shading of stream between 1000 and 1500 hrs.		X		X						X
Percent vegetative cover							X			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					
Baseflow Regime										X
Water level fluctuations								X		X
Stream margin substrate characterization (Y/N)		X								
Average velocity along stream margins		X		X						
Stream margin vegetation characterization				X						X
Substrate food production potential				X						
Average percentage of stable ground cover										X
Average depth thalweg									X	
Percent riffles	riffles					X				
Riffle substrate characterization		X	X	X		X				X
Average velocity in riffles		X	X	X						
Average depth of riffles		X								
Average maximum depth of riffles						X				
Percent fines in riffles										X
Percent pools	pools	X	X	X			X	X	X	X
Pool substrate characterization		X						X		
Pool classification			X	X					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

** Model has more variables, however only variables for adult component applied

*** 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

6.3.4.3 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. In some cases, the categorization was based on another statistic, such as the mode of stream depths within pools, or variability of water quality measurements (Figure 6-8). Categorized data were processed directly within Microsoft Excel spreadsheet HSI models.

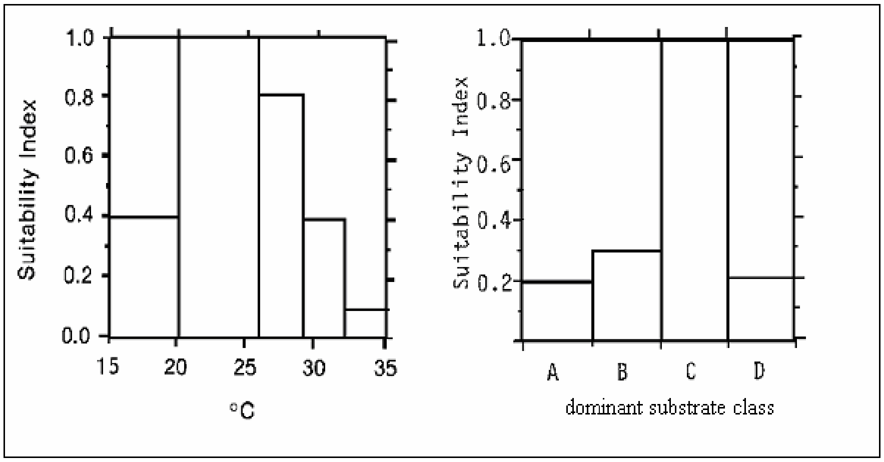


Figure 6-8 Categorized Expressions in HSI Models

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 6-9), 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.

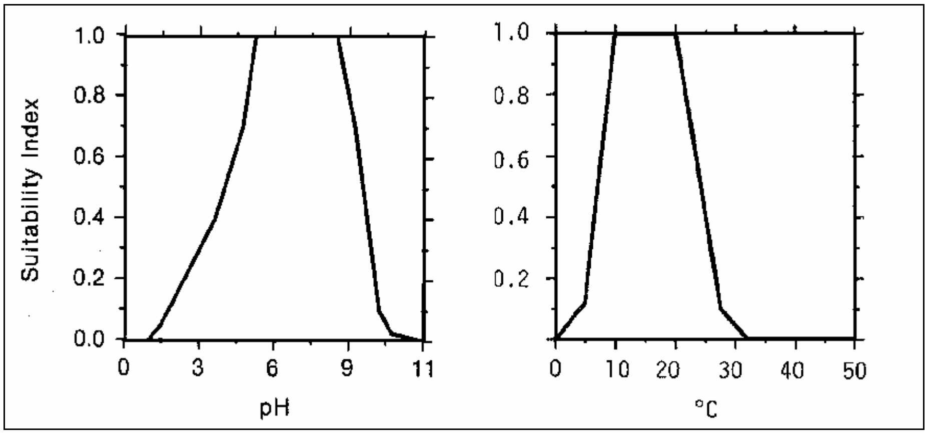


Figure 6-9 Linear Expressions in HSI Models

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 6-10). 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.

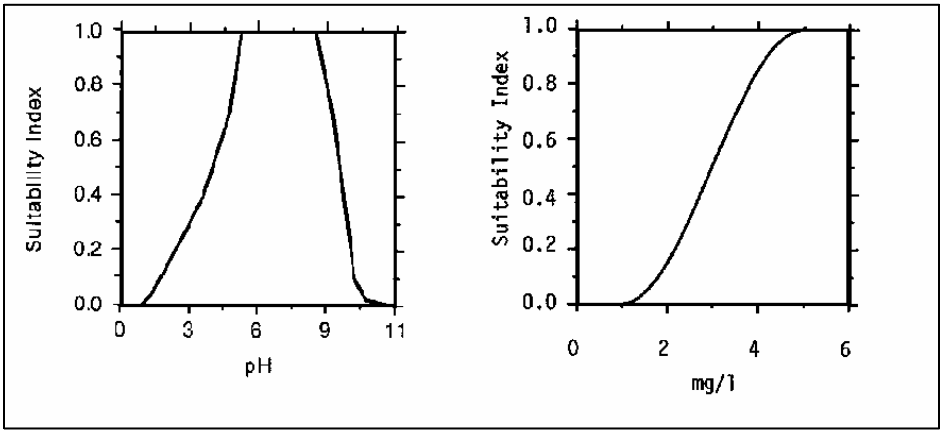


Figure 6-10 Curve Relationships in HSI Models

6.3.4.4 HSI MODEL SELECTION

HSI models for nine species were selected for Wissahickon Creek 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 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 naturally in Wissahickon Creek Watershed are American eels, native catadromous fish for which no HSI have been developed. Salmonid HSI models were used for brown trout (*Salmo trutta*) and rainbow trout (*Oncorhynchus mykiss*). While these coldwater fish generally cannot establish and maintain reproducing populations in warmwater streams, PFBC actively stocks both rainbow and brown trout in Wissahickon Creek Watershed (see section 5.1 for more information).

Four native minnow species were selected for HSI analysis: blacknose dace (*Rhinichthys atratulus*), common shiner (*Luxilis cornutus*), creek chub (*Semotilus atromaculatus*), and longnose dace (*Rhinichthys cataractae*). These minnow species have different habitat requirements and tend to occur in different portions of a watershed overall. Furthermore, these species are known to occur in Wissahickon Creek Watershed, and are generally common throughout Southeast Pennsylvania streams with appropriate habitat.

6.3.4.5 HSI MODEL EVALUATION

HSI model output for each site was compared to EPA habitat data results. With the exception of fallfish, brown trout and rainbow trout HSI data, HSI model output was compared to observed fish abundance and biomass with correlation analyses. As fish known to associate primarily with pool habitats generally grow to larger sizes, a successful model should perhaps correlate with the biomass per unit volume. Conversely, models that aim to predict habitat suitability for small minnows that inhabit riffles might be expected to have a stronger relationship with fish abundance per unit surface area. 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 Wissahickon Creek Watershed, it is hoped that such modifications will increase the usefulness of these models in the future. Simple correlations between habitat and fish abundance/biomass data are included in individual model results when appropriate, and PWD is currently exploring other statistical tools to study fish and macroinvertebrate habitat relationships.

6.3.5 RESULTS

6.3.5.1 SMALLMOUTH BASS HSI MODEL

Most sites in Wissahickon Creek Watershed received HSI scores above 0.60, indicating suitable habitat for smallmouth bass. Sites with lower scores, (*i.e.*, WS1210, WS1475, and WS1850) were limited by dissolved oxygen concentration, and in some cases, the availability of pools with good substrates. Smallmouth bass were collected mainly in downstream sites, a pattern that was not predicted by the HSI model. However, smallmouth bass abundance and biomass are generally expected to decrease in an upstream direction, as this species requires deeper, calmer water than is typically found in streams with small drainage areas. Upstream sites also had more frequent violations of instantaneous DO violations than downstream sites. This factor may have affected abundance, as smallmouth bass display optimal growth at DO concentrations above 6.0 mg/L.

Fewer smallmouth bass were collected from Wissahickon Creek Watershed than would be expected from the high HSI scores. It is possible that factors other than habitat influence their abundance. Stocked rainbow and brown trout seek out low velocity resting cover in the same habitats favored by smallmouth bass, and may compete for larger food items, such as small fish and crayfish. Another possibility is that certain variables have more influence than they carry in the model. For example, at many sites, all 15 variables received high scores with the exception of water fluctuation. However, water fluctuation had little effect on the final HSI scores. The exaggerated rise and fall of the water level characteristic of an urban stream, as well as the increased velocities present in a channelized stream, may have a greater effect than the water fluctuations and flood velocities typical of natural streams. 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.

HSI scores correlated most closely with percentage of pools and pool substrate type. Restoration and stabilization techniques that create, expand, or improve pool habitats probably will result in increased habitat suitability for smallmouth bass. For example, re-meandering of the stream channel and installation of flow diverters such as rock vanes and J-hooks should improve macrohabitat heterogeneity and enhance habitat for smallmouth bass and forage fish. Furthermore, stream restoration activities that increase the amount of instream and overhanging cover should improve habitat for smallmouth bass. These fish strongly associate with cover, such as accumulations of brush and fallen trees. Managing the amount, types, and distribution of available brush and downed tree cover can be very difficult in a multi-use setting such as Fairmount Park. Many park users do not understand the value of this type of habitat and consider it a nuisance because improperly disposed trash becomes snagged on tree branches and brush during storm events. Large accumulations of brush and logs may also threaten infrastructure.

Table 6-3 Smallmouth Bass HSI Data

HSI Variable	WS209	SI	WS354	SI	WS622	SI	WS899	SI	WS1075	SI	WS1210	SI	WS1475	SI	WS1850	SI	WSSR096	SI	WSPC017	SI
Substrate category	C	1.00	C	1.00	D	0.20	C	1.00	C	0.00	C	1.00	D	0.20	C	1.00	C	1.00	C	1.00
Percent pools	29.00	0.53	48.00	0.96	24.00	0.42	38.00	0.73	29.00	0.53	19.00	0.31	14.00	0.20	29.00	0.53	50.00	1.00	21.00	0.36
Average pool depth (m)	0.43	0.36	0.60	0.50	0.85	0.71	0.46	0.38	0.70	0.58	0.48	0.40	0.68	0.57	0.51	0.43	0.60	0.50	0.41	0.34
Percent cover	70.00	0.84	85.00	0.64	50.00	1.00	50.00	1.00	50.00	1.00	20.00	0.80	30.00	1.00	20.00	0.80	40.00	1.00	40.00	1.00
Average pH	8.06	0.89	7.94	0.93	8.00	0.89	8.00	0.89	7.65	0.99	7.62	0.99	7.62	0.99	7.50	0.99	8.00	0.89	8.00	0.89
Minimum DO (mg/L)	5.51	0.82	5.34	0.77	4.98	0.65	4.98	0.65	2.51	0.09	1.00	0.00	1.00	0.00	2.12	0.05	5.09	0.68	6.00	0.97
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	25.00	1.00
Temperature (adult) (growing season) (C)	27.24	1.00	27.08	1.00	27.44	1.00	27.44	1.00	28.09	1.00	27.64	1.00	27.64	1.00	28.94	1.00	26.00	1.00	26.00	1.00
Temperature (embryo) (spawning)	19.00	1.00	19.20	1.00	18.80	1.00	18.80	1.00	19.00	1.00	19.00	1.00	19.00	1.00	20.70	1.00	19.00	1.00	19.00	1.00
Temperature (fry) (growing season) (C)	27.24	1.00	27.08	1.00	27.44	1.00	27.44	1.00	28.09	1.00	27.64	1.00	27.64	1.00	28.94	1.00	26.00	1.00	26.00	1.00
Temperature (juvenile) (growing season) (C)	27.24	1.00	27.08	1.00	27.44	1.00	27.44	1.00	28.09	1.00	27.64	1.00	27.64	1.00	28.94	1.00	26.00	1.00	26.00	1.00
Water fluctuation category	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	A	0.30
Stream gradient (km/m)	2.75	1.00	2.88	1.00	2.35	1.00	1.05	1.00	0.34	0.43	2.02	1.00	5.12	0.94	3.84	1.00	0.99	1.00	6.64	0.67
Food component	0.77		0.85		0.44		0.90		0.00		0.63		0.34		0.75		1.00		0.71	
Cover Component	0.68		0.77		0.58		0.78		0.53		0.63		0.49		0.69		0.88		0.67	
Reproduction Component	0.80		0.76		0.63		0.79		0.00		0.00		0.00		0.53		0.80		0.84	
Other component	1.00		1.00		1.00		1.00		0.43		1.00		0.94		1.00		1.00		0.67	
HSI	0.83		0.86		0.68		0.87		0.00		0.00		0.00		0.53		0.91		0.76	
Abundance	32.00		26.00		16.00		3.00		1.00		7.00		15.00		0.00		1.00		2.00	
Biomass (g)	1426.00		2450.94		565.50		145.05		64.54		444.55		668.42		0.00		82.20		47.99	
Estimated surface area (m^2)	1673.95		1775.43		2142.86		1613.86		1693.90		1483.81		1189.38		710.80		909.35		473.25	
Estimated volume (m^3)	511.00		713.20		977.30		520.70		545.70		329.10		287.30		166.90		289.00		90.20	
Biomass/ surface area	0.85		1.38		0.26		0.09		0.04		0.30		0.56		0.00		0.09		0.10	
Biomass/ volume	2.79		3.44		0.58		0.28		0.12		1.35		2.33		0.00		0.28		0.53	

Correlations	r^2 Value
HSI: abundance	-0.06
HSI: biomass/ surface area	0.10
HSI: biomass/ volume	-0.02

* Due to data incompatibility, Turbidity was assigned an SI value of 1 at all sites

6.3.5.2 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"). SLR analysis of HSI scores and abundance yielded an r^2 value of 0.23. The relationship was slightly improved when comparing HSI scores to biomass/surface area and biomass/volume (0.34 and 0.26 respectively). HSI scores for two sites with the greatest abundance of redbreast sunfish, WS899 and WS1850, were limited by vegetative cover. Vegetative cover is important for predator avoidance as well as a substrate to increase invertebrate production for food. While these sites may have less vegetative cover than a natural stream, there were still sections of adequate cover.

Additionally, hard structural cover, which was not limiting, is used for the same purposes and may have compensated. Observations made during electrofishing surveys revealed the bulk of redbreast sunfish (and congeneric sunfishes) were collected in sections associated with cover. Many small sunfish were collected along stream margins in boulders and rubble, while larger fish were generally more associated with larger and better quality habitat features, such as deep pools, logs, and brush. Sites WS622 and WS1475 were very similar in regard to substrate composition, with abundant bedrock, and small sunfish were abundant along stream margins in both sites. Sites WS1850 and WS899 had the greatest abundance of redbreast sunfish, and both sites had large pools with vegetative cover.

HSI models are intended to be used to evaluate the suitability of a site for all life stages of the species in question, but scores for habitat attributes associated with spawning may not address the fact that fish may move considerable distances in search of adequate spawning habitat. For example, downstream sites in the City of Philadelphia (*i.e.*, WS209, WS354 and WS622) were very scoured, and found to be lacking substrate for nest construction. Moderate abundance of *L. auritus* at these sites suggests that the fish are making use of suitable substrates elsewhere, and probably in more depositional areas, such as dam impoundments.

Table 6-4 Redbreast Sunfish HSI Data

HSI Variable	WS209	SI	WS354	SI	WS622	SI	WS899	SI	WS1075	SI	WS1210	SI	WS1475	SI	WS1850	SI	WSSR096	SI	WSPC017	SI
Percent cover	70.00	1.00	85.00	0.92	50.00	1.00	50.00	1.00	50.00	1.00	20.00	0.88	30.00	1.00	20.00	0.88	40.00	1.00	40.00	1.00
Vegetated cover	5.00	0.50	5.00	0.50	5.00	0.50	10.00	0.60	5.00	0.50	5.00	0.50	5.00	0.50	5.00	0.50	10.00	0.60	15.00	0.70
Spawning temperature (summer) (C)	25.24	1.00	25.16	1.00	25.31	1.00	25.31	1.00	25.55	1.00	25.09	1.00	25.09	1.00	26.51	0.80	21.35	1.00	20.00	1.00
Percent pools	29.00	0.80	48.00	0.87	24.00	0.49	38.00	0.80	29.00	0.80	19.00	0.43	14.00	0.37	29.00	0.80	50.00	0.88	21.00	0.45
Percent sand/ gravel	16.00	0.39	20.00	0.44	22.00	0.46	39.00	1.00	53.00	1.00	46.00	1.00	22.00	0.46	51.00	1.00	66.00	1.00	74.00	1.00
Least suitable pH	9.14	0.77	9.60	0.51	9.25	0.74	9.25	0.74	8.88	0.87	9.15	0.77	9.15	0.77	8.73	0.94	7.90	1.00	7.00	1.00
Minimum DO category	A	1.00	A	1.00	A	1.00	A	1.00	B	0.70	B	0.70	B	0.70	B	0.70	B	0.70	A	1.00
Turbidity*	25.00	no JTU	25.00	no JTU	25.00	no JTU	25.00	no JTU	25.00	no JTU	25.00	no JTU	25.00	no JTU	25.00	no JTU	25.00	no JTU	25.00	no JTU
Max. temperature (growing season) (C)	25.24	1.00	25.16	1.00	25.31	1.00	25.31	1.00	25.55	1.00	25.09	1.00	25.09	1.00	26.51	1.00	26.00	1.00	26.00	1.00
Stream width (m)	16.74	1.00	17.75	1.00	21.43	1.00	16.14	1.00	16.94	1.00	14.84	1.00	11.89	1.00	6.74	1.00	9.09	1.00	4.73	0.70
HSI	0.39		0.44		0.46		0.60		0.50		0.43		0.37		0.50		0.60		0.45	
Abundance	22.00		57.00		72.00		111.00		6.00		26.00		82.00		103.00		12.00		22.00	
Biomass (g)	1189.76		3745.99		3656.26		7680.47		202.07		1225.09		3053.54		4218.25		536.34		503.74	
Estimated surface area (m^2)	1673.95		1775.43		2142.86		1613.86		1693.90		1483.81		1189.38		710.80		909.35		473.25	
Estimated volume (m^3)	511.00		713.20		977.30		520.70		545.70		329.10		287.30		166.90		289.00		90.20	
Biomass/ surface area	0.71		2.11		1.71		4.76		0.12		0.83		2.57		5.93		0.59		1.06	
Biomass/ volume	2.33		5.25		3.74		14.75		0.37		3.72		10.63		25.27		1.86		5.58	

Correlations	r^2 Value
HSI: abundance	0.23
HSI: biomass/ surface area	0.34
HSI: biomass/ volume	0.26

*Due to data incompatibility, Turbidity was assigned an SI value of 1 at all sites

6.3.5.3 LONGNOSE DACE

Longnose dace are riffle specialists, and abundance and biomass of longnose dace was strongly related to riffle attributes such as riffle substrate composition, depth and velocity. For example, with the exception of site WS1850, longnose dace were well represented at all sites where cobble was the dominant riffle substrate, while longnose dace were rare at sites with boulder or bedrock riffle substrates. Complete absence of longnose dace at WS1850, despite presence of suitable habitat, is a strong indication that poor water quality downstream of the wastewater treatment plant discharge is negatively impacting the fish assemblage. WS1850 was the only mainstem sampling location where longnose dace were not found. There may have also been an effect of interspecific competition from more tolerant blacknose dace, which are often found at upstream sites. Another site with poor longnose dace habitat conditions was site WSPC017, where substrates were mostly sand and gravel, and velocities were low. The longnose dace HSI model showed a good correlation with longnose dace abundance and biomass per unit surface area (r^2 = 0.51 and r^2= 0.44, respectively).

Table 6-5 Longnose Dace HSI Data

HSI Variable	WS209	SI	WS354	SI	WS622	SI	WS899	SI	WS1075	SI	WS1210	SI	WS1475	SI	WS1850	SI	WSSR096	SI	WSPC017	SI
Average velocity (cm/s)	35.00	0.86	34.00	0.84	20.00	0.39	26.00	0.61	28.00	0.67	23.00	0.50	12.00	0.15	19.00	0.37	15.00	0.23	3.00	0.02
Max. riffle depth (m)	0.64	1.00	0.46	1.00	0.76	1.00	0.49	1.00	0.34	1.00	0.27	1.00	0.27	1.00	0.27	1.00	0.30	1.00	0.12	0.63
Percent riffles	33.00	1.00	24.00	1.00	24.00	0.96	14.00	0.56	38.00	1.00	38.00	1.00	43.00	1.00	10.00	0.40	25.00	1.00	42.00	1.00
Percent substrate >5cm	33.00	0.66	33.00	0.66	22.00	0.44	41.00	0.82	33.00	0.66	50.00	1.00	13.00	0.26	37.00	0.74	30.00	0.60	25.00	0.50
Spring/ Summer max. temperature (C)	16.20	1.00	16.30	1.00	16.30	1.00	16.20	1.00	16.10	1.00	16.20	1.00	16.20	1.00	18.10	1.00	16.00	1.00	16.00	1.00
Percent cover	70.00	1.00	85.00	0.76	50.00	1.00	50.00	1.00	50.00	1.00	20.00	0.80	30.00	1.00	20.00	0.80	40.00	1.00	40.00	1.00
HSI	0.66		0.66		0.39		0.56		0.66		0.50		0.15		0.37		0.23		0.02	
Abundance	18.00		28.00		8.00		217.00		133.00		95.00		6.00		0.00		82.00		0.00	
Biomass (g)	147.00		178.91		85.24		726.84		568.10		465.76		46.91		0.00		290.36		0.00	
Estimated surface area (m^2)	1673.95		1775.43		2142.86		1613.86		1693.90		1483.81		1189.38		710.80		909.35		473.25	
Estimated volume (m^3)	511.03		713.19		977.28		520.69		545.66		329.12		271.67		166.90		289.02		90.19	
Biomass/ surface area	0.09		0.10		0.04		0.45		0.34		0.31		0.04		0.00		0.32		0.00	
Biomass/ volume	0.29		0.25		0.09		1.40		1.04		1.42		0.17		0.00		1.00		0.00	

Correlations	r^2 Value
HSI: abundance	0.51
HSI: biomass/ surface area	0.44
HSI: biomass/ volume	0.23

6.3.5.4 BLACKNOSE DACE HSI MODEL

The blacknose dace is classified as a "tolerant" fish. In fact, along with white suckers, American eels, and *Fundulus* spp. (mummichogs and banded killifish), blacknose dace is one of the most common fish in degraded streams in Southeast Pennsylvania. Blacknose dace appears to be an "upstream" species, as abundance and relative biomass generally increase in an upstream direction. The stream width and gradient factors in the HSI model probably address this aspect of the species' ecology. 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.

Wissahickon Creek Watershed data from 2005 were partially consistent with historic patterns, as the greatest number of blacknose dace were collected at site WS1850, the upstream-most assessment site. However, no other sites had good representation of blacknose dace (with the possible exception of site WSPC017). This finding contrasts strongly with other nearby watersheds such as Pennypack, Poquessing, Tookany/Tacony-Frankford, and Darby Cobbs creeks, where blacknose dace were not only abundant at the upstream-most site, but generally formed part of the fish community at intermediate sites as well. Wissahickon sites that were sampled in 2001 as part of PWD's baseline assessment and again in 2005 showed a marked decrease in blacknose dace abundance. Possible explanations for the decrease are water quality, disturbances such as flooding, interspecific competition, and direct predation; perhaps by stocked fish that appear to be present in some sites in very high relative abundance compared with forage fish species.

Though reduced numbers of tolerant species may appear to be a positive change, there was no evidence for more sensitive species becoming more numerous or other desirable changes in fish communities, so the decrease in blacknose dace abundance may be interpreted as a sign of increased impairment. Furthermore, blacknose dace were and have been consistently collected at reference sites, showing that although the species is tolerant, it can be found (or even may be expected) in moderate abundance even in unimpaired sites.

Despite the markedly reduced abundance in the 2005 dataset, the blacknose dace HSI model was a better predictor of abundance than HSI models for other species in Wissahickon Creek Watershed. SLR analysis of HSI score with observed abundance yielded an r^2 value of 0.49, and once the model was refined to exclude the effects of temperature, r^2 value increased to 0.68.

Table 6-6 Blacknose Dace HSI Data

HSI Variable	WS209	SI	WS354	SI	WS622	SI	WS899	SI	WS1075	SI	WS1210	SI	WS1475	SI	WS1850	SI	WSSR096	SI	WSPC017	SI
Percent shaded	50.00	1.00	40.00	1.00	70.00	1.00	50.00	1.00	85.00	1.00	35.00	1.00	95.00	0.67	40.00	1.00	75.00	1.00	80.00	1.00
Percent pools	29.00	0.86	48.00	1.00	24.00	0.80	38.00	0.98	29.00	0.86	19.00	0.74	14.00	0.68	29.00	0.86	50.00	1.00	21.00	0.76
Stream gradient (m/km)	10.00	1.00	10.00	1.00	10.00	1.00	10.00	1.00	10.00	1.00	10.00	1.00	10.00	1.00	10.00	1.00	10.00	1.00	10.00	1.00
Stream Width (m)	16.74	0.15	17.75	0.15	21.43	0.15	16.14	0.15	16.94	0.15	14.84	0.17	11.89	0.48	6.74	1.00	9.09	0.78	4.73	1.00
Temperature (growing season) (C)	26.73	0.32	26.30	0.39	26.23	0.40	26.23	0.40	27.07	0.28	26.68	0.33	26.68	0.33	28.32	0.10	23.27	0.82	22.00	1.00
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	25.00	1.00	25.00	1.00	25.00	1.00
Riffle substrate category	E	0.40	E	0.40	E	0.40	D	0.60	D	0.60	D	0.60	E	0.40	D	0.60	D	0.60	C	1.00
Riffle Depth (cm)	30.00	1.00	25.00	1.00	38.00	0.66	25.00	1.00	20.00	1.00	13.00	1.00	19.00	1.00	17.00	1.00	11.00	1.00	6.00	1.00
Riffle Velocity (cm/s)	50.00	0.75	67.00	0.00	32.00	1.00	42.00	1.00	55.00	0.50	43.00	1.00	20.00	1.00	24.00	1.00	41.00	1.00	4.50	0.00
Temperature (spawning season) (C)	20.10	1.00	20.00	1.00	19.70	1.00	19.70	1.00	20.00	1.00	20.00	1.00	20.00	1.00	21.70	1.00	20.00	1.00	20.00	1.00
Pool substrate category	E	0.20	E	0.20	E	0.20	C	1.00	A	0.80	D	1.00	E	0.20	C	1.00	C	1.00	A	0.80
Pool velocity (cm/s)	30.00	1.00	24.00	1.00	12.00	1.00	18.00	1.00	8.00	1.00	11.00	1.00	6.00	1.00	14.00	1.00	5.00	1.00	1.00	1.00
Riffle substrate category (juvenile habitat)	E	0.30	E	0.30	E	0.30	D	0.50	D	0.50	D	0.50	E	0.30	D	0.50	D	0.50	C	1.00
Riffle velocity (juvenile) (cm/s)	50.00	0.50	67.00	0.24	32.00	1.00	42.00	0.73	55.00	0.42	43.00	0.73	20.00	1.00	24.00	1.00	41.00	0.80	4.50	0.44
Stream margin substrate category (fry)	D	0.30	D	0.30	E	0.20	C	0.40	C	0.40	C	0.40	E	0.20	C	0.40	D	0.30	C	0.40
Food Cover Component	0.15		0.15		0.15		0.15		0.15		0.17		0.71		0.97		0.95		0.94	
Water Quality Component	0.32		0.39		0.40		0.40		0.28		0.33		0.33		0.10		0.88		1.00	
Reproduction Component	0.40		0.00		0.40		0.94		0.81		0.94		0.40		0.94		0.94		0.00	
Adult Component	0.20		0.20		0.20		1.00		0.89		1.00		0.20		1.00		1.00		0.89	
Juvenile Component	0.30		0.24		0.30		0.60		0.46		0.60		0.30		0.71		0.63		0.66	

HSI Variable	WS209	SI	WS354	SI	WS622	SI	WS899	SI	WS1075	SI	WS1210	SI	WS1475	SI	WS1850	SI	WSSR096	SI	WSPC017	SI
Fry Component	0.30		0.30		0.20		0.40		0.40		0.40		0.20		0.40		0.30		0.40	
HSI	0.15		0.00		0.15		0.15		0.15		0.17		0.20		0.10		0.30		0.00	
HSS	0.75		0.62		0.62		0.62		0.72		0.77		0.91		0.76		0.78		0.92	
Abundance	1.00		1.00		0.00		8.00		10.00		13.00		2.00		140.00		2.00		58.00	
Biomass (g)	7.50		1.50		0.00		31.40		43.32		39.01		4.40		388.69		4.36		127.86	
Estimated surface area (m2)	1674.00		1775.40		2142.90		1613.90		1693.90		1483.80		1189.40		710.8*		909.40		544.20	
Estimated volume (m3)	511.00		713.20		977.30		520.70		545.70		329.10		271.70		166.90		289.00		90.20	
Biomass/ surface area	0.00		0.00		0.00		0.02		0.03		0.03		0.00		0.55		0.00		0.23	
Biomass/ volume	0.01		0.00		0.00		0.06		0.08		0.12		0.02		2.33		0.02		1.42	

Correlations	r^2 Value
HSI: abundance	0.49
HSI: biomass/ surface area	0.39
HSI: biomass/ volume	0.44

* WS1850 Data: Surface Area measurement does not include 31.90 m^2 for secondary channel that was not included due to shallow depth.

** Due to data incompatibility, Turbidity was assigned an SI value of 1 at all sites

6.3.5.5 CREEK CHUB HSI MODEL

The creek chub, like blacknose dace, is generally an upstream species that seeks out pool habitats in smaller, typically 2nd order streams and tributaries. Though downstream sites have high HSI scores, creek chubs were collected from only two upstream sites. Thirty fish were collected from site WSPC017 and three fish were collected from site WS1210, and the small number of creek chubs collected from Wissahickon Creek Watershed thus hindered data analysis. HSI scores at upstream sites were limited by minimum DO concentration, however, the models were probably not intended to be used with continuous water quality data, and it is possible scores would not be limiting if only grab sample data was used in analysis.

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 6-7 Creek Chub Dace HSI Data

HSI Variable	**WS209**	**SI**	**WS354**	**SI**	**WS622**	**SI**	**WS899**	**SI**	**WS1075**	**SI**	**WS1210**	**SI**	**WS1475**	**SI**	**WS1850**	**SI**	**WSSR096**	**SI**	**WSPC017**	**SI**
Percent pools	29.00	0.86	48.00	1.00	24.00	0.71	38.00	1.00	29.00	0.86	19.00	0.57	14.00	0.43	29.00	0.86	50.00	1.00	21.00	0.63
Pool class category	B	0.60	A	1.00	B	0.60	B	0.60	A	1.00	B	0.60	A	1.00	A	1.00	A	1.00	B	0.60
Percent hard cover	70.00	1.00	85.00	1.00	50.00	1.00	50.00	1.00	50.00	1.00	20.00	0.59	30.00	0.88	20.00	0.59	40.00	1.00	40.00	1.00
Winter cover	Yes	0.60	Yes	0.80	Yes	0.55	Yes	0.64	Yes	0.75	Yes	0.39	Yes	0.52	Yes	0.60	Yes	0.80	Yes	0.52
Stream gradient (km/m)	2.75	0.60	2.88	0.80	2.35	0.55	1.05	0.64	0.34	0.75	2.02	0.39	5.12	0.52	3.84	0.60	0.99	0.80	6.64	0.52
Stream width (m)	16.74	0.43	17.75	0.45	21.43	0.36	16.14	0.19	16.94	0.15	14.84	0.31	11.89	0.85	6.74	0.63	9.09	0.19	4.73	0.96
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	25.00	1.00
pH category	B	1.00	C	1.00	B	1.00	B	1.00	A	1.00	B	1.00	B	1.00	A	2.00	A	3.00	A	4.00
Vegetation Index	120.00	0.80	100.00	0.40	100.00	0.80	95.00	0.80	80.00	1.00	97.50	0.80	130.00	0.80	110.00	1.00	110.00	1.00	115.00	1.00
Food substrate category	A	1.00	B	0.70	D	0.20	B	0.70	B	0.70	B	0.70	D	0.20	C	0.50	B	0.70	C	0.50
Average summer temperature (C)	22.90	1.00	22.90	0.70	21.70	0.20	21.70	0.70	22.80	0.70	23.00	0.70	23.00	0.20	24.20	0.50	20.90	0.70	20.00	0.50
Minimum summer DO (mg/L)	5.51	1.00	5.34	1.00	4.98	1.00	4.98	1.00	2.51	1.00	1.00	1.00	1.00	1.00	2.12	0.98	5.09	1.00	6.00	1.00
Average velocity	50.00	1.00	67.00	1.00	32.00	0.97	42.00	0.97	55.00	0.31	43.00	0.02	20.00	0.02	24.00	0.18	41.00	1.00	4.50	1.00
Average spring temperature (C)	16.20	0.89	16.30	0.37	16.20	1.00	16.20	1.00	16.10	0.75	16.20	1.00	16.20	1.00	18.10	1.00	16.00	1.00	16.00	0.64
Minimum spring DO (mg/L)	5.92	1.00	6.96	1.00	4.62	1.00	4.62	1.00	4.05	1.00	3.72	1.00	3.72	1.00	3.12	1.00	6.00	1.00	6.00	1.00
Average spring riffle velocity (cm/s)	50.00	0.92	67.00	1.00	32.00	0.66	42.00	0.66	55.00	0.52	43.00	0.43	20.00	0.43	24.00	0.28	41.00	0.93	4.50	0.93
Riffle substrate index	115.00	1.00	108.00	0.77	117.00	1.00	131.00	1.00	103.00	1.00	120.00	1.00	83.00	1.00	139.00	1.00	136.00	1.00	107.00	0.19
Average stream margin velocity (cm/s)	9.00	1.00	9.00	1.00	9.00	1.00	9.00	1.00	9.00	1.00	9.00	1.00	9.00	1.00	9.00	1.00	9.00	1.00	9.00	1.00
Percent shade (summer)	50.00	1.00	40.00	1.00	70.00	1.00	50.00	1.00	85.00	1.00	35.00	1.00	95.00	1.00	40.00	1.00	75.00	1.00	80.00	1.00
Average max depth	0.53	0.80	0.64	0.63	0.70	1.00	0.56	0.80	0.50	1.00	0.36	0.56	0.44	1.00	0.43	0.63	0.50	1.00	0.28	1.00
Food component	1.00	1.00	0.85	1.00	0.60	1.00	0.85	1.00	0.85	0.97	0.85	0.91	0.60	0.97	0.75	0.97	0.85	1.00	0.75	0.76
Cover component	0.81		0.81		0.79		0.85		0.88		0.65		0.76		0.82		0.96		0.71	
Water quality component	0.89		0.40		0.94		0.89		0.31		0.02		0.02		0.18		1.00		1.00	
Reproduction component	0.98		0.95		0.92		0.92		0.88		0.84		0.84		0.28		0.99		0.71	
Other component	0.56		0.56		0.52		0.49		0.46		0.51		0.75		0.87		0.62		0.91	
HSI	0.83		0.40		0.73		0.78		0.31		0.02		0.02		0.18		0.87		0.81	
Abundance	0.00		0.00		0.00		0.00		0.00		3.00		0.00		0.00		0.00		30.00	

HSI Variable	WS209	SI	WS354	SI	WS622	SI	WS899	SI	WS1075	SI	WS1210	SI	WS1475	SI	WS1850	SI	WSSR096	SI	WSPC017	SI
Biomass	0.00		0.00		0.00		0.00		0.00		26.40		0.00		0.00		0.00		273.75	
Estimated surface area (m2)	1673.95		1775.43		2142.86		1613.86		1693.90		1483.81		1189.38		710.80		909.35		473.25	
Estimated volume (m3)	511.03		713.19		977.28		520.69		545.66		329.12		271.67		166.90		289.02		90.19	
Biomass/ surface area	0.00		0.00		0.00		0.00		0.00		0.02		0.00		0.00		0.00		0.58	
Biomass/ volume	0.00		0.00		0.00		0.00		0.00		0.08		0.00		0.00		0.00		3.04	

Correlations	r^2 Value
HSI: abundance	0.39
HSI: biomass/ surface area	0.32
HSI: biomass/ volume	0.31

6.3.5.6 COMMON SHINER HSI MODEL

Common shiner HSI model results were poor indicators of their presence. SLR coefficients between HSI score and common shiner abundance and biomass were both negative. The HSI score at site WS1850, where common shiners were most abundant, was limited by the maximum summer temperature. However, water temperature during the assessment was 24 degrees C, and the maximum temperature used in the model was from a continuous database. Most downstream sites were limited by substrate material in riffles which is related to food availability. Site WSPC017 on Prophecy Creek received the highest HSI score and the second greatest abundance of common shiners was collected there.

Table 6-8 Common Shiner Dace HSI Data

HSI Variable	WS209	SI	WS354	SI	WS622	SI	WS899	SI	WS1075	SI	WS1210	SI	WS1475	SI	WS1850	SI	WSSR096	SI	WSPC017	SI
Max summer temperature	26.70	0.45	26.30	0.52	26.20	0.53	26.20	0.53	27.10	0.40	26.70	0.45	26.70	0.45	28.30	0.26	23.30	1.00	20.00	1.00
Least suitable pH throughout year	9.14	0.81	9.60	0.43	9.25	0.75	9.25	0.75	8.88	0.95	9.15	0.81	9.15	0.81	8.73	0.99	7.90	1.00	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	25.00	1.00
Riffle substrate category	E	0.20	E	0.20	E	0.20	D	0.80	D	0.80	D	0.80	E	0.20	D	0.80	D	0.80	C	1.00
Percent pools	29.00	0.67	48.00	0.99	24.00	0.53	38.00	0.89	29.00	0.67	19.00	0.35	14.00	0.15	29.00	0.67	50.00	0.99	21.00	0.42
Pool velocity (cm/s)	30.00	0.67	24.00	0.83	12.00	1.00	18.00	0.95	8.00	0.98	11.00	1.00	6.00	0.94	14.00	1.00	5.00	0.91	1.00	0.75
Pool class category	B	1.00	A	0.40	B	1.00	B	1.00	A	0.40	B	1.00	A	0.40	A	0.40	A	0.40	B	1.00
Adequate Spring temperature (spawning)	YES	1.00	YES	1.00	YES	1.00	YES	1.00	YES	1.00	YES	1.00	YES	1.00	YES	1.00	YES	1.00	YES	1.00
Riffle velocity (cm/s)	20.00	1.00	20.00	1.00	20.00	1.00	20.00	1.00	20.00	1.00	20.00	1.00	20.00	1.00	20.00	1.00	20.00	1.00	20.00	1.00
Food/Cover component	0.20		0.20		0.20		0.91		0.40		0.35		0.15		0.40		0.40		0.79	
Water quality component	0.72		0.61		0.74		0.74		0.40		0.72		0.72		0.26		1.00		1.00	
Reproduction component	0.20		0.20		0.20		0.89		0.89		0.89		0.20		0.89		0.89		1.00	
HSI	0.20		0.20		0.20		0.84		0.40		0.35		0.15		0.26		0.40		0.92	
Abundance	0.00		120.00		0.00		70.00		38.00		106.00		0.00		379.00		24.00		149.00	
Biomass	0.00		604.47		0.00		726.38		398.28		959.31		0.00		4711.90		233.99		1001.85	
Estimated surface area (m^2)	1673.95		1775.43		2142.86		1613.86		1693.90		1483.81		1189.38		710.80		909.35		473.25	
Estimated volume (m^3)	511.03		713.19		977.28		520.69		545.66		329.12		271.67		166.90		289.02		90.19	
Biomass/ surface area	0.00		0.34		0.00		0.45		0.24		0.65		0.00		6.63		0.26		2.12	
Biomass/ volume	0.00		0.85		0.00		1.40		0.73		2.91		0.00		28.23		0.81		11.11	

Correlations	r^2 Value
HIS: abundance	-0.04
HIS: biomass/ surface area	0.02
HSI: biomass/ volume	0.06

* Due to data incompatibility, Turbidity was assigned an SI value of 1 at all sites

6.3.5.7 BROWN TROUT HSI MODEL

Brown trout do not naturally reproduce in Wissahickon Creek Watershed; however, they are stocked throughout the fishing season by PFBC. Some brown trout are assumed to survive through the winter based on anecdotal angler reports and the collection during fish assessments of adult brown trout greater in size than the stocked fish cohort, or "year-class". Though the HSI model for brown trout includes variables for all life stages, only variables that influence the adult stage are considered. The model can be run using a simple limiting theory or a compensatory limiting factor theory.

The simple limiting theory assumes that each variable significantly affects the habitat and therefore the habitat is limited by the lowest variable score. Run in this fashion the HSI score for all sites is 0 except WSPC017 which received a score of 0.10. All mainstem sites received low scores for maximum water temperature. While water temperatures recorded in Wissahickon Creek Watershed might be expected to be detrimental to "wild" trout, stocked trout are bred for rapid growth and acclimated to greater temperatures in hatcheries. Therefore, negative effect of high temperatures may be more limited than one would expect from model documentation or literature studies based on exposing wild fish to experimental temperatures in a laboratory setting. Thermal impacts are, however, inexorably linked to dissolved oxygen concentration. Furthermore, a 10 year study of urbanization in Valley Creek, a nearby wild reproducing brown trout stream, showed decreases related to water temperature (Steffy and Kilham 2006).

Minimum DO was determined to be limiting at all sites, with the exception of WS1475 and WSPC017. The incipient lethal level of dissolved oxygen is approximately 3 mg/L and the optimal level is thought to be over 12 mg/L (for water temperatures above 10^0C). Additionally, high nitrate concentrations are limiting at all sites except WSPC017 (average concentration is 0.55 mg/L). In the model, the variable receives a 0 for concentrations greater than 2mg/L. All downstream sites had an average nitrate concentration above 5 mg/L during the late summer, and all mainstem sites upstream of WS1075 had a concentration above 10 mg/L. WSR058 had an average concentration of 9.5 mg/L during the same period. Running the model using the compensatory limiting theory, HSI scores are all above 0.50. Removing temperature from analysis brings up the score slightly at all sites.

Table 6-9 Brown Trout HSI Data

HSI Variable	WS209	SI	WS354	SI	WS622	SI	WS899	SI	WS1075	SI	WS1210	SI	WS1475	SI	WS1850	SI	WSSR096	SI	WSPC017	SI
Maximum Water Temp	26.70	0.04	26.30	0.09	26.20	0.10	26.20	0.10	27.10	0.00	26.70	0.04	26.70	0.04	28.30	0.00	23.30	0.46	23.00	0.50
Minimum DO	3.81	0.00	2.51	0.00	1.00	0.00	0.19	0.00	5.34	0.00	4.62	0.00	8.70	0.34	5.91	0.00	4.51	0.00	9.71	0.49
Percent cover	70.00	1.00	85.00	1.00	50.00	1.00	50.00	1.00	50.00	1.00	20.00	0.31	30.00	0.37	20.00	0.31	40.00	1.00	40.00	1.00
Riffle substrate category	A	1.00	A	1.00	C	0.30	A	1.00	A	1.00	A	1.00	C	0.30	B	0.60	B	0.60	B	0.60
Percent pools	29.00	0.58	48.00	0.96	24.00	0.48	38.00	0.76	29.00	0.58	19.00	0.38	14.00	0.28	29.00	0.58	50.00	1.00	21.00	0.42
Vegetation Index	120.00	0.93	100.00	0.85	100.00	0.85	95.00	0.82	80.00	0.68	97.50	0.84	130.00	0.96	110.00	0.89	110.00	0.89	115.00	0.91
Percent rooted vegetation	80.00	1.00	70.00	0.97	80.00	1.00	75.00	1.00	70.00	0.97	75.00	1.00	80.00	1.00	80.00	1.00	80.00	1.00	90.00	1.00
Lease suitable pH	9.14	0.21	9.60	0.00	9.25	0.15	9.25	0.15	8.88	0.36	9.15	0.21	9.15	0.21	8.73	0.45	7.90	0.94	7.92	0.93
Baseflow regime	78.00	1.00	78.00	1.00	78.00	1.00	78.00	1.00	58.00	1.00	58.00	1.00	58.00	1.00	58.00	1.00	58.00	1.00	58.00	1.00
Pool class category	B	0.60	A	1.00	B	0.60	B	0.60	A	1.00	B	0.60	A	1.00	A	1.00	A	1.00	B	0.60
Percent fines	0.00	1.00	0.00	1.00	0.00	1.00	5.98	1.00	11.85	0.95	15.69	0.85	0.00	1.00	8.14	1.00	3.33	1.00	35.59	0.32
Percent shade	50.00	1.00	40.00	0.86	70.00	1.00	50.00	1.00	85.00	0.91	35.00	0.79	95.00	0.66	40.00	0.86	75.00	1.00	80.00	0.96
Nitrate concentration	5.63	0.00	5.62	0.00	6.27	0.00	6.27	0.00	10.32	0.00	11.49	0.00	11.49	0.00	11.71	0.00	9.53	0.00	0.56	0.50
Peak flow as multiple of daily flow	0.20	0.10	0.20	0.10	0.20	0.10	0.20	0.10	0.20	0.10	0.20	0.10	0.20	0.10	0.20	0.10	0.20	0.10	0.20	0.10
HSI (limited)	0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.10	
HSI (compensatory)	0.60		0.63		0.54		0.61		0.61		0.51		0.52		0.56		0.71		0.67	
Abundance	66.00		46.00		21.00		4.00		7.00		2.00		0.00		0.00		1.00		0.00	
Biomass	10309.39		9455.80		3903.50		629.19		13205.54		399.97		0.00		0.00		618.00		0.00	
Estimated surface area (m^2)	1673.95		1775.43		2142.86		1613.86		1693.90		1483.81		1189.38		710.80		909.35		473.25	
Estimated volume (m^3)	511.03		713.19		977.28		520.69		545.66		329.12		271.67		166.90		289.02		90.19	
Biomass/SA	6.16		5.33		1.82		0.39		7.80		0.27		0.00		0.00		0.68		0.00	
Biomass/Vol	20.17		13.26		3.99		1.21		24.20		1.22		0.00		0.00		2.14		0.00	

6.3.5.8 RAINBOW TROUT HSI MODEL

Like brown trout, rainbow trout do not naturally reproduce in Wissahickon Creek Watershed; however, they are stocked throughout the fishing season by PFBC. Similar to brown trout, a minimal number of rainbow trout are assumed to survive through the winter based on anecdotal angler reports and collection during fish assessments of adult rainbow trout greater in size than the stocked fish cohort, or "year-class". Only the adult component of the HSI model was considered for the Wissahickon CCR, and HSI scores were very high for all sites. Only four variables were considered for the adult component and none of them were limiting.

Table 6-10 Rainbow Trout HSI Data

HSI Variable	WS209	SI	WS354	SI	WS622	SI	WS899	SI	WS1075	SI	WS1210	SI	WS1475	SI	WS1850	SI	WSSR096	SI	WSPC017	SI
Averaged depth along thalweg (cm)	53.00	1.00	64.00	1.00	70.00	1.00	56.00	1.00	50.00	1.00	36.00	0.81	39.00	0.90	43.00	0.97	50	1.00	28	0.97
Percent cover (pools)	70.00	1.00	85.00	1.00	50.00	1.00	50.00	1.00	50.00	1.00	20.00	0.94	30.00	1.00	20.00	0.94	40	1.00	40	1.00
Percent pools	29.00	0.91	48.00	1.00	24.00	0.83	38.00	1.00	29.00	0.91	19.00	0.73	14.00	0.63	29.00	0.91	50	1.00	21	0.77
Pool class category	B	0.60	A	1.00	B	0.60	B	0.60	A	1.00	B	0.60	A	1.00	A	1.00	A	1.00	B	0.60
HSI (adult component only)	0.90		1.00		0.89		0.92		0.98		0.80		0.90		0.96		1.00		0.87	
Abundance	18.00		8.00		4.00		0.00		1.00		3.00		0.00		0.00		0		0	
Biomass (g)	3219.40		1596.07		499.33		0.00		134.20		1050.00		0.00		0.00		0		0	
Estimated surface area (m^2)	1673.95		1775.43		2142.86		1613.86		1693.90		1483.81		1189.38		710.80		909.35		473.25	
Estimated volume (m^3)	511.03		713.19		977.28		520.69		545.66		329.12		271.67		166.90		289.02		90.19	
Biomass/ surface area	1.92		0.90		0.23		0.00		0.08		0.71		0.00		0.00		0.00		0.00	
Biomass/ volume	6.30		2.24		0.51		0.00		0.25		3.19		0.00		0.00		0.00		0.00	

6.3.6 HABITAT SUITABILITY SCORE CALCULATOR

The Habitat Suitability Score (HSS) Calculator was created by Canaan Valley Institute as a tool to help land owners predict the response of select fish species to stream management options. The model was created using fish and habitat data from US EPA Environmental Monitoring and Assessment Program for Streams of the Mid-Atlantic Region, 1993-8 (N=337). The relationship between habitat variables and the presence or absence of fish species were developed using multiple logistic regression analysis. The model was tested using goodness of fit statistics which were based on "leave one out cross validation" (each sample was sequentially left out and the model was run to predict presence/absence). Goodness of fit statistics for all species yielded a p-value < 0.001. Models were also tested against an independent data set collected by the West Virginia Department of Natural Resources 2001-2 (N=115).

The HSS calculator was used to determine if habitat variables in Wissahickon Creek were good predictors of fish species presence or absence. The model was used to predict the presence of four fish species and the results were mixed. The models were run for blacknose dace, creek chub, longnose dace and smallmouth bass.

HSS proved to be a good predictor of the presence of blacknose dace and creek chub, but a poor predictor for longnose dace and smallmouth bass. HSS scores for blacknose dace were high overall and blacknose dace were present at every site. Additionally, SLR analysis of HSS scores and abundance, biomass/surface area and biomass/volume all yielded an r^2 value above 0.5. HSS scores for creek chub were generally low and creek chub were absent from most sites. Creek chub were most abundant in the tributary Prophecy Creek and the HSS score was higher at that site. HSS was not a good predictor of longnose dace presence/absence. HSS scores were low, however longnose dace were plentiful at most sites. HSS scores were also a poor predictor for smallmouth bass. Scores were low, while smallmouth bass were abundant at most sites.

6.4 TREE CANOPY ANALYSIS

6.4.1 HERITAGE CONSERVANCY SOUTHEASTERN PA RIPARIAN BUFFER ASSESSMENT PROGRAM

Heritage Conservancy, a land trust organization in Doylestown, PA received funding from Pennsylvania Coastal Zone management and the PA Stream ReLeaf Program to document the presence/absence of forested riparian buffers throughout Southeast PA. The project was completed in two phases of grant funding, an initial study of tree canopy in the Perkiomen, Neshaminy, Valley, and Chester Creek Watersheds, and a second, more detailed inventory of the remaining watersheds in the 5 county region, including the Darby-Cobbs, French, Namaan, Pennypack, Pickering, Poquessing, Ridley-Crum, Tookany/Tacony-Frankford, and Wissahickon Creeks, as well as the Lower Schuylkill and Delaware Rivers (Heritage Conservancy 2001). Over 940 miles of stream were mapped using digital orthophotography and helicopter flyover video analysis.

Of 87.3 linear miles assessed in Wissahickon Creek, approximately 30% of the riparian land was found to be lacking a forested buffer on one or both banks (a forested buffer was defined as at least 50 ft. wide and at least 50% canopy closure). As GIS shapefiles were provided to watershed stakeholders, it was possible to analyze riparian buffer statistics by subwatershed and municipality. PWD analysis of the dataset found that 94% of the mainstem and 95% of the tributary river miles within the City of Philadelphia were considered to have complete tree canopy coverage (Figure 6-11).

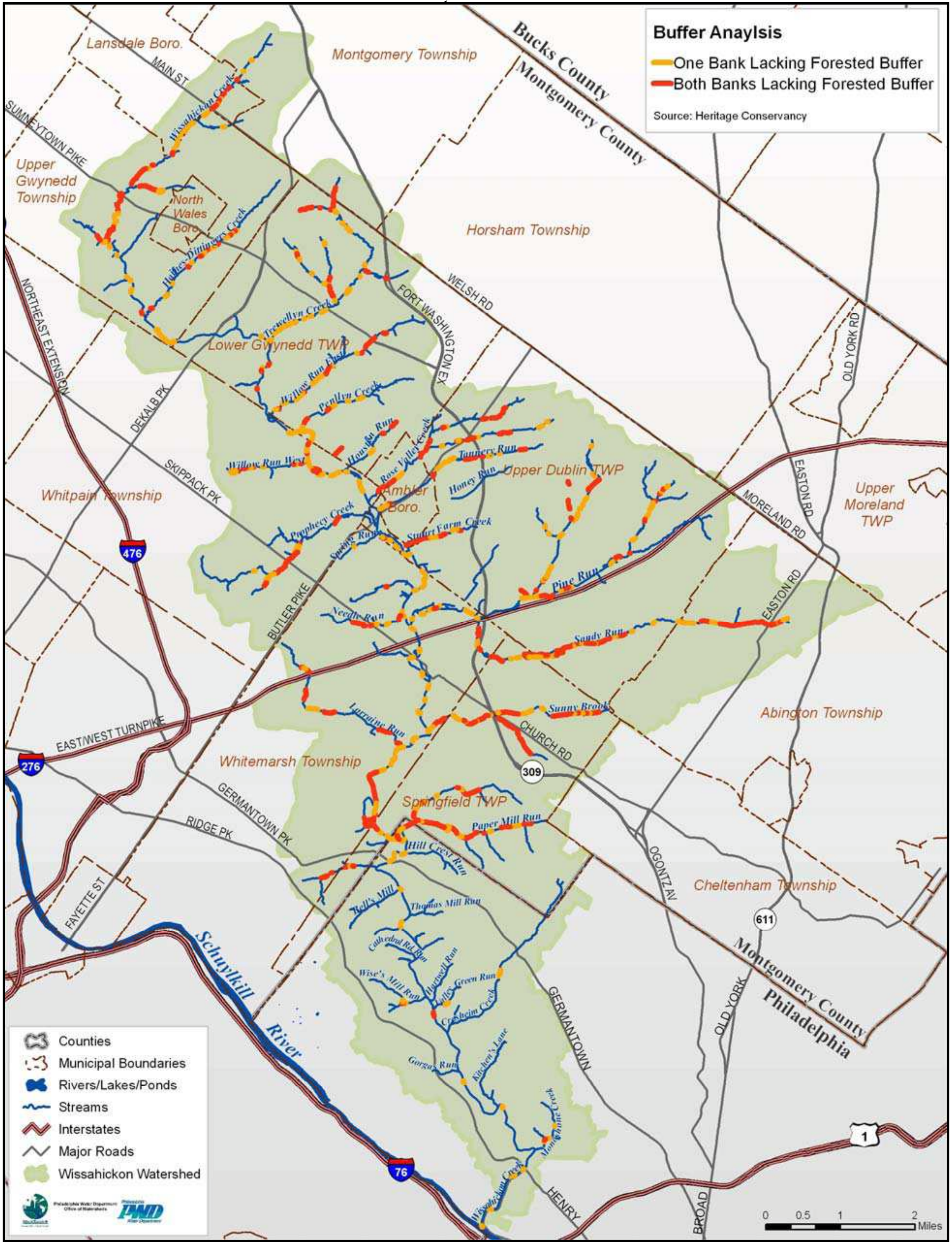


Figure 6-11 Wissahickon Creek Watershed Stream Segments Lacking a Forested Riparian Buffer on One or Both Banks (Redrawn from Heritage Conservancy 2001)

6.4.2 WATERSHED-WIDE TREE CANOPY ANALYSIS

While riparian forests are usually considered among the most critical factors affecting local habitat and stream stability, distributed tree cover can also affect a watershed in a number of ways, from aesthetic and wildlife uses to temperature and wind stabilization. Trees can also be a very effective stormwater management tool, delaying storm peaks and increasing evapotranspiration. Tree cover was recently evaluated for the Wissahickon Creek Watershed as a whole by two different organizations (Tables 6-11 and 6-12), and one study estimated tree cover separately for Philadelphia and Montgomery Counties, as well as the proportion of estimate tree cover over different land use classification types. The differences in estimates for total tree canopy cover are probably related to the methods used in the various studies. The USEPA study (2003) employed SPOT (Système Probatoire pour l'Observation de la Terre) satellite imagery from 2000, a technique which is more suited to evaluating tree canopy at a coarser scale, while American Forests used a more detailed approach, combining higher resolution satellite and aerial photography images. While more time consuming and processing-intense, this finer scale technique was able to resolve finer differences in tree canopy.

Though small and/or very patchy tree distribution patterns might appear to be less valuable than complete tree canopy, the influence of individual trees can be proportionally greater when trees are allowed to grow in lower densities. Potential for stormwater management can also be very high with certain stormwater BMP designs, such as infiltration trenches. These projects can be completed even on small scales and in very urbanized areas. In their 2003 study of urban tree canopy cover in Philadelphia, American Forests also considered the proportion of tree cover over impervious and pervious land surfaces (Table 6-12).

Table 6-11 Wissahickon Creek Watershed Tree Cover Estimates by County.

Source	Montgomery County Area (sq. mi)	Philadelphia County Area (sq. mi)	Wissahickon Watershed Total Area (sq. mi)	Estimated Montgomery County Tree Cover (%)	Estimated Philadelphia County Tree Cover (%)	Wissahickon Total Estimated Tree Cover Total (%)
American Forests, 2003	21.6	5.7	27.3	40.4	54.0	42.7
EPA, 2003	21.6	5.7	12.6			19.8

Table 6-12 Estimated Tree Cover Over Land Surface Types (American Forests 2003)

	Estimated Tree Cover Area (acres)	Total Area (acres)	Estimated Total Tree Cover (%)
Philadelphia Impervious	597	1,752	34
Philadelphia Pervious	3,035	4,959	61
Philadelphia Total	3,632	6,711	54

6.5 PRELIMINARY DOCUMENTATION OF INFRASTRUCTURE IMPACTS IN WISSAHICKON CREEK WATERSHED

6.5.1 INTRODUCTION

As an extension of the fluvial geomorphological investigation of stream channels within Wissahickon Creek Watershed during 2006, an infrastructure assessment was initiated. In order to document infrastructure throughout the basin, PWD staff and trained consultants walked along stream segments with GPS, digital photography, and portable computer equipment, compiling an inventory of every infrastructure feature encountered. These features included bridges, culverts, dams, stormwater outfalls and drain pipes greater than 8" in diameter, sewers, pipe crossings, confluences, manholes, and areas where one or more of the streambanks were artificially channelized. As of September 2006, approximately 84 linear miles of the Wissahickon Creek Watershed have been mapped, and the work is expected to be completed by spring 2007.

Preliminary findings of the infrastructure assessment are included herein to better integrate the results with the findings of other assessments (*e.g.*, to help explain observed impairments found in the biological assessments). Because the inventory of infrastructure features in the City of Philadelphia is complete and the City portion of the watershed, tributaries in particular, was subject to more scrutiny in other assessments, findings have been divided into features within the City of Philadelphia and features within Montgomery County.

6.5.2 INFRASTRUCTURE IMPACTS IN THE CITY OF PHILADELPHIA

6.5.2.1 STORMWATER OUTFALLS

As the Wissahickon Creek valley was developed later than older portions of the City, is served by a separate sewer system, and has generally not had its numerous small tributaries and stormwater conveyance flow paths encapsulated, stormwater outfalls in the basin tend to be more numerous than the predominantly combined sewer outfalls which are found in other urban streams (*e.g.*, Tacony Creek and Cobbs Creek). Additionally, a greater number of stormwater outfalls are located on tributaries in Wissahickon Creek Watershed than in the more urbanized Creeks (Figure 6-12). While mainstem Wissahickon Creek was not found to be severely affected by stormwater outfalls, geomorphic instability caused by stormwater outfalls was determined to be a serious problem in tributaries and smaller stream reaches. In essence, these natural streams have been integrated into the stormwater collection system without any protection of the stream channels. Stormwater outfalls and natural surface runoff flow paths (*i.e.*, gullies) have been scoured and enlarged as a result. Throughout this process, tributaries and gullies have contributed much sediment to the mainstem.

PWD is presently addressing a sediment TMDL for Wissahickon Creek Watershed with a study of tributaries to the Wissahickon Creek within Philadelphia. The TMDL sampling and modeling program is rooted in fluvial geomorphological principles, and combines empirical lateral erosion rate data with predictions of bank stability and erodibility, along with GIS analysis. Preliminary results of these studies and prioritization efforts will be included in PWD's 2006 Annual Stormwater report.

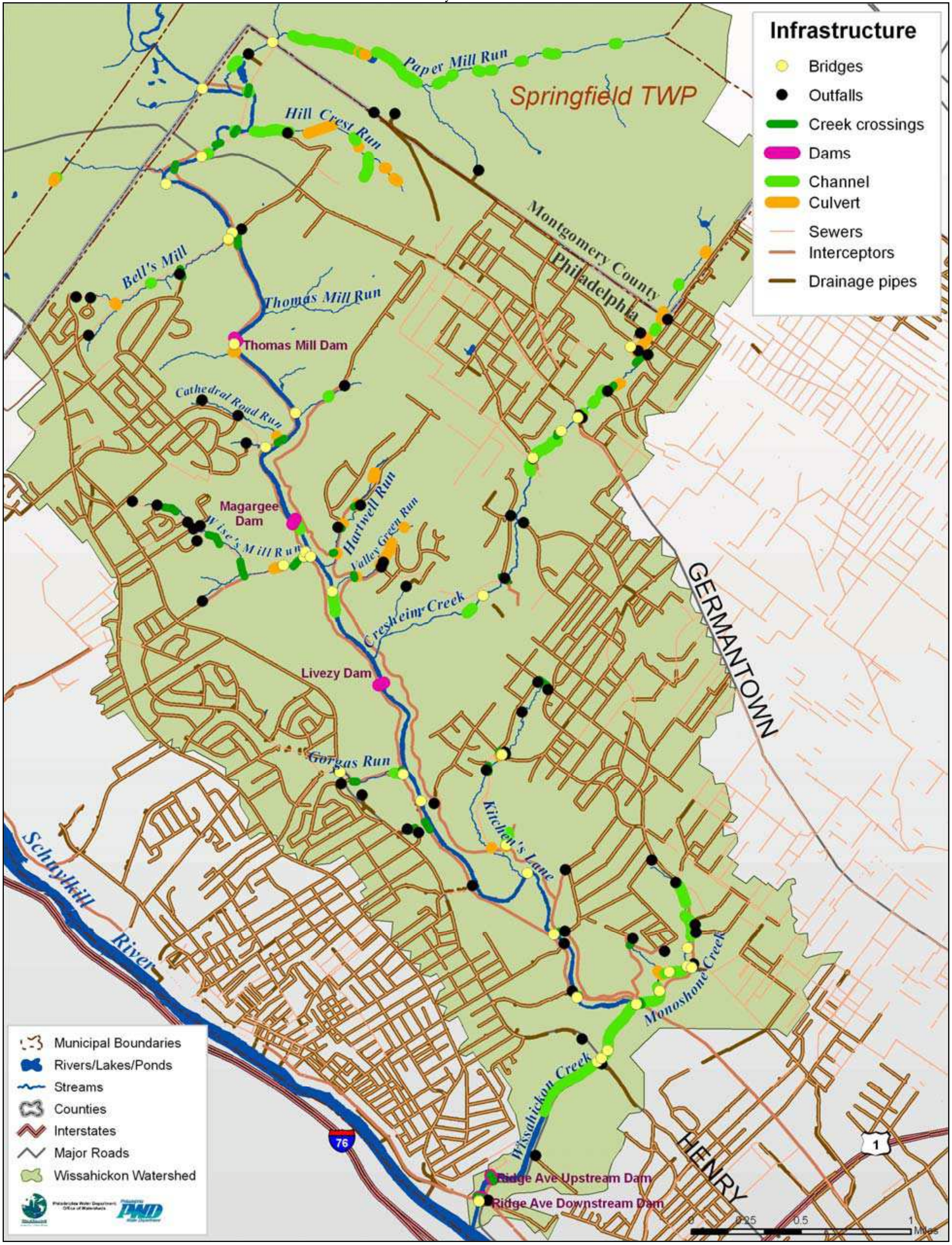


Figure 6-12 Infrastructure Locations in Wissahickon Creek within the City of Philadelphia, 2005

6.5.2.2 CULVERTS, BRIDGES, AND CHANNELIZATION

As the Wissahickon Valley is protected by the City of Philadelphia's Fairmount Park system, the number and severity of infrastructure impacts along mainstem Wissahickon Creek in the City is minimal. Major roads that cross the valley (*e.g.*, Walnut Lane and Henry Avenue) are generally elevated and do not constrain the stream channel or its floodplain. A few smaller bridges (*i.e.*, Bells Mill Road, Valley Green Road) may have a destabilizing effect during very high flows. Channelization of the mainstem is limited to a very short segment in front of Valley Green Inn, where a large channel bar also provides some evidence of instability due to the bridge.

Tributaries in the City of Philadelphia are much more severely affected by infrastructure (Figure 6-12). Aside from stormwater outfalls, there are several prominent examples of stream channels that are highly unstable or eroded due to constrictions at culverts (*e.g.*, Wises Mill Run at Summit Avenue, Carpenters Lane Run at Wissahickon Avenue) and areas where aquatic habitat conditions are very poor due to channelization (*e.g.*, Monoshone Creek and downstream segments of Hillcrest Run, where 48%, and 76% of total stream length, respectively, are affected by channelization or culverts).

6.5.2.3 DAMS

The Wissahickon Valley within Philadelphia was once home to many mills and associated mill dams and races. Of these, only 5 remain (Figure 6-12). In a report to the Fairmount Park Commission (1999) ANSP recommended removal or modification of these dams to allow fish passage, restore the stream to a more stable freely flowing state, and eliminate upstream impoundments of stagnant water. Though fish passage projects in Wissahickon Creek Watershed would undoubtedly benefit native and introduced game fish species, these projects should be assigned a lower priority than other obstructed streams in the City where anadromous fish have historically spawned. The fall line at or around the present-day location of the Ridge Avenue Dams probably was too steep to allow passage of migratory fish (other than American eels). No historical records of American shad or other migratory fish were found for Wissahickon Creek Watershed.

Ridge Avenue Dams

The dams at Ridge Avenue and the flood protection wall along Lincoln Drive constrain the stream, though there is moderate access to a narrow floodplain along the right bank. There are no riffles until the pull-offs on Lincoln Drive downstream of Henry Avenue Bridge (site WS076, a continuous monitoring site and the downstream-most location from which algal periphyton samples were taken). There is another riffle 100m upstream of the pedestrian footbridge, and the confluence with Monoshone Creek has the characteristic delta of large substrate particles found at the confluence of high energy tributaries

Livezy Dam

This dam is about 8ft high and creates an impoundment approximately 2500 ft long. The nearest upstream riffle is at Valley Green Inn, downstream of Valley Green tributary, where a flood protection wall has been constructed along the right bank. Increased stream energy due to the constriction at this site has resulted in undercutting and damage to the retaining wall and extensive deposition of sediment along the left bank.

Magargee Dam

This dam is situated upstream of Wises Mill tributary and creates an impoundment approximately 2200 ft. upstream (partially shown in Figure 6-3 above). This photograph taken 3/13/04 also shows a phytoplankton bloom, which is a common occurrence in springtime within the City of Philadelphia.

Thomas Mill Dam

Despite the fact that Thomas Mill Dam is partially breached, its impoundment extends approximately 3000 ft. to Bells Mill Road, where the Bells Mill tributary has created an extensive deposition of large sediment particles.

6.5.2.4 INFRASTRUCTURE IN MONTGOMERY COUNTY

Preliminary information was available for the infrastructure features within most stream segments Montgomery County. At the time of writing, however, data were still incomplete for several tributary segments.

Stormwater Outfalls

Because information regarding stormwater management facilities within Montgomery County were not readily available, the destabilizing effect of stormwater outfalls was assumed to be related to the relationship between outfall size and size of the receiving stream. This relationship ignores differences in slope and substrate composition that may be important in determining which outfalls have the greatest likelihood of causing stream stability problems. More than 550 stormwater outfalls greater than 8” in diameter were inventoried throughout the basin as of September 2006 (Figure 6-13). The relationship between the number and size of stormwater outfalls and potential impacts on stream stability appeared somewhat similar to that observed in Philadelphia, with the caveat that many tributaries in the City were steeper, owing to the underlying geology, and thus potentially more susceptible to instream erosion.

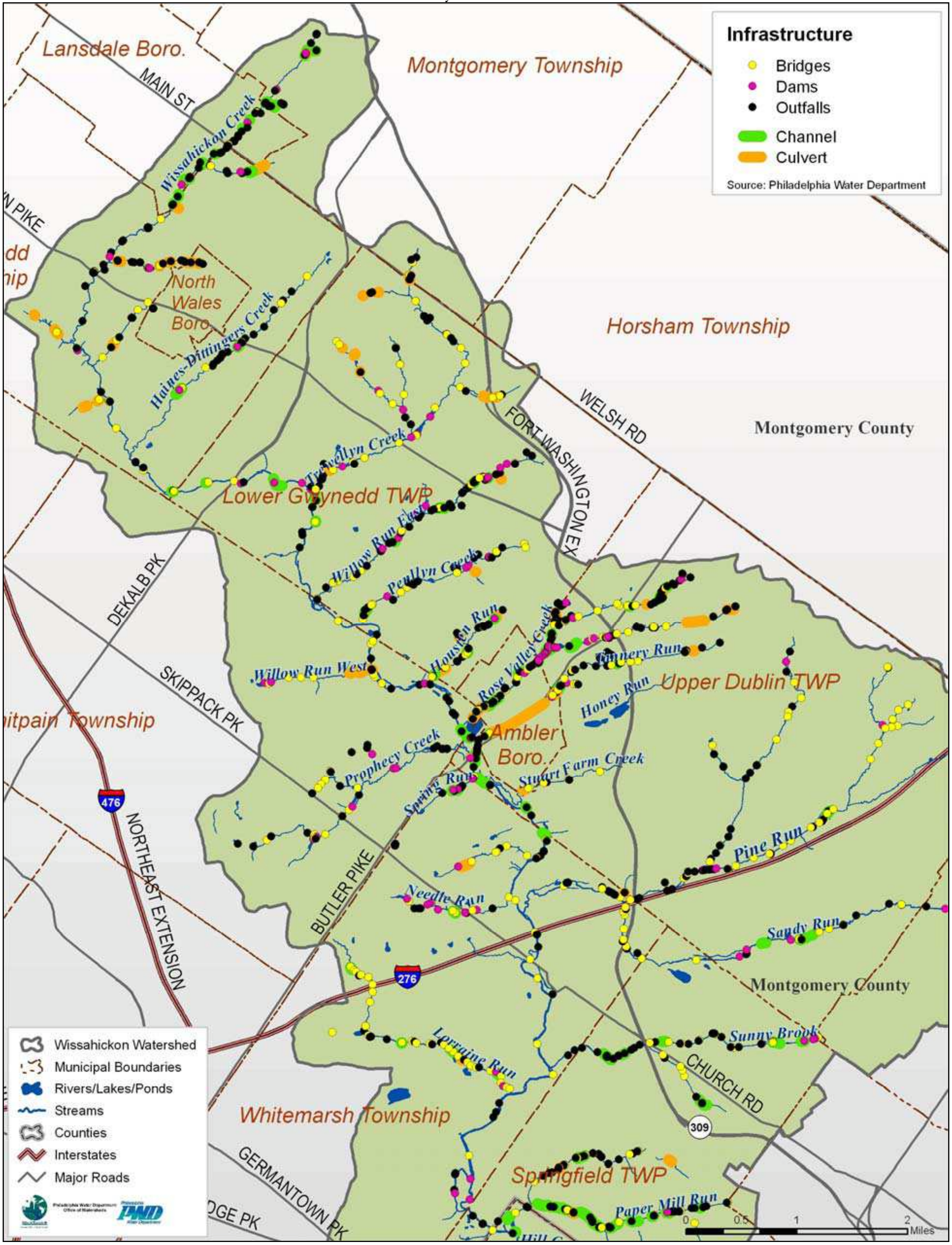


Figure 6-13 Partial Inventory of Infrastructure Locations in Wissahickon Creek within Montgomery County, 2005

Culverts, Bridges, and Channelization

Although the inventory of infrastructure features in Montgomery County was still incomplete at the time of writing, 250 bridges, 240 instances of channelization, and 100 culverts and encapsulated stream segments (Figure 6-13) were identified and mapped in the Montgomery County portion of the watershed. Bridges were much more numerous in Montgomery County than Philadelphia County, which can probably be attributed to physical factors (stream segments are generally smaller overall, most riparian land is privately owned and gentler slopes facilitated development in closer proximity to stream channels). Channelization was extensive in Rose Valley Creek and Tannery Run in the vicinity of Ambler Borough, as well as in Paper Mill Run.

Dams

Numerous small dams (n = 95) were found along Wissahickon Creek and its tributaries in Montgomery County. Though most of these dams are small, some are large relative to the streams they obstruct, and a few were observed to cause significant changes to the pattern and longitudinal profile of the stream, such as a series of three dams in Whitemarsh Township that create a large secondary channel, similar to the development of a natural "oxbow". This feature serves as a water hazard and source of irrigation water for Whitemarsh Country Club. Similar, but smaller diversions are found on Prophecy Creek and Sandy Run, where it appeared that private landowners had built dams and redirected the stream channel for landscaping purposes.

6.6 PROBLEM SUMMARY

Wissahickon Creek is an urbanized stream system that has been adversely affected by development and land use practices over the past century. Impervious cover is estimated at 28% of the watershed in total and 26% within the City of Philadelphia. Impervious cover, especially directly connected impervious cover, decreases groundwater recharge and the percent of annual streamflow represented by baseflow. Streams in the watershed are "flashy"– increases in streamflow and erosive forces occur quickly during storm events. Both maximum discharge and total runoff volume are increased compared to an undeveloped 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; Wissahickon Creek 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. Many 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. Philadelphia's 2006 stormwater ordinance and the Wissahickon Creek Integrated Watershed Management Plan (under development) will outline 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.

7 EXISTING POLLUTANT LOADS, FACILITIES AND MANAGEMENT PRACTICES

7.1 BASEFLOW LOADS

Estimates of natural baseflow due to groundwater inflow were discussed in the Characterization of Hydrology (Section 3). Because dry weather flow observed in the stream consists of natural baseflow and treated wastewater effluent, the pollutant load contributed by natural baseflow is difficult to estimate.

Estimates of concentrations and loads due to groundwater inflow to the creek were based on groundwater monitoring data available from PADEP (1998). According to this document, "PADEP's Bureau of Water Supply Management conducts a monitoring program of homeowner wells or springs and occasionally untreated water from public water and industrial supplies. It is the only PADEP program that monitors the ambient or general background groundwater quality on a watershed basis. Two combined programs (Ambient Surveys and FSN monitoring) are used to monitor the general quality of groundwater. These programs are described in a PADEP document (PADEP, 1997a). The FSN [fixed station network] program involves the sampling of selected groundwater basins over an extended period of time....FSN sampling can contribute to an understanding of long-term water quality trends, and can be used to gather information on the impact of land management practices on groundwater quality. An ambient survey is conducted the same way; however, only two groundwater samples are collected per monitoring point (over one year). Both monitoring programs were designed to provide a measure of regional (background) groundwater quality at sampling locations that are unaffected or minimally affected by obvious, specific point sources of contamination in the immediate vicinity."

The mean of 316 samples collected at 14 monitoring points in basin 65 was chosen to represent groundwater quality in Wissahickon Creek Watershed. Estimated pollutant loads were calculated as the product of mean annual baseflow (see Section 3) and mean groundwater concentrations (Table 7-2).

Table 7-1 Summary of PADEP Groundwater Quality Monitoring Data

Parameter	Concentration	Units
NH_3	0.02	mg/L as N
NO_2	0.005	mg/L as N
NO_3	2.70	mg/L as N
TN*	2.73	mg/L as N
TP	0.04	mg/L
Total Cu	31	µg/L
Total Fe	217	µg/L
Total Pb	5	µg/L
Total Zn	37	µg/L

* Total nitrogen (TN) is approximated as the sum of ammonia, nitrite, and nitrate.
Each value is a mean of the median values for each monitoring point.

Table 7-2 Estimated Loads Due to Natural Baseflow

Parameter	Concentration	Concentration Units	Baseflow Load (lb/yr)		
			Philadelphia	Montgomery County	Watershed
NH_3	0.02	mg/L as N	379	902	1,281
NO_2	0.005	mg/L as N	95	225	320
NO_3	2.70	mg/L as N	51,188	121,736	172,924
TN	2.73	mg/L as N	51,662	122,864	174,526
TP	0.04	mg/L	758	1,804	2,562
Cu	31	µg/L	588	1,398	1,985
Total Fe	217	µg/L	4,114	9,784	13,898
Pb	5	µg/L	95	225	320
Zn	37	µg/L	701	1,668	2,370

7.2 POINT SOURCES

There are five major municipal wastewater treatment plants discharging to Wissahickon Creek. These discharges are presented based on discharge monitoring reports by EPA (2004b) through May 2001 and by PWD between June 2001 and 2005 (Table 4-6). Table 7-3 lists mean concentrations reported on discharge monitoring reports for each plant. For Ambler, Abington, and North Wales, mean concentrations were determined for the period of record studied. For Upper Gwynedd and Upper Dublin, mean concentrations for the 2003-2005 period were chosen. Permitted and actual discharges for these plants have increased relative to the 1998-2001 period. Estimates of pollutant loads were obtained by multiplying representative discharges and flows at each plant and expressing results as mass per year. Tables 7-4 through 7-11 contain detailed results of discharge monitoring report analyses by EPA and PWD.

Table 7-3 Pollutant Load Estimates from Wastewater Treatment Plants

Load (lbs/yr)						
Parameter	North Wales	Upper Gwynedd	Ambler	Abington	Upper Dublin	Total
Period of Record	1/98-4/01, 1/03-5/05	6/02-8/03	1/89-5/01, 1/03-9/05	1/89-5/01, 1/03-8/05	1/03-5/05	
$CBOD_5$	8,874	30,995	68,734	62,422	15,804	186,829
TSS	13,499	53,640	215,252	80,539	39,866	402,796
NH_3-N	3,704	1,145	5,776	10,414	4,045	25,084
TP	4,013	28,588	42,742	37,101	*	112,445
Total Cu	43.2	460.8	*	*	135.2	639.2
Total Pb	6.39	18.08	*	*	*	24.47
Total Al	249	*	*	*	*	249
Fecal Coliform	2.50.E+11	1.53.E+11	*	1.43.E+12	7.27.E+11	2.56.E+12

* - Data not available

Table 7-4 Pollutant Concentration Estimates from Wastewater Treatment Plants

Mean Concentration (mg/L)					
Parameter	**North Wales**	**Upper Gwynedd**	**Ambler**	**Abington**	**Upper Dublin**
Period of Record	1/98-4/01, 1/03-5/05	6/02-8/03	1/89-5/01, 1/03-9/05	1/89-5/01, 1/03-8/05	1/03-5/05
CBOD5	5.46	3.16	5.36	6.36	5.65
TSS	8.30	5.46	16.77	8.21	14.24
NH3-N	2.28	0.12	0.45	1.06	1.45
TP	2.47	2.91	3.33	3.78	*
Total Cu	0.027	0.047	*	*	0.048
Total Pb	0.004	0.002	*	*	*
Total Al	0.153	*	*	*	*
Fecal Coliform	33.9	3.4	*	32.1	57.2

* - Data not available

Table 7-5 Point Source TSS Concentrations

TSS (mg/L)								
Service Area/ Water User	Period of Record	Source	Limit	Count	Min	Mean	Max	Standard Deviation
North Wales	1/98-4/01	EPA	30.0	32.0	3.800	8.11	19.3	NR
North Wales	1/03-5/05	PWD	30.0	28.0	4.250	8.57	15.5	2.74
Upper Gwynedd	9/90-5/02	EPA	30.0	147	2.80	9.01	51.9	NR
Upper Gwynedd	6/02-8/03	PWD	30.0	185	2.00	5.46	17.4	2.56
Ambler	1/89-5/01	EPA	30.0	152	1.00	16.8	41.0	NR
Ambler	1/03-9/05	PWD	30.0	29.0	1.00	1.38	4.00	0.677
Abington	1/89-5/01	EPA	30.0	55.0	3.00	6.95	14.0	NR
Abington	1/03-8/05	PWD	30.0	766	1.00	13.6	138	9.33
Upper Dublin	1/98-5/01	EPA	30.0	32.0	3.00	13.0	36.1	NR
Upper Dublin	1/03-5/05	PWD	30.0	25.0	9.00	14.2	21.5	3.38

NR – Not recorded

Table 7-6 Point Source TP Concentrations

TP (mg/L)								
Service Area/ Water User	Period of Record	Source	Limit	Count	Min	Mean	Max	Standard Deviation
North Wales	1/98-4/01	EPA	NL	18.0	1.21	2.54	4.44	NR
North Wales	1/03-5/05	PWD	NL	28.0	0.204	2.37	8.22	1.43
Upper Gwynedd	9/90-5/02	EPA	NL	15.0	2.74	3.45	4.50	NR
Upper Gwynedd	6/02-8/03	PWD	NL	122	0.230	2.91	4.33	0.843
Ambler	1/89-5/01	EPA	NL	42.0	0.137	3.33	4.80	NR
Ambler	1/03-9/05	PWD	NL	N/A	N/A	N/A	N/A	N/A
Abington	1/89-5/01	EPA	NL	30.0	3.30	3.83	4.40	NR
Abington	1/03-8/05	PWD	NL	492	1.00	3.57	7.50	0.726
Upper Dublin	1/98-5/01	EPA	NL	N/A	N/A	N/A	N/A	NR
Upper Dublin	1/03-5/05	PWD	NL	N/A	N/A	N/A	N/A	N/A

NR – Not recorded N/A – Not available

Table 7-7 Point Source CBOD5 Concentrations

CBOD5 (mg/L)								
Service Area/ Water User	Period of Record	Source	Limit	Count	Min	Mean	Max	Standard Deviation
North Wales	1/98-4/01	EPA	10.0	14.0	2.35	5.34	11.4	NR
North Wales	1/03-5/05	PWD	10.0	13.0	2.80	5.88	11.3	2.28
Upper Gwynedd	9/90-5/02	EPA	10.0	62.0	1.70	3.32	25.0	NR
Upper Gwynedd	6/02-8/03	PWD	10.0	118	1.30	2.89	7.30	1.09
Ambler	1/89-5/01	EPA	10.0	58.0	2.80	5.00	11.3	NR
Ambler	1/03-9/05	PWD	10.0	N/A	N/A	N/A	N/A	N/A
Abington	1/89-5/01	EPA	10.0	82.0	1.00	5.10	10.0	NR
Abington	1/03-8/05	PWD	10.0	147	2.00	6.55	41.0	5.05
Upper Dublin	1/98-5/01	EPA	15.0	13.0	3.50	8.38	13.4	NR
Upper Dublin	1/03-5/05	PWD	15.0	11.0	3.00	5.00	7.00	1.18
North Wales	1/98-4/01	EPA	20.0	18.0	2.50	5.22	11.8	NR
North Wales	1/03-5/05	PWD	20.0	16.0	2.90	5.53	10.7	2.15
Upper Gwynedd	9/90-5/02	EPA	20.0	67.0	1.70	4.08	25.0	NR
Upper Gwynedd	6/02-8/03	PWD	20.0	64.0	1.20	3.42	6.20	1.08
Ambler	1/89-5/01	EPA	20.0	62.0	2.00	5.71	9.80	NR
Ambler	1/03-9/05	PWD	20.0	N/A	N/A	N/A	N/A	N/A
Abington	1/89-5/01	EPA	20.0	55.0	3.00	6.95	14.0	NR
Abington	1/03-8/05	PWD	20.0	159	2.00	9.05	43.0	7.5
Upper Dublin	1/98-5/01	EPA	20.0	19.0	5.90	10.2	15.6	NR
Upper Dublin	1/03-5/05	PWD	20.0	14.0	4.00	6.29	10.0	1.68

NR – Not recorded N/A – Not available

Table 7-8 Point Source Fecal Coliform Concentrations

Fecal Coliform (#COL/100mL)								
Service Area/ Water User	Period of Record	Source	Limit	Count	Min	Mean	Max	Standard Deviation
North Wales	1/98-4/01	EPA	200	32.0	2.00	34.0	197	NR
North Wales	1/03-5/05	PWD	200	28.0	10.0	33.9	92.0	21.3
Upper Gwynedd	9/90-5/02	EPA	200	146	1.00	7.00	78.0	NR
Upper Gwynedd	6/02-8/03	PWD	200	122	1.00	3.44	63.0	6.49
Ambler	1/89-5/01	EPA	N/A	N/A	N/A	N/A	N/A	NR
Ambler	1/03-9/05	PWD	N/A	N/A	N/A	N/A	N/A	N/A
Abington	1/89-5/01	EPA	200	148	1.00	17.0	147	NR
Abington	1/03-8/05	PWD	200	847	1.00	96.8	10000	493
Upper Dublin	1/98-5/01	EPA	200	32.0	16.0	45.0	146	NR
Upper Dublin	1/03-5/05	PWD	200	25.0	15.0	57.2	138	36.3

NR – Not recorded N/A – Not available

Table 7-9 Point Source Ammonia Concentrations

NH3-N (mg/L)								
Service Area/ Water User	Period of Record	Source	Limit	Count	Min	Mean	Max	Standard Deviation
North Wales	1/98-4/01	EPA	2.50	14.0	0.210	1.62	4.40	NR
North Wales	1/03-5/05	PWD	2.50	13.0	0.270	1.21	3.10	0.831
Upper Gwynedd	9/90-5/02	EPA	1.80	70.0	0	0.340	1.60	NR
Upper Gwynedd	6/02-8/03	PWD	1.80	119	0.100	0.116	0.700	0.0856
Ambler	1/89-5/01	EPA	1.50	74	0.100	0.800	0.230	NR
Ambler	1/03-9/05	PWD	1.50	N/A	N/A	N/A	N/A	N/A
Abington	1/89-5/01	EPA	2.00	72.0	0.0600	0.700	4.37	NR
Abington	1/03-8/05	PWD	2.00	237	0	0.384	15.5	1.19
Upper Dublin	1/98-5/01	EPA	2.50	13.0	0.300	1.10	3.70	NR
Upper Dublin	1/03-5/05	PWD	2.50	11.0	0.300	1.05	3.00	0.761
North Wales	1/98-4/01	EPA	6.50	18.0	0.500	3.50	7.40	NR
North Wales	1/03-5/05	PWD	6.50	15.0	0.970	2.57	4.40	1.18
Upper Gwynedd	9/90-5/02	EPA	4.30	78.0	0	0.300	1.30	NR
Upper Gwynedd	6/02-8/03	PWD	4.30	64.0	0.100	0.117	1.07	0.122
Ambler	1/89-5/01	EPA	4.50	76.0	0.100	1.50	0.500	NR
Ambler	1/03-9/05	PWD	4.50	N/A	N/A	N/A	N/A	N/A
Abington	1/89-5/01	EPA	4.00	76.0	0.0200	1.60	20.7	NR
Abington	1/03-8/05	PWD	4.00	262	0	0.978	14.75	2.01
Upper Dublin	1/98-5/01	EPA	6.00	19.0	0.500	2.30	7.60	NR
Upper Dublin	1/03-5/05	PWD	6.00	14.0	0.500	1.84	3.70	1.01

NR – Not recorded N/A – Not available

Table 7-10 Point Source Copper Concentrations

Total Cu (mg/L)								
Service Area/ Water User	Period of Record	Source	Limit	Count	Min	Mean	Max	Standard Deviation
North Wales	1/03-5/05	PWD	N/A	28.0	0.0162	0.0266	0.0526	0.00789
Upper Gwynedd	6/02-8/03	PWD	N/A	14.0	0.0210	0.0469	0.120	0.0254
Ambler	1/03-9/05	PWD	N/A	N/A	N/A	N/A	N/A	N/A
Abington	1/03-8/05	PWD	N/A	N/A	N/A	N/A	N/A	N/A
Upper Dublin	1/03-5/05	PWD	N/A	25.0	0.024	0.0483	0.0693	0.0138

N/A – Not available

Table 7-11 Point Source Lead Concentrations

Total Pb (mg/L)								
Service Area/ Water User	Period of Record	Source	Limit	Count	Min	Mean	Max	Standard Deviation
North Wales	1/03-5/05	PWD	N/A	28.0	<.00500	0.00393	0.00500	0.00289
Upper Gwynedd	6/02-8/03	PWD	N/A	63.0	<.00300	0.00184	0.00500	0.00194
Ambler	1/03-9/05	PWD	N/A	N/A	N/A	N/A	N/A	N/A
Abington	1/03-8/05	PWD	N/A	N/A	N/A	N/A	N/A	N/A
Upper Dublin	1/03-5/05	PWD	N/A	N/A	N/A	N/A	N/A	N/A

N/A – Not available

Table 7-12 Point Source Aluminum Concentrations

Total Al (mg/L)								
Service Area/ Water User	Period of Record	Source	Limit	Count	Min	Mean	Max	Standard Deviation
North Wales	1/03-5/05	PWD	N/A	28.0	<.100	0.153	0.379	0.115
Upper Gwynedd	6/02-8/03	PWD	N/A	N/A	N/A	N/A	N/A	N/A
Ambler	1/03-9/05	PWD	N/A	N/A	N/A	N/A	N/A	N/A
Abington	1/03-8/05	PWD	N/A	N/A	N/A	N/A	N/A	N/A
Upper Dublin	1/03-5/05	PWD	N/A	N/A	N/A	N/A	N/A	N/A

N/A – Not available

7.3 STORMWATER RUNOFF

Pollutant loads due to stormwater runoff were estimated using an event mean concentration (EMC) approach. 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.

Data used to determine EMCs is derived from the National Stormwater Quality Database (NSQD) (Pitt et al., 2004). This database includes data collected nationwide as part of the NPDES Phase I stormwater permit program. Sites and events were excluded when they may have represented true untreated EMCs. Sites with stormwater quality controls were eliminated, including grass swales, detention structures, wet ponds, and dry ponds. First flush samples, where only part of an event was sampled, were also eliminated.

For the parameters TSS, BOD_5, COD, TP (total phosphorus), TN (total nitrogen), total Cu, total Zn, total Fe and fecal coliform, a simple substitution method was used for values that fell below the detection limit. Half the detection limit was substituted for these values. For sites and events where total nitrogen was not reported, other reported nitrogen species were summed to determine TN. The possible combinations, in order of preference, are: (nitrite + nitrate) + TKN, (nitrite + nitrate) + ammonia + organic nitrogen, nitrite + nitrate + TKN, and nitrite + nitrate + ammonia + organic. All species were expressed as nitrogen equivalents.

In the NSQD, more than 15% of EMC estimates were below the detection limit for two parameters (total lead and total cadmium) (Table 7-12). EPA (2006) recommends using a simple substitution method when less than 15% of samples are below detection. However, when more than 15% of samples are reported as below the detection limit, a more detailed statistical analysis is recommended. This rule of thumb often is applied to individual water quality samples, and in this study it is assumed to apply to flow-weighted EMC estimates based on several samples.

Table 7-13 Station-Storms with Below-Detection Values in NSQD

Pollutant	Total No. of Observations	No. of Observations Below Detection Limit	% Below Detection Limit
TSS	3462	42	1.21
BOD_5	3096	109	3.52
COD	2750	44	1.60
TP	3269	99	3.03
Cu	2713	334	12.31
Zn	2991	87	2.91
Fe	48	0	0.00
Fecal Coliform	1611	57	3.54
TN	558	37	6.63
Pb	2852	562	19.71
Cd	2392	1346	56.27

For lead and cadmium, EMC summary statistics were adjusted for below-detection-limit samples according to the MR method recommended in EPA (2004), Appendix Q. The MR method is appropriate for data sets with multiple detection limits and a high proportion of below-detection samples. The method helps to eliminate bias in summary statistics by assigning a plotting position based on where each sample most probably lies within the distribution of above-detection data. A lognormal distribution is fit to above-detection samples based on this plotting position, and the results of a best-fit line are used to predict values of the below-detection values. These “predicted” values are then used to calculate summary statistics such as mean, median, and standard deviation.

In Figures 7-1 through 7-3, results are shown for regression of natural log of total lead versus standard normal statistic. The results suggest that the lognormal model may not be an ideal fit for the above-detection values. However, the MR method should still reduce bias compared to a simple substitution method. Similar results were found for total cadmium.

<u>Regression Results:</u>

ln Total Lead = 2.860 + 1.307 X
ln Total Cadmium = -1.755 + 1.932 X
where X = standard normal statistic corresponding to plotting position

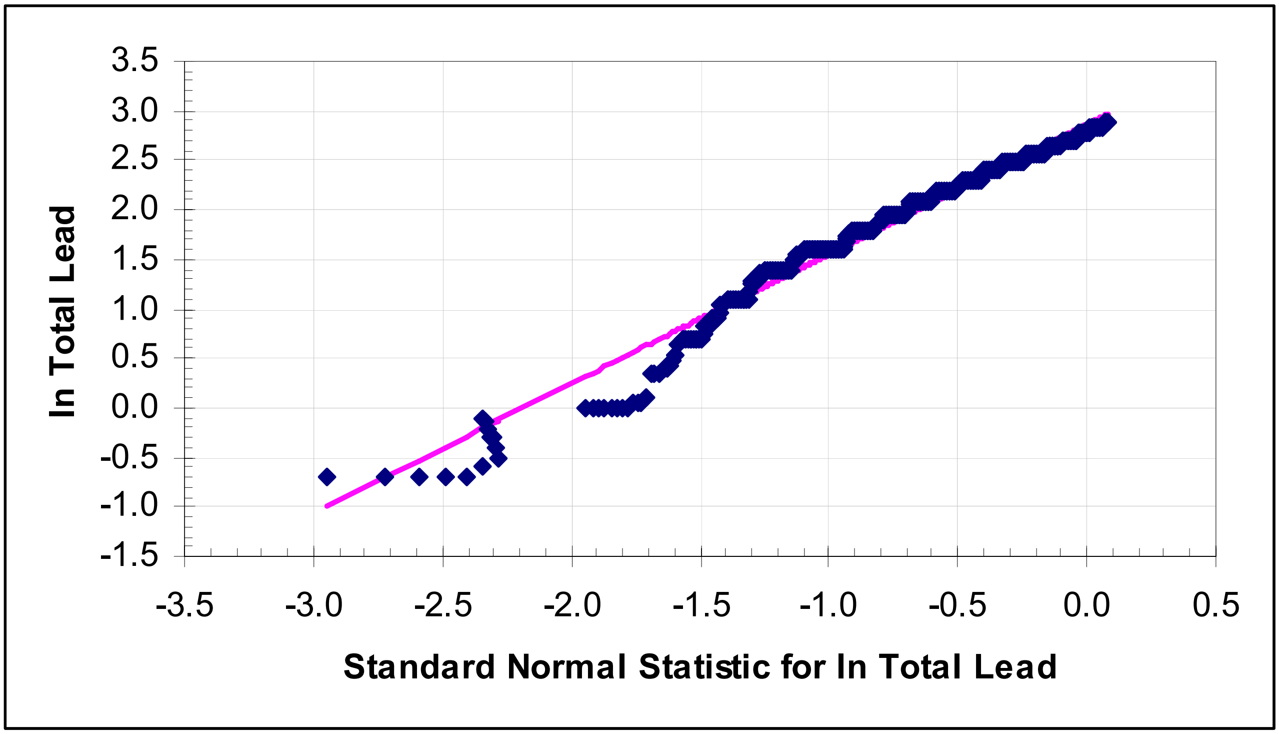


Figure 7-1 Linear Regression Results for Total Lead

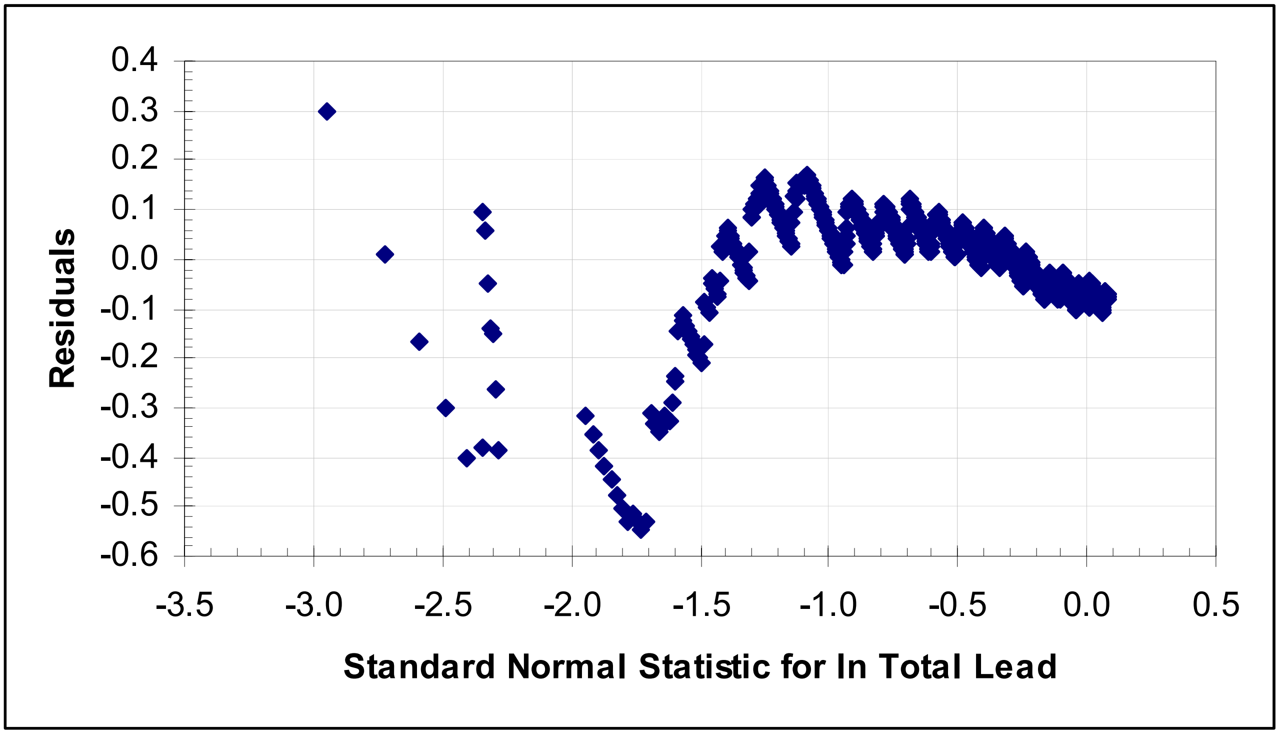


Figure 7-2 Linear Regression Residual Plot for Total Lead

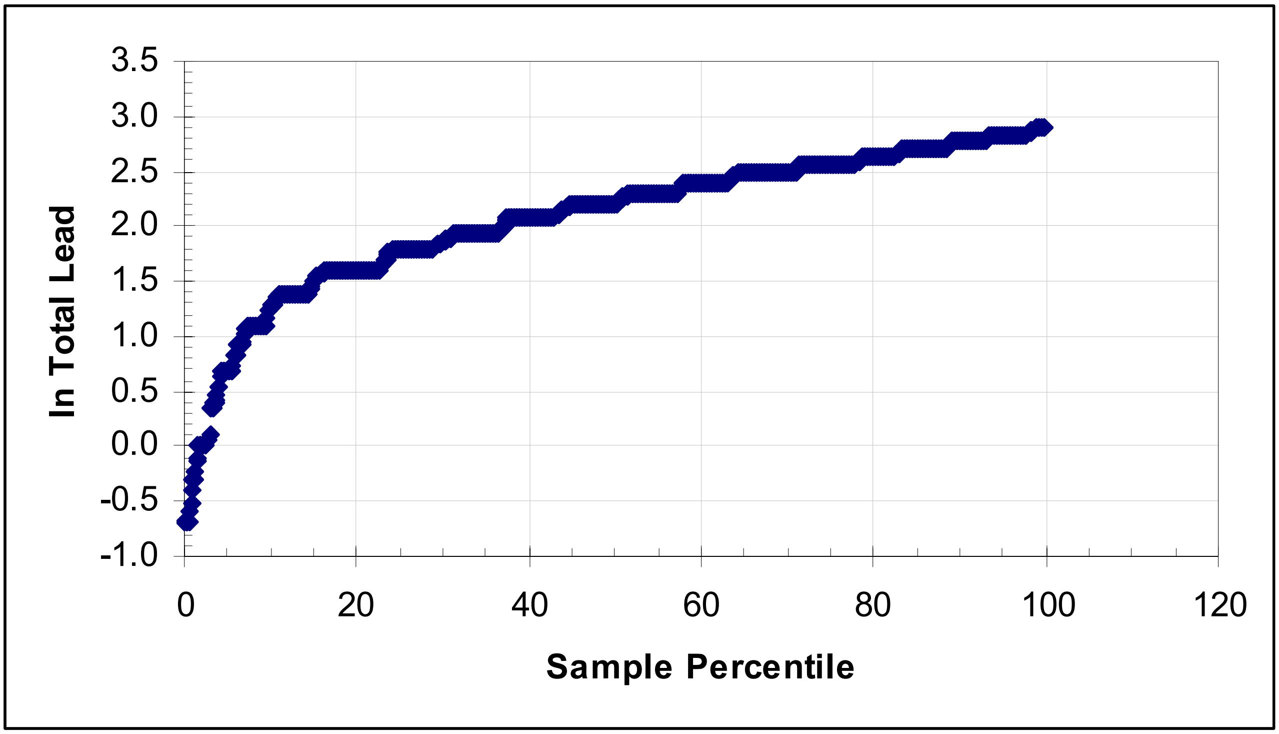


Figure 7-3 Normal Probability Plot for Total Lead

Land uses in the NSQD were grouped into three broader categories. Lands that were coded as residential, institutional, commercial, and industrial were combined into a single group (R/C/I). Urban open spaces were assigned to a group, and freeways were assigned to a group. Pooled EMCs representing all urban land uses were also calculated for comparison to earlier studies. Table 7-13 summarizes the EMCs chosen for the study. Because EMCs are lognormally distributed, median values were used for stormwater load estimates. EMCs were applied to land use data from the Delaware River Basin Commission as in Table 7-14.

Table 7-14 Event Mean Concentrations based on NSQD

Parameter	Units	Land Use	Mean	Median	CV	n
TSS	(mg/L)	R/C/I	125	61.0	1.63	2,176
TSS	(mg/L)	transportation	172	98.5	2.60	134
TSS	(mg/L)	urban open	186	85.0	1.91	48
TSS	(mg/L)	pooled	132	64.0	1.74	2,600
BOD$_5$	(mg/L)	R/C/I	20.2	9.25	7.93	1,909
BOD$_5$	(mg/L)	transportation	14.9	8.00	1.26	22
BOD$_5$	(mg/L)	urban open	6.55	4.75	1.24	40
BOD$_5$	(mg/L)	pooled	19.4	9.00	7.71	2,190
COD	(mg/L)	R/C/I	87.7	59.0	1.07	1,681
COD	(mg/L)	transportation	139	100	1.07	67
COD	(mg/L)	urban open	25.7	20.0	0.986	45
COD	(mg/L)	pooled	87.4	57.0	1.12	2,023
TP	(mg/L)	R/C/I	0.443	0.290	1.34	2,027
TP	(mg/L)	transportation	0.429	0.250	1.77	128
TP	(mg/L)	urban open	0.374	0.195	1.32	48
TP	(mg/L)	pooled	0.430	0.280	1.35	2,447
Total Cu	(μg/L)	R/C/I	31.7	15.7	2.40	1,764
Total Cu	(μg/L)	transportation	47.8	33.4	0.959	97
Total Cu	(μg/L)	urban open	11.2	8.00	1.15	51
Total Cu	(μg/L)	pooled	30.8	15.0	2.30	2,103
Total Zn	(μg/L)	R/C/I	268	125	3.41	1,838
Total Zn	(μg/L)	transportation	272	194	1.03	93
Total Zn	(μg/L)	urban open	89.3	45.0	1.66	49
Total Zn	(μg/L)	pooled	253	120	3.32	2,221
Total Fe	(μg/L)	R/C/I	3,293	1,575	1.80	14
Total Fe	(μg/L)	transportation	5,097	4,000	1.09	27
Total Fe	(μg/L)	urban open				0
Total Fe	(μg/L)	pooled	4,481	2,300	1.27	41
Fecal Coliform	(#COL /100 mL)	R/C/I	52,653	6,700	4.47	1,035
Fecal Coliform	(#COL /100 mL)	transportation	7,530	1,700	1.95	49
Fecal Coliform	(#COL /100 mL)	urban open	29,854	3,400	2.52	33
Fecal Coliform	(#COL /100 mL)	pooled	47,990	5,700	4.50	1,274
TN	(μg/L)	R/C/I	2.90	1.88	2.03	277
TN	(μg/L)	transportation				0
TN	(μg/L)	urban open	1.70	1.56	0.681	6
TN	(μg/L)	pooled	2.75	1.82	1.96	339
Total Pb	(μg/L)	R/C/I	45.3	20.0	1.74	1,429
Total Pb	(μg/L)	transportation	48.8	25.0	1.45	107
Total Pb	(μg/L)	urban open	37.7	8.00	2.24	31
Total Pb	(μg/L)	pooled	38.5	16.0	1.86	2,111

Legend:
R/C/I = residential/industrial/commercial
n = number of station-storms
pooled = includes station storms from all urban land uses

Table 7-15 DRBC Land Use Categories

DRBC Land Use	EMC Study Land Use
Agriculture	Urban Open
Cemetery	Urban Open
Commercial	R/C/I
Community Services	Urban Open
Golf Course	Urban Open
Manufacturing: Light Industrial	R/C/I
Mining	R/C/I
Recreation	Urban Open
Residential: Mobile Home	R/C/I
Residential: Multi-Family	R/C/I
Residential: Row Home	R/C/I
Residential: Single-Family Detached	R/C/I
Transportation	Freeway
Utility	Urban Open
Vacant	Urban Open
Water	not considered
Wooded	Urban Open

Load Calculations

A weighted EMC was determined for each subshed based on the proportion of land uses in that subshed and assumptions about impervious cover.

$$\text{subshed EMC} = \frac{\sum_{i=1}^{n}\left[\text{EMC}_i \times (\text{percent impervious})_i \times (\text{area})_i\right]}{\sum_{i=1}^{n}\left[(\text{percent impervious})_i \times (\text{area})_i\right]}$$

where i = an individual land use (e.g., 1=residential, 2=commercial, etc.)
n = number of land uses in an individual subshed

For the purposes of this weighted-EMC estimation, residential/commercial/industrial areas were assumed to be 75% impervious and freeways to be 90% impervious; based on measurements in unsewered areas in Philadelphia, urban open space was assumed to be 10.15% impervious.

An average annual runoff volume was estimated for each modeled subshed using a calibrated computer model as described in Section 3: Characterization of Hydrology section. Additional details on computer simulation methods may be found in the appendix.

A pollutant load is calculated for each water quality parameter, hydrologic subshed as defined in the computer model, and land use.

load = EMC x runoff

where:
load = pollutant load for a given subshed and parameter [mass/time or organism count/time]
EMC = weighted event mean concentration for a given parameter and subshed (mass/volume or organism count/volume)
runoff = average annual surface runoff from a subshed, determined from the calibrated hydrologic model [volume/time]

The calculations are identical for areas with storm sewers and areas draining directly to surface water by overland flow. However, because these areas are modeled separately, pollutant loads contributed by each type of drainage area can be distinguished.

Table 7-16 Philadelphia Runoff Load Summary

Parameter	MS4 Load		Direct Runoff Load		Total Stormwater Load	
	(lb/yr)	(lb/ac/yr)	(lb/yr)	(lb/ac/yr)	(lb/yr)	(lb/ac/yr)
BOD5	76,293	18.8	24,999	9.43	101,292	15.1
TSS	639,209	157	260,909	98.4	900,118	134
COD	486,201	120	148,302	56.0	634,503	94.6
TN	16,065	3.96	5.91	0.002	16,071	2.39
TP	2,490	0.613	860	0.325	3,350	0.499
Cu	138	0.034	44.9	0.017	183	0.027
Pb	163	0.040	51.2	0.019	215	0.032
Zn	1,028	0.253	316	0.119	1,344	0.200
Fe	12,420	3.06	3,228	1.22	15,648	2.33
Fecal Coliform	2.42E+14	5.96E+10	7.95E+13	3.00E+10	3.21E+14	4.79E+10

Table 7-17 Montgomery County Runoff Load Estimates

Parameter	Total Stormwater Load	
	(lb/yr)	(lb/ac/yr)
BOD5	565,374	16.7
TSS	3,504,595	103
COD	3,370,713	99.4
TN	129,824	3.83
TP	19,005	0.560
Cu	981	0.029
Pb	1,167	0.034
Zn	7,196	0.212
Fe	76,445	2.25
Fecal Coliform	1.83E+15	5.40E+10

Additional discussion of sediment loads, including a comparison of TSS load estimates above to estimates reported in Wissahickon Creek TMDL, is included in the appendix.

7.4 ILLICIT DISCHARGES

Illicit discharges of wastewater into water bodies may include dry weather sanitary sewer discharges, wet weather sanitary sewer overflows, and improper connection of sanitary sewer laterals from homes to storm sewers. Discharges from sanitary sewers were not quantified for this study.

Loads from improper connections were estimated based on information submitted by PWD to PADEP covering illicit connection detection and abatement through March, 2005 (PWD, 2005). PWD is required to submit a quarterly report under its NPDES Phase I stormwater permit. The results (Table 7-18) suggest that the improper connection rate in Wissahickon Creek Watershed is similar to the City as a whole and is approximately 3%.

Table 7-18 PWD Illicit Connection Detection through March 2005

Watershed	Outfalls	Improper Connections	Connections Tested	Improper Connection Rate
Tacony-Frankford	T-088-01	130	2828	4.6%
Manayunk Canal	S-051-06, S-058-01, S-059-01 through S-059-11	59	2444	2.4%
Wissahickon (Monoshone)	W-060-04, W-060-08, W-060-09, W-060-10, W-060-11, W-068-04, W-068-05	90	2735	3.3%
Wissahickon	W-060-01	16	610	2.6%
City-Wide		662	24444	2.7%

For planning purposes, loads from improper connections were estimated using the following assumptions:

- Households in the Philadelphia portion of Wissahickon Creek Watershed (2000 U.S. Census): 22,366
- Households with improper lateral connections: 3% (671 homes total)
- Average of 2.5 people per household
- 50 gallons per person per day discharged to storm sewer
- Sanitary sewage pollutant concentrations as shown in Table 7-19

Table 7-19 Sanitary Sewage Pollutant Concentrations and Illicit Discharge Loads (Philadelphia)

Parameter	Sanitary Concentration	Concentration Units	Estimated Load	Load Units
BOD51	134	mg/L	34,237	lb/yr
TSS1	116	mg/L	29,638	lb/yr
COD1	351	mg/L	89,680	lb/yr
TN1	22	mg/L	5,621	lb/yr
TP1	3.33	mg/L	851	lb/yr
Cu1	81.4	µg/L	20.8	lb/yr
Pb1	15.7	µg/L	4.01	lb/yr
Zn1	259	µg/L	66.2	lb/yr
Fe2	300	µg/L	76.6	lb/yr

1 - PWD dry weather combined sewer sampling
2 - Metcalf and Eddy, 1979

Table 7-20 Estimated Illicit Discharge Loads (Montgomery County)

Parameter	Estimated Load for Assumed Improper Connection Rate 1.0%	2.0%	2.7%	Load Units
BOD5	20,598	41,196	55,615	lb/yr
TSS	17,831	35,662	48,144	lb/yr
COD	53,955	107,909	145,678	lb/yr
TN	3,382	6,764	9,131	lb/yr
TP	512	1,024	1,382	lb/yr
Cu	12.5	25.0	33.8	lb/yr
Pb	2.41	4.83	6.52	lb/yr
Zn	39.8	79.6	107	lb/yr
Fe	46.1	92.2	125	lb/yr

Monoshone Creek Project Implementation and Water Quality Assessment 1999-2006

This study provides an alternative estimate of illicit discharge fecal coliform loads for stormwater outfalls along Monoshone Creek. Outfall discharges and fecal coliform concentrations were measured in dry weather by PWD's Industrial Waste Unit before, during, and after abatement of 82 improper connections in sewershed W-068-04/05. Observed dry weather flow was assumed to consist of an unknown combination of sanitary sewage and groundwater inflow. Tables 7-21 and 7-22 reproduce selected information from this study.

Table 7-21 Fecal Coliform Concentrations and Loadings in W-068-04/05 Before and After Defective Lateral Abatements and Sewer Relining (Table 3 in original study)

	Avg Fecal Concentrations (#/100mL)	Avg Fecal Loadings (#/day)
Before 1999 (prior to abatements)	137,025	7.74E+10
1999-2003 (following abatements)	18,481	9.34E+09
2004-2006 (following sewer relining)	9,256	5.21E+09

Table 7-22 Dry Weather Fecal Coliform Loading Contributions from Monoshone Outfalls Since 2003 (Table 7 in original study)

Outfall	Avg Flow (gal/yr)	Avg fecal conc (#/100mL)	Avg Fecal Loading (#/yr)	# samples
W-060-04	NA	NA	NA	0
W-060-08	NA	NA	NA	0
W-060-09	534,426	7,657	1.55E+11	7
W-060-10	2,940,060	6,794	7.56E+11	12
W-060-11	2,052,168	2,665	2.07E+11	11
W-068-04/05	5,543,669	10,989	2.31E+12	73

The load estimate for sewershed W-068-04/05 before abatement was scaled to provide an estimate of the impact of improper connections watershed-wide.

- In sewershed W-068-04/05, 82 improper connections contribute to a load of 7.74x1010/day, 2.82x1013/yr, or 3.44x1011/yr per improper connection.
- At a 3% improper connection rate, there are approximately 672 households in the Philadelphia portion of the watershed and 1,219 in the Montgomery County portion with improper connections.

- Watershed-wide load estimates can be derived by multiplying the load per improper connection by the number of improper connections. Table 7-23 compares these loads to loads based on the planning assumptions in the previous section.

Table 7-23 Comparison of Improper Connection Loads

County	Philadelphia	Montgomery
Households	22,411	40,625
Estimated improper connections (3%)	672	1,219
Load based on planning assumptions (/yr)	1.82E+15	2.96E+15
Load based on Monoshone data (/yr)	2.31E+14	4.19E+14

As a check on these per-household loads, expected instream concentrations were calculated by scaling unit-area flows at W-068-04/05 at the watershed scale. Observed flow from the outfall was multiplied by the ratio of watershed drainage area to outfall drainage area. Dilution calculations were then performed using flows and concentrations based on the two analysis methods and observed dry weather streamflow. Simplifying assumptions included groundwater, treated wastewater effluent, and quarry effluent fecal coliform concentrations of zero; and no natural attenuation of bacteria in the stream (Table 7-24).

Table 7-24 Load Check Using Predicted Instream Concentrations

Flow at Wissahickon mouth (cfs)	58.0
W-068-04/05 observed flow (cfs)	0.0235
Scaled W-068-04/05 flow (cfs)	1.34
Predicted sanitary flow (cfs)	0.366
W-068-04/05 concentration (/100 mL)	1.37E+05
Sanitary concentration (/100 mL)	1.57E+06
Instream conc. based on planning assumptions (/100 mL)	9.84E+03
Instream conc. based on Monoshone unit-area analysis (/100 mL)	3.10E+03
Observed instream concentrations (/100 mL)	28 – 429

A number of conclusions can be drawn from these analyses:

- Load estimates due to improper connections are subject to high uncertainty.
- Loads estimated using the number of households with improper connections and wastewater planning assumptions are approximately an order of magnitude greater than load estimates based on observations at the W-068-04/05 outfall. A possible explanation is that, although a home is designated as having an improper connection, all fixtures in the home are not necessarily improperly connected, and the improperly connected fixtures are not necessarily all sources of sanitary sewage.
- Instream concentrations estimated using wastewater planning assumptions and dilution calculations are approximately three times greater than instream concentrations estimated using unit-area Monoshone loads.
- Instream concentrations estimated using both methods are approximately an order of magnitude greater than observed dry weather concentrations. This result makes sense because bacteria are attenuated instream through die-off and settling of solids.

- No significant bacteria problem has been observed in the stream in dry weather. For this reason, the lower estimates derived from the Monoshone data see more reasonable than the higher estimates derived from the wastewater planning assumptions.

7.5 ON-LOT DISPOSAL (SEPTIC TANKS)

Unsewered areas of Philadelphia are displayed in Figure 7-4. The total number of households in unsewered areas within Philadelphia was determined from 2000 U.S. Census data to be 345. The following assumptions were used to estimate pollutant loads in Table 7-25.

- Average of 2.5 people per household
- 50 gallons per person per day discharged to groundwater
- Total nitrogen concentration discharged to soil = 40 mg/L (Canter and Knox, 1985)
- Total phosphorus concentration discharged to soil = 15 mg/L (Canter and Knox, 1985)
- Failure rate = 15% (fraction of systems where load reaches groundwater, which ultimately discharges to surface water as natural baseflow)

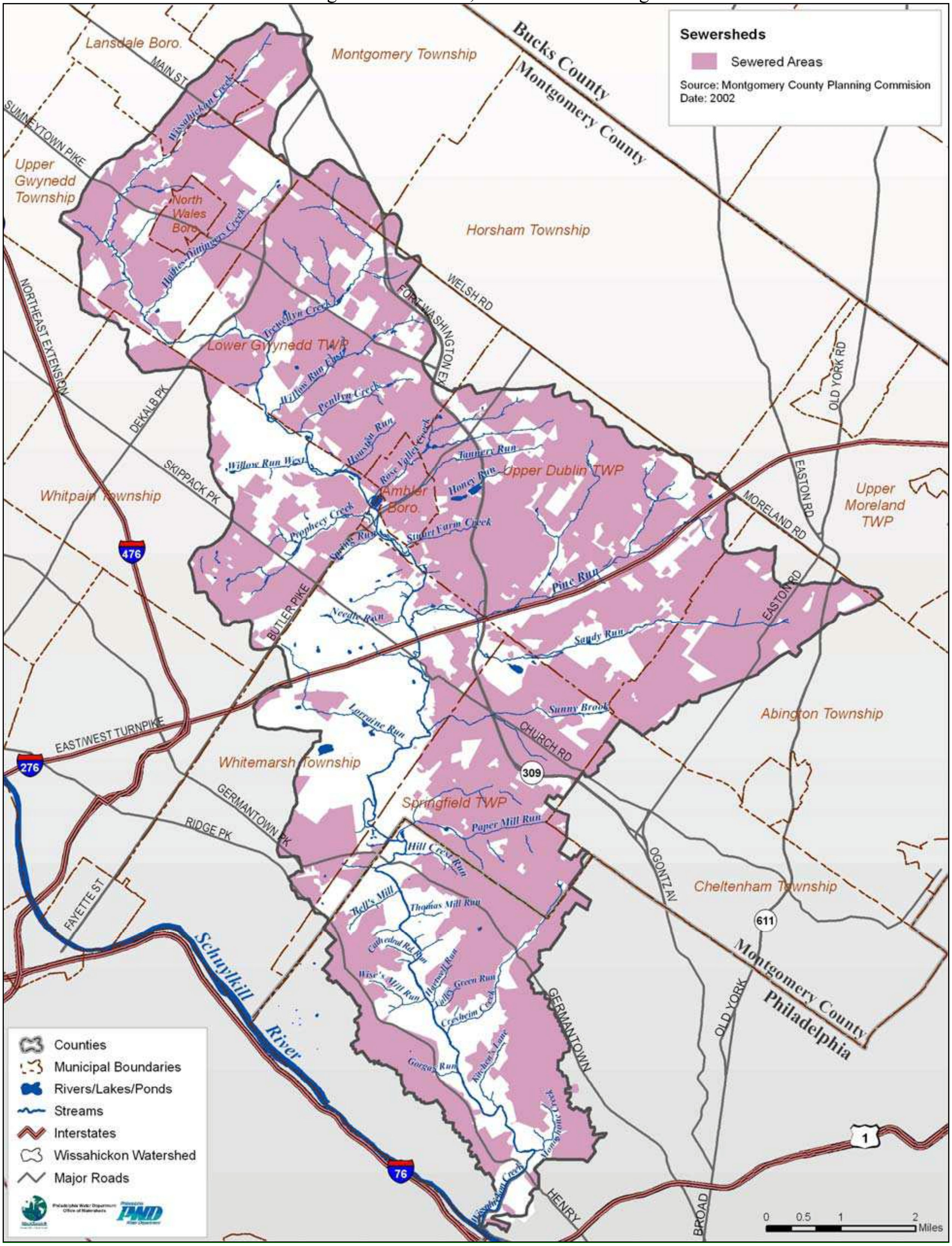


Figure 7-4 Unsewered Areas within the Wissahickon Creek Watershed

Table 7-25 Septic Tank Pollutant Loads

Pollutant	Philadelphia Load
Total Nitrogen (lb/yr)	788
Total Phosphorus (lb/yr)	296

Septic tank pollutant loads outside the City of Philadelphia were not assessed.

7.6 STREAM CHANNEL EROSION

An ongoing, detailed study of sediment loads due to stream channel erosion in the City of Philadelphia is being conducted. This section presents some preliminary estimates for planning purposes.

Sediment loads due to streambank erosion outside the City of Philadelphia were not assessed. For planning purposes, the percentage of streambank erosion load relative to total load was assumed to be equal inside and outside Philadelphia. More detailed study of streambank erosion loads outside Philadelphia is recommended.

Table 7-26 Planning-Level Estimates of TSS Loads Due to Streambank Erosion

System	TSS Load (lb/yr)	TSS Load (lb/ac/yr)	Calculation Method
Philadelphia Tributaries Only	3,142,358	633	BEHI/NBS Analysis (see appendix for details)
Philadelphia Tributaries and Main Stem	3,685,717	549	(total load from TSS-flow regression) - (estimated runoff load)
Philadelphia Streambank Load / Total Load	80.4%	N/A	(streambank load) / (total load)
Montgomery County	14,350,278	423	assumes same percentage relative to total load

7.7 PROBLEM SUMMARY

Pollutant loads, and the proportional contribution of various sources, are summarized in Table 7-27 for Philadelphia, Montgomery County, and the watershed as a whole. The pollutant loading analysis leads to a number of conclusions as listed below. It is important to note that this study treats load estimates deterministically. This approach is a useful simplification for planning purposes. However, all estimates above can be treated as random variables within a range of uncertainty. Sensitivity analysis and probability-based methods may be appropriate before important management decisions are made based on these numbers.

- Stormwater runoff and groundwater are dominant sources of model estimated copper, lead, and zinc loads. Stormwater and treated wastewater effluent are the dominant sources of BOD_5, nitrogen and phosphorus loads. However, it is important to note that concentrations of these constituents will be diluted by higher stormwater flows, while acute effects will be greatest during point source discharges in dry weather. This distinction is a crucial ideological issue in ecological, toxicological, and water resources management.
- Improper lateral connections appear to be a significant source of several pollutants. The results suggest that they represent approximately 10-25% of modeled BOD5, total nitrogen, and total phosphorus loads and approximately 40% of bacteria loads in the City of Philadelphia. However, these estimates are subject to a high degree of uncertainty.

- Treated wastewater effluent is not a significant source of modeled TSS, lead, or fecal coliform loads.
- Groundwater appears to be the dominant source of modeled total copper load. Stormwater is also a significant source. Dry weather concentrations, despite being influenced by municipal discharges, are smaller than assumed groundwater concentrations. Median dry weather concentrations are similar to median stormwater concentrations from the NSQD database.
- Streambank erosion is the dominant source of modeled TSS loads.
- Septic systems represent approximately 5% of model estimated phosphorus loads to the system. They were assessed only within the City of Philadelphia.
- Stormwater runoff appears to be the dominant source of modeled iron load. Iron contributed by groundwater is also significant.

Table 7-27 Pollutant Load Summary

		Loads (lb/yr, /yr for fecal coliform)			Loads (% of total)	
Parameter	**Source**	**Philadelphia**	**Montgomery County**	**Watershed**	**Philadelphia**	**Montgomery County**
BOD_5	Groundwater	~0	~0	~0	~0	~0
BOD_5	Wastewater Effluent	0	188,864	188,864	0%	23%
BOD_5	MS4 Runoff	76,293	NA	NA	56%	NA
BOD_5	Direct Runoff	24,999	NA	NA	18%	NA
BOD_5	Stormwater Runoff	101,292	565,374	666,665	75%	70%
BOD_5	Illicit Discharges	34,237	55,615	89,852	25%	7%
BOD_5	On-Lot Disposal	~0	~0	~0	~0	~0
BOD_5	Stream Channel Erosion	~0	~0	~0	~0	~0
TSS	Groundwater	~0	~0	~0	~0	~0
TSS	Wastewater Effluent	0	420,258	420,258	0%	2%
TSS	MS4 Runoff	639,209	NA	NA	14%	NA
TSS	Direct Runoff	260,909	NA	NA	6%	NA
TSS	Stormwater Runoff	900,118	3,504,595	4,404,713	20%	19%
TSS	Illicit Discharges	29,638	48,144	77,782	1%	0.3%
TSS	On-Lot Disposal	~0	~0	~0	~0	~0
TSS	Stream Channel Erosion	3,685,717	14,350,278	18,035,994	80%	78%
TN	Groundwater	51,662	122,864	174,526	70%	41%
TN	Wastewater Effluent	0	34,488	34,488	0%	12%
TN	MS4 Runoff	16,065	NA	NA	22%	NA
TN	Direct Runoff	6	NA	NA	0.01%	NA
TN	Stormwater Runoff	16,071	129,824	145,895	22%	44%
TN	Illicit Discharges	5,621	9,131	14,752	8%	3%

Parameter	Source	Loads (lb/yr, /yr for fecal coliform)			Loads (% of total)	
		Philadelphia	Montgomery County	Watershed	Philadelphia	Montgomery County
TN	On-Lot Disposal	788	NA	NA	1%	NA
TN	Stream Channel Erosion	NA	NA	NA	NA	NA
TP	Groundwater	758	1,804	2,562	14%	1%
TP	Wastewater Effluent	0	119,028	119,028	0%	84%
TP	MS4 Runoff	2,490	NA	NA	47%	NA
TP	Direct Runoff	860	NA	NA	16%	NA
TP	Stormwater Runoff	3,350	19,005	22,355	64%	13%
TP	Illicit Discharges	851	1,382	2,233	16%	1%
TP	On-Lot Disposal	296	NA	NA	6%	NA
TP	Stream Channel Erosion	NA	NA	NA	NA	NA
Cu	Groundwater	588	1,398	1,985	74%	46%
Cu	Wastewater Effluent	0	649	649	0%	21%
Cu	MS4 Runoff	138	NA	NA	17%	NA
Cu	Direct Runoff	45	NA	NA	6%	NA
Cu	Stormwater Runoff	183	981	1,165	23%	32%
Cu	Illicit Discharges	20.8	33.8	54.6	3%	1%
Cu	On-Lot Disposal	~0	~0	~0	~0	~0
Cu	Stream Channel Erosion	~0	~0	~0	~0	~0
Pb	Groundwater	95	225	320	30%	16%
Pb	Wastewater Effluent	0	24.8	24.8	0%	2%
Pb	MS4 Runoff	163	NA	NA	52%	NA
Pb	Direct Runoff	51	NA	NA	16%	NA
Pb	Stormwater Runoff	215	1,167	1,382	68%	82%
Pb	Illicit Discharges	4.01	6.52	10.5	1%	0%
Pb	On-Lot Disposal	~0	~0	~0	~0	~0
Pb	Stream Channel Erosion	~0	~0	~0	~0	~0
Zn	Groundwater	701	1,668	2,370	33%	19%
Zn	Wastewater Effluent	0	NA	NA	NA	NA
Zn	MS4 Runoff	1,028	NA	NA	49%	NA
Zn	Direct Runoff	316	NA	NA	15%	NA

		Loads (lb/yr, /yr for fecal coliform)			Loads (% of total)	
Parameter	Source	Philadelphia	Montgomery County	Watershed	Philadelphia	Montgomery County
Zn	Stormwater Runoff	1,344	7,196	8,541	64%	80%
Zn	Illicit Discharges	66.2	107	174	3%	1%
Zn	On-Lot Disposal	~0	~0	~0	~0	~0
Zn	Stream Channel Erosion	~0	~0	~0	~0	~0
Fe	Groundwater	4,114	9,784	13,898	21%	11%
Fe	Wastewater Effluent	0	NA	NA	NA	NA
Fe	MS4 Runoff	12,420	NA	NA	63%	NA
Fe	Direct Runoff	3,228	NA	NA	16%	NA
Fe	Stormwater Runoff	15,648	76,445	92,093	79%	89%
Fe	Illicit Discharges	76.6	125	201	0.4%	0.1%
Fe	On-Lot Disposal	~0	~0	~0	~0	~0
Fe	Stream Channel Erosion	NA	NA	NA	NA	NA
Fecal Coliform	Groundwater	~0	~0	~0	~0	~0
Fecal Coliform	Wastewater Effluent	0	5.22E+05	5.22E+05	0%	~0
Fecal Coliform	MS4 Runoff	2.42E+14	NA	NA	38%	NA
Fecal Coliform	Direct Runoff	7.95E+13	NA	NA	9%	NA
Fecal Coliform	Stormwater Runoff	3.21E+14	1.83E+15	2.15E+15	51%	81%
Fecal Coliform	Illicit Discharges	2.31E+14	4.19E+14	6.50E+14	42%	19%
Fecal Coliform	On-Lot Disposal	~0	~0	~0	~0	~0
Fecal Coliform	Stream Channel Erosion	~0	~0	~0	~0	~0

Notes:

Loads were determined by parameter, geographic region, and percent of total load.

Stormwater runoff load is the sum of MS4 runoff and direct runoff. These components were estimated separately only in the City of Philadelphia.

* Estimated illicit discharge loads for Montgomery County assume that the improper connection rate is equal to the one measured in Philadelphia.

** Estimated stream channel erosion for Montgomery County assumes that the percent of total TSS load attributed to stream channel erosion is the same as the percent measured in Philadelphia.

~0: This component is assumed to be negligible.

NA: This component was not assessed.

APPENDIX A: 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 2.2.1 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 A-1 Criteria Applied to Determine Sonde DO Data Reliability

CRITERIA (Accept data with 5 or more points.)	**CHARACTERISTICS OF 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 "WS_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 database:**"Wissahickon.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 **"WS_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 WS_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 **"WS_Sonde"** with the export query. Output is **"Export_WS_Sonde.csv"**.
- Rerun the program DOPlots.sas. Output will be several graphics files.
- Check the graphs for consistency.

APPENDIX B: INTERVALS OF SONDE PROBE FAILURE

Table B-1 Intervals of Sonde Probe Failure

Deployment	Start Date	End Date
4004	8/13/2004 0:46	8/18/2004 11:01
4005	8/30/2004 23:46	9/3/2004 9:46
4008	8/19/2004 20:31	8/21/2004 16:46
5029	5/14/2005 19:31	5/17/2005 11:31
5034	5/28/2005 15:31	5/31/2005 11:16
5047	6/23/2005 2:16	7/6/2005 12:02
5048	7/2/2005 20:00	7/5/2005 11:00
5049	7/16/2005 20:30	7/20/2005 10:45
5055	8/15/2005 22:00	8/18/2005 9:30
5061	8/20/2005 8:01	9/7/2005 9:31
5067	9/26/2005 12:01	9/27/2005 10:01
5068	9/7/2005 11:01	9/27/2005 22:31
5071	9/14/2005 10:31	9/19/2005 11:01
5073	10/11/2005 0:01	10/19/2005 9:46
5075	10/8/2005 13:01	10/8/2005 23:55
5079	10/29/2005 0:01	11/3/2005 0:01
5080	10/19/2005 9:46	11/3/2005 0:01
5081	10/23/2005 0:01	11/2/2005 0:01
5074	10/13/2005 6:46	10/19/2005 10:31

APPENDIX C: CONTINUOUS DISSOLVED OXYGEN

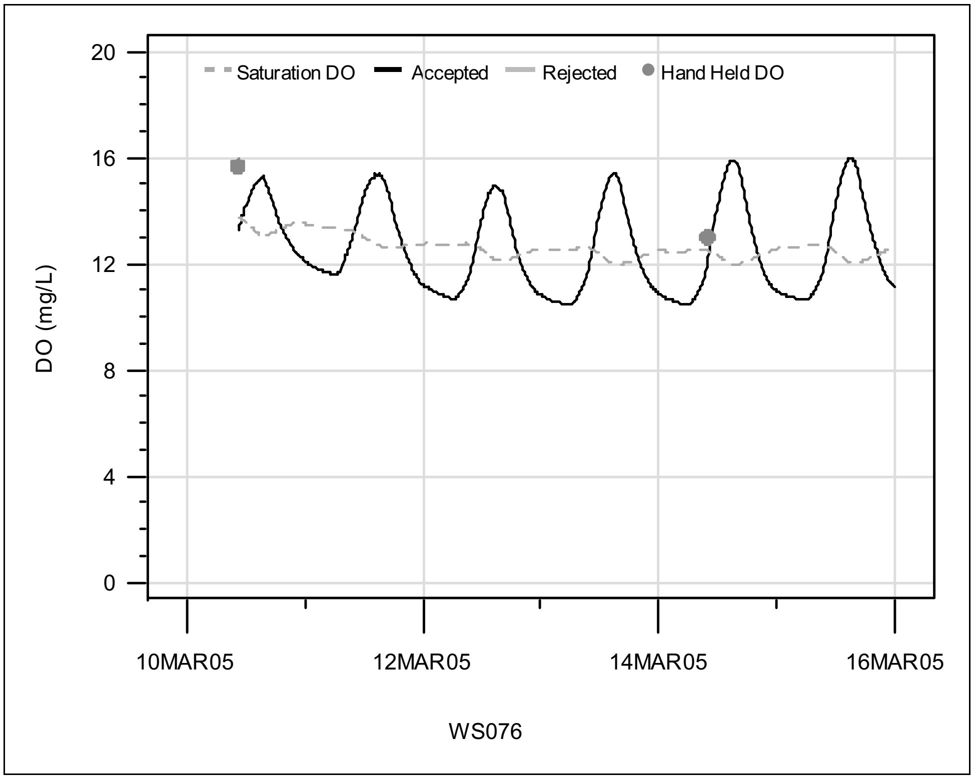


Figure C-1 Continuous Dissolved Oxygen (DO) with Calculated DO Saturation, 10MAR05 to 16MAR05, Site WS076

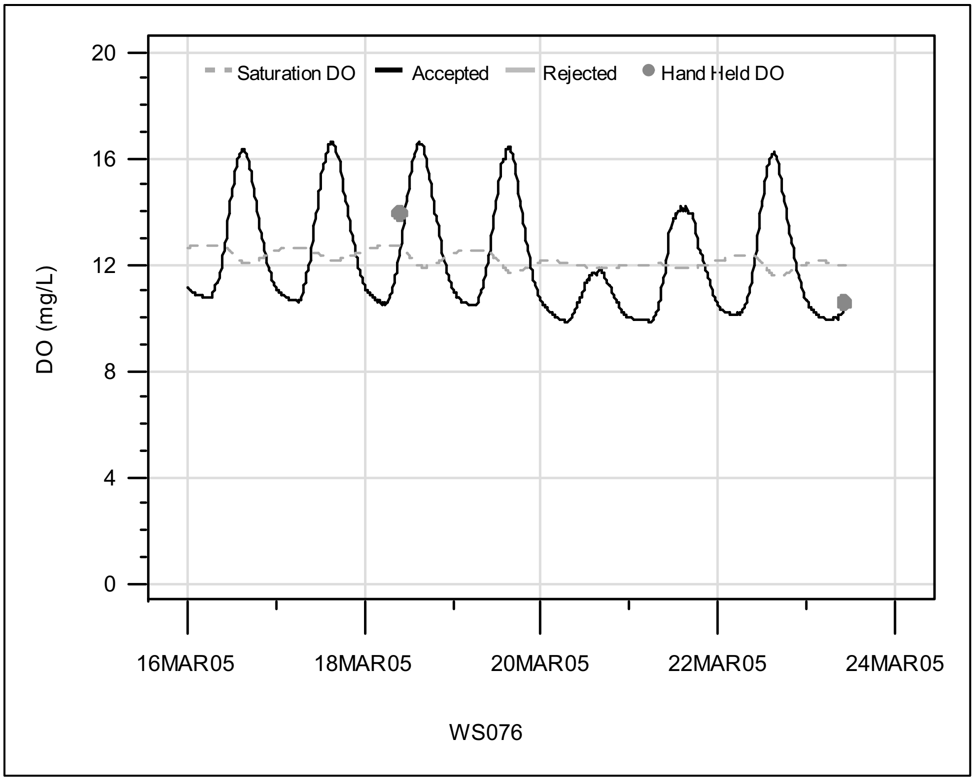


Figure C-2 Continuous Dissolved Oxygen (DO) with Calculated DO Saturation, 16MAR05 to 24MAR05, Site WS076

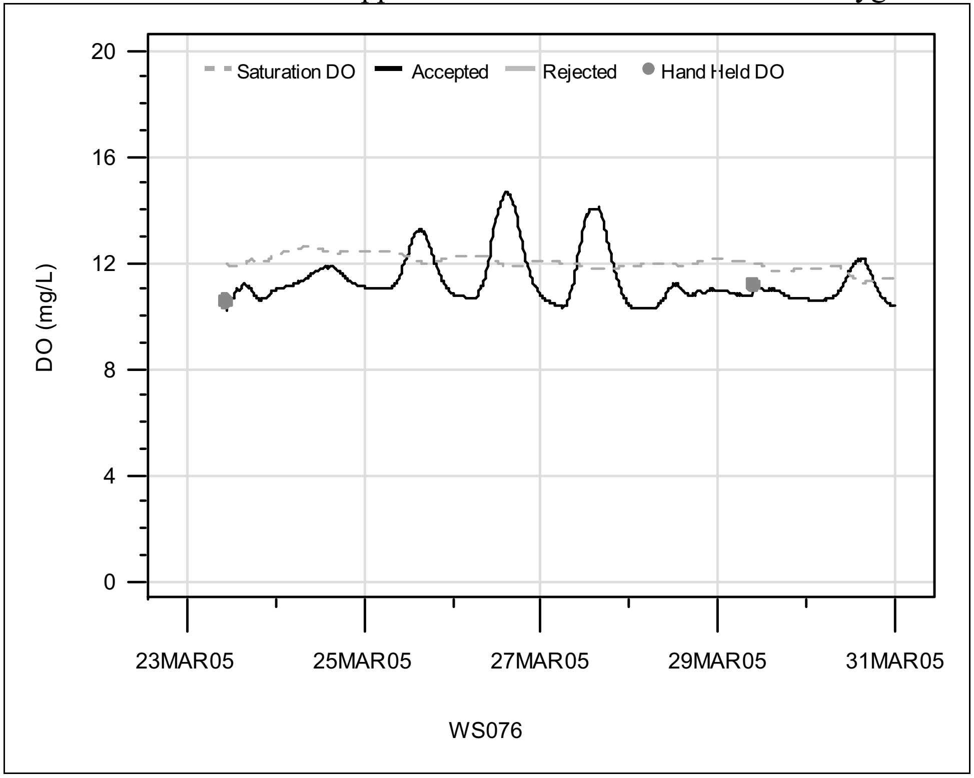


Figure C-3 Continuous Dissolved Oxygen (DO) with Calculated DO Saturation, 23MAR05 to 31MAR05, Site WS076

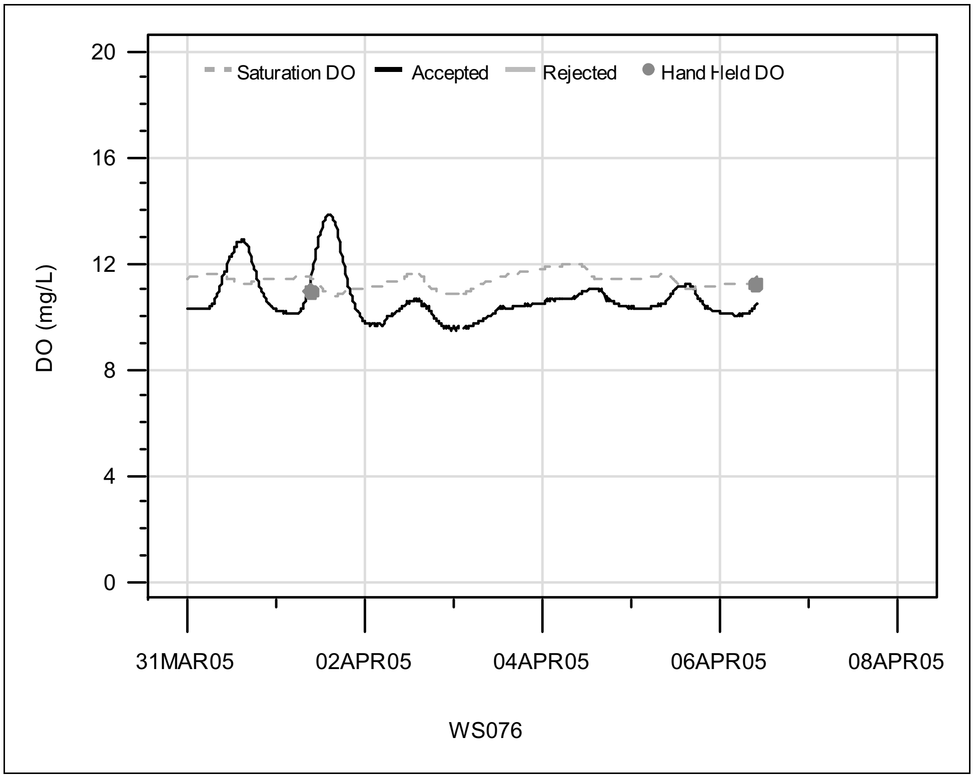


Figure C-4 Continuous Dissolved Oxygen (DO) with Calculated DO Saturation, 31MAR05 to 08APR05, Site WS076

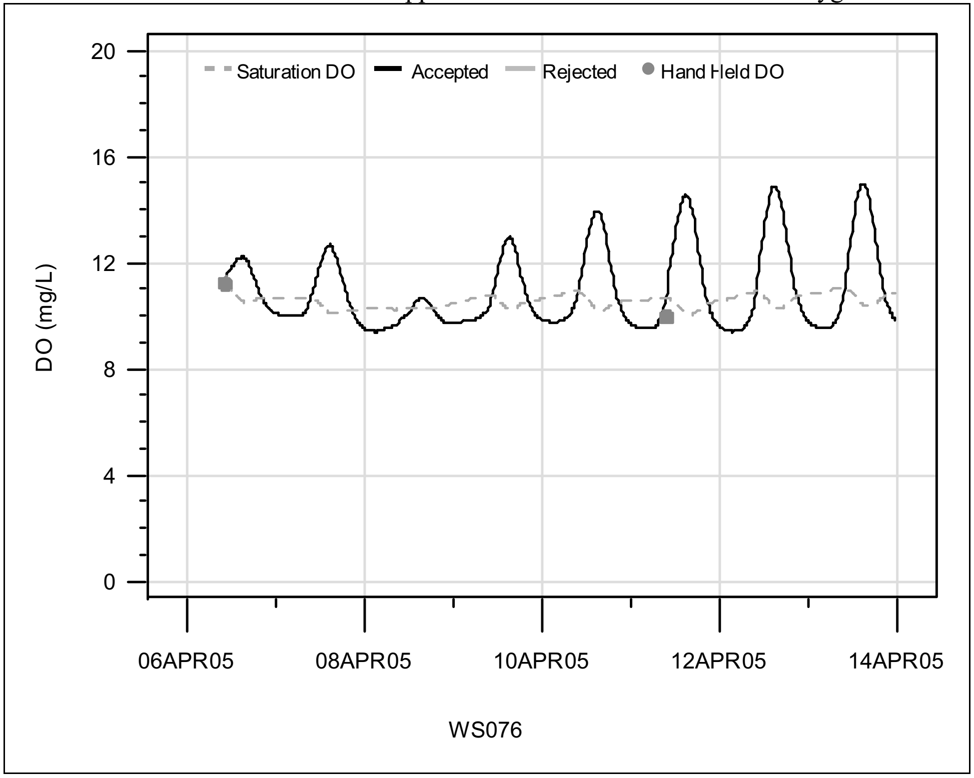


Figure C-5 Continuous Dissolved Oxygen (DO) with Calculated DO Saturation, 06APR05 to 14APR05, Site WS076

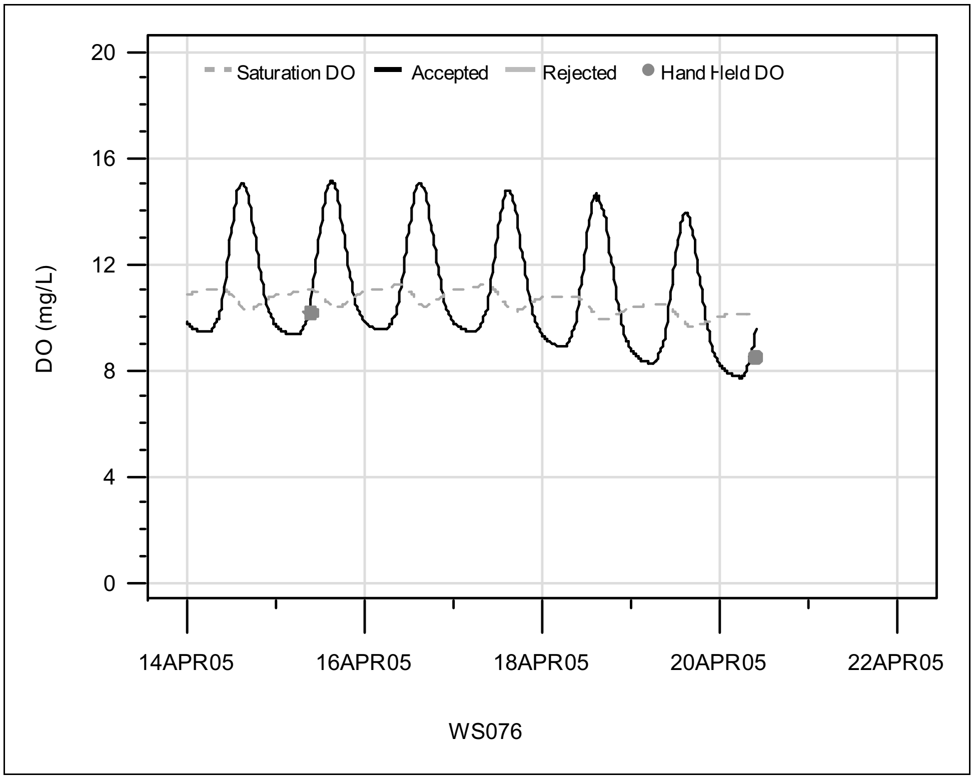


Figure C-6 Continuous Dissolved Oxygen (DO) with Calculated DO Saturation, 14APR05 to 22APR05, Site WS076

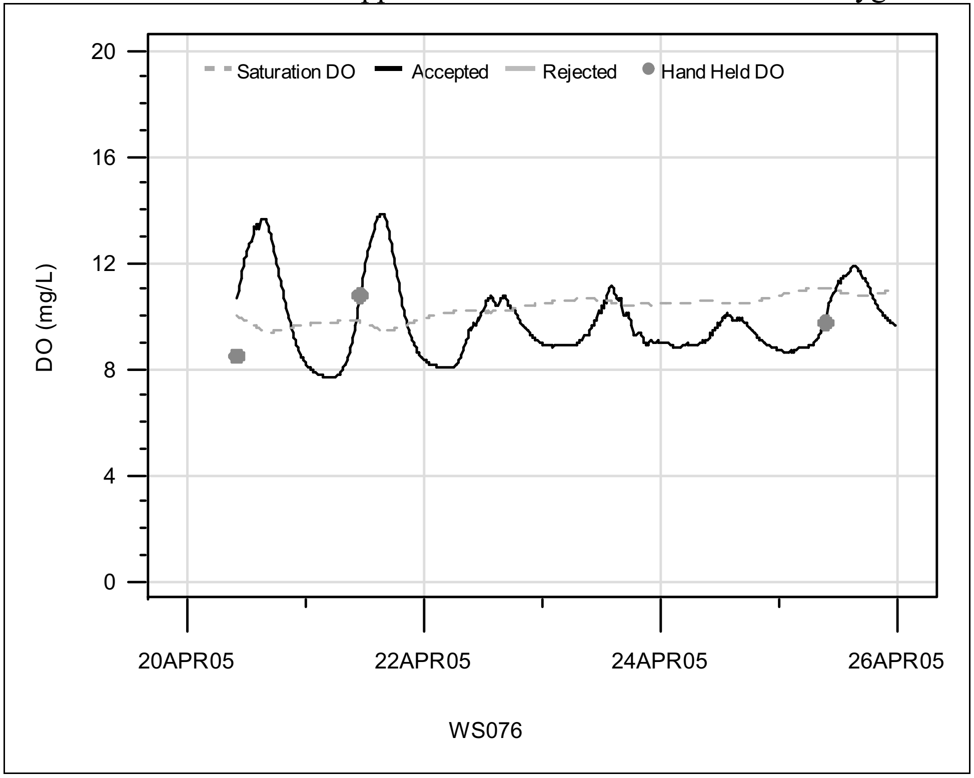


Figure C-7 Continuous Dissolved Oxygen (DO) with Calculated DO Saturation, 20APR05 to 26APR05, Site WS076

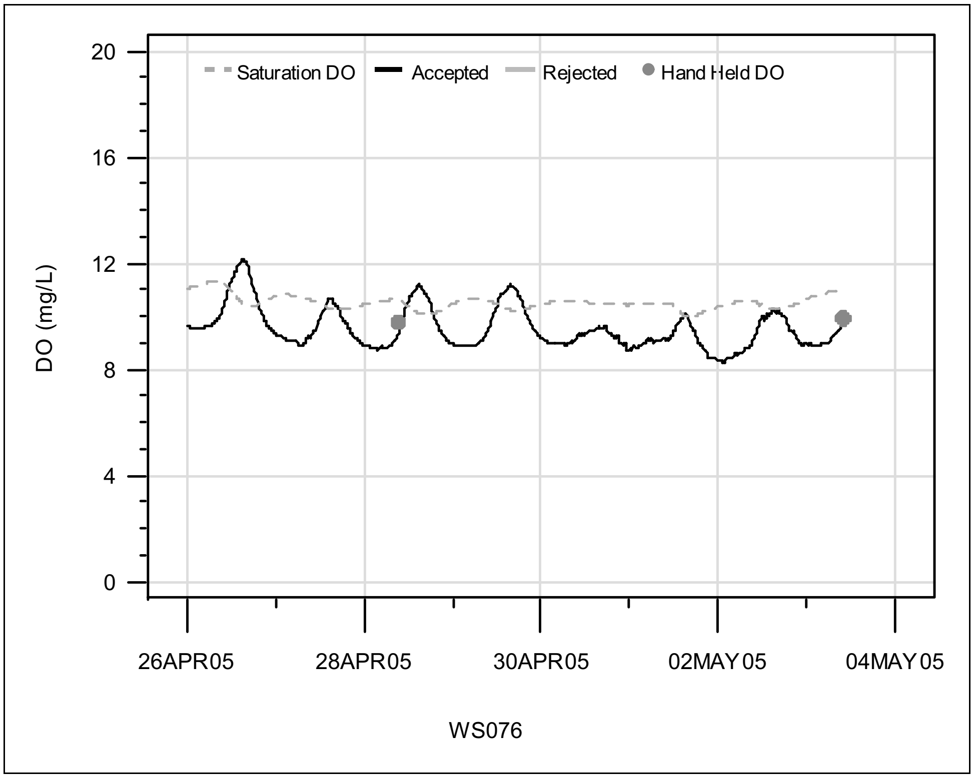


Figure C-8 Continuous Dissolved Oxygen (DO) with Calculated DO Saturation, 26APR05 to 04MAY05, Site WS076

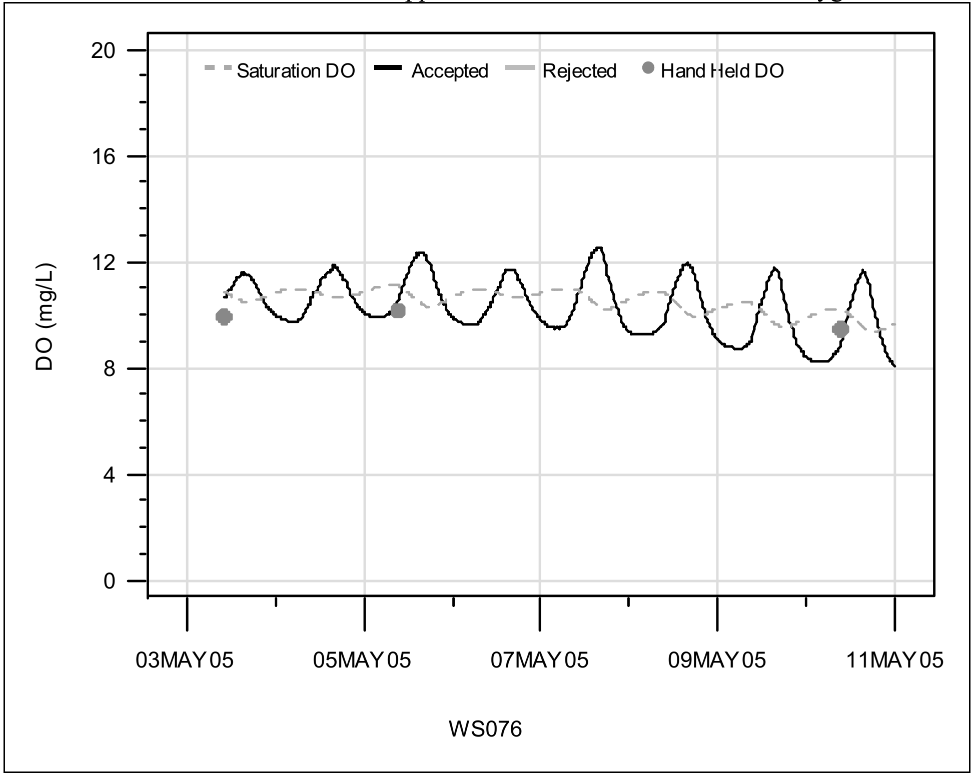


Figure C-9 Continuous Dissolved Oxygen (DO) with Calculated DO Saturation, 03MAY05 to 11MAY05, Site WS076

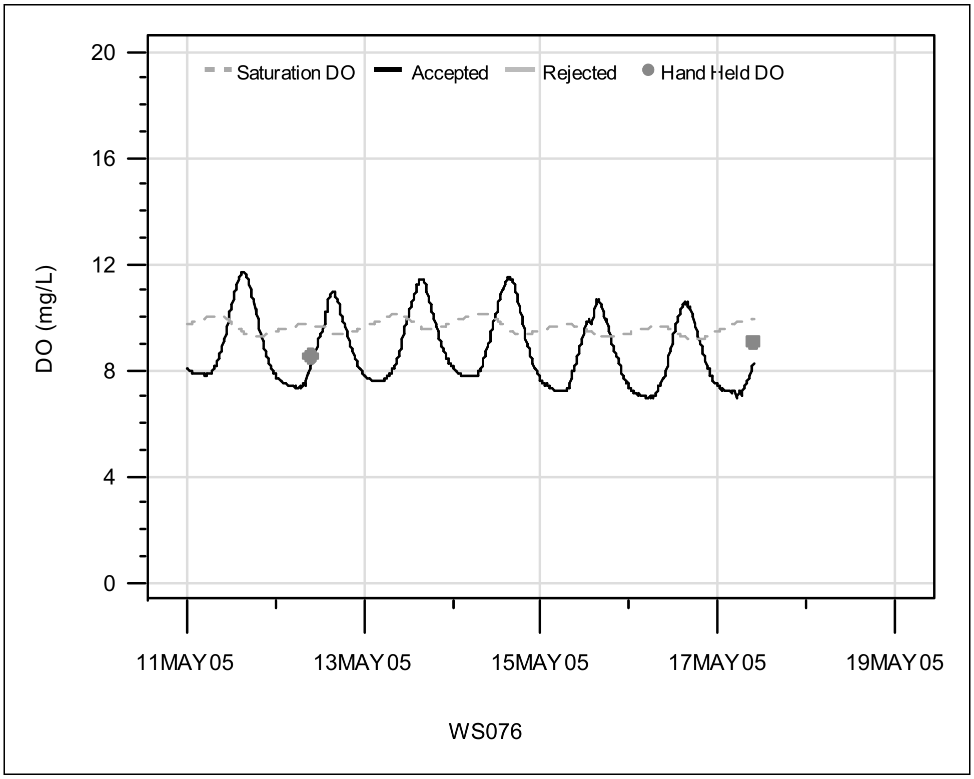


Figure C-10 Continuous Dissolved Oxygen (DO) with Calculated DO Saturation, 11MAY05 to 19MAY05, Site WS076

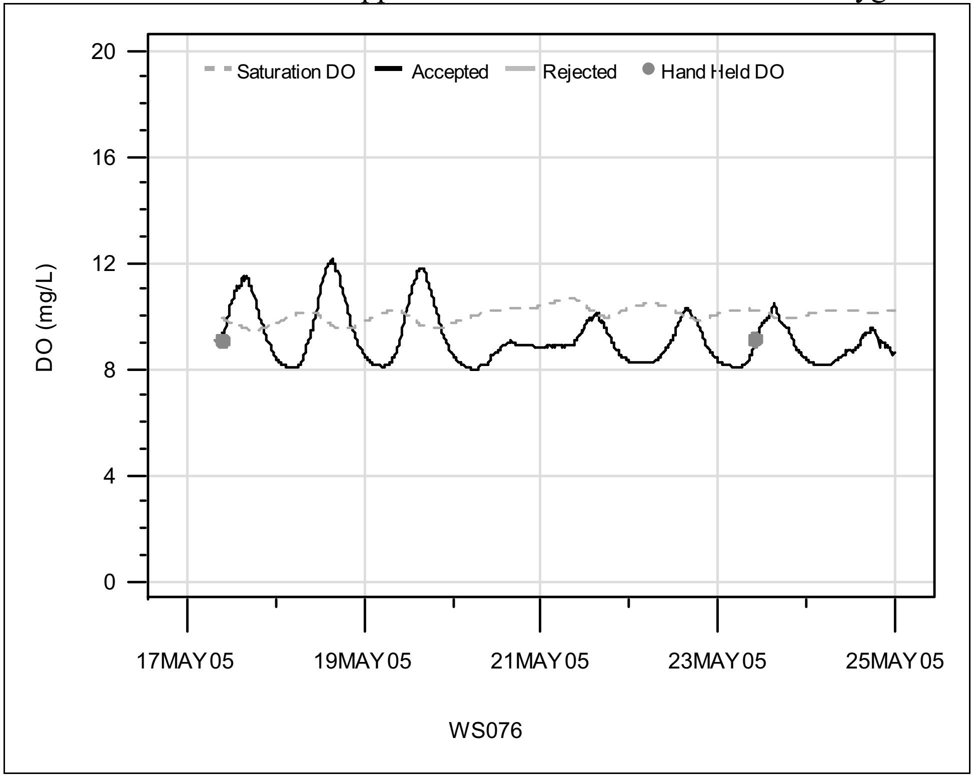


Figure C-11 Continuous Dissolved Oxygen (DO) with Calculated DO Saturation, 17MAY05 to 25MAY05, Site WS076

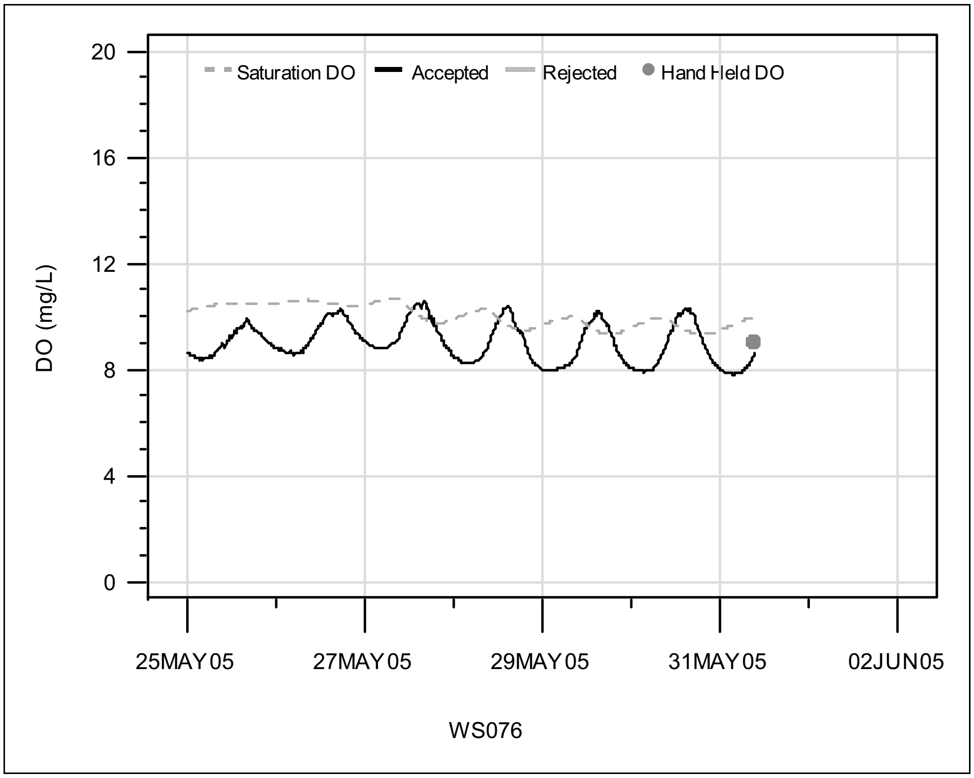


Figure C-12 Continuous Dissolved Oxygen (DO) with Calculated DO Saturation, 25MAY05 to 02JUN05, Site WS076

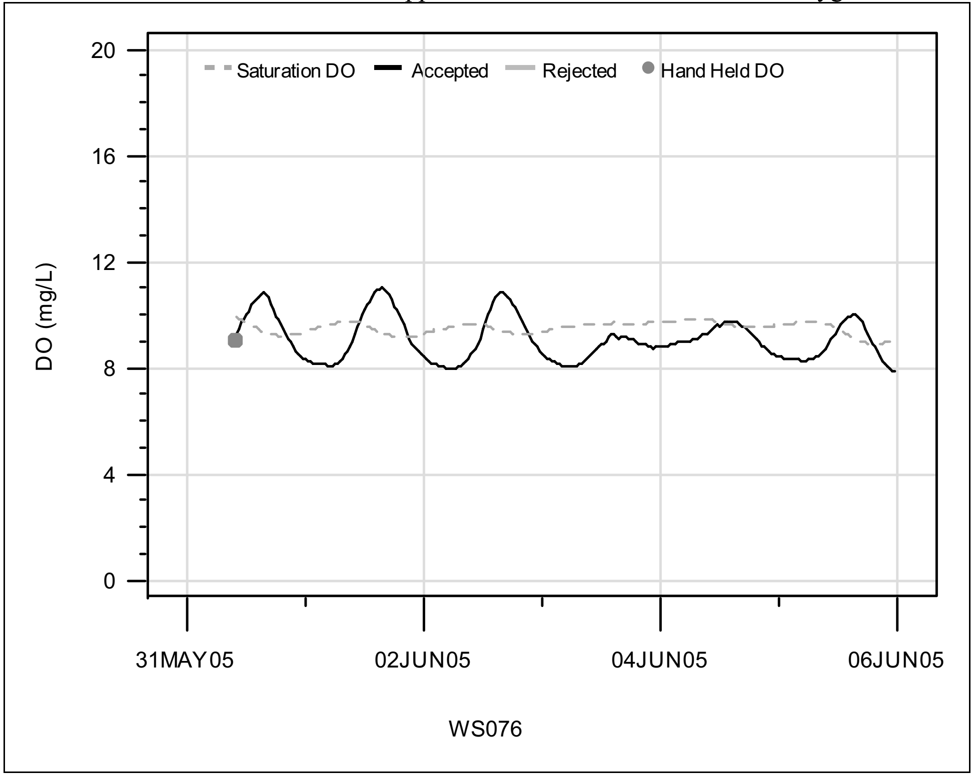


Figure C-13 Continuous Dissolved Oxygen (DO) with Calculated DO Saturation, 31MAY05 to 06JUN05, Site WS076

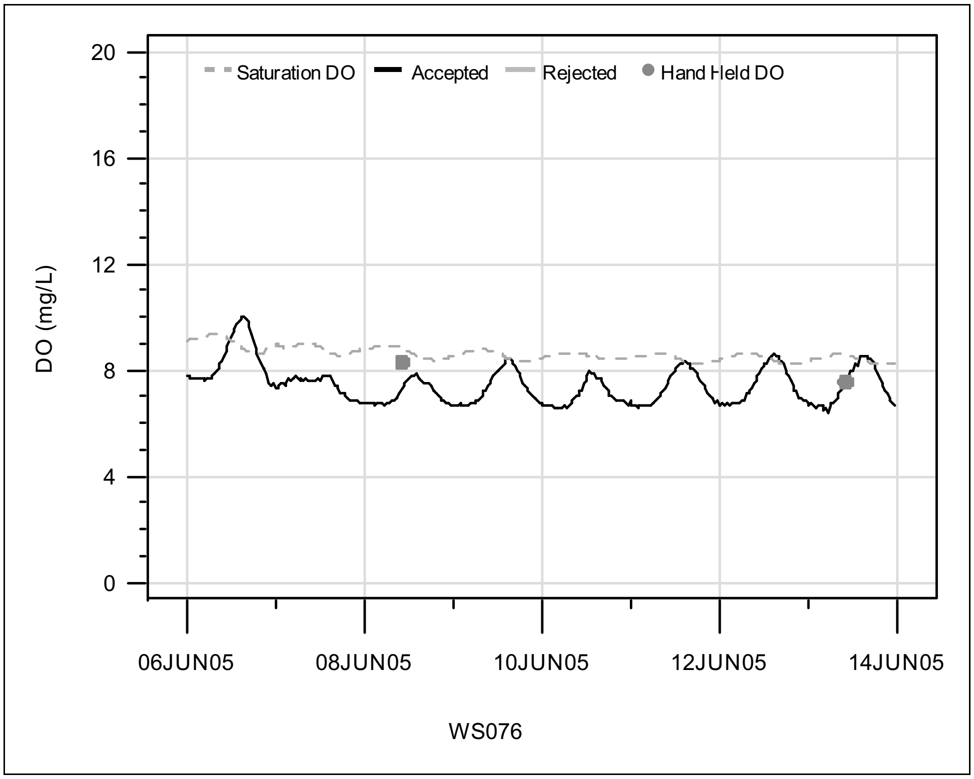


Figure C-14 Continuous Dissolved Oxygen (DO) with Calculated DO Saturation, 06JUN05 to 14JUN05, Site WS076

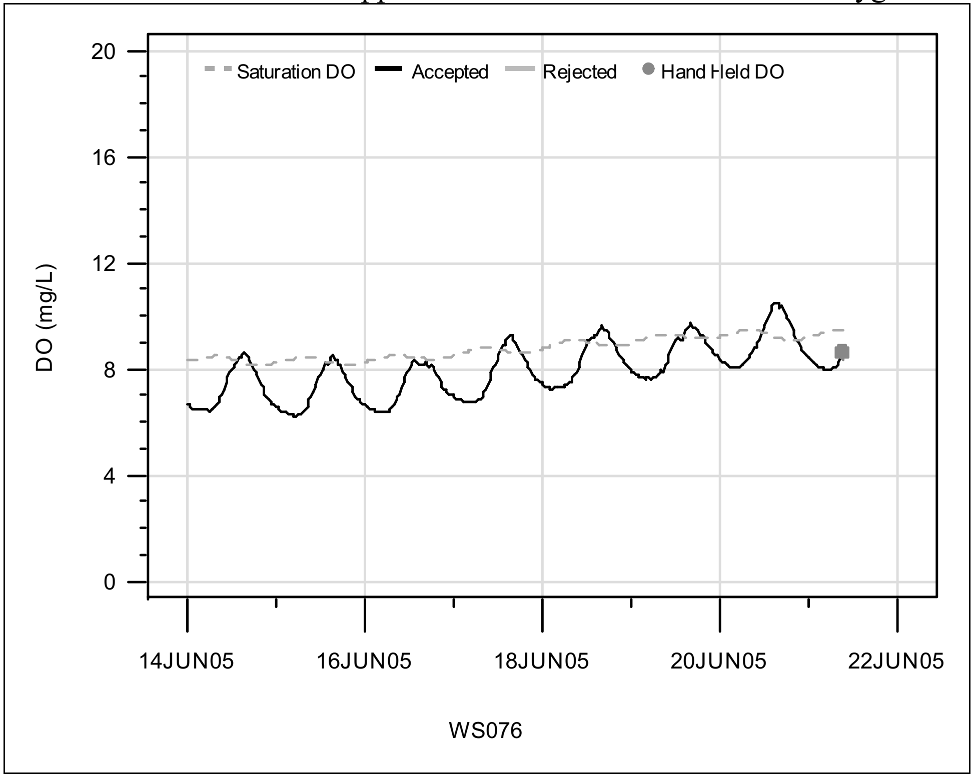


Figure C-15 Continuous Dissolved Oxygen (DO) with Calculated DO Saturation, 14JUN05 to 22JUN05, Site WS076

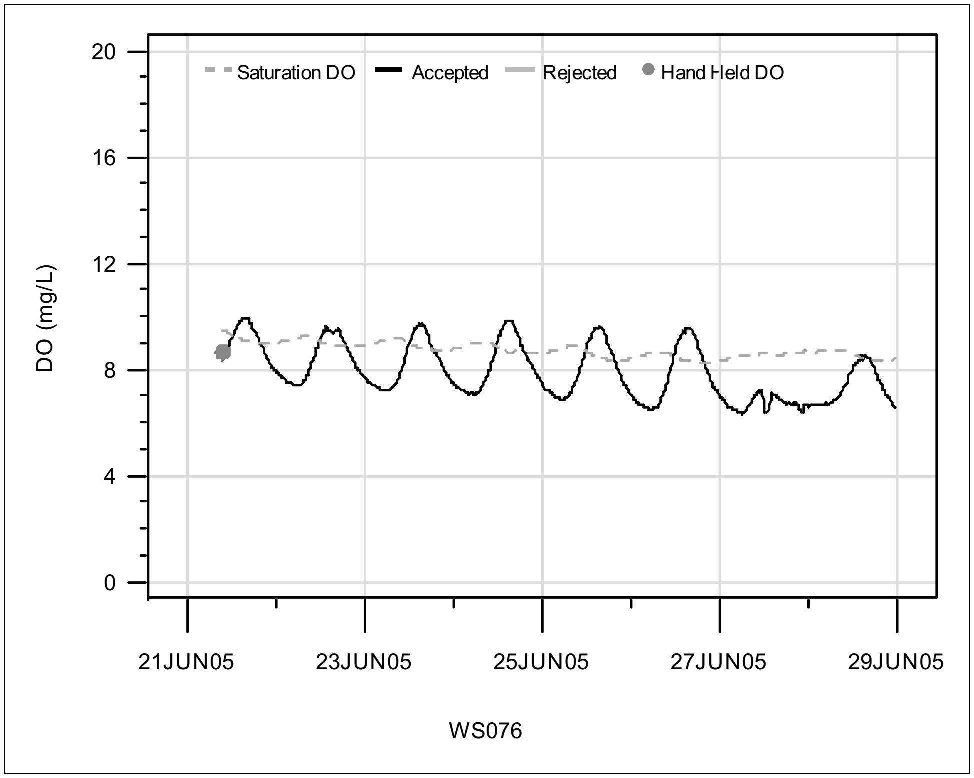


Figure C-16 Continuous Dissolved Oxygen (DO) with Calculated DO Saturation, 21JUN05 to 29JUN05, Site WS076

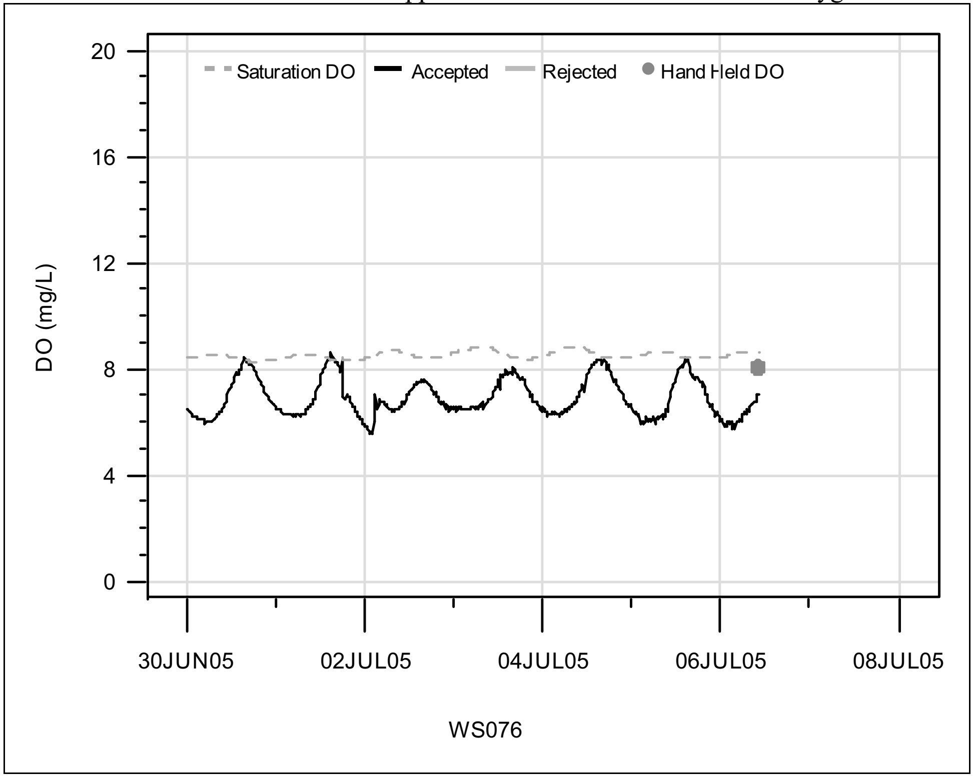


Figure C-17 Continuous Dissolved Oxygen (DO) with Calculated DO Saturation, 30JUN05 to 08JUL05, Site WS076

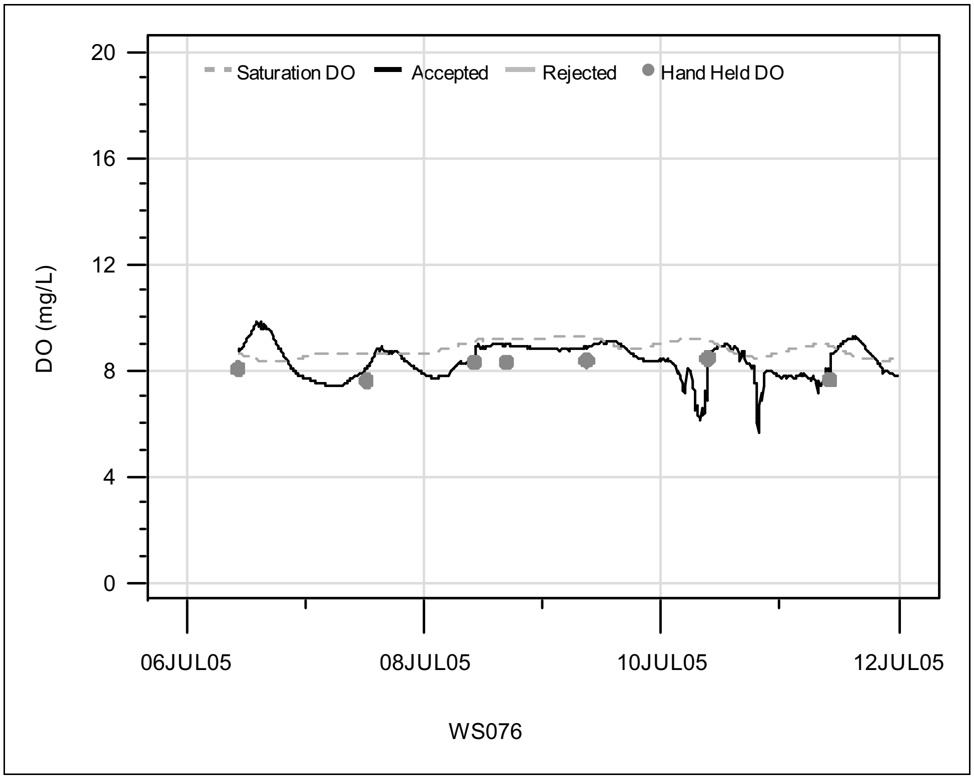


Figure C-18 Continuous Dissolved Oxygen (DO) with Calculated DO Saturation, 06JUL05 to 12JUL05, Site WS076

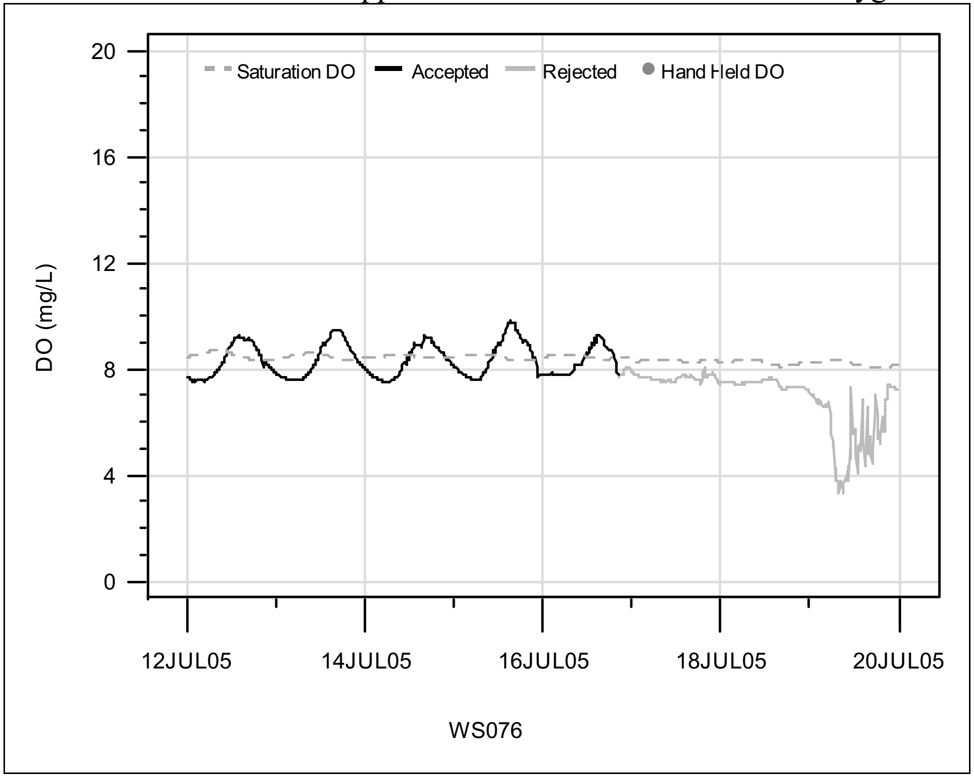


Figure C-19 Continuous Dissolved Oxygen (DO) with Calculated DO Saturation, 12JUL05 to 20JUL05, Site WS076

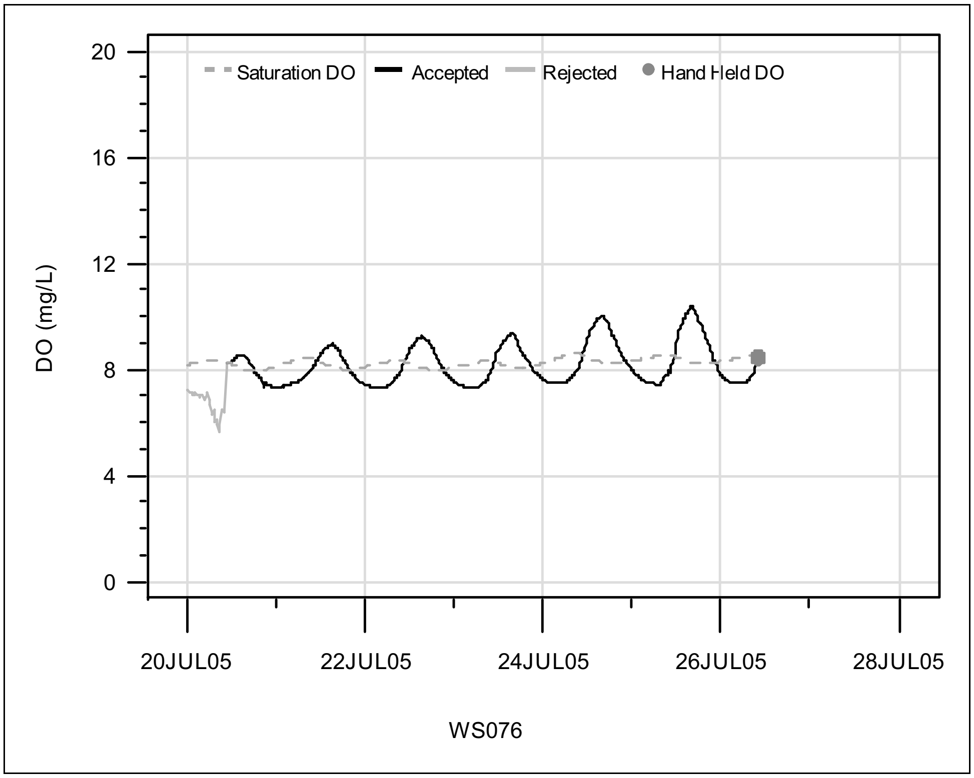


Figure C-20 Continuous Dissolved Oxygen (DO) with Calculated DO Saturation, 20JUL05 to 28JUL05, Site WS076

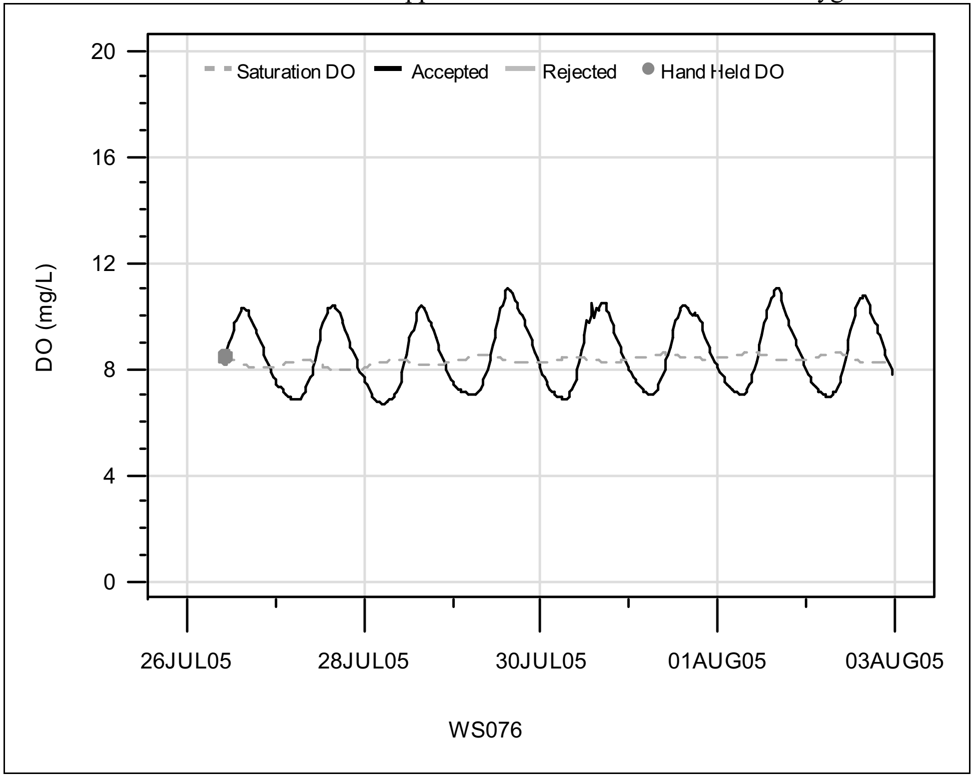


Figure C-21 Continuous Dissolved Oxygen (DO) with Calculated DO Saturation, 26JUL05 to 03AUG05, Site WS076

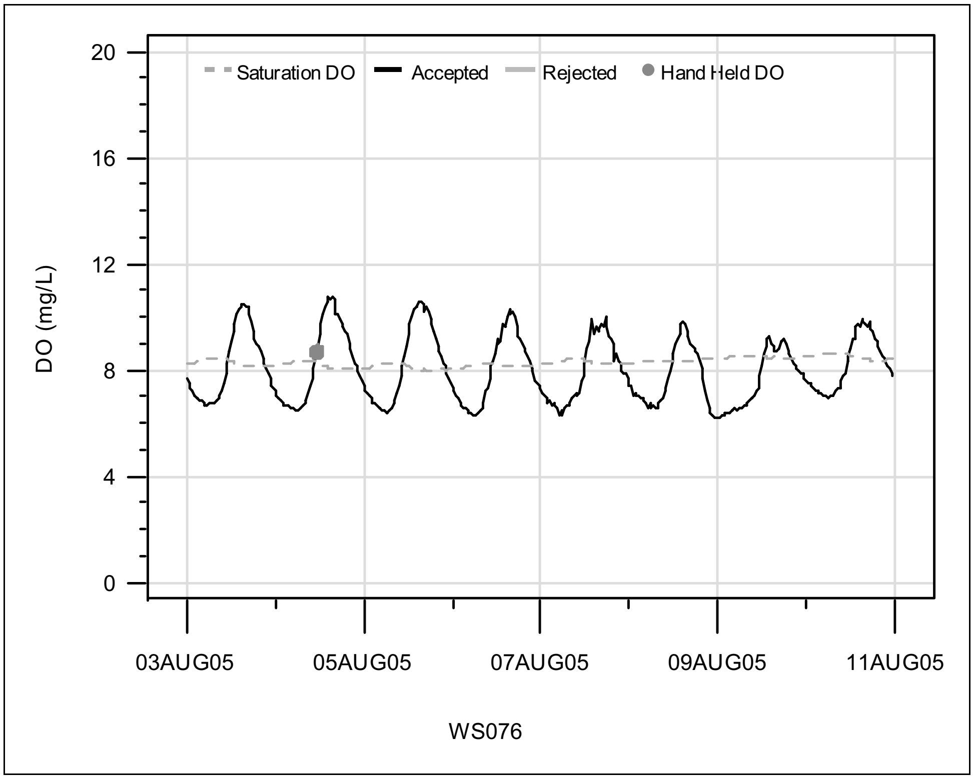


Figure C-22 Continuous Dissolved Oxygen (DO) with Calculated DO Saturation, 03AUG05 to 11AUG05, Site WS076

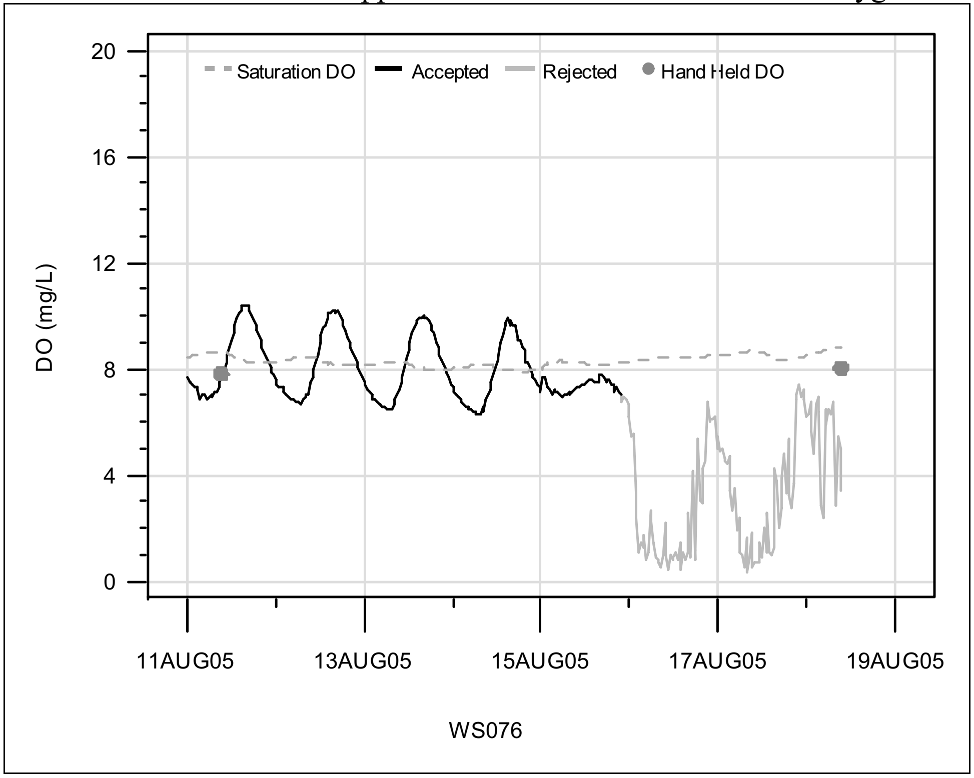


Figure C-23 Continuous Dissolved Oxygen (DO) with Calculated DO Saturation, 11AUG05 to 19AUG05, Site WS076

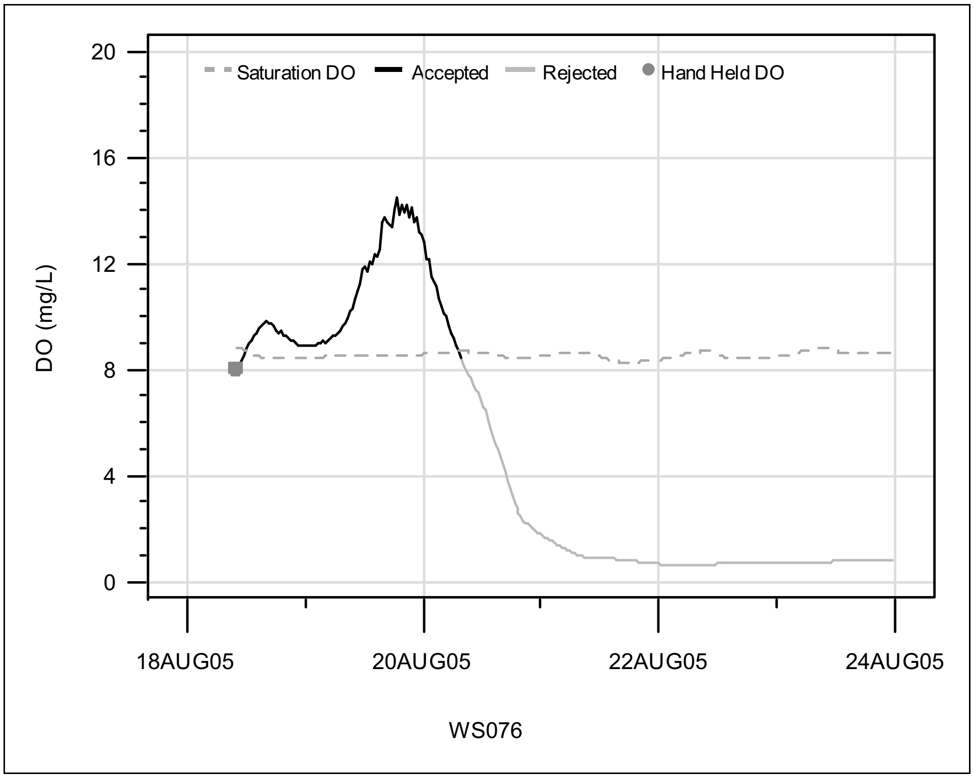


Figure C-24 Continuous Dissolved Oxygen (DO) with Calculated DO Saturation, 18AUG05 to 24AUG05, Site WS076

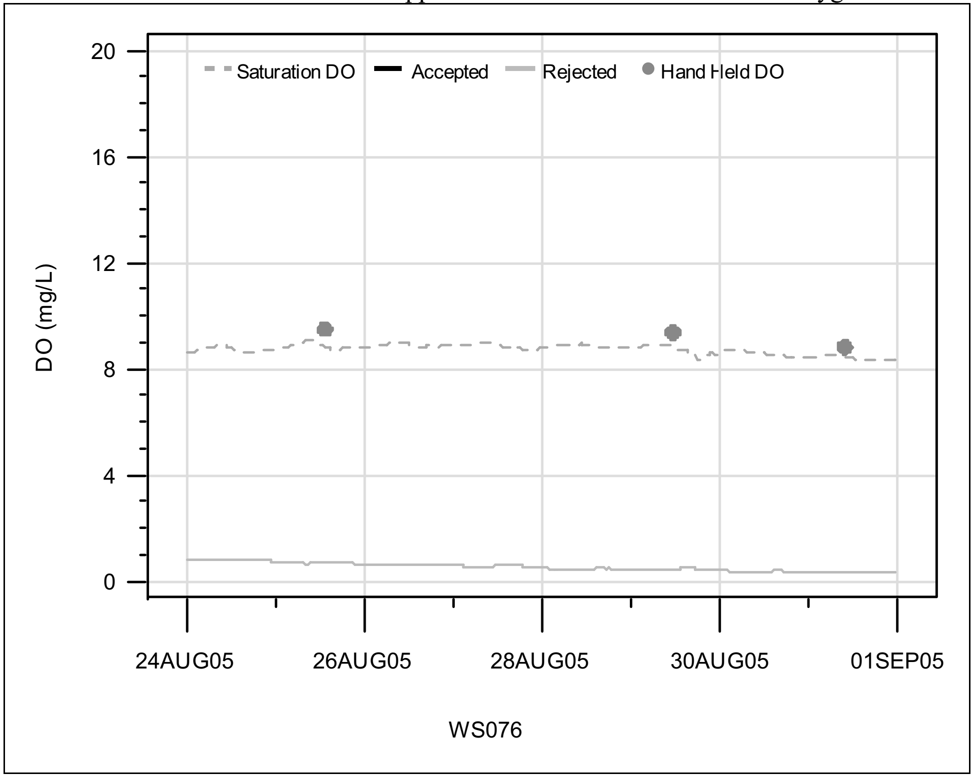


Figure C-25 Continuous Dissolved Oxygen (DO) with Calculated DO Saturation, 24AUG05 to 01SEP05, Site WS076

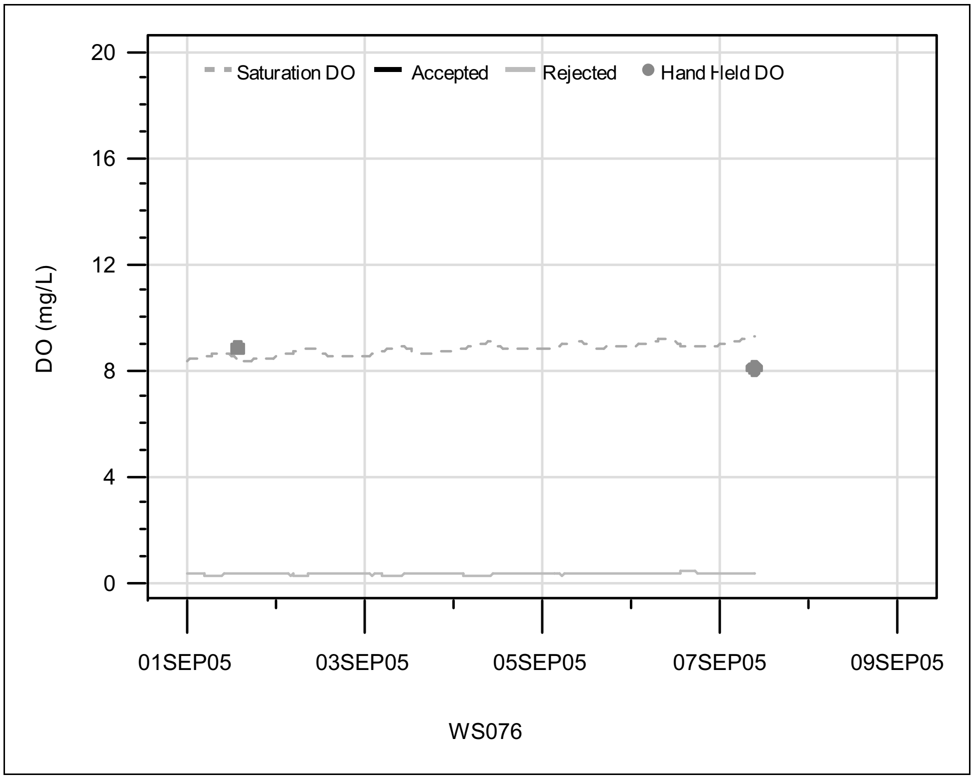


Figure C-26 Continuous Dissolved Oxygen (DO) with Calculated DO Saturation, 01SEP05 to 09SEP05, Site WS076

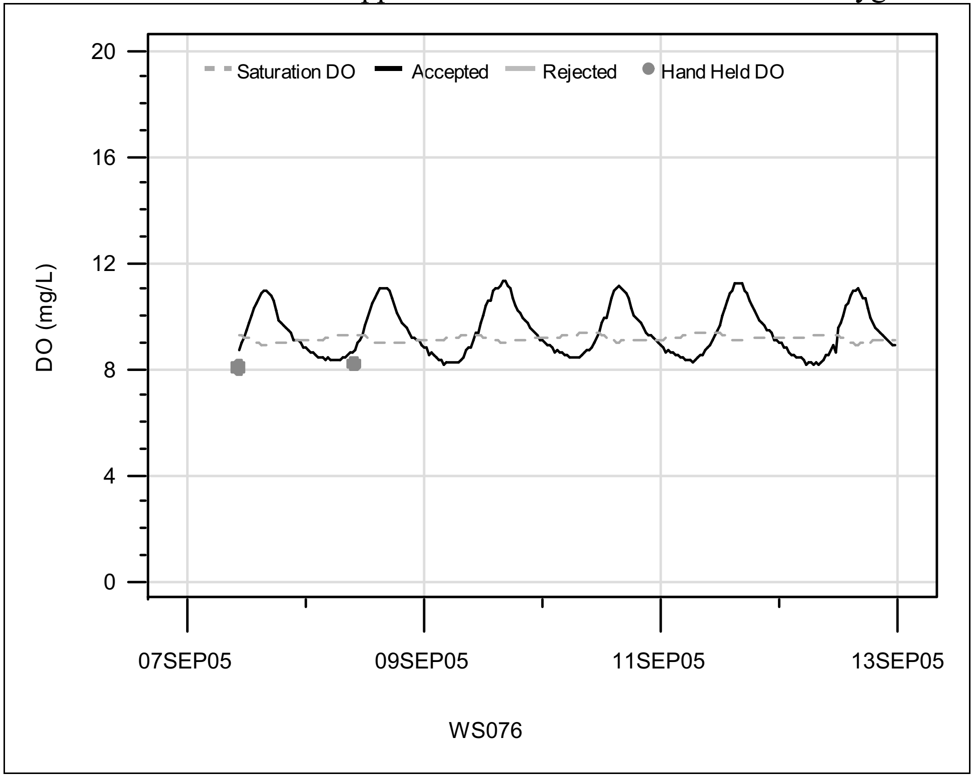


Figure C-27 Continuous Dissolved Oxygen (DO) with Calculated DO Saturation, 07SEP05 to 13SEP05, Site WS076

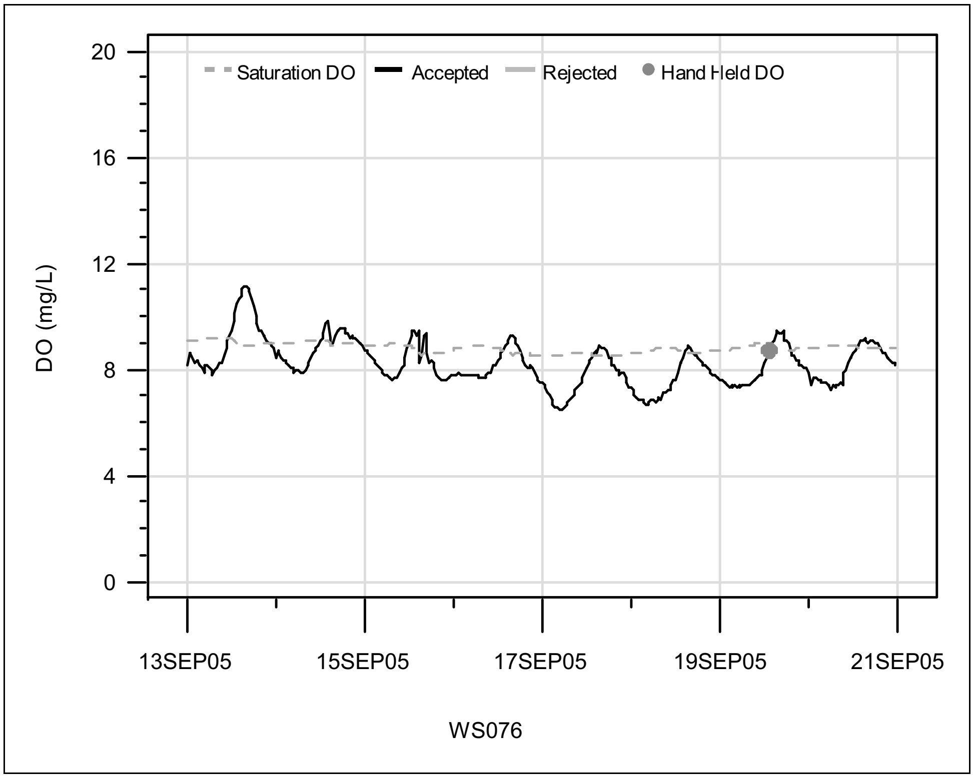


Figure C-28 Continuous Dissolved Oxygen (DO) with Calculated DO Saturation, 13SEP05 to 21SEP05, Site WS076

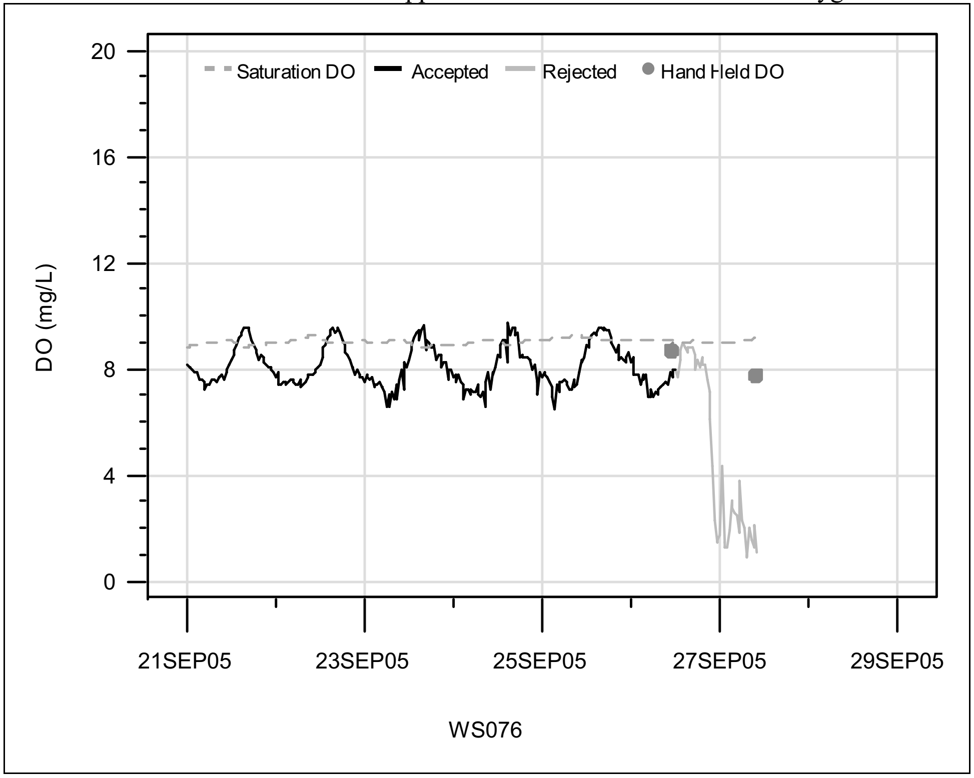


Figure C-29 Continuous Dissolved Oxygen (DO) with Calculated DO Saturation, 21SEP05 to 29SEP05, Site WS076

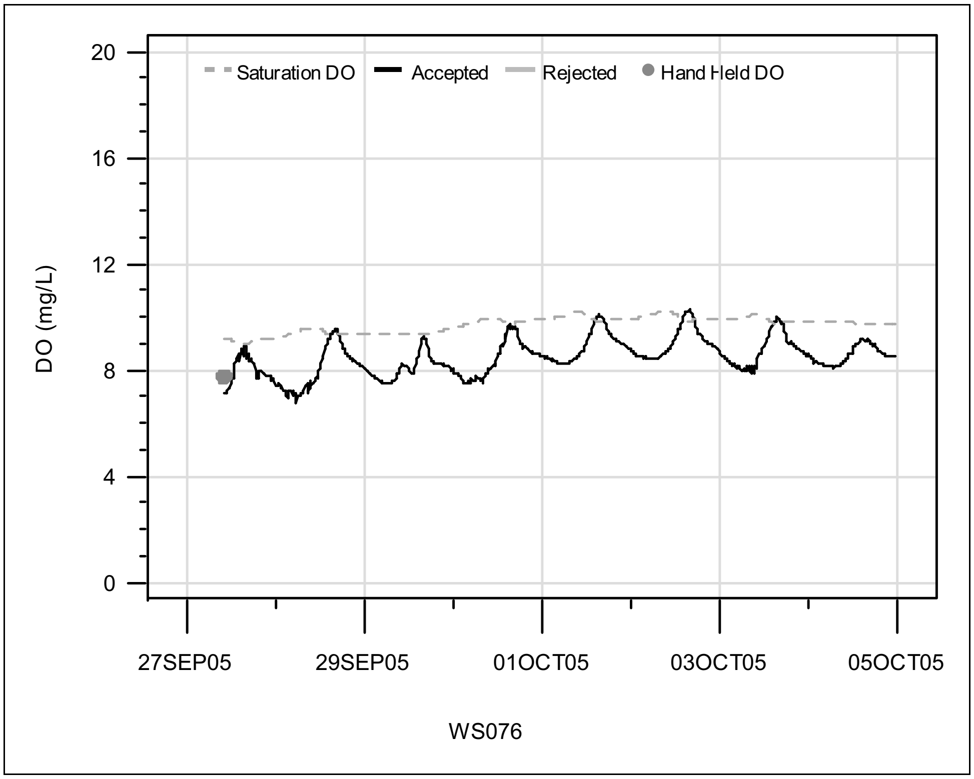


Figure C-30 Continuous Dissolved Oxygen (DO) with Calculated DO Saturation, 27SEP05 to 05OCT05, Site WS076

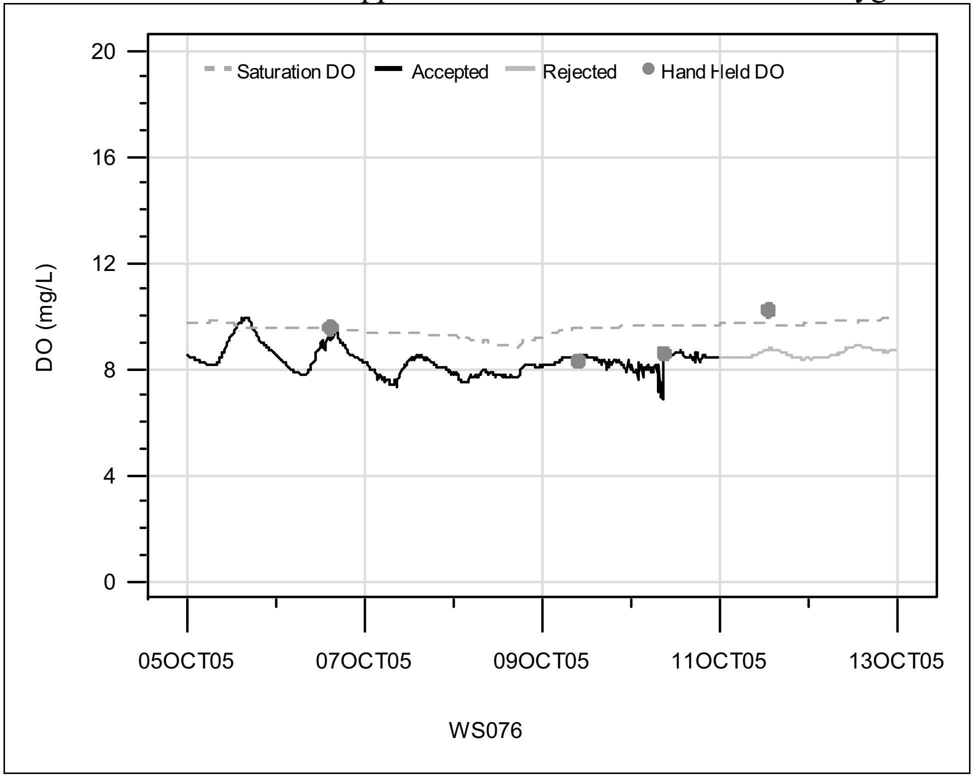


Figure C-31 Continuous Dissolved Oxygen (DO) with Calculated DO Saturation, 05OCT05 to 13OCT05, Site WS076

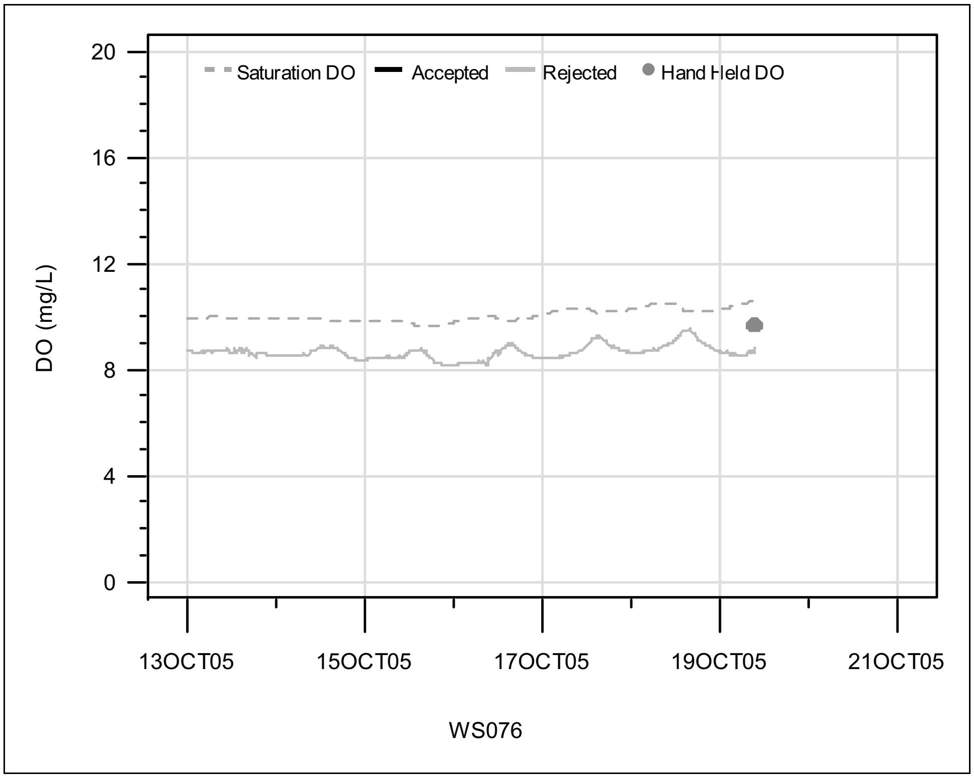


Figure C-32 Continuous Dissolved Oxygen (DO) with Calculated DO Saturation, 13OCT05 to 21OCT05, Site WS076

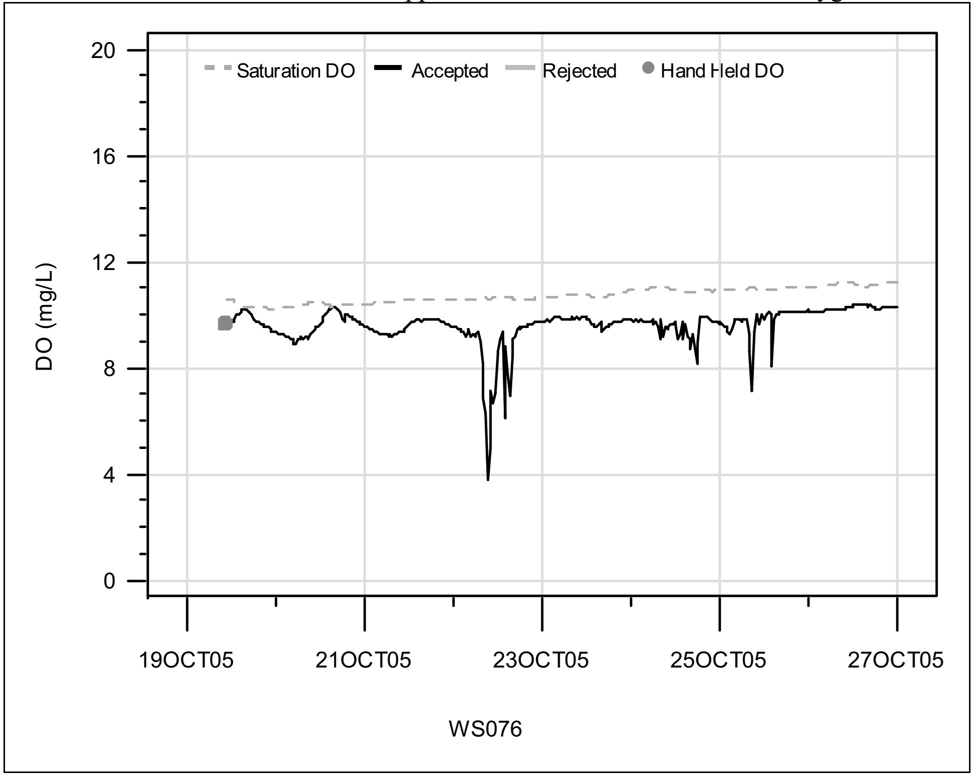


Figure C-33 Continuous Dissolved Oxygen (DO) with Calculated DO Saturation, 19OCT05 to 27OCT05, Site WS076

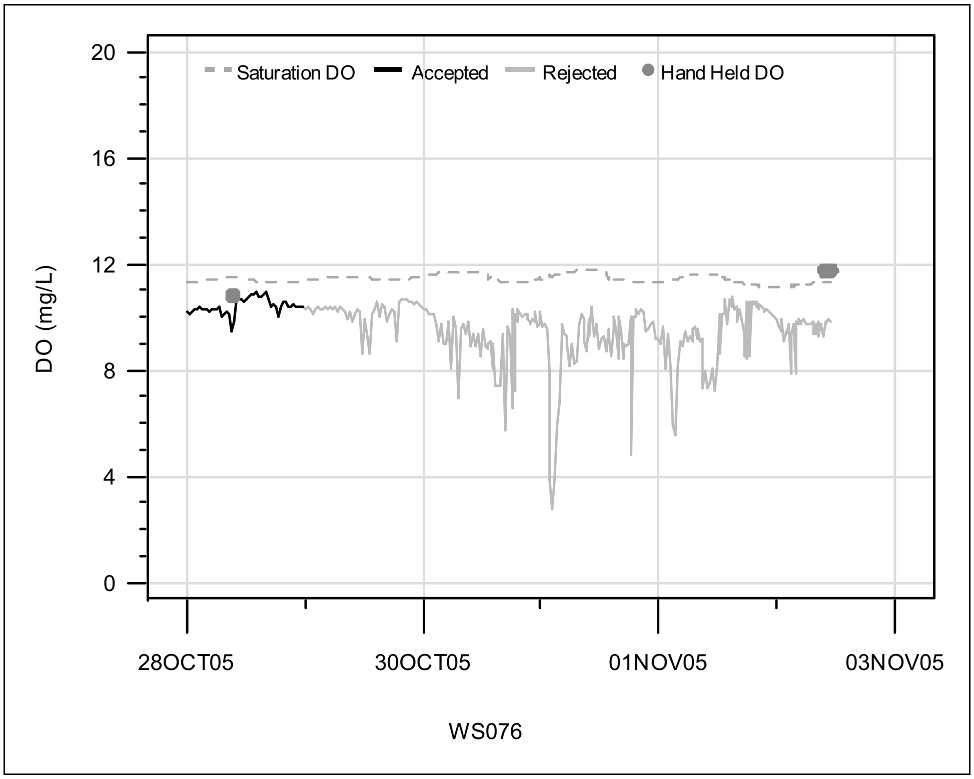


Figure C-34 Continuous Dissolved Oxygen (DO) with Calculated DO Saturation, 28OCT05 to 03NOV05, Site WS076

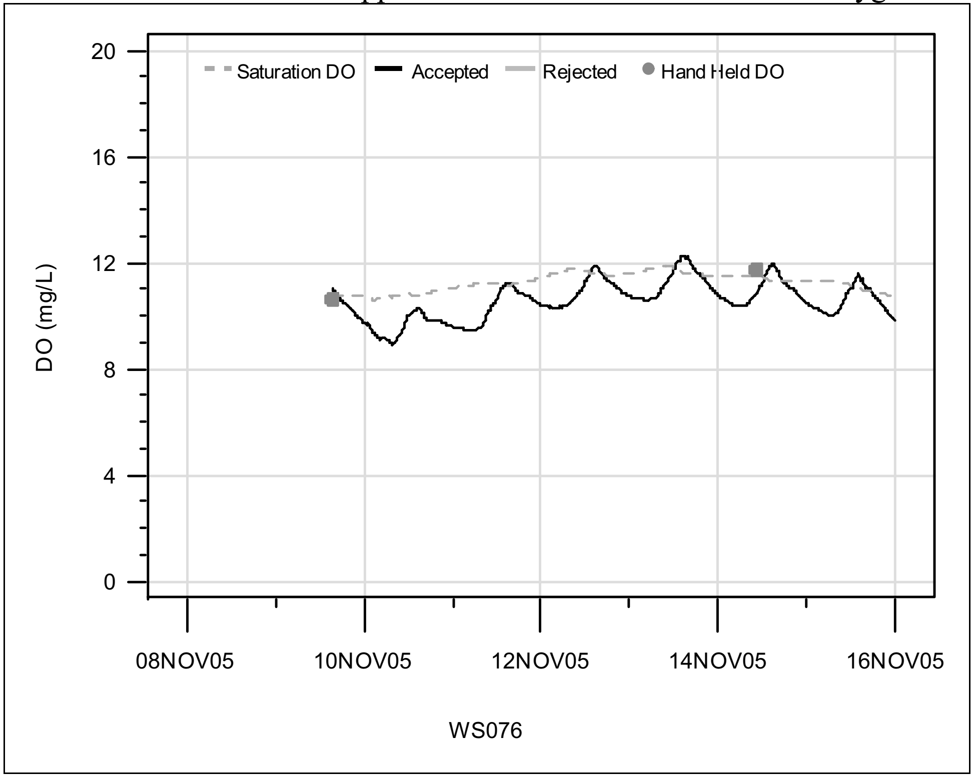


Figure C-35 Continuous Dissolved Oxygen (DO) with Calculated DO Saturation, 08NOV05 to 16NOV05, Site WS076

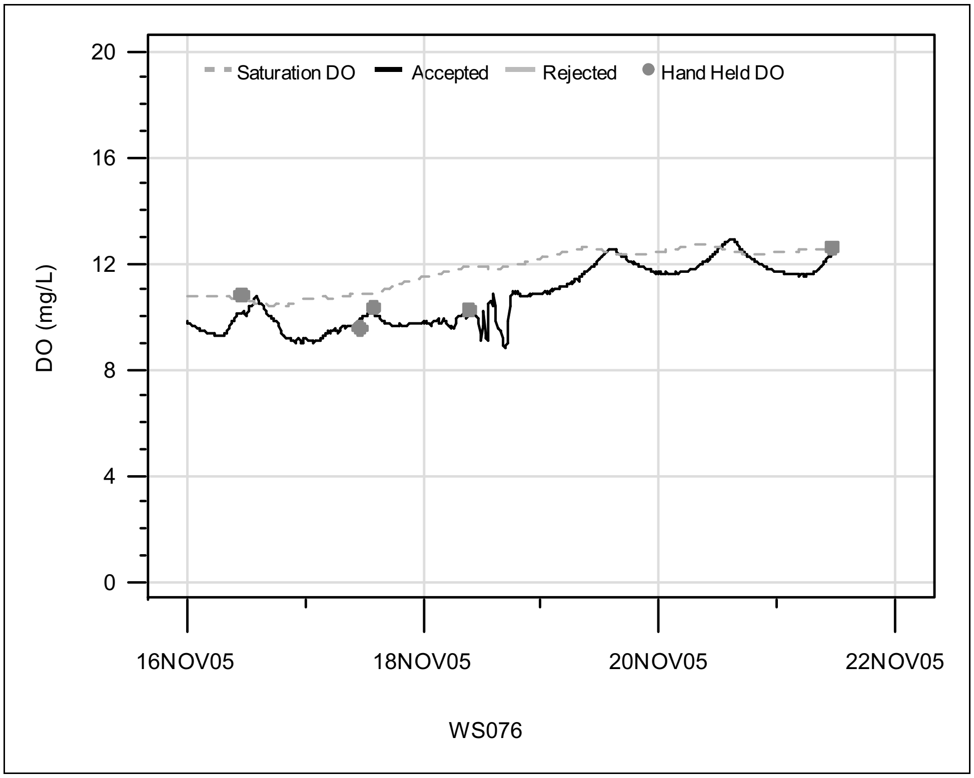


Figure C-36 Continuous Dissolved Oxygen (DO) with Calculated DO Saturation, 16NOV05 to 22NOV05, Site WS076

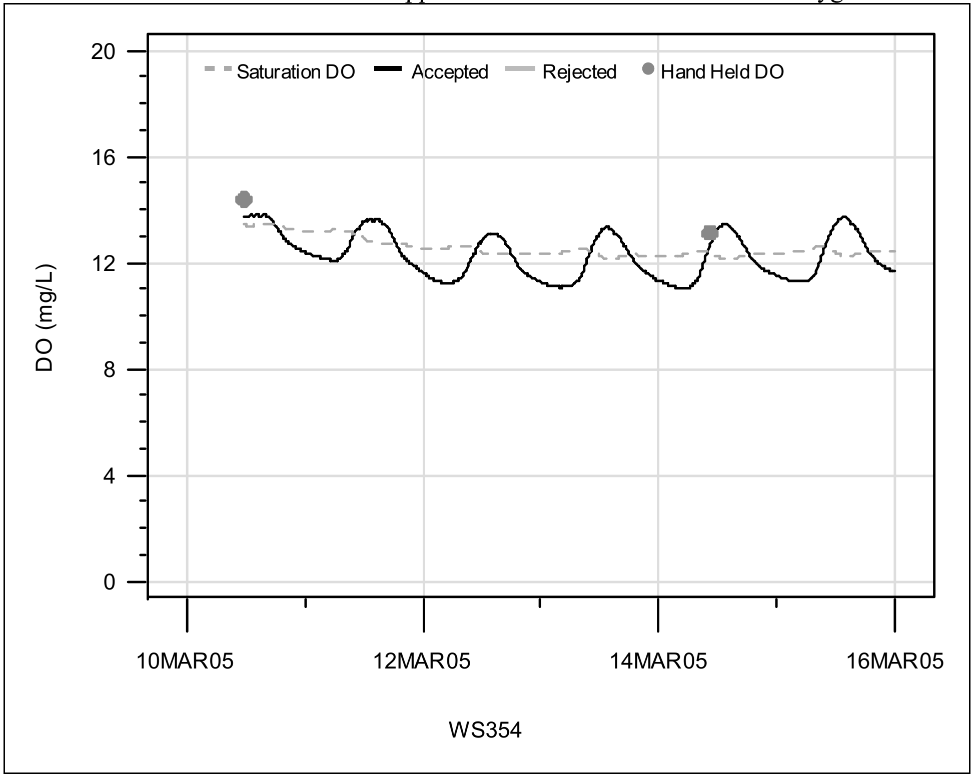


Figure C-37 Continuous Dissolved Oxygen (DO) with Calculated DO Saturation, 10MAR05 to 16MAR05, Site WS354

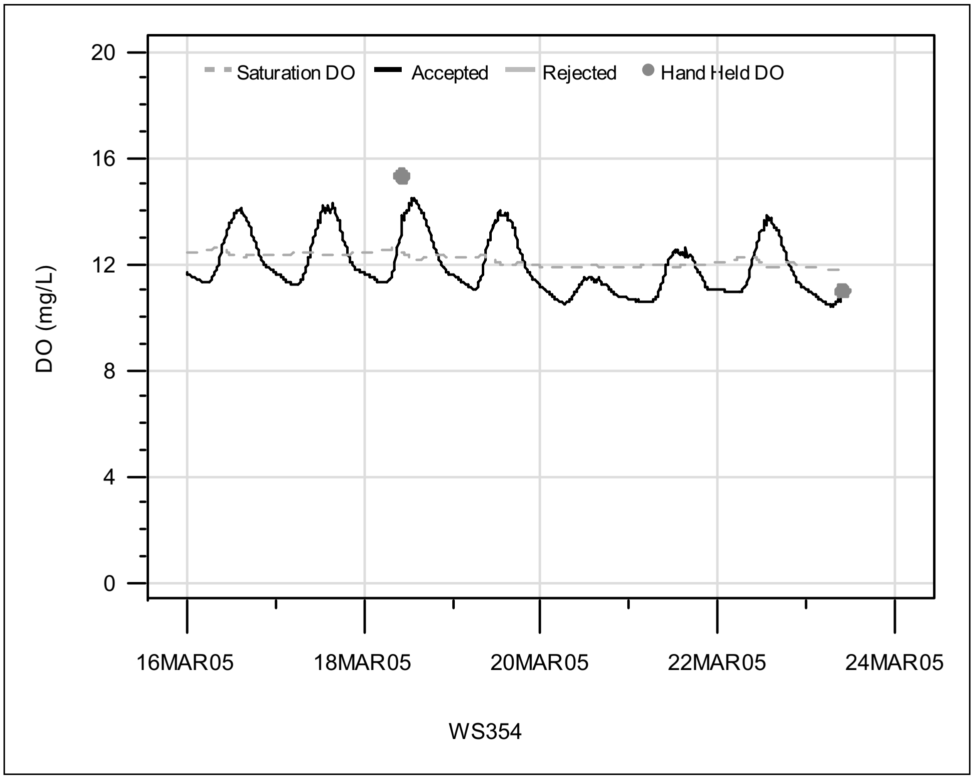


Figure C-38 Continuous Dissolved Oxygen (DO) with Calculated DO Saturation, 16MAR05 to 24MAR05, Site WS354

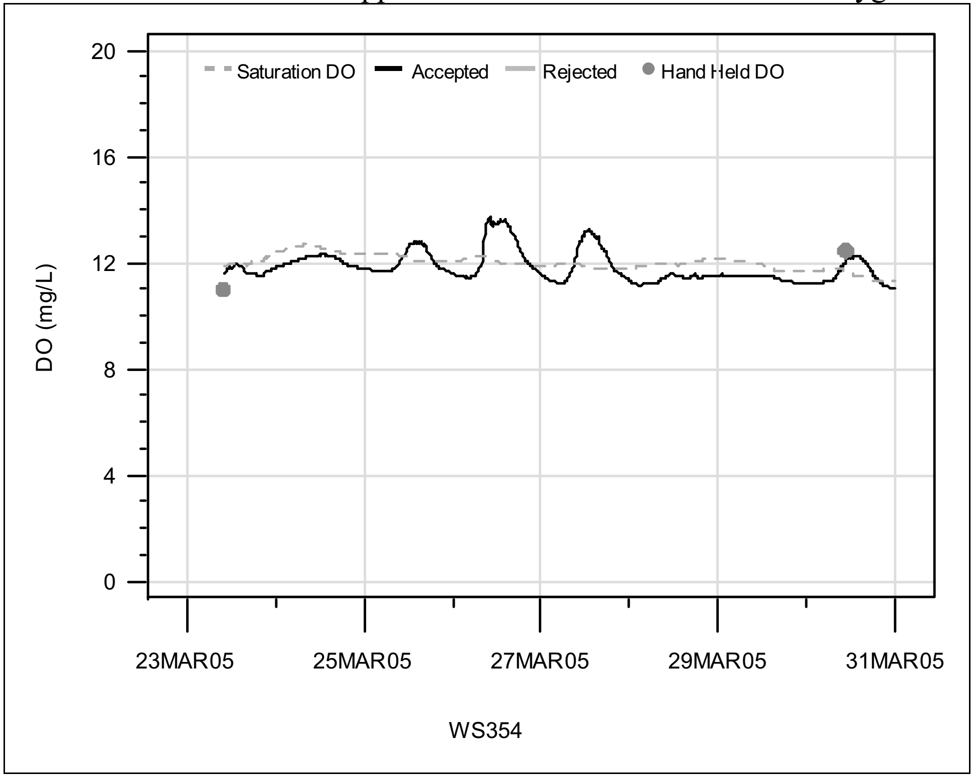


Figure C-39 Continuous Dissolved Oxygen (DO) with Calculated DO Saturation, 23MAR05 to 31MAR05, Site WS354

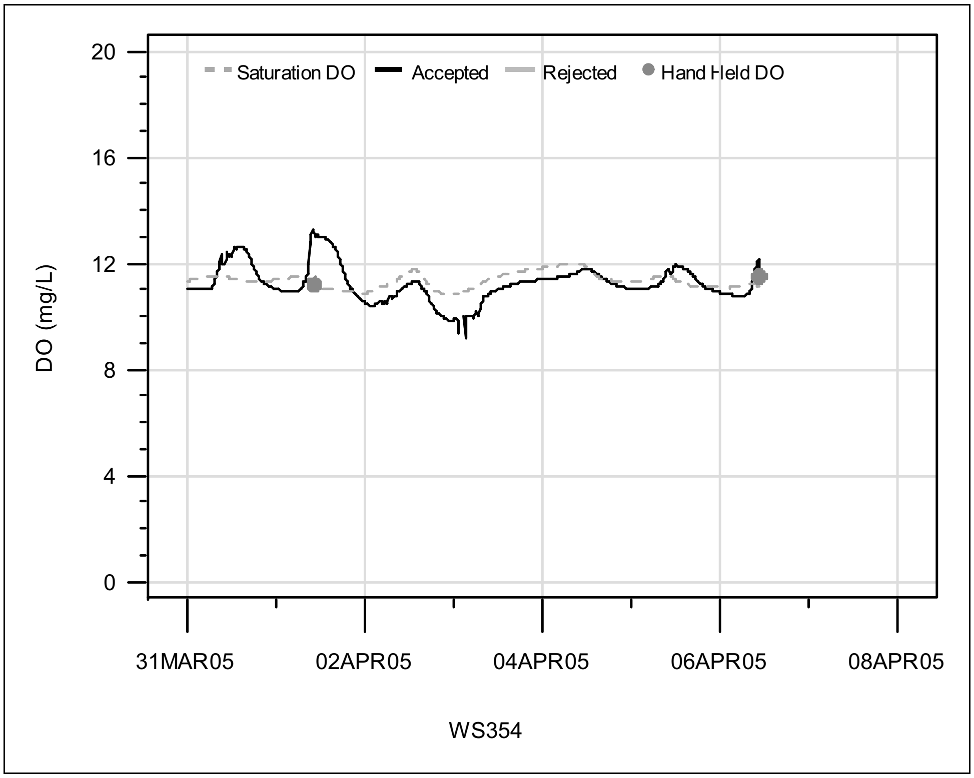


Figure C-40 Continuous Dissolved Oxygen (DO) with Calculated DO Saturation, 31MAR05 to 08APR05, Site WS354

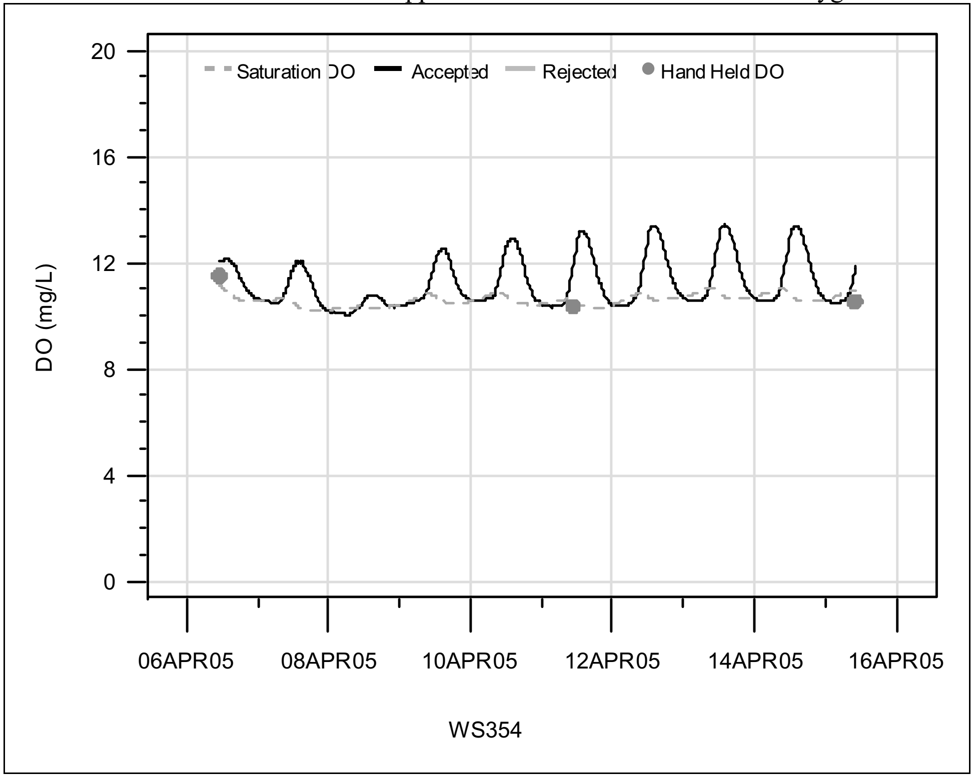


Figure C-41 Continuous Dissolved Oxygen (DO) with Calculated DO Saturation, 06APR05 to 16APR05, Site WS354

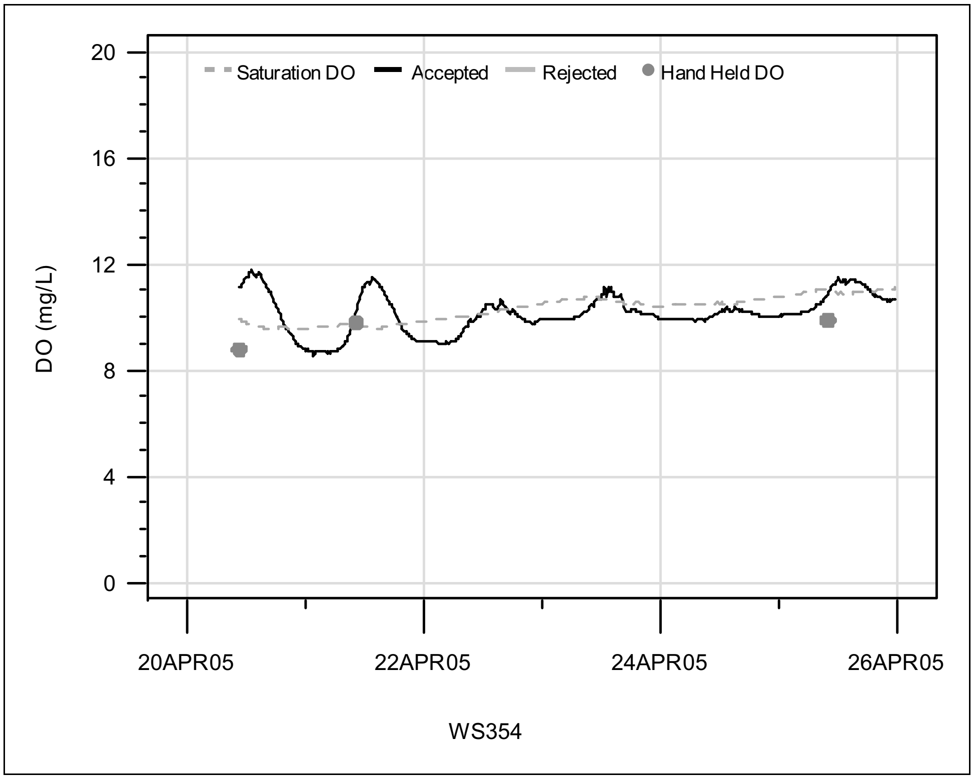


Figure C-42 Continuous Dissolved Oxygen (DO) with Calculated DO Saturation, 20APR05 to 26APR05, Site WS354

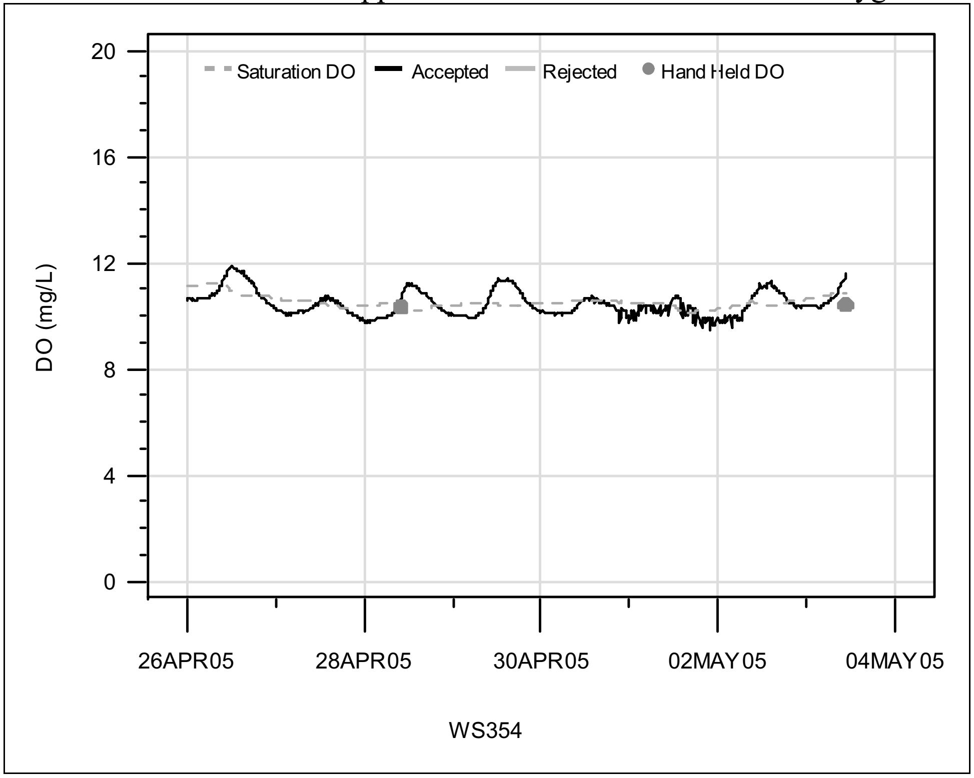


Figure C-43 Continuous Dissolved Oxygen (DO) with Calculated DO Saturation, 26APR05 to 04MAY05, Site WS354

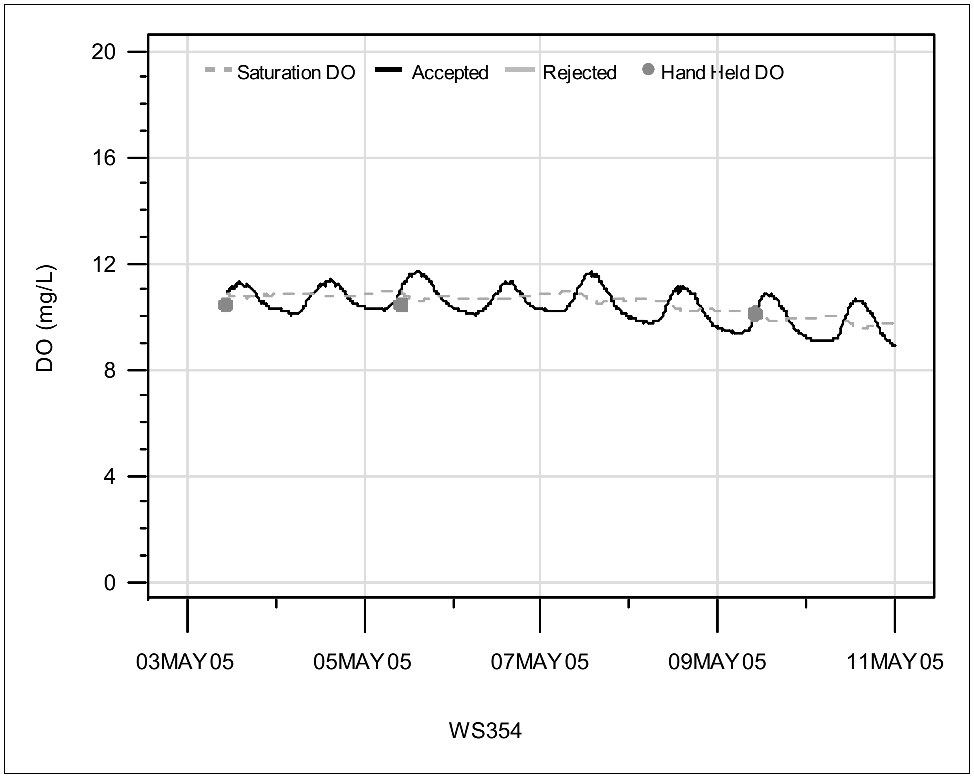


Figure C-44 Continuous Dissolved Oxygen (DO) with Calculated DO Saturation, 03MAY05 to 11MAY05, Site WS354

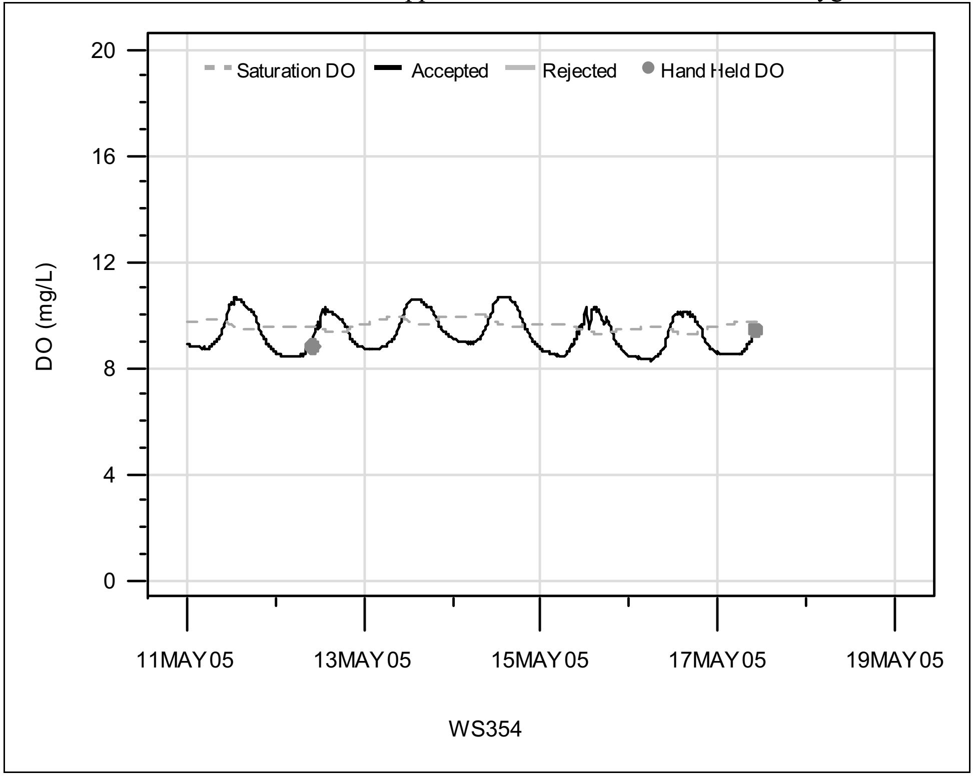


Figure C-45 Continuous Dissolved Oxygen (DO) with Calculated DO Saturation, 11MAY05 to 19MAY05, Site WS354

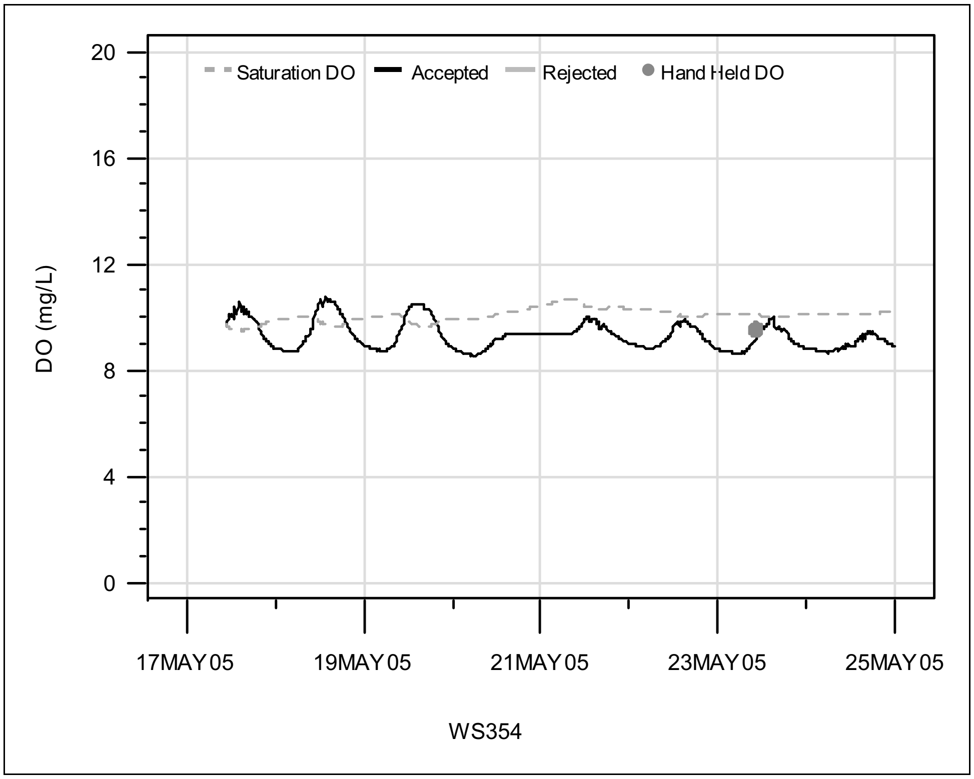


Figure C-46 Continuous Dissolved Oxygen (DO) with Calculated DO Saturation, 17MAY05 to 25MAY05, Site WS354

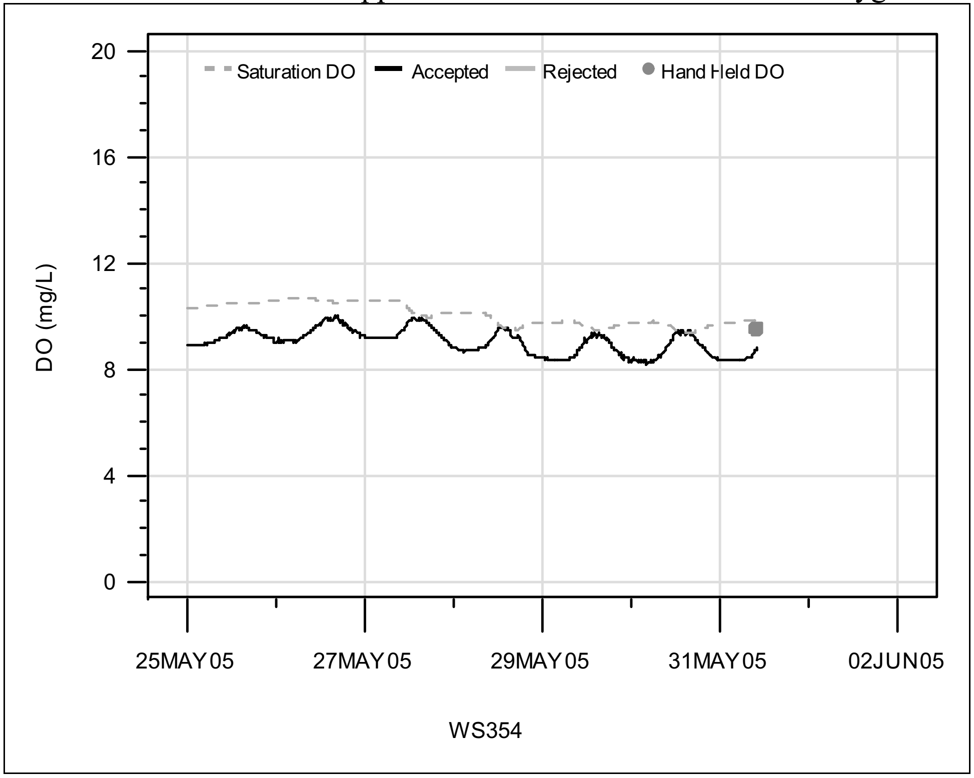


Figure C-47 Continuous Dissolved Oxygen (DO) with Calculated DO Saturation, 25MAY05 to 02JUN05, Site WS354

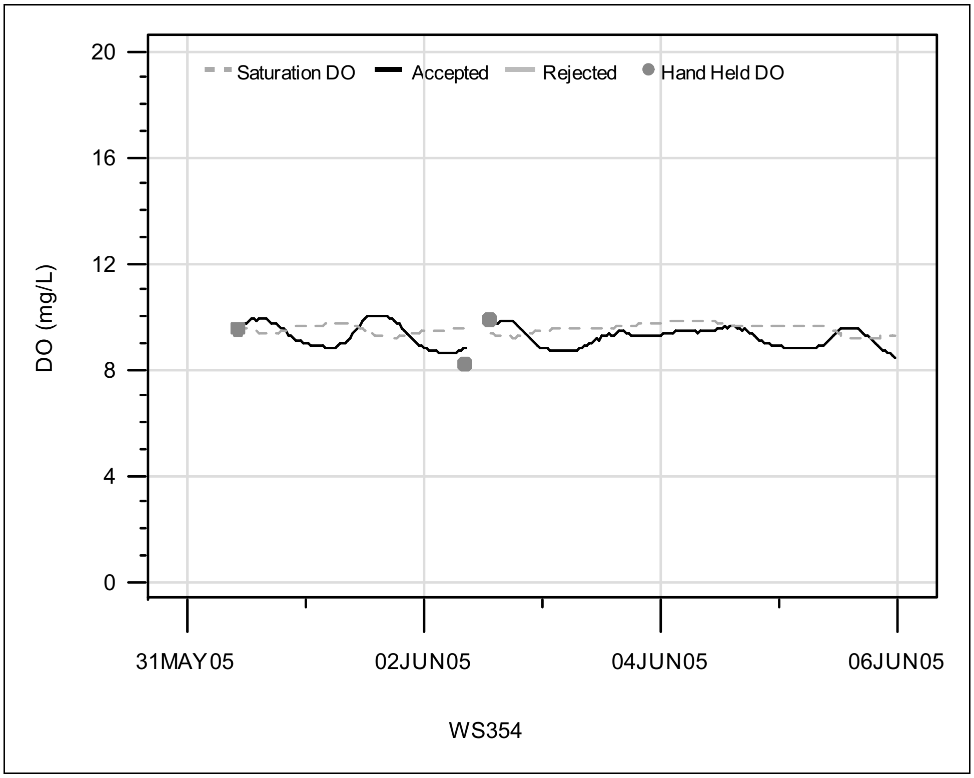


Figure C-48 Continuous Dissolved Oxygen (DO) with Calculated DO Saturation, 31MAY05 to 06JUN05, Site WS354

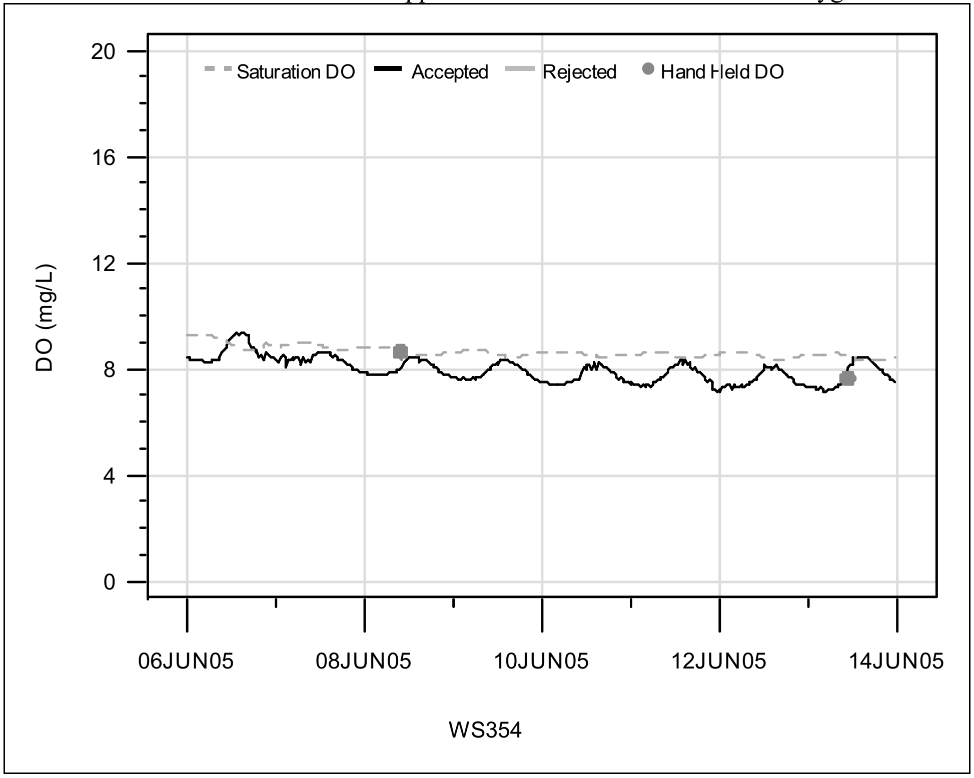


Figure C-49 Continuous Dissolved Oxygen (DO) with Calculated DO Saturation, 06JUN05 to 14JUN05, Site WS354

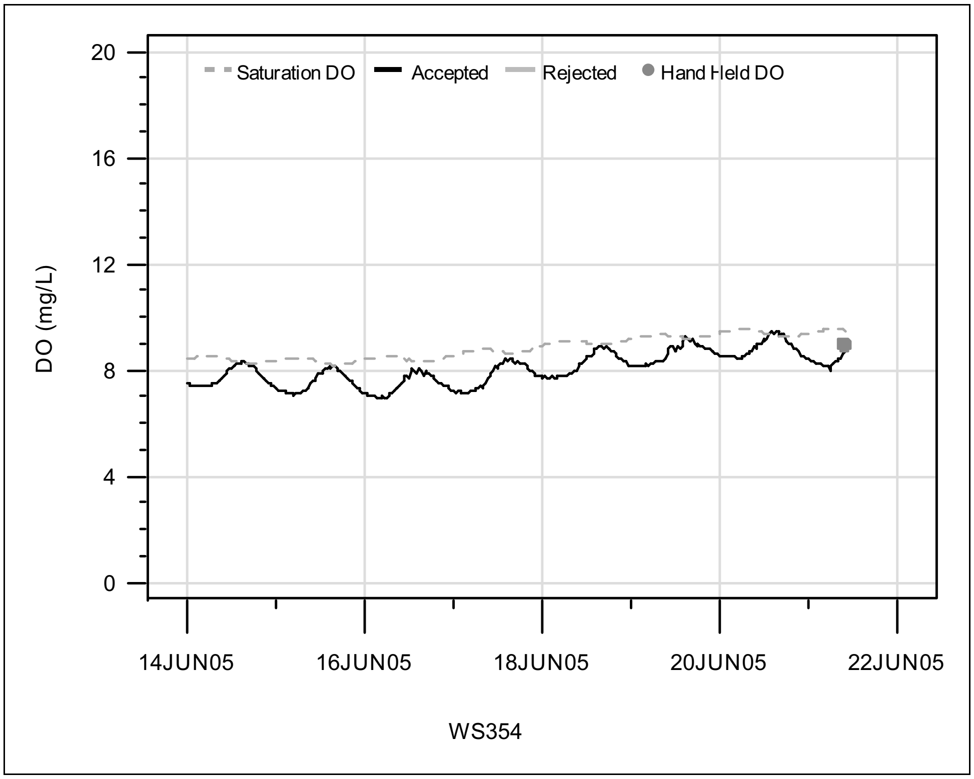


Figure C-50 Continuous Dissolved Oxygen (DO) with Calculated DO Saturation, 14JUN05 to 22JUN05, Site WS354

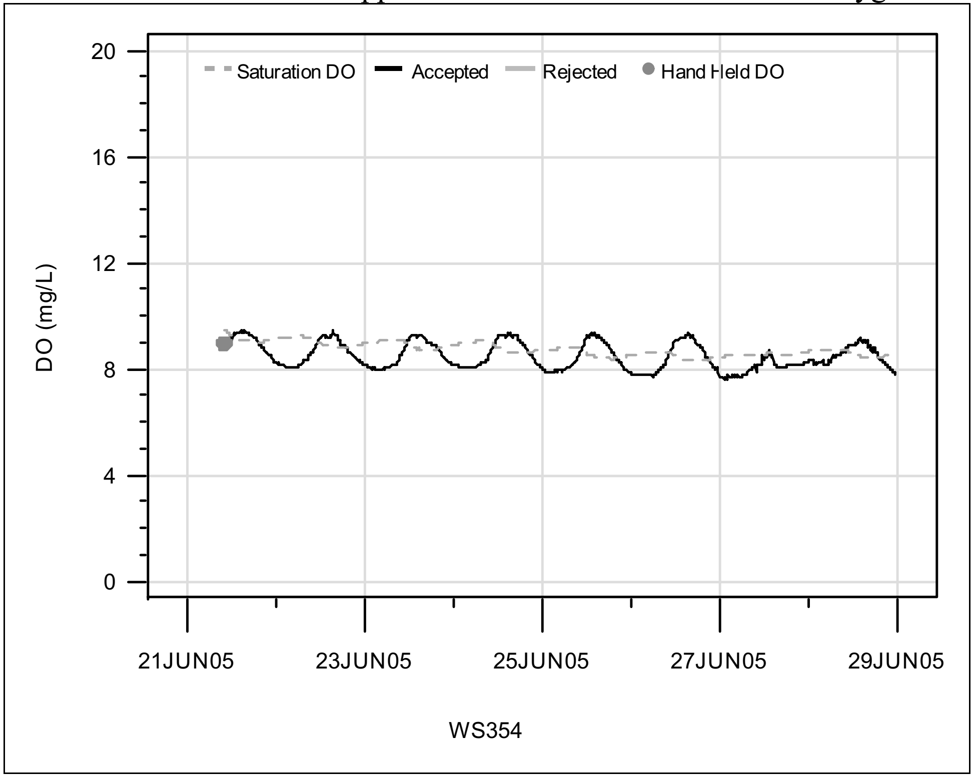


Figure C-51 Continuous Dissolved Oxygen (DO) with Calculated DO Saturation, 21JUN05 to 29JUN05, Site WS354

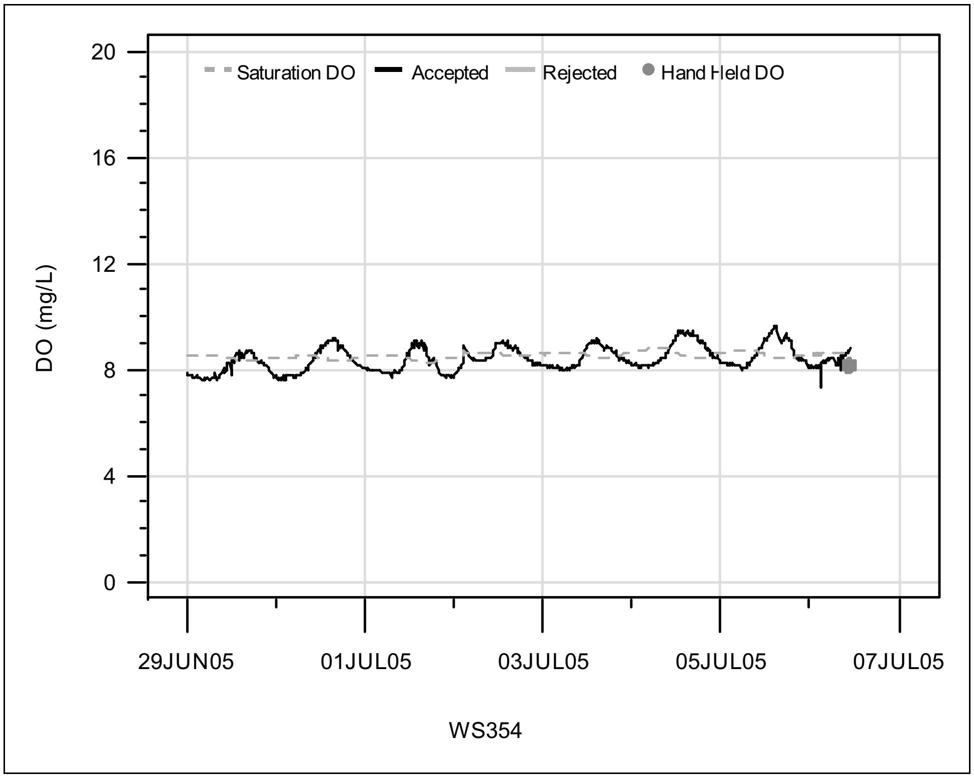


Figure C-52 Continuous Dissolved Oxygen (DO) with Calculated DO Saturation, 29JUN05 to 07JUL05, Site WS354

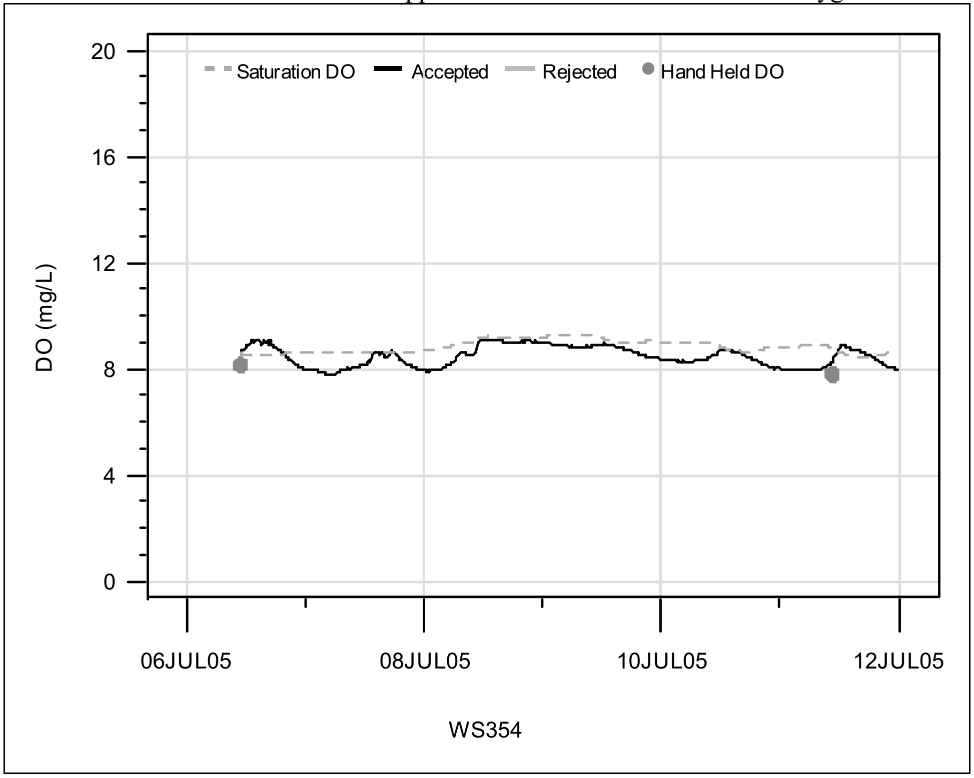


Figure C-53 Continuous Dissolved Oxygen (DO) with Calculated DO Saturation, 06JUL05 to 12JUL05, Site WS354

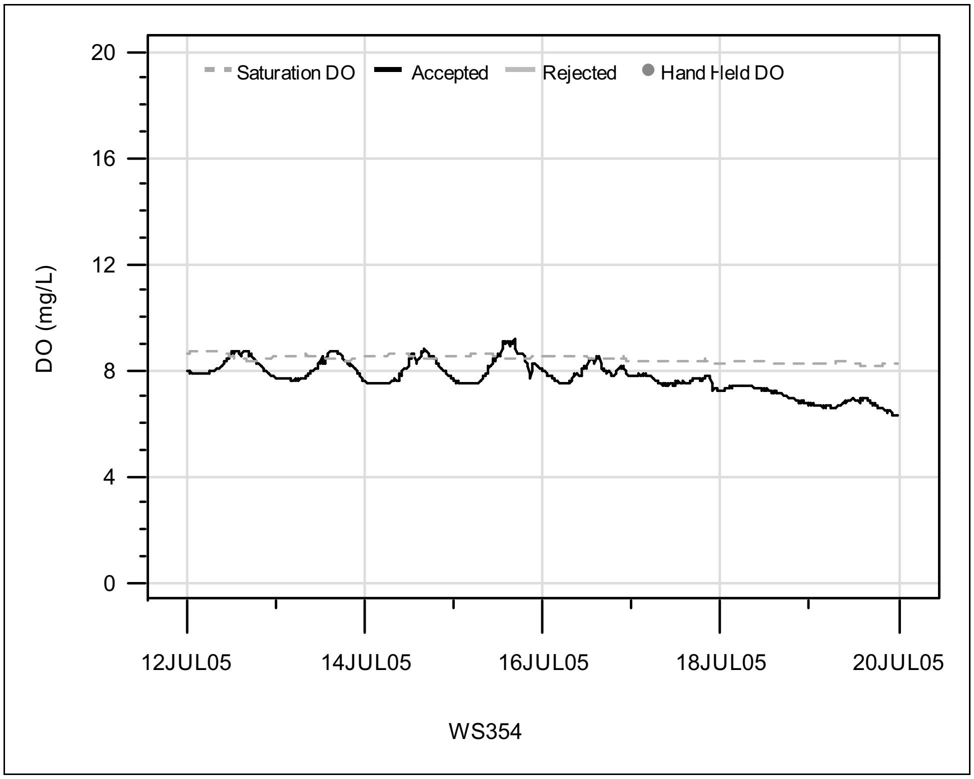


Figure C-54 Continuous Dissolved Oxygen (DO) with Calculated DO Saturation, 12JUL05 to 20JUL05, Site WS354

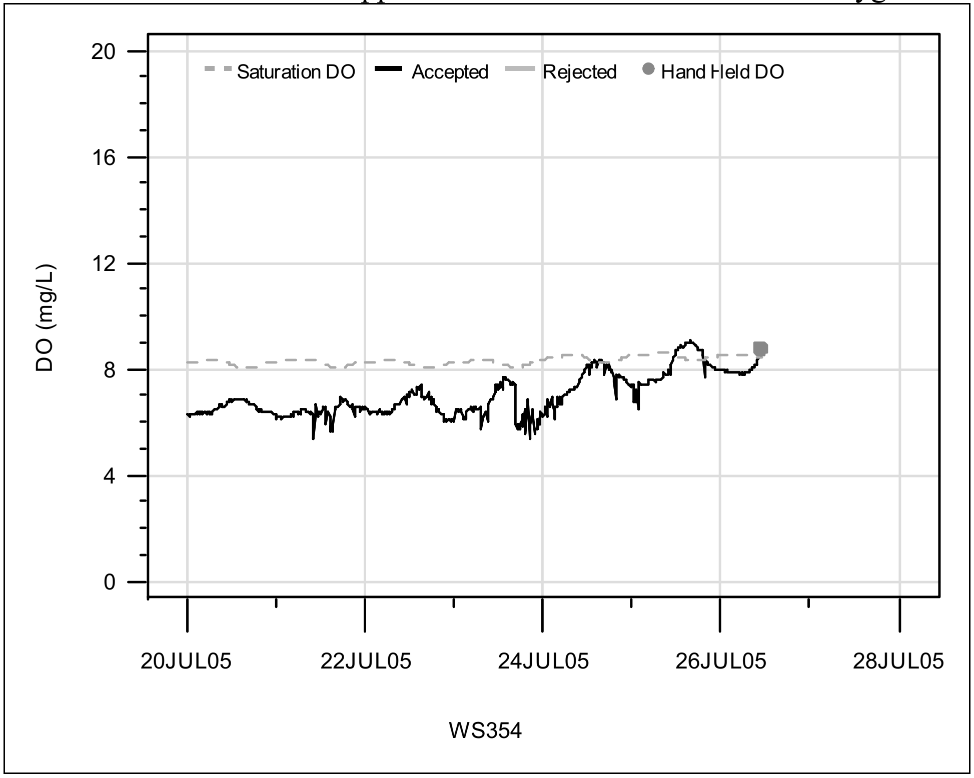


Figure C-55 Continuous Dissolved Oxygen (DO) with Calculated DO Saturation, 20JUL05 to 28JUL05, Site WS354

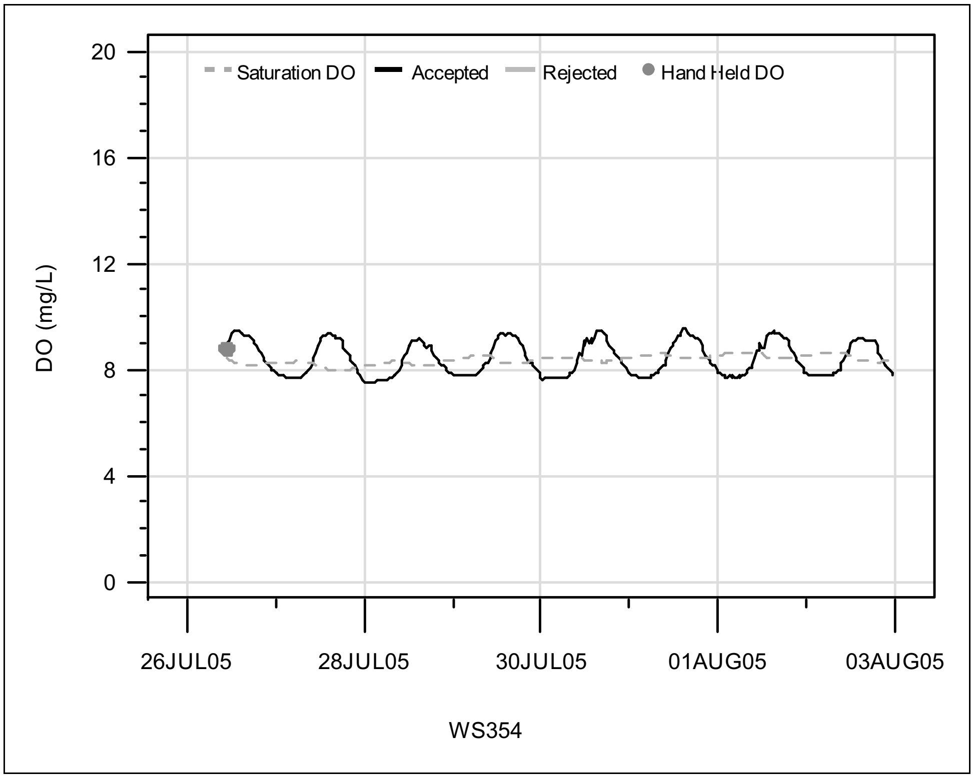


Figure C-56 Continuous Dissolved Oxygen (DO) with Calculated DO Saturation, 26JUL05 to 03AUG05, Site WS354

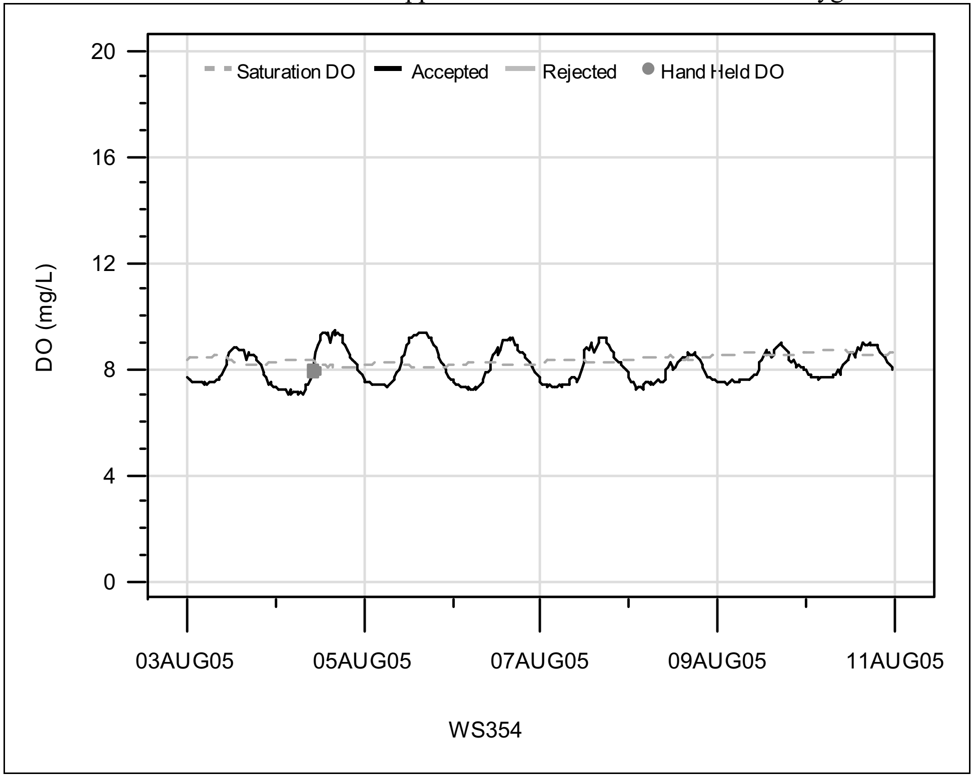


Figure C-57 Continuous Dissolved Oxygen (DO) with Calculated DO Saturation, 03AUG05 to 11AUG05, Site WS354

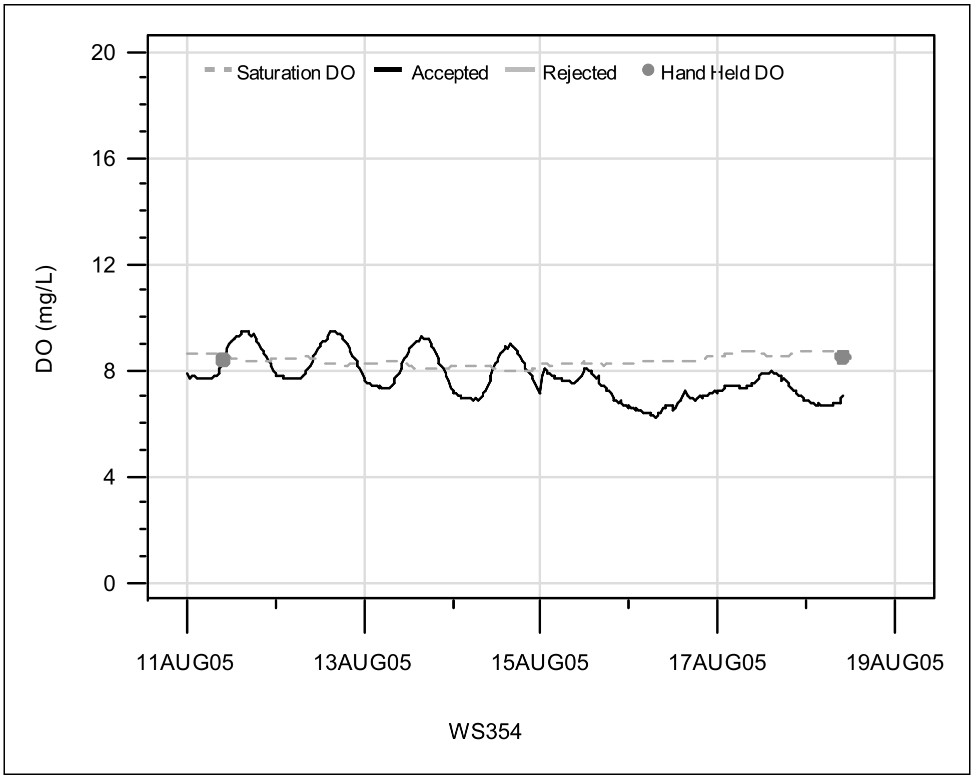


Figure C-58 Continuous Dissolved Oxygen (DO) with Calculated DO Saturation, 11AUG05 to 19AUG05, Site WS354

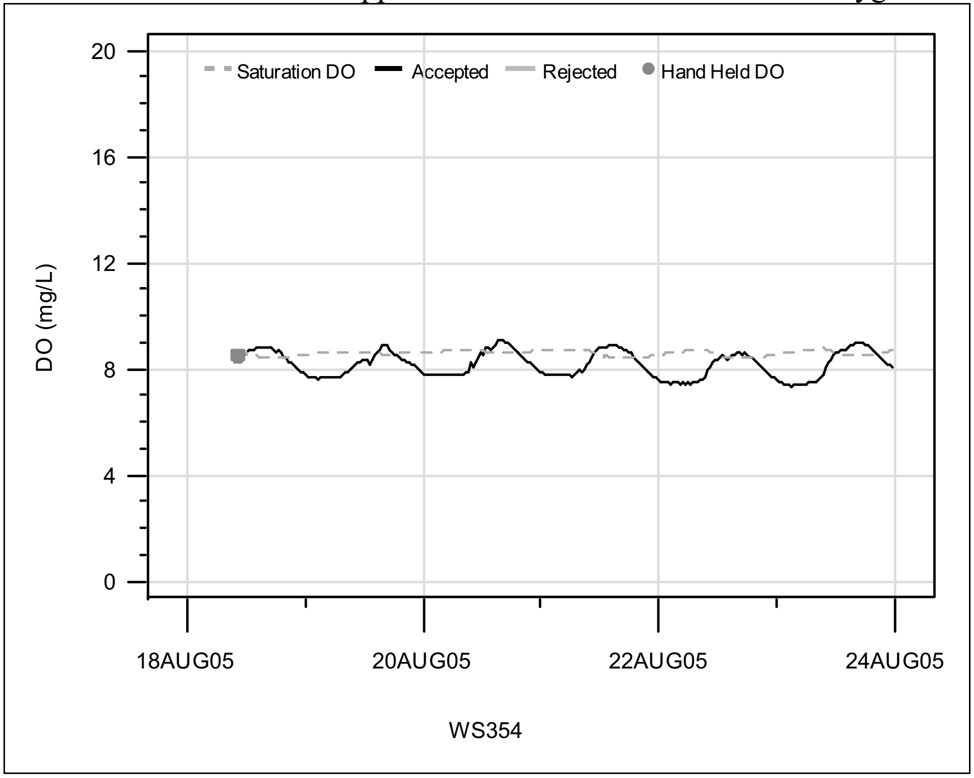


Figure C-59 Continuous Dissolved Oxygen (DO) with Calculated DO Saturation, 18AUG05 to 24AUG05, Site WS354

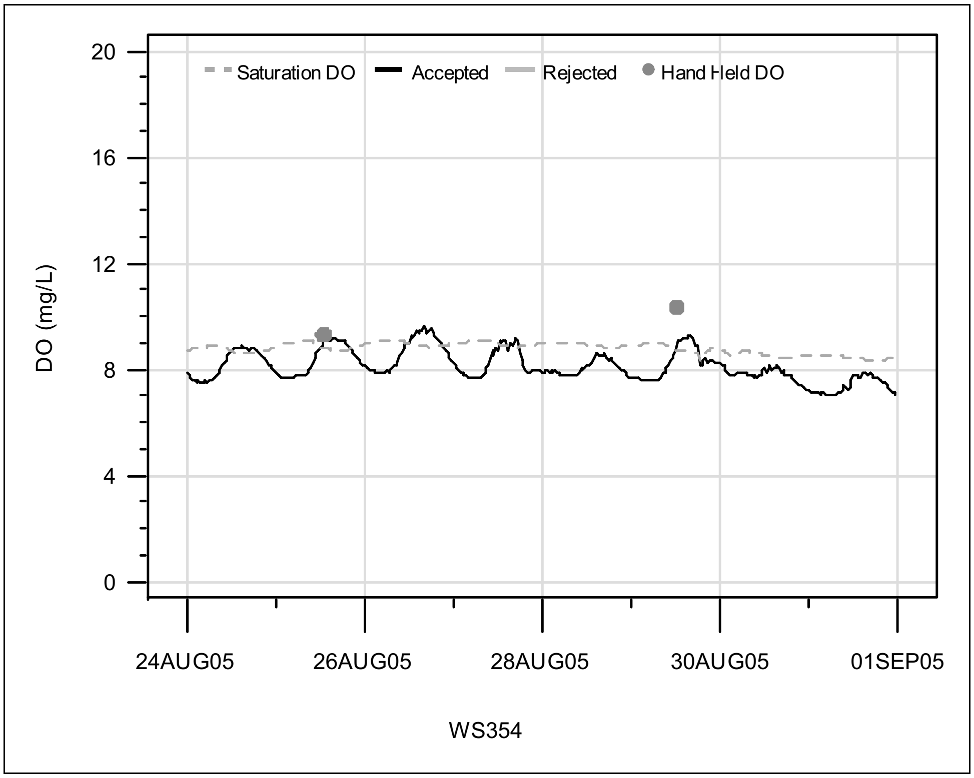


Figure C-60 Continuous Dissolved Oxygen (DO) with Calculated DO Saturation, 24AUG05 to 01SEP05, Site WS354

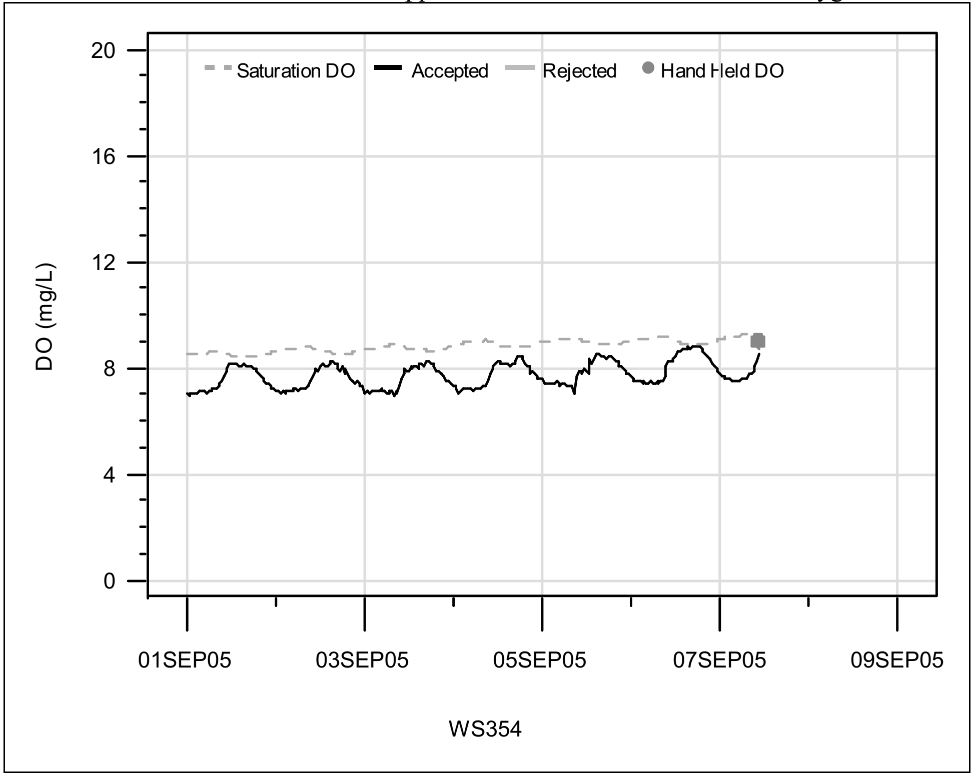


Figure C-61 Continuous Dissolved Oxygen (DO) with Calculated DO Saturation, 01SEP05 to 09SEP05, Site WS354

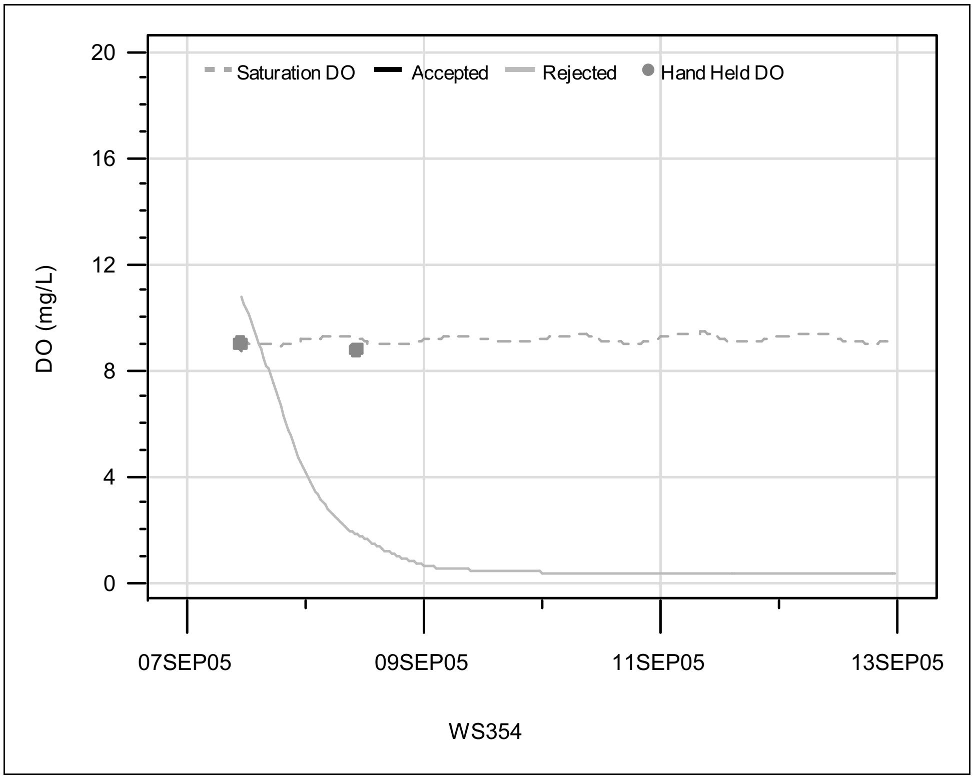


Figure C-62 Continuous Dissolved Oxygen (DO) with Calculated DO Saturation 07SEP05 to 13SEP05, Site WS354

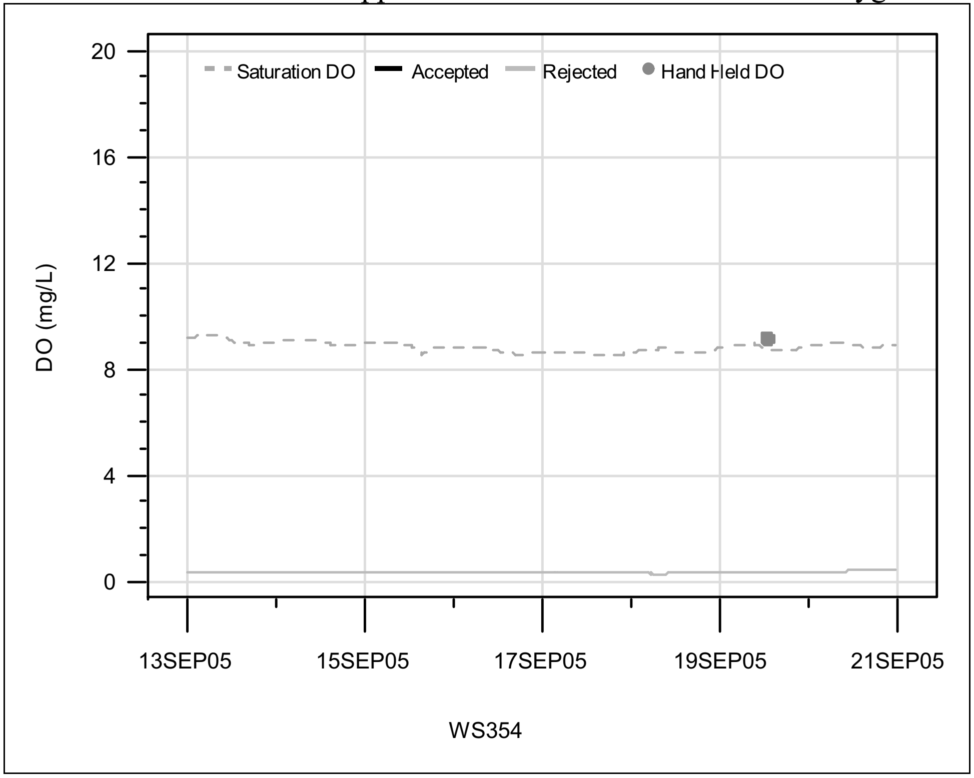


Figure C-63 Continuous Dissolved Oxygen (DO) with Calculated DO Saturation, 13SEP05 to 21SEP05, Site WS354

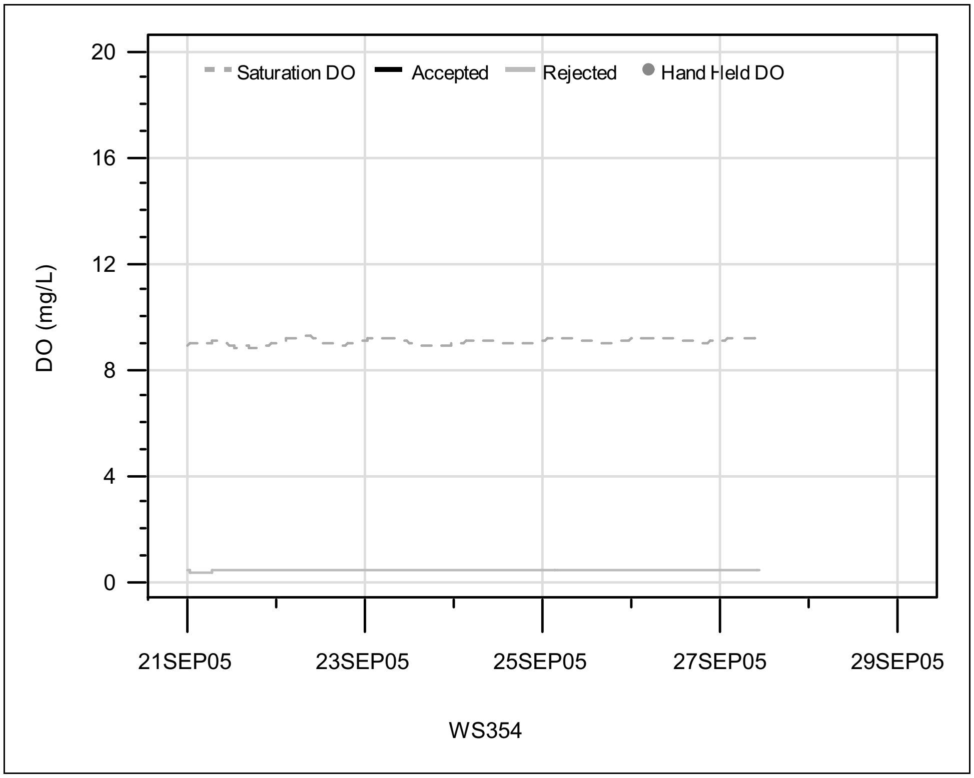


Figure C-64 Continuous Dissolved Oxygen (DO) with Calculated DO Saturation, 21SEP05 to 29SEP05, Site WS354

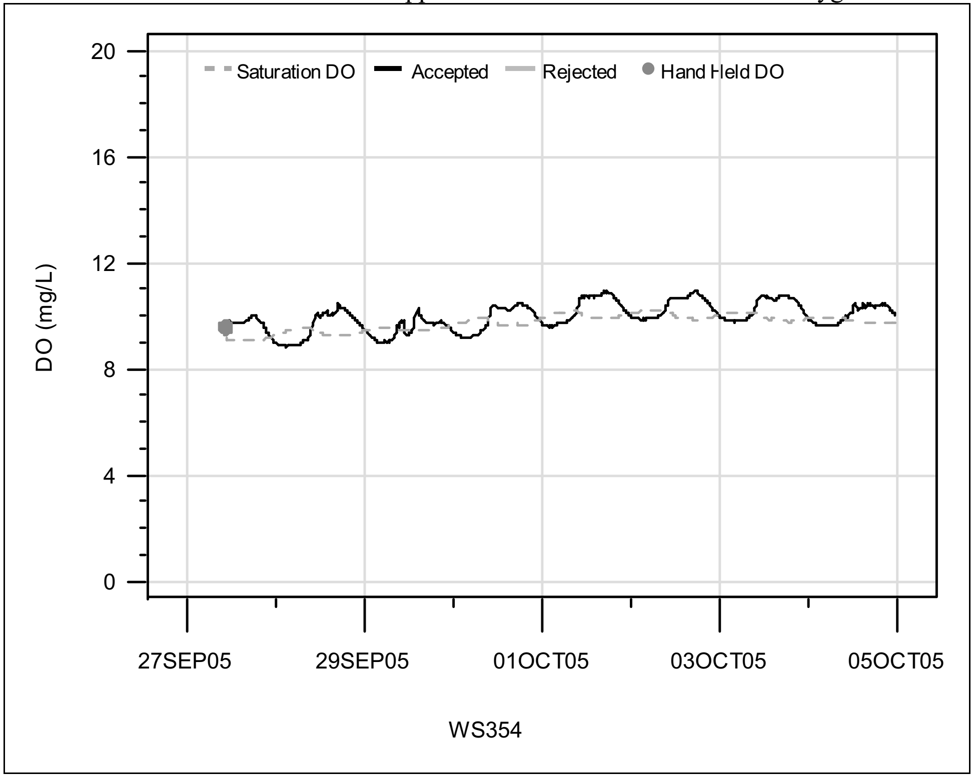


Figure C-65 Continuous Dissolved Oxygen (DO) with Calculated DO Saturation, 27SEP05 to 05OCT05, Site WS354

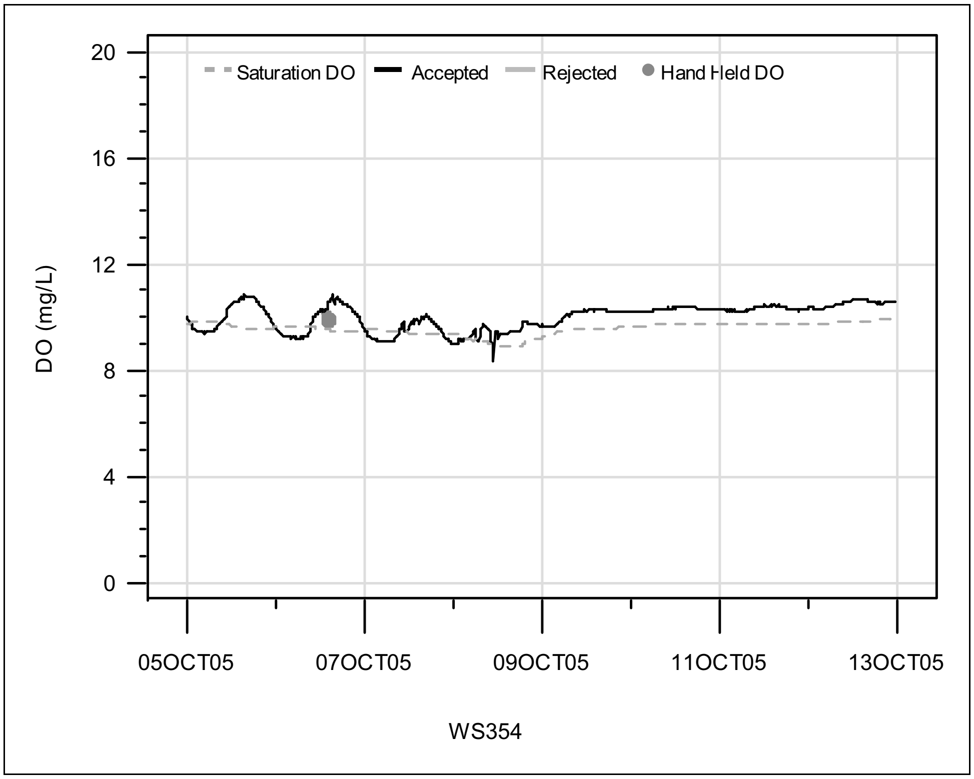


Figure C-66 Continuous Dissolved Oxygen (DO) with Calculated DO Saturation, 05OCT05 to 13OCT05, Site WS354

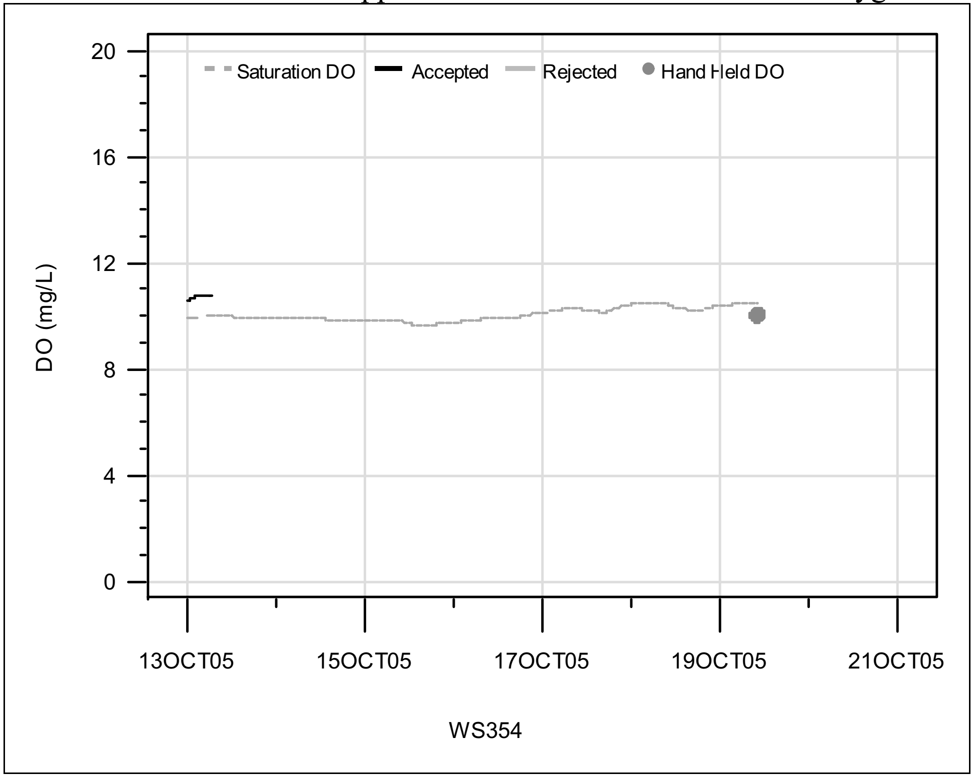


Figure C-67 Continuous Dissolved Oxygen (DO) with Calculated DO Saturation, 13OCT05 to 21OCT05, Site WS354

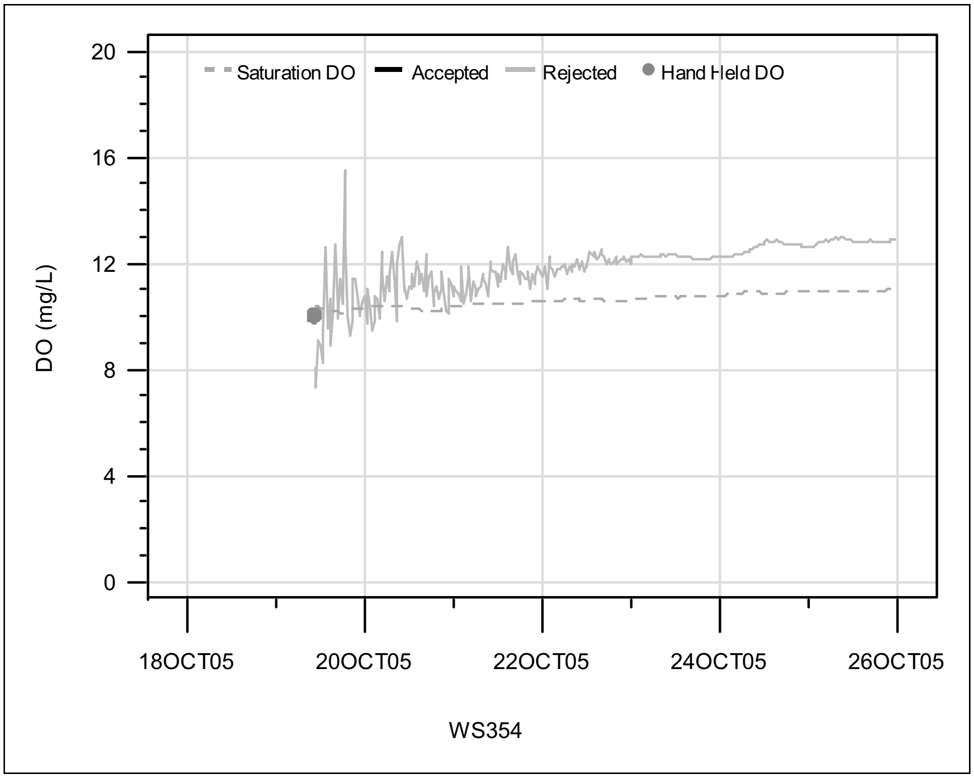


Figure C-68 Continuous Dissolved Oxygen (DO) with Calculated DO Saturation, 18OCT05 to 26OCT05, Site WS0354

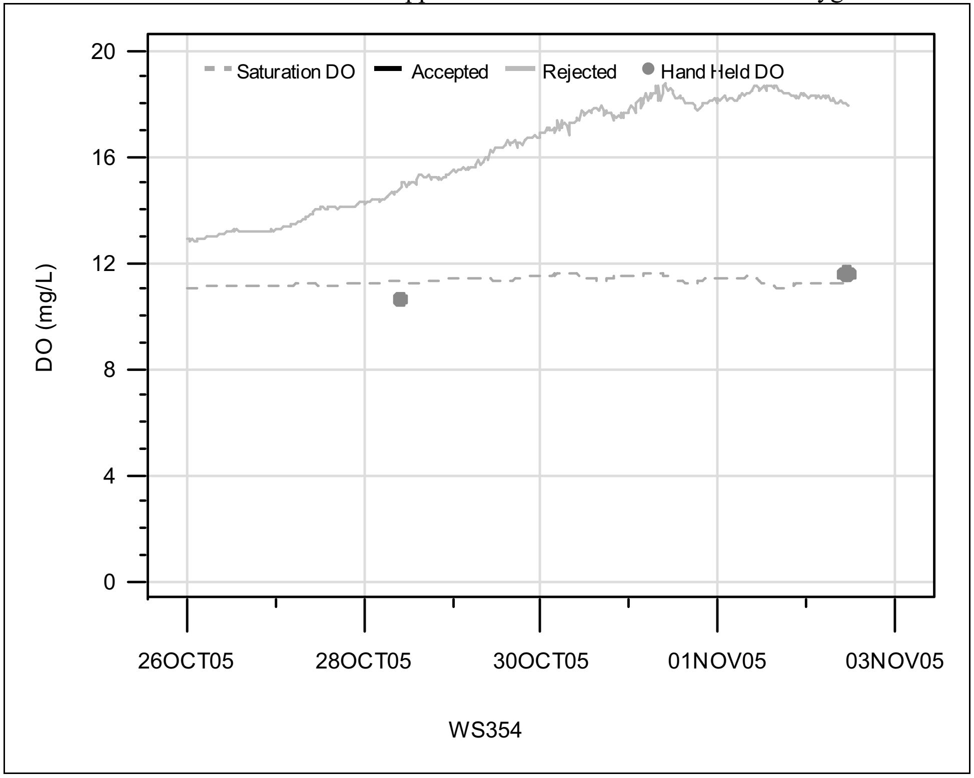


Figure C-69 Continuous Dissolved Oxygen (DO) with Calculated DO Saturation, 26OCT05 to 03NOV05, Site WS354

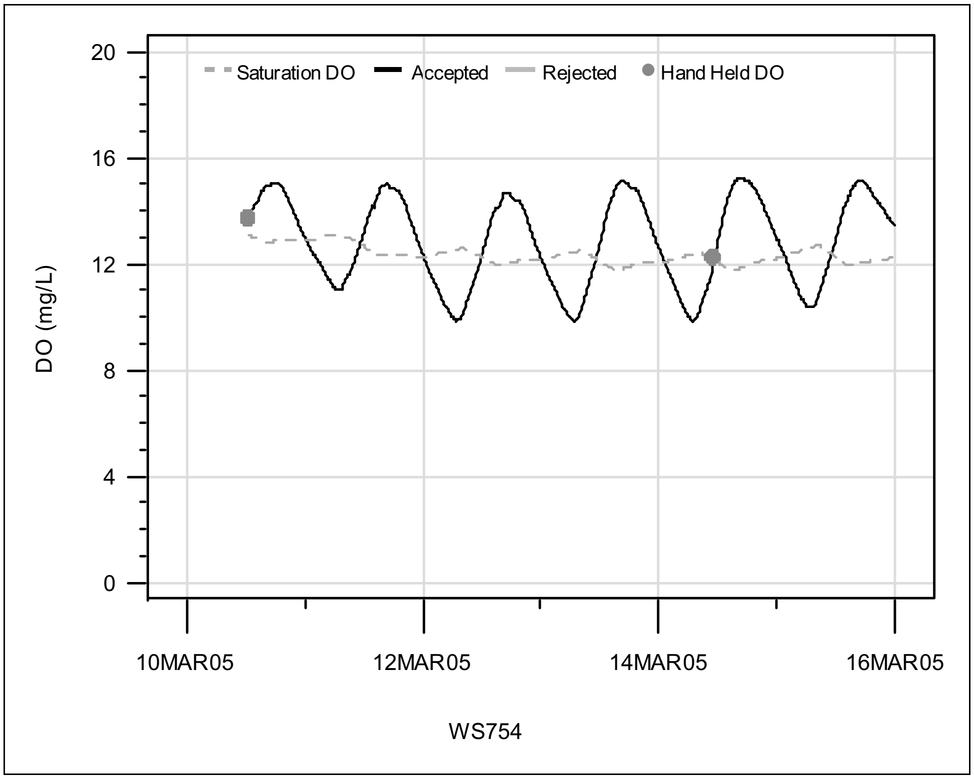


Figure C-70 Continuous Dissolved Oxygen (DO) with Calculated DO Saturation, 10MAR05 to 16MAR05, Site WS754

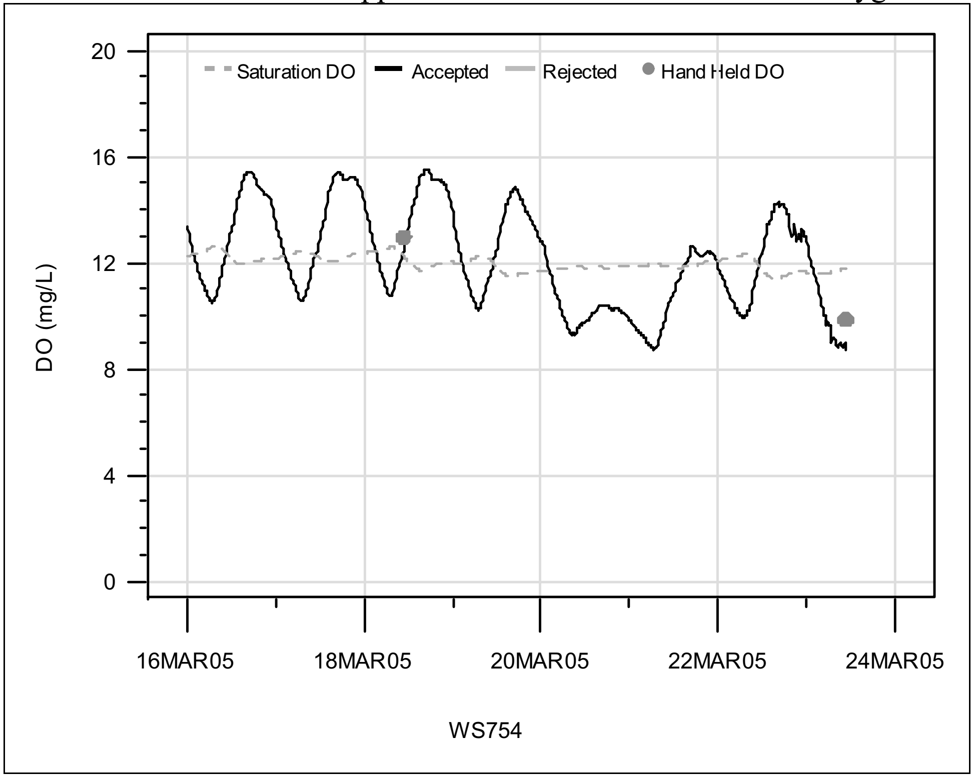


Figure C-71 Continuous Dissolved Oxygen (DO) with Calculated DO Saturation, 16MAR05 to 24MAR05, Site WS754

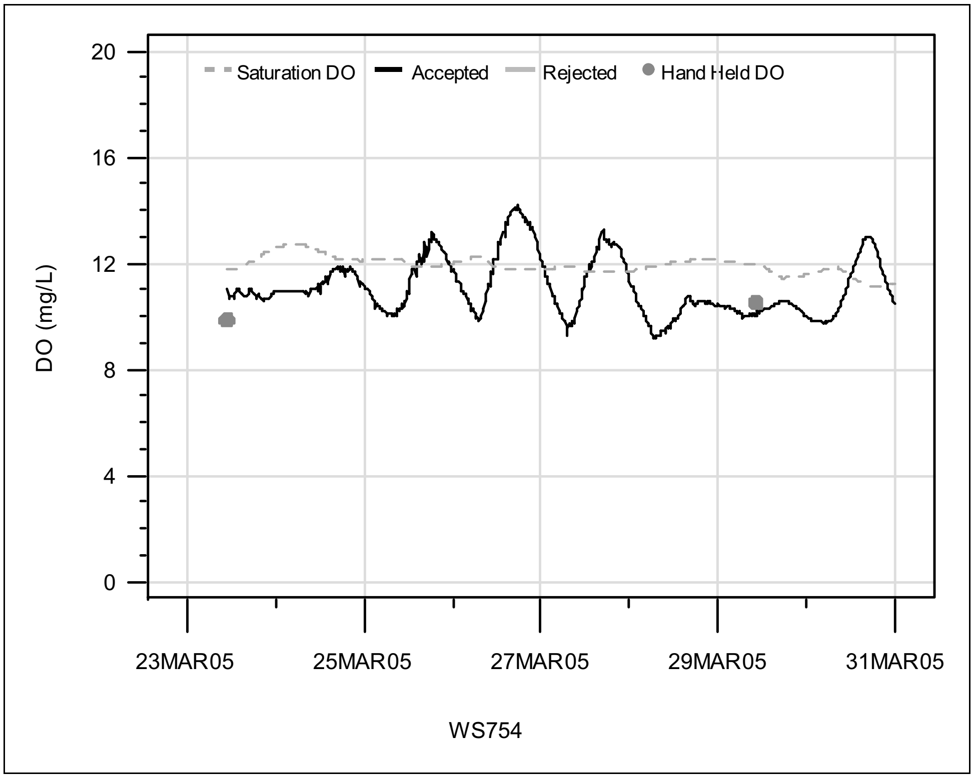


Figure C-72 Continuous Dissolved Oxygen (DO) with Calculated DO Saturation, 23MAR05 to 31MAR05, Site WS754

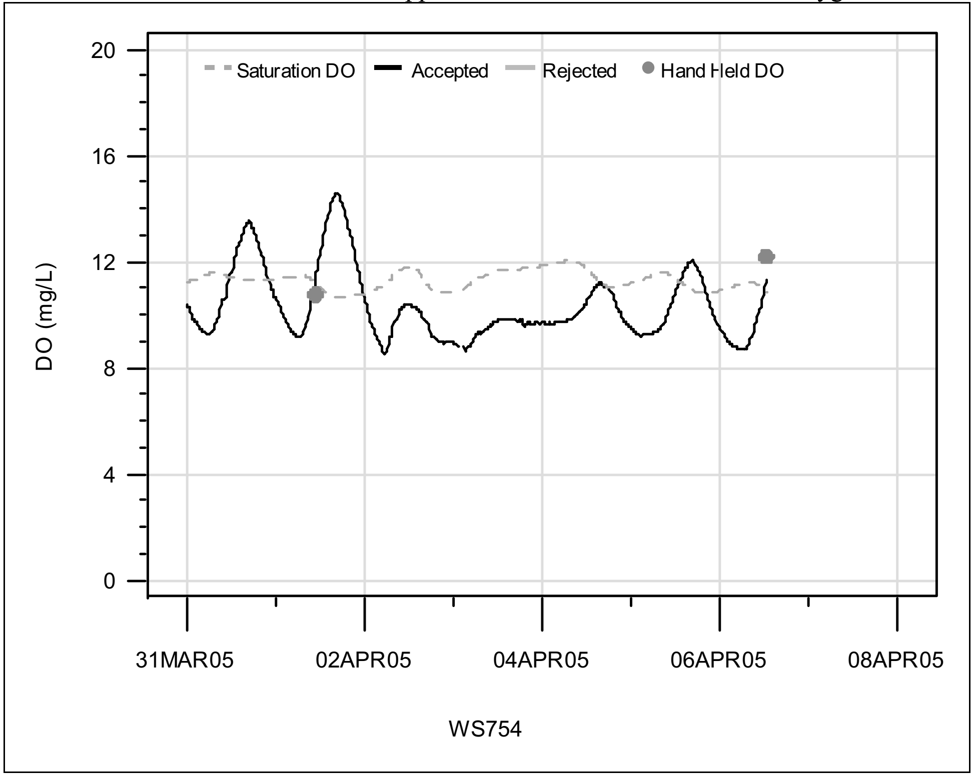


Figure C-73 Continuous Dissolved Oxygen (DO) with Calculated DO Saturation, 31MAR05 to 08APR05, Site WS754

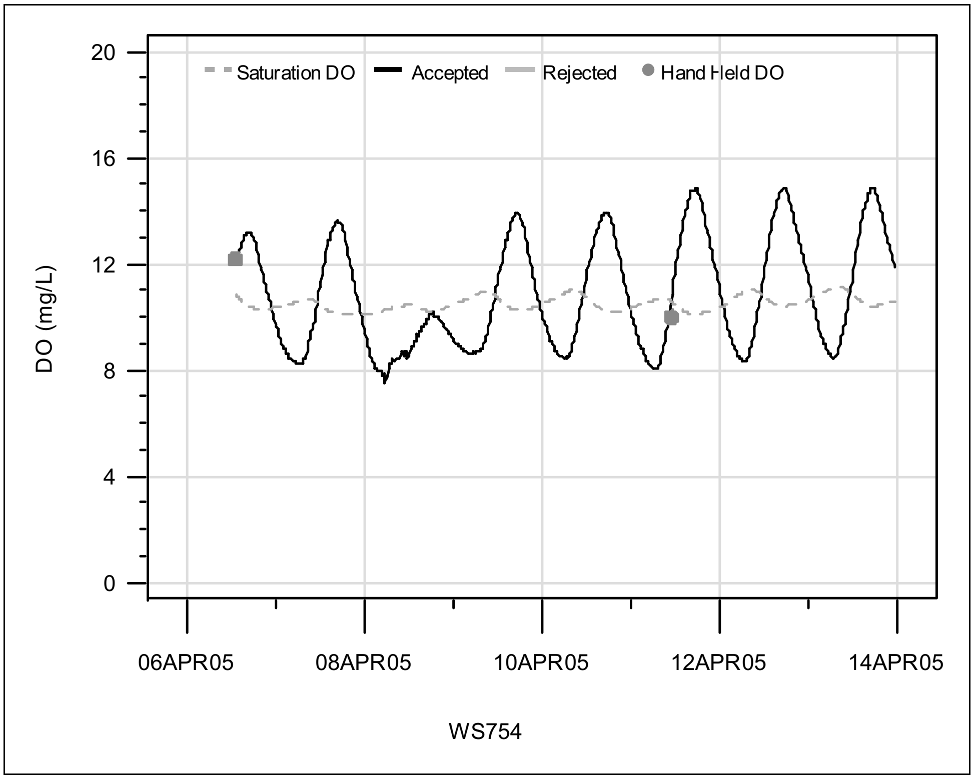


Figure C-74 Continuous Dissolved Oxygen (DO) with Calculated DO Saturation, 06APR05 to 14APR05, Site WS754

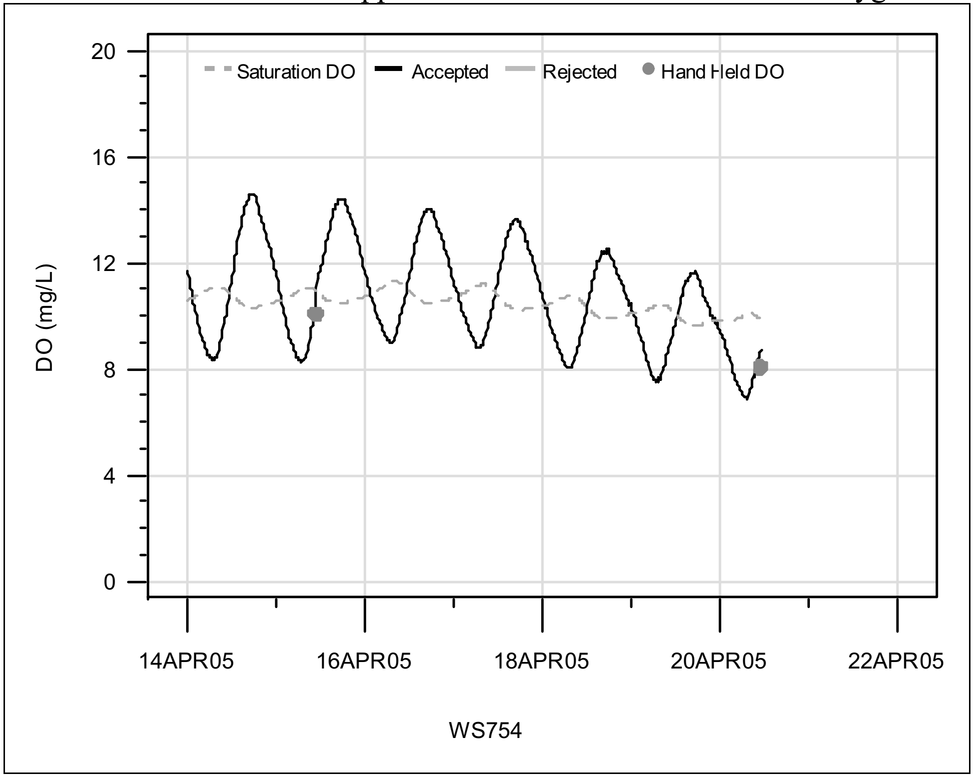


Figure C-75 Continuous Dissolved Oxygen (DO) with Calculated DO Saturation, 14APR05 to 22APR05, Site WS754

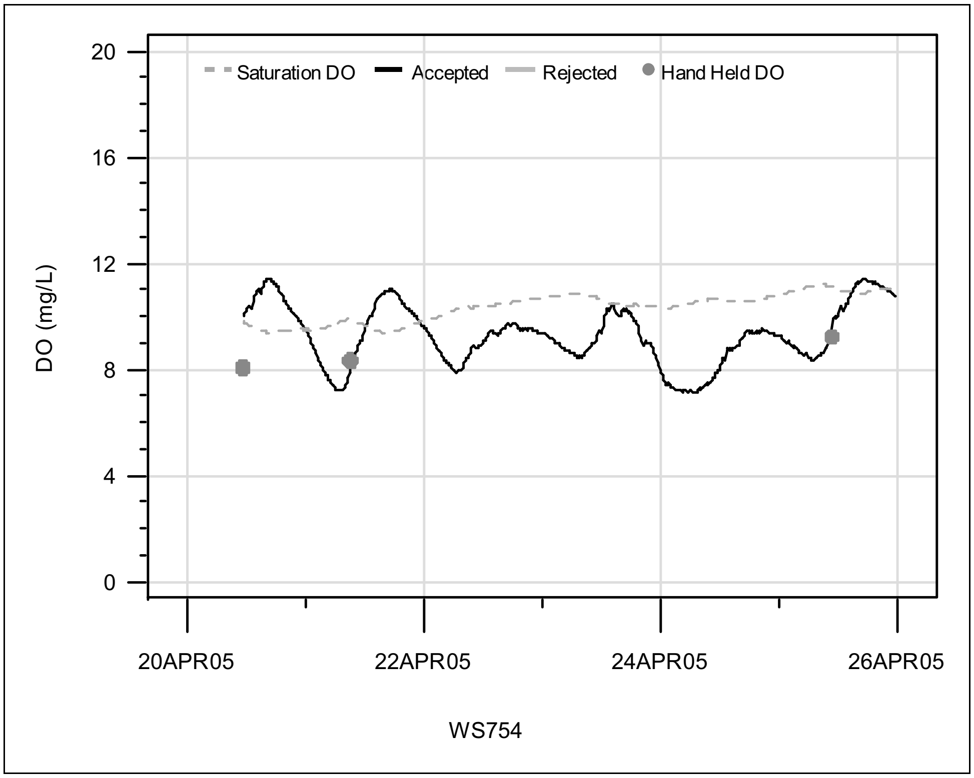


Figure C-76 Continuous Dissolved Oxygen (DO) with Calculated DO Saturation, 20APR05 to 26APR05, Site WS754

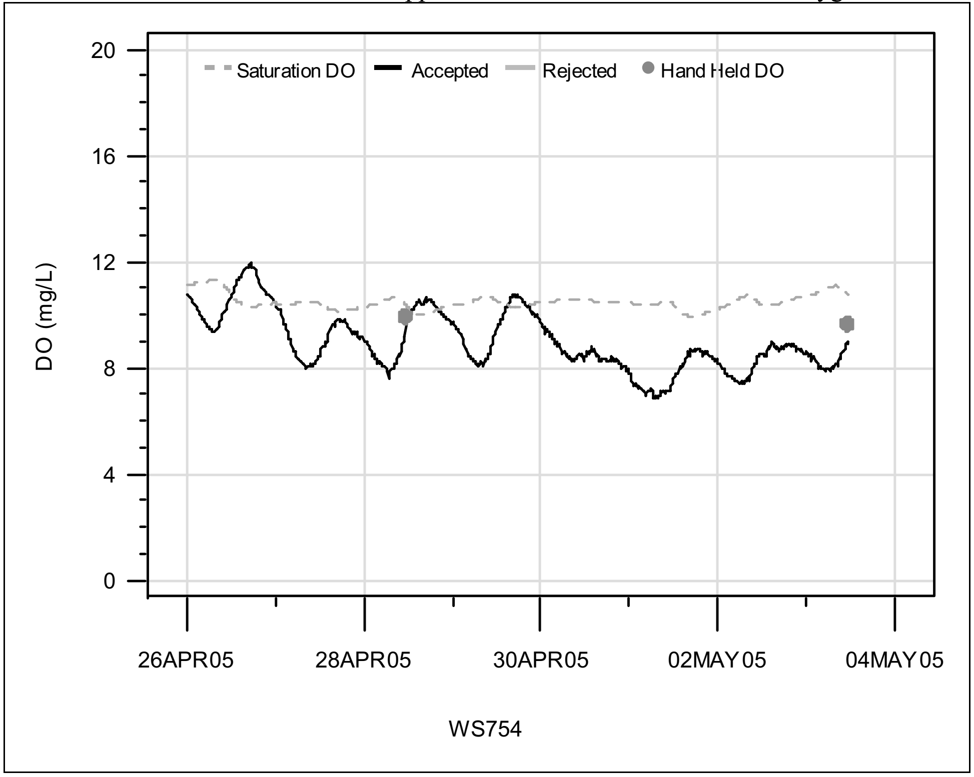


Figure C-77 Continuous Dissolved Oxygen (DO) with Calculated DO Saturation, 26APR05 to 04MAY05, Site WS754

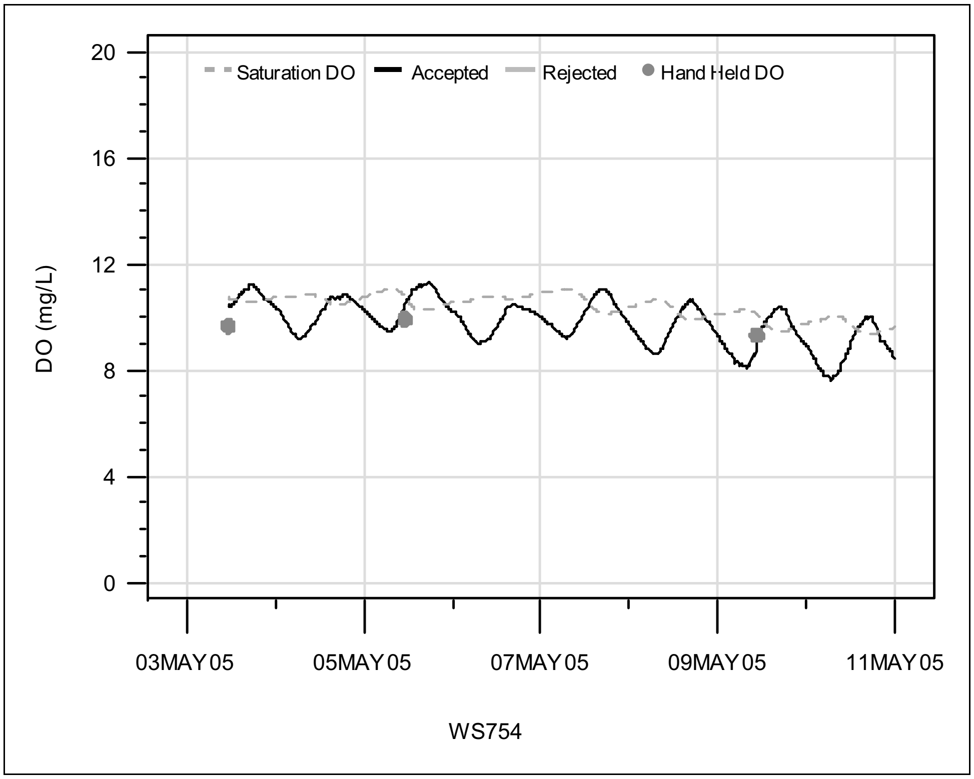


Figure C-78 Continuous Dissolved Oxygen (DO) with Calculated DO Saturation, 03MAY05 to 11MAY05, Site WS754

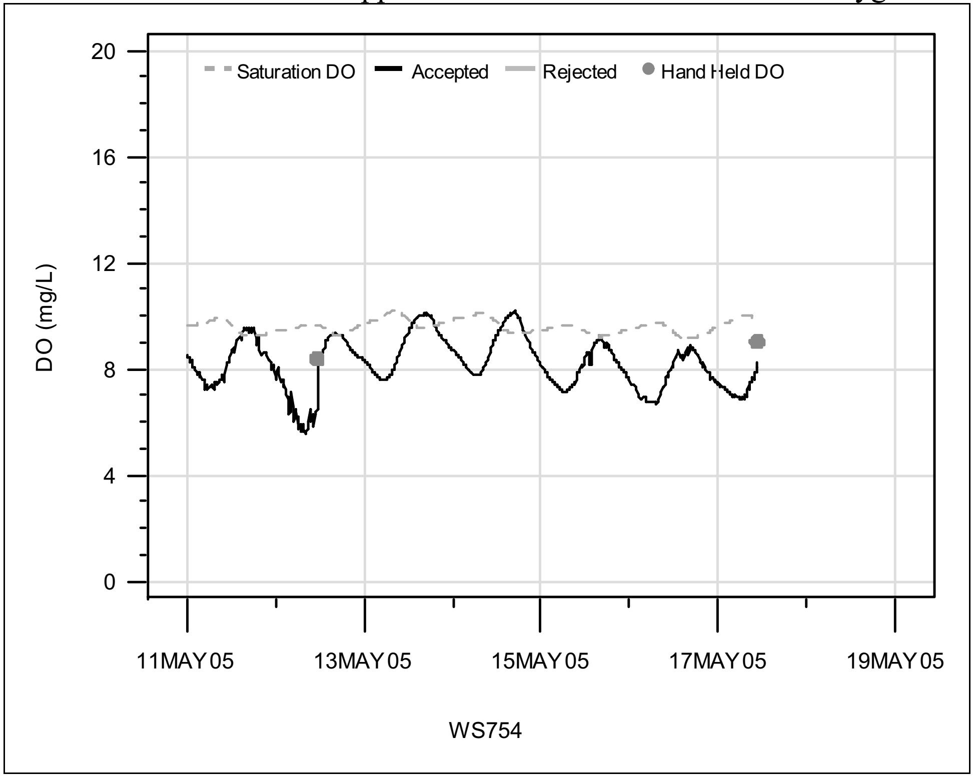


Figure C-79 Continuous Dissolved Oxygen (DO) with Calculated DO Saturation, 11MAY05 19MAY05, Site WS754

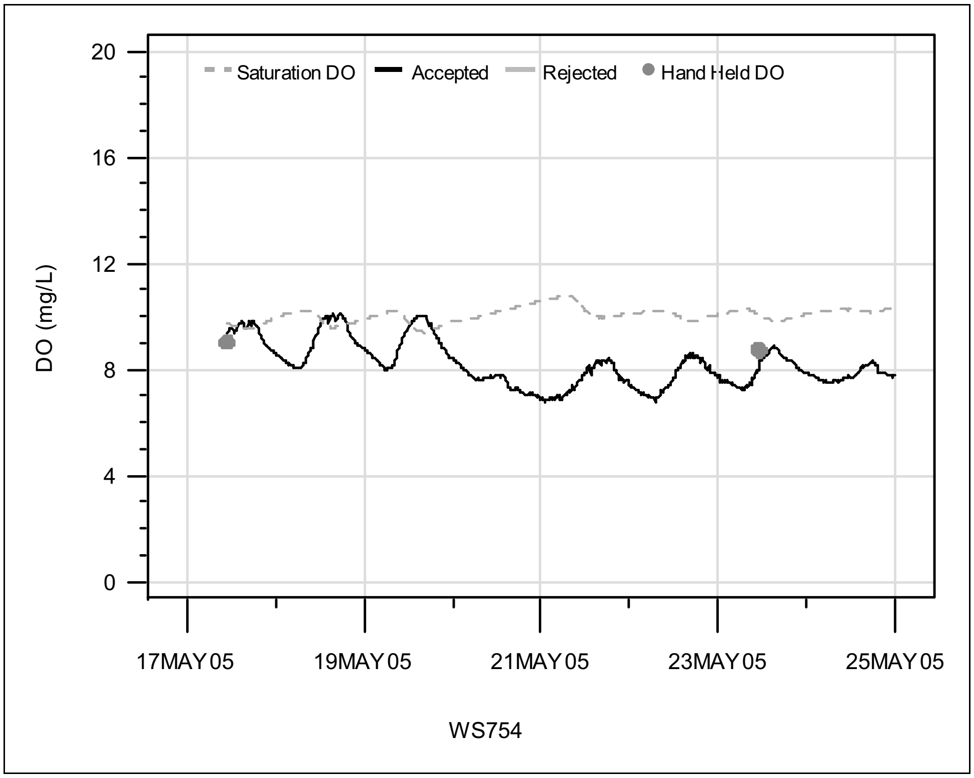


Figure C-80 Continuous Dissolved Oxygen (DO) with Calculated DO Saturation, 17MAY05 to 25MAY05, Site WS754

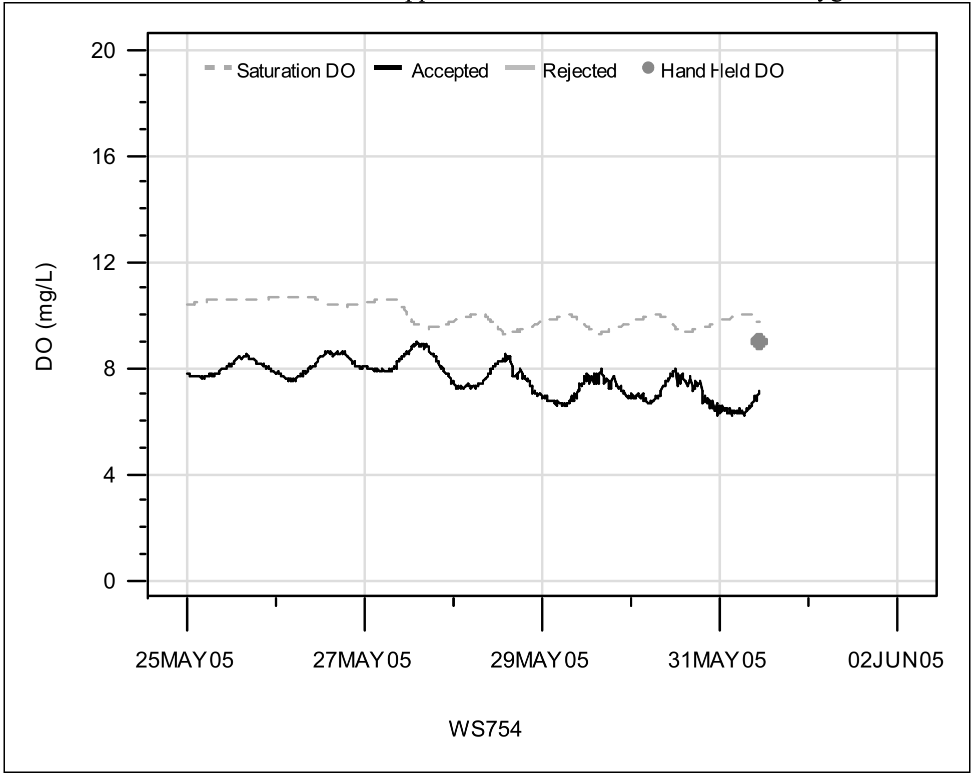


Figure C-81 Continuous Dissolved Oxygen (DO) with Calculated DO Saturation, 25MAY05 to 02JUN05, Site WS754

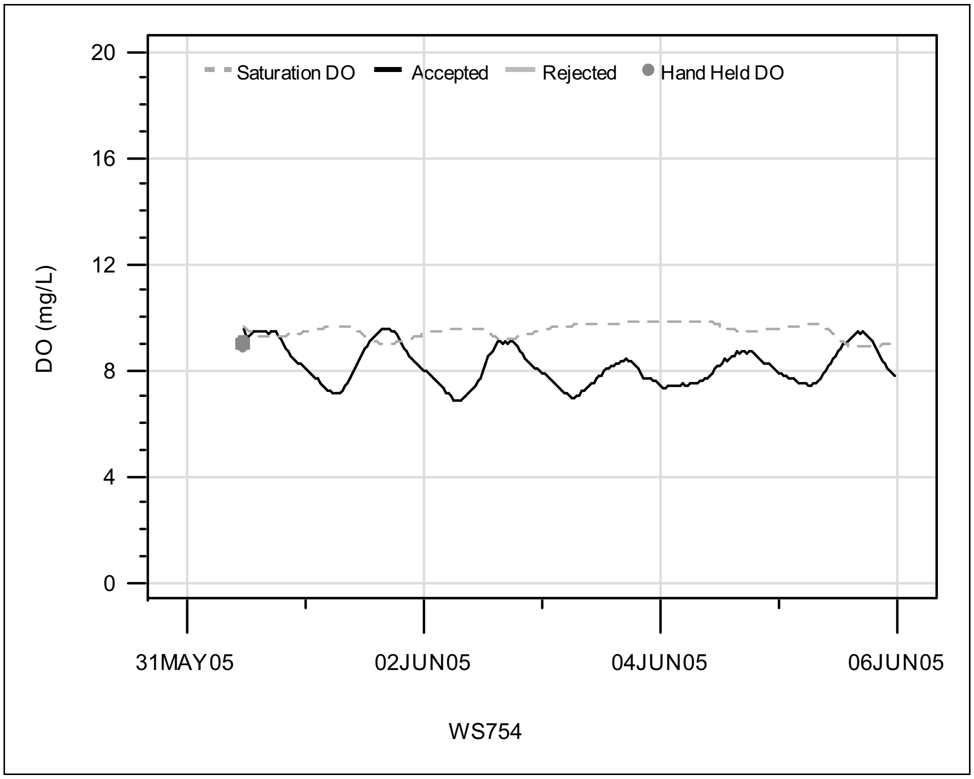


Figure C-82 Continuous Dissolved Oxygen (DO) with Calculated DO Saturation, 31MAY05 to 06JUN05, Site WS754

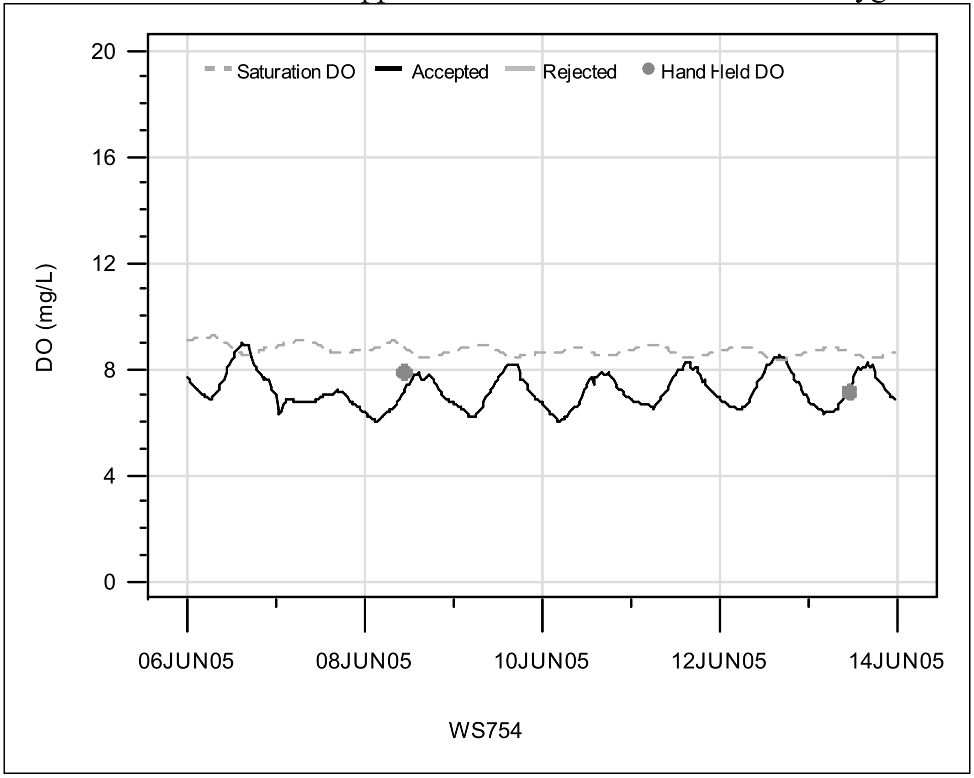


Figure C-83 Continuous Dissolved Oxygen (DO) with Calculated DO Saturation, 06JUN05 to 14JUN05, Site WS754

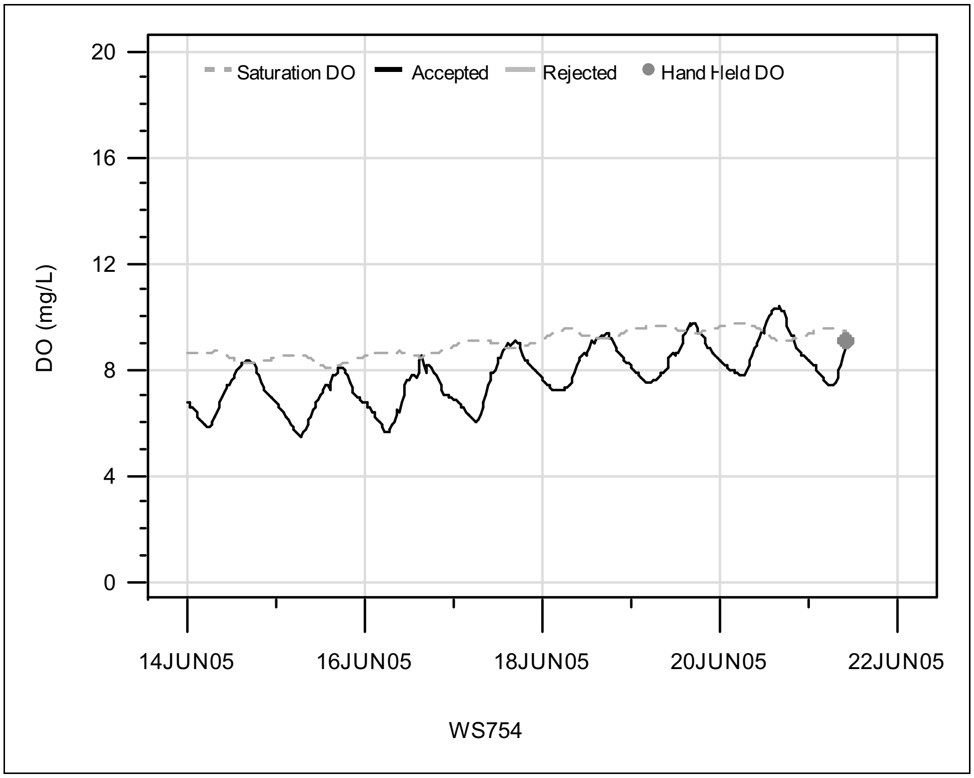


Figure C-84 Continuous Dissolved Oxygen (DO) with Calculated DO Saturation, 14JUN05 to 22JUN05, Site WS754

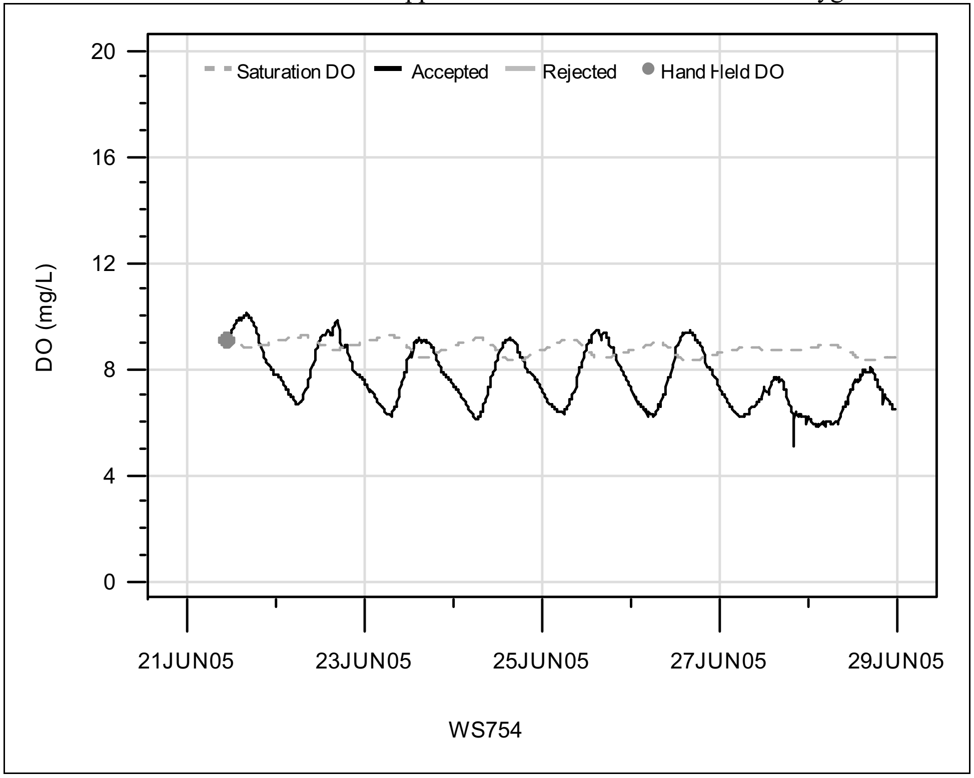


Figure C-85 Continuous Dissolved Oxygen (DO) with Calculated DO Saturation, 21JUN05 to 29JUN05, Site WS754

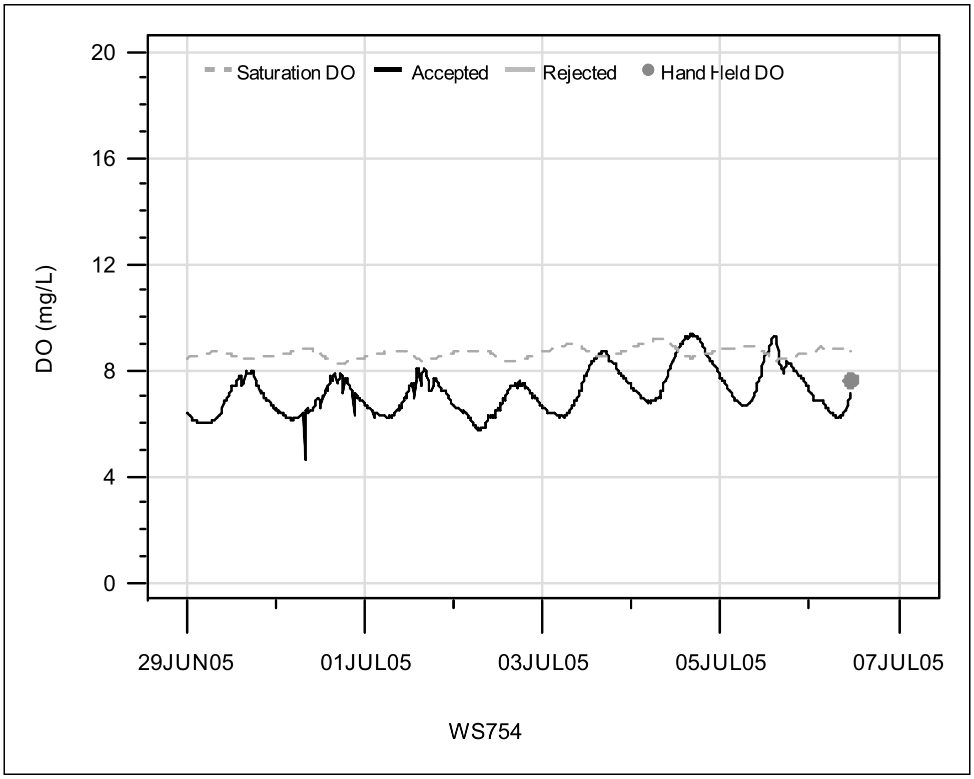


Figure C-86 Continuous Dissolved Oxygen (DO) with Calculated DO Saturation, 29JUN05 to 07JUL05, Site WS754

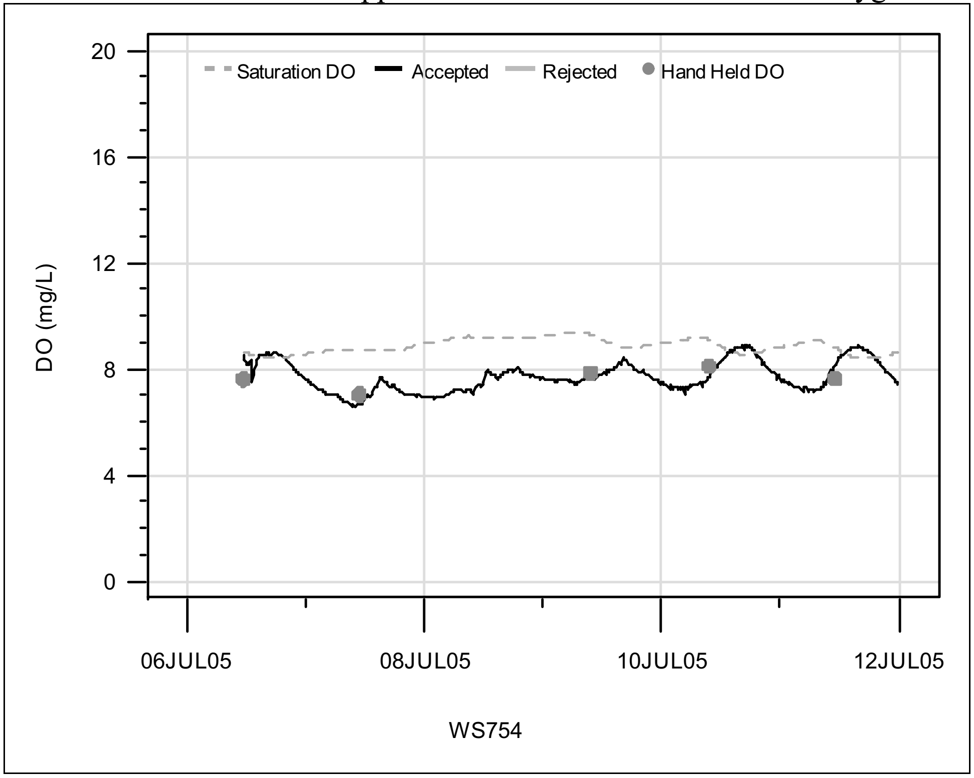


Figure C-87 Continuous Dissolved Oxygen (DO) with Calculated DO Saturation, 06JUL05 to 12JUL05, Site WS754

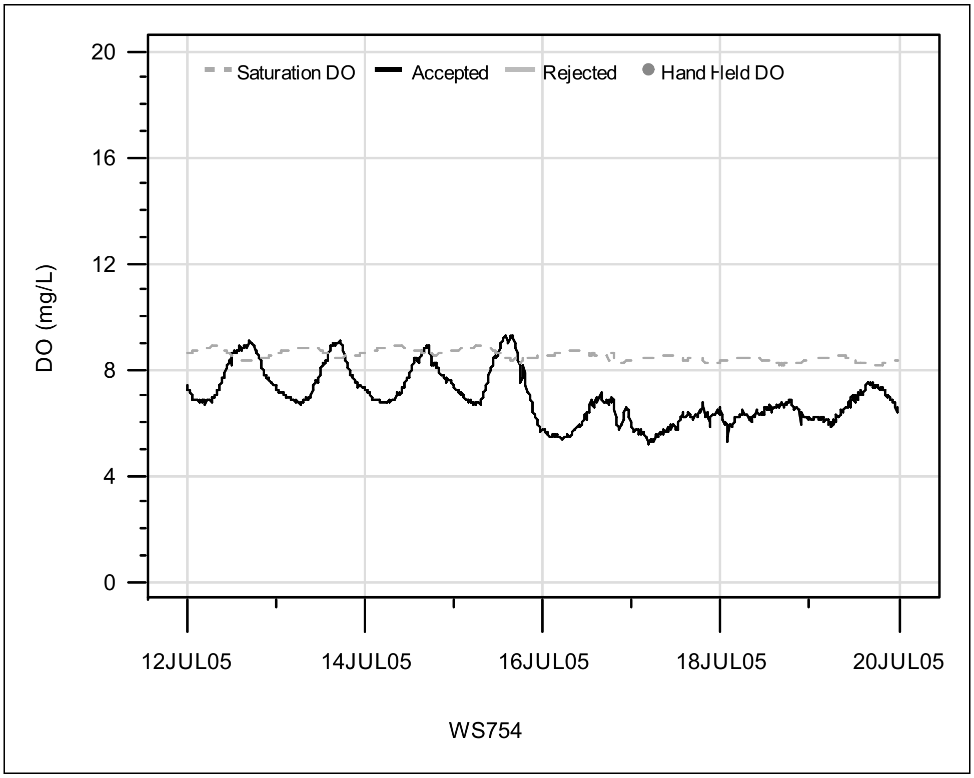


Figure C-88 Continuous Dissolved Oxygen (DO) with Calculated DO Saturation, 12JUL05 to 20JUL05, Site WS754

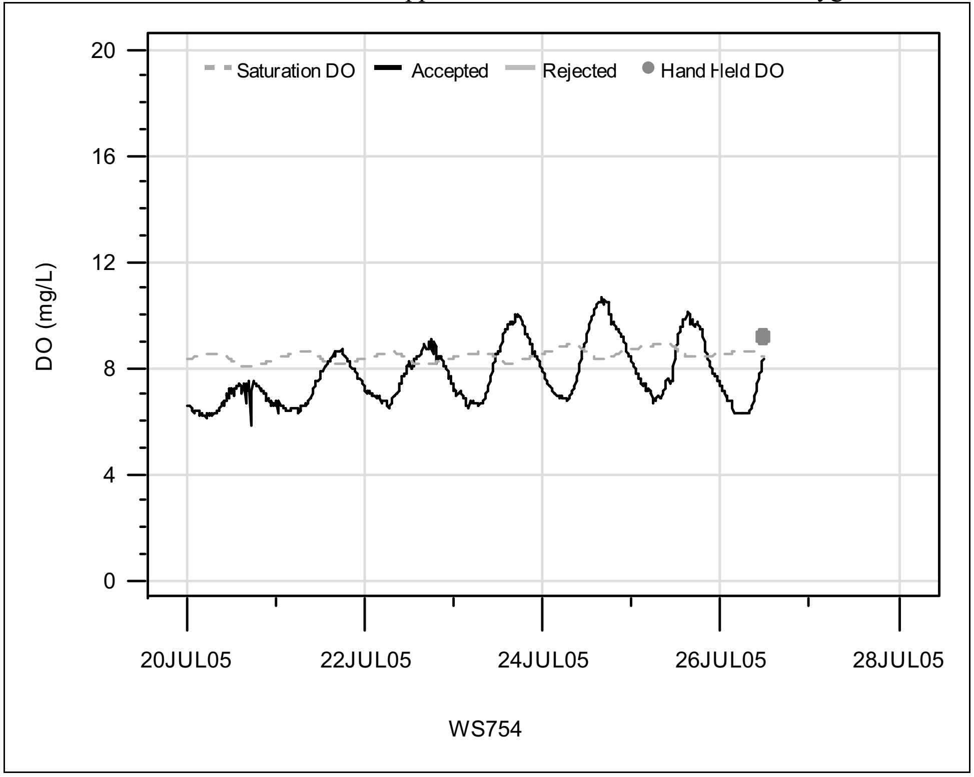


Figure C-89 Continuous Dissolved Oxygen (DO) with Calculated DO Saturation, 20JUL05 to 28JUL05, Site WS754

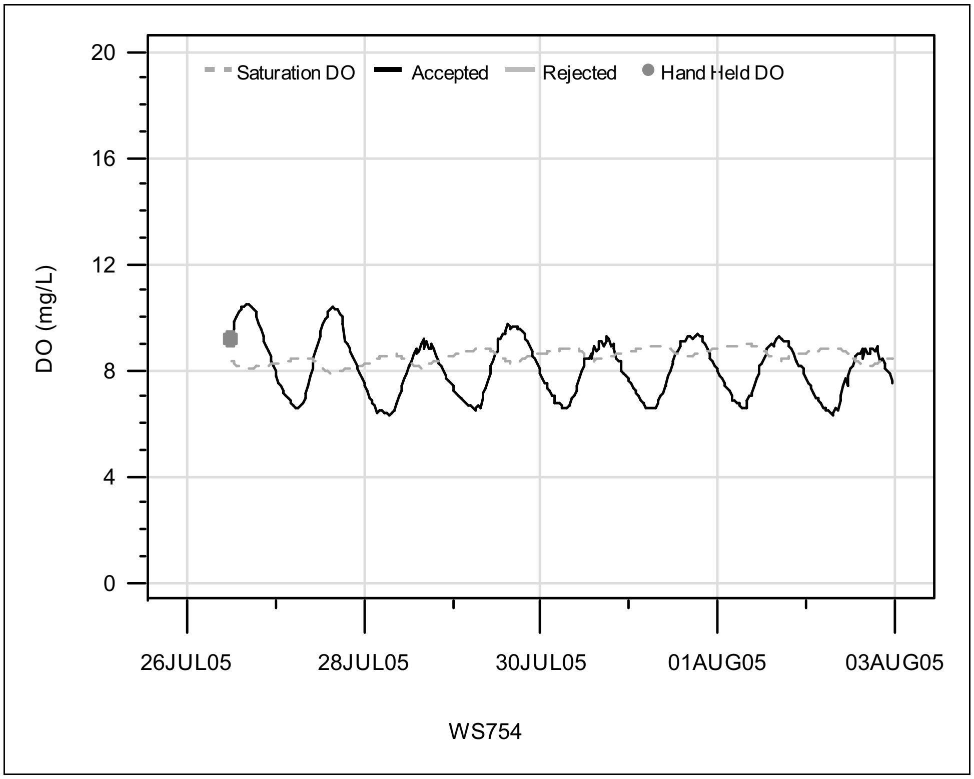


Figure C-90 Continuous Dissolved Oxygen (DO) with Calculated DO Saturation, 26JUL05 to 03AUG05, Site WS754

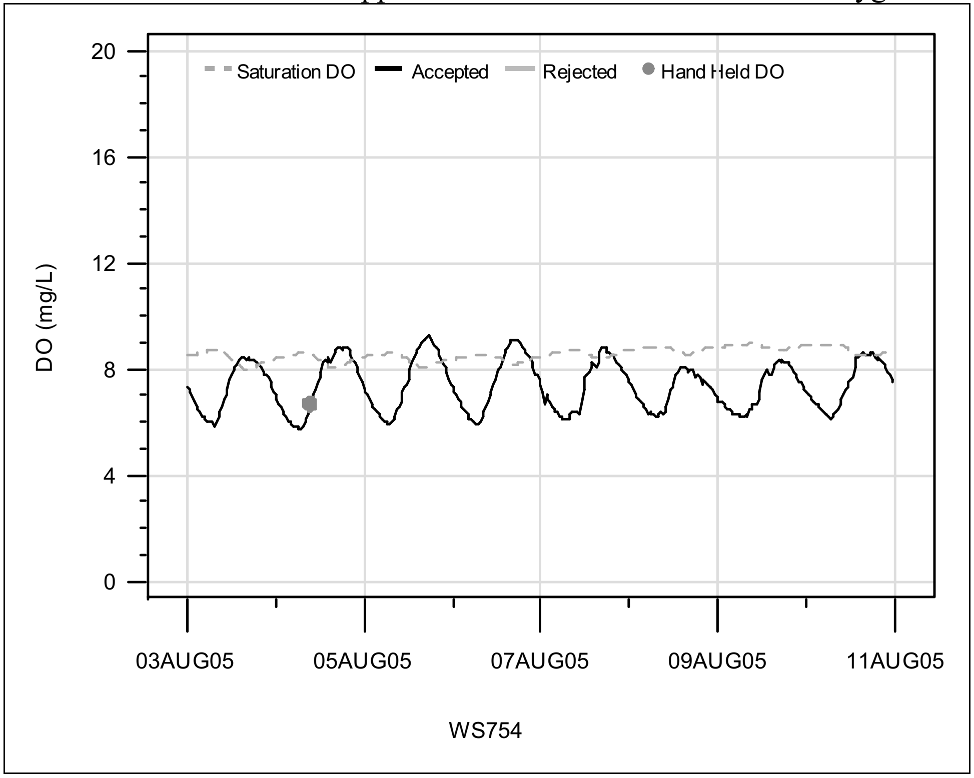


Figure C-91 Continuous Dissolved Oxygen (DO) with Calculated DO Saturation, 03AUG05 to 11AUG05, Site WS754

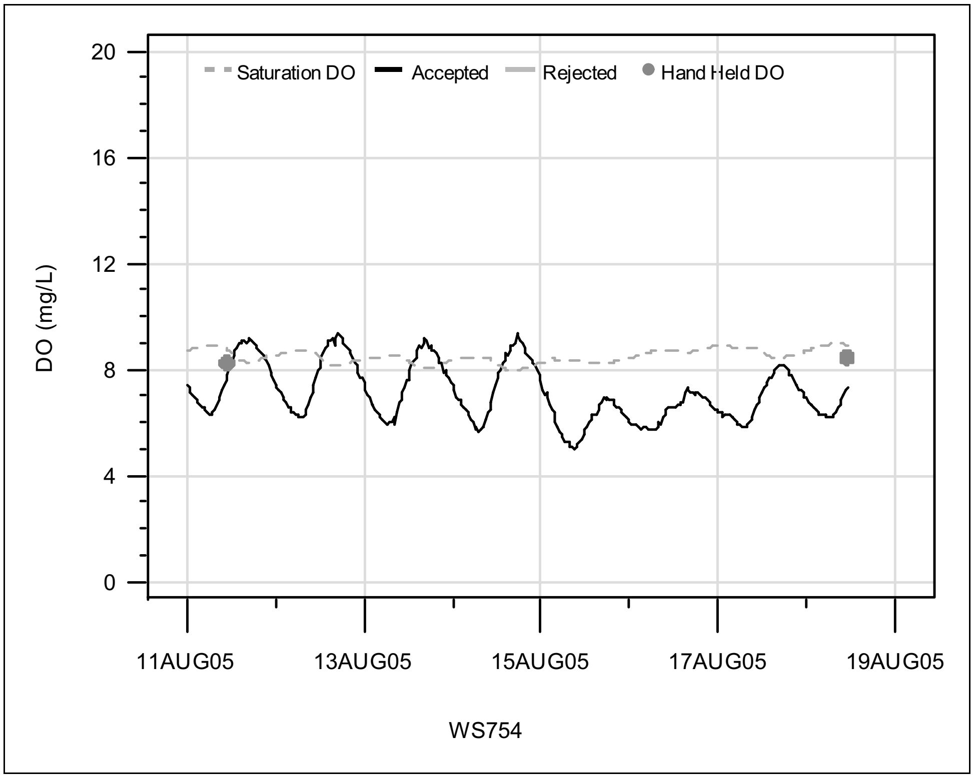


Figure C-92 Continuous Dissolved Oxygen (DO) with Calculated DO Saturation, 11AUG05 to 19AUG05, Site WS754

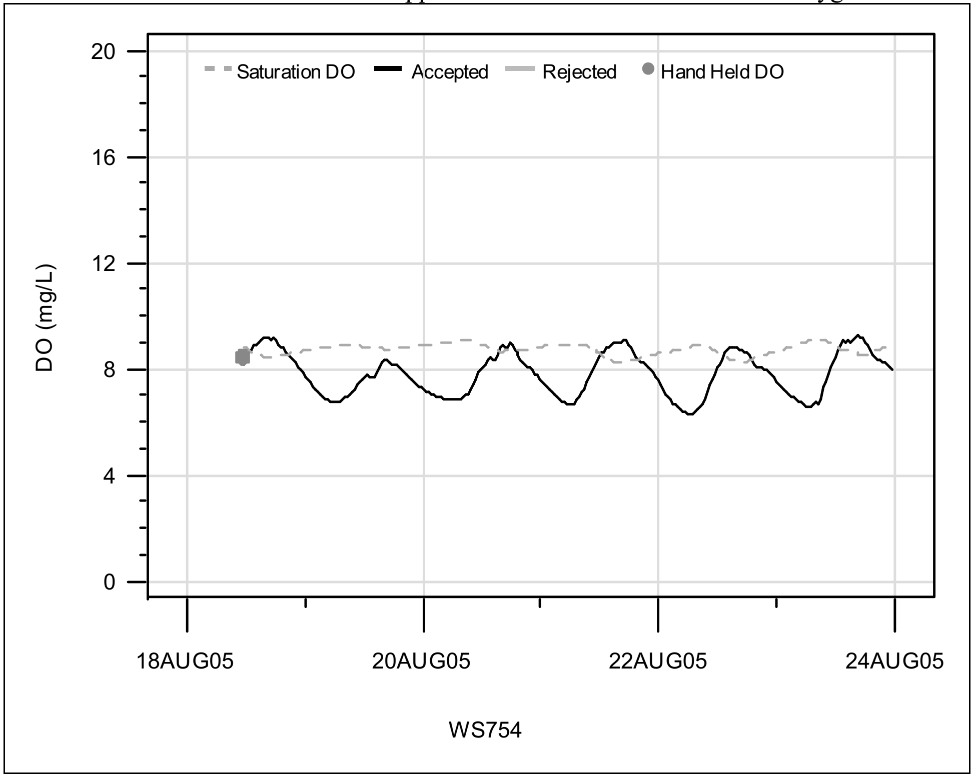


Figure C-93 Continuous Dissolved Oxygen (DO) with Calculated DO Saturation, 18AUG05 to 24AUG05, Site WS754

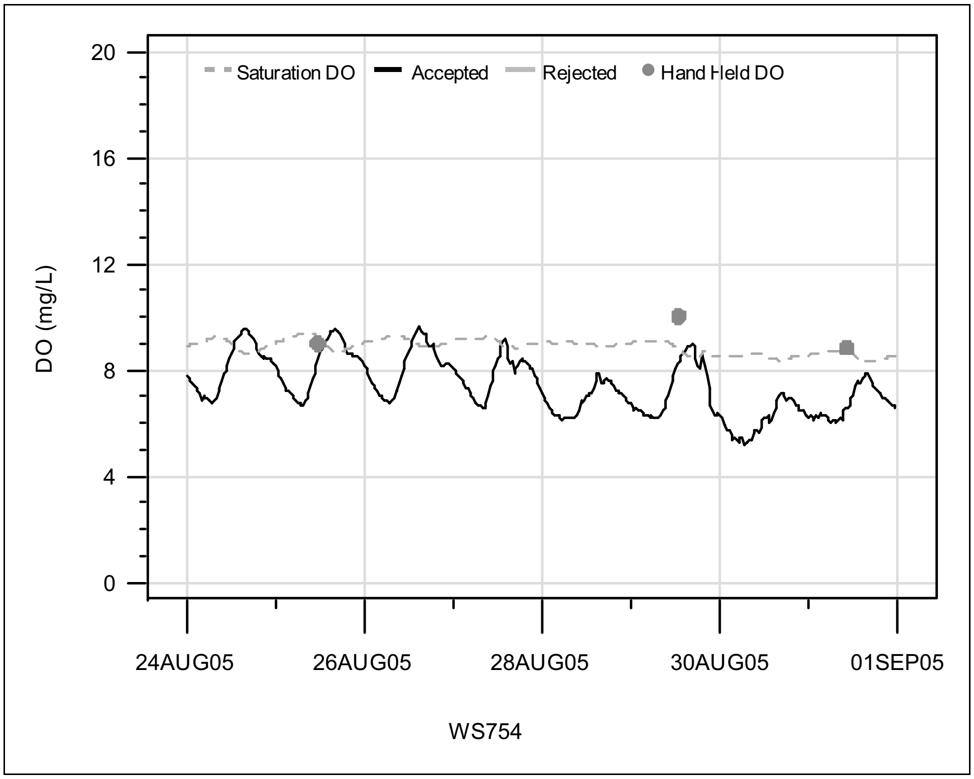


Figure C-94 Continuous Dissolved Oxygen (DO) with Calculated DO Saturation, 24AUG05 to 01SEP05, Site WS754

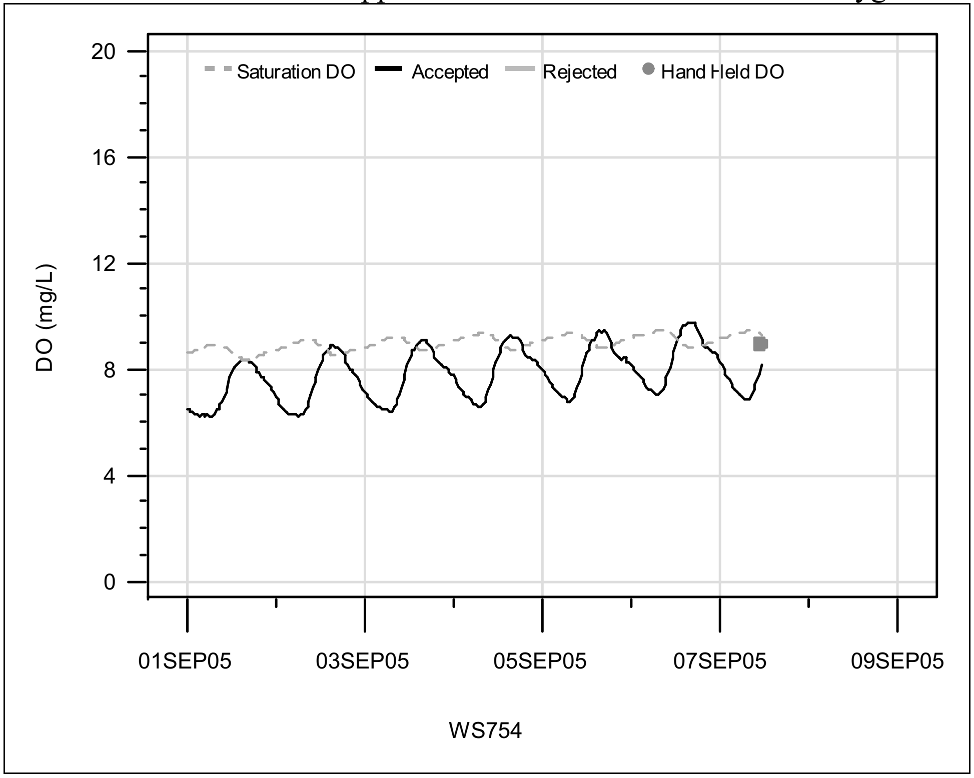


Figure C-95 Continuous Dissolved Oxygen (DO) with Calculated DO Saturation, 01SEP05 to 09SEP05, Site WS754

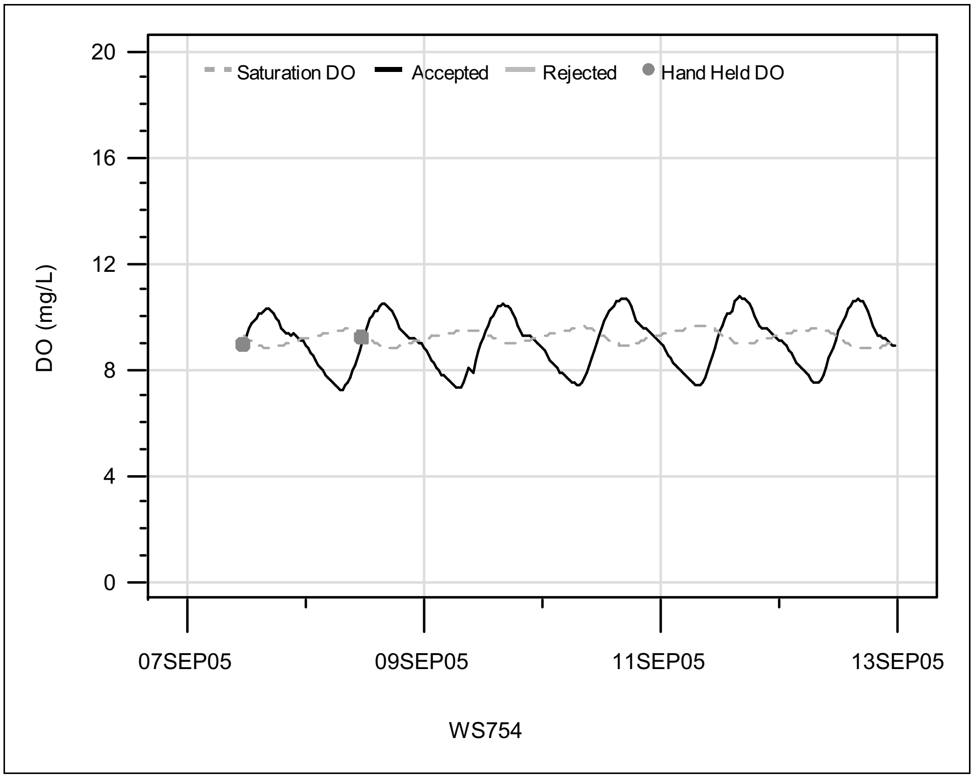


Figure C-96 Continuous Dissolved Oxygen (DO) with Calculated DO Saturation, 07SEP05 to 13SEP05, Site WS754

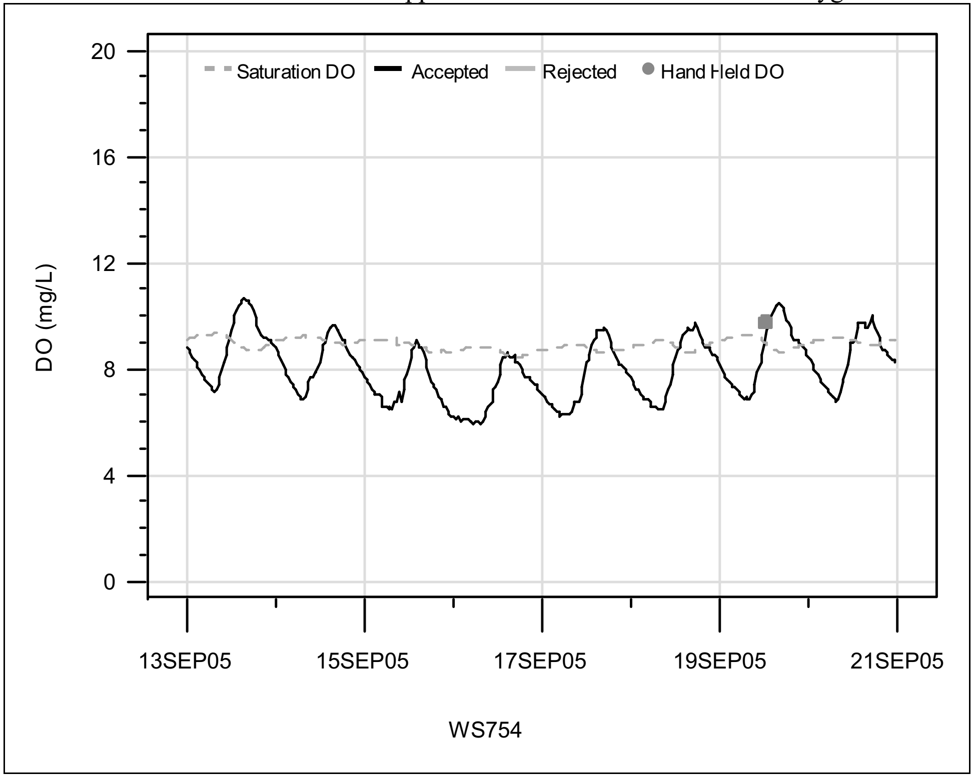


Figure C-97 Continuous Dissolved Oxygen (DO) with Calculated DO Saturation, 13SEP05 to 21SEP05, Site WS754

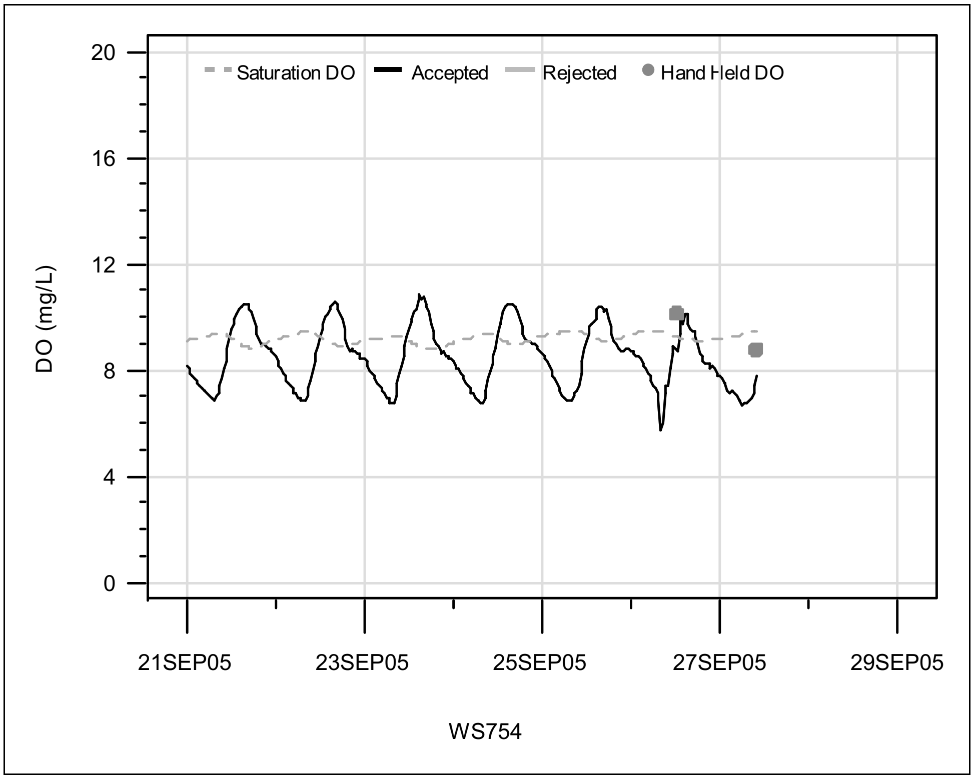


Figure C-98 Continuous Dissolved Oxygen (DO) with Calculated DO Saturation, 21SEP05 to 29SEP05, Site WS754

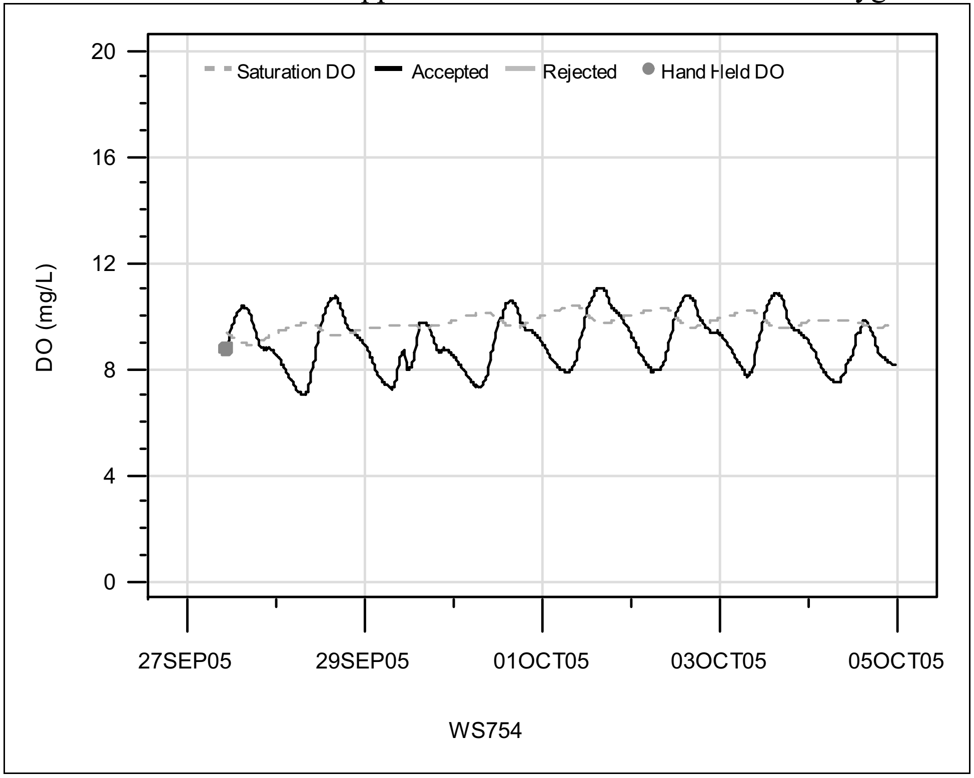


Figure C-99 Continuous Dissolved Oxygen (DO) with Calculated DO Saturation, 27SEP05 to 05OCT05, Site WS754

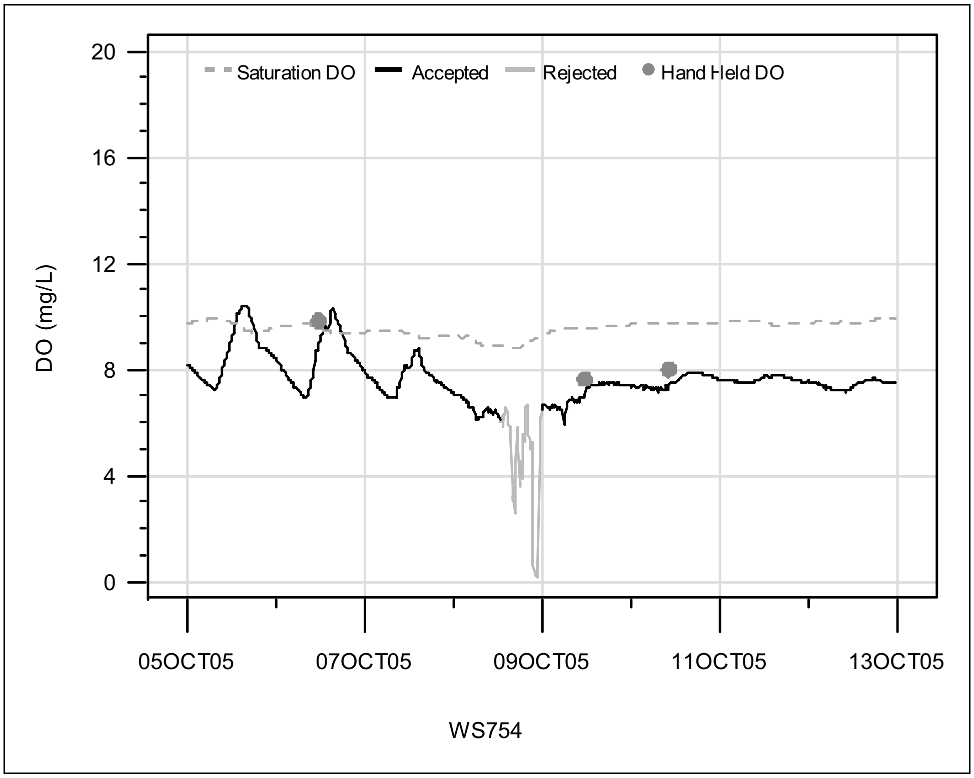


Figure C-100 Continuous Dissolved Oxygen (DO) with Calculated DO Saturation, 05OCT05 to 13OCT05, Site WS754

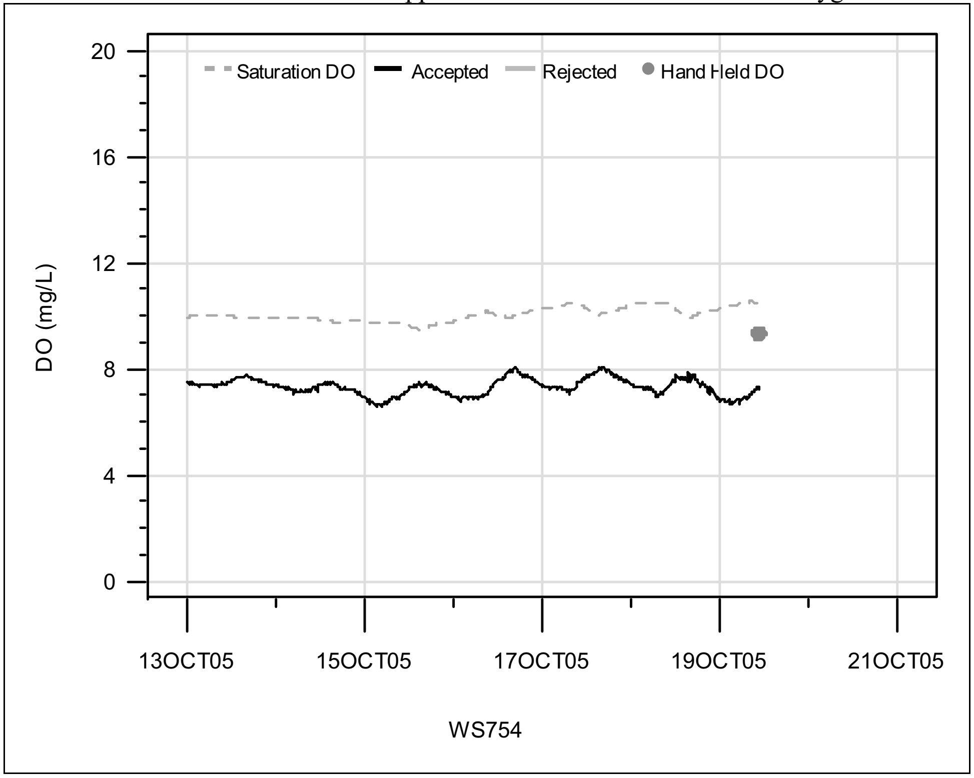


Figure C-101 Continuous Dissolved Oxygen (DO) with Calculated DO Saturation, 13OCT05 to 21OCT05, Site WS754

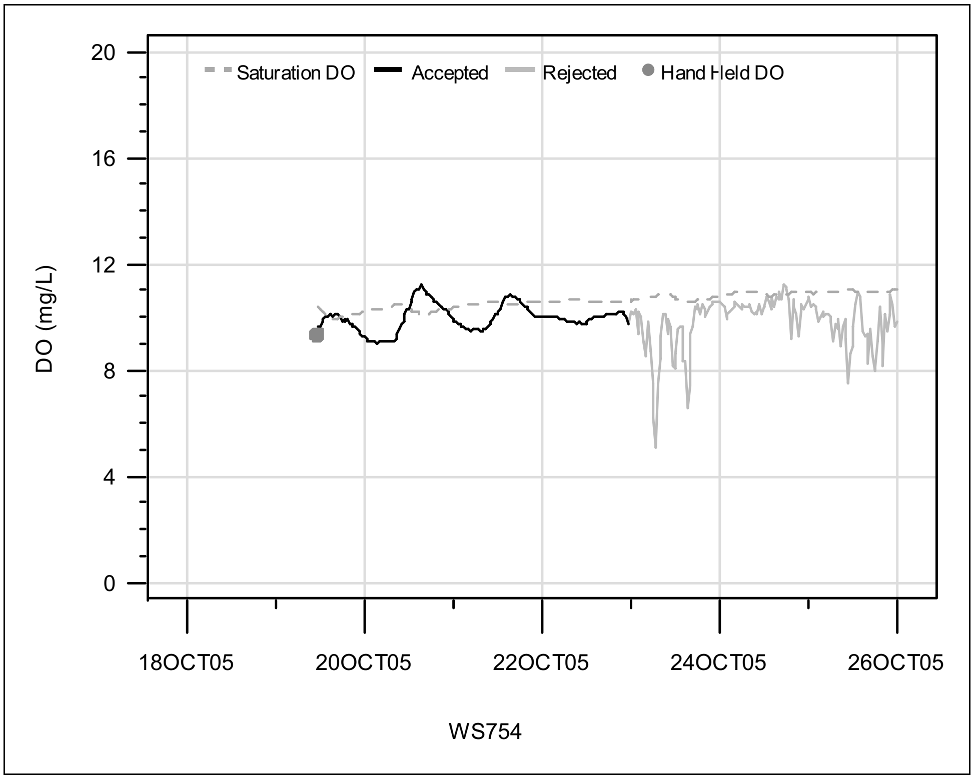


Figure C-102 Continuous Dissolved Oxygen (DO) with Calculated DO Saturation, 18OCT05 to 26OCT05, Site WS754

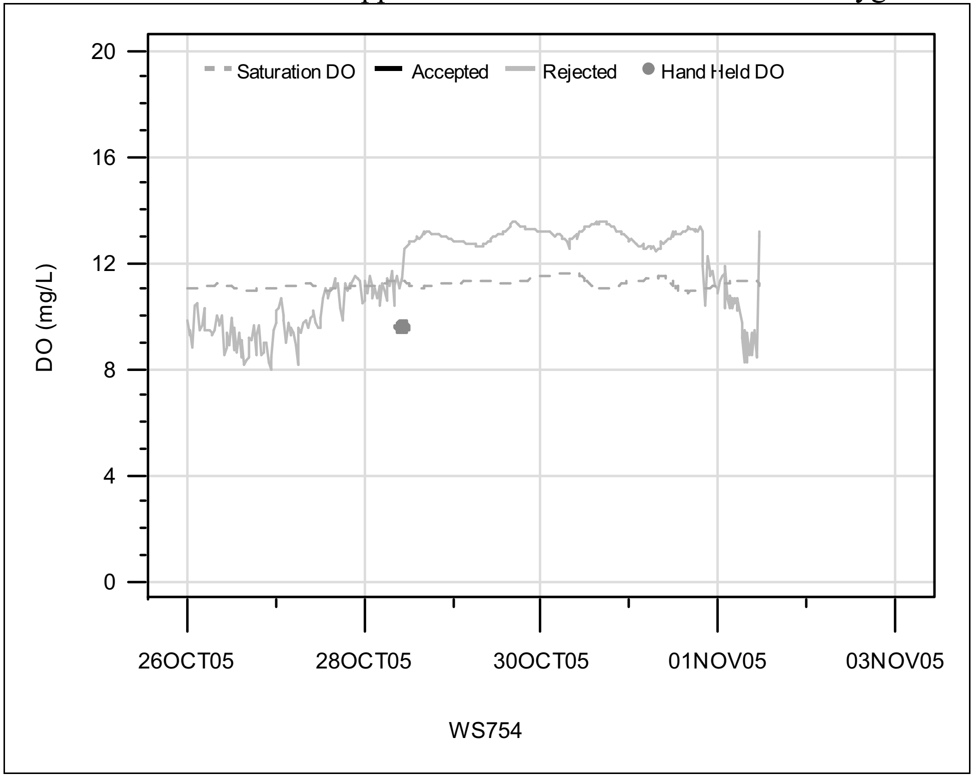


Figure C-103 Continuous Dissolved Oxygen (DO) with Calculated DO Saturation, 26OCT05 to 03NOV05, Site WS754

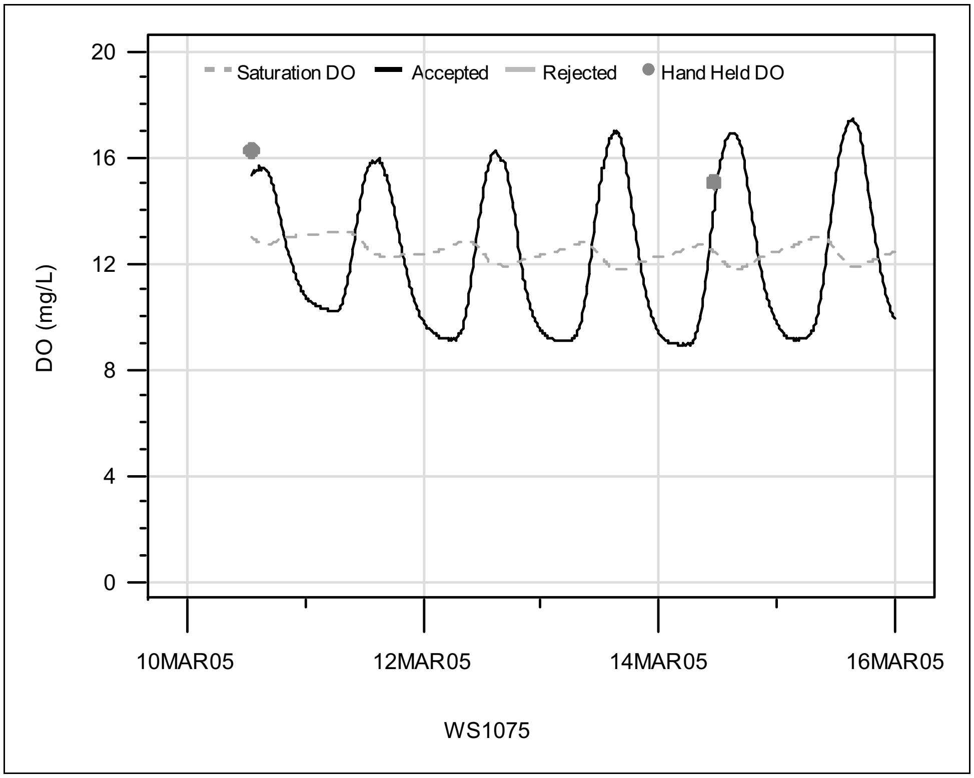


Figure C-104 Continuous Dissolved Oxygen (DO) with Calculated DO Saturation, 10MAR05 to 16MAR05, Site WS1075

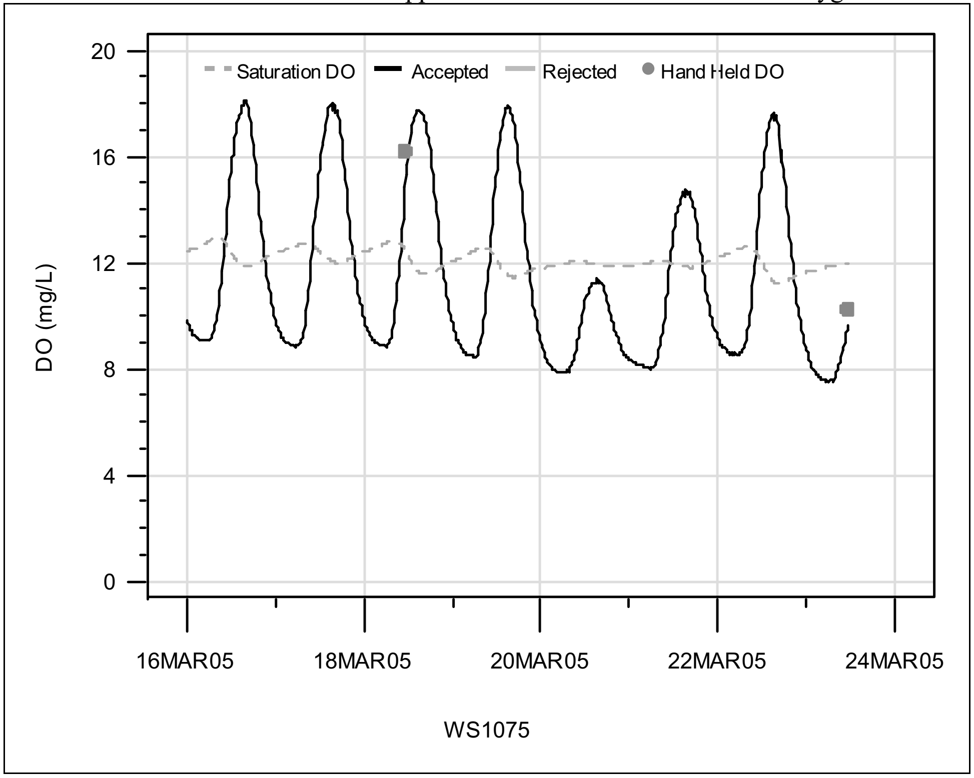


Figure C-105 Continuous Dissolved Oxygen (DO) with Calculated DO Saturation, 16MAR05 to 24MAR05, Site WS1075

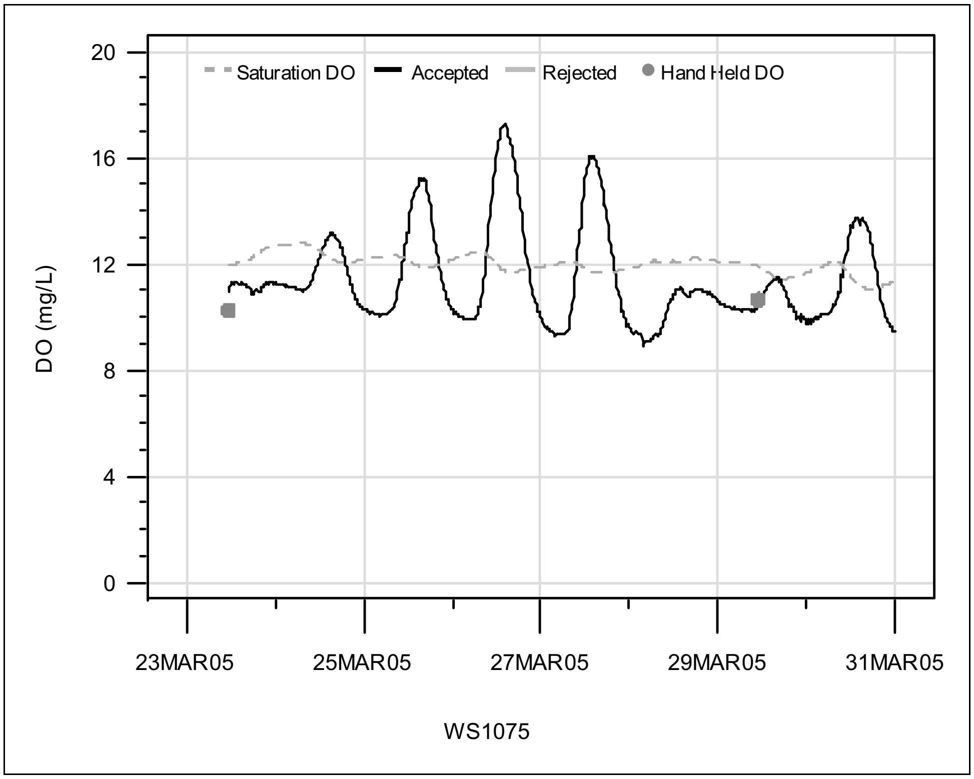


Figure C-106 Continuous Dissolved Oxygen (DO) with Calculated DO Saturation, 23MAR05 to 31MAR05, Site WS1075

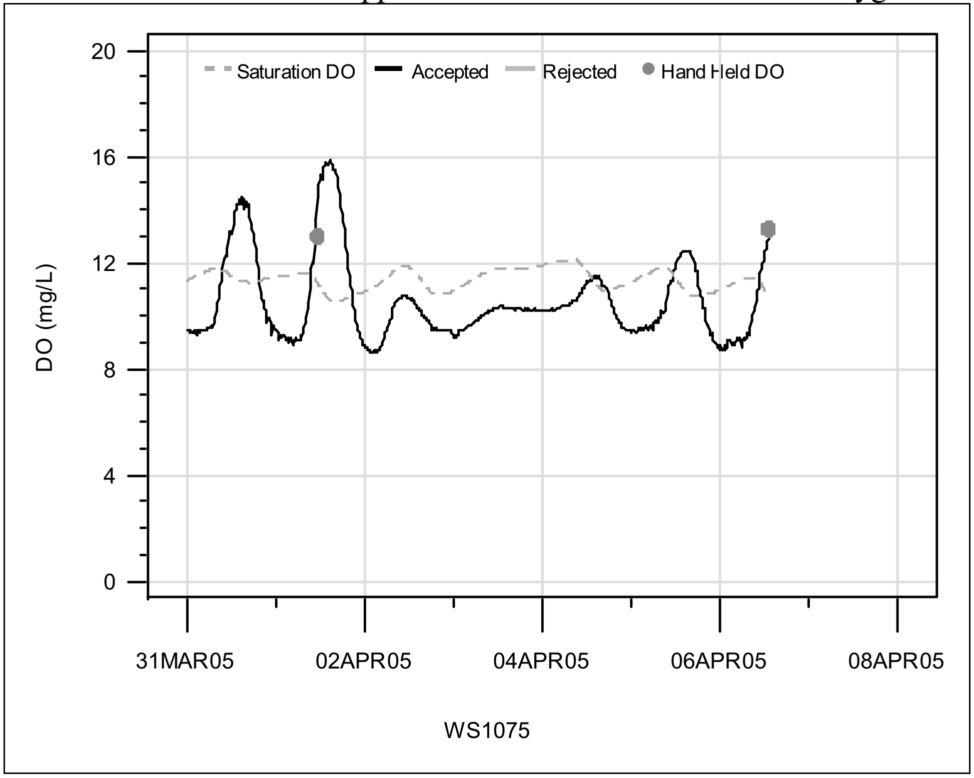


Figure C-107 Continuous Dissolved Oxygen (DO) with Calculated DO Saturation, 31MAR05 to 08MAR05, Site WS1075

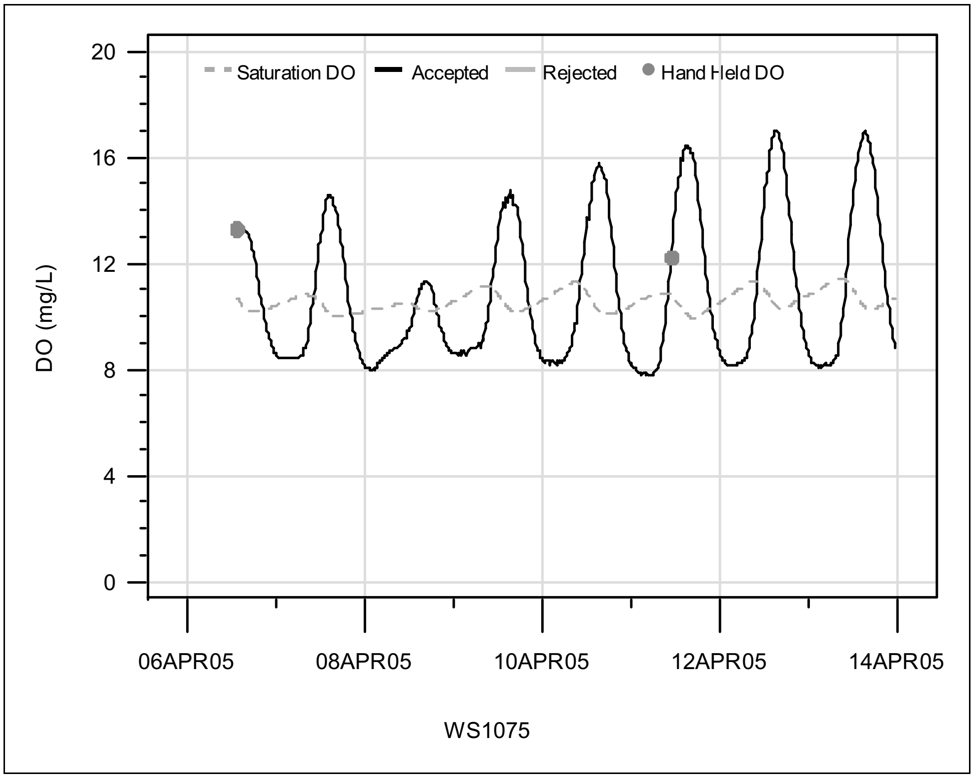


Figure C-108 Continuous Dissolved Oxygen (DO) with Calculated DO Saturation, 06APR05 to 14APR05, Site WS1075

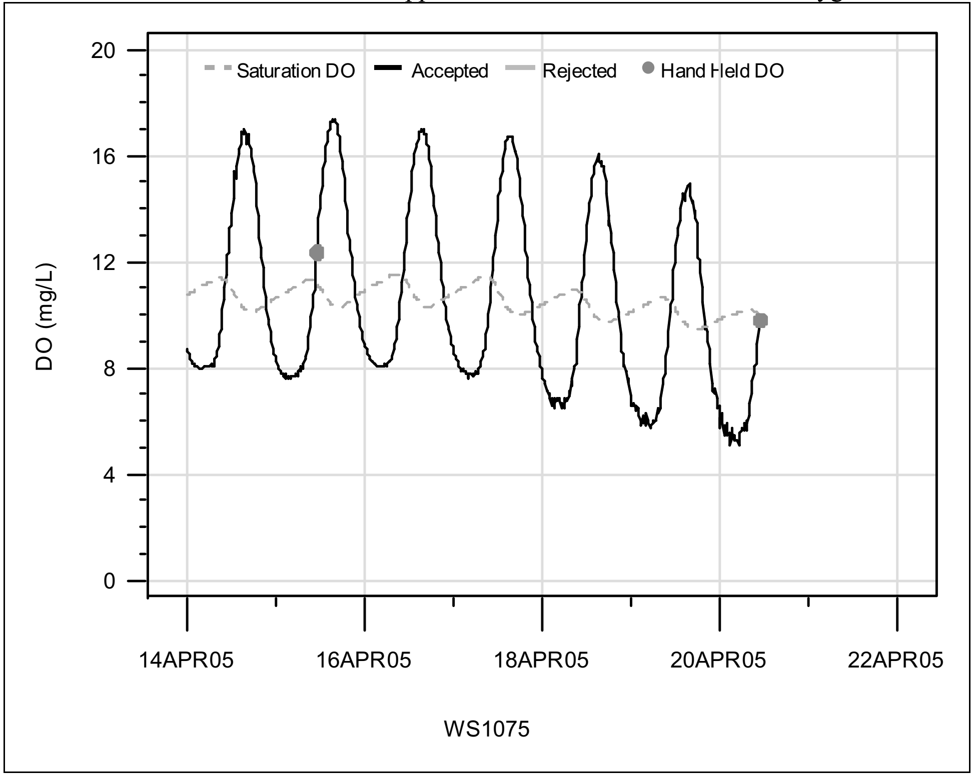


Figure C-109 Continuous Dissolved Oxygen (DO) with Calculated DO Saturation, 14APR05 to 22APR05, Site WS1075

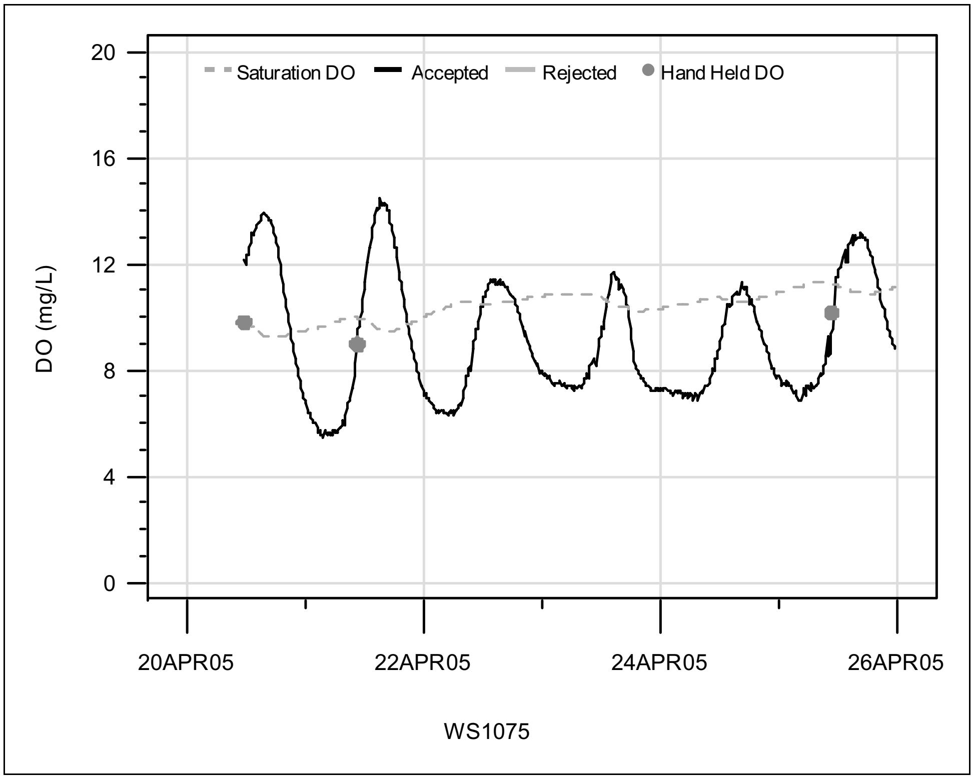


Figure C-110 Continuous Dissolved Oxygen (DO) with Calculated DO Saturation, 20APR05 to 26APR05, Site WS1075

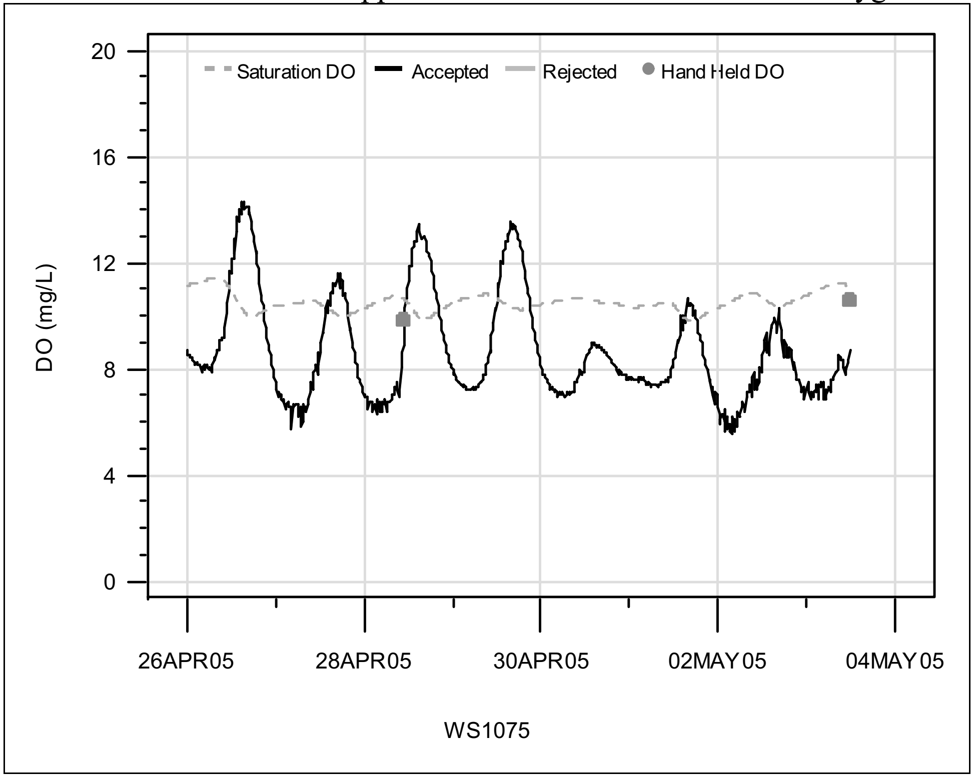


Figure C-111 Continuous Dissolved Oxygen (DO) with Calculated DO Saturation, 26APR05 to 04MAY05, Site WS1075

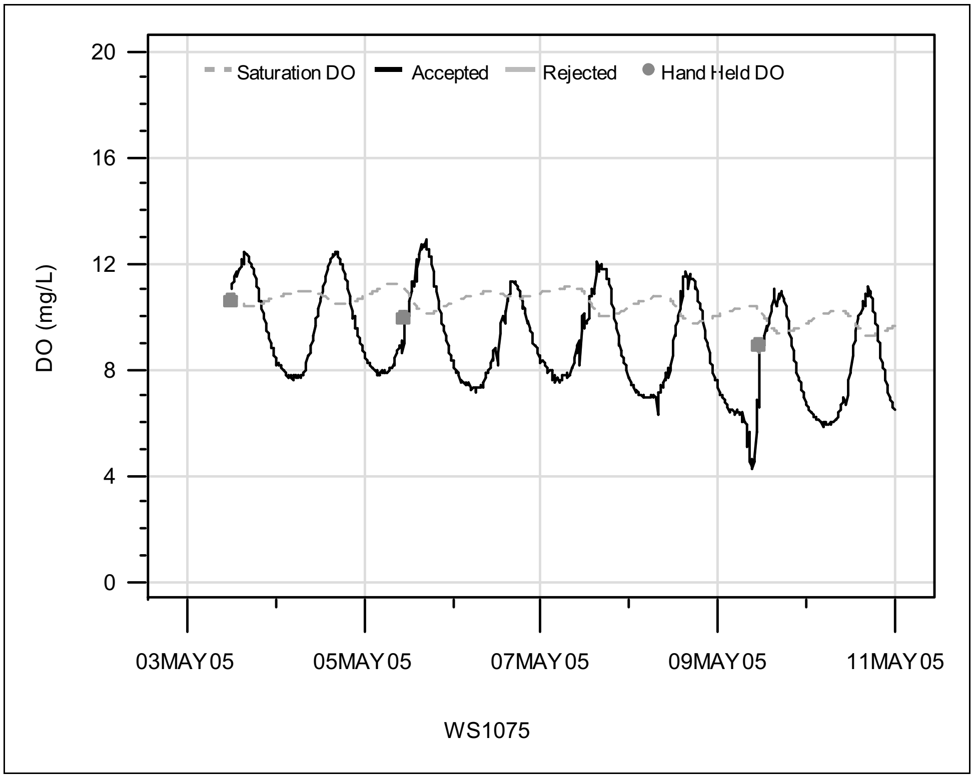


Figure C-112 Continuous Dissolved Oxygen (DO) with Calculated DO Saturation, 03MAY05 to 11MAY05, Site WS1075

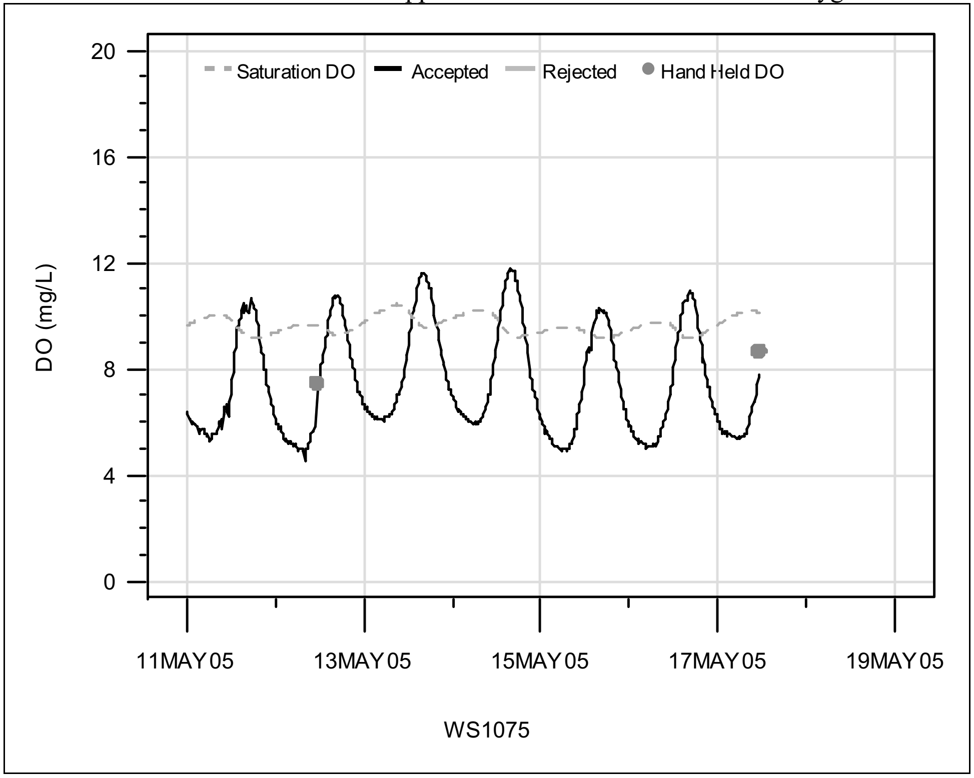


Figure C-113 Continuous Dissolved Oxygen (DO) with Calculated DO Saturation, 11MAY05 to 19MAY05, Site WS1075

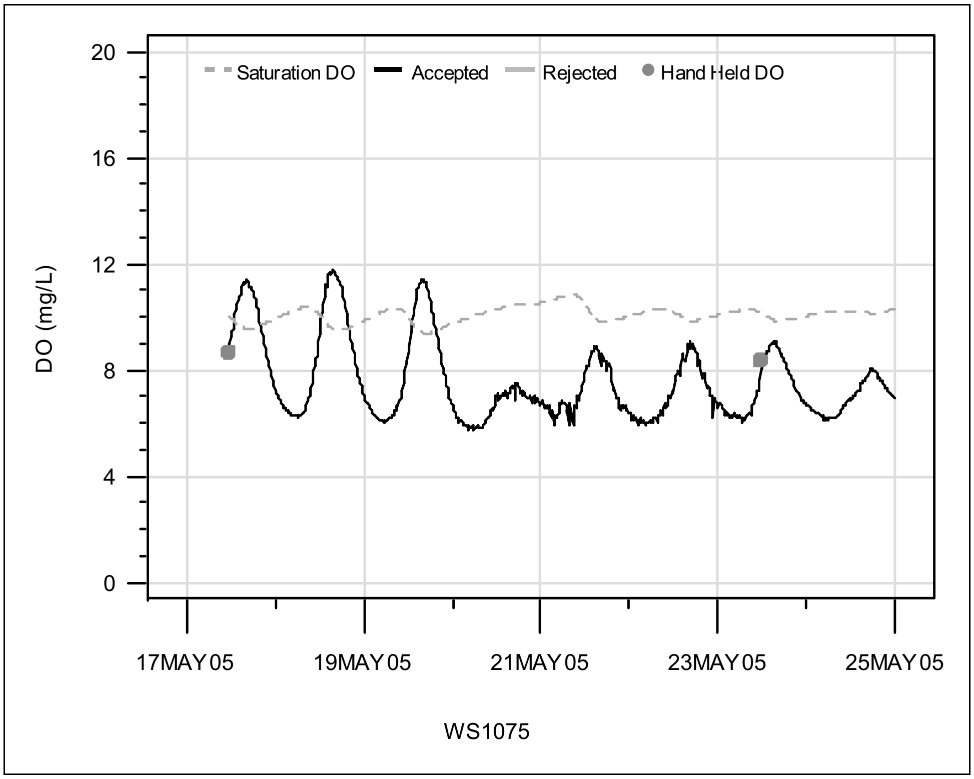


Figure C-114 Continuous Dissolved Oxygen (DO) with Calculated DO Saturation, 17MAY05 to 25MAY05, Site WS1075

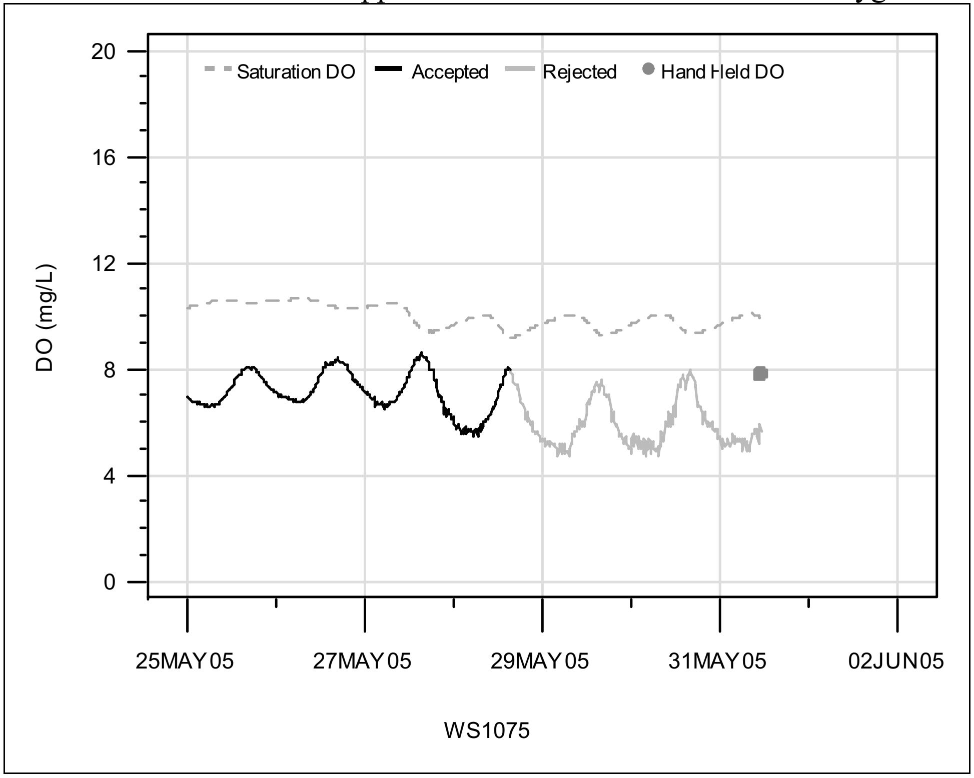


Figure C-115 Continuous Dissolved Oxygen (DO) with Calculated DO Saturation, 25MAY05 to 02JUN05, Site WS1075

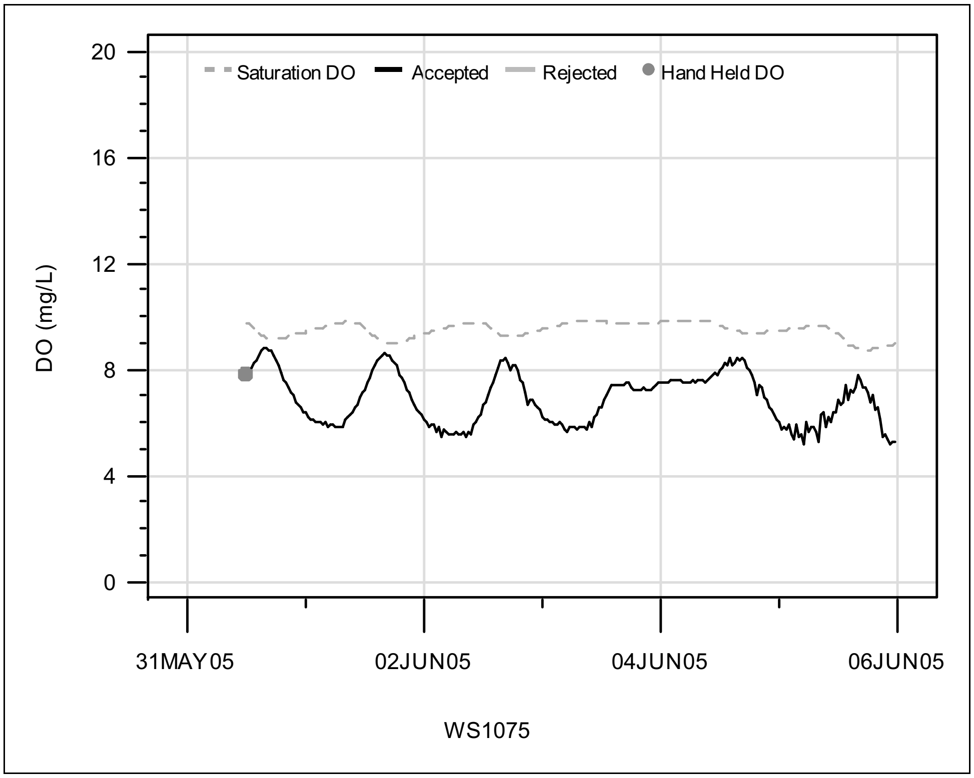


Figure C-116 Continuous Dissolved Oxygen (DO) with Calculated DO Saturation, 31MAY05 to 06JUN05, Site WS1075

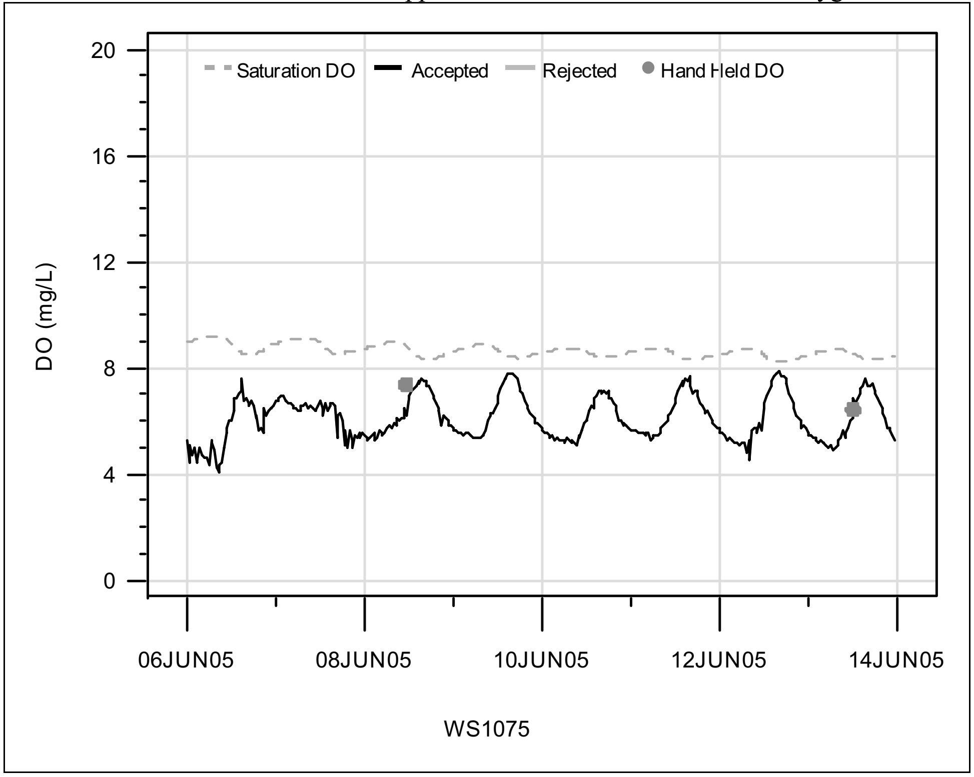


Figure C-117 Continuous Dissolved Oxygen (DO) with Calculated DO Saturation, 06JUN05 to 14JUN05, Site WS1075

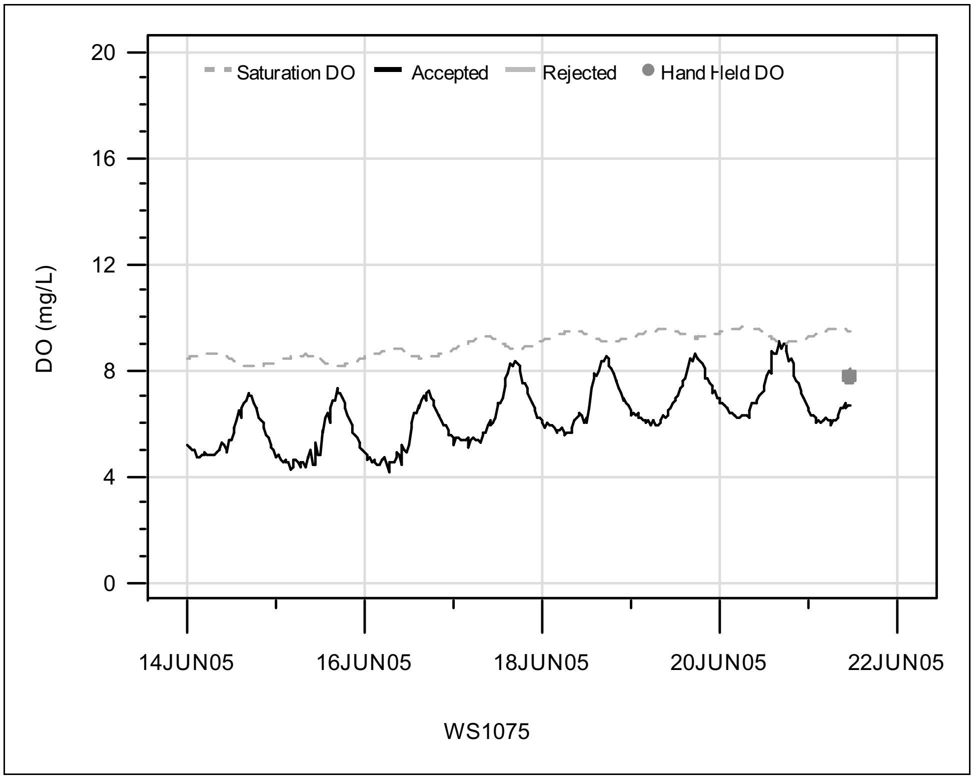


Figure C-118 Continuous Dissolved Oxygen (DO) with Calculated DO Saturation, 14JUN05 to 22JUN05, Site WS1075

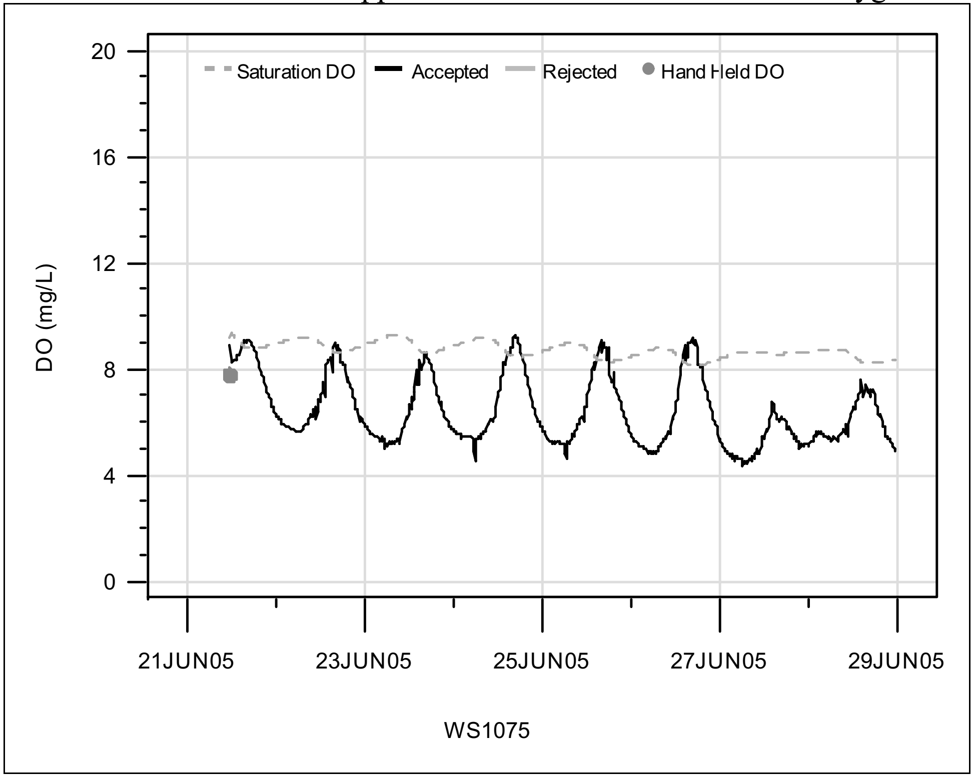


Figure C-119 Continuous Dissolved Oxygen (DO) with Calculated DO Saturation, 21JUN05 to 29JUN05, Site WS1075

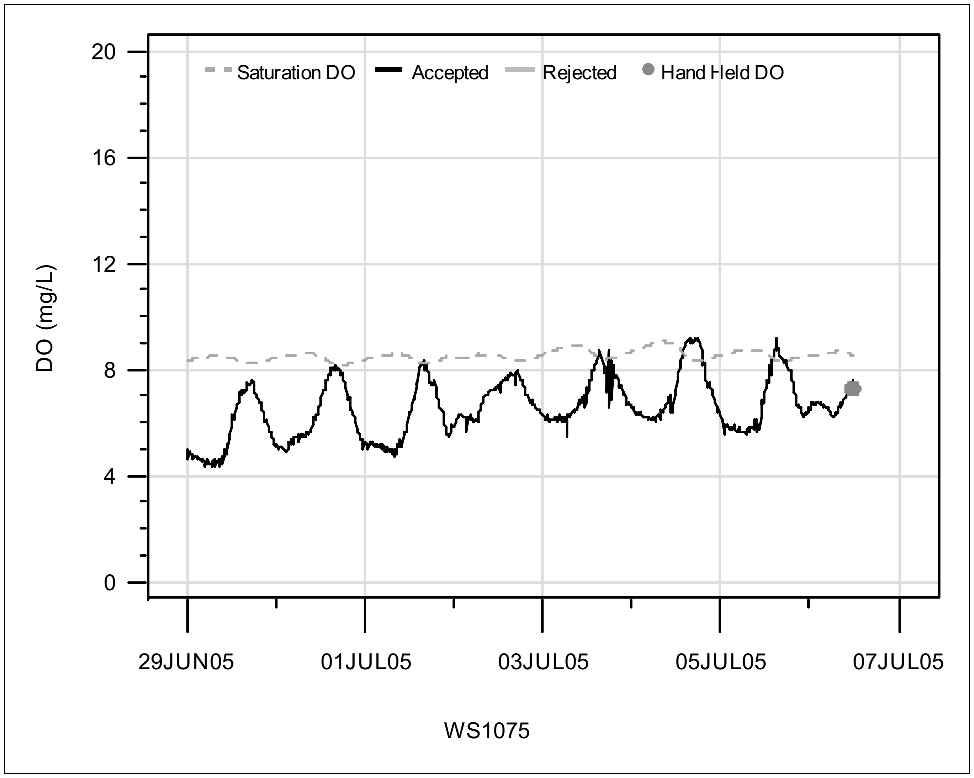


Figure C-120 Continuous Dissolved Oxygen (DO) with Calculated DO Saturation, 29JUN05 to 07JUL05, Site WS1075

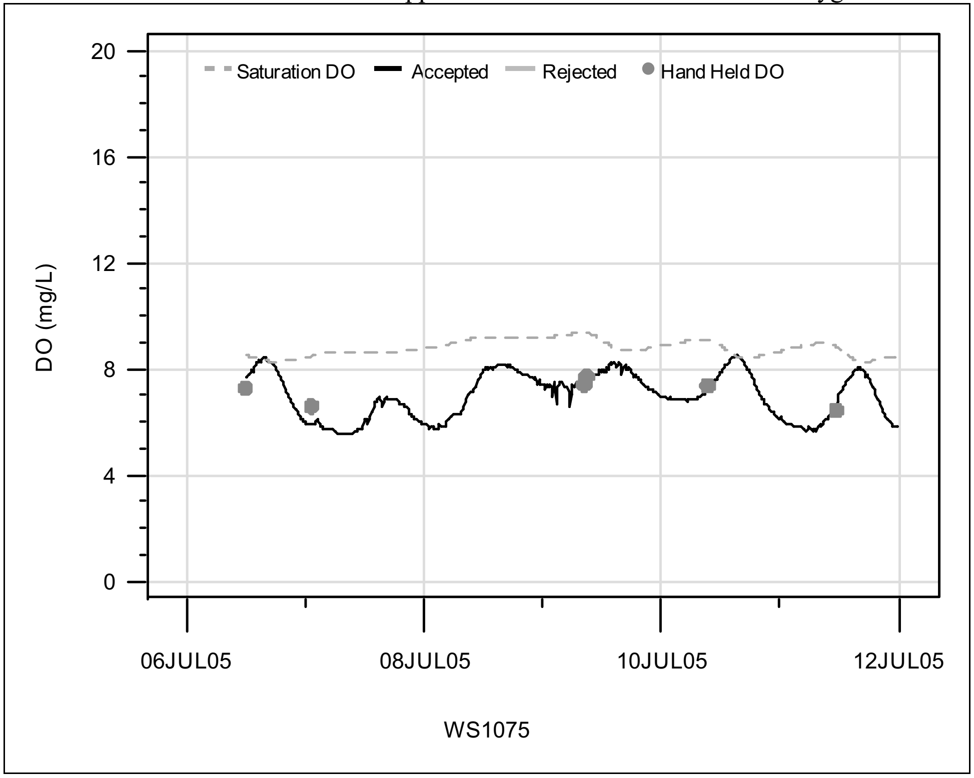


Figure C-121 Continuous Dissolved Oxygen (DO) with Calculated DO Saturation, 06JUL05 to 12JUL05, Site WS1075

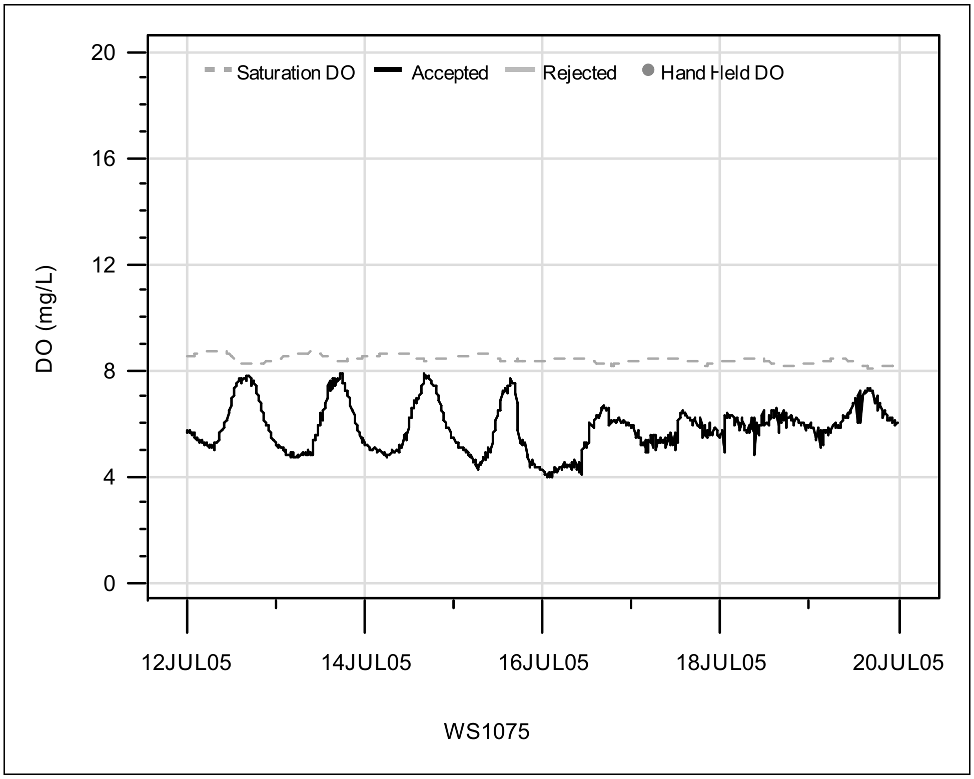


Figure C-122 Continuous Dissolved Oxygen (DO) with Calculated DO Saturation, 12JUL05 to 20JUL05, Site WS1075

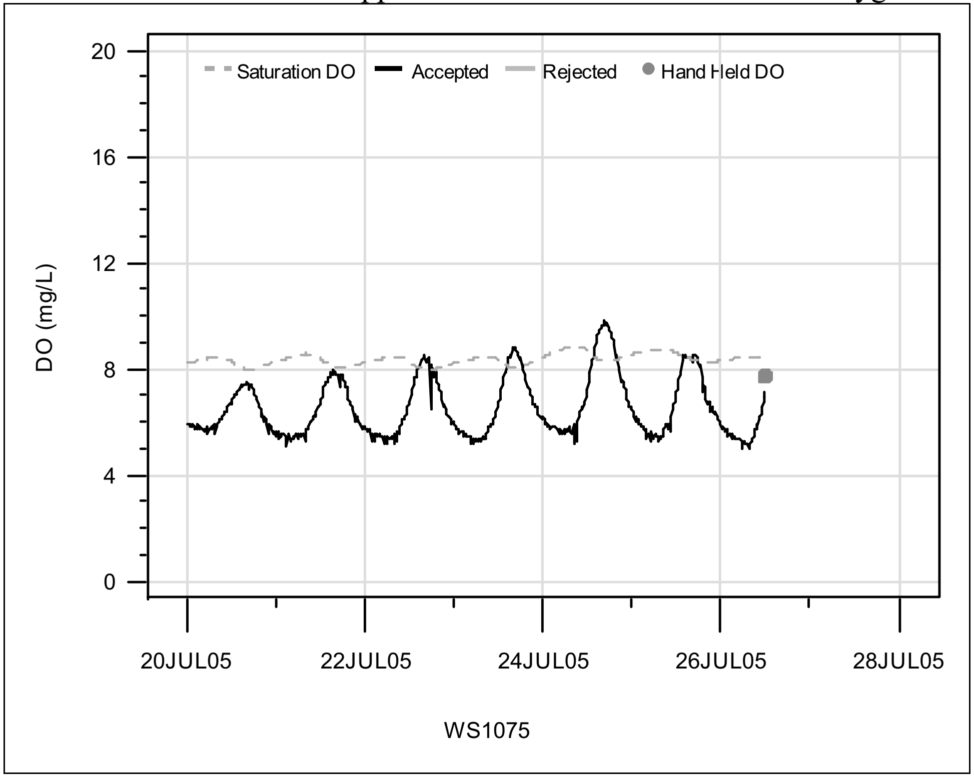


Figure C-123 Continuous Dissolved Oxygen (DO) with Calculated DO Saturation, 20JUL05 to 28JUL05, Site WS1075

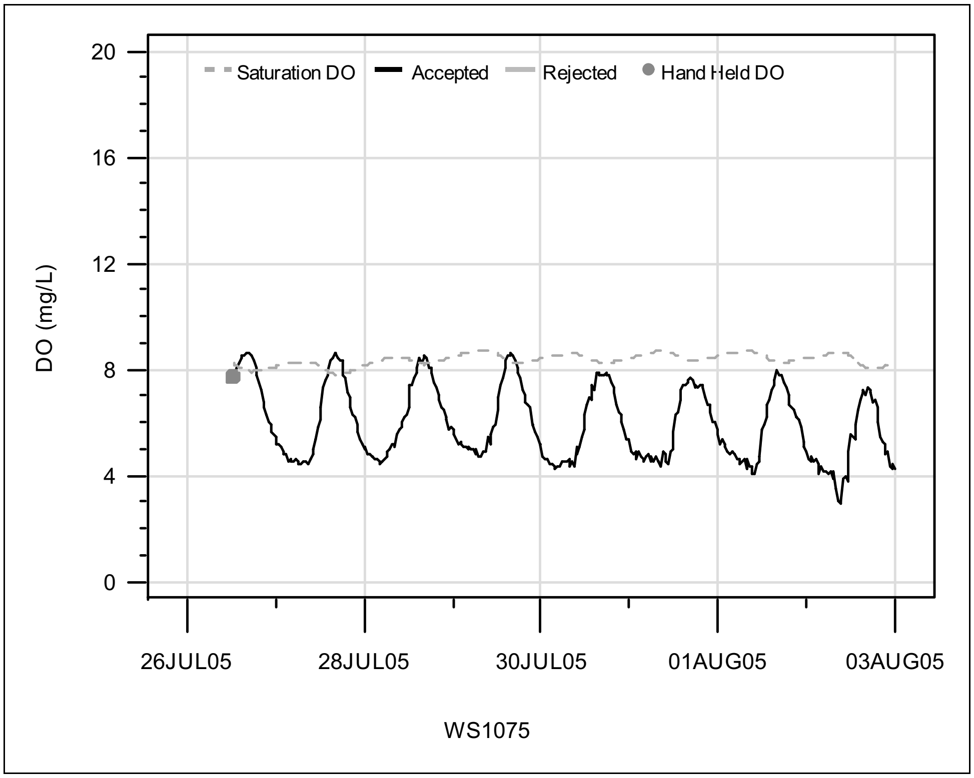


Figure C-124 Continuous Dissolved Oxygen (DO) with Calculated DO Saturation, 26JUL05 to 03AUG05, Site WS1075

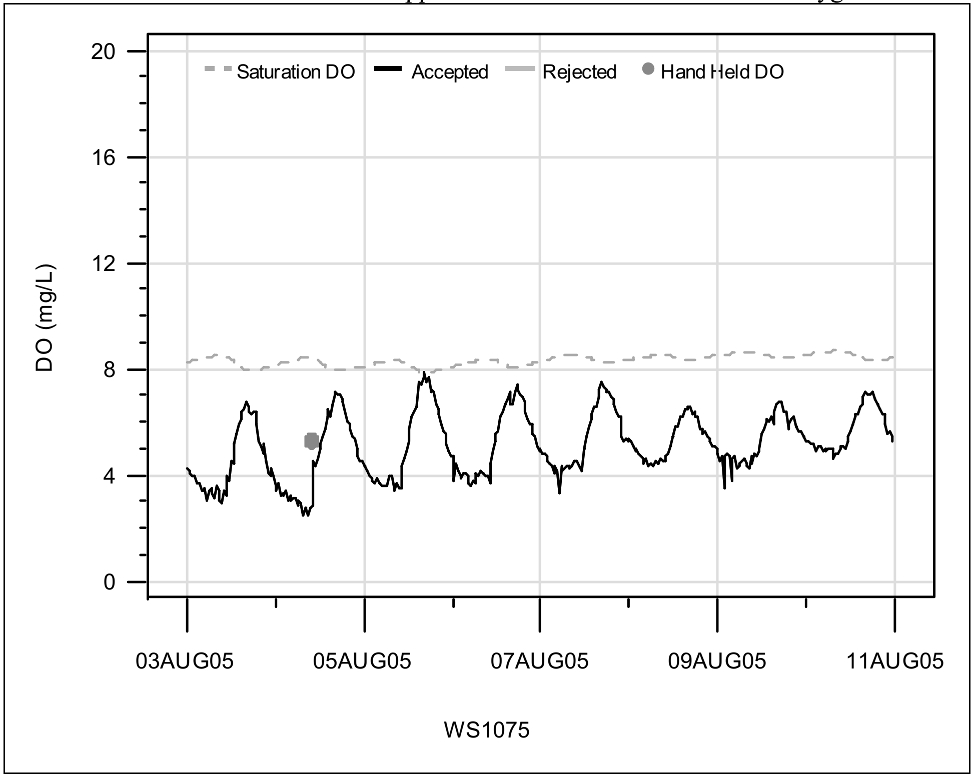


Figure C-125 Continuous Dissolved Oxygen (DO) with Calculated DO Saturation, 03AUG05 to 11AUG05, Site WS1075

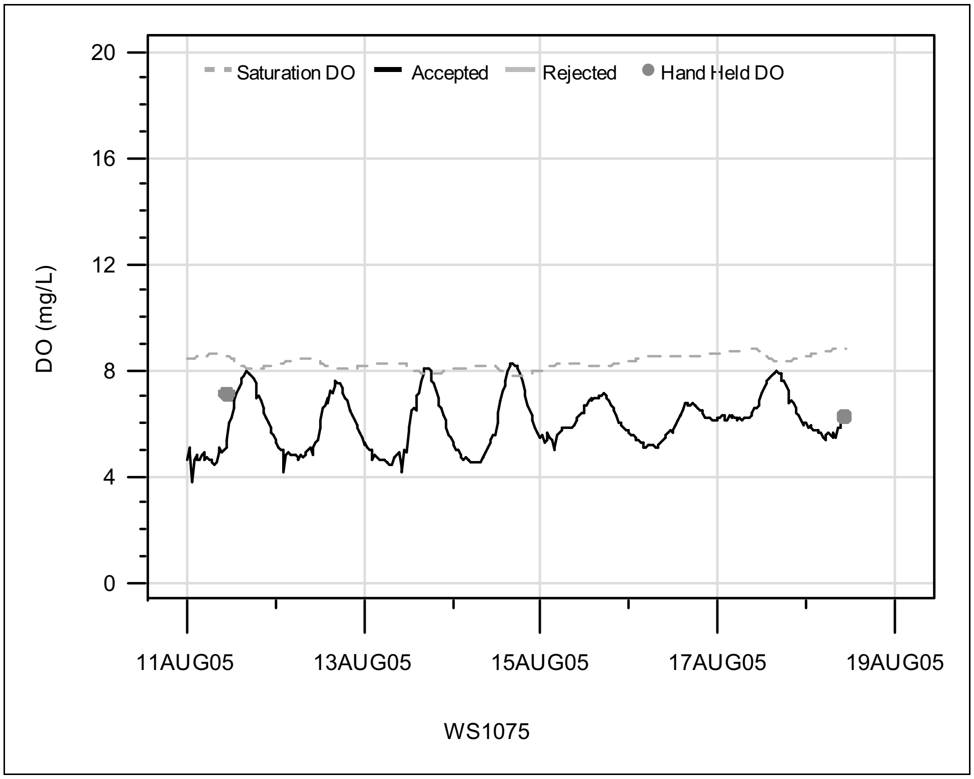


Figure C-126 Continuous Dissolved Oxygen (DO) with Calculated DO Saturation, 11AUG05 to 19AUG05, Site WS1075

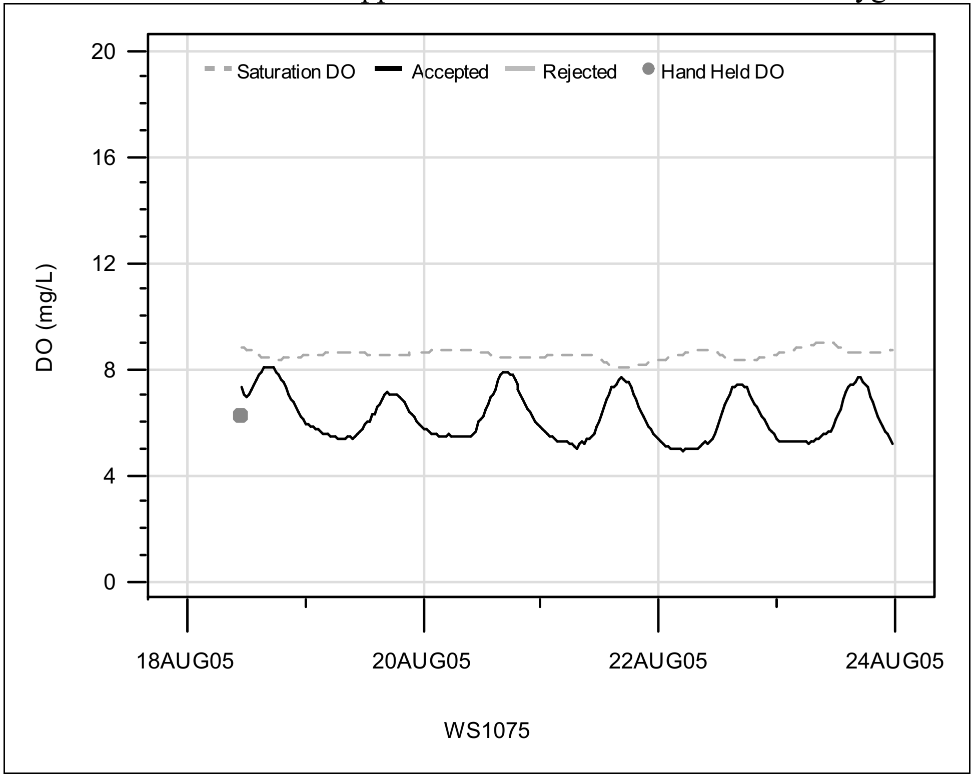


Figure C-127 Continuous Dissolved Oxygen (DO) with Calculated DO Saturation, 18AUG05 to 24AUG05, Site WS1075

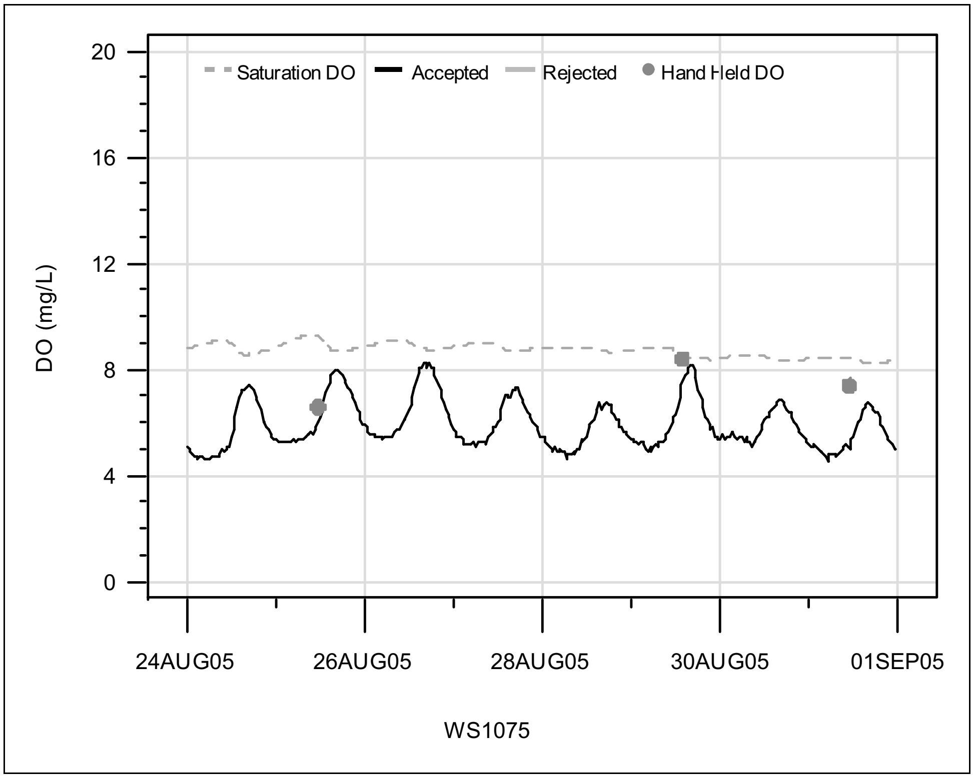


Figure C-128 Continuous Dissolved Oxygen (DO) with Calculated DO Saturation, 24AUG05 to 01SEP05, Site WS1075

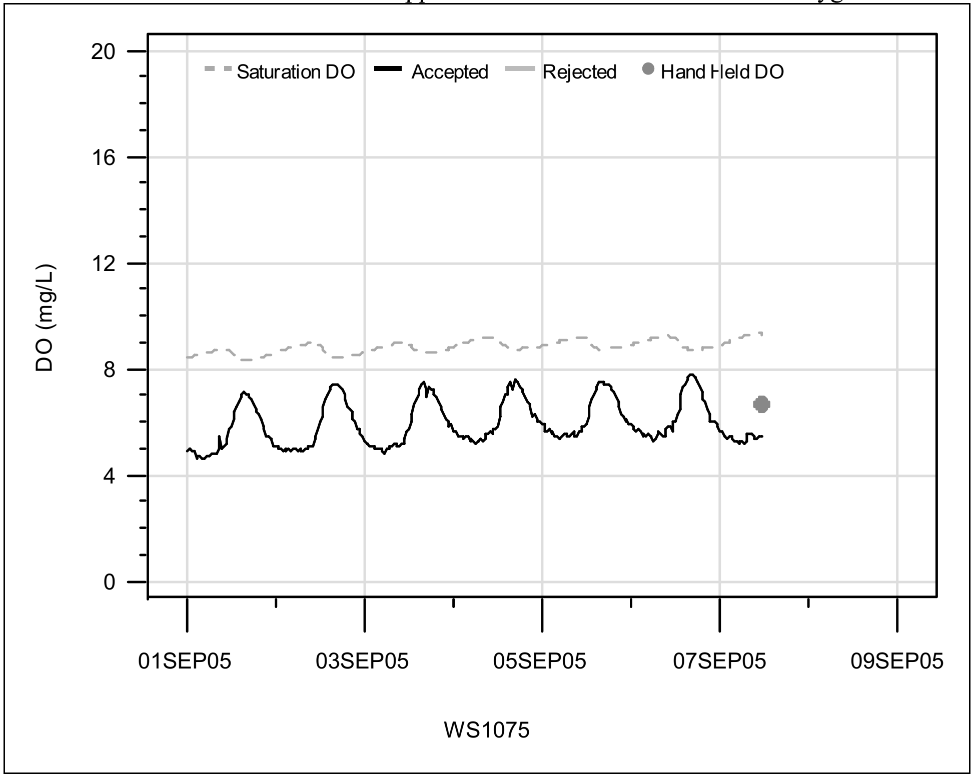


Figure C-129 Continuous Dissolved Oxygen (DO) with Calculated DO Saturation, 01SEP05 to 09SEP05, Site WS1075

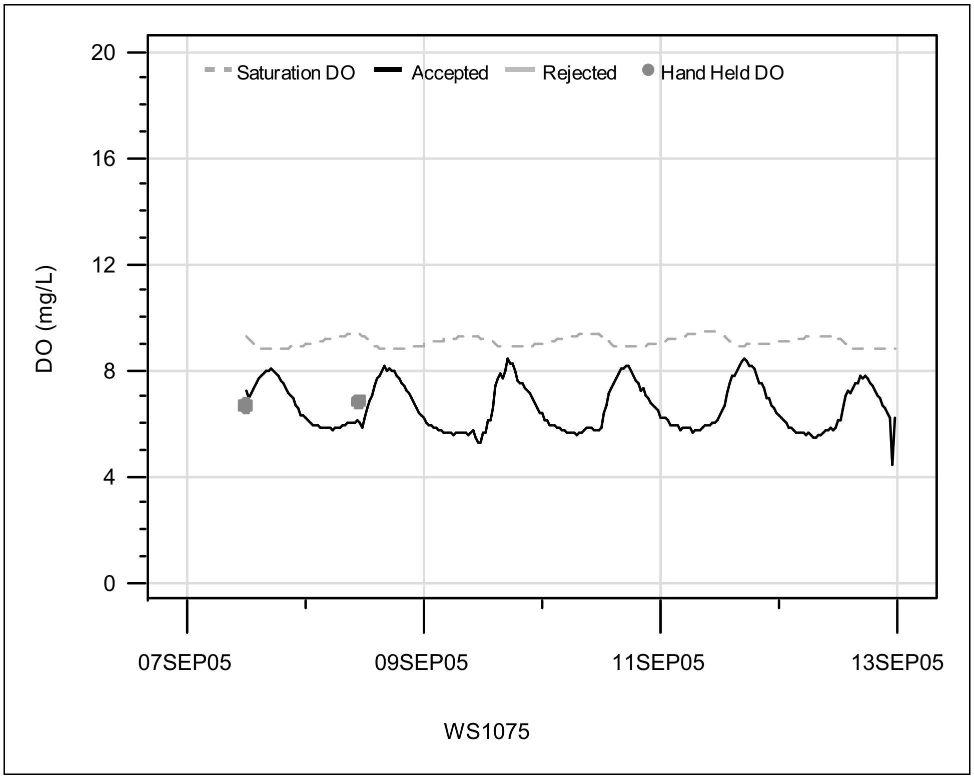


Figure C-130 Continuous Dissolved Oxygen (DO) with Calculated DO Saturation, 07SEP05 to 13SEP05, Site WS1075

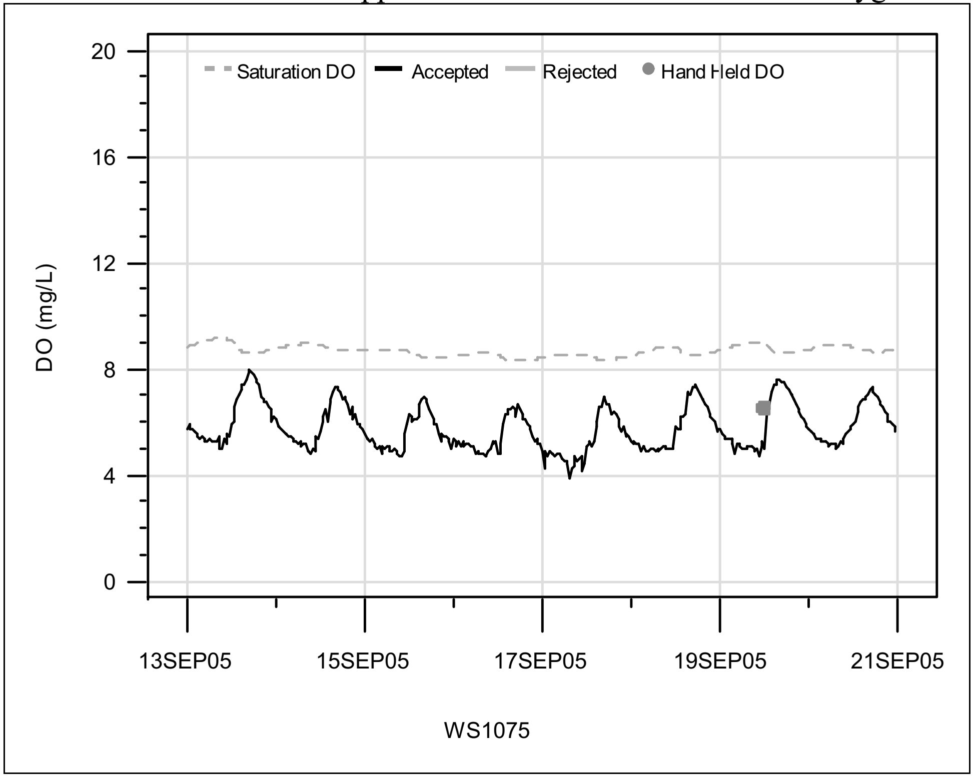


Figure C-131 Continuous Dissolved Oxygen (DO) with Calculated DO Saturation, 13SEP05 to 21SEP05, Site WS1075

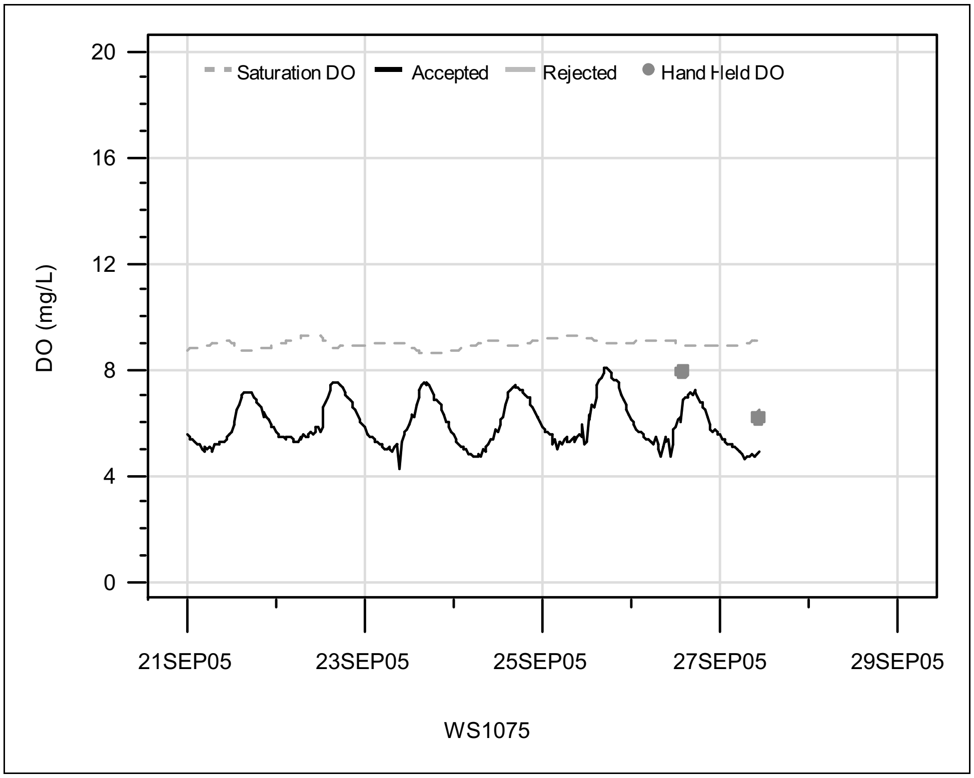


Figure C-132 Continuous Dissolved Oxygen (DO) with Calculated DO Saturation, 21SEP05 to 29SEP05, Site WS1075

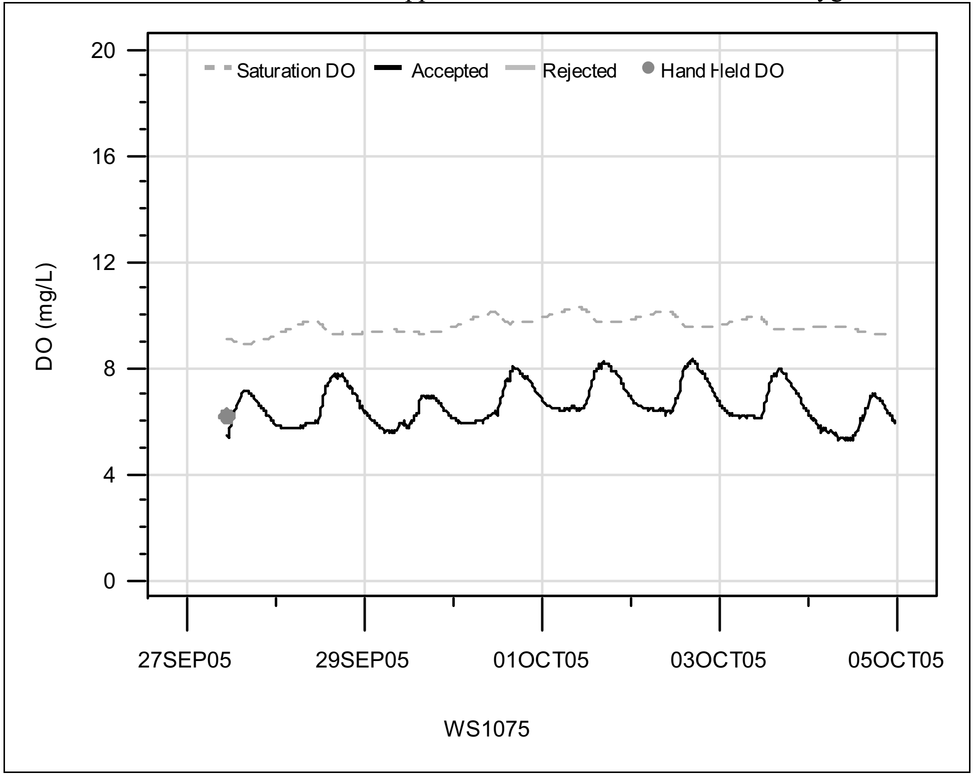


Figure C-133 Continuous Dissolved Oxygen (DO) with Calculated DO Saturation, 27SEP05 to 05OCT05, Site WS1075

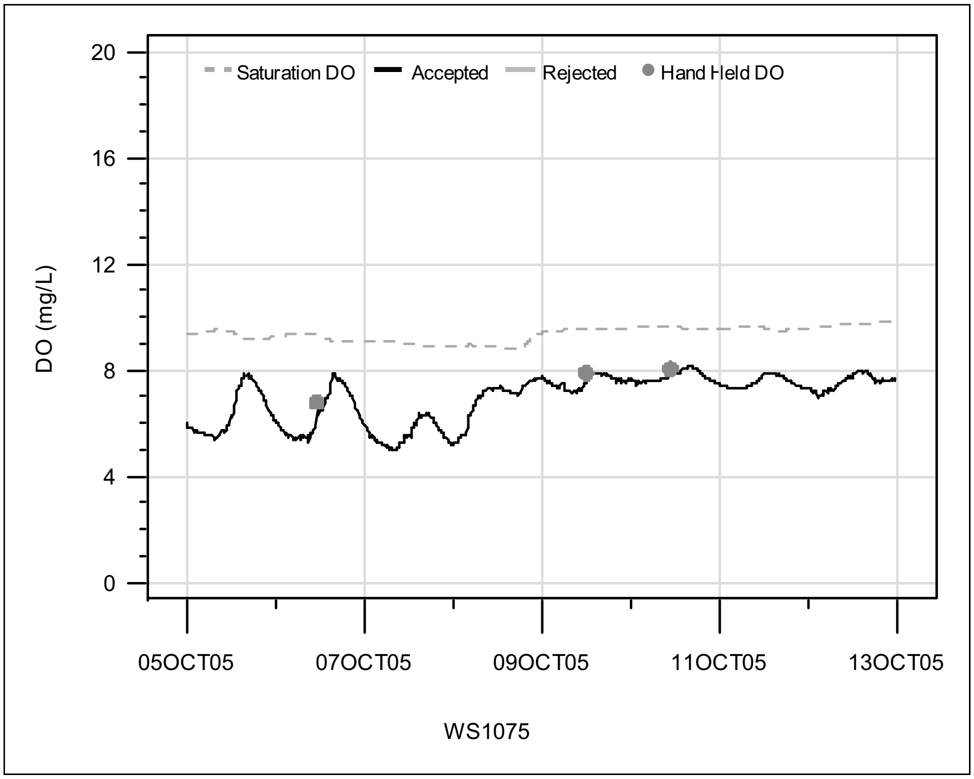


Figure C-134 Continuous Dissolved Oxygen (DO) with Calculated DO Saturation, 05OCT05 to 13OCT05, Site WS1075

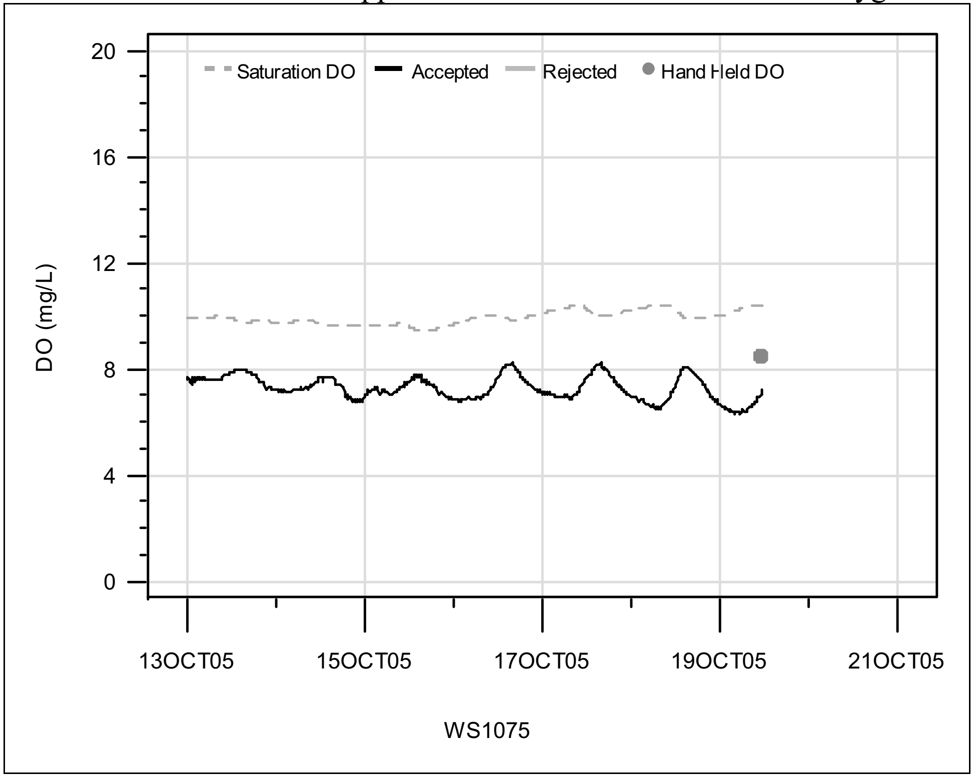


Figure C-135 Continuous Dissolved Oxygen (DO) with Calculated DO Saturation, 13OCT05 to 21OCT05, Site WS1075

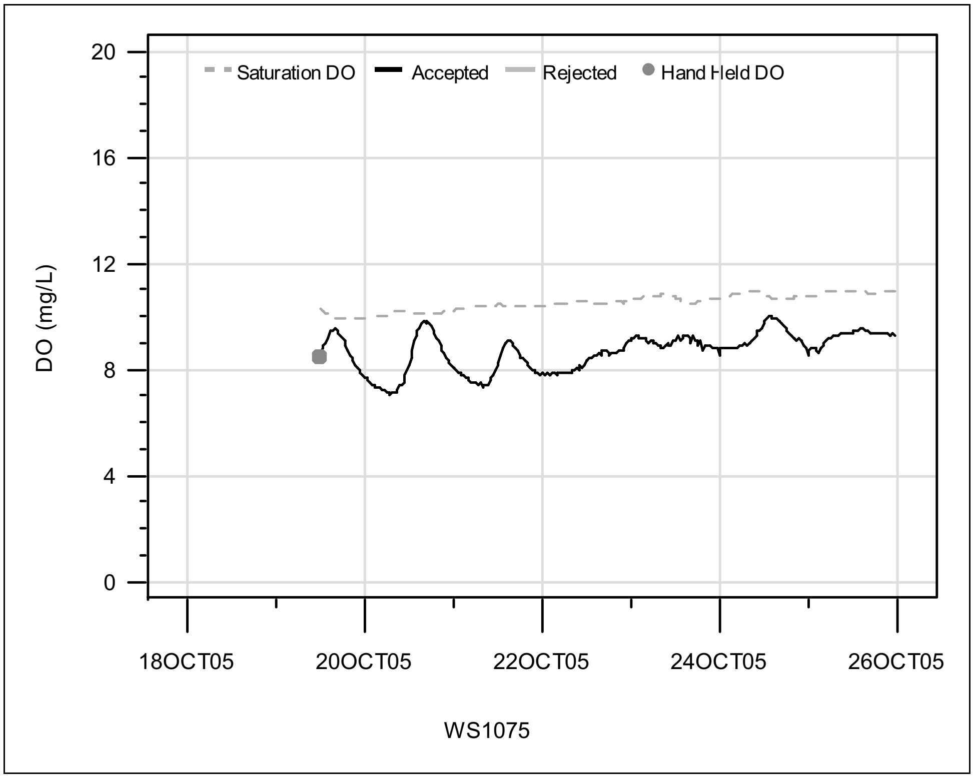


Figure C-136 Continuous Dissolved Oxygen (DO) with Calculated DO Saturation 18OCT05 to 26OCT05, Site WS1075

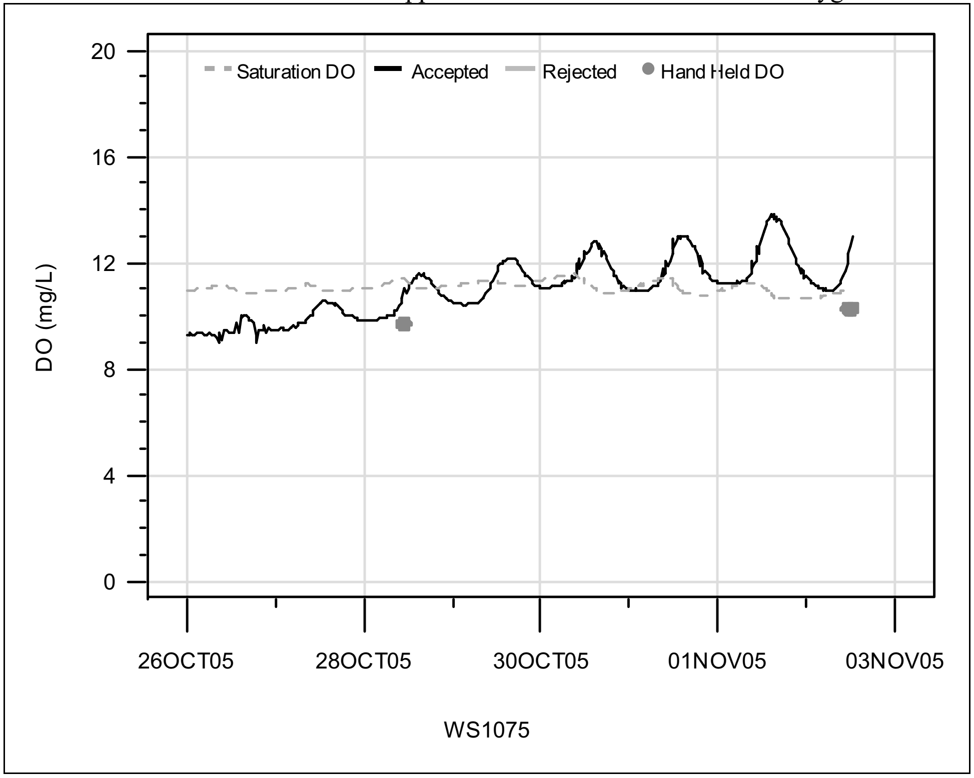


Figure C-137 Continuous Dissolved Oxygen (DO) with Calculated DO Saturation, 26OCT05 to 03NOV05, Site WS1075

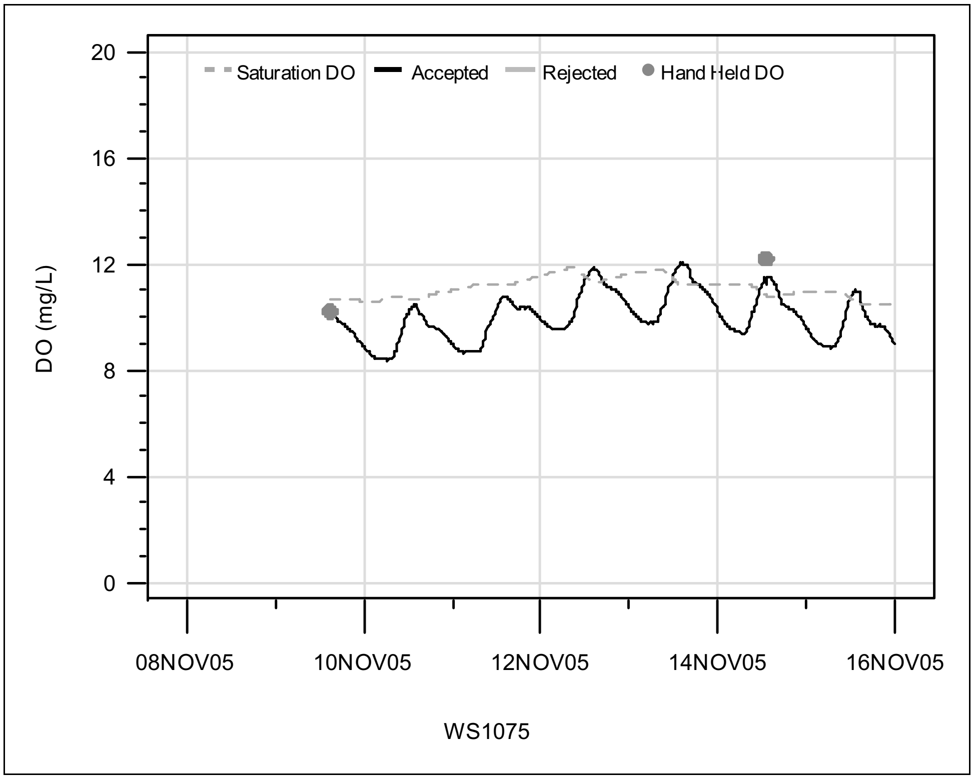


Figure C-138 Continuous Dissolved Oxygen (DO) with Calculated DO Saturation, 08NOV05 to 16NOV05, Site WS1075

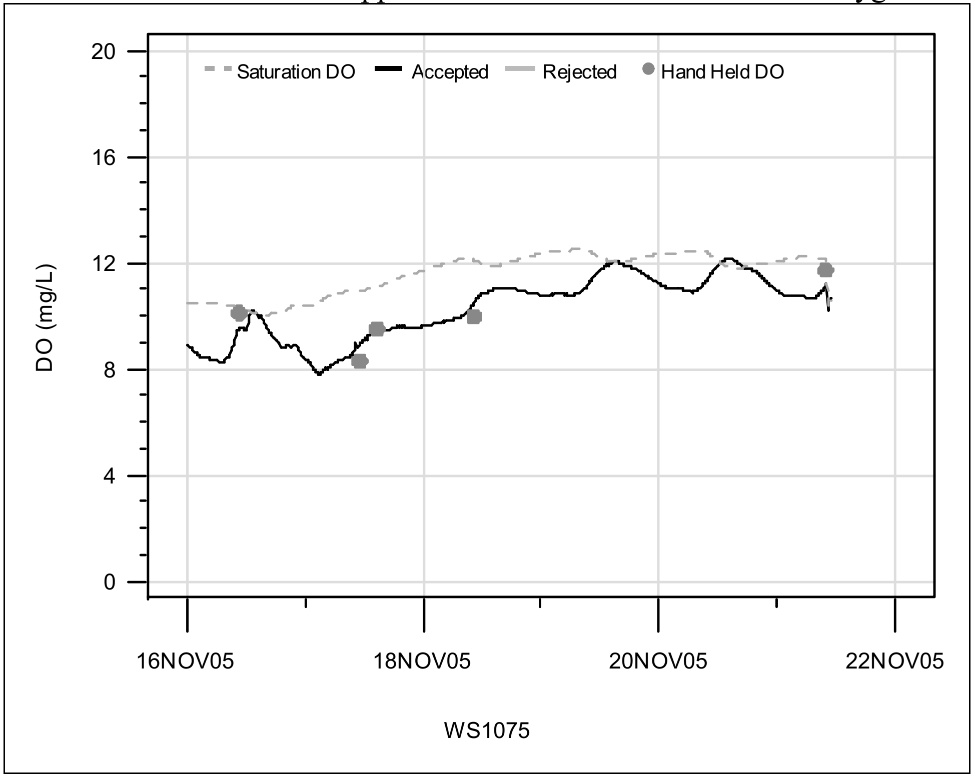


Figure C-139 Continuous Dissolved Oxygen (DO) with Calculated DO Saturation, 16NOV05 to 22NOV05, Site WS1075

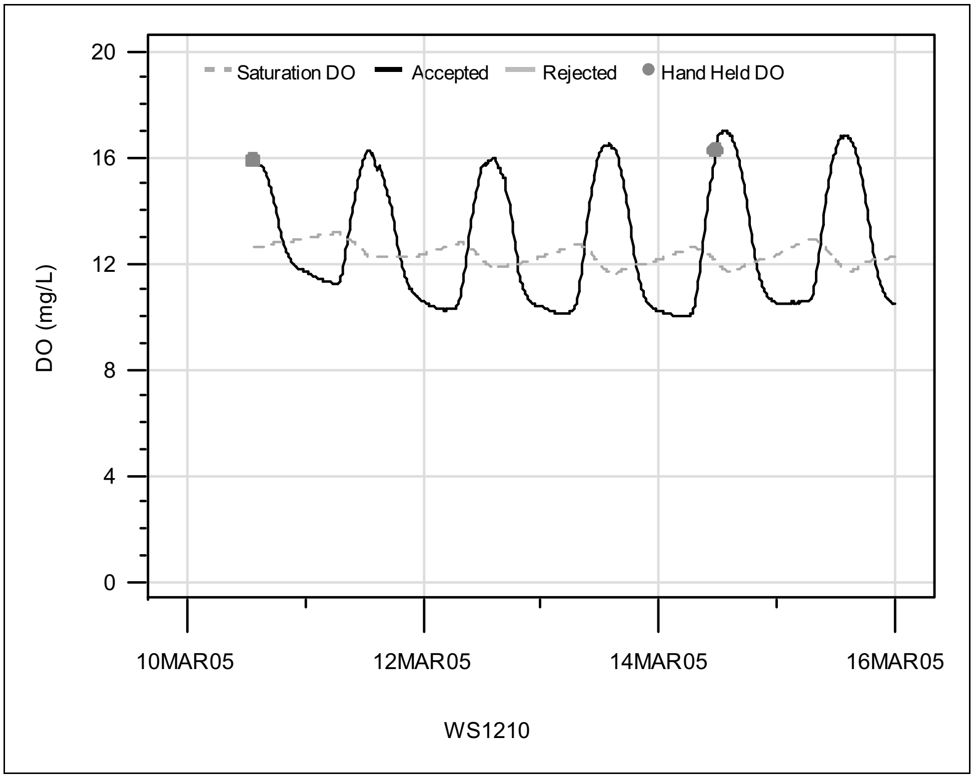


Figure C-140 Continuous Dissolved Oxygen (DO) with Calculated DO Saturation, 10MAR05 to 16MAR05, Site WS1210

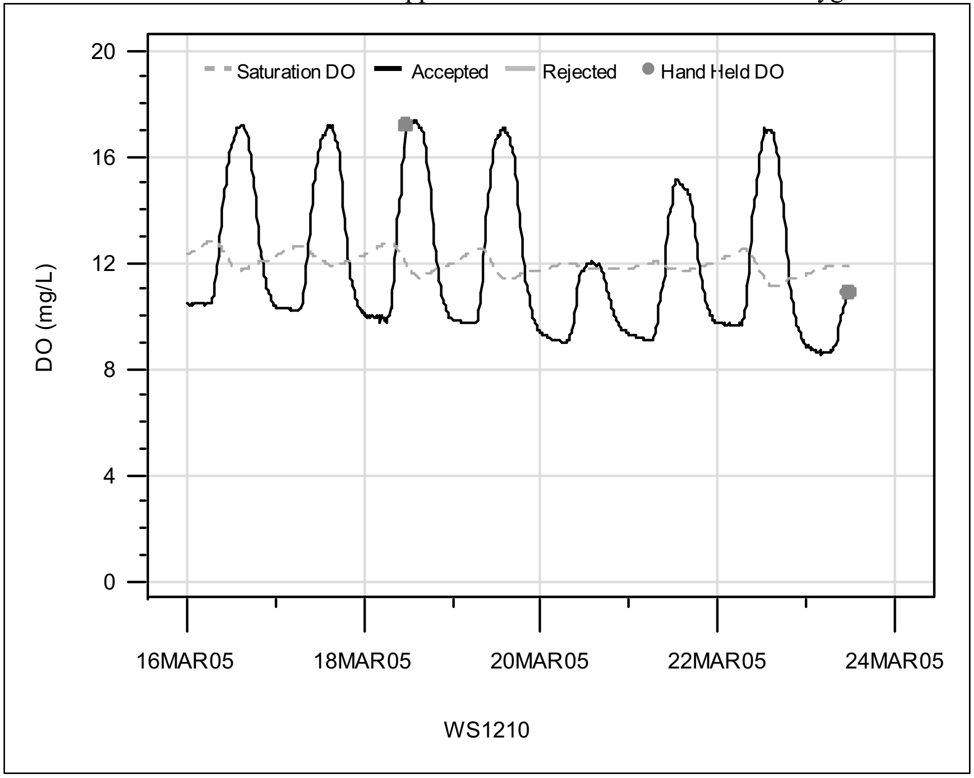


Figure C-141 Continuous Dissolved Oxygen (DO) with Calculated DO Saturation, 15MAR05 to 24MAR05, Site WS1210

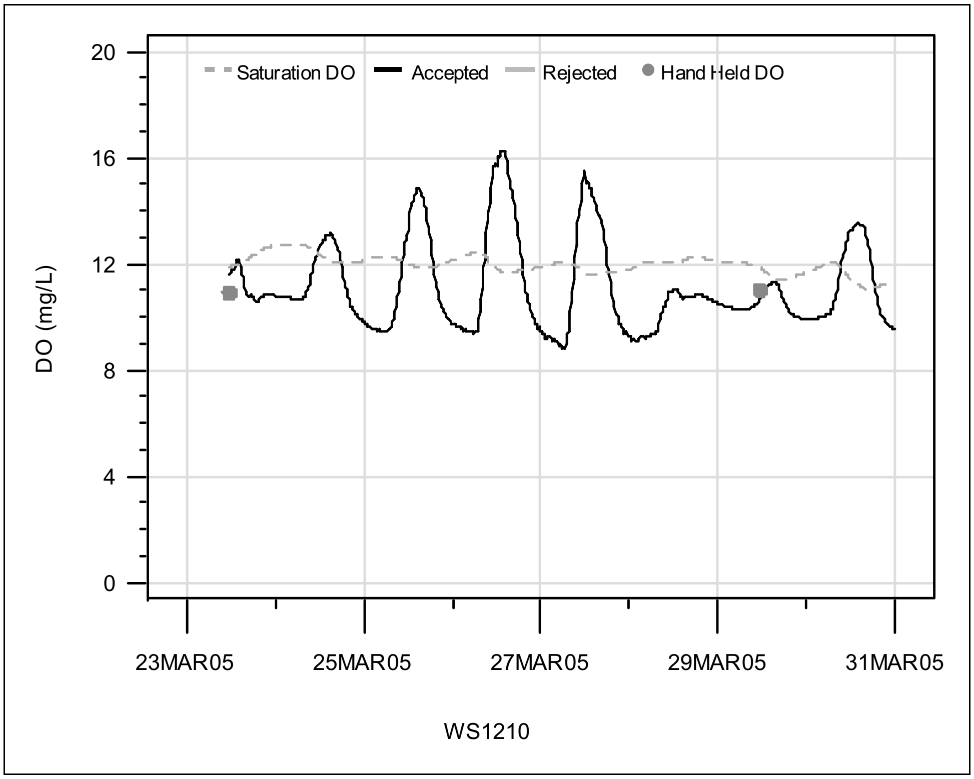


Figure C-142 Continuous Dissolved Oxygen (DO) with Calculated DO Saturation, 23MAR05 to 31MAR05, Site WS1210

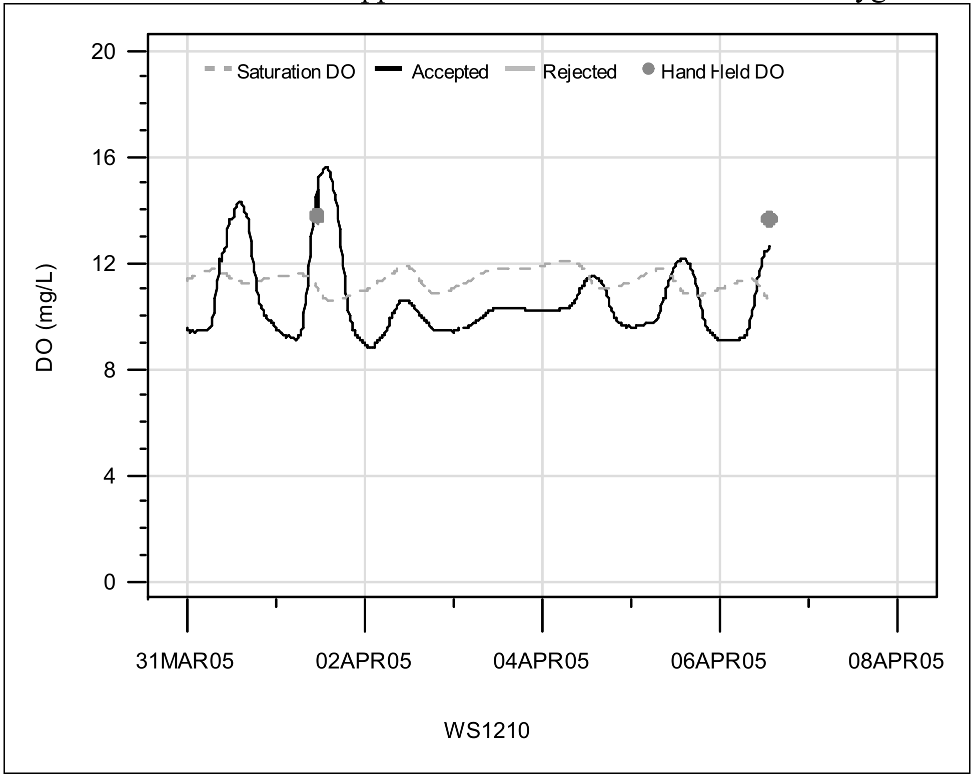


Figure C-143 Continuous Dissolved Oxygen (DO) with Calculated DO Saturation, 31MAR05 to 08APR05, Site WS1210

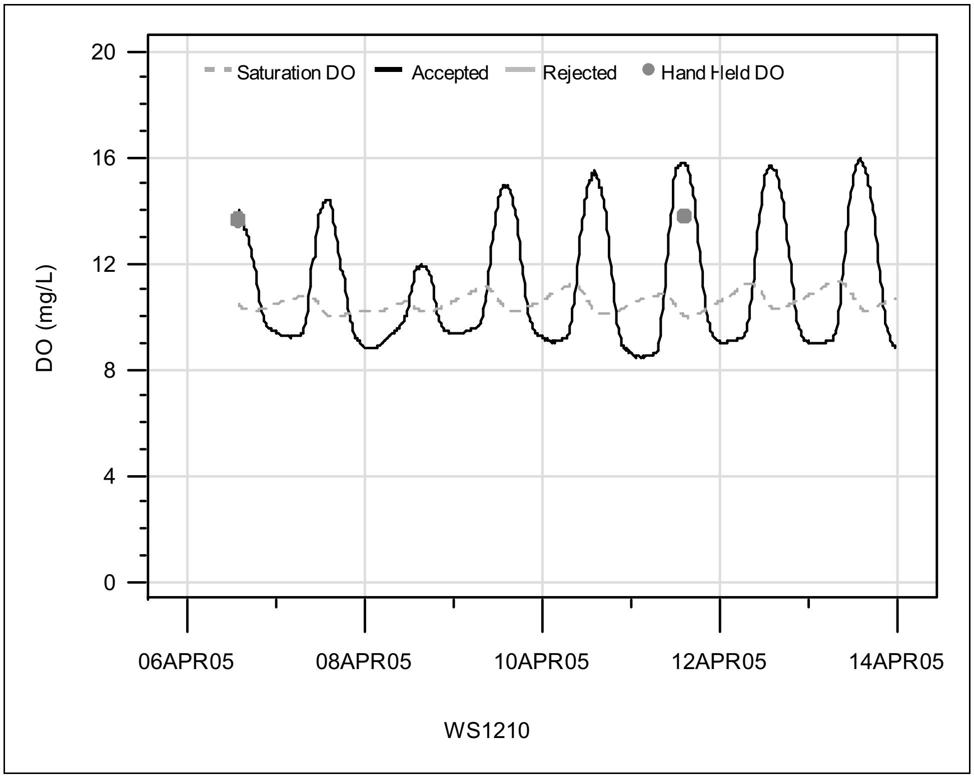


Figure C-144 Continuous Dissolved Oxygen (DO) with Calculated DO Saturation, 06APR05 to 14APR05, Site WS1210

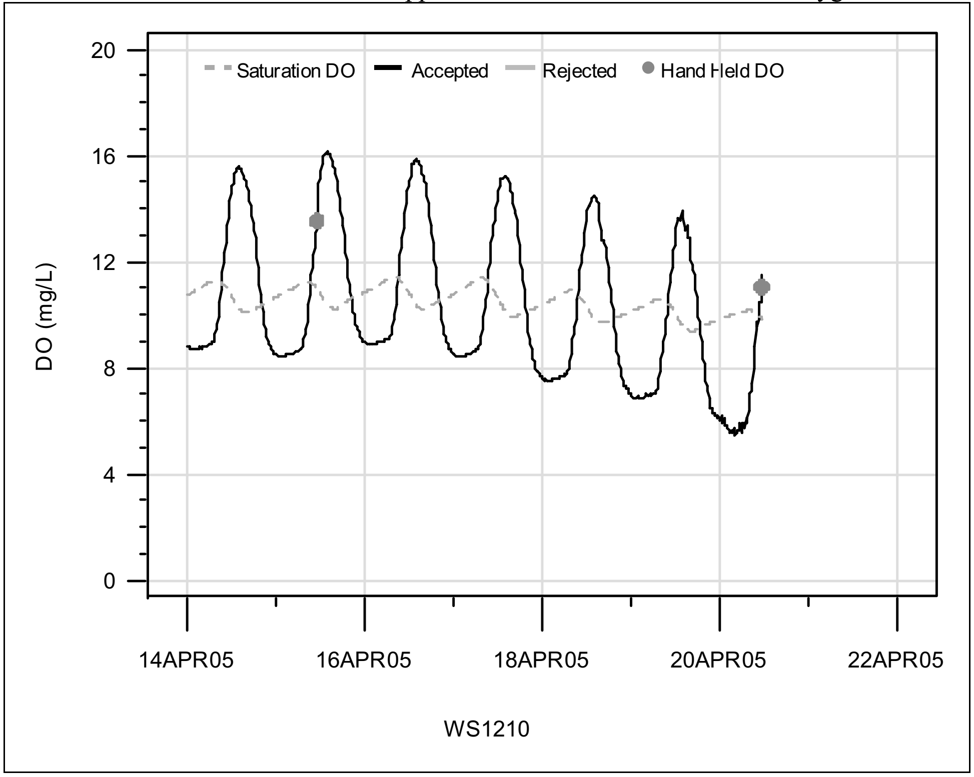


Figure C-145 Continuous Dissolved Oxygen (DO) with Calculated DO Saturation, 14APR05 to 22APR05, Site WS1210

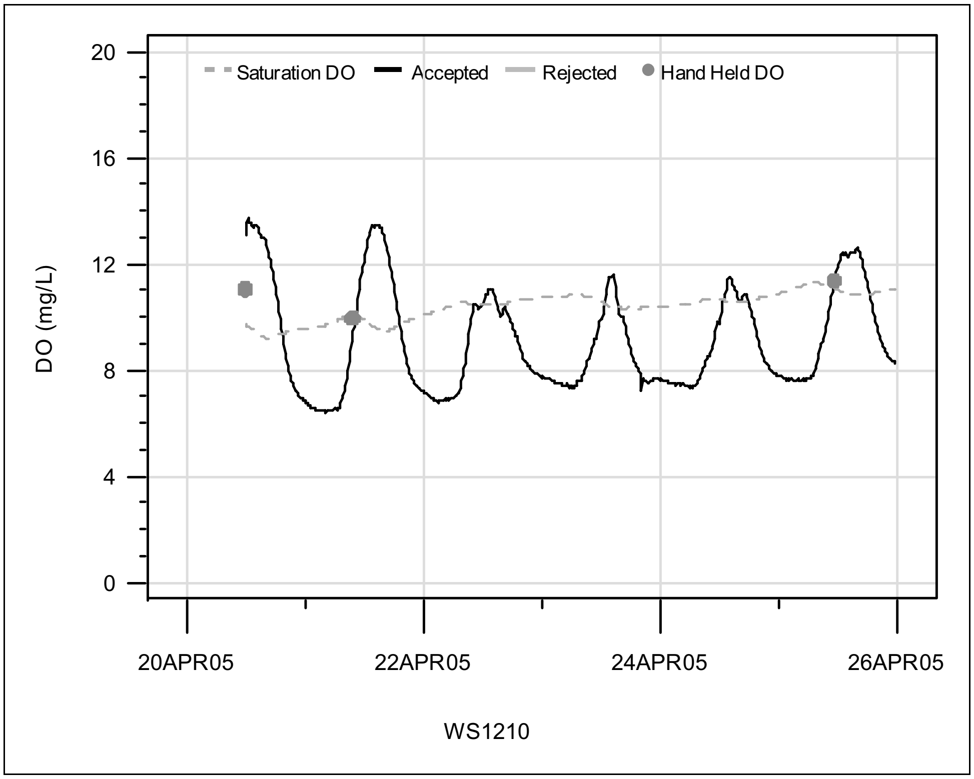


Figure C-146 Continuous Dissolved Oxygen (DO) with Calculated DO Saturation, 20APR05 to 26APR05, Site WS1210

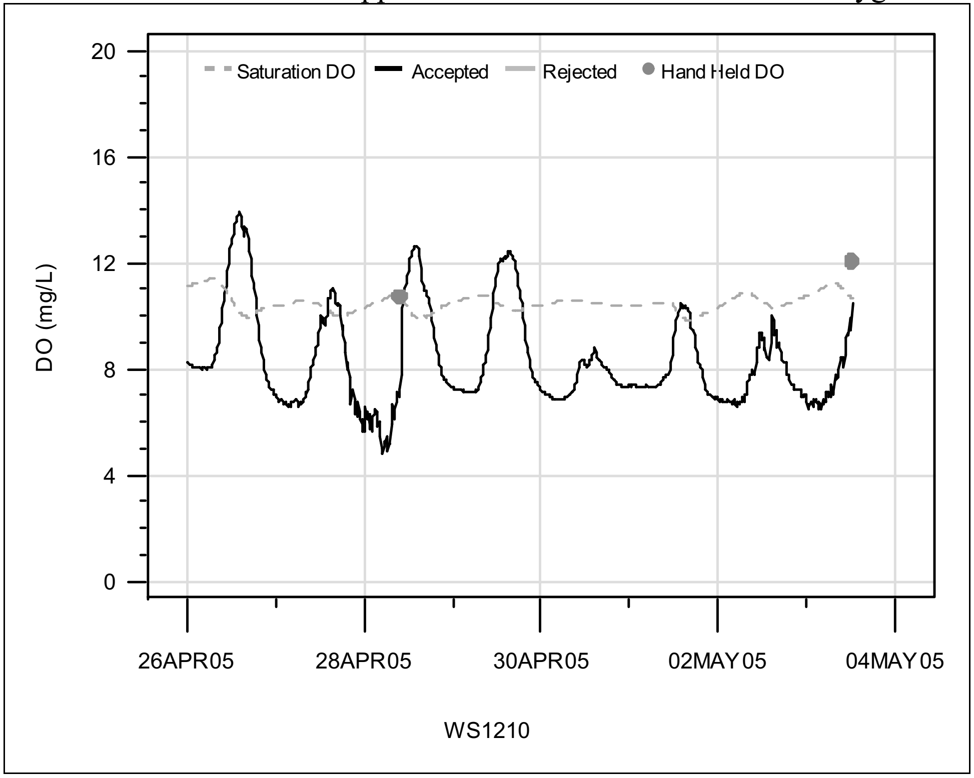


Figure C-147 Continuous Dissolved Oxygen (DO) with Calculated DO Saturation, 26APR05 to 04MAY05, Site WS1210

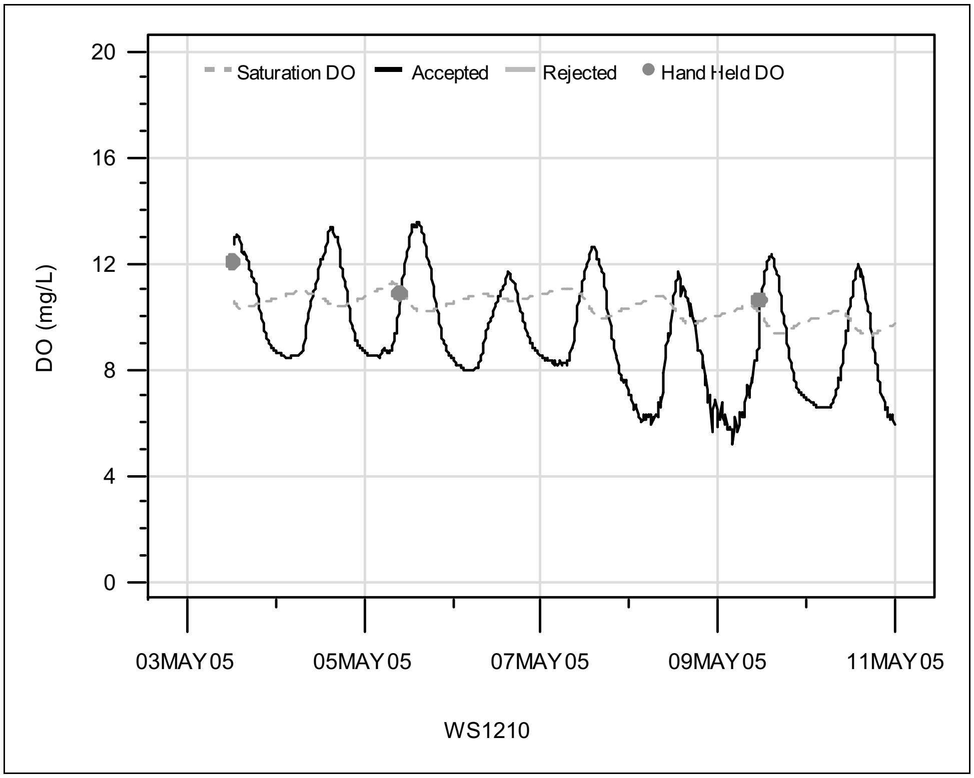


Figure C-148 Continuous Dissolved Oxygen (DO) with Calculated DO Saturation, 03MAY05 to 11MAY05, Site WS1210

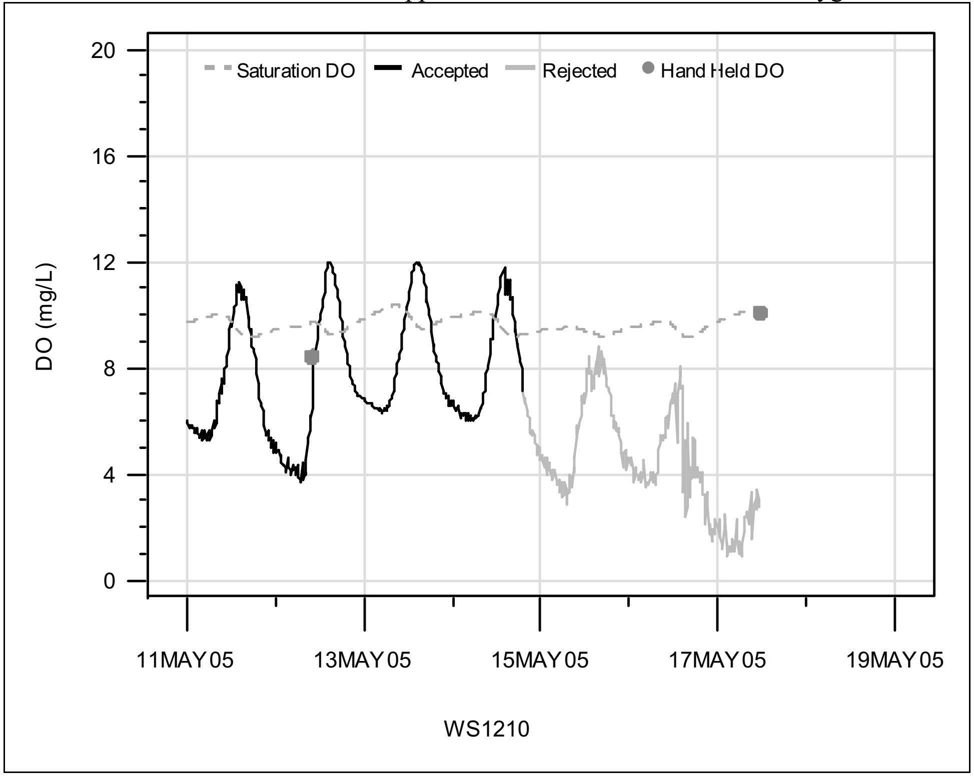


Figure C-149 Continuous Dissolved Oxygen (DO) with Calculated DO Saturation, 11MAY05 to 19MAY05, Site WS1210

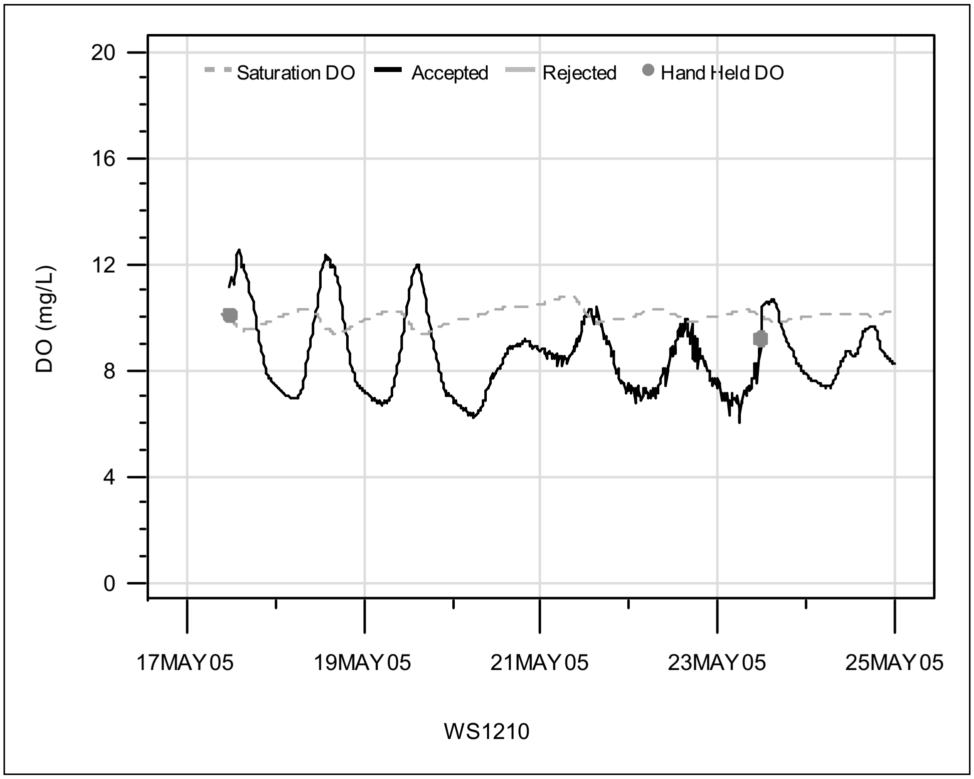


Figure C-150 Continuous Dissolved Oxygen (DO) with Calculated DO Saturation, 17MAY05 to 25MAY05, Site WS1210

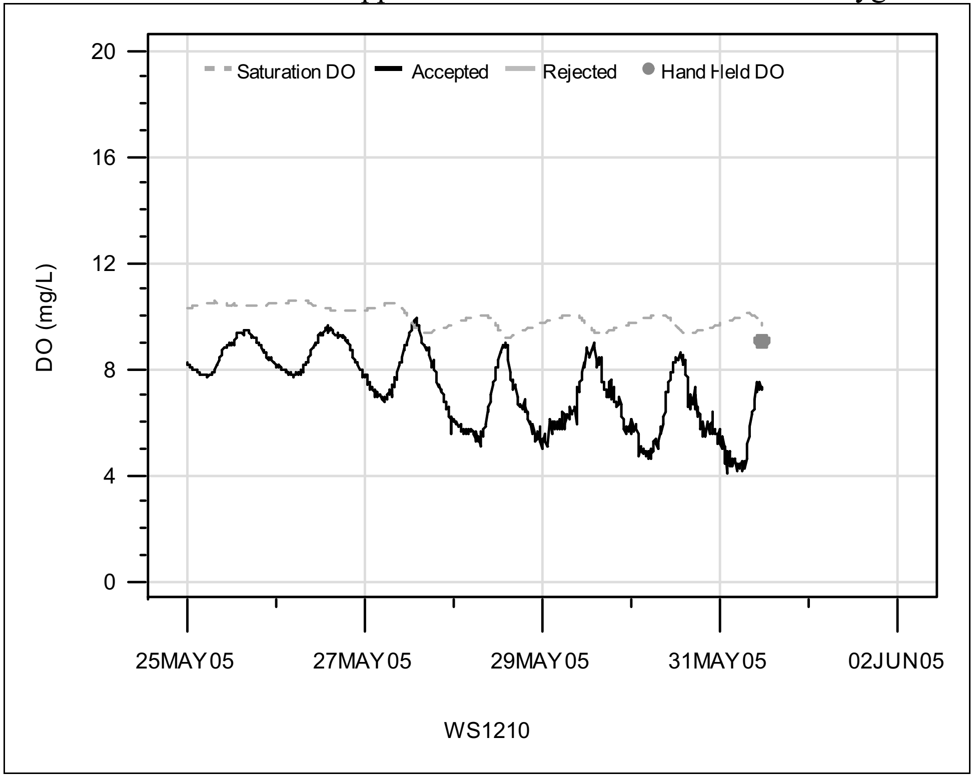


Figure C-151 Continuous Dissolved Oxygen (DO) with Calculated DO Saturation, 25MAY05 to 02JUN05, Site WS1210

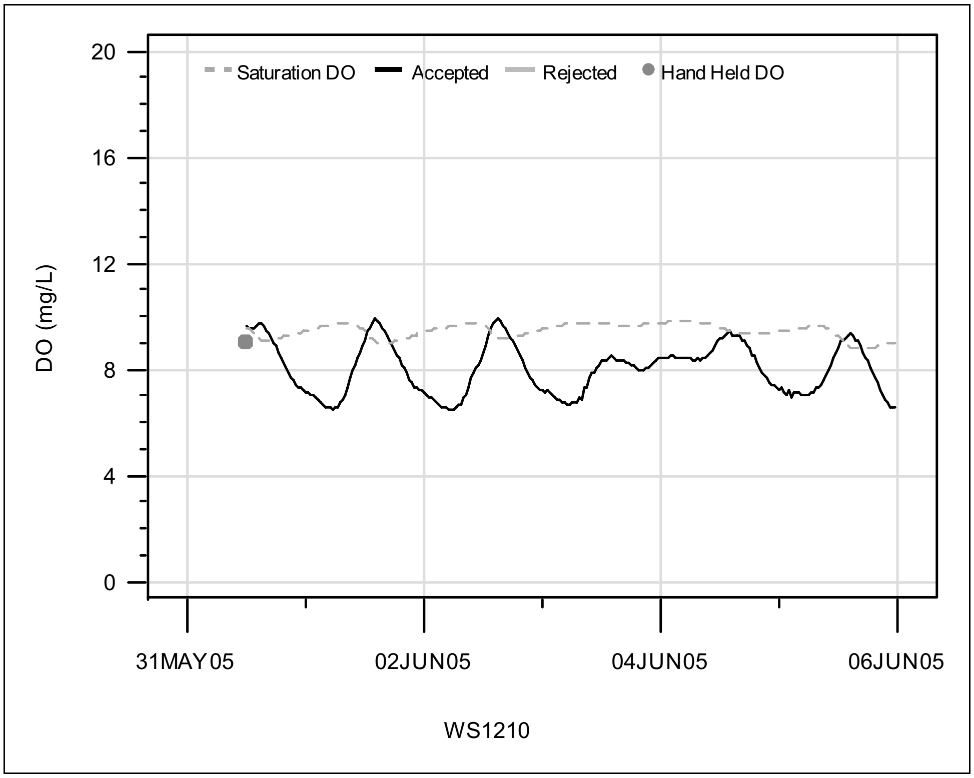


Figure C-152 Continuous Dissolved Oxygen (DO) with Calculated DO Saturation, 31MAY05 to 06JUN05, Site WS1210

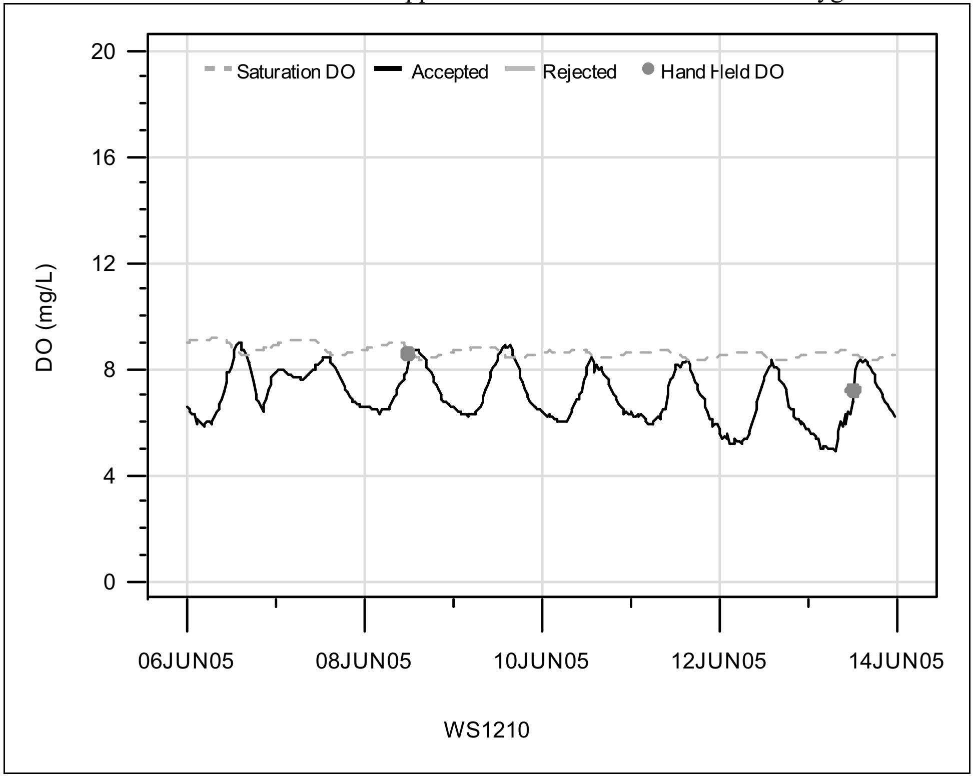


Figure C-153 Continuous Dissolved Oxygen (DO) with Calculated DO Saturation, 06JUN05 to 14JUN05, Site WS1210

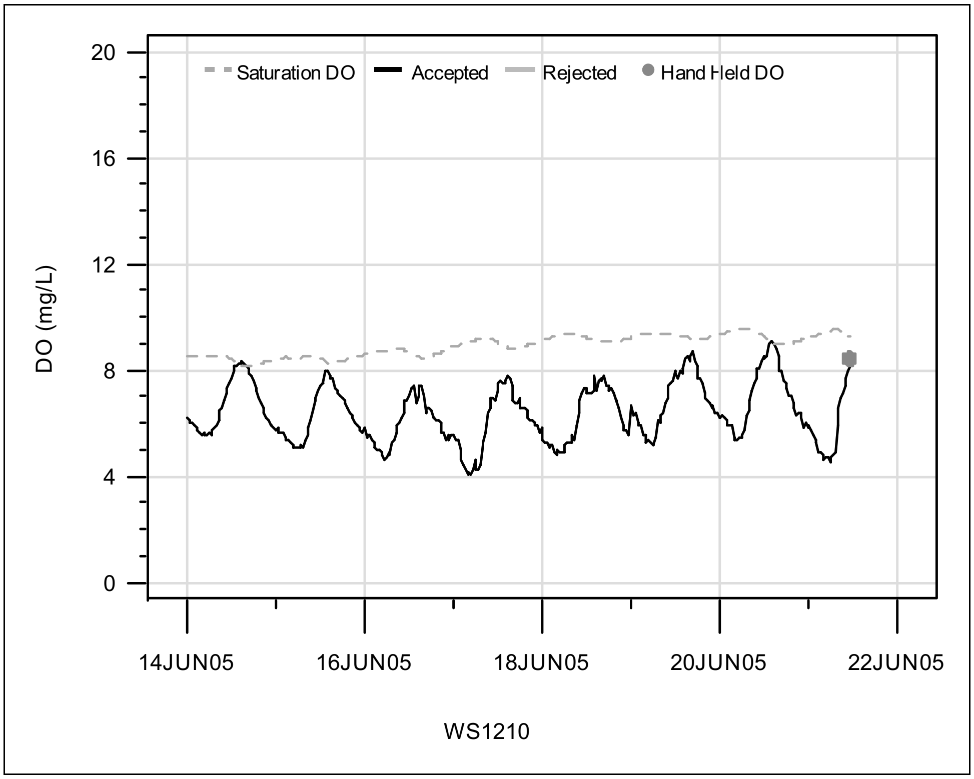


Figure C-154 Continuous Dissolved Oxygen (DO) with Calculated DO Saturation, 14JUN05 to 22JUN05, Site WS1210

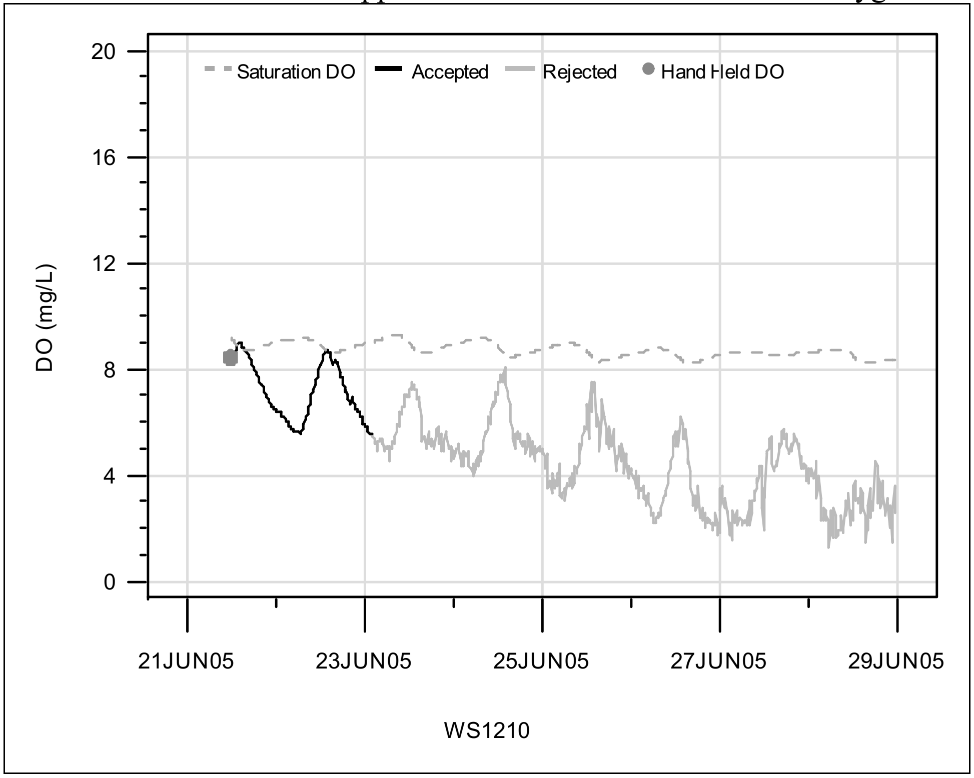


Figure C-155 Continuous Dissolved Oxygen (DO) with Calculated DO Saturation, 21JUN05 to 29JUN05, Site WS1210

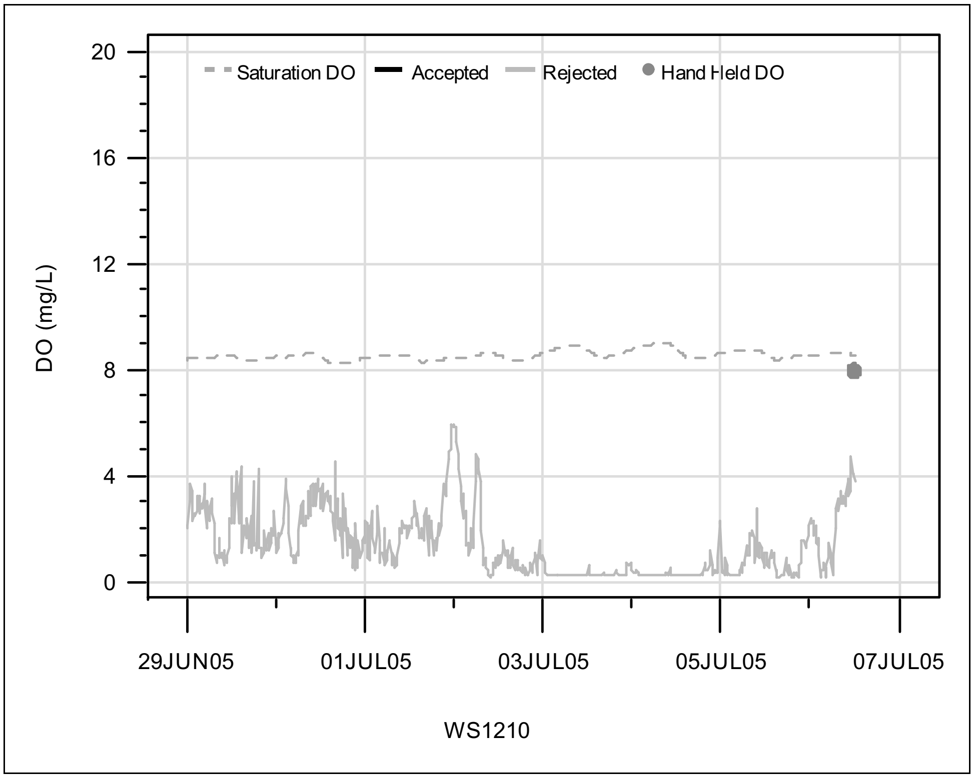


Figure C-156 Continuous Dissolved Oxygen (DO) with Calculated DO Saturation, 29JUN05 to 07JUL05, Site WS1210

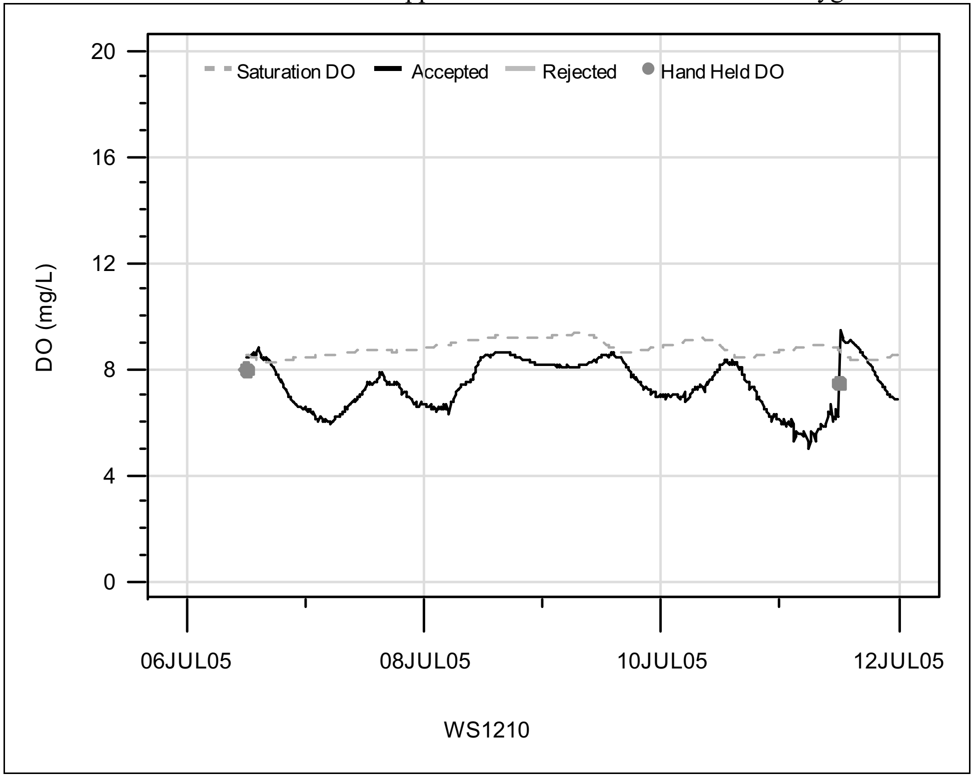


Figure C-157 Continuous Dissolved Oxygen (DO) with Calculated DO Saturation, 06JUL05 to 12JUL05, Site WS1210

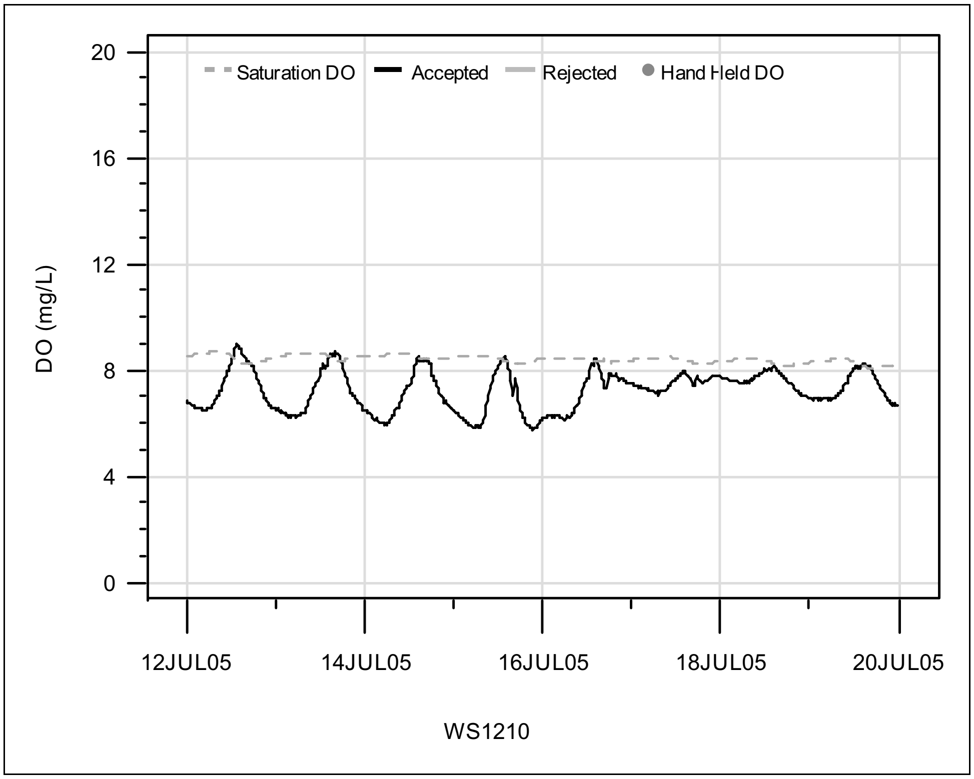


Figure C-158 Continuous Dissolved Oxygen (DO) with Calculated DO Saturation, 12JUL05 to 20JUL05, Site WS1210

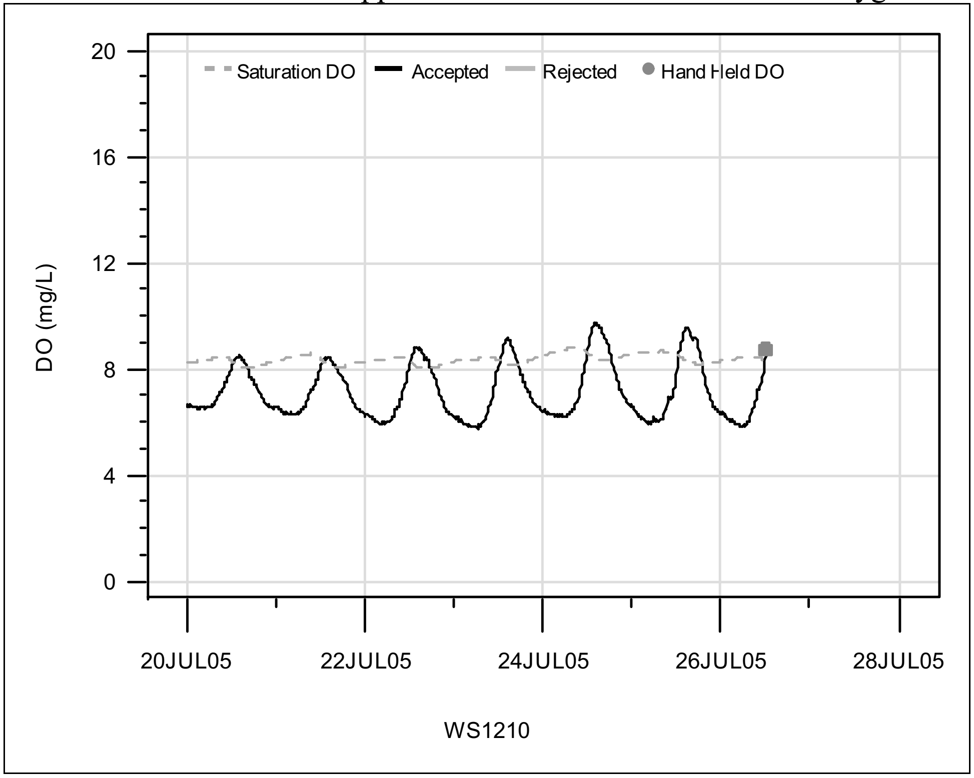


Figure C-159 Continuous Dissolved Oxygen (DO) with Calculated DO Saturation, 20JUL05 to 28JUL05, Site WS1210

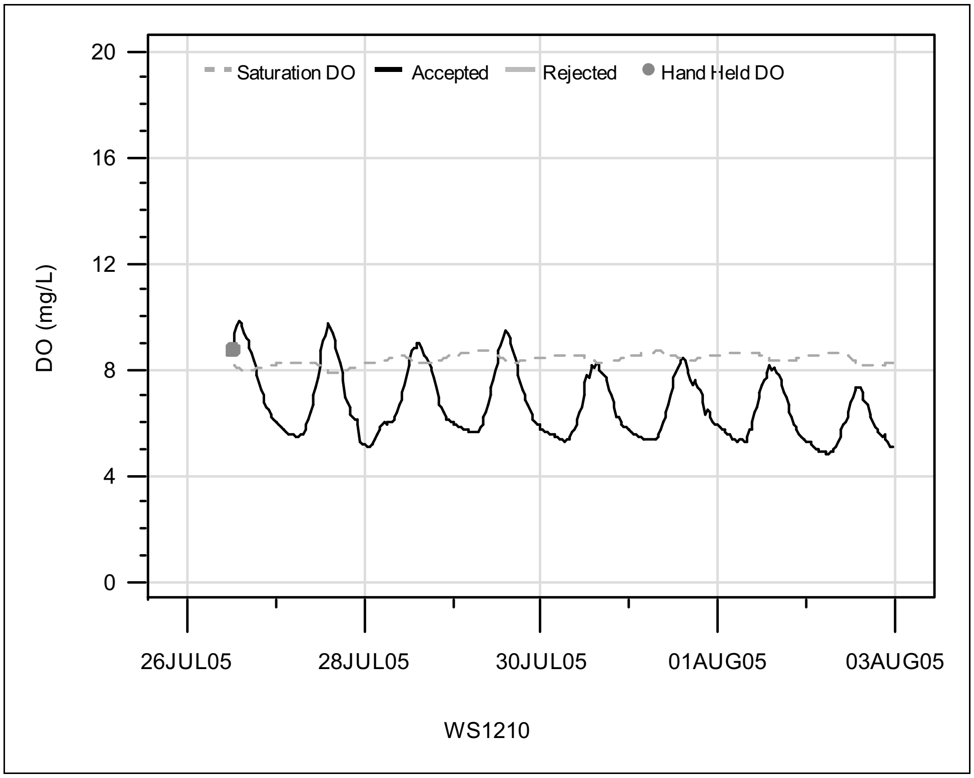


Figure C-160 Continuous Dissolved Oxygen (DO) with Calculated DO Saturation, 26JUL05 to 03AUG05, Site WS1210

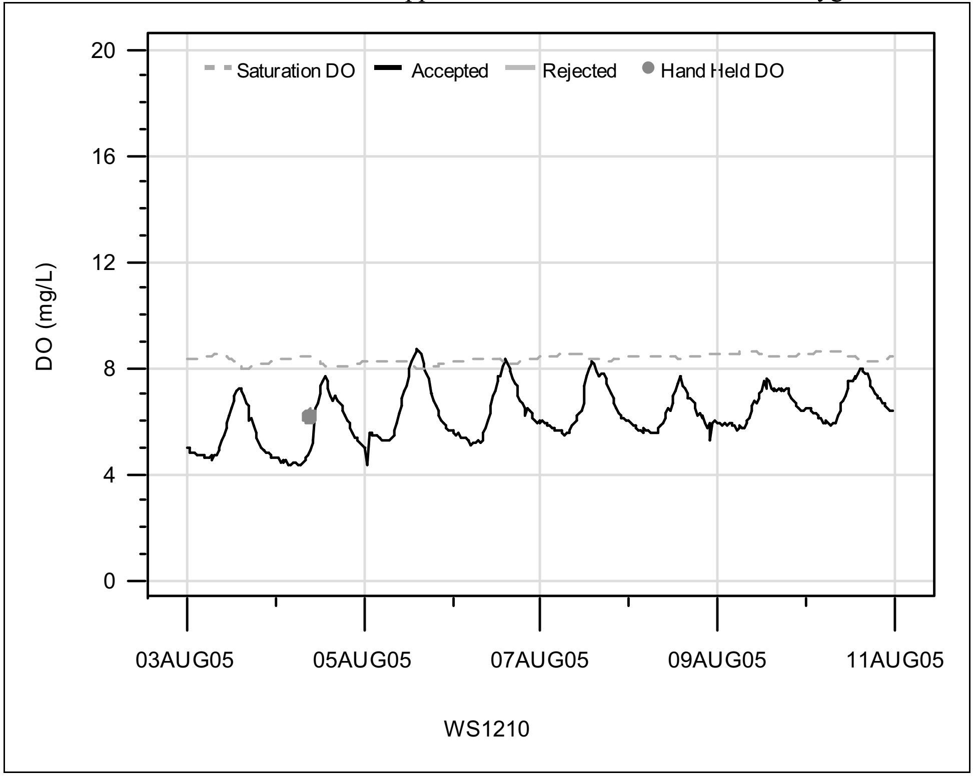


Figure C-161 Continuous Dissolved Oxygen (DO) with Calculated DO Saturation, 03AUG05 to 11AUG05, Site WS1210

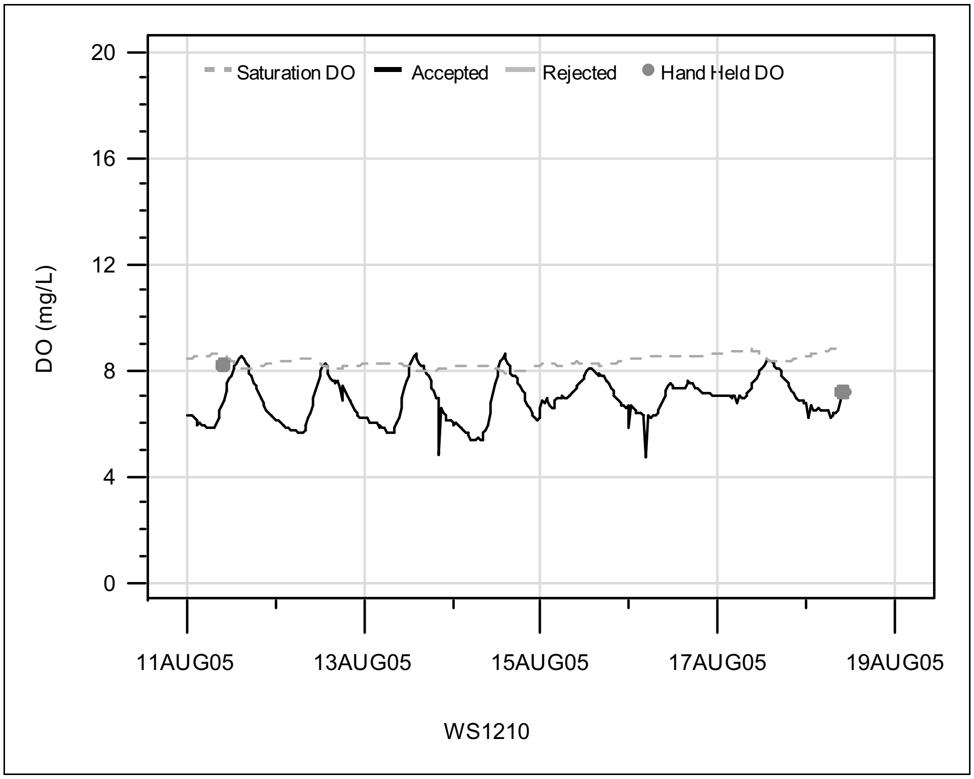


Figure C-162 Continuous Dissolved Oxygen (DO) with Calculated DO Saturation, 11AUG05 to 19AUG05, Site WS1210

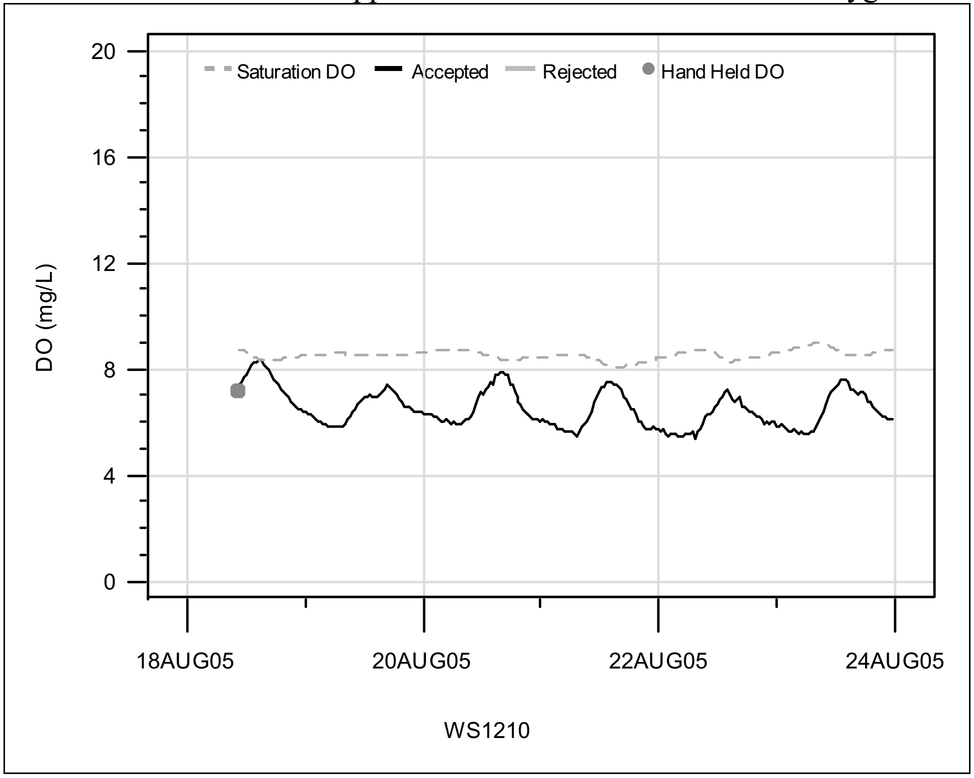


Figure C-163 Continuous Dissolved Oxygen (DO) with Calculated DO Saturation, 18AUG05 to 24AUG05, Site WS1210

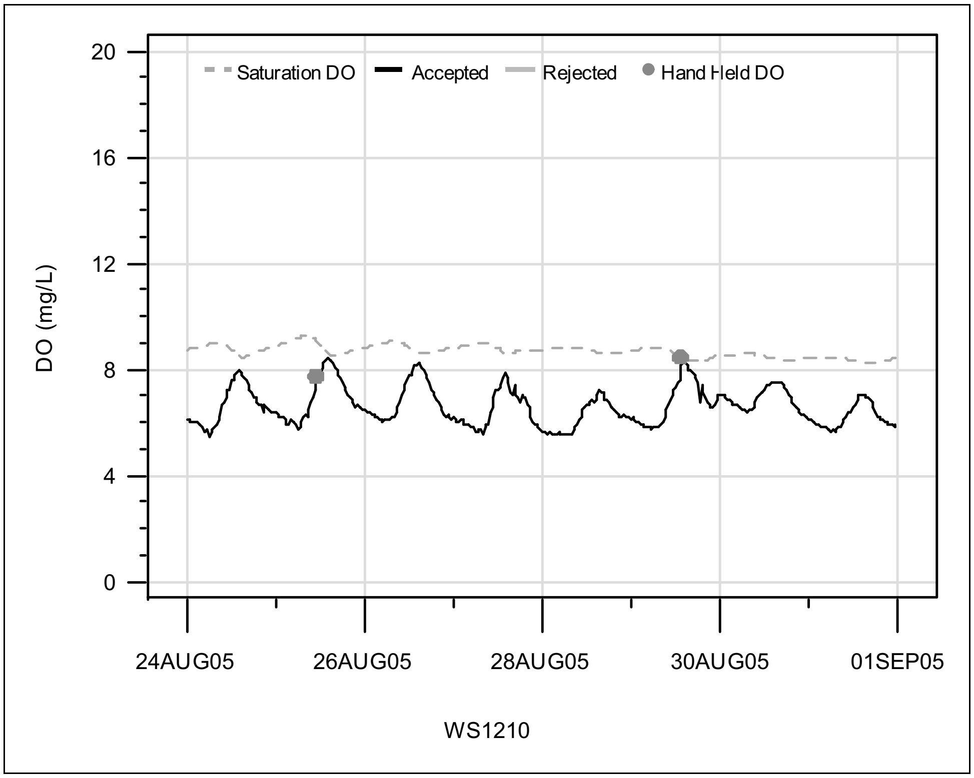


Figure C-164 Continuous Dissolved Oxygen (DO) with Calculated DO Saturation, 24AUG05 to 01SEP05, Site WS1210

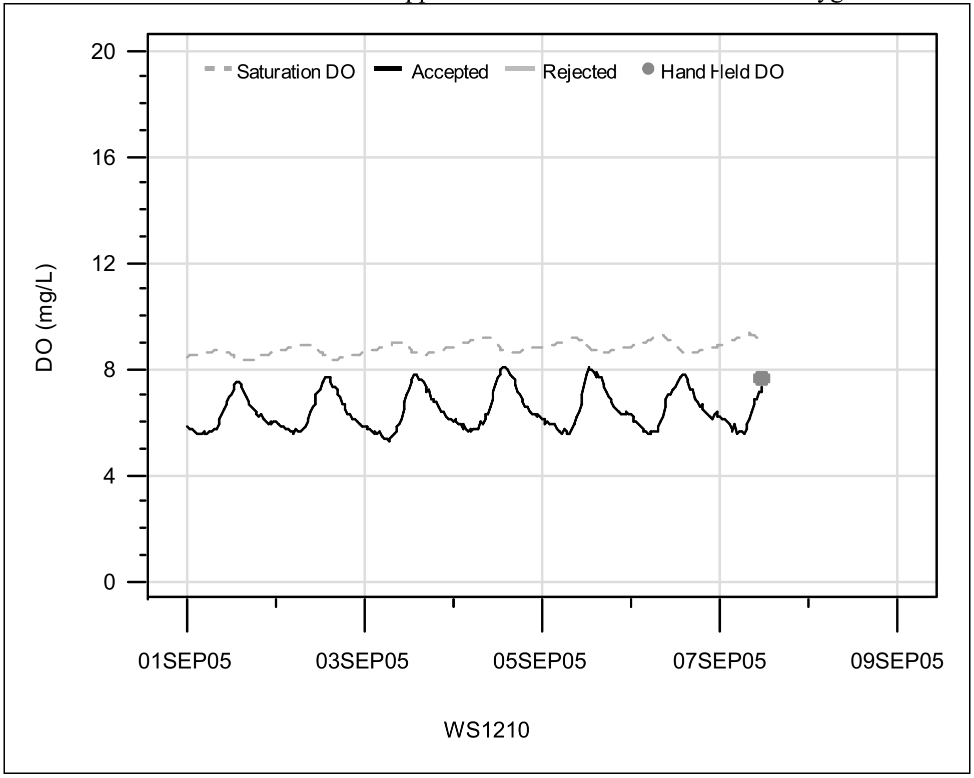


Figure C-165 Continuous Dissolved Oxygen (DO) with Calculated DO Saturation, 01SEP05 to 09SEP05, Site WS1210

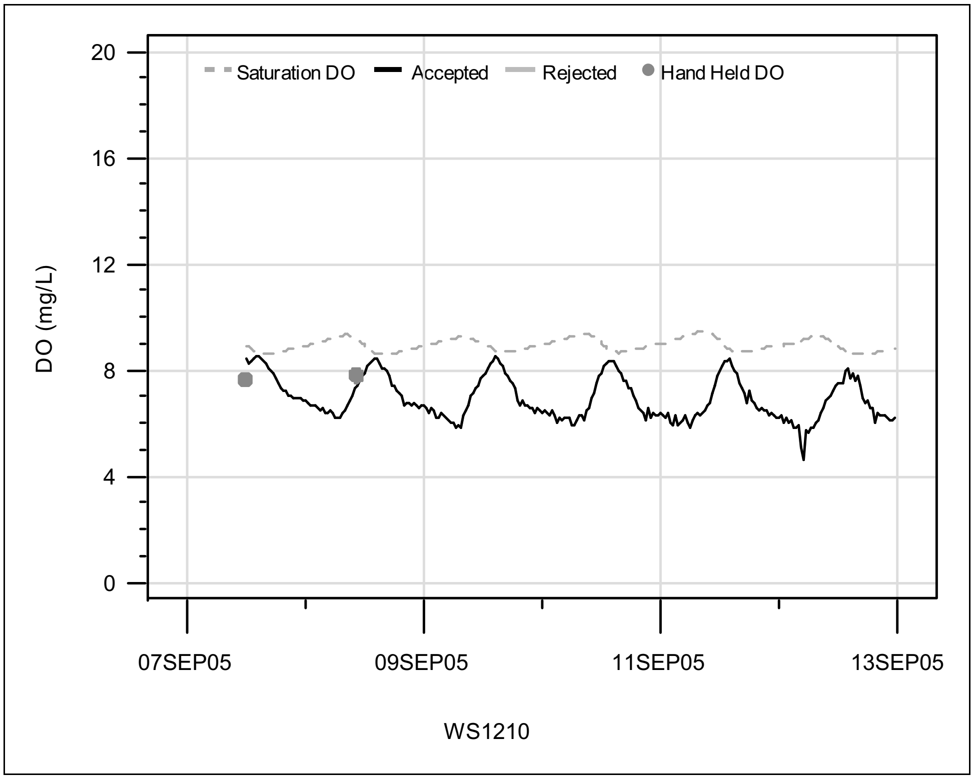


Figure C-166 Continuous Dissolved Oxygen (DO) with Calculated DO Saturation, 07SEP05 to 13SEP05, Site WS1210

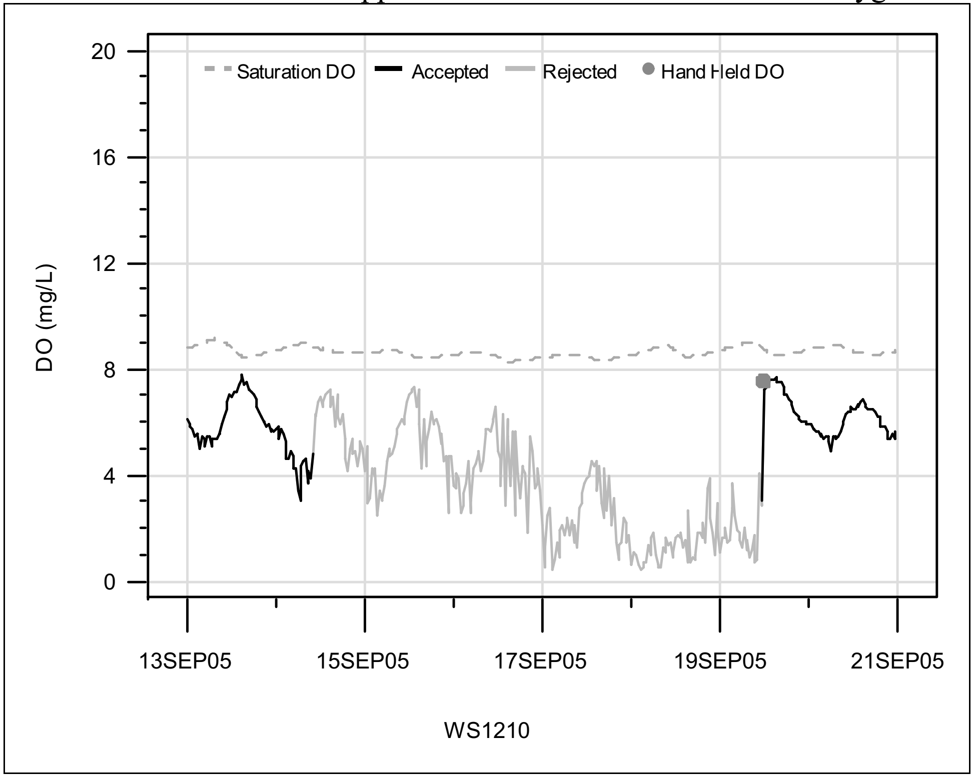


Figure C-167 Continuous Dissolved Oxygen (DO) with Calculated DO Saturation, 13SEP05 to 21SEP05, Site WS1210

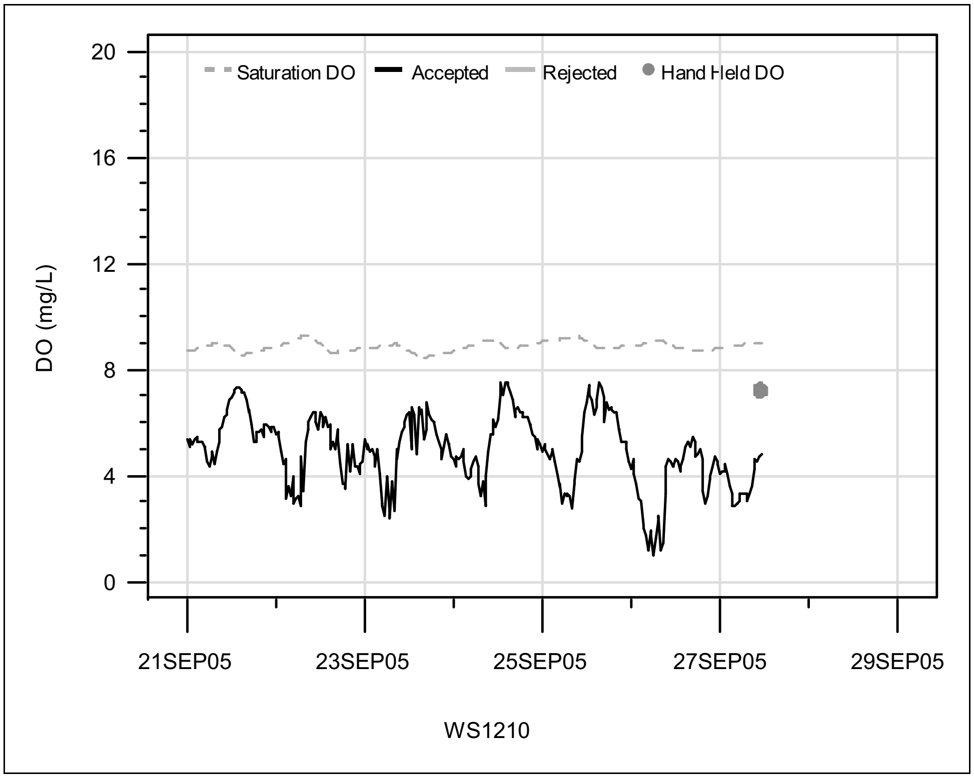


Figure C-168 Continuous Dissolved Oxygen (DO) with Calculated DO Saturation, 21SEP05 to 29SEP05, Site WS1210

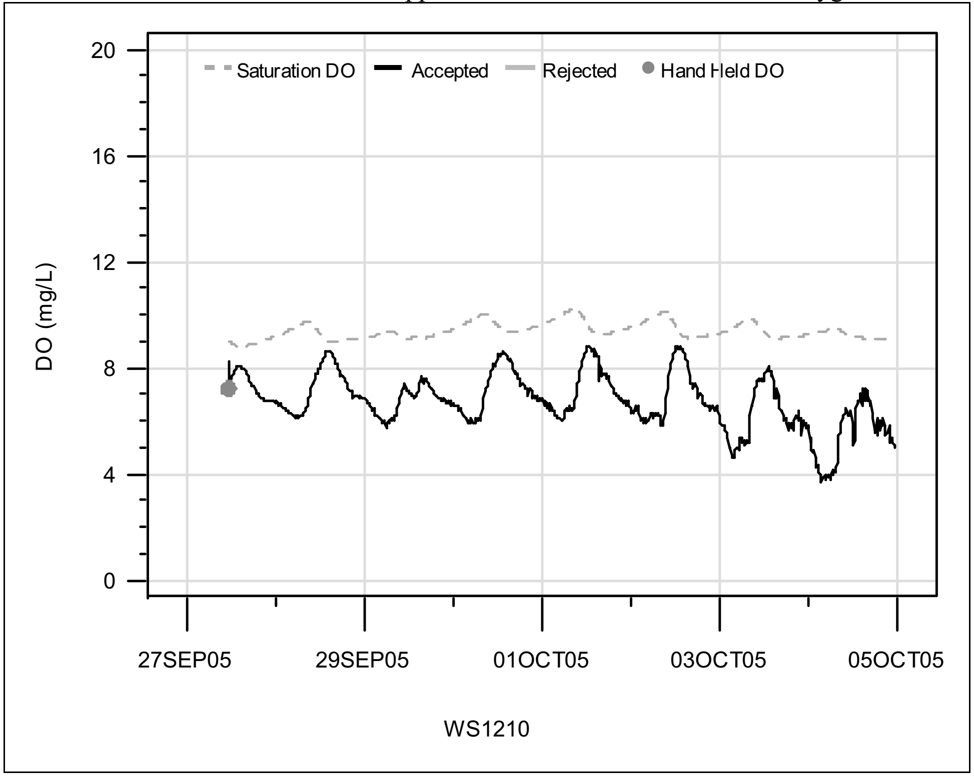


Figure C-169 Continuous Dissolved Oxygen (DO) with Calculated DO Saturation, 27SEP05 to 05OCT05, Site WS1210

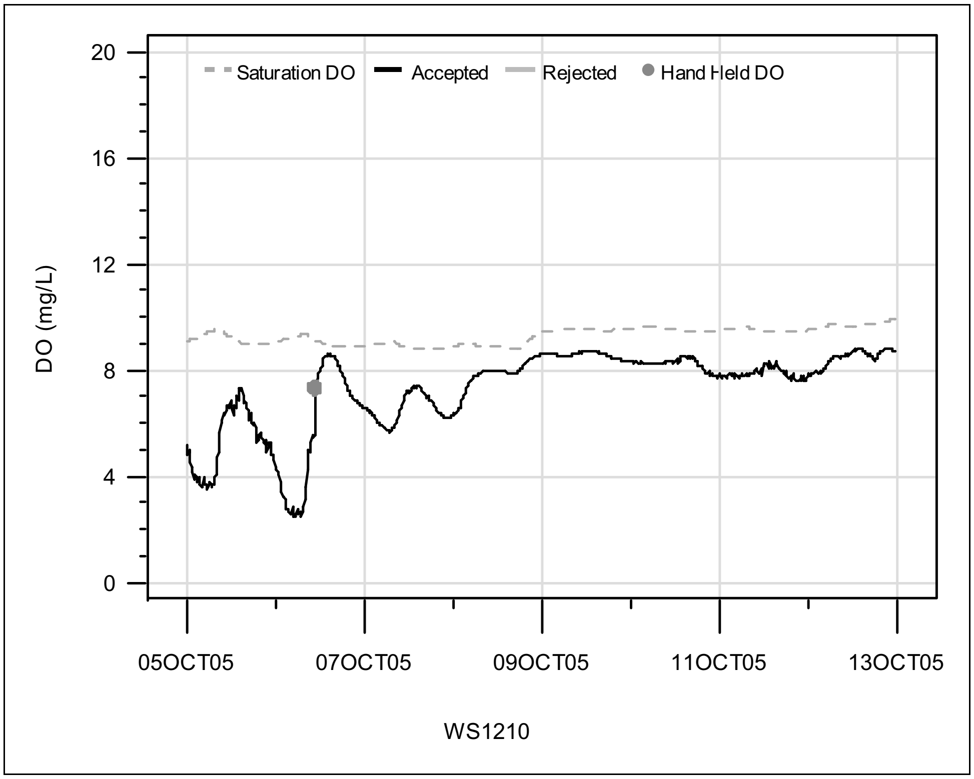


Figure C-170 Continuous Dissolved Oxygen (DO) with Calculated DO Saturation, 05OCT05 to 13OCT05, Site WS1210

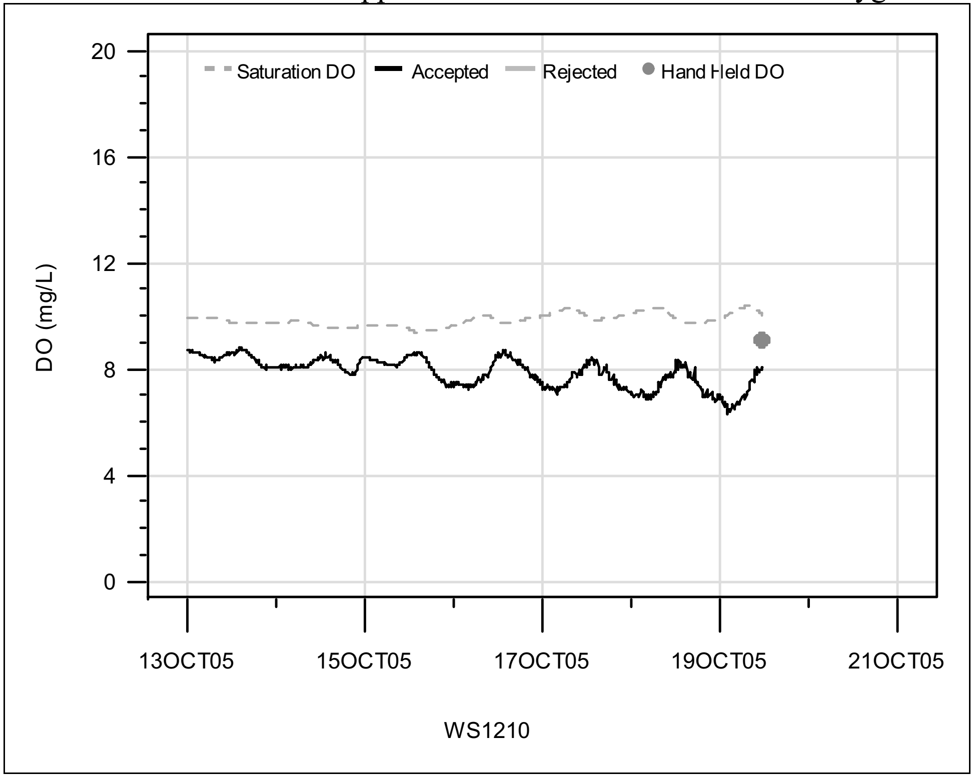


Figure C-171 Continuous Dissolved Oxygen (DO) with Calculated DO Saturation, 13OCT05 to 21OCT05, Site WS1210

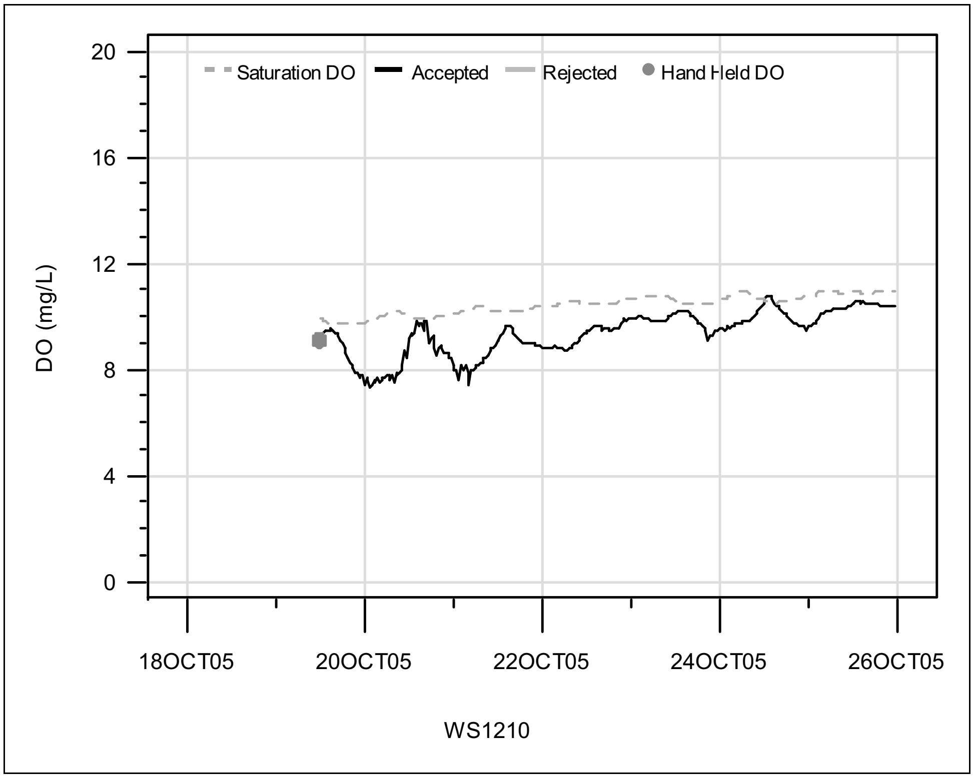


Figure C-172 Continuous Dissolved Oxygen (DO) with Calculated DO Saturation, 18OCT05 to 26OCT05, Site WS1210

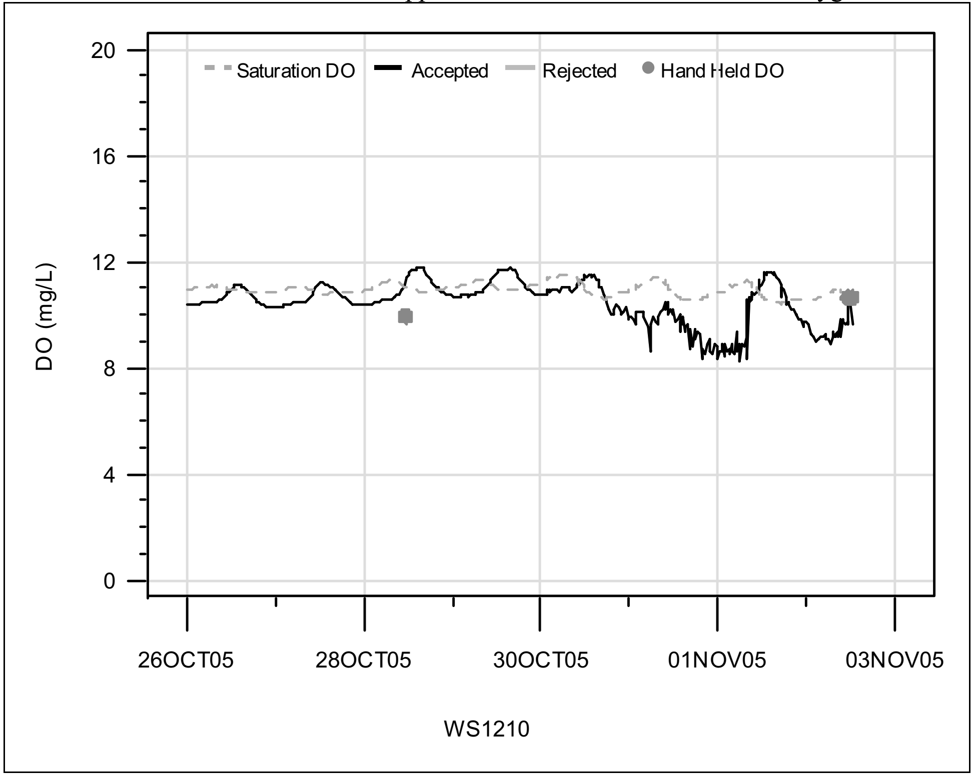


Figure C-173 Continuous Dissolved Oxygen (DO) with Calculated DO Saturation, 26OCT05 to 03NOV05, Site WS1210

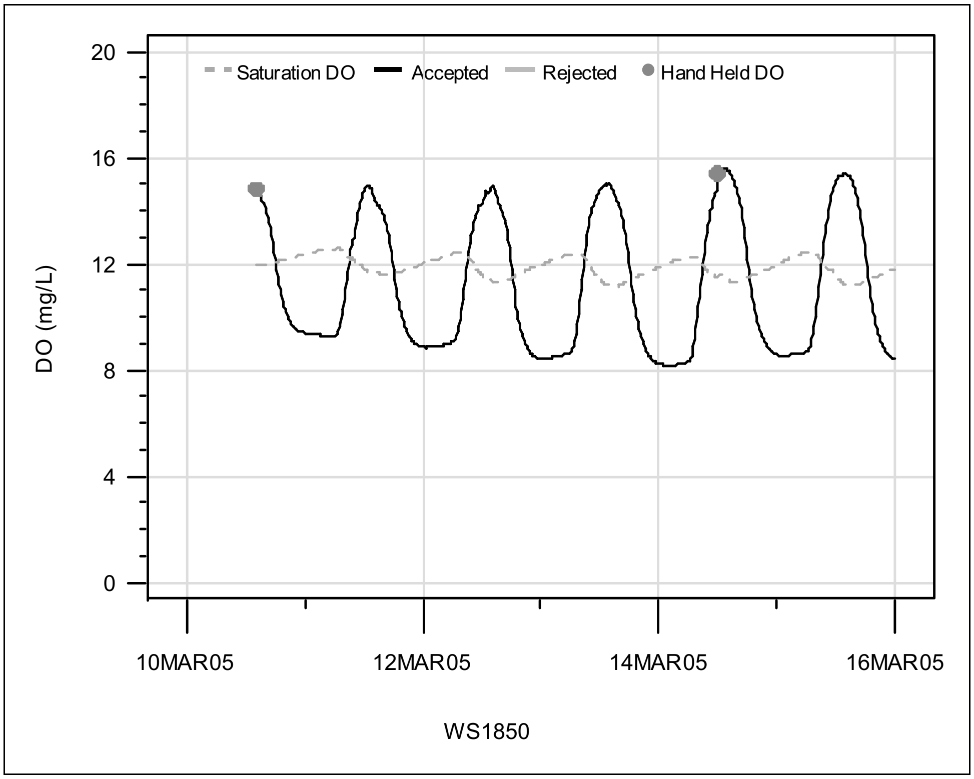


Figure C-174 Continuous Dissolved Oxygen (DO) with Calculated DO Saturation, 10MAR05 to 16MAR05, Site WS1850

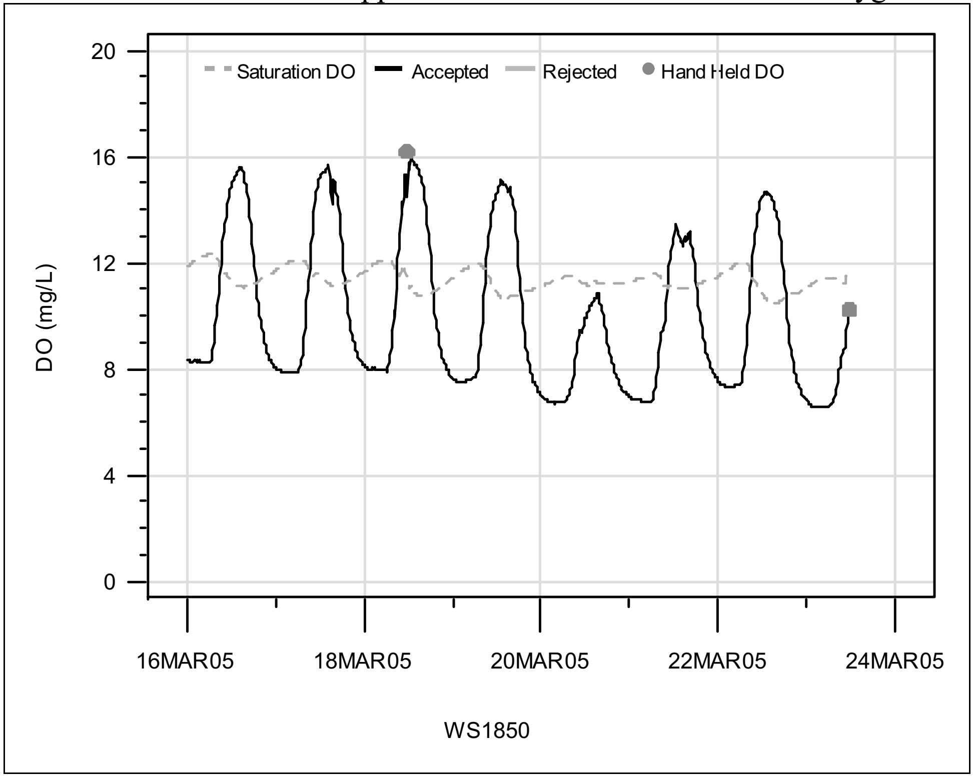


Figure C-175 Continuous Dissolved Oxygen (DO) with Calculated DO Saturation, 16MAR05 to 24MAR05, Site WS1850

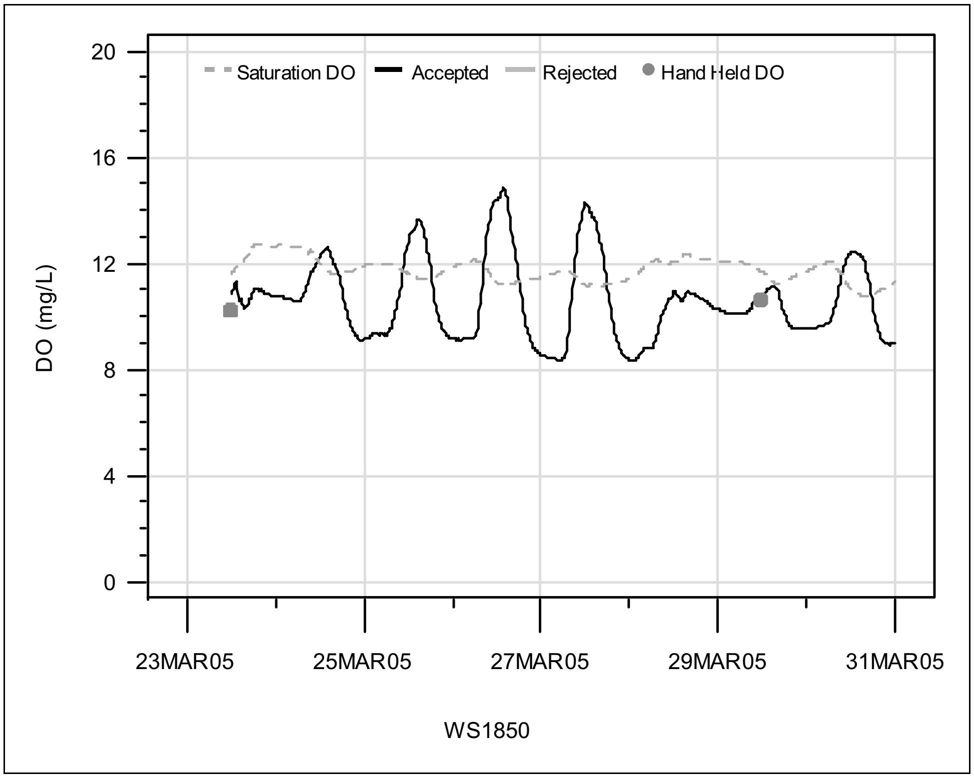


Figure C-176 Continuous Dissolved Oxygen (DO) with Calculated DO Saturation, 23MAR05 to 31MAR05, Site WS1850

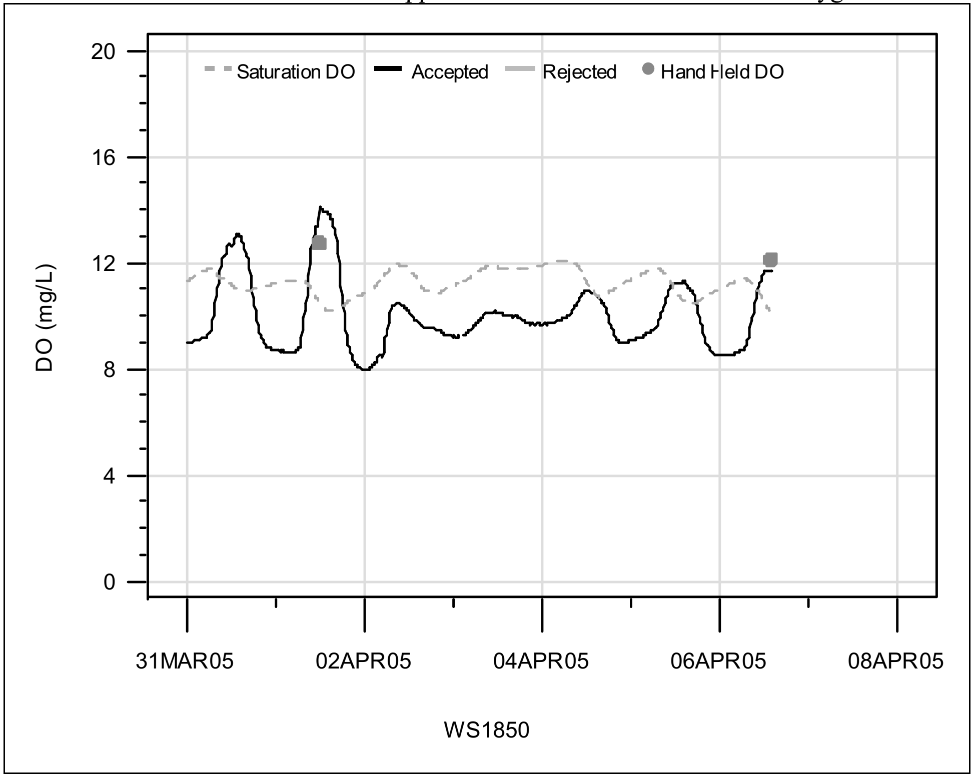


Figure C-177 Continuous Dissolved Oxygen (DO) with Calculated DO Saturation, 31MAR05 to 08APR05, Site WS1850

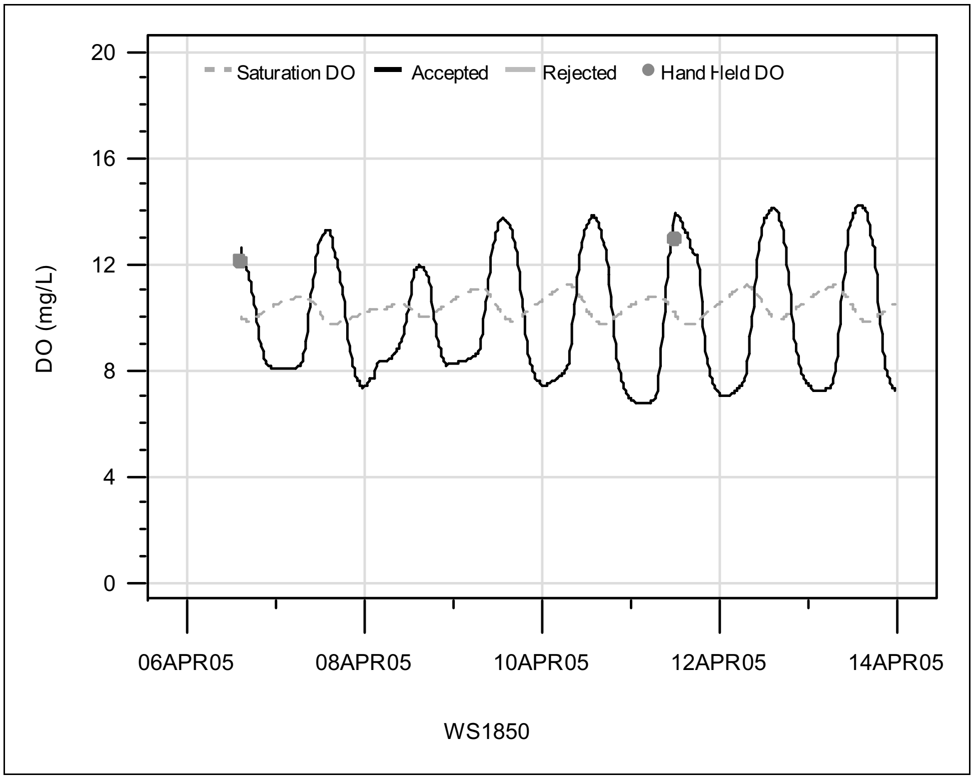


Figure C-178 Continuous Dissolved Oxygen (DO) with Calculated DO Saturation, 06APR05 to 14APR05, Site WS1850

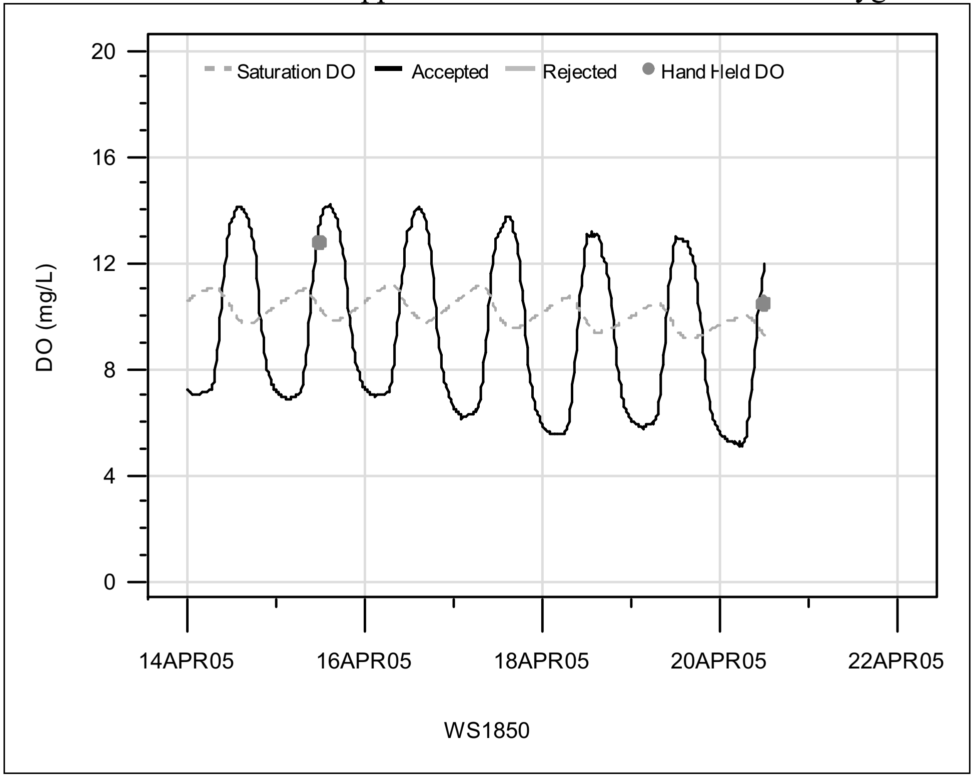


Figure C-179 Continuous Dissolved Oxygen (DO) with Calculated DO Saturation, 14APR05 to 22APR05, Site WS1850

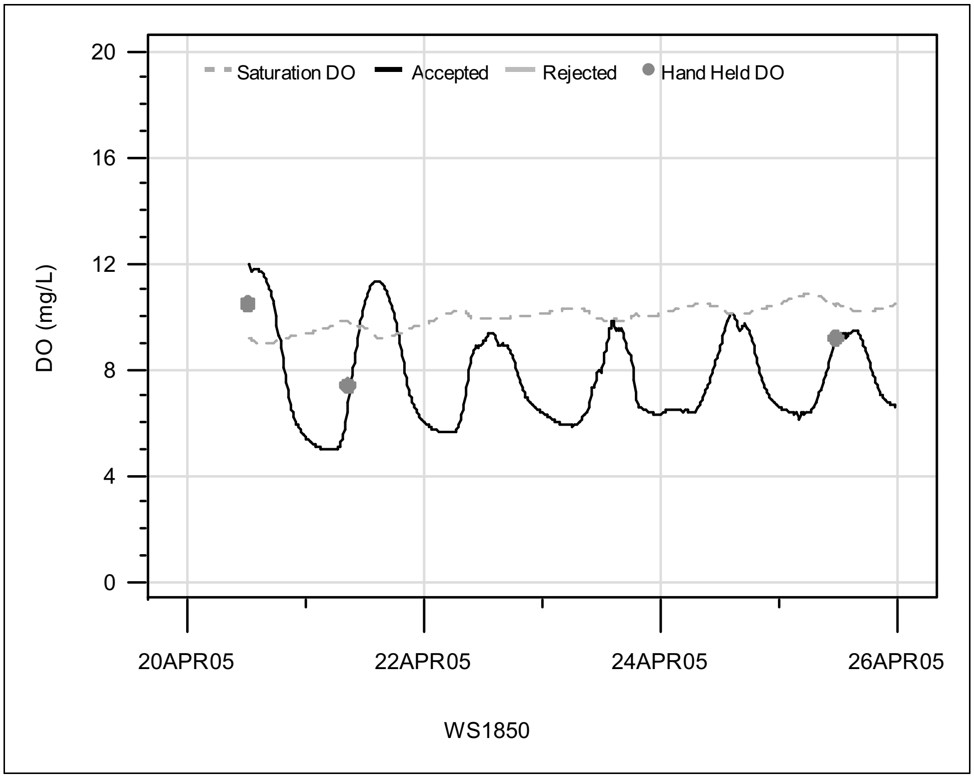


Figure C-180 Continuous Dissolved Oxygen (DO) with Calculated DO Saturation, 20APR05 to 26APR05, Site WS1850

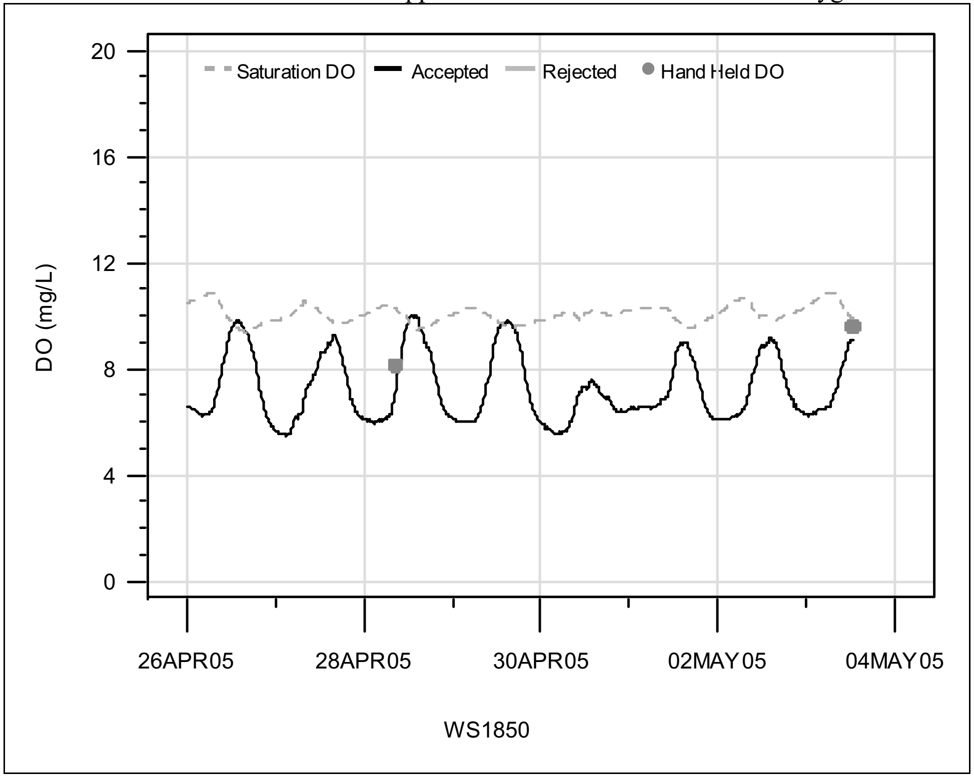


Figure C-181 Continuous Dissolved Oxygen (DO) with Calculated DO Saturation, 26APR05 to 04MAY05, Site WS1850

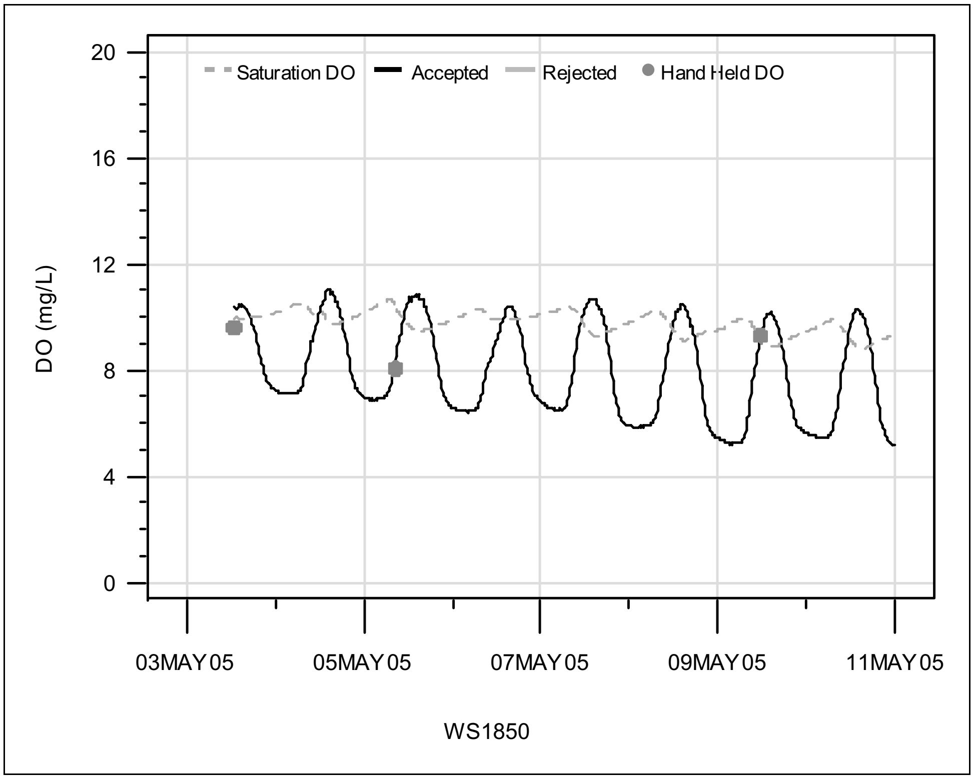


Figure C-182 Continuous Dissolved Oxygen (DO) with Calculated DO Saturation, 03MAY05 to 11MAY05, Site WS1850

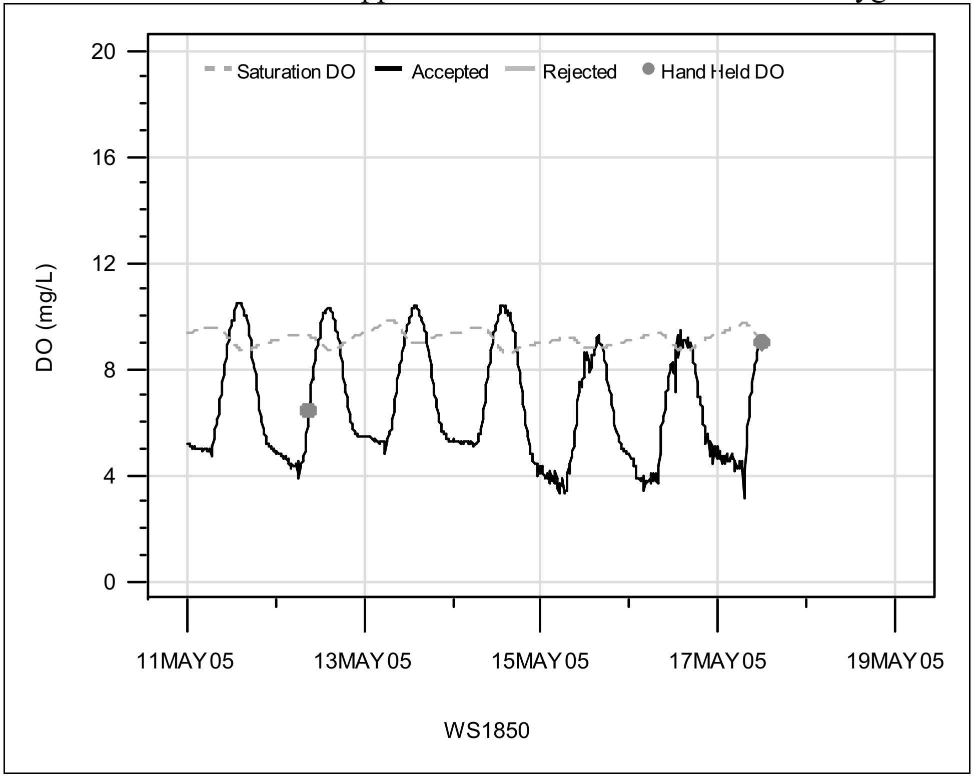


Figure C-183 Continuous Dissolved Oxygen (DO) with Calculated DO Saturation, 11MAY05 to 19MAY05, Site WS1850

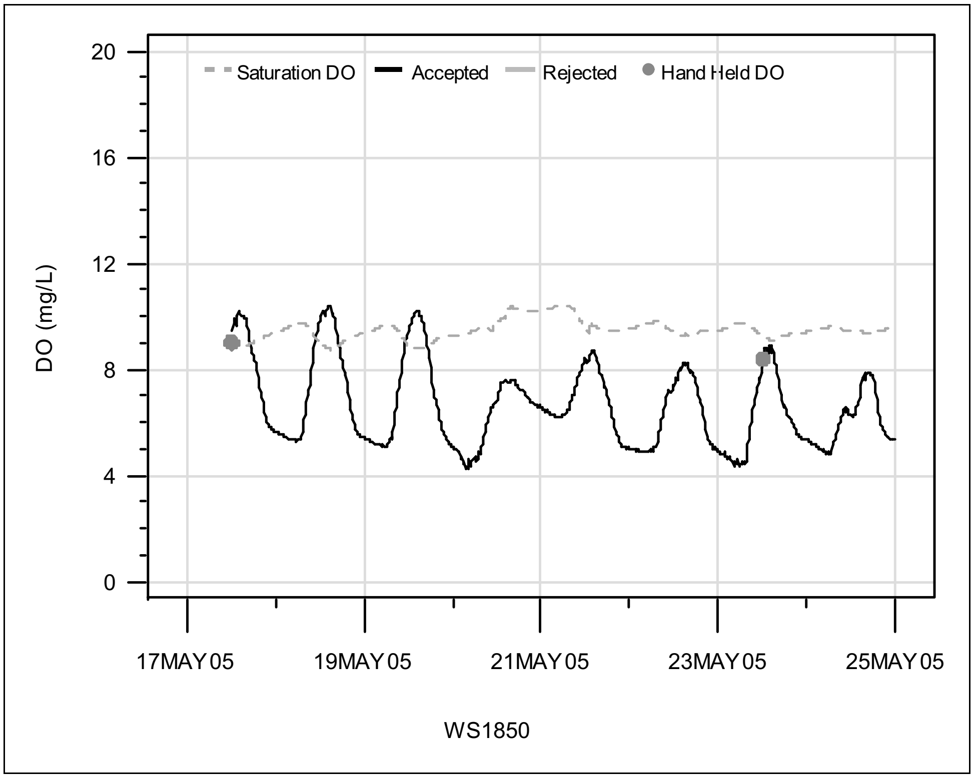


Figure C-184 Continuous Dissolved Oxygen (DO) with Calculated DO Saturation, 17MAY05 to 25MAY05, Site WS1850

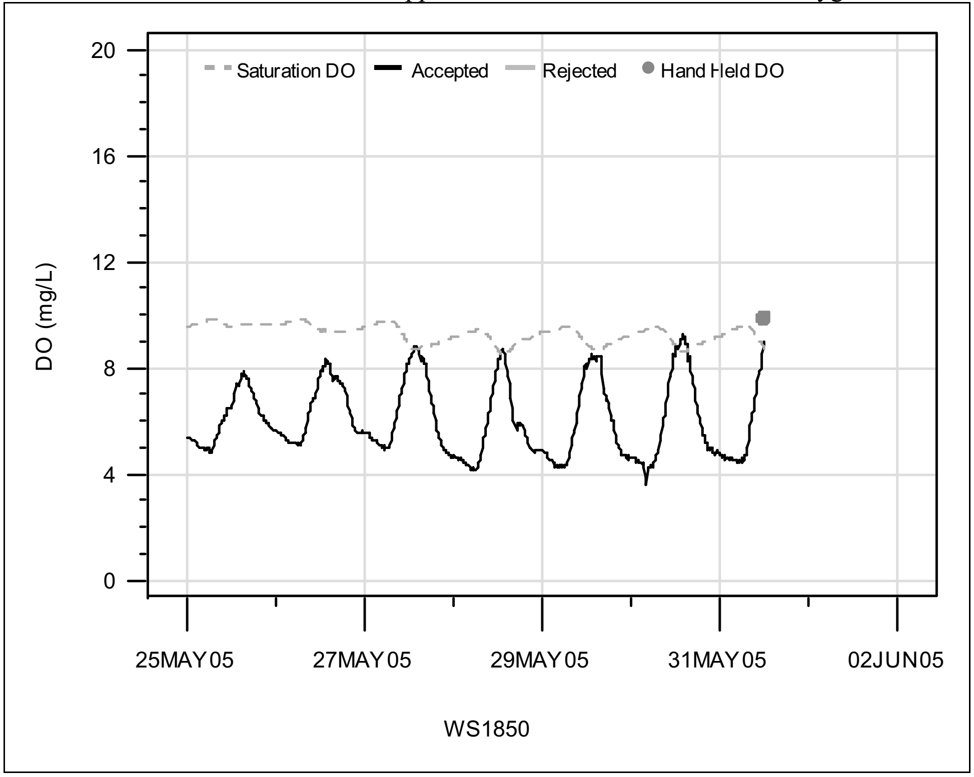


Figure C-185 Continuous Dissolved Oxygen (DO) with Calculated DO Saturation, 25MAY05 to 02JUN05, Site WS1850

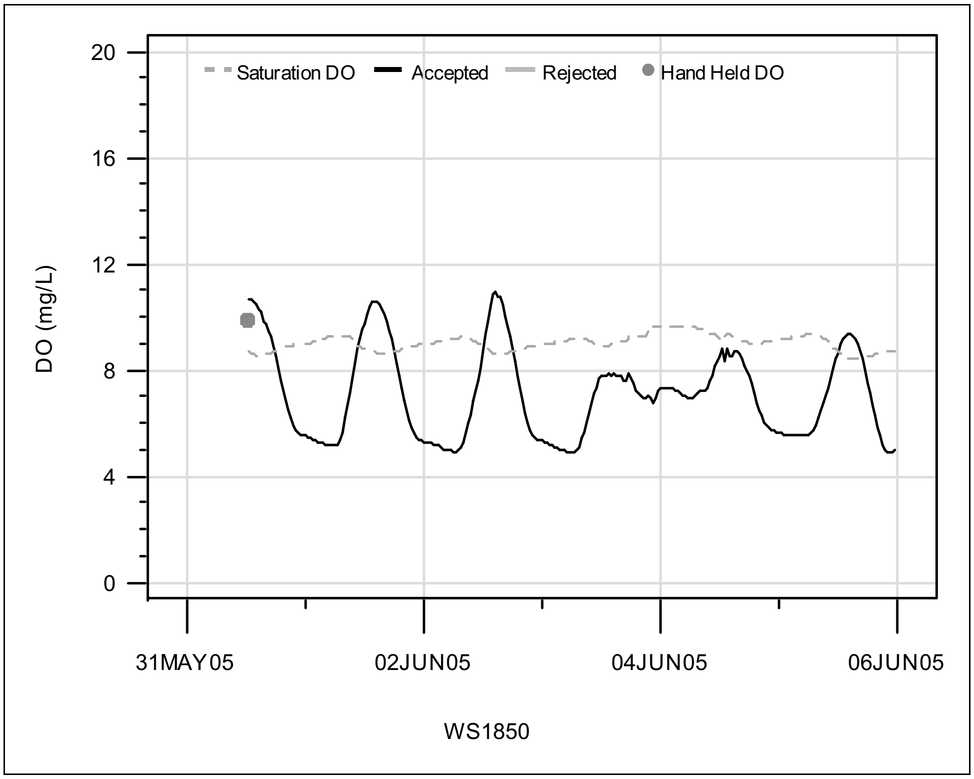


Figure C-186 Continuous Dissolved Oxygen (DO) with Calculated DO Saturation, 31MAY05 to 06JUN05, Site WS1850

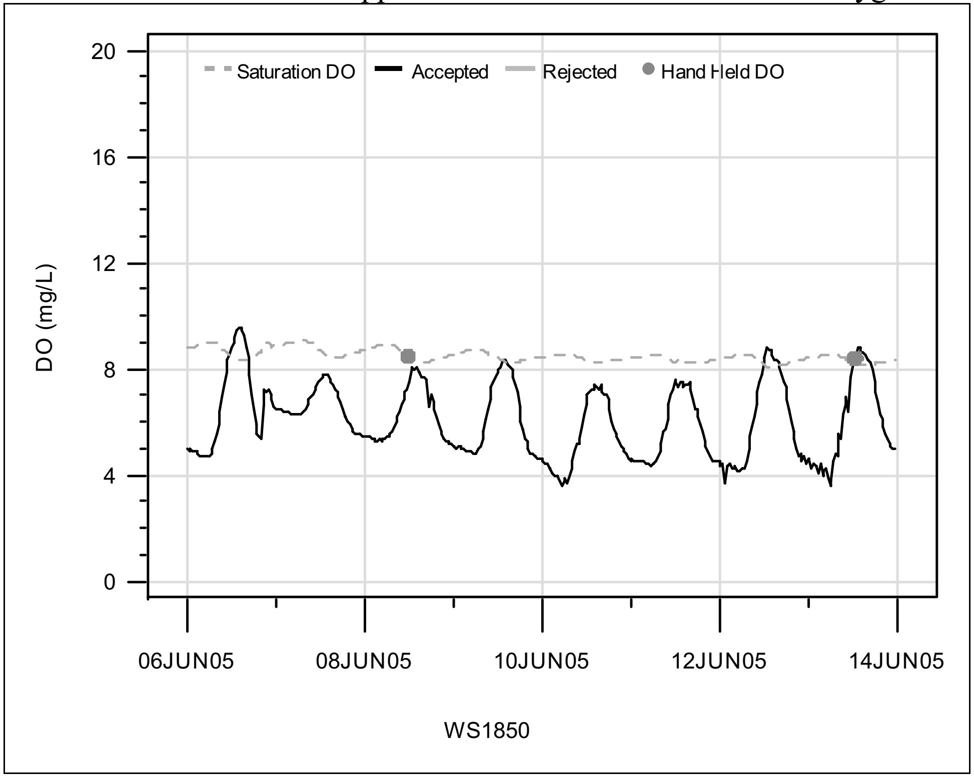


Figure C-187 Continuous Dissolved Oxygen (DO) with Calculated DO Saturation, 06JUN05 to 14JUN05, Site WS1850

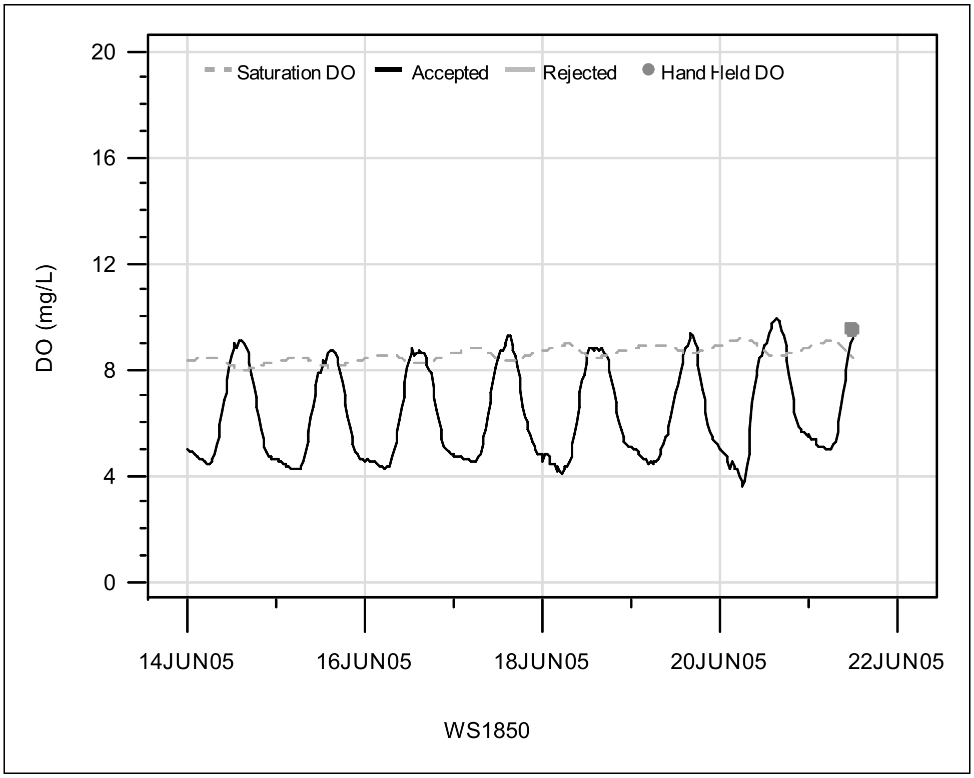


Figure C-188 Continuous Dissolved Oxygen (DO) with Calculated DO Saturation, 14JUN05 to 22JUN05, Site WS1850

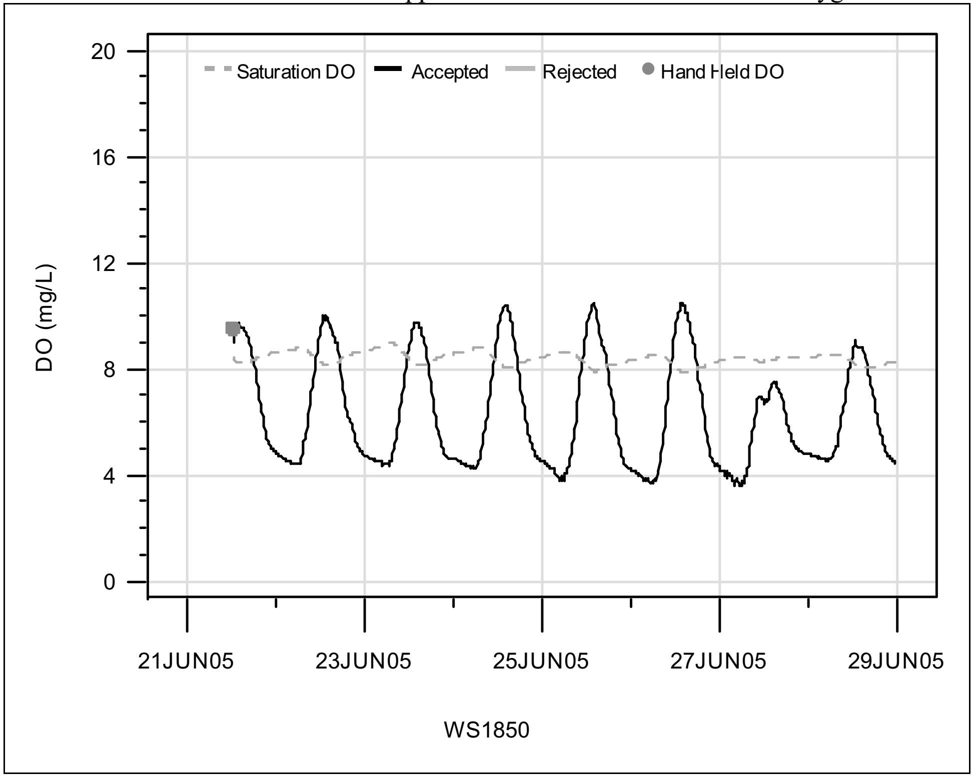


Figure C-189 Continuous Dissolved Oxygen (DO) with Calculated DO Saturation, 21JUN05 to 29JUN05, Site WS1850

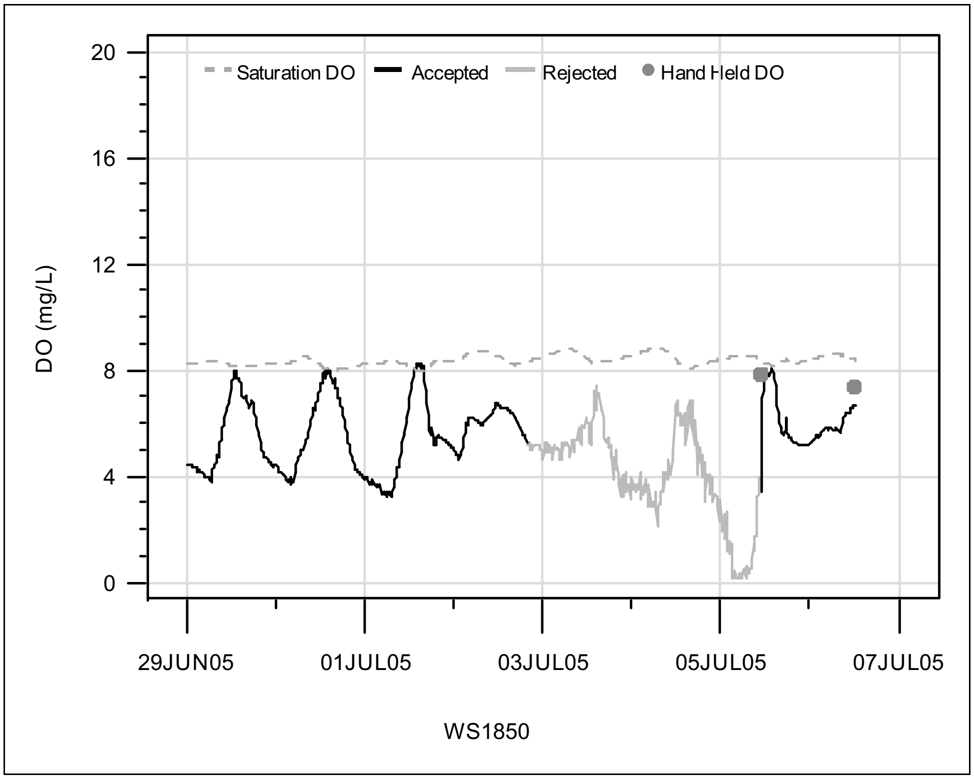


Figure C-190 Continuous Dissolved Oxygen (DO) with Calculated DO Saturation, 29JUN05 to 07JUL05, Site WS1850

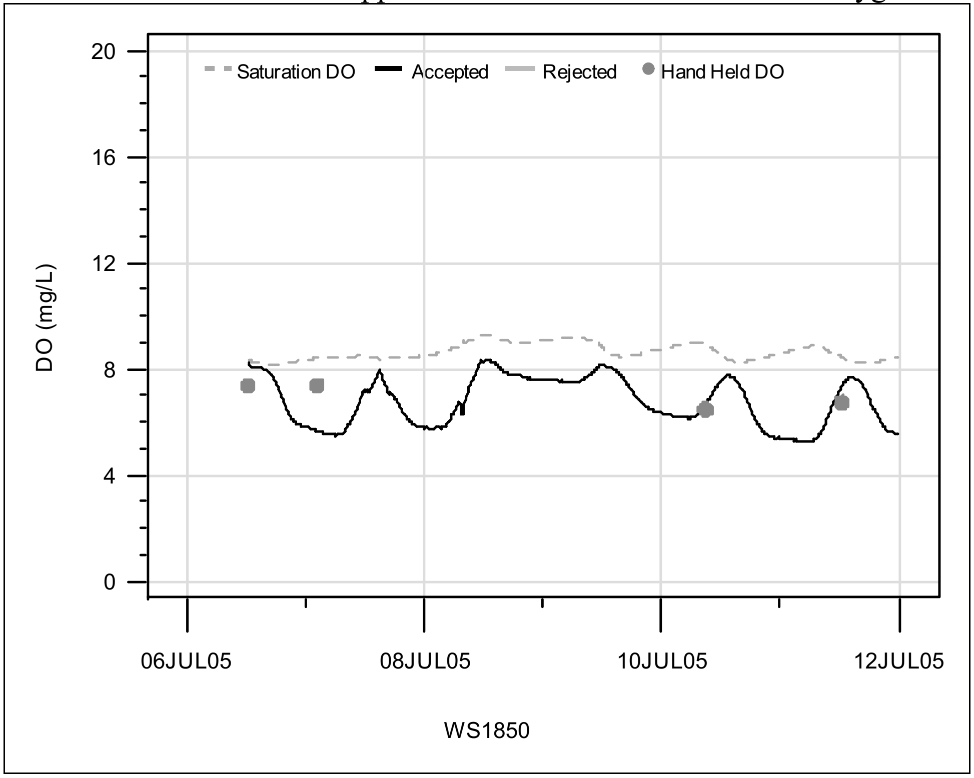


Figure C-191 Continuous Dissolved Oxygen (DO) with Calculated DO Saturation, 06JUL05 to 12JUL05, Site WS1850

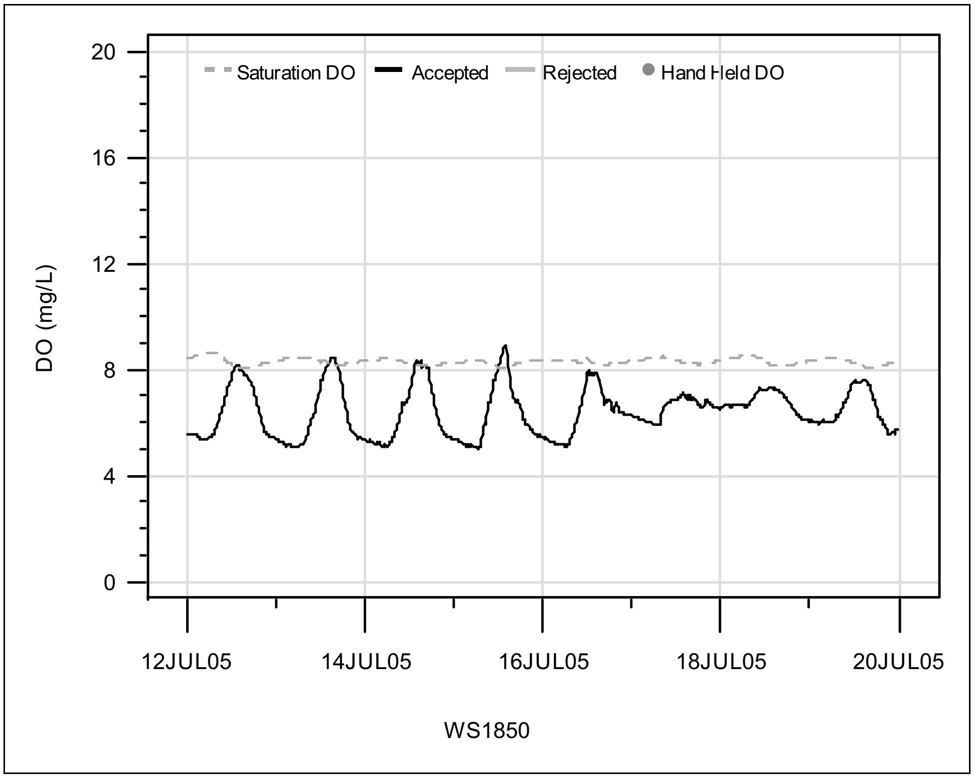


Figure C-192 Continuous Dissolved Oxygen (DO) with Calculated DO Saturation, 12JUL05 to 20JUL05, Site WS1850

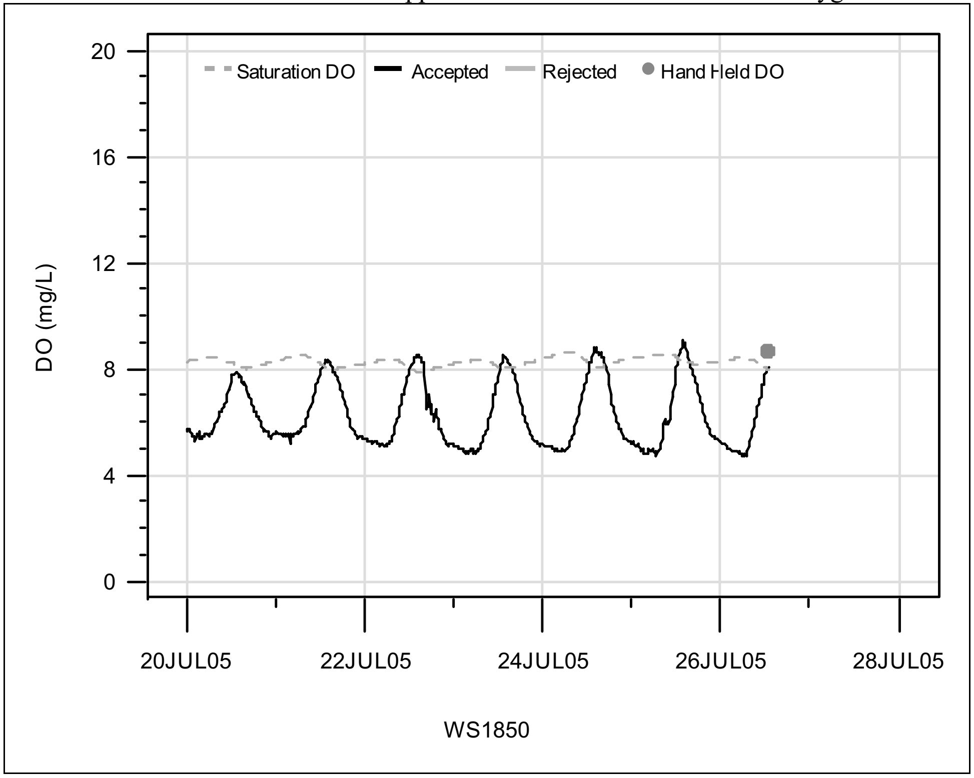


Figure C-193 Continuous Dissolved Oxygen (DO) with Calculated DO Saturation, 20JUL05 to 28JUL05, Site WS1850

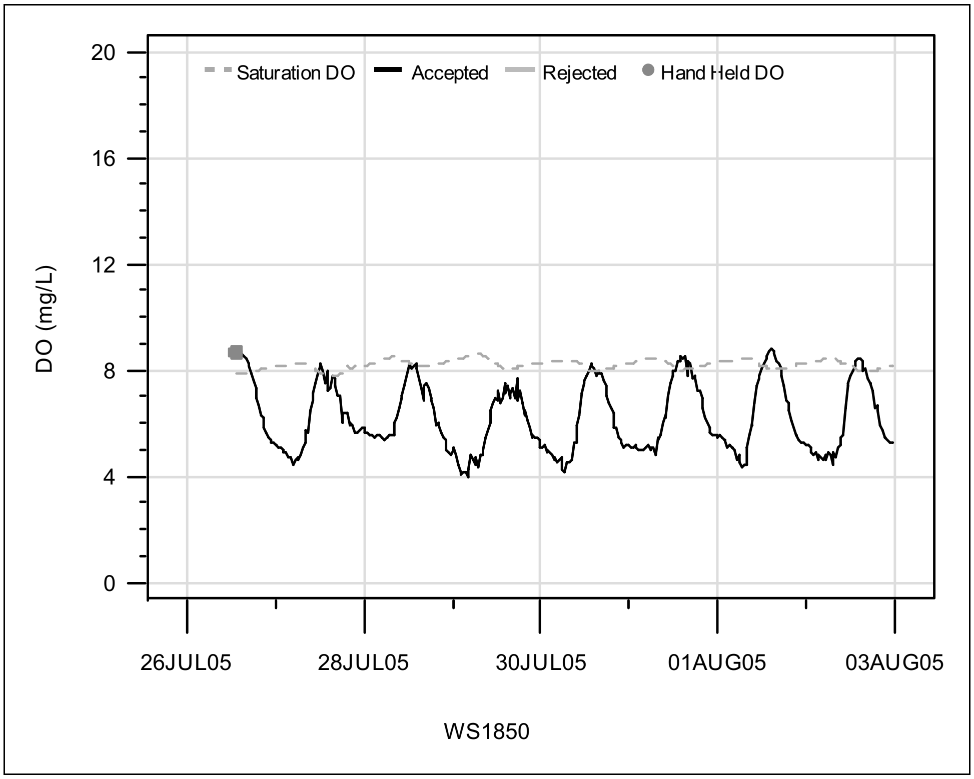


Figure C-194 Continuous Dissolved Oxygen (DO) with Calculated DO Saturation, 26JUL05 to 03AUG05, Site WS1850

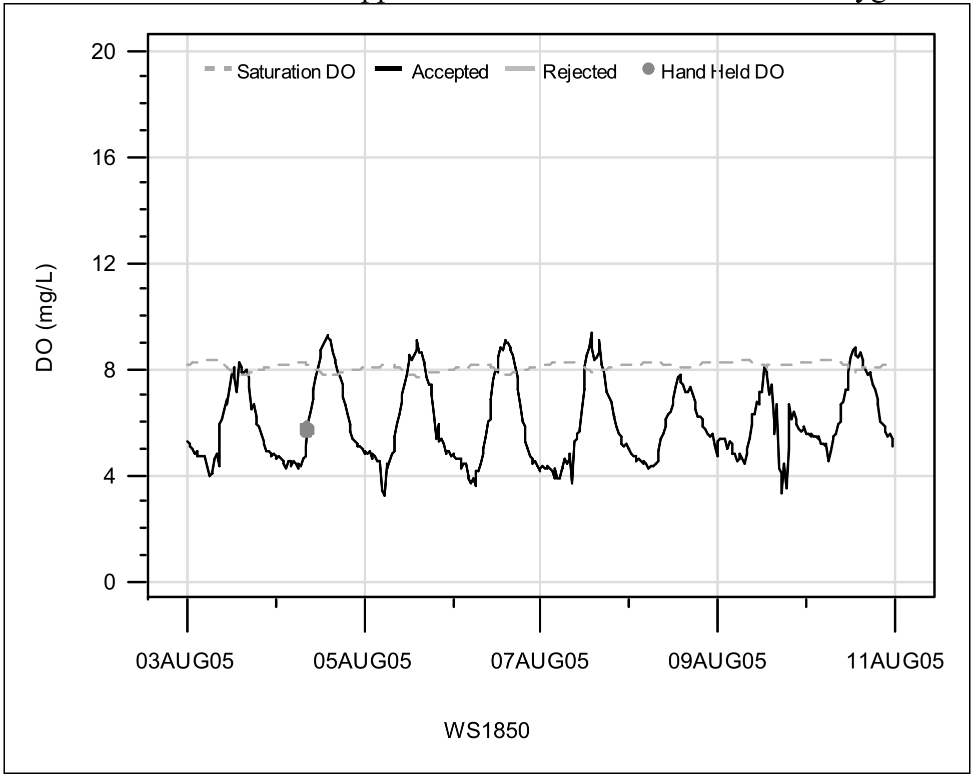


Figure C-195 Continuous Dissolved Oxygen (DO) with Calculated DO Saturation, 03AUG05 to 11AUG05, Site WS1850

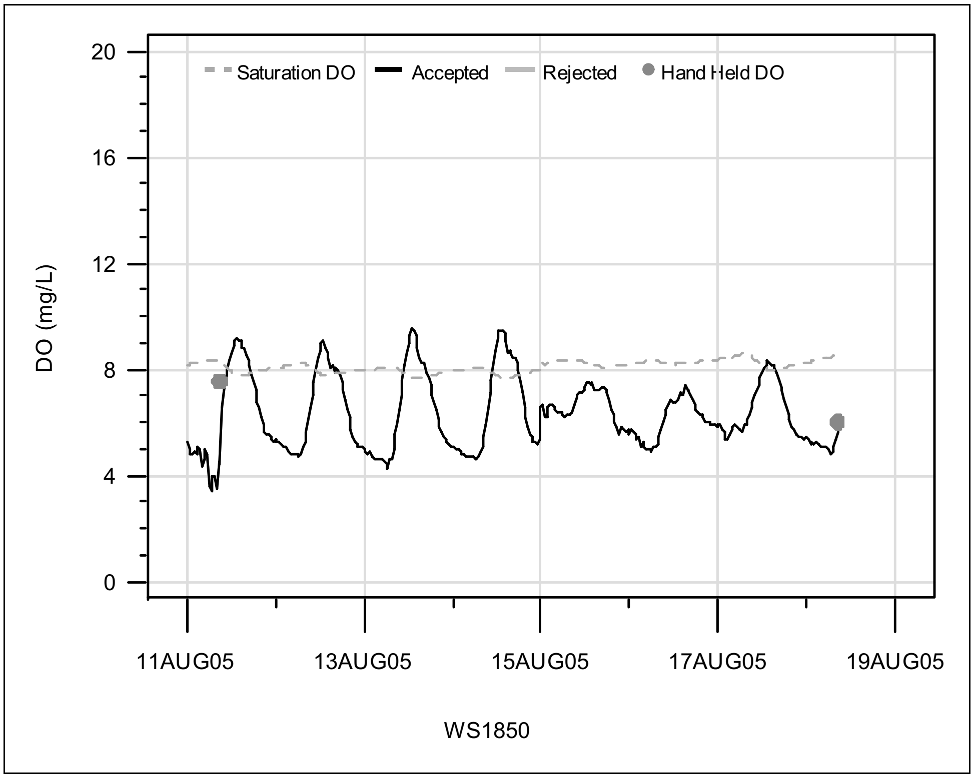


Figure C-196 Continuous Dissolved Oxygen (DO) with Calculated DO Saturation, 11AUG05 to 19AUG05, Site WS1850

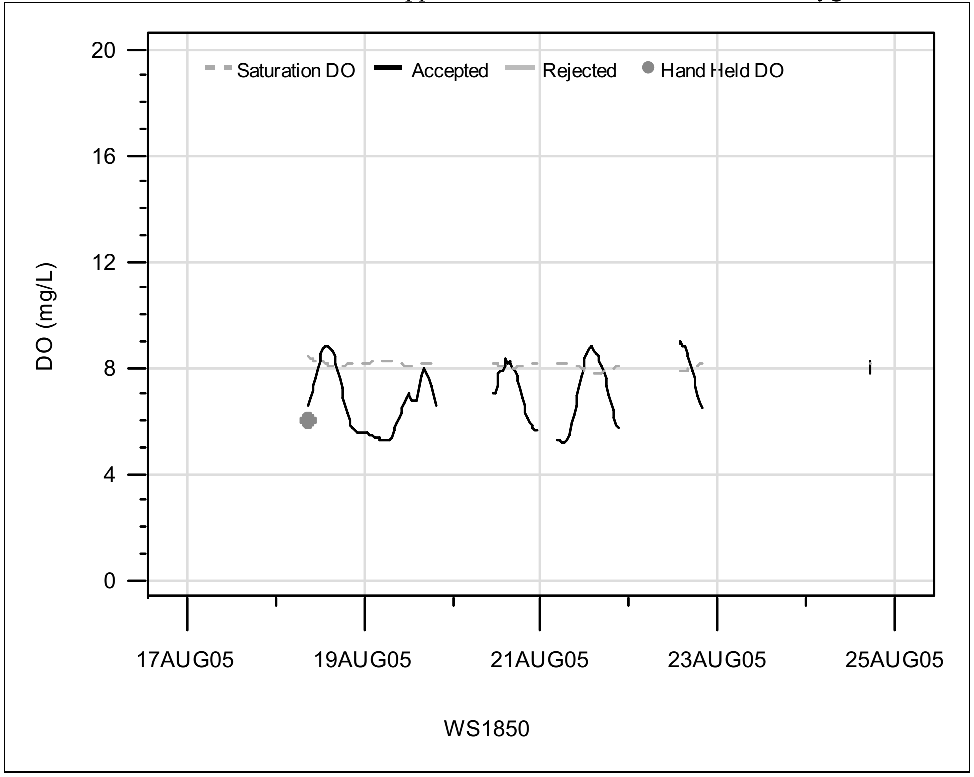


Figure C-197 Continuous Dissolved Oxygen (DO) with Calculated DO Saturation, 17AUG05 to 25AUG05, Site WS1850

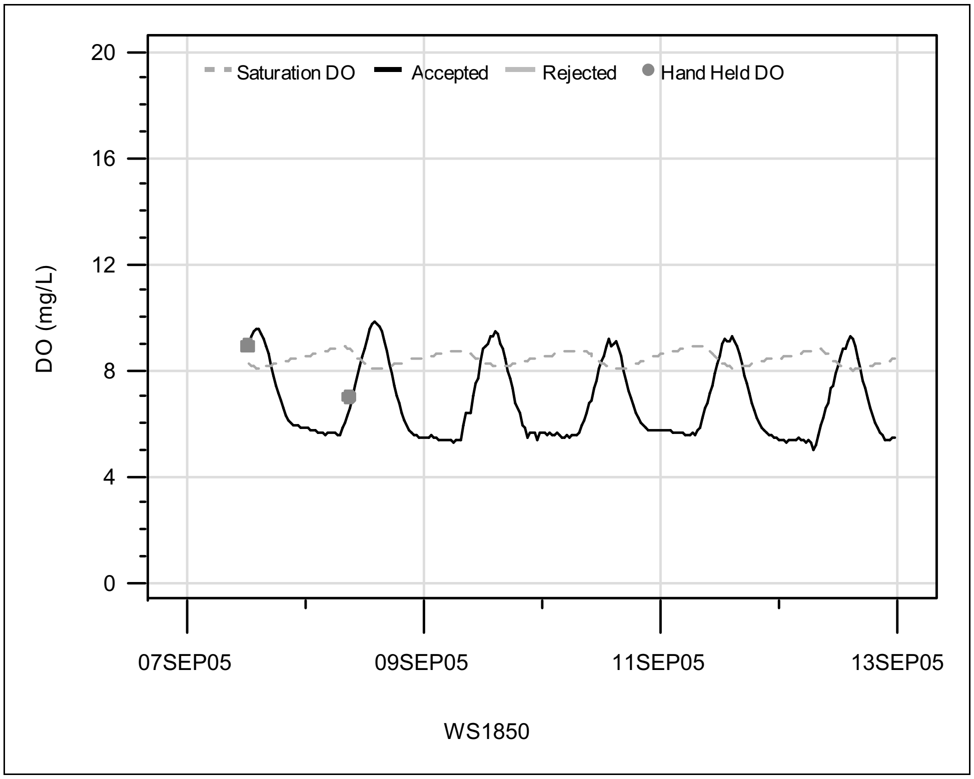


Figure C-198 Continuous Dissolved Oxygen (DO) with Calculated DO Saturation, 07SEP05 to 13SEP05, Site WS1850

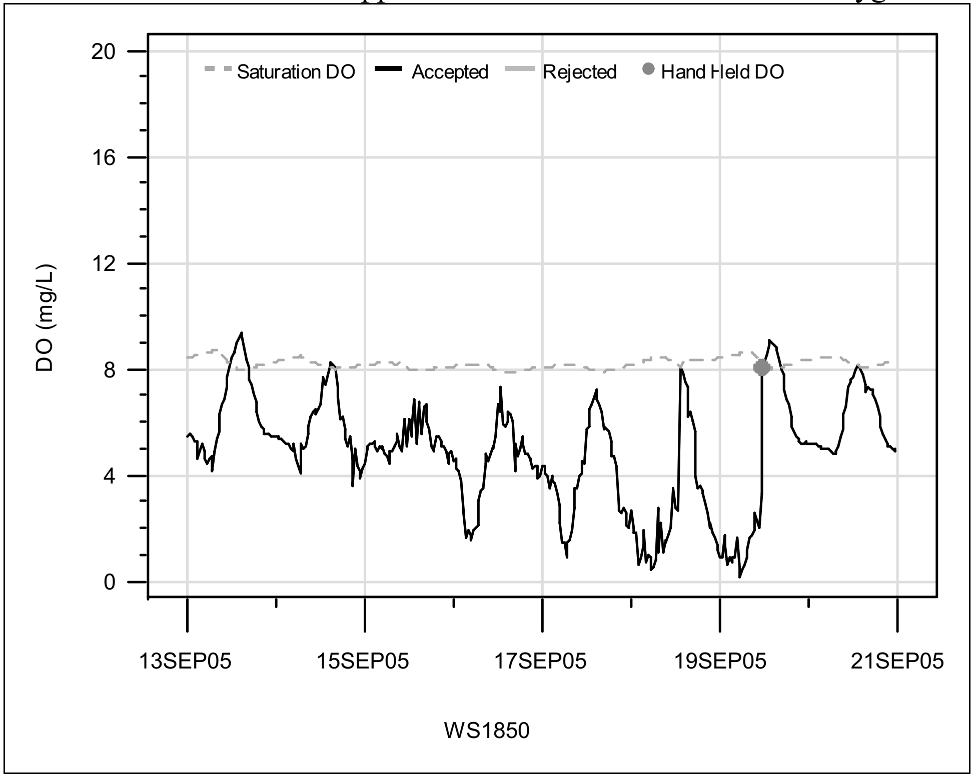


Figure C-199 Continuous Dissolved Oxygen (DO) with Calculated DO Saturation, 13SEP05 to 21SEP05, Site WS1850

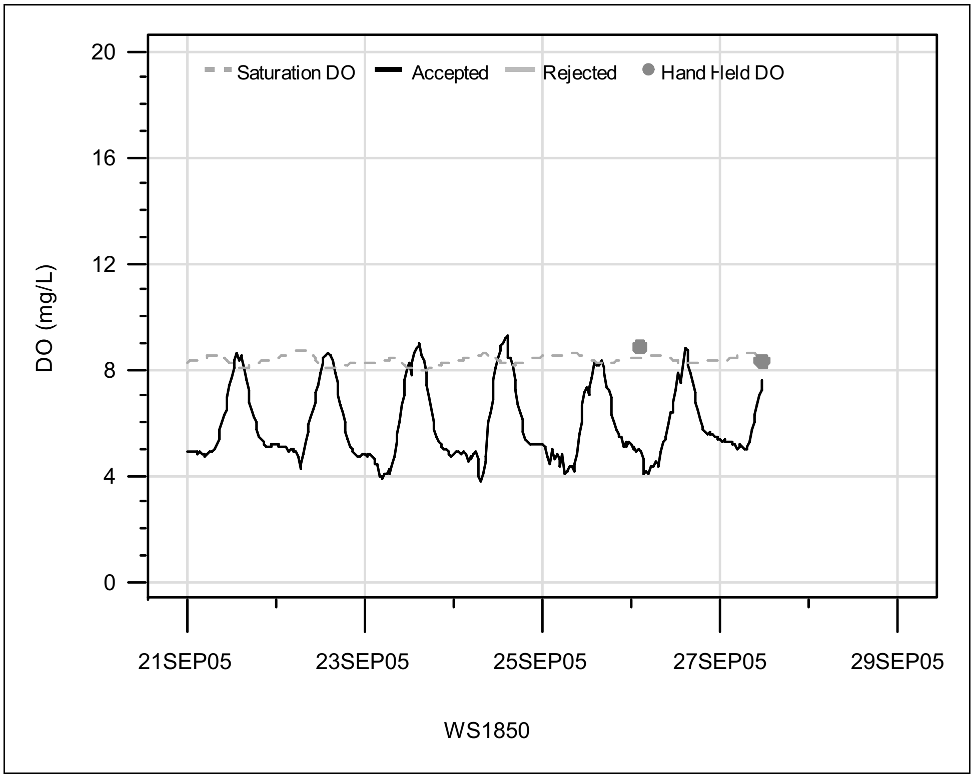


Figure C-200 Continuous Dissolved Oxygen (DO) with Calculated DO Saturation, 21SEP05 to 29SEP05, Site WS1850

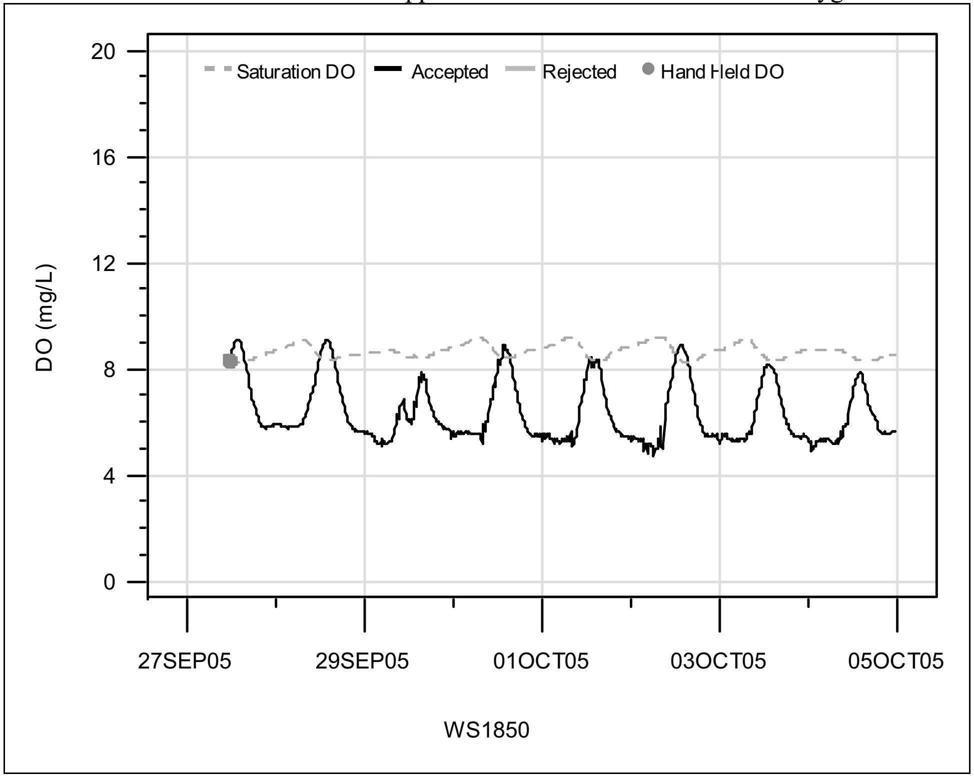


Figure C-201 Continuous Dissolved Oxygen (DO) with Calculated DO Saturation, 27SEP05 to 05OCT05, Site WS1850

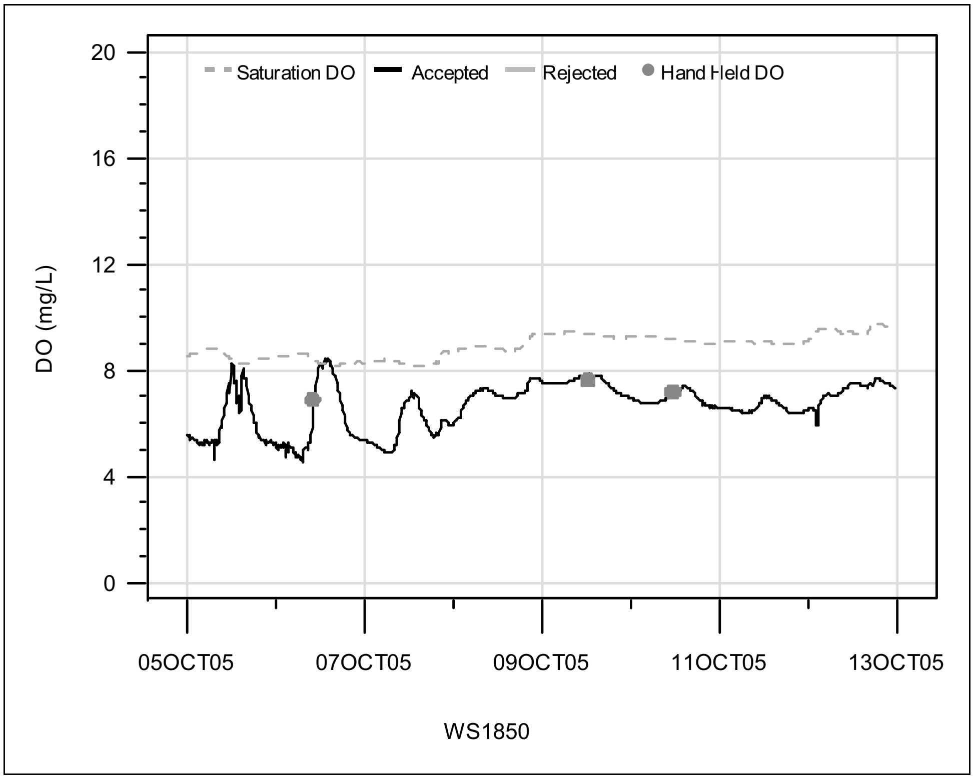


Figure C-202 Continuous Dissolved Oxygen (DO) with Calculated DO Saturation, 05OCT05 to 13OCT05, Site WS1850

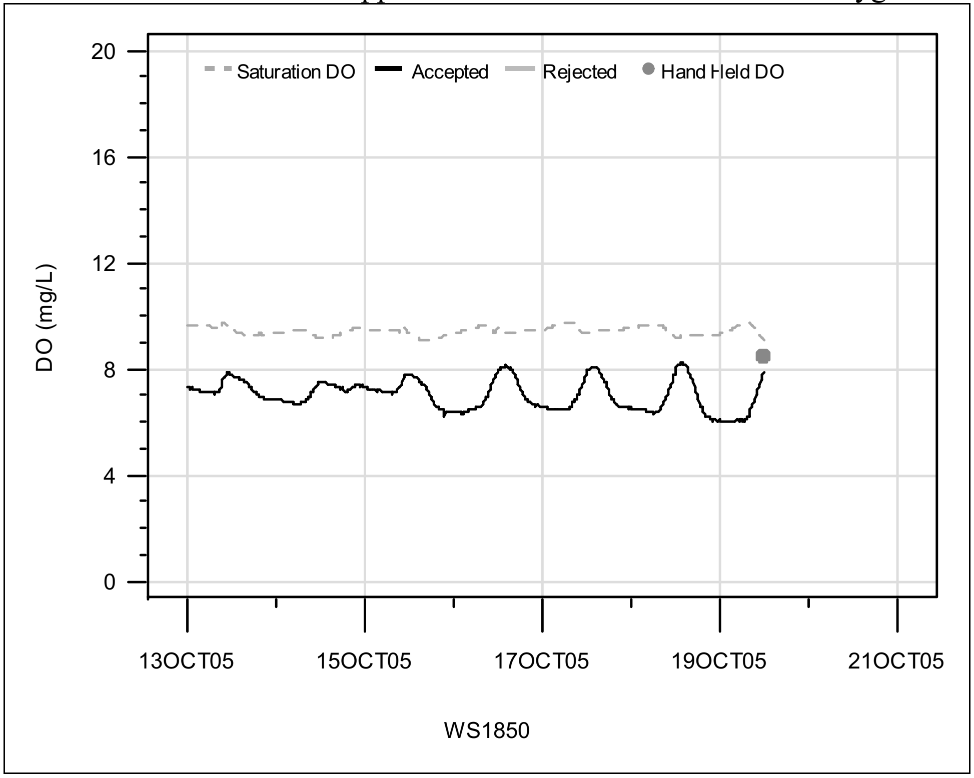


Figure C-203 Continuous Dissolved Oxygen (DO) with Calculated DO Saturation, 13OCT05 to 21OCT05, Site WS1850

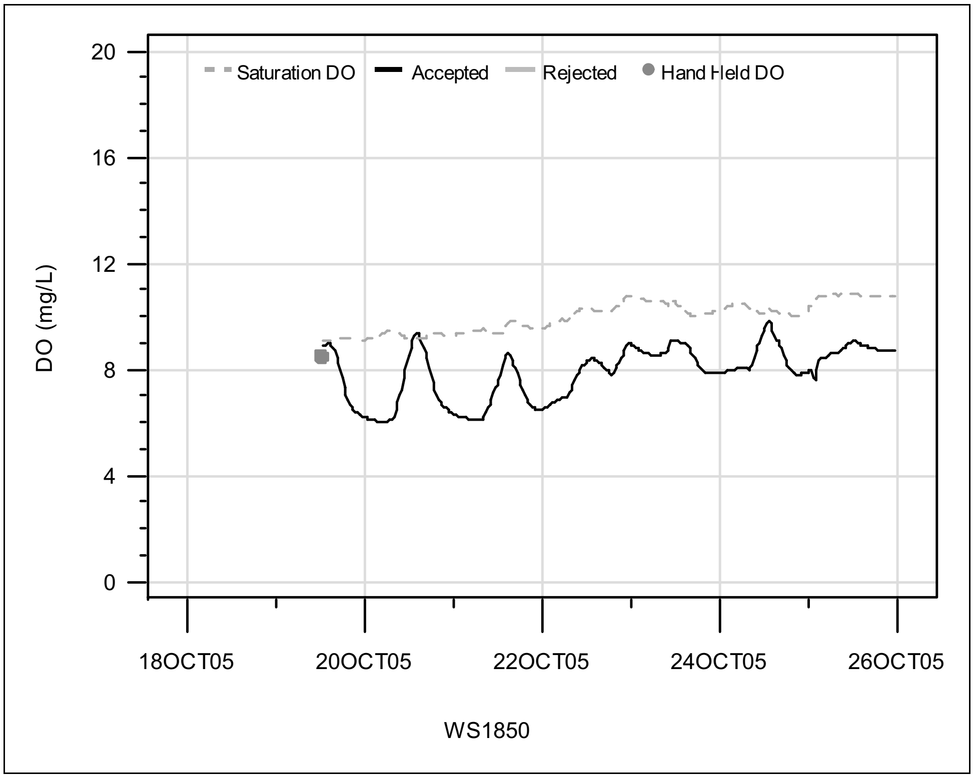


Figure C-204 Continuous Dissolved Oxygen (DO) with Calculated DO Saturation, 18OCT05 to 26OCT05, Site WS1850

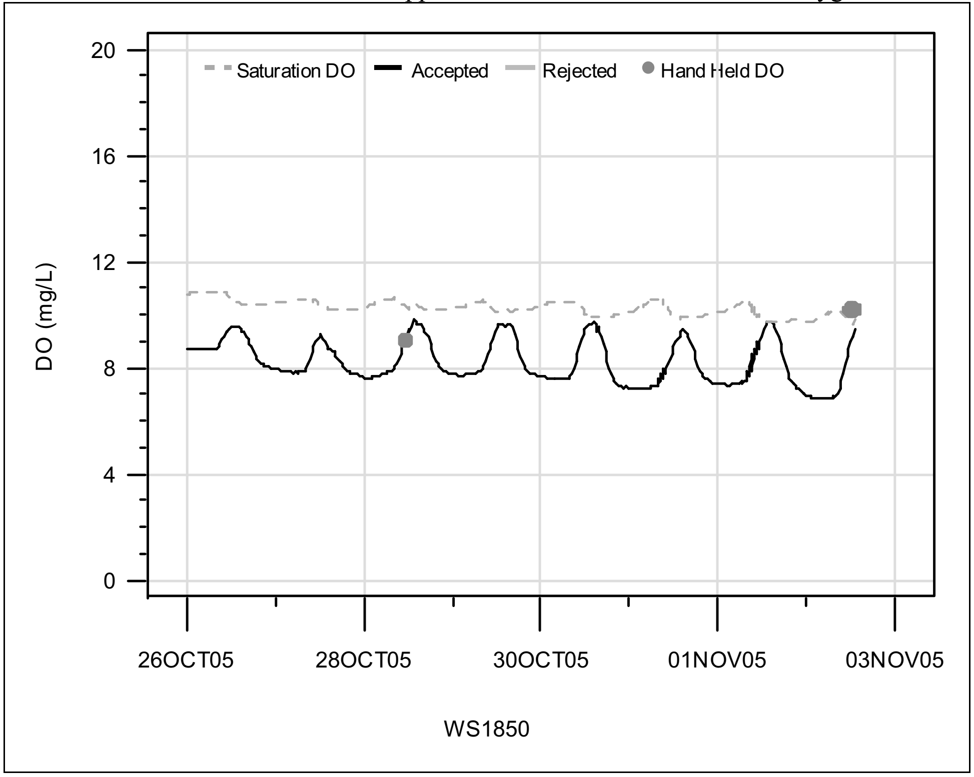


Figure C-205 Continuous Dissolved Oxygen (DO) with Calculated DO Saturation, 26OCT05 to 03NOV05, Site WS1850

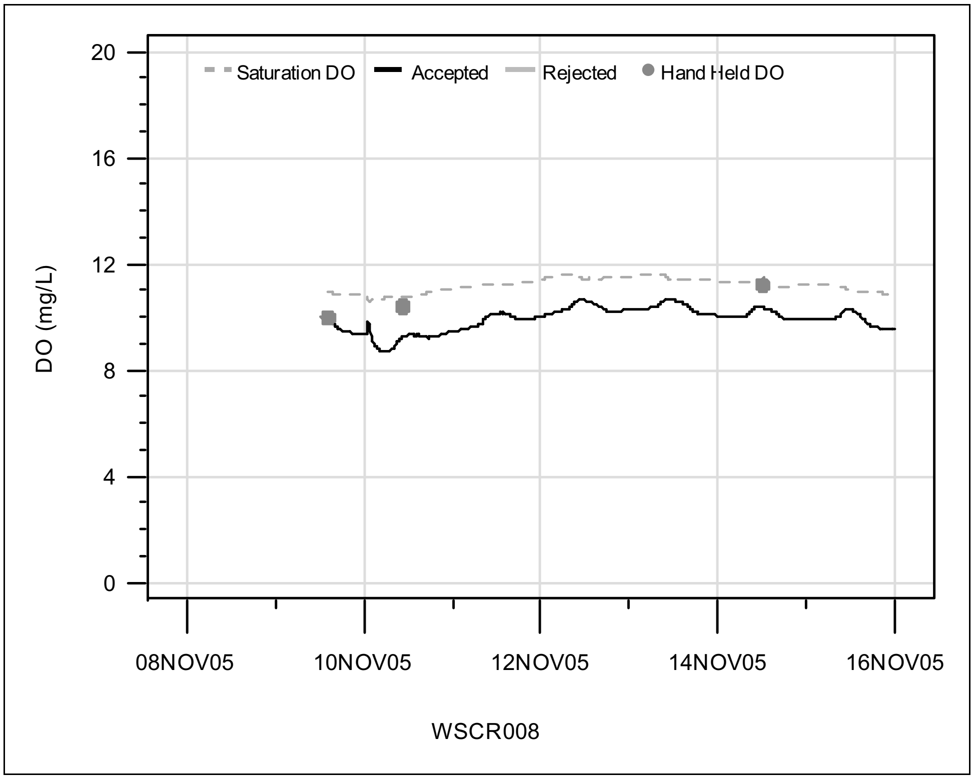


Figure C-206 Continuous Dissolved Oxygen (DO) with Calculated DO Saturation, 08NOV05 to 16NOV05, Site WSCR008

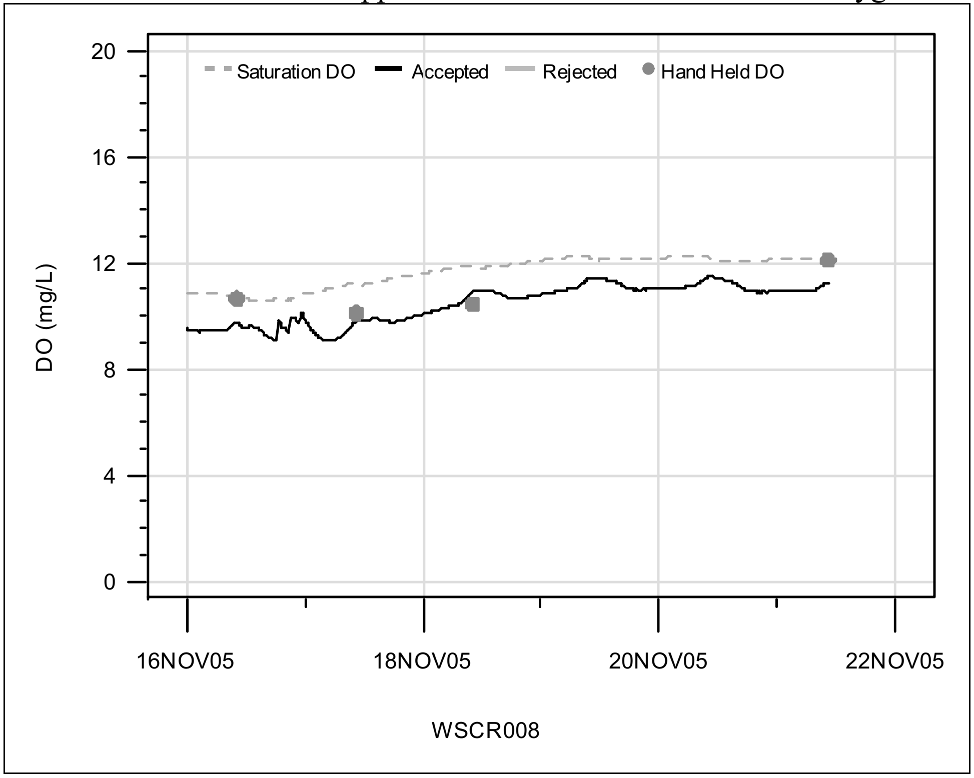


Figure C-207 Continuous Dissolved Oxygen (DO) with Calculated DO Saturation, 16NOV05 to 22NOV05, Site WSCR008

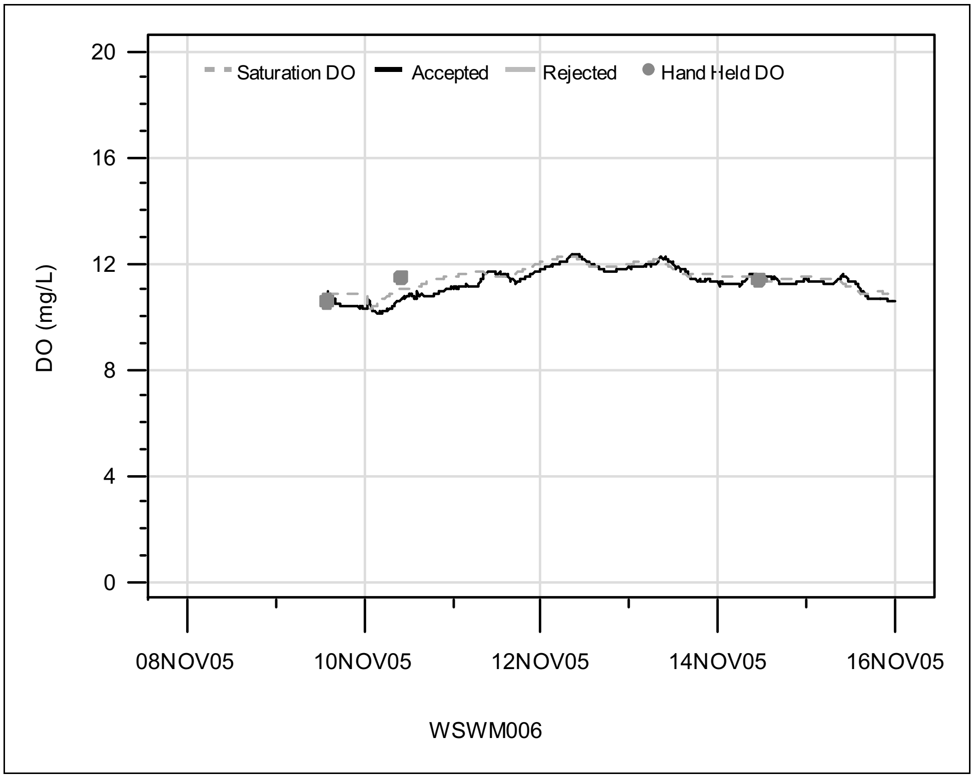


Figure C-208 Continuous Dissolved Oxygen (DO) with Calculated DO Saturation, 08NOV05 to 16NOV05, Site WSWM006

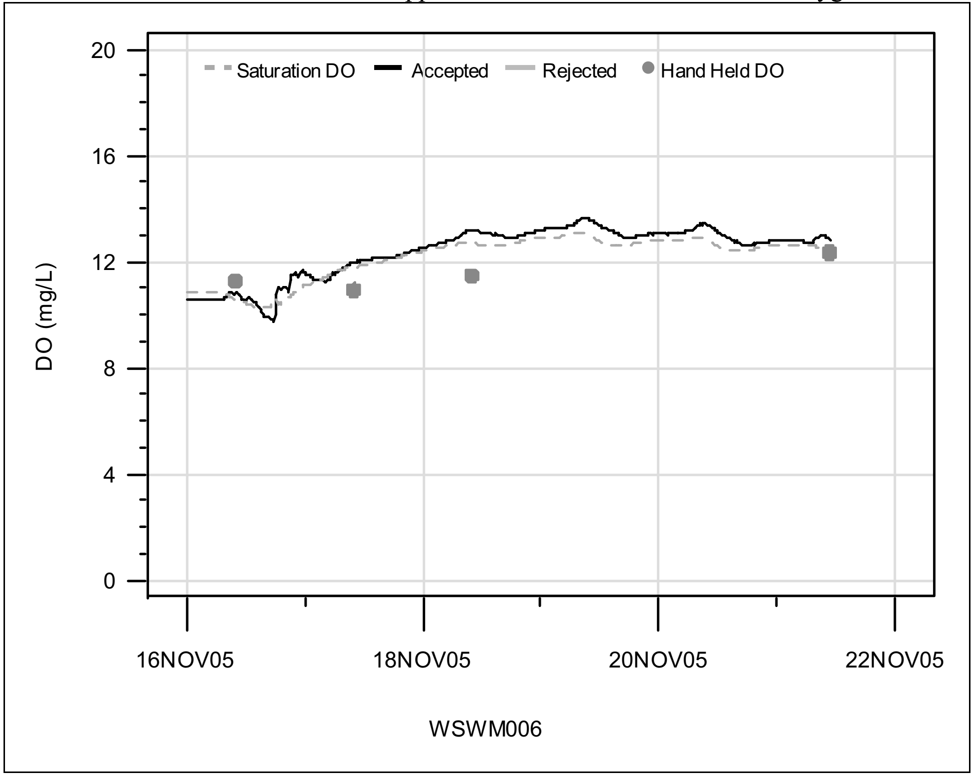


Figure C-209 Continuous Dissolved Oxygen (DO) with Calculated DO Saturation, 16NOV05 to 22NOV05, Site WSWM006

APPENDIX D: TEMPERATURE PLOTS

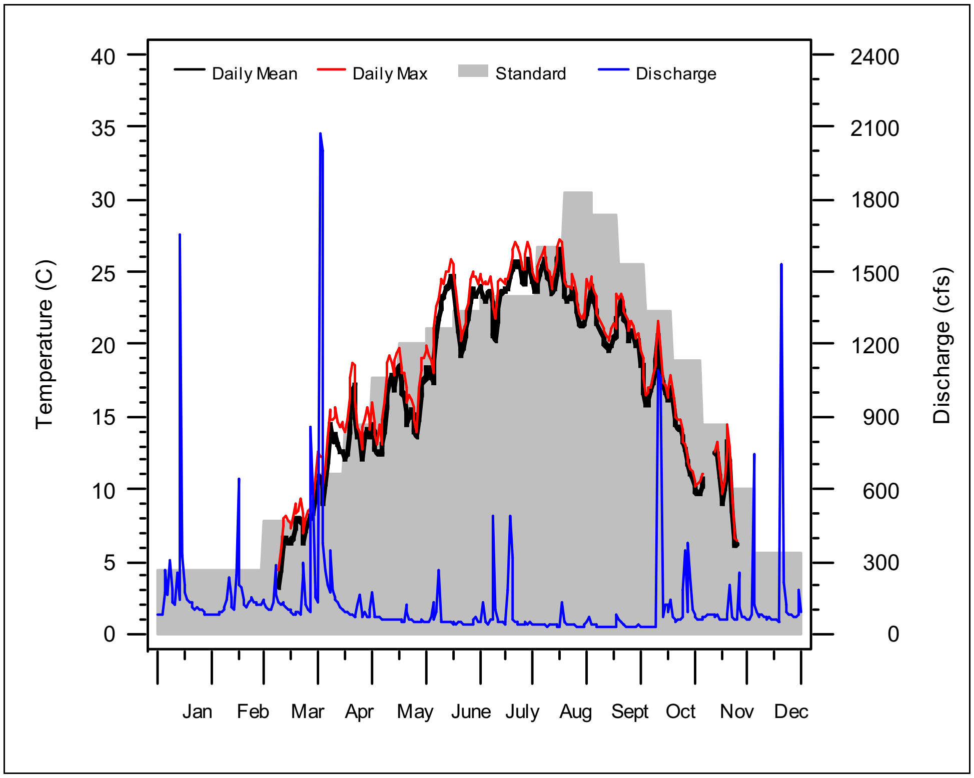


Figure D-1 2005 Continuous Temperature Data at Site WS076 with Comparison to PA Ch. 96 Water Quality Standards for Trout Stocking Fishery

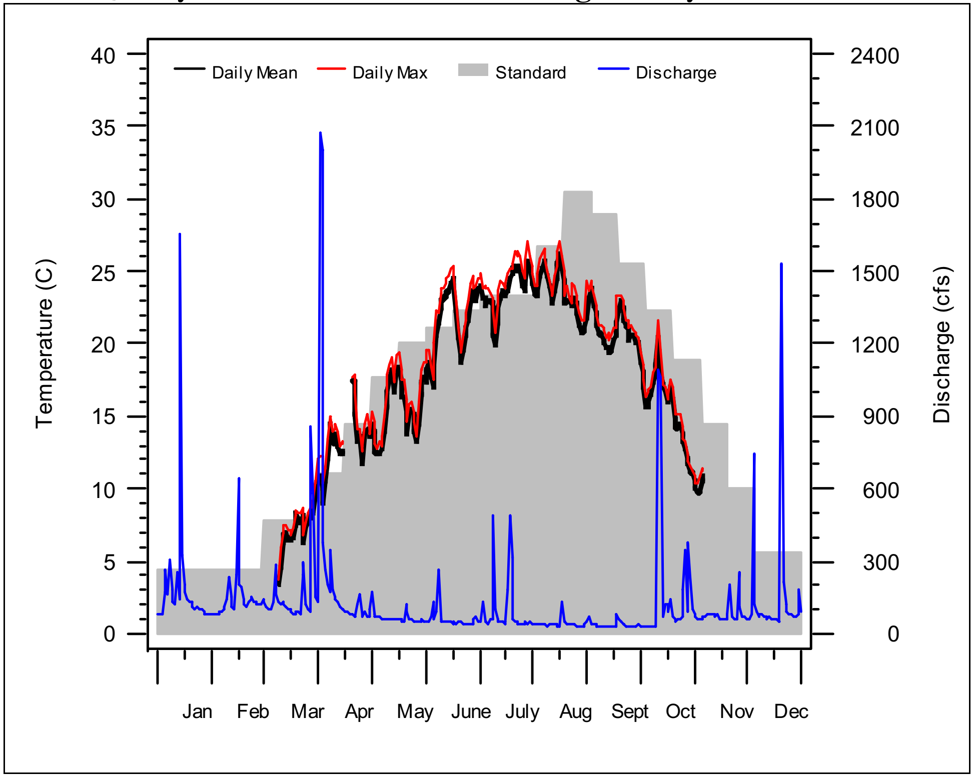


Figure D-2 2005 Continuous Temperature Data at Site WS354 with Comparison to PA Ch. 96 Water Quality Standards for Trout Stocking Fishery

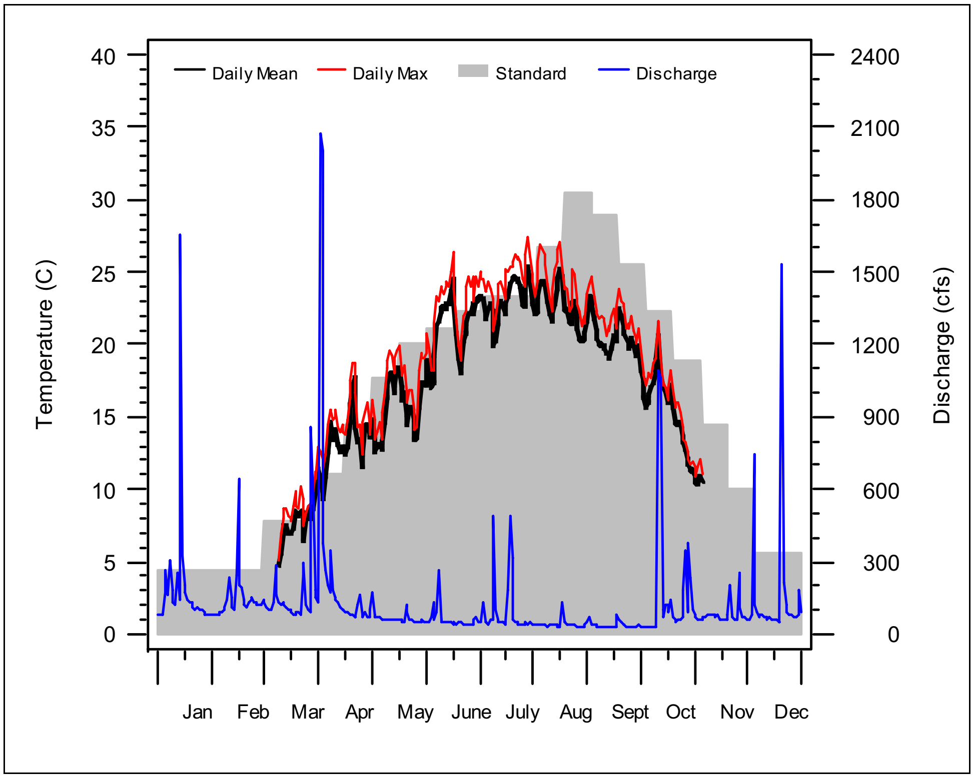


Figure D-3 2005 Continuous Temperature Data at Site WS754 with Comparison to PA Ch. 96 Water Quality Standards for Trout Stocking Fishery

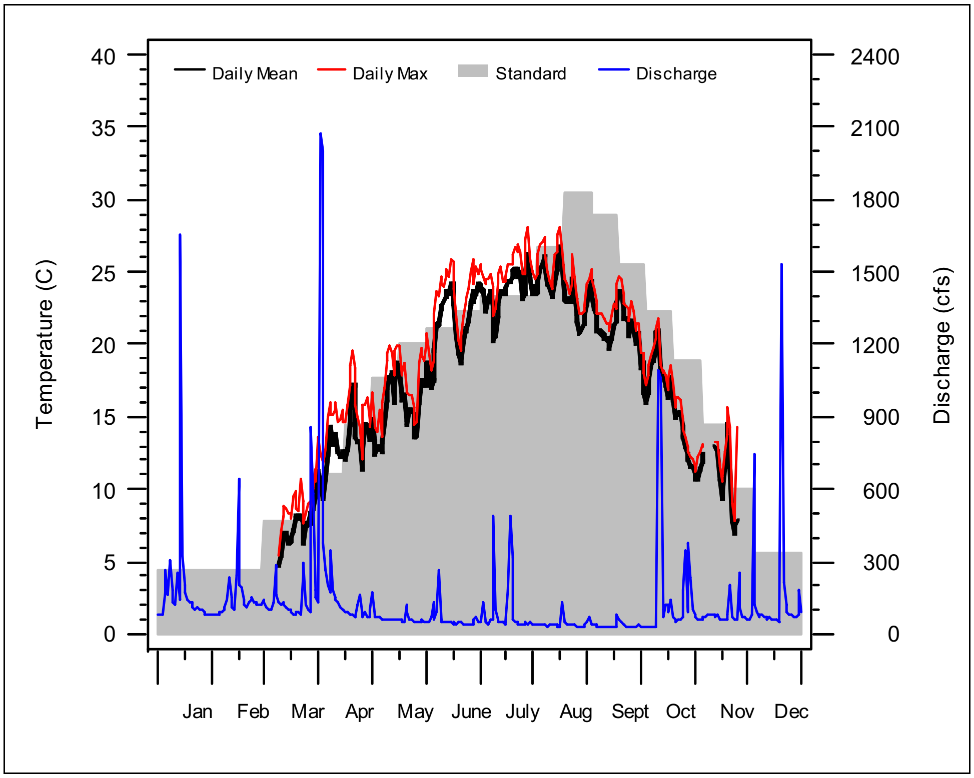


Figure D-4 2005 Continuous Temperature Data at site WS1075 with Comparison to PA Ch. 96 Water Quality Standards for Trout Stocking Fishery

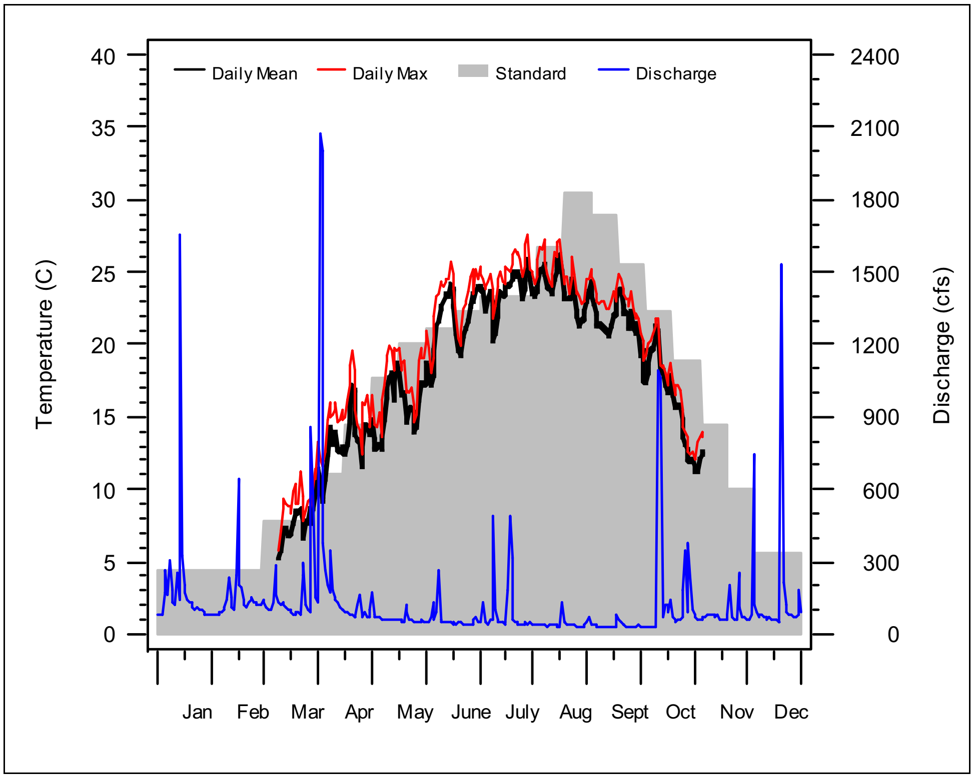


Figure D-5 2005 Continuous Temperature Data at Site WS1210 with Comparison to PA Ch. 96 Water Quality Standards for Trout Stocking Fishery

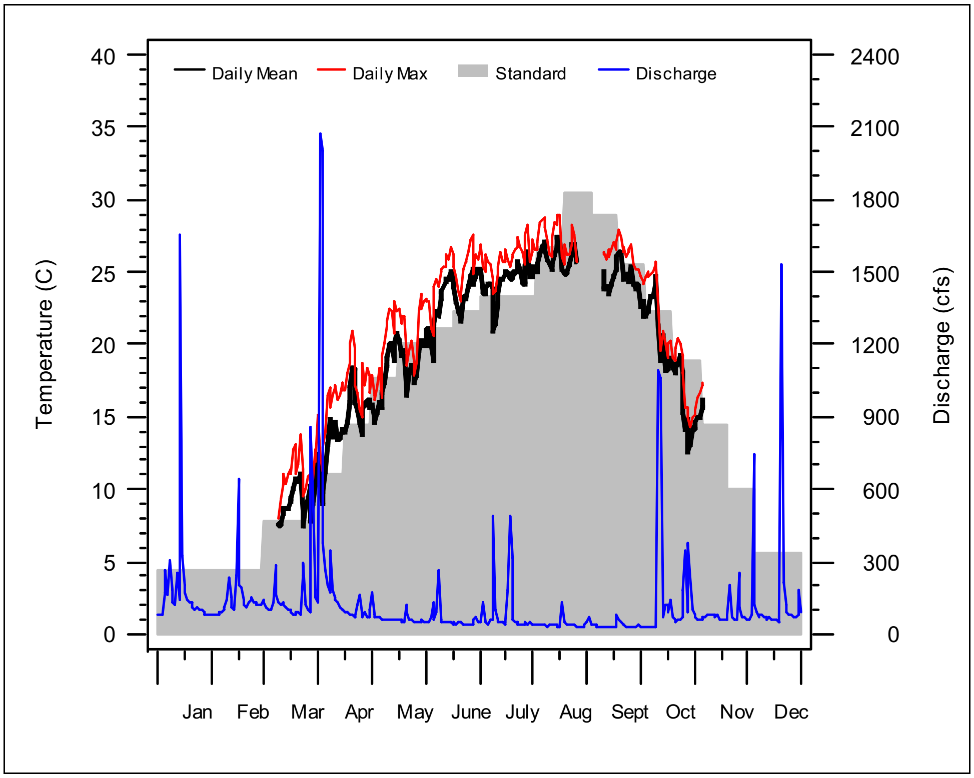


Figure D-6 2005 Continuous Temperature Data at site WS1850 with Comparison to PA Ch. 96 Water Quality Standards for Trout Stocking Fishery

APPENDIX E: WSWQ STANDARDS

Parameter	Code	Standard	Period	Dry				Wet			
				No. Obs.	No. Exceed	No. Poss. Exceed	% Exceed	No. Obs	No. Exceed	No. Poss. Exceed	% Exceed
Al	AlAcMax	PA DEP Standard	01/13/05 - 10/09/05	110	2	0	1.82	212	127	0	59.91
Alk	Alkmin	PA DEP Standard	01/04/05 - 12/06/05	131	0	0	0.00	285	18	0	6.32
BOD30	nostandard	No Standard	01/13/05 - 09/08/05	96	0	0	0.00	23	0	0	0.00
BOD5	nostandard	No Standard	01/13/05 - 09/08/05	99	0	0	0.00	23	0	0	0.00
Chla	TChlMax	Reference	01/13/05 - 09/08/05	86	40	0	46.51	10	1	0	10.00
DO	dominave	PA DEP Standard	01/13/05 - 11/18/05	116	1	0	0.86	38	1	0	2.63
DO	domininst	PA DEP Standard	01/13/05 - 11/18/05	116	0	0	0.00	38	0	0	0.00
DissCd	DissCdAcmax	PA DEP Standard	01/13/05 - 09/08/05	94	0	0	0.00	22	0	0	0.00
DissCd	DissCdhhmax	PA DEP Standard	01/13/05 - 09/08/05	94	0	0	0.00	22	0	0	0.00
DissCr	DissCracmax	PA DEP Standard	01/13/05 - 09/08/05	94	0	0	0.00	22	0	0	0.00
DissCu	DissCuAcmax	PA DEP Standard	01/13/05 - 09/08/05	90	13	0	14.44	22	1	0	4.55
DissCu	DissCuhhmax	PA DEP Standard	01/13/05 - 09/08/05	90	0	0	0.00	22	0	0	0.00
DissFe	DissFemax	PA DEP Standard	01/13/05 - 09/08/05	94	0	0	0.00	22	0	0	0.00
DissPb	DissPbAcmax	PA DEP Standard	01/13/05 - 09/08/05	94	0	0	0.00	22	0	0	0.00
DissPb	DissPbhhmax	PA DEP Standard	01/13/05 - 09/08/05	94	0	0	0.00	22	0	0	0.00
DissZn	DissZnAcmax	PA DEP Standard	01/13/05 - 09/08/05	84	0	0	0.00	22	0	0	0.00
DissZn	DissZnhhmax	PA DEP Standard	01/13/05 - 09/08/05	84	0	0	0.00	22	0	0	0.00
Ecoli	nostandard	No Standard	01/04/05 - 12/06/05	167	0	0	0.00	330	0	0	0.00
F	Fmax	PA DEP Standard	01/13/05 - 09/08/05	97	0	0	0.00	23	0	0	0.00
Fe	Femax	PA DEP Standard	01/04/05 - 11/01/05	117	1	0	0.85	237	120	0	50.63
Hardness	nostandard	No Standard	01/04/05 - 11/01/05	117	0	0	0.00	189	0	0	0.00
Mn	Mnmax	PA DEP Standard	01/04/05 - 11/01/05	117	0	0	0.00	189	0	0	0.00
NH3T	NH3Tmax	PA DEP Standard	01/13/05 - 11/17/05	113	0	0	0.00	33	0	0	0.00
NO2	nostandard	No Standard	01/13/05 - 11/17/05	128	0	0	0.00	303	0	0	0.00
NO23	NO23max	PA DEP Standard	01/13/05 - 11/17/05	128	19	0	14.84	303	4	0	1.32
NO3	NO3hhmax	Reference	01/04/05 - 12/06/05	136	19	0	13.97	307	4	0	1.30
PO4	nostandard	No Standard	01/04/05 - 12/06/05	134	0	0	0.00	306	0	0	0.00

Parameter	Code	Standard	Period	Dry				Wet			
				No. Obs.	No. Exceed	No. Poss. Exceed	% Exceed	No. Obs	No. Exceed	No. Poss. Exceed	% Exceed
SpCond	nostandard	No Standard	01/04/05 - 12/06/05	124	0	0	0.00	41	0	0	0.00
TDS	TDSmax	PA DEP Standard	01/04/05 - 11/01/05	104	8	0	7.69	27	1	0	3.70
TKN	TKNmax	Reference	01/13/05 - 11/17/05	123	52	0	42.28	281	211	0	75.09
TP	TPmax	Reference	01/13/05 - 10/09/05	98	91	0	92.86	195	156	0	80.00
TSS	TSSmax	Reference	01/13/05 - 11/17/05	123	2	0	1.63	303	177	0	58.42
TempF	TstdF	PA DEP Standard	01/13/05 - 11/18/05	116	24	0	20.69	37	6	0	16.22
Total Nitrogen	TNmax	Reference	01/13/05 - 11/17/05	123	87	0	70.73	281	79	0	28.11
Turbidity	Turbmax	Reference	01/04/05 - 12/06/05	157	8	0	5.10	308	184	0	59.74
Fecal Coliform	Fecalmax	PA DEP Standard	01/04/05 - 12/06/05	167	46	0	27.54	330	272	0	82.42
pH	pHmax	PA DEP Standard	01/04/05 - 12/06/05	124	0	0	0.00	41	0	0	0.00
pH	pHmin	PA DEP Standard	01/04/05 - 12/06/05	124	0	0	0.00	41	0	0	0.00

Color Coding
0-2%
2-10%
10-100%

APPENDIX F: WATER QUALITY SAMPLING RESULTS WITH POSSIBLE CONTAMINATION

Table F-1 Sampling Results with Possible Contamination

Sample ID	Site	Date	Time	Parameter	Value	Units
DW050421-0067	WS076	4/21/2005	11:10	DissZn	0.01	mg/L
DW050421-0067	WS076	4/21/2005	11:10	Zn	0.007	mg/L
DW050428-0058	WS122	4/28/2005	9:15	DissZn	0.014	mg/L
DW050428-0058	WS122	4/28/2005	9:15	Zn	0.011	mg/L
DW050512-0105	WS122	5/12/2005	9:30	DissZn	0.023	mg/L
DW050512-0105	WS122	5/12/2005	9:30	Zn	0.011	mg/L
DW050908-0079	WS122	9/8/2005	9:35	DissCu	0.014	mg/L
DW050908-0079	WS122	9/8/2005	9:35	Cu	0.008	mg/L
DW050421-0065	WS354	4/21/2005	10:25	DissZn	0.011	mg/L
DW050421-0065	WS354	4/21/2005	10:25	Zn	0.008	mg/L
DW050428-0060	WS354	4/28/2005	10:10	DissZn	0.014	mg/L
DW050428-0060	WS354	4/28/2005	10:10	Zn	0.011	mg/L
DW050804-0071	WS354	8/4/2005	10:30	DissZn	0.017	mg/L
DW050804-0071	WS354	8/4/2005	10:30	Zn	0.011	mg/L
DW050908-0081	WS354	9/8/2005	10:30	DissCu	0.017	mg/L
DW050908-0081	WS354	9/8/2005	10:30	Cu	0.01	mg/L
DW050428-0062	WS754	4/28/2005	11:40	DissZn	0.019	mg/L
DW050428-0062	WS754	4/28/2005	11:40	Zn	0.014	mg/L
DW050908-0083	WS754	9/8/2005	11:30	DissCu	0.016	mg/L
DW050908-0083	WS754	9/8/2005	11:30	Cu	0.012	mg/L
DW050505-0067	WS1075	5/5/2005	10:50	NH3T	1.74	mg/L_as_N
DW050505-0067	WS1075	5/5/2005	10:50	TKN	0.729	mg/L
DW050908-0078	WS1075	9/8/2005	11:10	PO4	2.35	mg/L
DW050908-0078	WS1075	9/8/2005	11:10	TP	2.33	mg/L
DW050203-0061	WS1850	2/3/2005	8:40	DissZn	0.055	mg/L
DW050203-0061	WS1850	2/3/2005	8:40	Zn	0.048	mg/L
DW050421-0058	WS1850	4/21/2005	8:45	DissZn	0.042	mg/L
DW050421-0058	WS1850	4/21/2005	8:45	Zn	0.038	mg/L
DW050707-0129	WS1850	7/7/2005	14:55	PO4	3.394	mg/L
DW050707-0129	WS1850	7/7/2005	14:55	TP	3.26	mg/L
DW050804-0064	WS1850	8/4/2005	8:25	DissZn	0.057	mg/L
DW050804-0064	WS1850	8/4/2005	8:25	Zn	0.049	mg/L
DW050908-0074	WS1850	9/8/2005	9:00	PO4	2.581	mg/L
DW050908-0074	WS1850	9/8/2005	9:00	TP	2.25	mg/L
DW050908-0077	WSSR058	9/8/2005	10:50	DissCu	0.02	mg/L
DW050908-0077	WSSR058	9/8/2005	10:50	Cu	0.014	mg/L

APPENDIX G: FRENCH CREEK REFERENCE SITES

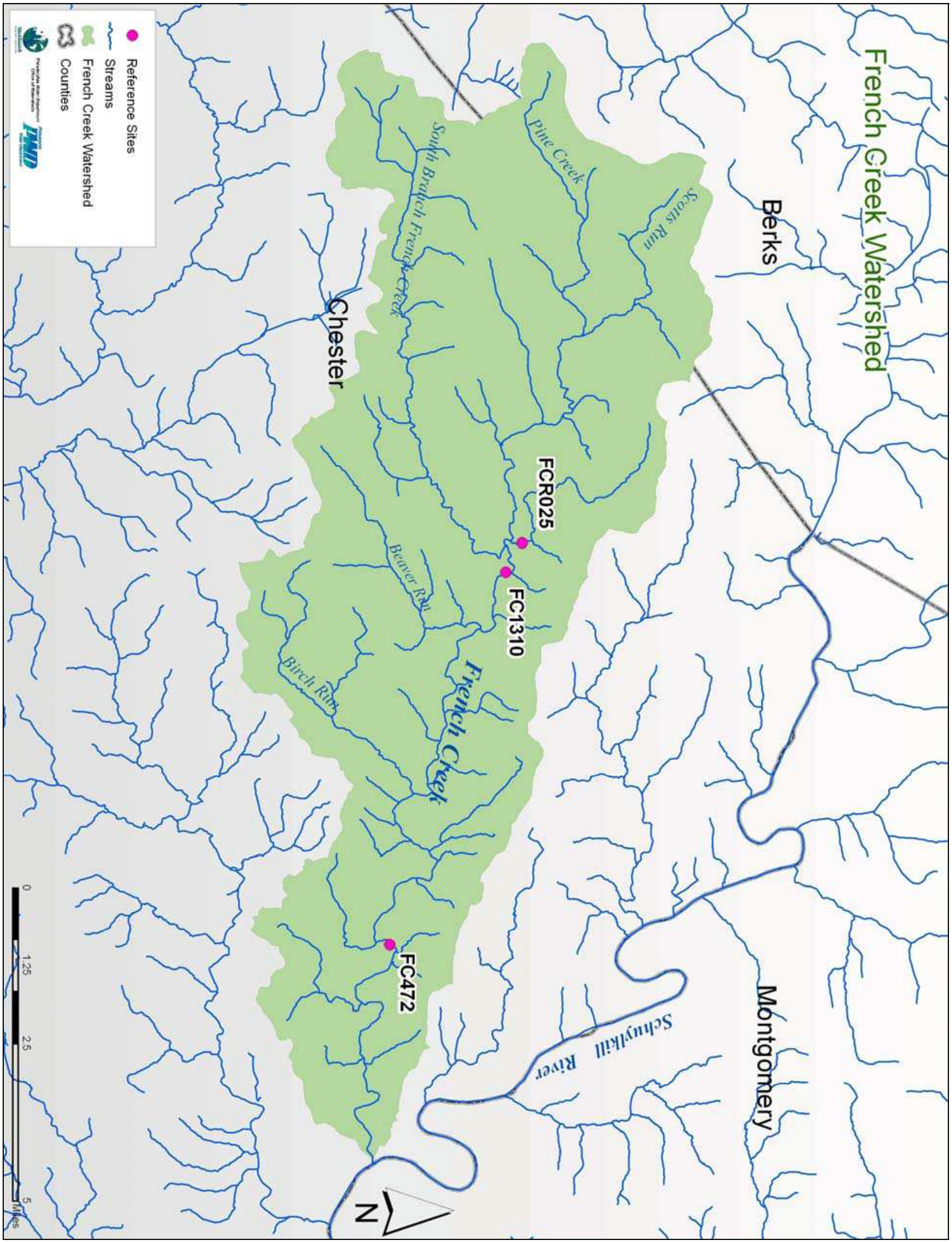


Figure G-1 French Creek Reference Sites

APPENDIX H: PCA FACTOR LOADING

Table H-1 PCA Factor Loadings

Parameter	Factor 1	Factor 2
Epifaunal Substrate	-0.942336	0.089480
Pool Substrate	-0.916309	0.176525
Pool Variability	-0.851000	0.368049
Sediment Deposition	-0.886822	0.032092
Channel Flow Status	-0.668981	0.565929
Channel Alteration	-0.735284	-0.398007
Channel Sinuosity	-0.735505	-0.218668
Bank Stability	-0.786899	-0.038924
Vegetative Protection	-0.847463	-0.073424
Riparian Vegetation	-0.663472	-0.522491
Embeddedness	-0.781907	-0.122324
Velocity/Depth Regime	-0.786200	0.414111
Riffle Frequency	-0.430304	-0.704788
Variance explained	7.959669	1.665240
Proportion of Total	0.612282	0.128095

APPENDIX I: WISSAHICKON CREEK WATERSHED HYDROLOGIC MODEL DEVELOPMENT

Terminology

The following terminology is used in this document:

drainage area: general term for the land area draining to a specific point, such as the mouth of a creek or tributary; may refer to a watershed, subwatershed, or subshed as used in this document; terms such as "catchment" and "basin" are synonyms

watershed: Wissahickon drainage area

subwatershed: drainage area for a tributary of the Wissahickon

subshed: may refer to an MS4 subshed or direct drainage subshed as defined below; generally corresponds to an area represented as a single unit in the computer model

MS4 subshed: drainage area to a specific municipal separate storm sewer (MS4) outfall

direct drainage subshed: unsewered drainage area to a surveyed stream cross-section; does not include MS4 drainage

Hydrologic Model Development

The procedure for developing geographic information for the Wissahickon model started with the delineation of the subsheds. For this task the subsheds were delineated to each surveyed stream cross-section with consideration taken where municipal separate storm sewer (MS4) subsheds alter the natural drainage. ESRI's ArcHydro extension was used to delineate the subsheds with some adjustments based on best professional judgment. ArcHydro is a tool that uses a digital elevation model (DEM) to automatically create boundaries in a given drainage area.

The next step was distinguishing MS4 subsheds from direct drainage subsheds (primarily park land). In many instances the engineering of storm sewers captures runoff from areas that differ from the natural drainage. In these cases the delineation of the MS4 subshed took precedence over the direct drainage subshed.

Once the subsheds were finalized, intersects with impervious cover, soils and slopes were performed. Inside the City of Philadelphia, a planimetric impervious layer developed from 1996 orthophotography was used. This layer classifies all surface elements as either impervious or natural surfaces. For each subshed, the sum of the impervious area in acres was generated for input to the model. Excluded from this summation were some hydrologic features (i.e., pools, lakes, ponds and marshes) which are not considered hydrologically effective as they do not contribute runoff directly to Wissahickon Creek.

Soil types available from the U.S. Department of Agriculture, Natural Resources Conservation Service (NRCS) Soil Survey Geographic (SSURGO) Database were downloaded from the internet (www.soils.usgs.gov). The soil layer was classified based on the soil textures (i.e., loam, silt, sand, etc.) and intersected with the subsheds. A table showing the area of each texture in each subshed was created for input to the model. Soil properties were assigned to each subshed based on soil texture classification. Table 1 lists the parameter ranges for several different soil classifications, based on U.S. Department of Agriculture's (USDA) Natural Resources Conservation Service (NRCS). Soil classifications can vary widely within each subcatchment and an area-weighted initial value was calculated for each of the three parameters in each subcatchment.

Table I-1 Soil Infiltration Parameter Estimates for Several Soil Texture Classifications (based on Rawls et al., 1982)

USDA Soil Texture Classification	Saturated Hydraulic Conductivity	Initial Moisture Deficit for Soil (Vol. Air / Vol. of Voids, expressed as a fraction)	Avg. Capillary Suction
	(in/hr)	Moist Soil Climates (Eastern US)	(in)
Sand	9.27	0.346	1.95
Loamy Sand	2.35	0.312	2.41
Sandy Loam	0.86	0.246	4.33
Loam	0.52	0.193	3.50
Silt Loam	0.27	0.171	6.57
Sandy Clay Loam	0.12	0.143	8.60
Clay Loam	0.08	0.146	8.22
Silty Clay Loam	0.08	0.105	10.75
Sandy Clay	0.05	0.091	9.41
Silty Clay	0.04	0.092	11.50
Clay	0.02	0.079	12.45

The DEM used for developing the subsheds was also used for determining the area-weighted percent slope for each subshed. The DEM, which is a raster of elevation, was converted to a raster of percent slope. ESRI's Spatial Analyst was used to derive slope from the DEM. The area-weighted average percent slope was calculated using the zonal statistic tool in Spatial Analyst. This tool determines the average slope value of every cell that falls within a zone; the zone is the subshed. Since the cells analyzed are all a uniform size (10 m by 10 m for this task) the average slope calculated for each modeling shed is an area-weighted average. It should be noted that the area-weighted average percent slope may not be the same as the slope of the overland flow path.

Depression Storage

For all subcatchments, impervious depression storage was set initially as 0.02 inches and pervious depression storage was set at 0.15 inches. These values were modified for each modeled tributary during calibration to match monitored event runoff totals.

Manning's Roughness Coefficient

Manning's roughness values must be estimated for both pervious and impervious overland flow. For the Wissahickon Creek watershed model, all subsheds were assigned a Manning's n value of 0.013 for impervious areas and 0.020 for pervious areas.

Hydrologic Input Data

Precipitation Data

Fifteen minute precipitation data was obtained from PWD rain gauges for the calibration of the model. The fifteen minute data from the nearest PWD rain gauge to a subshed was used as input to the model. Data from the other gauges close to the watershed was compared to this gauge in order to determine the spatial variability of individual rainfall events and to determine if precipitation observed at the nearest gauge is representative for the entire watershed.

Evaporation Data

Limited long-term daily evaporation data exists for the Philadelphia area. The Philadelphia Airport does not record evaporation data. Average monthly evaporation (inches per day) from a site in Wilmington, Delaware was used for the Wissahickon Creek hydrologic model. This data is discussed in more detail in the Hydrologic Characterization section of the Comprehensive Characterization Report.

Watershed Model Calibration Summary

Watershed Model Calibration Data

Hydraulic and hydrologic data sets were obtained from several sources for varying time periods and used in the calibration process. Precipitation drives the hydrologic and subsequently hydraulic models of the watershed. A detailed precipitation dataset is an important element of the calibration process and was obtained from the PWD rain gauge network. Streamflow data were obtained for two active USGS gauges in Wissahickon Creek and for each tributary with available level monitoring data.

Precipitation data

The main goal in acquiring precipitation data was to get the most detailed (temporally and spatially) data available for the periods in which hydraulic data were available for the Wissahickon Creek watershed. For the period of time that the USGS gauges were actively recording data, hourly rainfall data is available only for one rain gauge located within the boundaries of the watershed and three additional rain gauges near the watershed. The primary calibration period selected is the 4.5 year period, 6/1/2001 – 12/31/2005. This period was selected because data was available for both USGS gauges. It is inappropriate to calibrate to all observed precipitation events, as temporal and spatial variation in precipitation can vary significantly and rainfall observed at a single point may not be representative of the precipitation over the entire watershed. In order to determine the events that may not be representative, additional data were obtained from three other PWD rain gauges near the Wissahickon Creek watershed. The data from these gauges were used to determine the potential rainfall variability for precipitation events recorded at the two USGS gauges and four tributary level monitors in Wissahickon Creek.

USGS and Level Monitoring Data

Additional data used in the calibration of the hydrologic model was 15 minute average flows obtained from the two USGS gauge stations in Wissahickon Creek. Also, data from four tributaries with level monitors were obtained. Rating curves converting levels to flow were used for three tributaries, Bells Mill Run, Monoshone Creek and Wises Mill Run. For Cathedral Run, level data measured in a culvert was converted into flows using survey data and Manning's equation.

In order to isolate the rainfall response from the streamflow hydrographs, a baseflow separation was performed on the USGS data sets and level converted to flow data sets for the four tributaries. The baseflow, surface runoff, and point source components were separated from the streamflow hydrographs at the two gauging stations. The sliding interval baseflow separation method used by the USGS HYSEP program was employed to complete this task.

Calibration Data Set Selection

Calibration of the model was calibrated to observed flows on four tributaries and to average daily flow obtained from the three USGS gauges. This allows the calibration of hydrologic parameters so that simulated runoff volumes approximately match volumes generated from observed precipitation events in the watershed. These parameters include effective impervious acreage, hydraulic conductivity of pervious areas, and depression storage.

Since the effect of precipitation measurement uncertainty is greatest for small storms, a strict set of criteria was developed to remove all events that may be regarded as non-representative. This was done using the PWD rainfall data as follows:

- All events for which the precipitation total at the nearest PWD rain gauge was less than 0.2-inches were removed from the calibration data set

- Any event for which the precipitation total at the nearest PWD rain gauges was one or more inches different from the total at PWD rain gauge 21, near Ridge Ave., was eliminated from the calibration data set.

- Any event for which the precipitation total at the nearest PWD rain gauges was 50% or more different from the total at PWD rain gauge 21, near Ridge Ave., was eliminated from the calibration data set.

Additionally, since snowmelt was not simulated, snowfall and all potential snow-melt events were removed from the calibration data set. This determination was based on precipitation and temperature data obtained from the Philadelphia International Airport. These criteria yielded a data set containing 121 hydrologic events to calibrate to at each of the two gauges for the watershed scale model. A varying number of events were selected for calibration to the level monitoring data of each tributary.

Model Calibration

The model calibration philosophy divides storms into three magnitudes:

1. Small storms where no runoff occurs from pervious or impervious areas. These storms allow rough calibration of depression storage, although depression storage may be of a similar magnitude to uncertainty in rainfall and flow measurements.

2. Medium storms where runoff occurs from impervious surfaces but not from pervious surfaces. These storms allow calibration of directly connected impervious area (DCIA).

3. Large storms where runoff occurs from both impervious and pervious areas. These storms allow calibration of soil properties. For the current study, only saturated hydraulic conductivity was modified.

Model validation consists of choosing a set of physical parameters that allows the model to achieve a best fit between observed and simulated runoff event volumes. Choice of the best fit scenario is made by a combination of quantitative methods and best professional judgment. For this model validation, the quantitative method used was a simple error function. The areas below the cumulative distribution function (CDF) graph for both observed and simulated events were calculated and the error was difference between these two values. DCIA, impervious and pervious depression storage and hydraulic conductivity were then modified to minimize this error. In addition, professional judgment was used in certain instances. For example, it was considered important to calibrate larger (greater runoff) events as closely as possible, but not at the expense of misrepresenting a large percentage of events.

Calibration of the model is an iterative process by which model variables are changed, within acceptable ranges based on available data, from initial estimated values to ones that quantitatively and qualitatively provide the best match between modeled results and observed data. The events are distinguished by those included in the calibration process and those excluded using the set of protocols described previously. The four tributaries with available data were calibrated first. Summaries of each tributary's model calibration are included below. These calibrated tributaries were then combined with the remaining area of Wissahickon Creek within Philadelphia, and the remainder of the system was calibrated so that the system as a whole matched USGS gauge station data.

Bells Mill

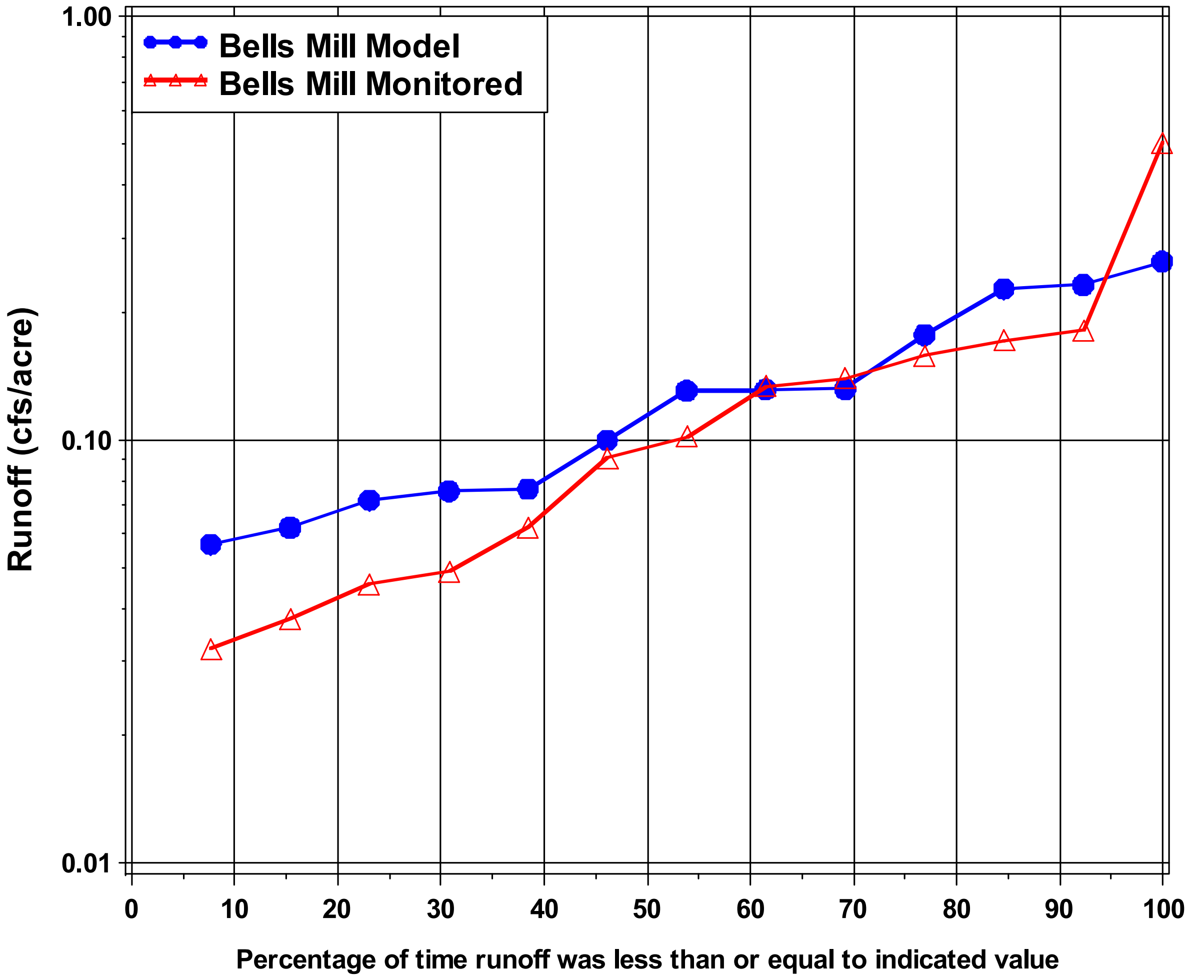
In the first simulation, area-weighted values of soil parameters derived from GIS were used without adjustment. Initial directly-connected impervious areas were estimated as the percentage of total impervious area and the simulation indicated that runoff volumes were greater than to observed data (Bells Mill monitoring data). Table 2 documents changes made to the model.

Table I-2 Bells Mill Model Calibration Summary

Simulation	**DCIA** %	**Impervious Depression Storage (in)**	**Pervious Depression Storage (in)**	**Hydraulic Conductivity** %	**Error (difference between measured and simulated)** %
1	GIS	0.05	0.15	GIS	-40.4
2	-25	0.05	0.15	GIS	-11.1
3	-30	0.08	0.15	GIS	-2.0
4	***-20***	***0.08***	***0.15***	***150***	***-1.7***
5	-20	0.1	0.20	150	2.7
6	-30	0.1	0.20	GIS	4.9
7	-30	0.08	0.25	-50	-26.0

(*GIS – refers to initial estimates calculated using GIS techniques; percentages are relative to original GIS data, i.e. -20% is equal to the initial value minus 20% of that value)

Simulation 4 was selected because it had the least error (see figure 1). This simulation reduced directly connected impervious area by 20% and increased hydraulic conductivity by 150%. Impervious depression storage was set at 0.08 inches. Other simulations were performed in order to match a larger modeled event to a large monitored event. These simulations (5 through 7) were not selected because the error between monitored and observed was greater than desired.



F

iFigure I-1 Bells Mill Model Cumulative Distribution Function of Simulated and Observed Event Volumes

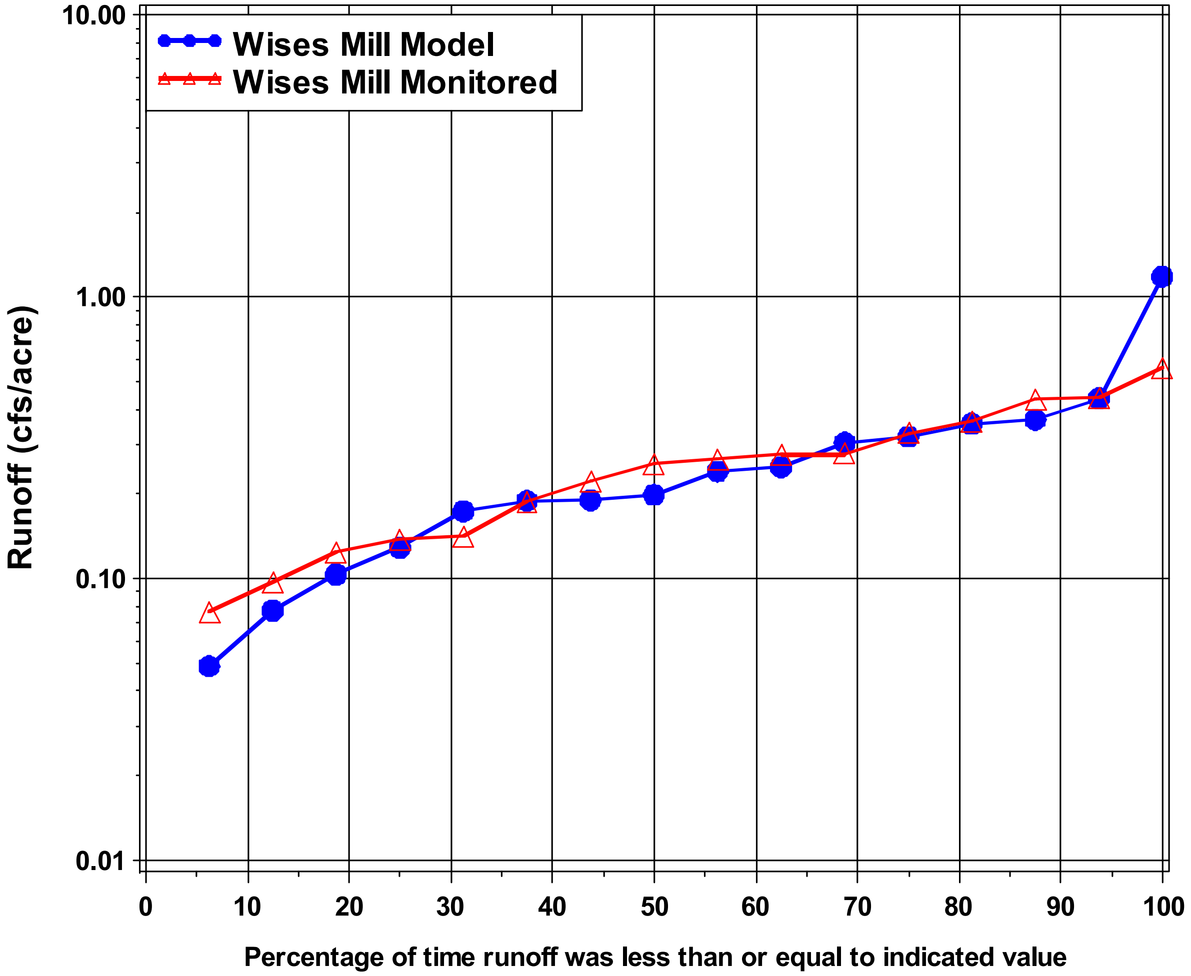
Wises Mill

In the first simulation, area-weighted values of soil parameters were used. Initial directly-connected impervious areas were estimated as the percentage of total impervious area, and the simulation indicated that runoff volumes were higher than desired when compared to Wises Mill monitoring data. Table 3 is a summary of model simulations.

Table I-3 Wises Mill Model Calibration Summary

Simulation	**DCIA** %	**Impervious Depression Storage (in)**	**Pervious Depression Storage (in)**	**Hydraulic Conductivity** %	**Error (difference between measured and simulated)** %
1	GIS	0.05	0.15	GIS	-33.9
2	-15	0.02	0.15	150	-15.5
3	***-25***	***0.02***	***0.15***	***200***	***-1.8***
4	-20	0.02	0.20	200	-8.4

Simulation 3 was selected because it had very low error and matched large measured runoff events well (see figure 2). This simulation reduced directly connected impervious area by 25% and increased hydraulic conductivity by 200%. Impervious depression storage was set at 0.02 inches and pervious depression storage was set at 0.15 inches.



F

iFigure I-2 Wises Mill Model Cumulative Distribution Function of Simulated and Observed Event Volumes

Monoshone Creek

In the first simulation, area-weighted values of soil parameters were used. Initial directly-connected impervious areas were estimated as the percentage of total impervious area and the simulation indicated that runoff volumes were greater than observed data. Table 4 is a summary of model simulations.

Table I-4 Monoshone Creek Model Calibration Summary

Simulation	**DCIA** %	**Impervious Depression Storage (in)**	**Pervious Depression Storage (in)**	**Hydraulic Conductivity %**	**Error (difference between measured and simulated)** %
1	GIS	0.05	0.15	GIS	-255.0
2	-50	0.05	0.15	GIS	-88.2
3	***-70***	***0.05***	***0.15***	***200***	***-5.1***
4	-60	0.05	0.15	250	-39.1

Simulation 3 was selected because it had the least error (see Figure 3). This simulation reduced directly connected impervious area by 70% and increased hydraulic conductivity by 200%. Impervious depression storage was set at 0.05 inches and pervious depression storage was set at 0.15 inches. Another simulation was performed in order to match a larger modeled event to a large monitored event. This simulation, 4, was not selected because the error between monitored and observed was greater than desired.

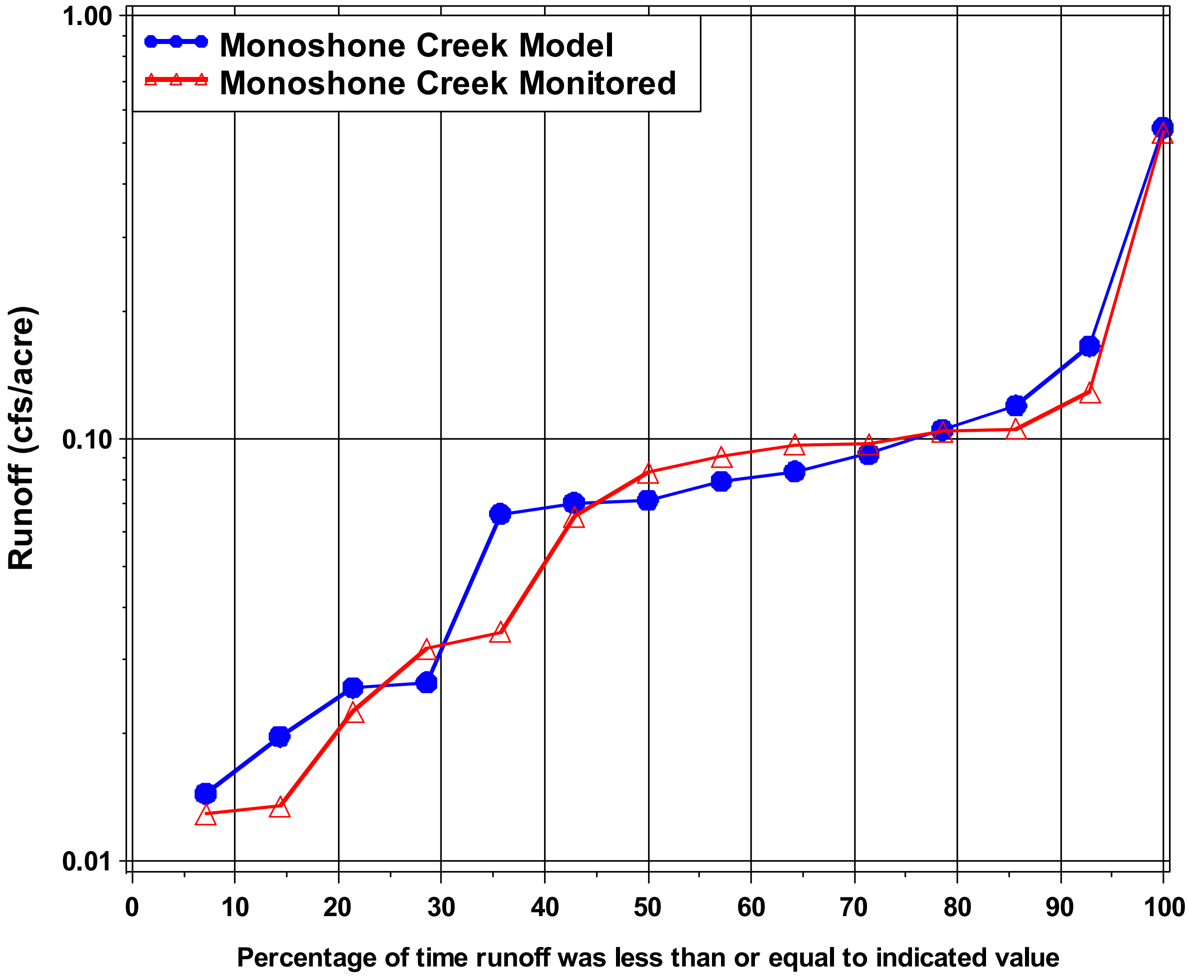


Figure I-3 Monoshone Creek Model Cumulative Distribution Function of Simulated and Observed Event Volumes

Cathedral Run

In the first simulation area weighted values of soil parameters were used. Initial directly-connected impervious areas were estimated as the percentage of total impervious area and the simulation indicated that runoff volumes were greater than monitoring data. Table 5 is a summary of model simulations.

Table I-5 Cathedral Run Model Calibration Summary

Simulation	**DCIA** %	**Impervious Depression Storage (in)**	**Pervious Depression Storage (in)**	**Hydraulic Conductivity** %	**Error (difference between measured and simulated)** %
1	GIS	0.05	0.15	GIS	-98.4
2	-50	0.05	0.15	GIS	-1.8
3	***-60***	***0.08***	***0.15***	***50***	***0.9***

Simulation 3 was selected because it had very low error and matched large measured runoff events well (see figure 4). This simulation reduced directly connected impervious area by 60% and decreased hydraulic conductivity to 50% of the original. Impervious depression storage was set at 0.08 inches and pervious depression storage was set at 0.15 inches.

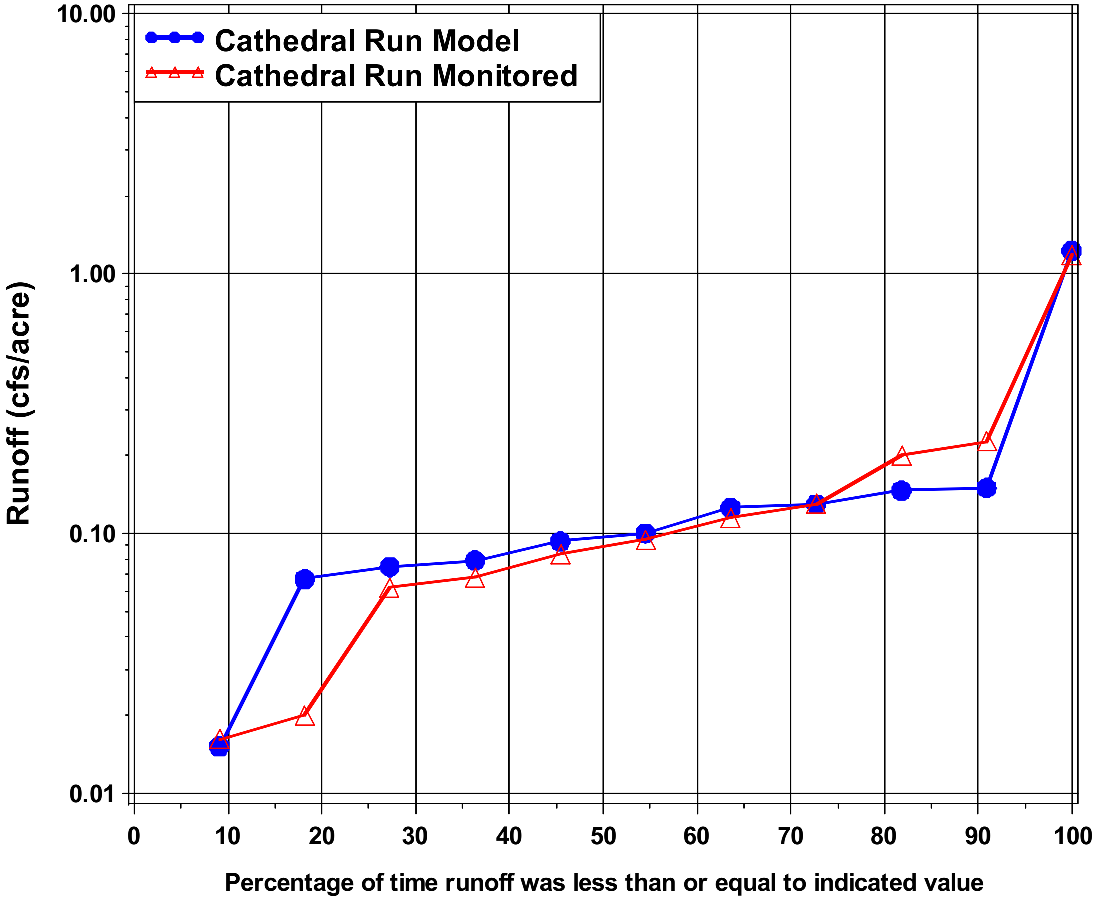


Figure I-4 Cathedral Run Model Cumulative Distribution Function of Simulated and Observed Event Volumes

Wissahickon Creek (Main Stem and Tributaries in Philadelphia)

In the first simulation, area-weighted values of soil parameters were used. Initial directly-connected impervious areas were estimated as the percentage of total impervious area. Calibrated soil parameters were used for areas calibrated to tributary monitoring data (Cathedral Run, Bells Mill Run, Wises Mill Run and Monoshone Creek). The simulation indicated that runoff volumes were greater than volumes derived from USGS streamflow data. Table 6 documents changes made to the model in order to calibrate to streamflow data.

Table I-6 Wissahickon Creek Model Calibration Summary

Simulation	**DCIA** %	**Impervious Depression Storage (in)**	**Pervious Depression Storage (in)**	**Hydraulic Conductivity** %	**Error (difference between measured and simulated)** %
1	GIS	0.08	0.15	GIS	10.0
2	-10	0.08	0.1	-50	6.1
3	-15	0.08	0.08	-70	-7.5
4	-13	0.08	0.1	-60	2.1
5	-25	0.08	0.08	-80	-18.6
6	-30	0.08	0.1	-75	-3.6
7	***-30***	***0.08***	***0.15***	***-75***	***1.5***

Simulation 7 was selected because it had the least error (see figure 5). This simulation reduced directly connected impervious area by 30% and decreased hydraulic conductivity to 25% of the original. Impervious depression storage was set at 0.08 inches and pervious depression storage was set at 0.15 inches.

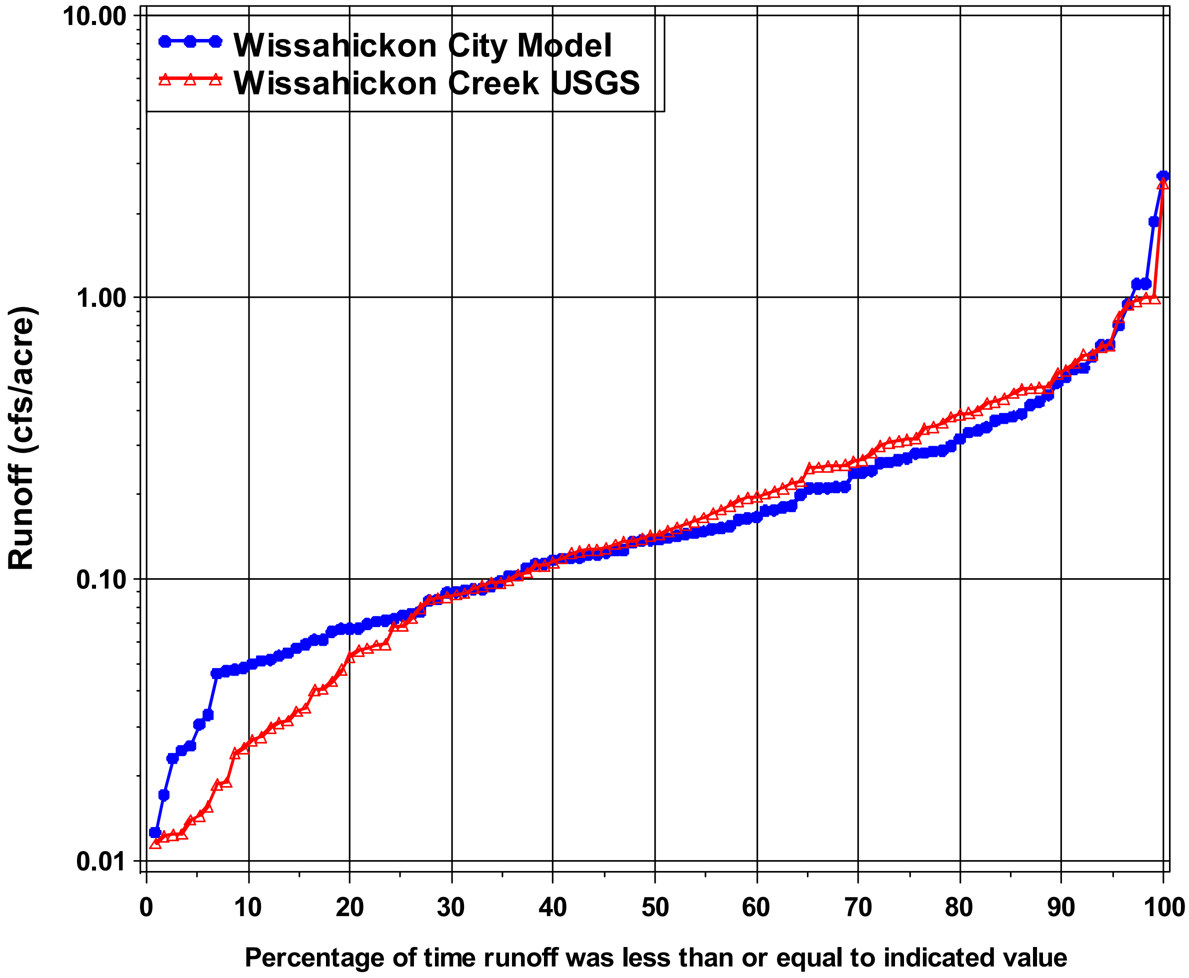


Figure I-5 Wissahickon Creek Model Cumulative Distribution of Simulated and Observed Event Volumes

Calibration by Building Area Disconnection

A supplement to the model calibration was performed to determine the effect of disconnecting buildings. This was completed by using the IFLOWP option in RUNOFF to route building area runoff of a subshed to the pervious area of the subshed, effectively simulating building disconnection. This approach is an alternative to reduction of total impervious cover to match observed runoff volume. Table 7 is a summary of model simulations.

Table I-7 Bells Mill Building Area Disconnection Calibration Summary

Simulation	Building Disconnected %	Pervious Flow Length (ft)	Impervious Depression Storage (in)	Pervious Depression Storage (in)	Hydraulic Conductivity %	Error (difference between measured and simulated) %
1	50	50	0.05	0.15	GIS	1.01
2	50	50	0.07	0.25	150	20.33
3	50	50	0.07	0.25	50	-21.99
4	75	50	0.07	0.25	50	-1.89
5	63	50	0.07	0.25	75	11.84
6	57	50	0.07	0.25	100	18.05
7	63	50	0.07	0.15	75	-3.16
7	65	50	0.07	0.15	75	-1.13

Simulations 1, 4 and 8 each had error of less than 2%, suggesting that nearly equivalent results can be obtained by disconnecting additional buildings and increasing soil permeability. Simulation 1 was selected because it had the least quantitative error and because no additional information on soil properties was available (see figure 6). This simulation disconnected 50% of buildings from the drainage system and did not alter hydraulic conductivity from initial values. Impervious depression storage was set at 0.08 inches and pervious depression storage was set at 0.15 inches. These results suggest that calibration through disconnecting only building areas leads to reasonable results. Other tributaries and the remainder of the model could be calibrated in a similar manner, possibly providing more accurate model results and improving evaluation of management alternatives.

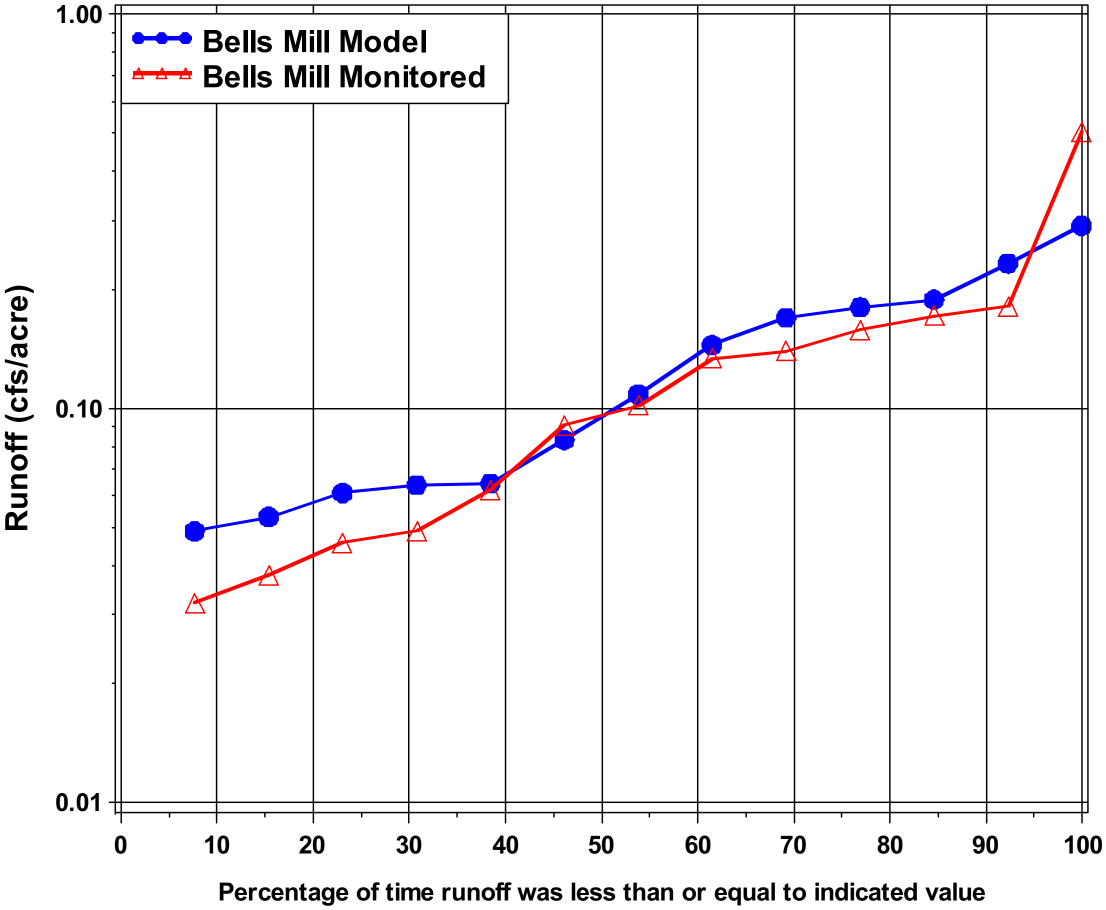


Figure I-6 Bells Mill Building Area Disconnection Cumulative Distribution of Simulated and Observed Event Volumes – Simulation 1

References

Rawls, W.J., D.L. Brakensiek, and K.E. Saxton. 1982. "Estimating Soil Water Retention from Soil Properties." Journal of Irrigation and Drainage Engineering. 108 (1982) IR2: 166-171.

APPENDIX J: WISSAHICKON CREEK WATERSHED SEDIMENT MONITORING METHODS

1. Streambank Erosion Load Field Methods

In conjunction with Section D (*Sediment Total Maximum Daily Load (TMDL) For Wissahickon Creek*) of the City's stormwater permit, PWD has initiated a monitoring plan that addresses the adverse impacts to instream habitats as a result of transport of sediment and/or streambank erosion. Baseline data from 12 perennial tributaries that originate in the City will be monitored to define their contribution of sediment loading.

There are two elements to the monitoring program. The first estimates the sediment load originating from streambanks. The second estimates the total sediment load being carried by the stream. Data collection is ongoing for both parts.

1.1 Sediment Load Originating from Streambank Erosion

In order to estimate the sediment load originating from streambank erosion a bank erosion hazard index (BEHI) and near bank stress (NBS) assessment were completed. Once the assessment was concluded bank pins were installed to collect empirical data on streambank erosion rates.

1.1.1 BEHI/NBS Assessments

PWD employed the BEHI and NBS as defined by Rosgen (1996) to predict erosion rates and classify erosion potential. Three hundred and sixty eight reaches in 12 tributaries were assessed using BEHI and NBS criteria (Table 1). Reaches were assessed based on visual inspection of obvious signs of erosion. BEHI and NBS scores were grouped as very low, low, moderate, high or very high.

Table J-1 Portion of Each Tributary Assessed Using BEHI/NBS Method

Site	BEHI/NBS Assessed (ft)	Channelized (ft)	Visually Assessed (ft)
Monoshone	147	3,074	9,537
Kitchens Ln	1,250	0.00	12,946
Cresheim	1,835	1,062	29,143
Valley Green Run	270	277	3,859
Hartwell	340	0.00	6,358
Rex Ave	270	0.00	2,982
Thomas Mill	625	0.00	6,895
Hill Crest	75.0	2,128	6,929
Paper Mill	2,640	8,576	48,298
Gorgas Ln	350	325	3,261
Wises Mill	1,042	1,057	11,301
Cathedral	1,135	0.00	4,227
Bells Mill	1,759	0.00	7,781

1.1.2 Bank Profile Measurements

Bank pins were installed in Bells Mill, Cathedral Run, Wises Mill and Monoshone tributaries in October and November 2005. Nine bank pin sites were chosen in each of the tributaries listed with the exception of Monoshone. Only four bank pin sites were chosen in Monoshone because much of the tributary is channelized. Bank pins were installed in reaches with varying BEHI and NBS scores in order to validate and calibrate the prediction model. Three of the 9 sites were in reaches visually assessed to have low erosion potential. Additional bank pin sites in these tributaries and others are planned for the future (Figure 1).

Bank pins were installed where the bend in the bank was greatest. If possible, at least one bank pin was put in below bankfull height and they were spaced no closer than 1 ft (Figure 2). The number of bank pins at a site was dependent on bank height and ranged from one to three. After installation, bank pins were spray painted orange to facilitate visibility (Figure 3).

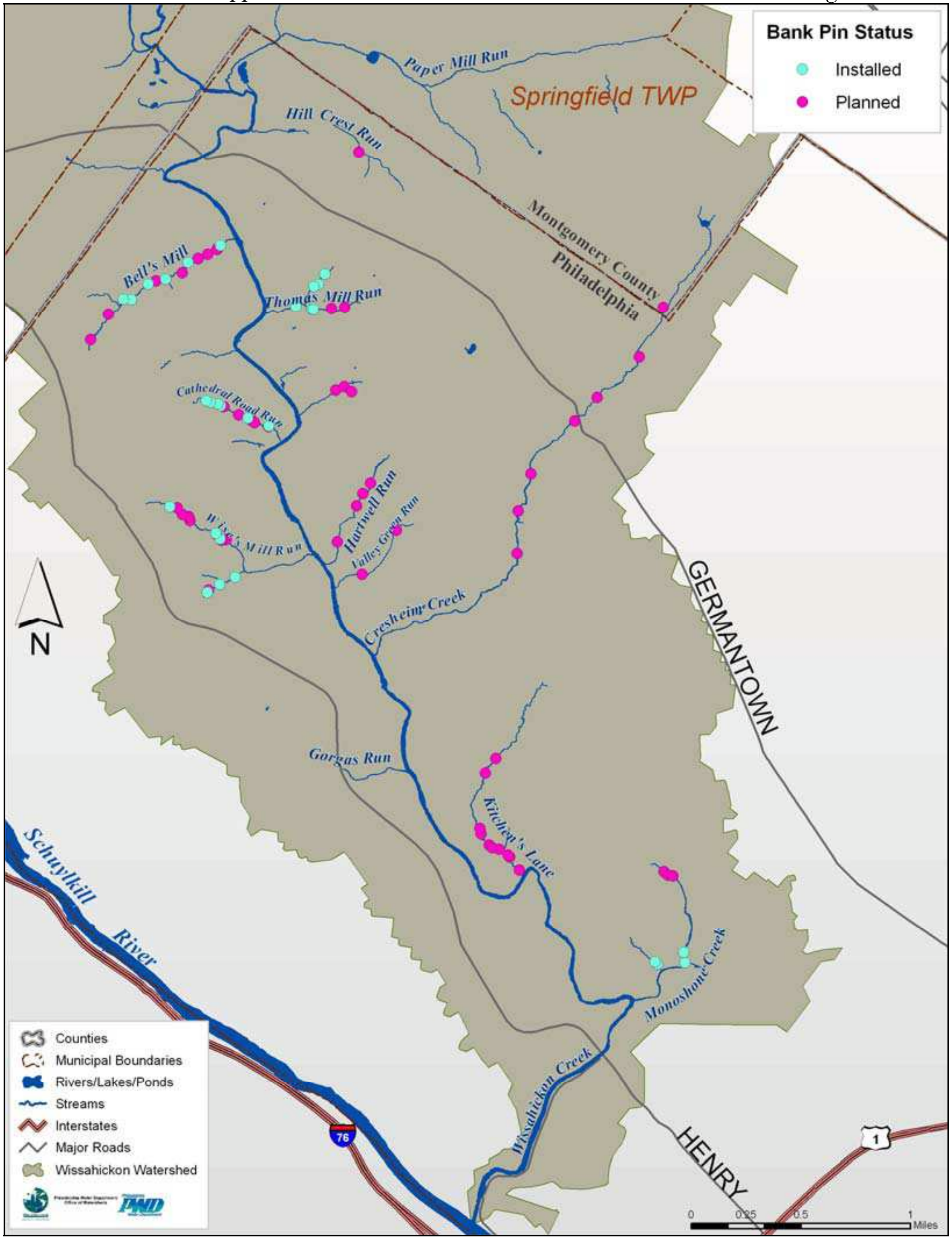


Figure J-1 Current and Planned Bank Pin Site Locations

Figure J-2 Bank Pin Installation in Wises Mill Tributary

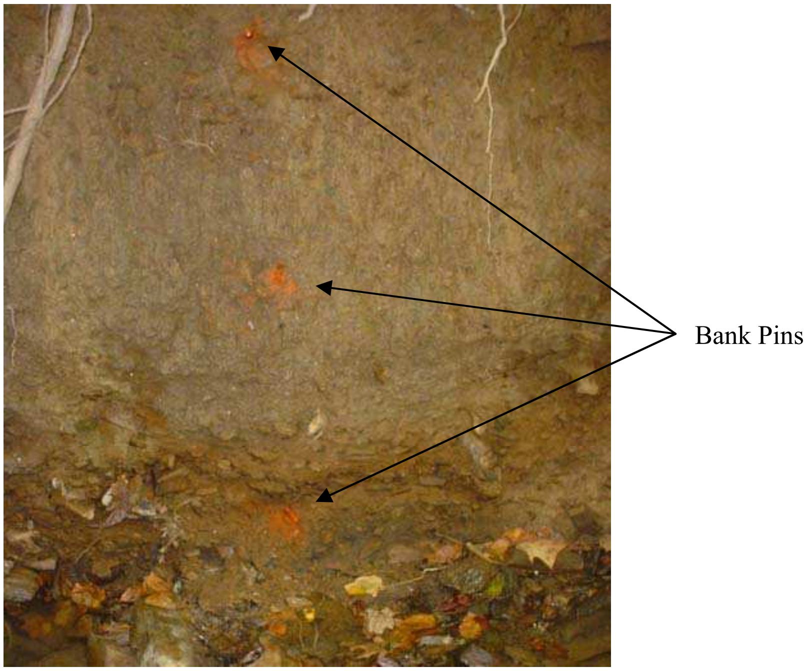


Figure J-3 Spray Painted Bank Pins in Wises Mill Tributary

Toe pins are bank offset pins driven vertically into the bed surface (Figure 4). The toe pin offers a permanent location to measure the bank profile from. The profile was measured with a survey rod, a Keson pocket rod and two levels. The survey rod was placed on the edge of the toe pin and kept straight using a level. The pocket rod was placed against the bank, on top the bank pin, and kept straight using a level. The distance from the bank to the edge of the survey rod closest to the bank was recorded on a field data sheet (Figure 5).

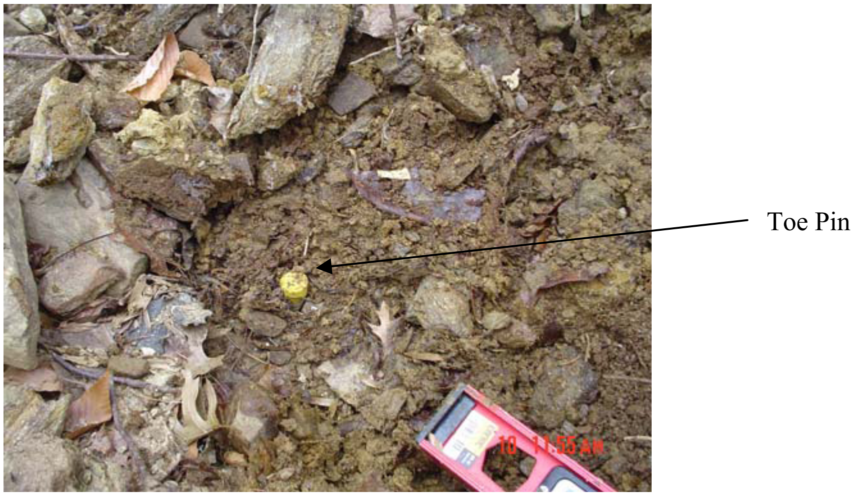


Figure J-4 Toe Pin Installed in a Wissahickon Tributary

Figure J-5 Bank Profile Measurement in Cathedral Run

1.1.3 Channel Stability

Bar samples, sub-pavement samples and pebble counts were collected at 9 sites in 5 tributaries to Wissahickon Creek in order to gather information on channel stability (Figures 6 and 7). Bar and sub-pavement samples as well as pebble counts were collected following methods described on EPA's Watershed Assessment of River Stability and Sediment Supply (WARSSS) website. Additionally, Riffle Stability Index (RSI) Assessments and pebble counts were completed at 14 sites in the same 5 tributaries. RSI methods are described in Kappesser (1994). RSI assessments were done in place of bar samples in cases where sediment bars were not prominent due to high slope. In some cases RSI assessments were done in close proximity to bar or sub-pavement samples in order to compare results from the two methods. All samples were collected in April and May 2006.

Figure J-6 Sieving During Bar Sample Collection

Figure J-7 Draining Water During Bar Sample Collection

1.2 Total Suspended Sediment Load

To estimate the total suspended sediment load in the steam both a stage discharge and a sediment discharge rating curve were generated. Stage was continuously recorded and used in conjunction with the rating curves to calculate an estimated sediment load per year.

1.2.1 Stage Data

Stage data from Bells Mill, Cathedral Run, Wises Mill and Monoshone were recorded near the Wissahickon confluence downstream of all stormwater outfalls. Stage was measured every six minutes by either an ultrasonic down-looking water level sensor or a pressure transducer and recorded on a Sigma620 (Figures 8 and 9). PWD staff periodically downloaded stage data and performed quality assurance. Any data determined to be incorrect was removed and saved in another location.

Dates of ultrasonic down-looking sensor installation in Bells Mill, Cathedral Run and Wises Mill were May 2005, September 2005 and August 2005 respectively. Pressure transducers were installed in Monoshone in July 2005 and Bells Mill in November 2005. Stage data will continue to be recorded at these sites and additional collection sites are planned.

Figure J-8 Ultrasonic Down-looking Acoustic Water Level Sensor Installed in a Pipe in Cathedral Run Tributary

Figure J-9 Pressure Transducer for Water Level Measurement Installed in Monoshone Tributary

1.2.2 Stage Discharge Rating Curve

Staff gages were installed in Monoshone, Wises Mill and Bells Mill concurrent with ultrasonic downlooker or pressure transducer installation (Figure 10). Staff gages are located next to the stage recording device in culverts with concrete floors to ensure that the cross section will not change over time.

Discharge rating curves were established in Monoshone, Wises Mill and Bells Mill following a modified version of the USGS protocol (Buchanan and Somers 1969). Discharge was measured in a cross section close to the staff gage using a SonTek Flowtraker Handheld ADV and plotted against the stage it was recorded at. Due to lack of a suitable monitoring location, the discharge rating curve in Cathedral Run will be mathematically modeled instead of measured in the field.

Figure J-10 Staff Gage, Pressure Transducer, and Ultrasonic Down-looking Sensor in Bells Mill Tributary

1.2.3 Sediment Discharge Rating Curve

In order to create a sediment concentration discharge rating curve, suspended sediment concentration was measured at various flows. Automated water collection devices (ISCO model no. 6712) were used to collect water samples during wet weather events in 4 Wissahickon Creek tributaries (Figure 11 and 12). In an attempt to characterize the entire storm, automated samplers were triggered by a 0.2 ft elevation change in stream height and samples were collected every 20 minutes for the first hour. Following this step, samples were collected every 2-4 hours until discharge returned to baseflow conditions. The stage at which water samples were collected was related to the stage discharge rating curve in order to generate a sediment concentration discharge rating curve.

Total suspended sediment samples were collected from Monoshone Creek (5/20/2005 and 7/8/2005), Wises Mill (11/16/2005), Cathedral Run (11/10/2005 and 11/16/2005) and Bells Mill (9/15/2005, 9/26/2005 and 10/8/2005). Sample collection followed methods described in Section 4 for wet weather monitoring. Additional sample collections are planned for these 4 tributaries as well as other tributaries.

Figure J-11 Automated Water Sampler Installation

Figure J-12 Automated Sampler Locations

APPENDIX K: THE DIURNAL OXYGEN-CURVE METHOD FOR ESTIMATING PRIMARY PRODUCTIVITY AND COMMUNITY METABOLISM IN THE WISSAHICKON CREEK

The diurnal oxygen-curve method for estimating primary productivity and community metabolism in streams (USGS 1987) was applied for single station analysis to Wissahickon Creek 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 K1.

$$k_2 = 5.026\ (V^{9.69})\ (R^{-1.673}) \qquad \text{(K1)}$$

- 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°C

The reaeration rate constant was adjusted for temperature (T) using:

$$K = 1.024^{(T-20)}\ k_2 \qquad \text{(K2)}$$

And, the reaeration rate was estimated by:

$$D_a = K\ (C_s - C_o) \qquad \text{(K3)}$$

- 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 (K2)

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 gage station's located at Fort Washington, 10.75 miles upstream of the mouth, and Philadelphia near the mouth. 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 reaeration 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 WS1850 on June 23 through June 27, 2005 are shown in Figure K-1. 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 K-1. 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 rain gage 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 Wissahickon Creek and across seasons, various statistical analyses of productivity and respiration estimates were performed. The results of these analyses are presented in figures K-2 through K-5. 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 K-6 through K-29.

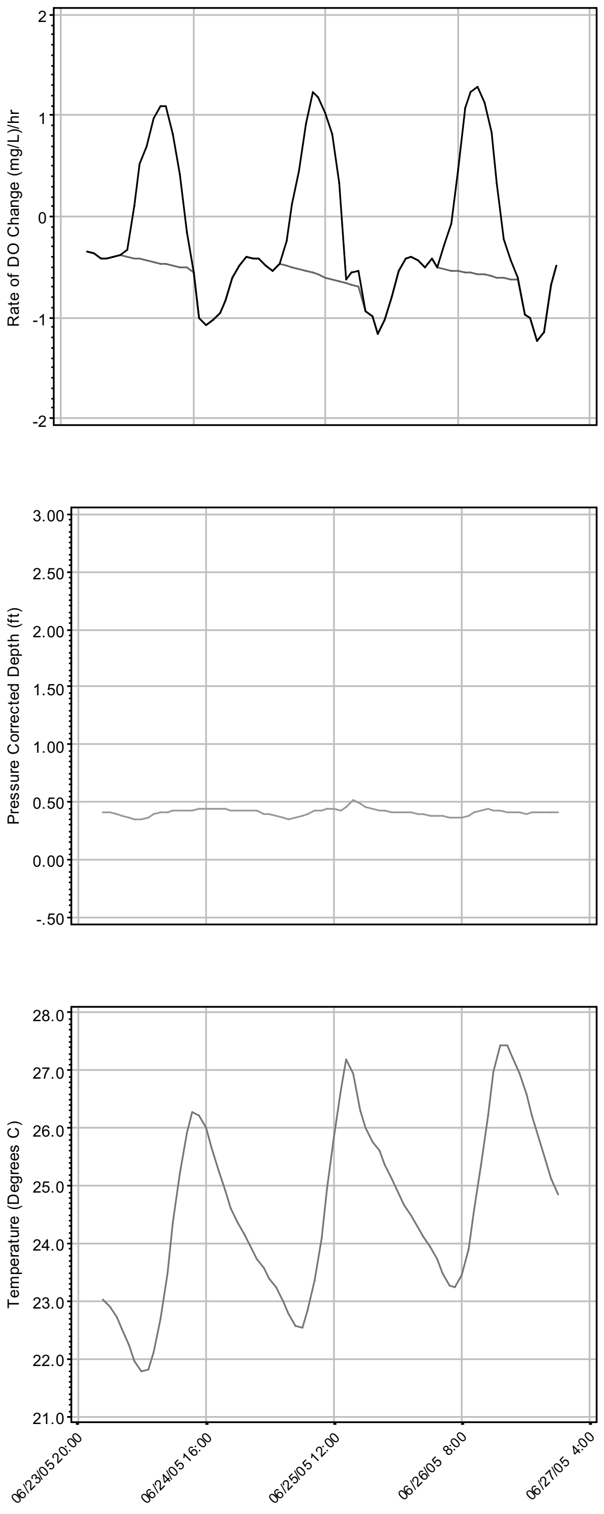


Figure K-1 Wissahickon Continuous Monitoring Results at Site WS1850 for June 23 through June 27, 2005 (Top) Corrected Rate of DO Change and Estimated Daytime Respiration (Middle) Pressure Corrected Sonde Depth (Bottom) Sonde Temperature measurement

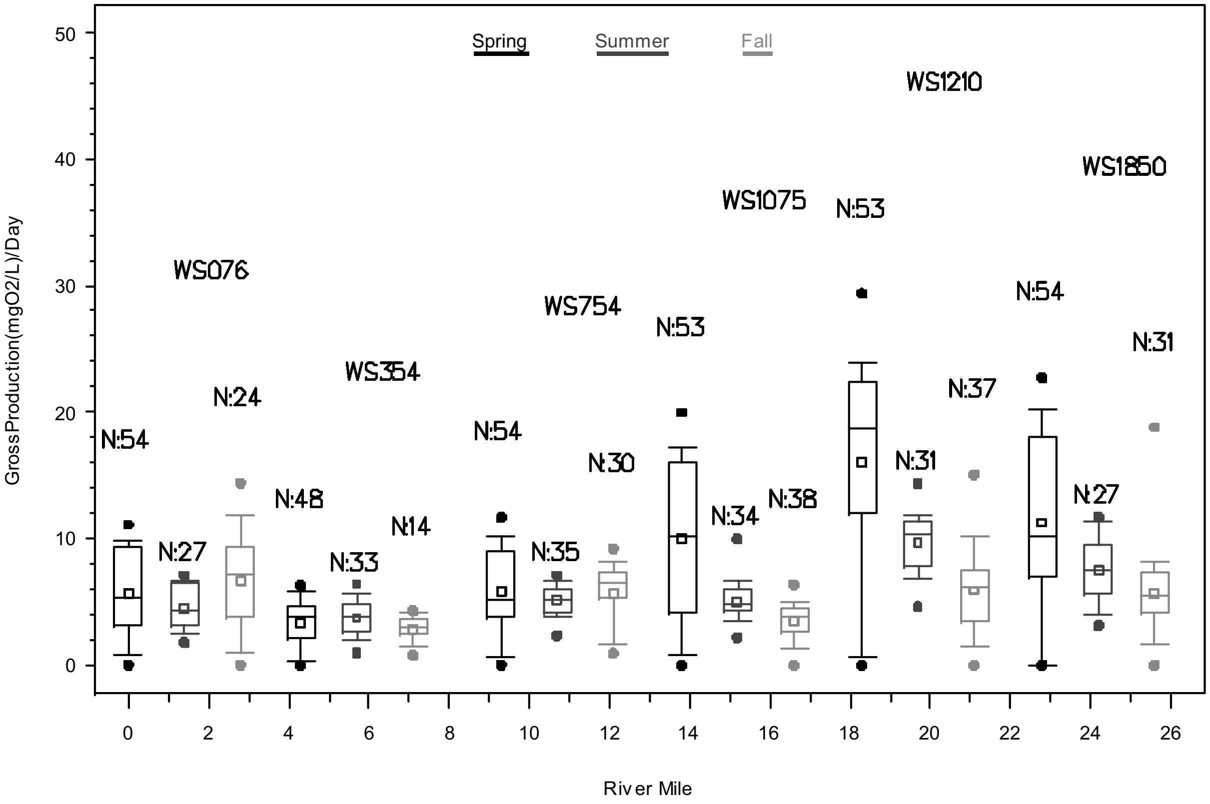


Figure K-2 Comparison of Statistical Analysis Results Showing Seasonal Variations in Gross Productivity Across Wissahickon Monitoring Locations

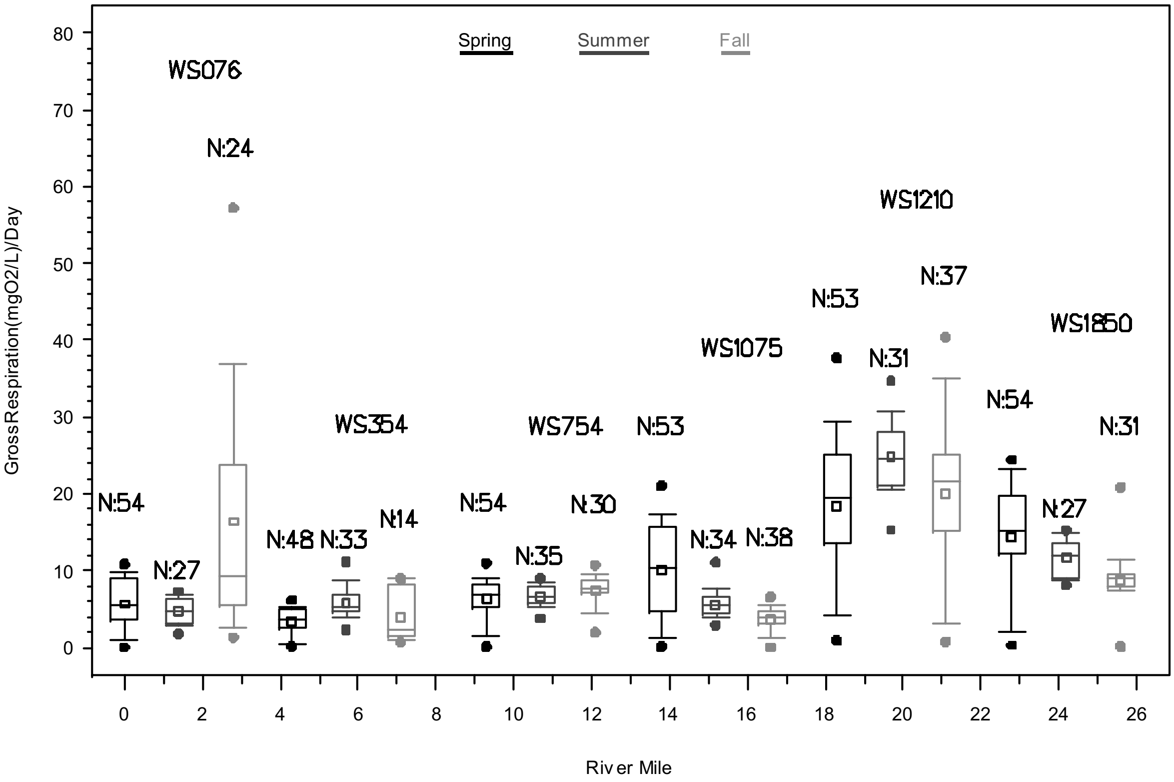


Figure K-3 Comparison of Statistical Analysis Results Showing Seasonal Variations in Gross Respiration Across Wissahickon Monitoring Locations

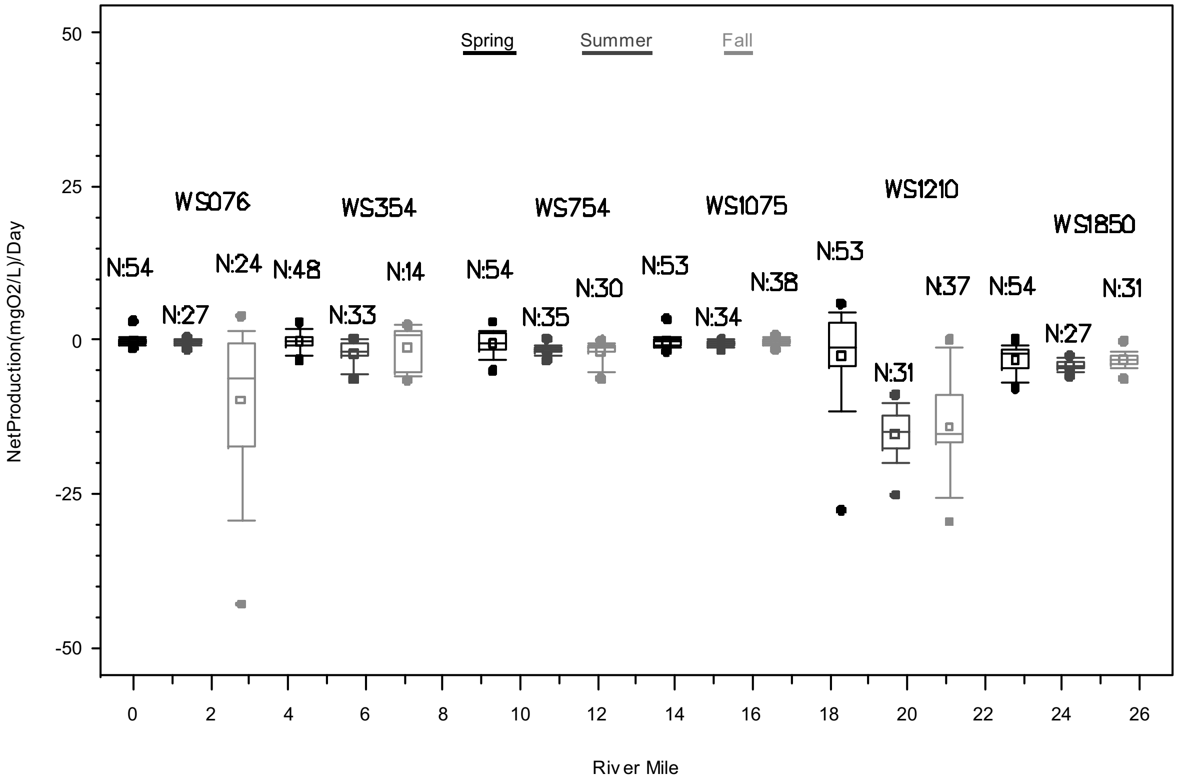


Figure K-4 Comparison of Statistical Analysis Results Showing Seasonal Variations in Net Productivity Across Wissahickon Monitoring Locations

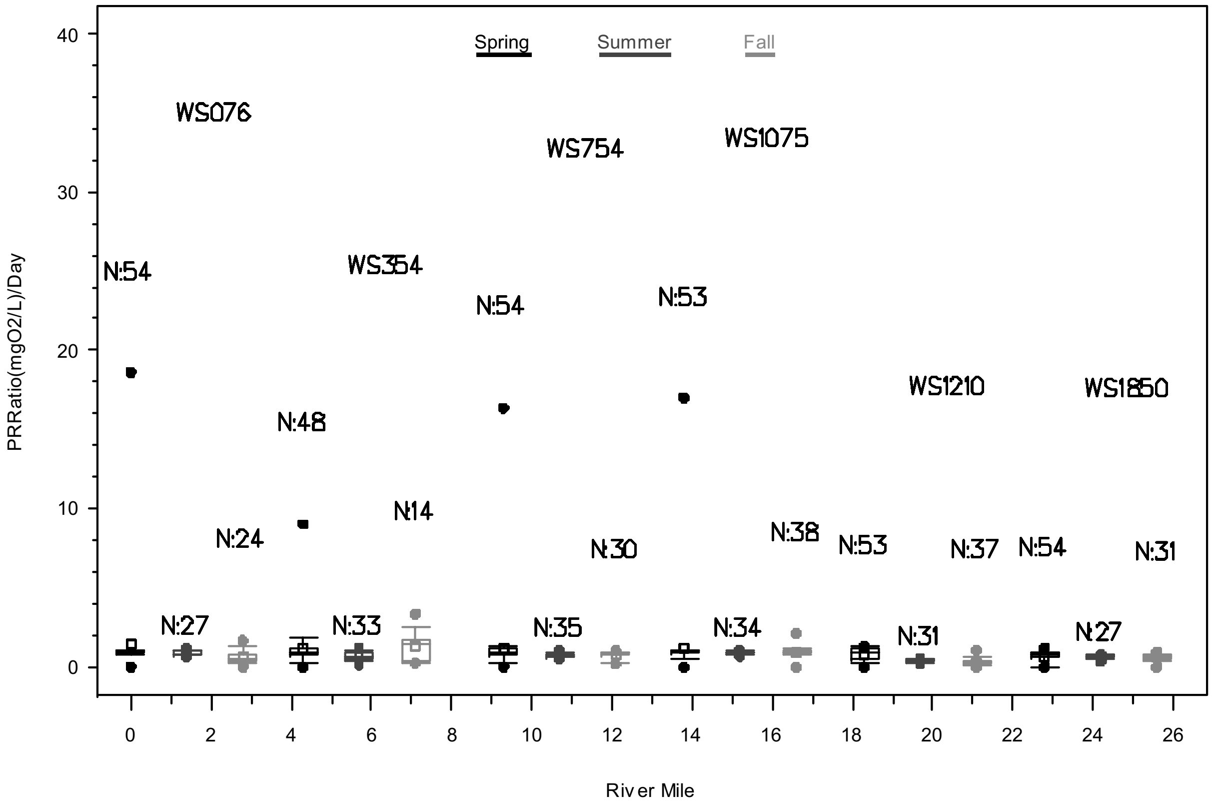
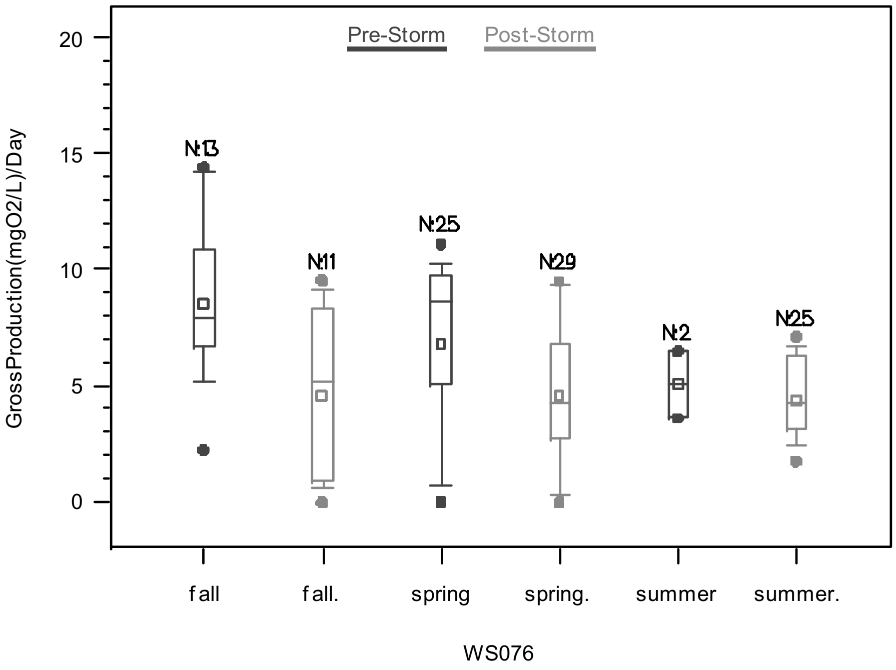
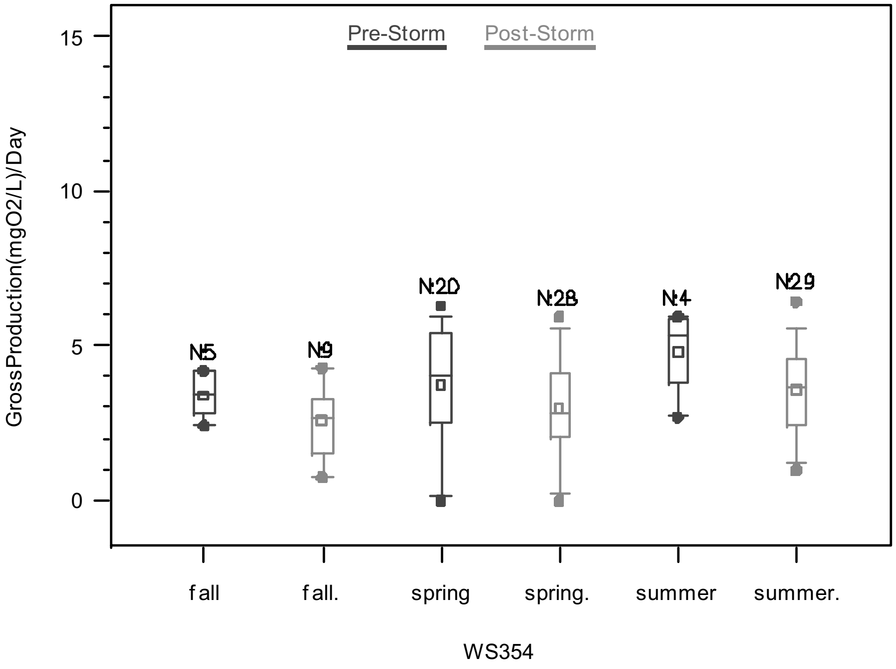


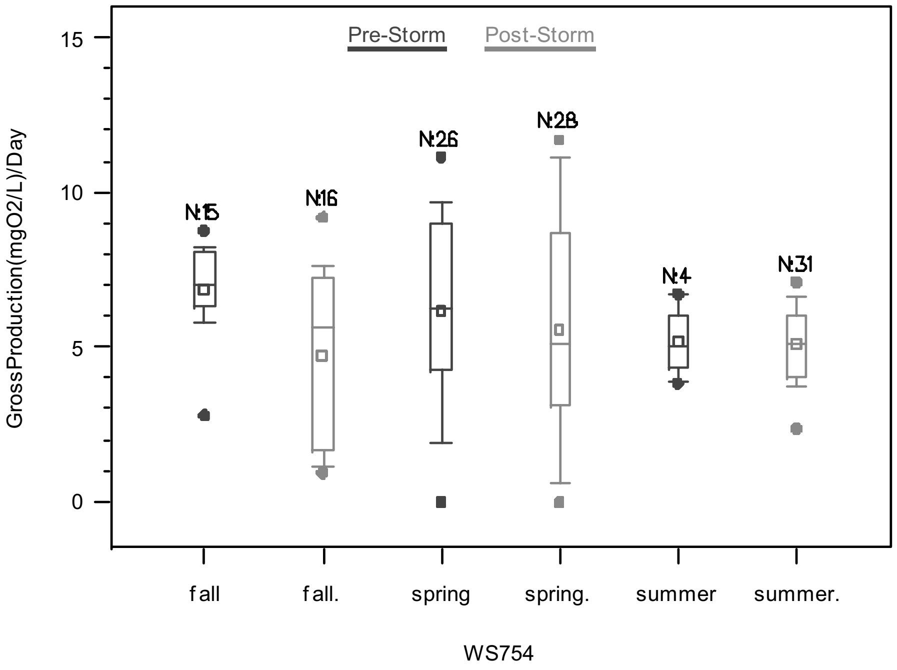
Figure K-5 Comparison of Statistical Analysis Results Showing Seasonal Variations in P:R Ratios Across Wissahickon Monitoring Locations



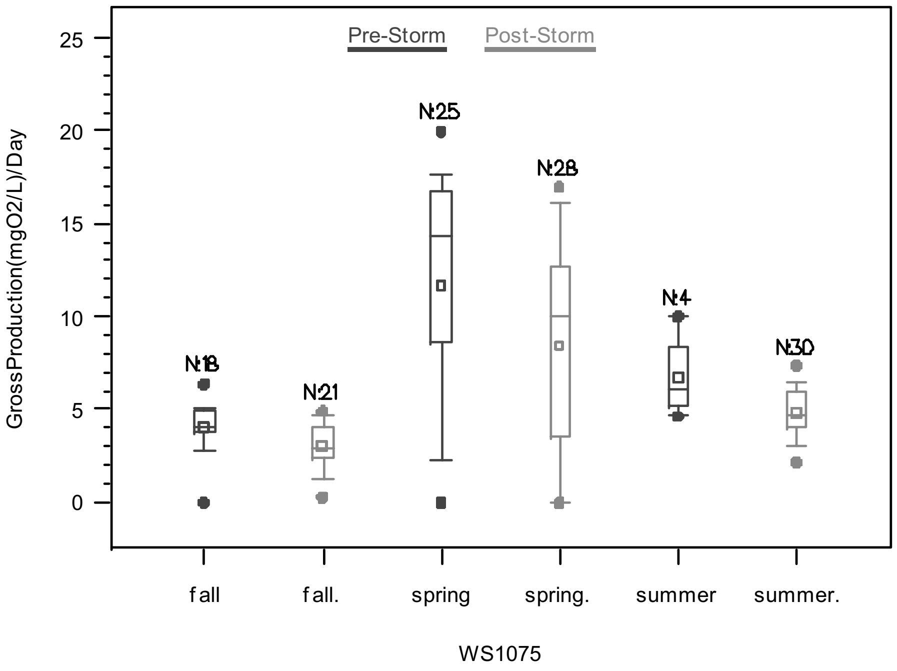
Figures K-6 Comparison of Statistical Analysis Results for "Pre" and "Post" Storm Monitoring Showing Seasonal Variations in Gross Productivity for Site WS076



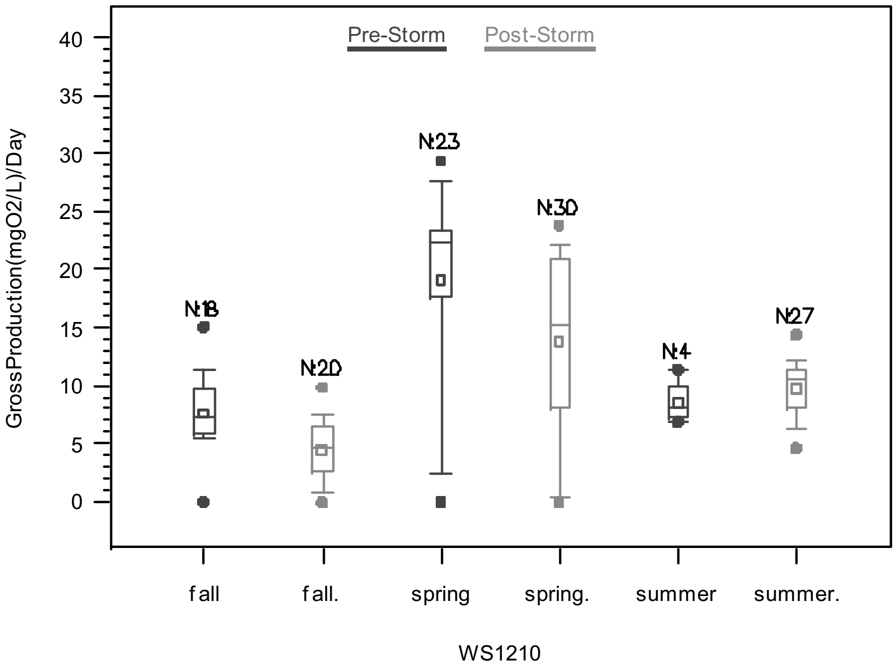
Figures K-7 Comparison of Statistical Analysis Results for "Pre" and "Post" Storm Monitoring Showing Seasonal Variations in Gross Productivity for Site WS354



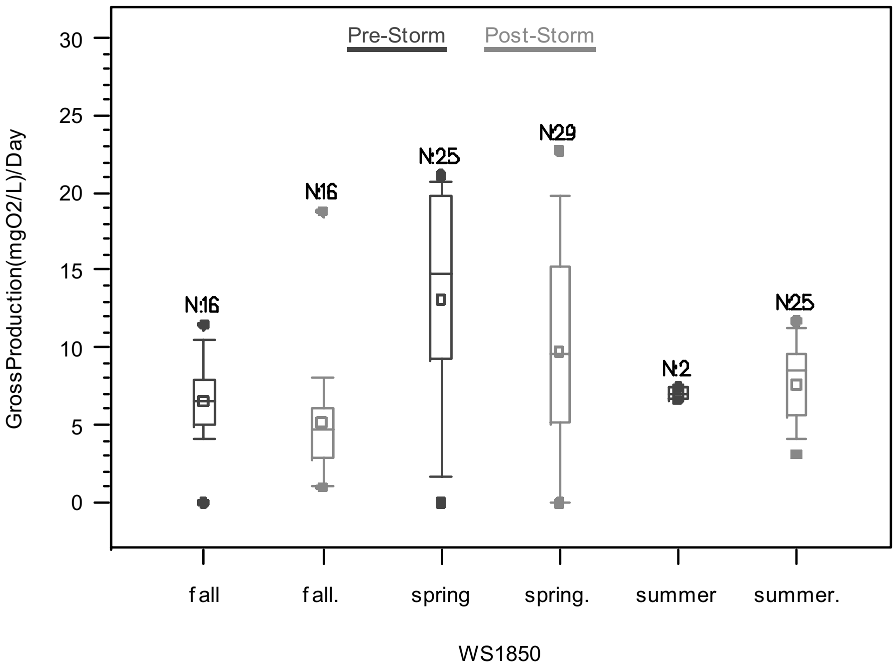
Figures K-8 Comparison of Statistical Analysis Results for "Pre" and "Post" Storm Monitoring Showing Seasonal Variations in Gross Productivity for Site WS754



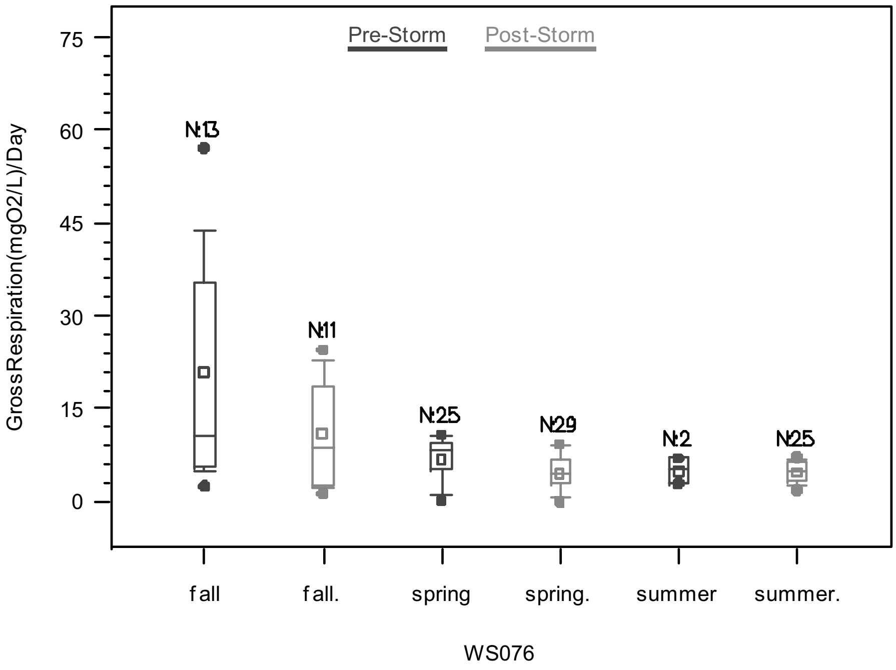
Figures K-9 Comparison of Statistical Analysis Results for "Pre" and "Post" Storm Monitoring Showing Seasonal Variations in Gross Productivity for Site WS1075



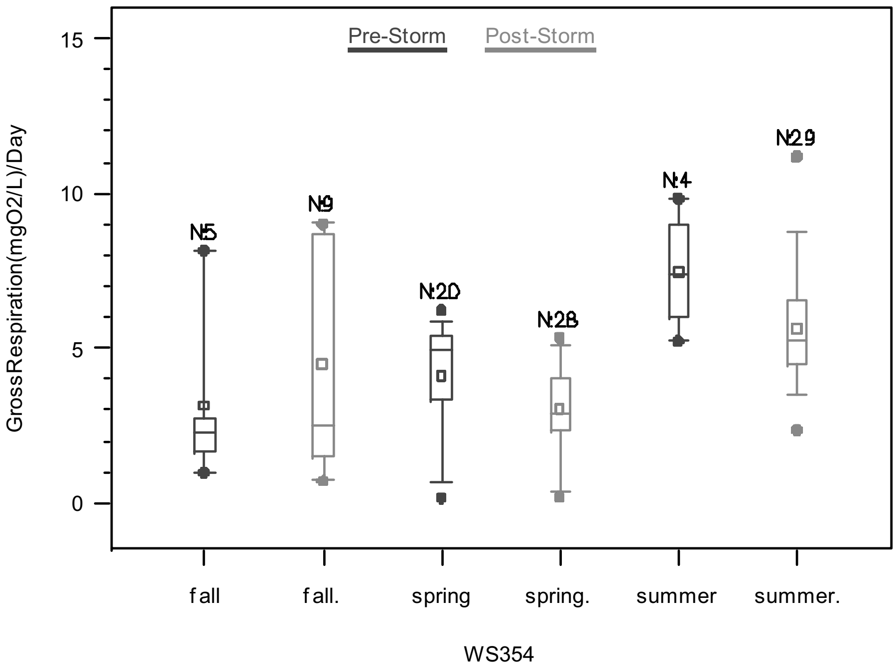
Figures K-10 Comparison of Statistical Analysis Results for "Pre" and "Post" Storm Monitoring Showing Seasonal Variations in Gross Productivity for Site WS1210



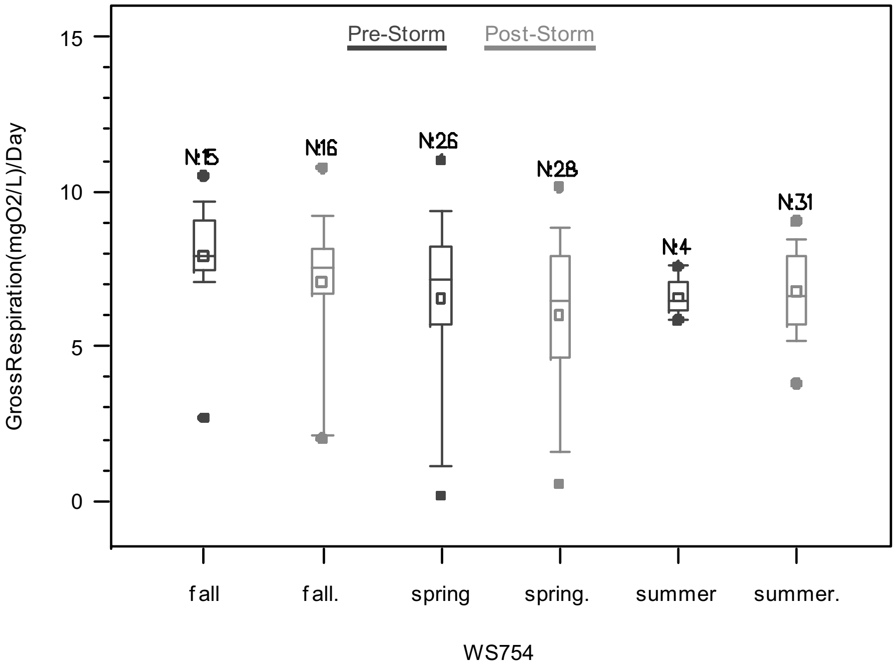
Figures K-11 Comparison of Statistical Analysis Results for "Pre" and "Post" Storm Monitoring Showing Seasonal Variations in Gross Productivity for Site WS1850



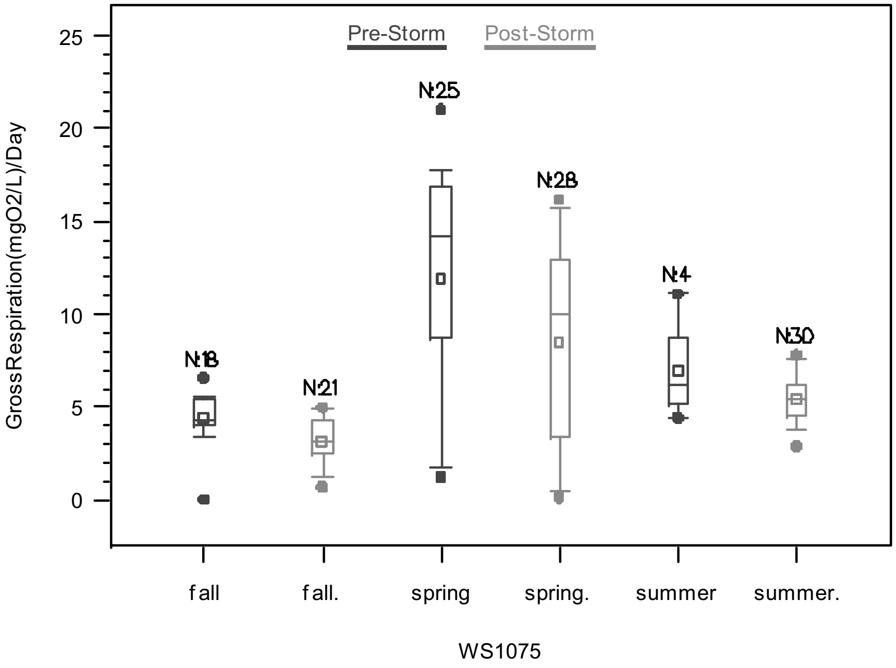
Figures K-12 Comparison of Statistical Analysis Results for "Pre" and "Post" Storm Monitoring Showing Seasonal Variations in Gross Respiration for Site WS076



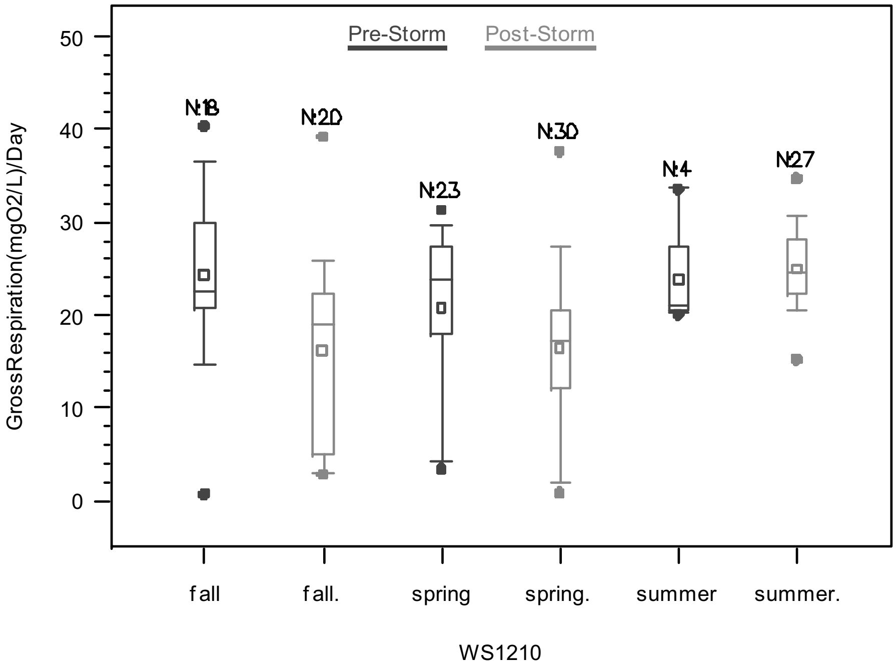
Figures K-13 Comparison of Statistical Analysis Results for "Pre" and "Post" Storm Monitoring Showing Seasonal Variations in Gross Respiration for Site WS354



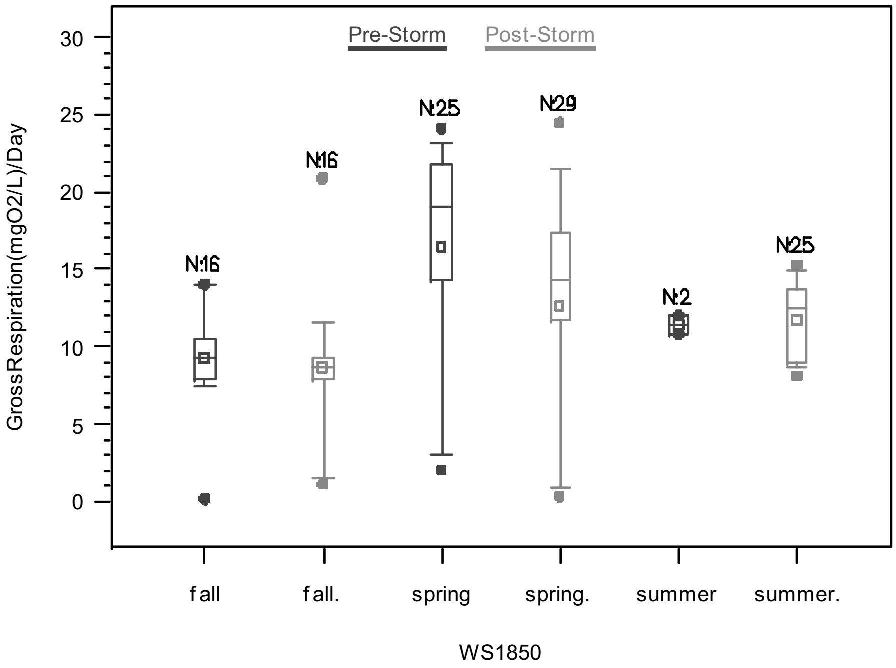
Figures K-14 Comparison of Statistical Analysis Results for "Pre" and "Post" Storm Monitoring Showing Seasonal Variations in Gross Respiration for Site WS754



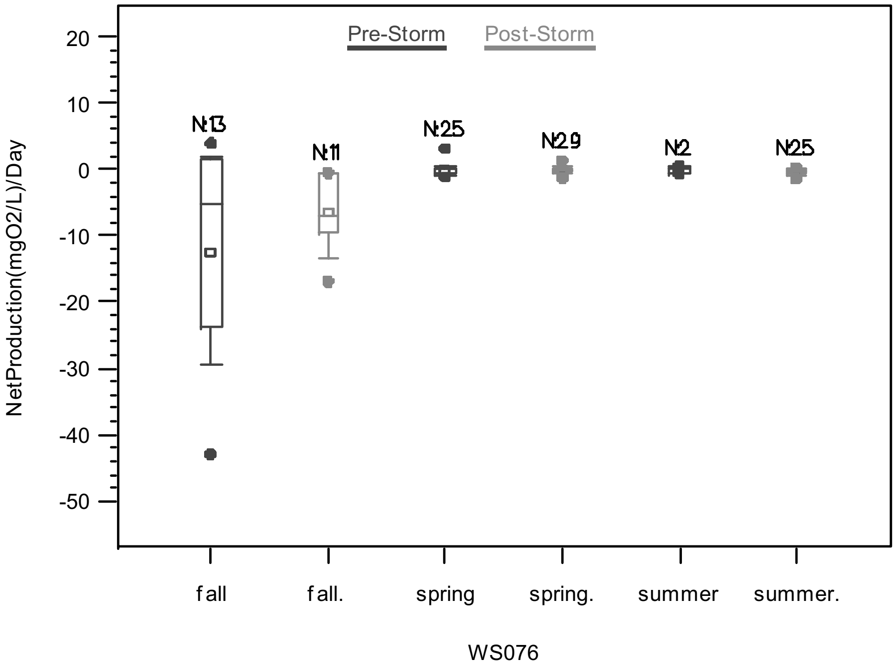
Figures K-15 Comparison of Statistical Analysis Results for "Pre" and "Post" Storm Monitoring Showing Seasonal Variations in Gross Respiration for Site WS1075



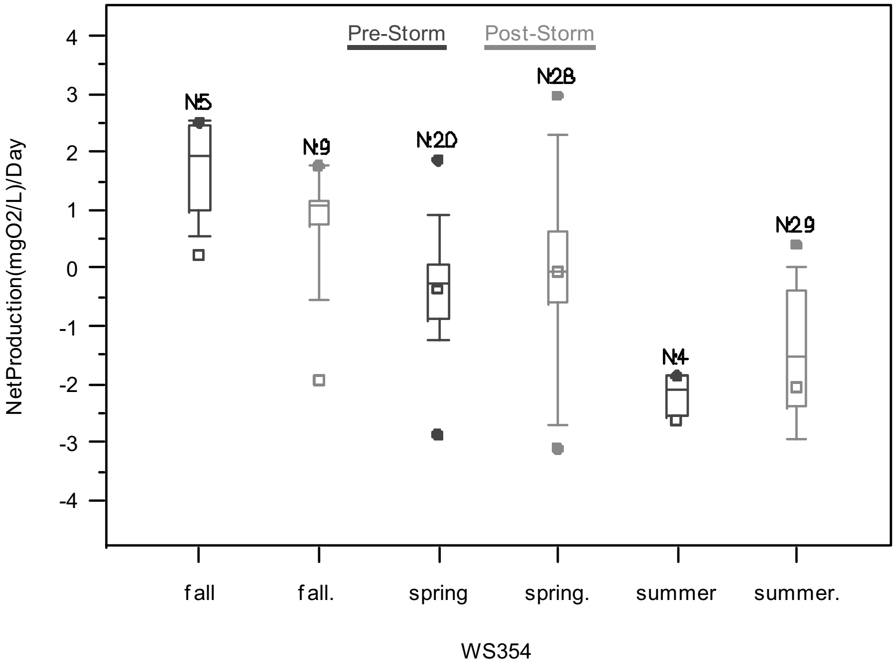
Figures K-16 Comparison of Statistical Analysis Results for "Pre" and "Post" Storm Monitoring Showing Seasonal Variations in Gross Respiration for Site WS1210



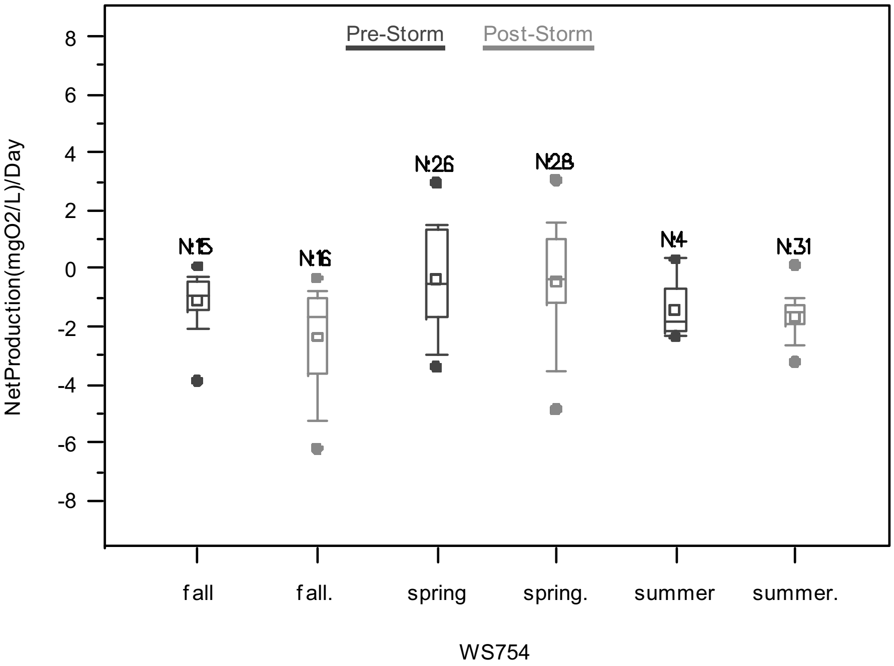
Figures K-17 Comparison of Statistical Analysis Results for "Pre" and "Post" Storm Monitoring Showing Seasonal Variations in Gross Respiration for Site WS1850



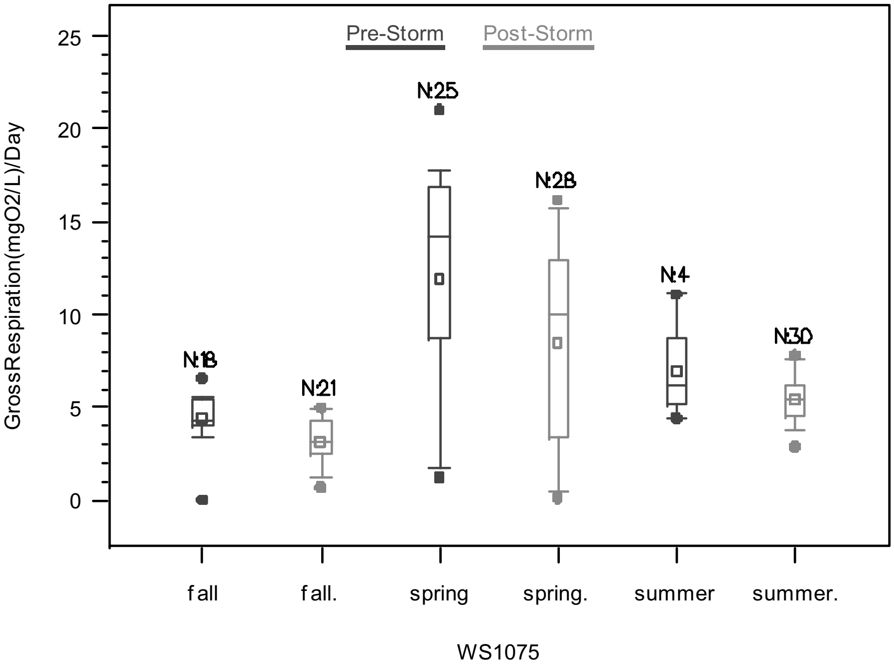
Figures K-18 Comparison of Statistical Analysis Results for "Pre" and "Post" Storm Monitoring Showing Seasonal Variations in Net Productivity for Site WS076



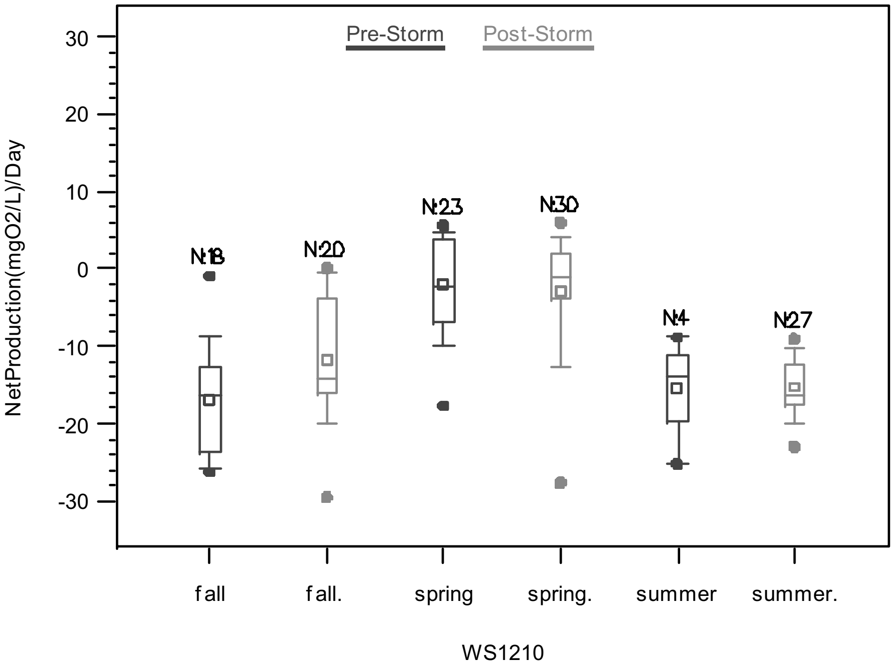
Figures K-19 Comparison of Statistical Analysis Results for "Pre" and "Post" Storm Monitoring Showing Seasonal Variations in Net Productivity for Site WS354



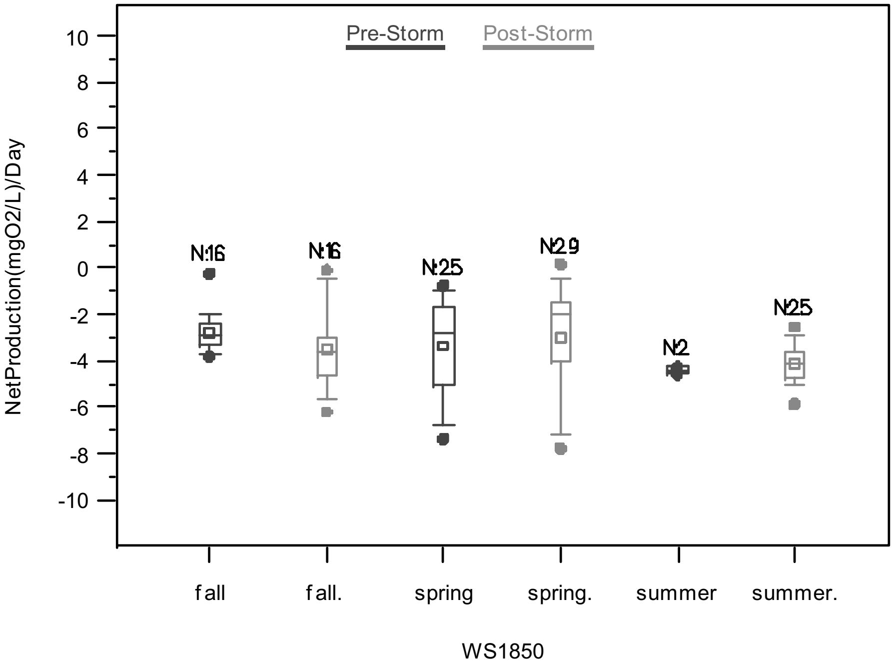
Figures K-20 Comparison of Statistical Analysis Results for "Pre" and "Post" Storm Monitoring Showing Seasonal Variations in Net Productivity for Site WS754



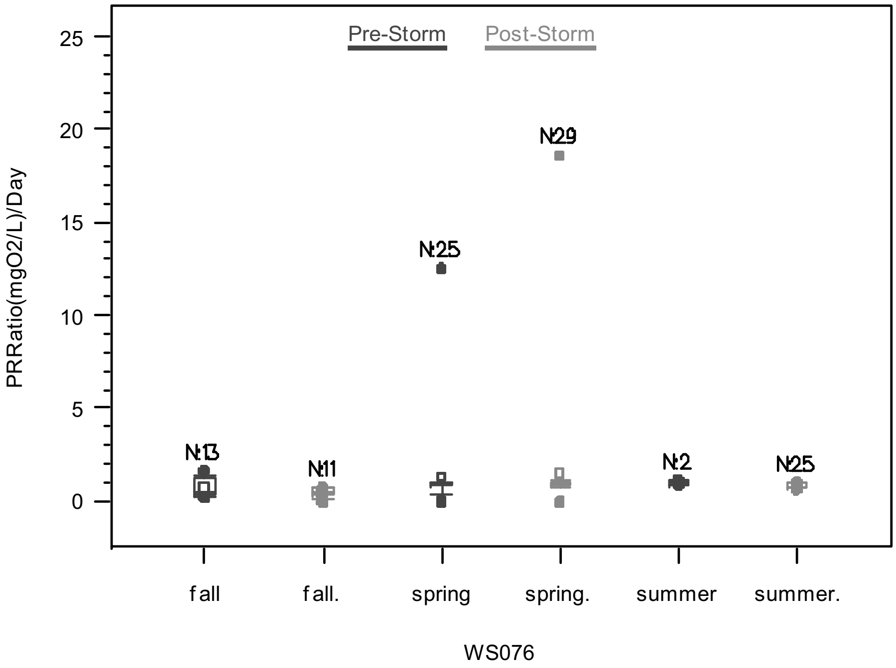
Figures K-21 Comparison of Statistical Analysis Results for "Pre" and "Post" Storm Monitoring Showing Seasonal Variations in Net Productivity for Site WS1075



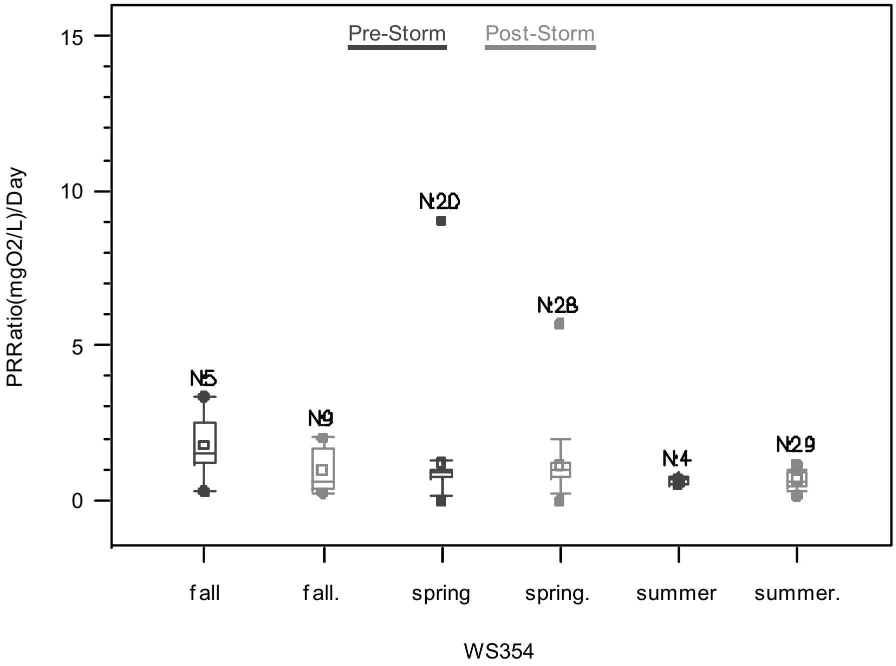
Figures K-22 Comparison of Statistical Analysis Results for "Pre" and "Post" Storm Monitoring Showing Seasonal Variations in Net Productivity for Site WS1210



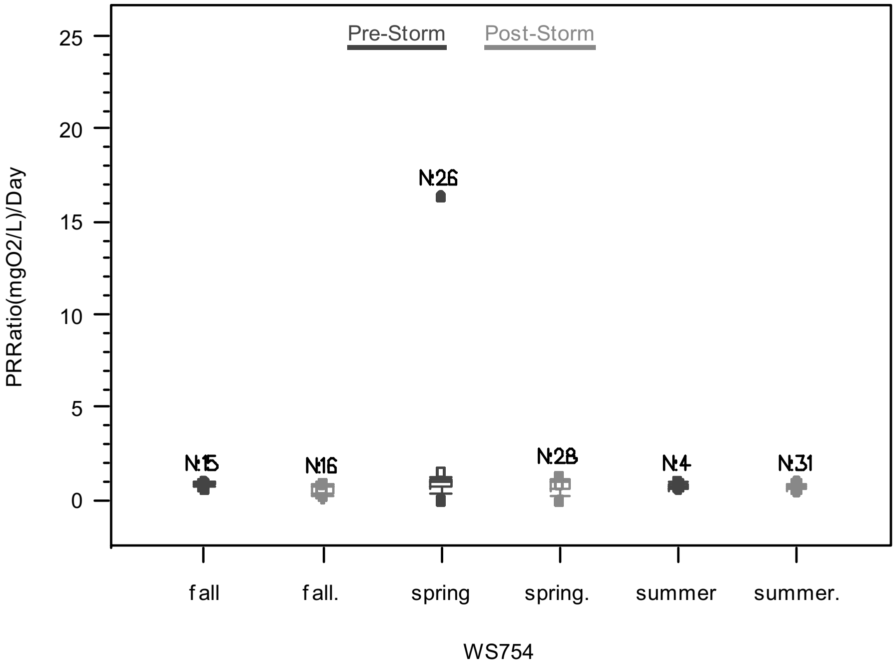
Figures K-23 Comparison of Statistical Analysis Results for "Pre" and "Post" Storm Monitoring Showing Seasonal Variations in Net Productivity for Site WS1850



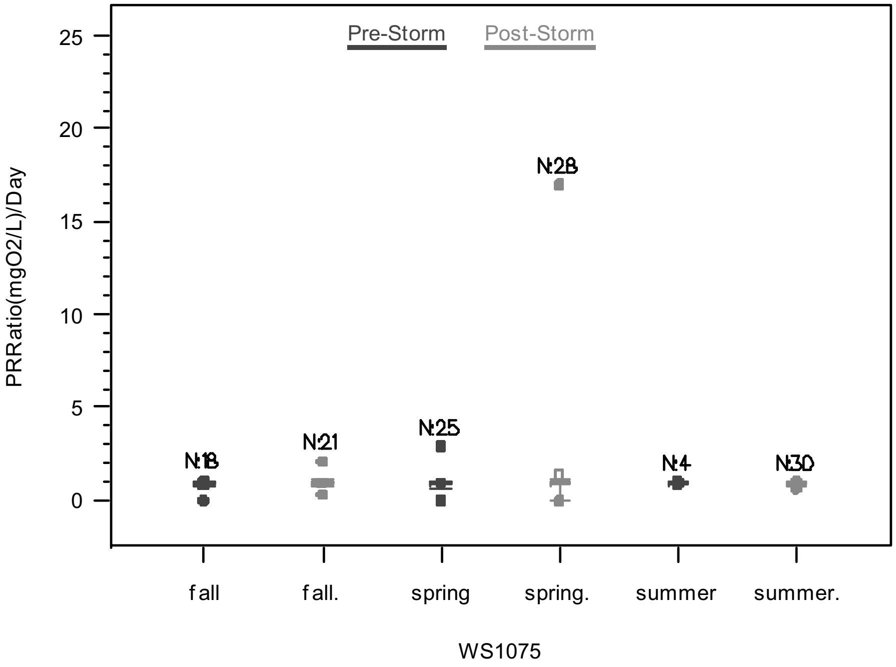
Figures K-24 Comparison of Statistical Analysis Results for "Pre" and "Post" Storm Monitoring Showing Seasonal Variations in P:R Ratios for Site WS076



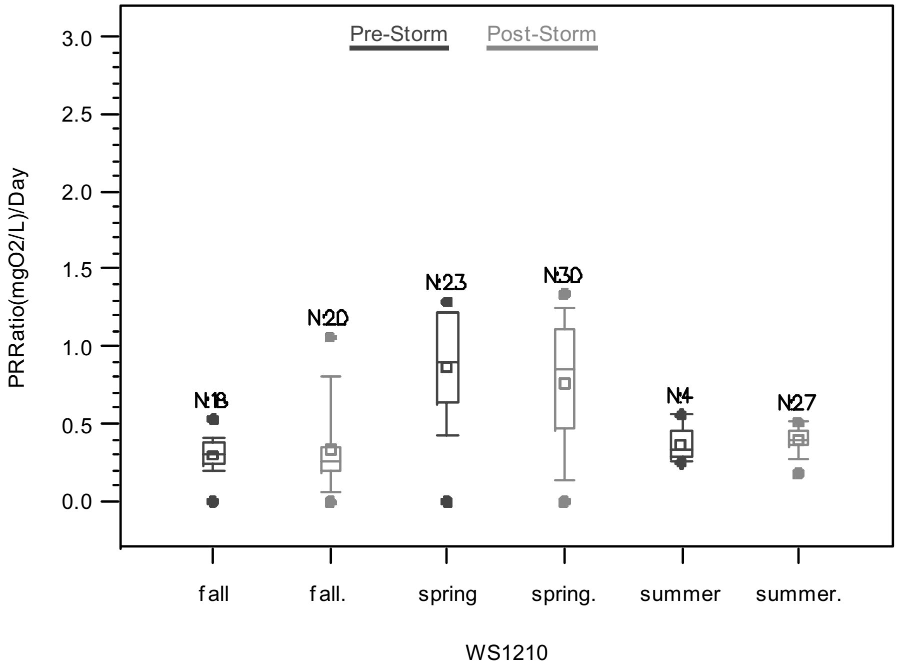
Figures K-25 Comparison of Statistical Analysis Results for "Pre" and "Post" Storm Monitoring Showing Seasonal Variations in P:R Ratios for Site WS354



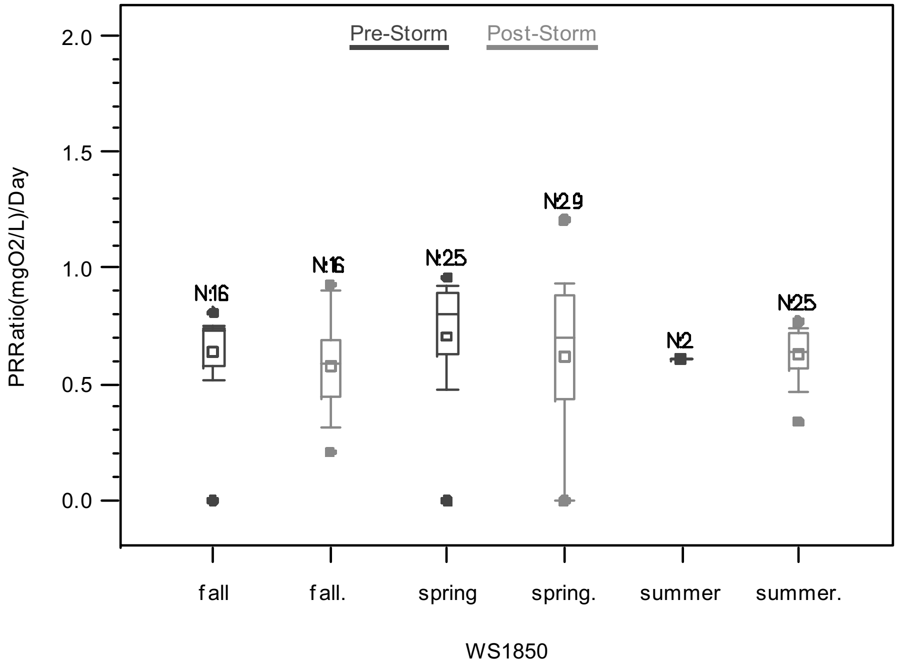
Figures K-26 Comparison of Statistical Analysis Results for "Pre" and "Post" Storm Monitoring Showing Seasonal Variations in P:R Ratios for Site WS754



Figures K-27 Comparison of Statistical Analysis Results for "Pre" and "Post" Storm Monitoring Showing Seasonal Variations in P:R Ratios for Site WS1075



Figures K-28 Comparison of Statistical Analysis Results for "Pre" and "Post" Storm Monitoring Showing Seasonal Variations in P:R Ratios for Site WS1210



Figures K-29 Comparison of Statistical Analysis Results for "Pre" and "Post" Storm Monitoring Showing Seasonal Variations in P:R Ratios for Site 1850

References:

http://permanent.access.gpo.gov/waterusgsgov/water.usgs.gov/pubs/twri/twri5a4/html/pdf.html

Britton, L.J. and Greeson, P.E. Editors, 1987, Methods For Collection and Analysis of Aquatic Biological and Microbiological Samples U.S. Geological Survey, Techniques of Water-Resources Investigations, Book 5, Chapter A4, Section 12 (B-8120-85) Diurnal oxygen-curve method for estimating primary productivity and community metabolism in streams. p. 285-290.

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 L: REFERENCES

1. Academy of Natural Sciences. 1999. Natural Lands Restoration Master Plan. Fairmount Park Commission.

2. Bartholow, J.M. 1989. Stream temperature investigations: field and analytic methods. Instream flow information paper no. 13. Biological Report 89(17). U.S. Fish and Wildlife Service, Fort Collins, Co.

3. Barbour, M. T., J. Gerritsen, B. D. Snyder and J. B. Stribling. 1999. Rapid Bioassessment Protocols for Use in Streams and Wadeable Rivers: Periphyton, Benthic Macroinvertebrates, and Fish. EPA/841/B-99-002. Office of Water, U.S. Environmental Protection Agency, Washington, DC.

4. Biggs, B. J. F. 2000. Eutrophication of streams and rivers: dissolved nutrient-chlorophyll relationships for benthic algae. Journal of the North American Benthological Society 19: 17-31.

5. Biggs, B. J. F. and M. E. Close. 1989. Periphyton biomass dynamics in a gravel bed river: the relative effect of flow and nutrients. Freshwater Biology 22: 209-231.

6. Booth, D.B. 1990. Stream-Channel Incision Following Drainage-Basin Urbanization. Water Resources Bulletin. 26(3): 407 – 417.

7. Borchardt, M. A. 1996. Nutrients. Pages 183-227 in: Algal Ecology (R. J. Stevenson, M. L. Bothwell, and R. L. Lowe, eds.), Academic Press, San Diego.

8. Borgmann, U., and W.P. Norwood. 1997. Toxicity and Accumulation of Zinc and Copper in *Hyalella azteca* exposed to metal-spiked sediments. Canadian Journal of Fisheries and Aquatic Sciences 54(5) 1046-1054.

9. Bothwell, M. L. 1988. Growth rate responses of lotic periphytic diatoms to experimental phosphorus enrichment. Canadian Journal of Fisheries and Aquatic Sciences 45: 261.-270.

10. Bothwell, M. L. 1989. Phosphorus-limited growth dynamics of lotic periphytic diatom communities: Areal biomass and cellular growth rate responses. Canadian Journal of Fisheries and Aquatic Sciences 46: 1293-1301.

11. Brower, J., J. Zar and C. VanEnde. 1990. Field and laboratory methods for general ecology. 3rd ed. WM C. Brown, Dubuque, Iowa.

12. Butler, R. L., Cooper, E. L., Crawford, J. K., Hales, D. C., Kimmel, W. G. & Wagner, C. C. 1973. Fish and food organisms in acid mine waters of Pennsylvania. U.S. Environmental Protection Agency EPA-R3-73-032.

13. Canter, L., & R. Knox, (1985) Septic Tank System Effects on Groundwater Quality. Lewis Publishers, Chelsea, MI.

14. Carrick, H.J. 2004. Using periphyton to estimate TMDL endpoints and assess impairment in an urban-suburban stream (Skippack Creek, Pennsylvania). PA Dept. Environ. Protection, Final Report, 18 p.

15. Carrick, H.J., and C.M. Godwin. 2005. TMDL endpoint estimates for an urban-suburban stream based upon in-stream periphyton assemblages Neshaminy Creek, Pennsylvania). PA Dept. Environ. Protection, Final Report, 20 p.

16. Carrick, H.J., and C.M. Godwin. 2006. TMDL endpoint estimates for an urban-suburban stream based upon in-stream periphyton assemblages (Wissahickon Creek, Pennsylvania). PA Dept. Environ. Protection, Final Report, 11 p.

17. CDM (2006) Technical Memorandum. "Wissahickon Hydrologic Model Development, Calibration, and Validation."

18. Charles, D.F., F.W. Acker, D.D. Hart, C.W. Reimer, and P.B. Cotter. 2006. Large-scale regional variation in diatom-water chemistry relationships: rivers of the eastern United States. Hydrobiologia 561:27-57.

19. Chetelat, J., F. R. Pick, A. Morin, and P. B. Hamilton. 1999. Periphyton biomass and community composition in rivers of different nutrient status. Canadian Journal of Fisheries and Aquatic Sciences 56: 560-569.

20. Clements, W.H., D.S. Cherry, and J. Cairns, Jr. 1988. The impact of heavy metals on macroinvertebrate communities: a comparison of observational and experimental results. Can. J. Fish. Aquat. Sci. 45:2017-2025.

21. Crockett, Christopher (2000). The Impact of Storm Events on *Giardia* and *Cryptosporidiu*m Occurrence. *Not yet published.*

22. Commonwealth of Pennsylvania Department of Environmental Protection. 2001. Pennsylvania Code Title 25. Environmental Protection. Chapter 16. Water Quality Toxics Management Strategy.

23. Commonwealth of Pennsylvania Department of Environmental Protection. 2001. Pennsylvania Code Title 25. Environmental Protection. Chapter 93. Water Quality Standards. 226p.

24. Commonwealth of Pennsylvania Department of Environmental Protection. 2001. Pennsylvania Code Title 25. Environmental Protection. Chapter 96. Water Qulaity Standards Implementation.

25. PA Safe Drinking Water Act. 1971. *PA Code*, Chapter 109. From http://www.pacode.com/secure/data/025/chapter109/subchapAtoc.html

26. Coughlin, R.E. and T.R. Hammer. 1973. "Environmental Study of the Wissahickon Watershed within the City of Philadelphia." A Report to the City of Philadelphia by the Regional Science Research Institute.

27. Daniels, R., K. Riva-Murray, D. Halliwell, D. Vana-Miller and M. Bilger. 2002. An Index of Biological Integrity for Northern Mid-Atlantic Slope Drainages. Transactions of American Fisheries Society. 131: 1044-1060.

28. Department of Environmental Protection, 1997a, Pennsylvania's Groundwater Quality Monitoring Network: Ambient and Fixed Station Network (FSN) Monitoring Programs, 383-3200-009 / 6/97.

29. Department of Environmental Protection. 2005. Fact Sheet: Cryptosporidium and your Water Supply.

30. Department of Environmental Protection. Drinking Water Treatment Technologies for Groundwater Systems Under the Direct Influence of Surface Water. (http://www.dep.state.pa.us/dep/DEPUTATE/Watermgt/WSM/WSM_DWM/Technol/Trt_GUDI.htm)

31. Discharge measurements at gaging stations, by T. J. Buchanan and W. P. Somers: USGS--TWRI Book 3, Chapter A8. 1969.

32. Di Toro, D.M., H.E. Allen, H.L. Bergman, J.S. Meyer, P.R. Paquin and R.C. Santore, 2001. A Biotic Ligand Model of the Acute Toxicity of Metals. I. Technical Basis, Environmental Toxicology and Chemistry. 20:2383-2396.

33. Dodds, W. K., V. H. Smith, and B. Zander. 1997. Developing nutrient targets to control benthic chlorophyll levels in streams: a case study of the Clark Fork River. Water Research 31: 1738-1750.

34. Dodds, W. K., J. R. Jones, and E. B. Welch. 1998. Suggested classification of stream trophic state: distributions of temperate stream types by chlorophyll, total nitrogen, and phosphorus. Water Research 32: 1455-1462.

35. Dodds, W. K., V. H. Smith, and K. Lohman. 2002a. Nitrogen and phosphorus relationships to benthic algal biomass in temperate streams. Canadian Journal of Fisheries and Aquatic Sciences 59: 865-874.

36. Dodds, W. K., A. J. Lopez, W. B. Bowden, S. Gregory, N. B. Grimm, S. K. Hamilton, A. E. Hershey, E. Marti, W. H. McDowell, J. L. Meyer, D. Morrall, P. J. Mulholland, B. J. Peterson, J. L. Tank, H. M. Valett, J. R. Webster, and W. Wollheim. 2002b. N uptake as a function of concentration in streams. Journal of the North American Benthological Society 21: 206-220.

37. Duncan, S. W. and D. W. Blinn. 1989. Importance of physical variables on the seasonal dynamics of epilithic algae in a highly shaded canyon stream. Journal of Phycology 25: 455-461.

38. Dutka , B.J. and K.K. Kwan. 1980. Bacterial Die-off and Stream Transport Studies. Water Research 74: 909-915.

39. Everett, A.C. and West, N. 1998. Periphyton Standing Crop and Diatom Assemblages in the Wissahickon Watershed. PADEP Internal Report.

40. Fairchild, G. W., J. W. Sherman, and F. W. Acker. 1989. The effects of nutrients (N, P, C) enrichment, grazing, and depth upon littoral periphyton of a softwater lake. Hydrobiologia 179: 69-83.

41. Fairchild, G. W. and J. W. Sherman. 1993. Algal periphyton response to acidity and nutrients in softwater lakes: Lake comparison vs. nutrient enrichment approaches. Journal of the North American Benthological Society 12: 157-167.

42. Fairmount Park Commission. 2000. "Wissahickon Creek River Conservation Plan" Retrieved from: http://www.fairmountpark.org/EcologicalRestoration.asp

43. Faulkner, G., F. Horner, and W. Simonis. 1980. The regulation of the energy-dependent phosphate uptake by the blue-green alga Anacystis nidulans. Planta 149: 138-143.

44. Federal Emergency Management Agency. "Mitigation Success: Buyouts After '96 Flood Enabled Madison Avenue to Weather Tropical Storm Allison" http://www.fema.gov/news/newsrelease.fema?id=5271

45. Ferguson, R. I., 1986: River loads underestimated by rating curves. Water Resources Research, Vol. 22, NO. 1, 74-76.

46. Food Safety and Inspection Service. Parasites and Foodborne Illness. (http://www.fsis.usda.gov/OA/pubs/parasite.htm)

47. Francouer, S. N. 2001. Meta-analysis of lotic nutrient amendment experiments: detecting and quantifying subtle responses. Journal of the North American Benthological Society 20: 358-368.

48. LaPoint, T.W., S.M.Melancan, and M.K. Morris. 1984. Relationships among Observed Metals Concentrations, Criteria, and Benthic Community Structural Responses in 15 Streams. J. Water Pollut. Control Fed. 56:1030-1038.

49. Lowe, R.L., 1974, Environmental requirements and pollution tolerance of freshwater diatoms: Cincinnati, Ohio, U.S. Environmental Protection Agency, National Environmental Research Center, Office of Research and Development, EPA-670/4-74-005, 334 p.

50. Gerba, C.P. 1976. Effect of Sediments on the Survival of Escherichia coli in Marine Waters. Appl. Environ. Microbiol. 32: 114.

51. Gerhardt, A. 1994. Short term toxicity of iron (Fe) and lead (Pb) to the mayfly *Leptophlebia marginata* (L.) (Insecta) in relation to freshwater acidification. Hydrobiologia 284 (2): 157-168.

52. Goldman, J. C. 1979. Temperature effects on steady-state growth, phosphorus uptake, and the chemical composition of a marine phytoplankter. Microbial Ecology 5: 153-166.

53. Eaton, A.D., L.S. Clesceri, E.W. Rice, and A.E. Greenberg (eds). 2005. Standard methods for the examination of water and wastewater (21st edition). American Public Health Association, Washington, D.C.

54. Grimm, N. B. and S. G. Fisher. 1986. Nitrogen limitation in a Sonoran Desert stream. Journal of the North American Benthological Society 5: 2-15.

55. Halliwell, D. B., R. W. Langdon, R. A., J. P. Kurtenbach, and R. A. Jacobson. 1999. Classification of freshwater fish species of the northeastern United States for use in the development of IBIs. pp. 301-337 in T. P. Simon (ed.). Assessing the sustainability and biological integrity of water resources using fish communities. CRC Press, Boca Raton, Florida.

56. Hammer, T.R. 1972. Stream Channel Enlargement Due to Urbanization. Water Resources Research 8(6): 1530 – 1540.

57. Heritage Conservancy. Riparian Buffer Assessment of Southeastern Pennsylvania. Retrieved from: http://www.heritageconservancy.org/news/download.php

58. Hill, W. R. and A. W. Knight. 1988a. Nutrient and light limitation of algae in two northern California streams. Journal of Phycology 24: 125-132.

59. Hill, W.R. and A.W. Knight. 1988b. Concurrent grazing effects of two stream insects on periphyton. Limnology and Oceanography. 33:15-26.

60. Horner, R. R., E. B. Welch, and R. B. Veenstra. 1983. Development of nuisance periphytic algae in laboratory streams in relation to enrichment and velocity. Pages 121-134 in: Periphyton of Freshwater Ecosystems (R. G. Wetzel, ed.). Dr. W. Junk Publishers, The Hague.

61. Jenkins, R.E. and N.M. Burkhead. 1994. Freshwater fishes of Virginia. American Fisheries Society, Bethesda, Maryland. 1079 pp.

62. Jones, J. R., M. M. Smart, and J. N. Burroughs. 1984. Factors related to algal biomass in Missouri Ozark streams. Verh. Int. Ver. Limnol (International Association of Theoretical and Applied Limnology) 22: 1867-1875.

63. Karr, J. R. 1981. Assessment of biotic integrity using fish communities. Fisheries 66: 21-27.

64. Karr, J.R., K.D. Fausch, P.L. Angermeier, P.R. Yant, and J. Schlosser. 1986. Assessing biological integrity in running waters: A method and its rationale. Special publication 5. Illinois Natural History Survey.

65. Kemp, M. J. and W. K. Dodds. 2002. The influence of ammonium, nitrate, and dissolved oxygen concentrations on uptake, nitrification, and denitrification rates associated with prairie stream substrata. Limnology and Oceanography 47: 1380-1393.

66. Kjeldsen, K. 1994. The relationship between phosphorus and peak biomass of benthic algae in small lowland streams. Verh. Int. Ver. Limnol. Limnol (International Association of Theoretical and Applied Limnology) 25: 1530-1533.

67. Klausen, Cecilie, Nicolaisen, Mette H., Strobel, Bjarne W., Warnecke, Falk, Nielsen, Jeppe L. & Jørgensen, Niels O.G. (2005) Abundance of actinobacteria and production of geosmin and 2-methylisoborneol in Danish streams and fish ponds. *FEMS Microbiology Ecology* **52** (2), 265-278.

68. Klein, M., 1984: Anti clockwise hysteresis in suspended sediment concentration during individual storms. Catena, 11, 251-257.

69. Kugel, J, Dalbey, D., Reese, A., Godshall, S., and McGovern, K. 2006. "Drowning Office Park Rescued by Students During High Tide" The New Planner. Retrieved from: http://www.planning.org/thenewplanner/nonmember/default1.htm

70. Lohman, K., J. R. Jones, and C. Baysinger-Daniel. 1991. Experimental evidence for nitrogen limitation in a northern Ozark stream. Journal of the North American Benthological Society 19: 14-23.

71. Lohman, K., J. R. Jones, and B. D. Perkins. 1992. Effects of nutrient enrichment and flood frequency on periphyton biomass in northern Ozark streams. Canadian Journal of Fisheries and Aquatic Sciences 49: 1198-1205.

72. Martens, Gary. May 27, 2005 CDM/OOW Memorandum. "Long Term Historical Precipitation Analysis and Determination of a Recent Representative Short-term Period."

73. McHarg, I. 1969. Design with Nature. Natural History Press: Garden City, N.Y., pp.31-41.

74. Metcalf and Eddy, Inc. (1979) Wastewater Engineering: Treatment, Disposal, Reuse. McGraw-Hill, New York.

75. Montgomery County Planning Commission (2005) *Water Resources Plan, Shaping Our Future: A Comprehensive Plan for Montgomery County.*

76. Morel, F.M.M. and J.G. Hering. 1993. Principles and Applications of Aquatic Chemistry. John Wiley and Sons, New York.

77. Morin, A. and A. Cattaneo. 1992. Factors affecting sampling variability of freshwater periphyton and the power of periphyton studies. Canadian Journal of Fisheries and Aquatic Sciences 49: 1695-1703.

78. Odum, H. T. 1956. Primary production in flowing waters. Limnology and Oceanography 1: 102-117.

79. Ohio EPA. 1987. Biological criteria for the protection of aquatic life: volumes I-III. Ohio Environmental Protection Agency, Columbus, Ohio.

80. Ongley, E. Sediment measures. Chapter 13 in Water Quality Monitoring - A Practical Guide to the Design and Implementation of Freshwater Quality Studies and Monitoring Programmes Edited by Jamie Bartram and Richard Ballance Published on behalf of United Nations Environment Programme and the World Health Organization © 1996 UNEP/WHO

81. Paquin, Paul, R. Santore and R. Mathew. 2005. Biotic Ligand Model (BLM) Version 2.1.2 User's Guide and Reference Manual. Hydroqual Inc.

82. Peterson, C. G. and N. B. Grimm. 1992. Temporal variation in enrichment effects during periphyton succession in a nitrogen-limited desert stream ecosystem. Journal of the North American Benthological Society11: 20-36.

83. Philadelphia Water Department. 2004. Tookany-Tacony/Frankford Watershed Comprehensive Characterization Report.

84. Philadelphia Water Department (1998) Internal PWD Memorandum. "Summary of Dye Tracer Studies to Determine Wissahickon Creek Influence on Queen Lane WTP Intake: BLS Perspective."

85. Philadelphia Water Department, 2005, "Defective Lateral Connections Status Report" (Covering Period from January 1, 2005 to March 31, 2005)," City of Philadelphia.

86. Philadelphia Water Department Office of Watersheds. 2006. Monoshone Creek Project Implementation and Water Quality Assessment 1999-2006.

87. Pitt, R., Alex Maestre, Renee Morguecho, Ted Brown, Tom Schueler, Karen Cappiella, Paul Sturm, & Chris Swann. (2004) Research Progress Report: Findings from the National Stormwater Quality Database (NSQD). University of Alabama, Tuscaloosa, Alabama & Center for Watershed Protection, Ellicott City, Maryland.

88. Plafkin, J. L., M. T. Barbour, K. D. Porter, S. K. Gross, and R. M. Hughes. 1989. Rapid Bioassessment Protocols for Use in Streams and Rivers: Benthic Macroinvertebrates and Fish. EPA/440/4-89-001. Office of Water, U.S. Environmental Protection Agency, Washington, DC.

89. Potapova, M.G., D.F. Charles, K.C. Ponader, and D.M. Winter. 2004. Quantifying species indicator values for trophic diatom indices: a comparison of approaches. Hydrobiologia, 517: 25-41.

90. Pringle, C. M. 1987. Effects of water and substratum nutrient supplies on lotic periphyton growth: An integrated bioassay. Canadian Journal of Fisheries and Aquatic Sciences 44: 619-629.

91. Redfield, A. C. 1958. The biological control of chemical factors in the environment. American Scientist 46: 205-222.

92. Reese, S.O. (1998) Summary of Groundwater Quality Monitoring Data (1985 - 1997) from Pennsylvania's Ambient and Fixed Station Network (FSN) Monitoring Program: Selected

Groundwater Basins in Southwestern, Southcentral and Southeastern Pennsylvania. PADEP Document No.: 3800-BK-DEP2246, http://www.dep.state.pa.us.

93. Regional Science Research Institute (1973) "Analysis and Findings." *Environmental Study of the Wissahickon Watershed within the City of Philadelphia.*

94. Reynolds, C. S. 1988. Potamoplankton: paradigms, paradoxes, and prognoses. Pages 285-311 in Algae and the aquatic environment (R. E. Round, ed), Biopress, Ltd., Bristol.

95. Rhee, G. Y. and I. J. Gotham. 1981a. The effect of environmental factors on phytoplankton growth: Temperature and the interactions of temperature with nutrient limitation. Limnology and Oceanography 26: 635-648.

96. Rhee, G. Y. and I. J. Gotham. 1981b. The effect of environmental factors on phytoplankton growth: Light and the interactions of light with nitrate limitation. Limnology and Oceanography 26: 649-659.

97. Rosemarin, A. S. 1982. Phosphorus nutrition of two potentially competing filamentous algae, Cladophora glomerata (L.) Kutz and Stigeoclonium tenue (Agardh) Kutz. From Lake Ontario. Journal of Great Lakes Research 8: 66-72.

98. Rosen, J.S., Sobrinho, J.A.H., Campbell, J., and Hargy, T. (2006, July 20). 2001-2006 Protozoa Data Analysis for Philadelphia Water Department. *Report Prepared for the Philadelphia Water Department by Clancy Environmental Consultants, Inc.*

99. Rosgen, Dave. Applied River Morphology. Colorado: Wildland Hydrology, 1996.

100. Schrader, KK; Blevins, WT.1993. Geosmin-producing species of Streptomyces and Lyngbya from aquaculture ponds Canadian Journal of Microbiology/Revue Canadienne de Microbiologie [CAN. J. MICROBIOL./REV. CAN. MICROBIOL.]. Vol. 39, no. 9, pp. 834-840. 1993.

101. Sloto R. (2004) *Geohydrology of the French Creek basin and simulated effects of drought and ground-water withdrawals, Chester County, Pennsylvania.* USGS Dept. of the Interior, New Cumberland, PA. Water Resources Investigation Report: 03-4263.

102. Sloto R. (2005) *Water Budgets for Selected Watersheds in the Delaware River Basin, eastern Pennsylvania and western New Jersey.* USGS Scientific Investigation Report 2005-5113, p 15-19.

103. Sloto, R. & Michèle Y. Crouse. (1996) *HYSEP: A Computer Program for Streamflow Hydrograph Separation and Analysis.* United States Geological Survey (USGS) WRIR: 96-4040, http://pa.water.usgs.gov/reports/wrir96-4040.pdf.

104. Smullen, J.T., A.L. Shallcross, & K.A. Cave. (1999) "Updating the U.S. Nationwide Urban Runoff Quality Database." Water Science and Technology. Vol. 39, No. 12, p 9-16.

105. Stark, K. "Creeks mix in the foul with the fish".Philadelphia Inquirer, 4/13/1993

106. Assessing environmental conditions in rivers and streams with diatoms Stevenson, RJ; Pan, Y The Diatoms: Applications for the Environmental and Earth Sciences. pp. 11-40. 1999.

107. Sutcliff, D.W., and T.R. Carrick. 1973. Studies on Mountain Streams in the English lake District. I. pH, Calcium, and the Distribution of Invertebrates in the River Duddon. Freshwater Biol. 3: 437-462

108. Discharge measurements at gaging stations, by T. J. Buchanan and W. P. Somers: USGS--TWRI Book 3, Chapter A8.

109. Tellus Institute (2004) Development of a Water Budget for the Wissahickon Creek Watershed, Southeastern Pennsylvania. AwwaRF project 2853 Decision Support System for Sustainable Water Supply Planning, p 16-24.

110. Trial, J.G., C.S. Wade, J.G. Stanley, and P.C. Nelson. 1983. Habitat Suitability Information: Common Shiner. U.S. Dept. Int., Fish Wildlife Serv. FWS/OBS-82/10.40. 22pp.

111. Trial, J.G., C.S. Wade, J.G. Stanley, and P.C. Nelson. 1983. Habitat Suitability Information: Fallfish. U.S. Dept. Int., Fish Wildlife Serv. FWS/OBS-82/10.48. 15pp.

112. Triska, F. J., V. C. Kennedy, R. J. Avanzino, and B. N. Reilly. 1983. Effect of simulated canopy cover on regulation of nitrate uptake and primary production by natural periphyton communities. Pages 129-159 in Dynamics of lotic ecosystems (T. D. Fontaine and S. M. Bartell, eds.), Ann Arbor Scientific Publisher, Ann Arbor, MI.

113. United States Environmental Protection Agency. 2000. Ambient Water Quality Criteria Recommendations: Rivers and Streams in Nutrient Ecoregion IX. EPA 822-B-00-019. Office of Water, U.S. Environmental Protection Agency, Washington D.C.

114. United States Environmental Protection Agency. Drinking Water Priority Rulemaking: Microbial and Disinfection Byproduct Rules. (http://www.epa.gov/ogwdw/mdbp/mdbp.html)

115. United States Environmental Protection Agency (USEPA). (2004) Local Limits Development Guidance Appendices. EPA Document No.: 833R04002B, http://www.epa.gov/npdes/pubs/final_local_limits_appendices.pdf.

116. United States Environmental Protection Agency. 2003a. Modeling Report for Wissahickon Creek, Pennsylvania Siltation TMDL Development, U.S. EPA Region 3, Philadelphia, PA, pp 13-16.

117. United States Environmental Protection Agency. 2003b. Total Maximum Daily Load For Sediment and Nutrients Wissahickon Creek Watershed.

118. United States Environmental Protection Agency. 2003c. Modeling Report for Wissahickon Creek, Pennsylvania Nutrient TMDL Development.

119. United States Environmental Protection Agency. 2002. Data Review for Wissahickon Creek, Pennsylvania, U.S. Environmental Protection Agency Region 3, Philadelphia, PA.

120. United States Environmental Protection Agency. 2000. Ambient Water Quality Criteria Recommendations: Rivers and Streams in Nutrient Ecoregion IX. EPA 822-B-00-019. Office of Water, U.S. Environmental Protection Agency, Washington, DC.

121. Environmental Protection Agency (2002, January 14). National Primary Drinking Water Regulations: Long Term 1 Enhanced Surface Water Treatment Rule. *Federal Register*, Volume 67, Number 9, pp. 1811-1844. Retrieved from http://www.epa.gov/safewater/mdbp/lt1eswtr.html

122. Environmental Protection Agency (2006, January 5). National Primary Drinking Water Regulations: Long Term 2 Enhanced Surface Water Treatment Rule. *Federal Register,* Volume 71, Number 3, pp. 653-786. Retrieved from http://www.epa.gov/safewater/disinfection/lt2/regulations.html

123. United States Environmental Protection Agency (USEPA). (2006) Data Quality Assessment: Statistical Methods for Practitioners (EPA QA/G-9S). EPA Document No.: EPA/240/B-06/003, http://www.epa.gov/quality/qs-docs/g9s-final.pdf.

124. Van Donsel, D.J., Geldreich, E.D., and N.A. Clarke. 1967. "Seasonal Variations in Survival of Indicator Bacteria in Soil and their Contribution to Stormwater Pollution." Appl Microbiol 15, 1362-1370 (1967).

125. van Donk, E. and S. S. Kilham. 1990. Temperature effects on silicon- and phosphorus-limited growth and competitive interactions among three diatoms. Journal of Phycology 26: 40-50.

126. Vannote, R. L., G. W. Minshall, K. W. Cummins, J. R. Sedell, and C. E. Cushing. 1980. The river continuum concept. Can. J. Fish. Aquat. Sci. 37:130-137.

127. Van Sickle, J., Beschta, R. L., 1983: Supply-based models of suspended sediment transport in streams. Water Resources Research, 19, 768-778.

128. Welch, E. B., J. M. Jacoby, R. R. Horner, and M. R. Seeley. 1988. Nuisance biomass levels of periphytic algae in streams. Hydrobiologia 157: 161-168.

129. Warnick, S.L., and H.L. Bell. 1969. The Acute Toxicity of some Heavy Metals to different Species of Aquatic Insects. J. Water Pollut. Control Fed. 41:280-284.

130. Wetzel, R. G. 2001. Limnology: Lake and River Ecosystems, 3rd Edition. Academic Press, San Diego, 1006 pg.

131. Winterbourn, M. J. 1990. Interactions among nutrients, algae, and invertebrates in a New Zealand mountain stream. Freshwater Biology 23: 463-474.

132. Wurtz, C. B. and B.G. Nicholas, A Biological Survey of the Wissahickon Creek. Proceedings of the Pennsylvania Academy of Science, pages 82-88. Vol. XXXIX, 1965

133. Wynne, D. and G.-Y. Rhee. 1986. Effects of light intensity and quality on the relative N and P requirement (the optimum N:P ratio) of marine phytoplanktonic algae. Journal of Plankton Research 8: 91-108.

134. Wynne, D. and G.-Y. Rhee. 1988. Changes in alkaline phosphotase activity and phosphate uptake in P-limited phytoplankton, induced by light intensity and spectral quality. Hydrobiologia 160: 173-178.

APPENDIX M: 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 (NH_3) 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/ 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
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/	describes the uses a waterbody is intended to support, such as stocking

Designated Use	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 Index (HBI)	A biological index of stream health that employs a scale of sensitivity of 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.
LD_{50}	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 (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
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
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