Philadelphia Combined Sewer Overflow Long Term Control Plan Update

Supplemental Documentation
Volume 14

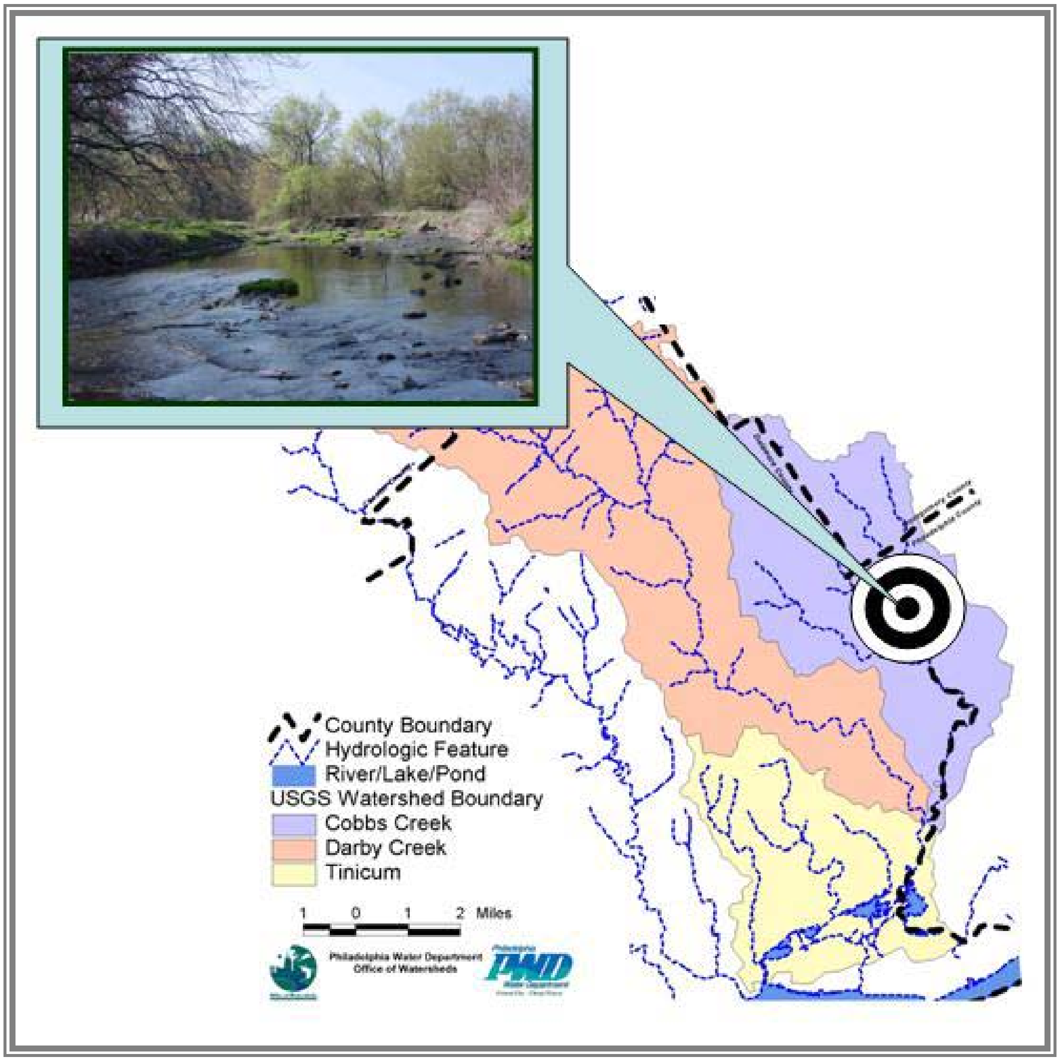
Darby-Cobbs Watershed Comprehensive Characterization Report

Updated: September 1, 2009

Darby-Cobbs Watershed Comprehensive Characterization

Technical Companion to the Cobbs Creek Integrated Watershed Management Plan

Updated June 2004 (includes data collected through December 2002)



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Section 1 Introduction

To meet the regulatory requirements and long-term goals of its CSO, stormwater, and drinking water source protection programs, The Philadelphia Water Department (PWD) has embraced a comprehensive watershed characterization, planning, and management program. Watershed management fosters the coordinated implementation of programs to control sources of pollution, reduce polluted runoff, and foster managed growth in the city and surrounding areas, while protecting the region’s drinking water supplies, fishing and other recreational activities, and preserving sensitive natural resources such as parks and streams. PWD has helped form watershed partnerships including surrounding urban and suburban communities to explore regional cooperation based on an understanding of the impact of land use and human activities on water quality.

Coordination of these different programs has been greatly facilitated by PWD's recent creation of the Office of Watersheds (OOW). This newly formed organization is composed of staff from the PWD's planning and research, CSO, collector systems, laboratory services, and other key functional groups, allowing the newly established organization to combine resources to realize the common goal of watershed protection. OOW is responsible for characterization and analysis of existing conditions in local watersheds to provide a basis for long-term watershed planning and management.

OOW is developing a series of watershed management programs on each of its watersheds. Cobbs Creek is the first watershed to complete a management plan. This report contains a series of technical documents that form the technical basis for the Cobbs Creek Integrated Watershed Management Plan (CCIWMP), released in 2004. The report characterizes the land use, geology, soils, topography, demographics, meteorology, hydrology, water quality, ecology, fluvial geomorphology, and pollutant loads found in the Darby-Cobbs Creek watershed. It presents and discusses data collected through the end of 2002. The report is not intended as a single, comprehensive document, but rather a compilation of background documents that can be periodically updated as additional field work or data analysis is completed. The sections of the report were written at different times by a variety of groups, and no attempt at consistency in style or formatting has been made. Some sections of the report, including wetlands and fluvial geomorphology, are incorporated by reference to other reports.

Section 2 Characterization of the Study Area

2.1 Watershed Description and Demographics

The Darby-Cobbs watershed is defined as the land area that drains to the mouth of Darby Creek at the Delaware Estuary, encompassing approximately 80 square miles in southeastern Pennsylvania. This area includes portions of Chester, Delaware, Montgomery, and Philadelphia Counties. The watershed may be subdivided into the Cobbs Creek, Darby Creek, and Tinicum subwatersheds. Figures 2-1 and 2-2 include the watershed boundaries, hydrologic features, and political boundaries. Much of the information is based on the U.S. Census Bureau's TIGER (Topologically Integrated Geographic Encoding and Referencing) database.

Cobbs Creek drains approximately 14,500 acres or 27% of the total watershed area. The upper portions and headwaters of Cobbs Creek, including East and West Branch Indian Creek, include portions of Philadelphia, Montgomery, and Delaware Counties. The lower portion of Cobbs Creek watershed, including the lower mainstem and Naylors Run, drains parts of Philadelphia and Delaware Counties. Cobbs Creek discharges to Darby Creek.

The Darby Creek watershed drains approximately 29,000 acres or 55% of the total study area. The watershed is located primarily in Delaware County. The northwest corner of the watershed, including the headwaters of the mainstem, is located in Chester County. Darby Creek has a number of small tributaries, including Little Darby Creek, Ithan Creek, and Foxes Run.

The Darby-Cobbs watershed discharges to the Delaware River through the wetlands of the Tinicum Refuge. The Tinicum watershed includes portions of Philadelphia and Delaware Counties and totals 9800 acres or 18% of the total. Much of the area consists of low-lying wetlands, including the John Heinz National Wildlife Refuge. Named streams in the subwatershed include Hermesprota, Muckinipattis, and Stony Creeks.

In a relatively undisturbed watershed, watershed boundaries follow topographic high points or contours. The U.S. Geological Survey (USGS) has further subdivided the Darby-Cobbs watershed based on topography, as shown in Figure 2-3. These USGS subwatersheds are determined from the land area draining to a particular point of interest, such as a stream confluence or gauging site. These boundaries allow initial determinations of drainage areas and modeling elements. However, it is important in the urban environment to include the effects of man-made changes to natural drainage patterns.

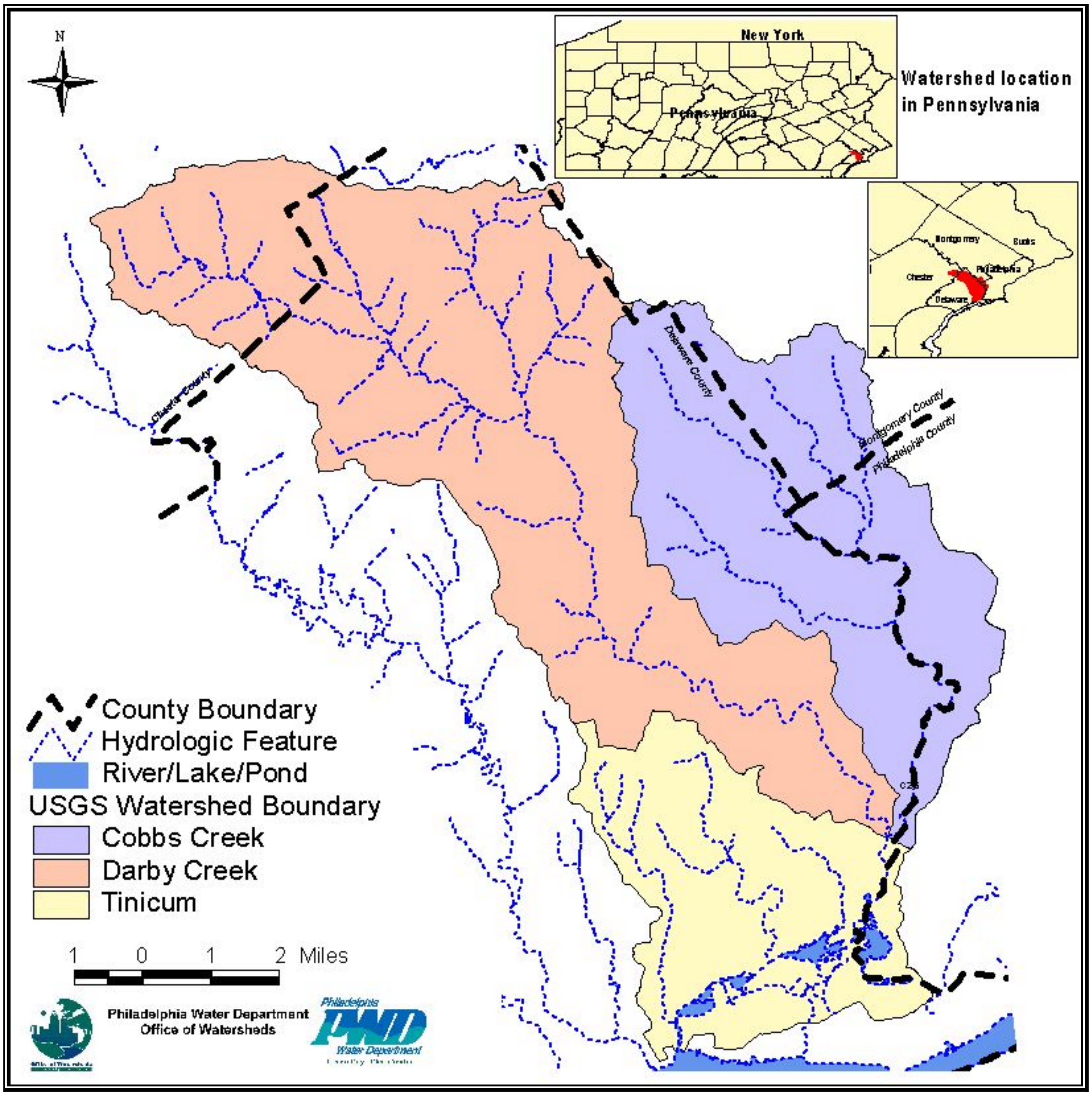


Figure 2-1 Darby-Cobbs Study Watershed

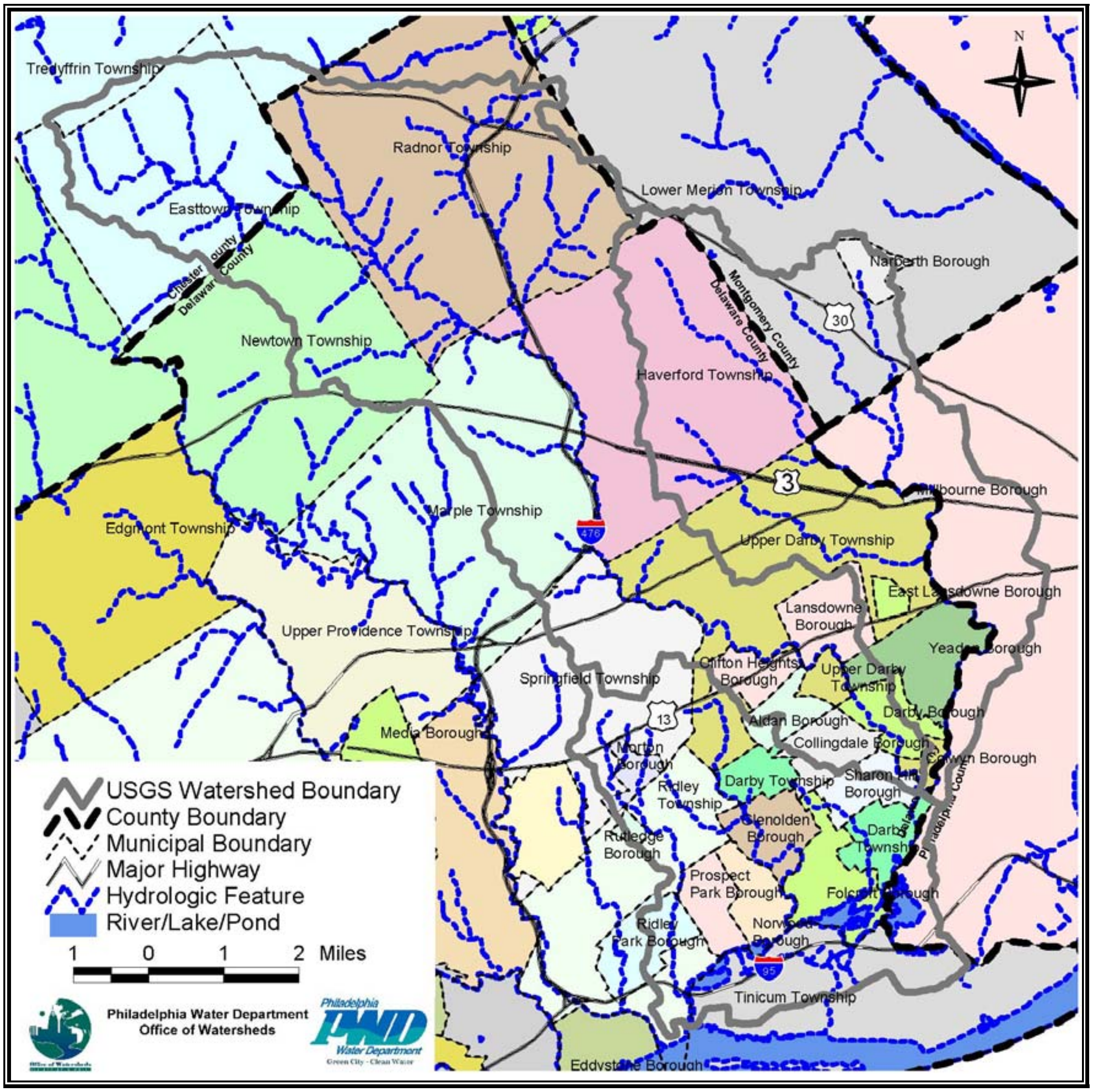


Figure 2-2 Darby-Cobbs Study Area

Geology and Soils

Geology and soils play a role in the hydrology, water quality, and ecology of a watershed. The Darby-Cobbs watershed falls within the Coastal Plain and Piedmont physiographic provinces. Geologic formations on the surface in the area include gneiss, schist, and serpentine formations in most of the watershed (Piedmont) and layers of sediment in the downstream reaches (Coastal Plain) as shown in Figure 2-4. Soils in the upper portions of the Darby Creek subwatershed include loams and silty loams, as shown in Figure 2-5. Soil in much of the rest of the watershed is classified as urban or made land and is not representative of the original undisturbed soil. Wetland soils are present in the Tinicum area.

Demographic Information

Population density and other demographic information in the watershed are available from the results of the 2000 census. Approximately 500,000 people live within the drainage area of the Darby and Cobbs Creeks. Figure 2-6 shows the population density in the watershed at the census block level. Spatial trends in population correspond closely to land use, with multi-family row homes displaying the greatest population density of 20 people per acre or more, single-family homes displaying a lower density, and other land use types displaying the lowest density. In addition to population data, the U.S. Census Bureau provides a range of socioeconomic data that are often useful in watershed planning and general planning studies. Median household income and mean home value (Figures 2-7 and 2-8) are two of the many sample datasets provided.

Figure 2-3 USGS Topographic Subwatersheds

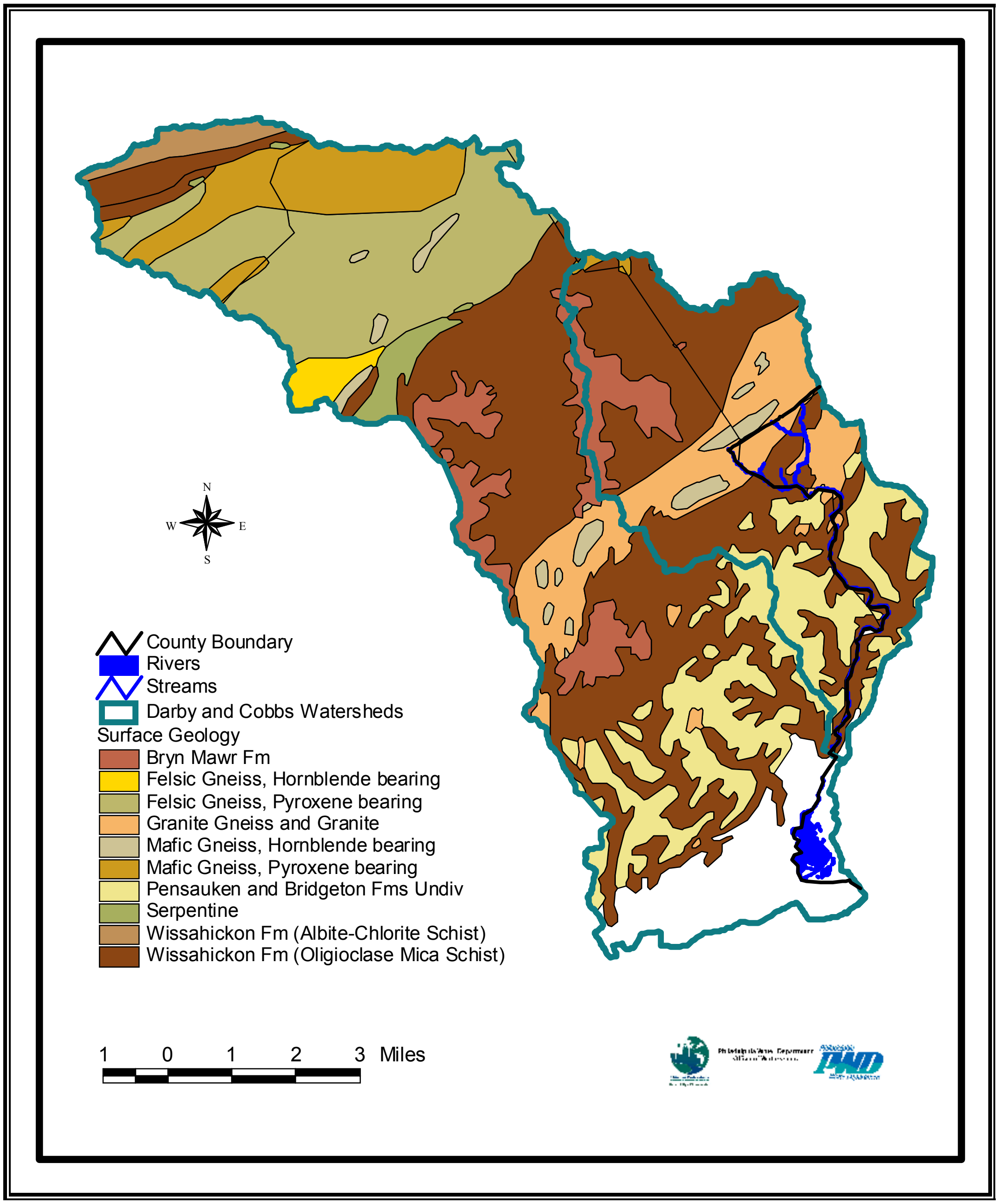


Figure 2-4 Surface Geologic Formations

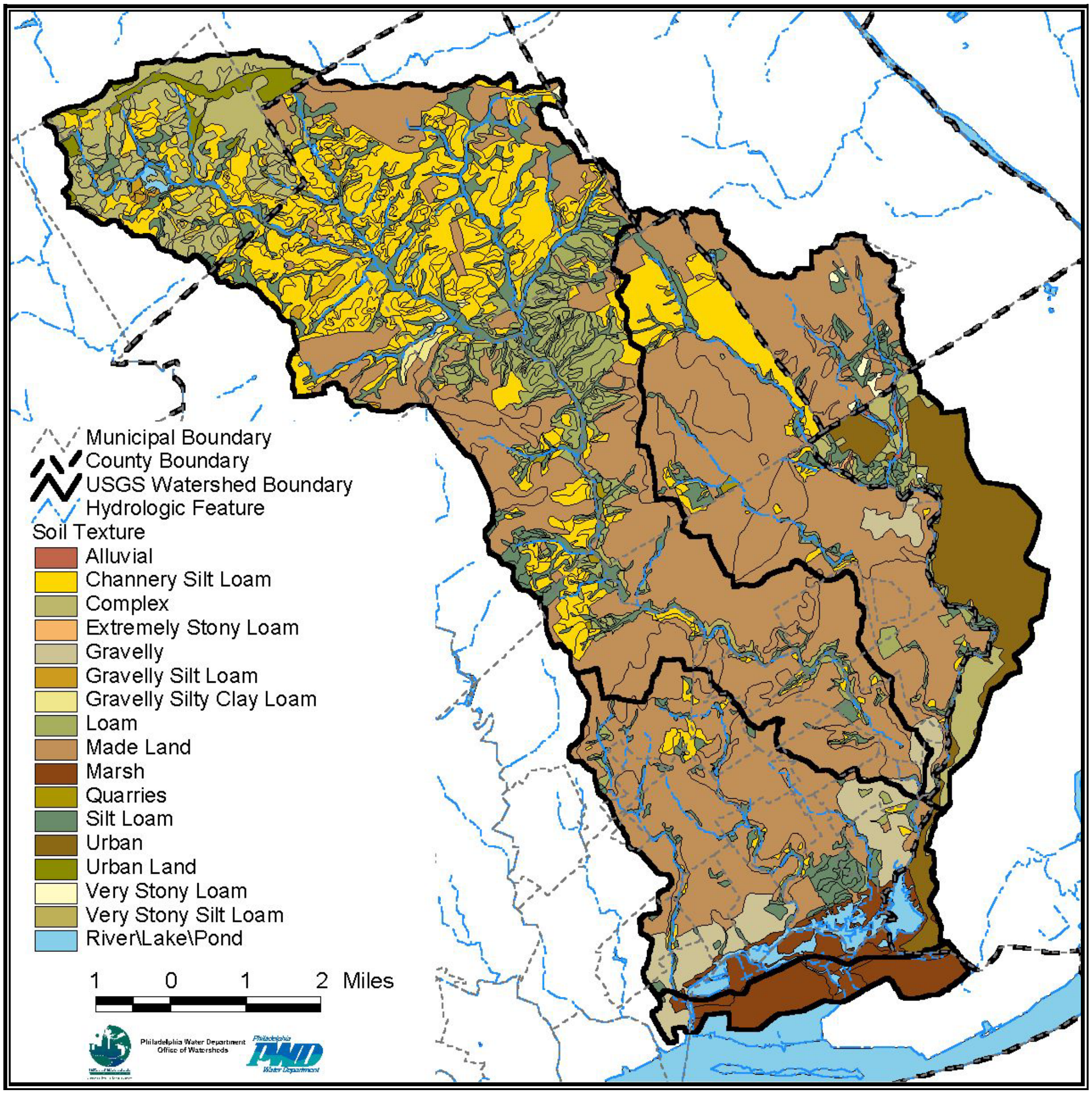


Figure 2-5 Soil Types in the Darby-Cobbs Watershed

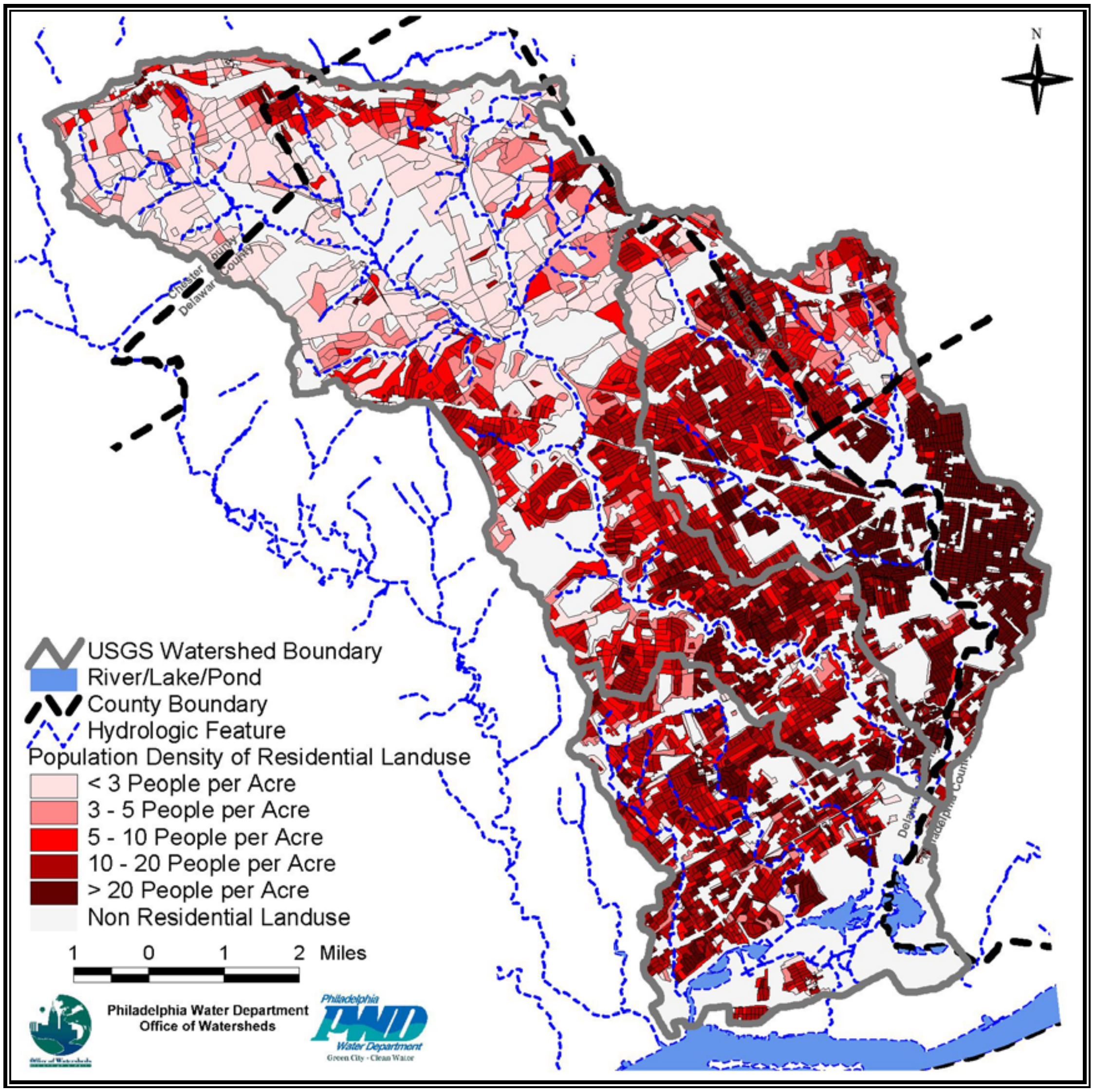


Figure 2-6 Population Density Based on 2000 Census Data

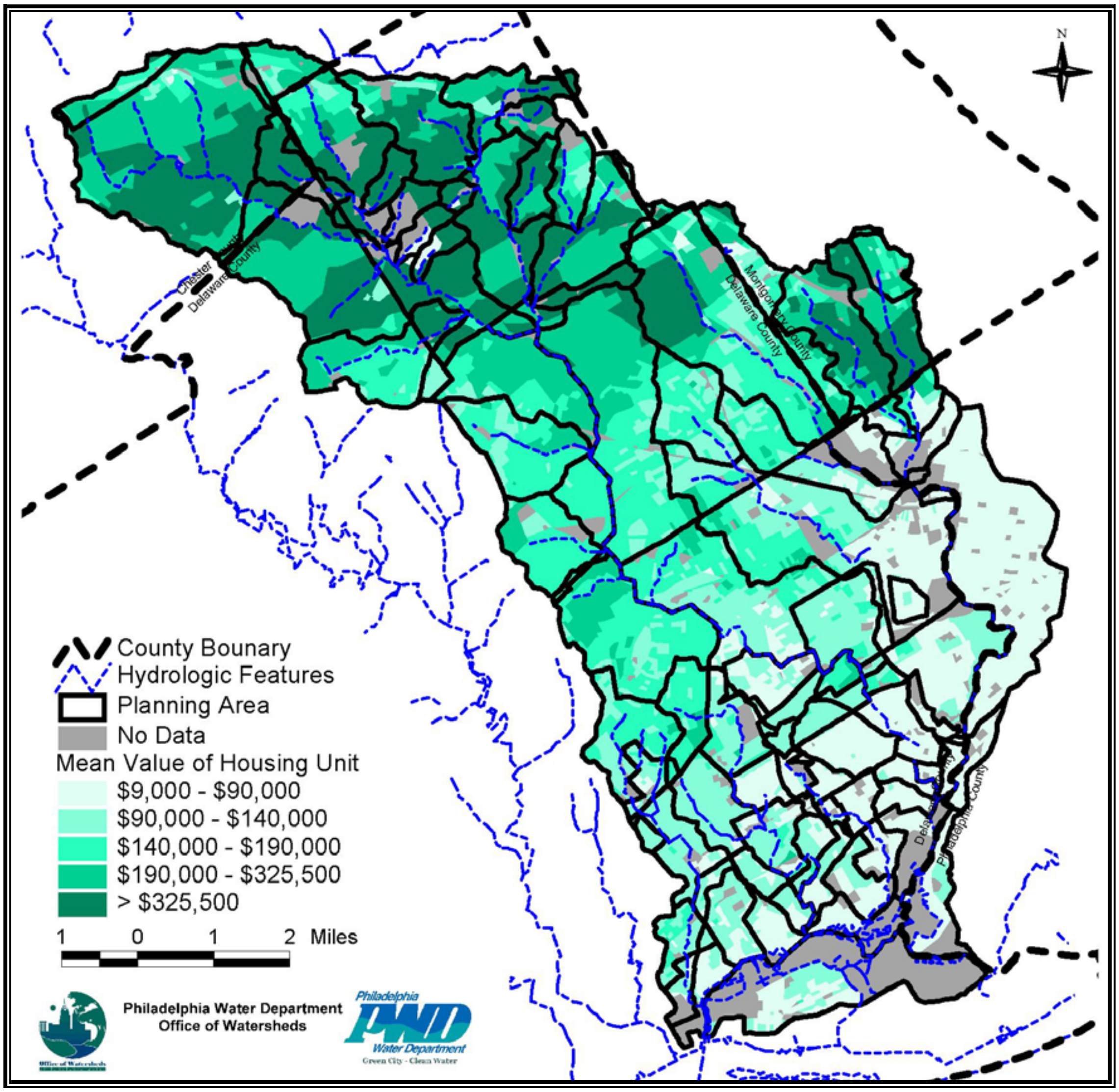


Figure 2-7 Mean Home Value

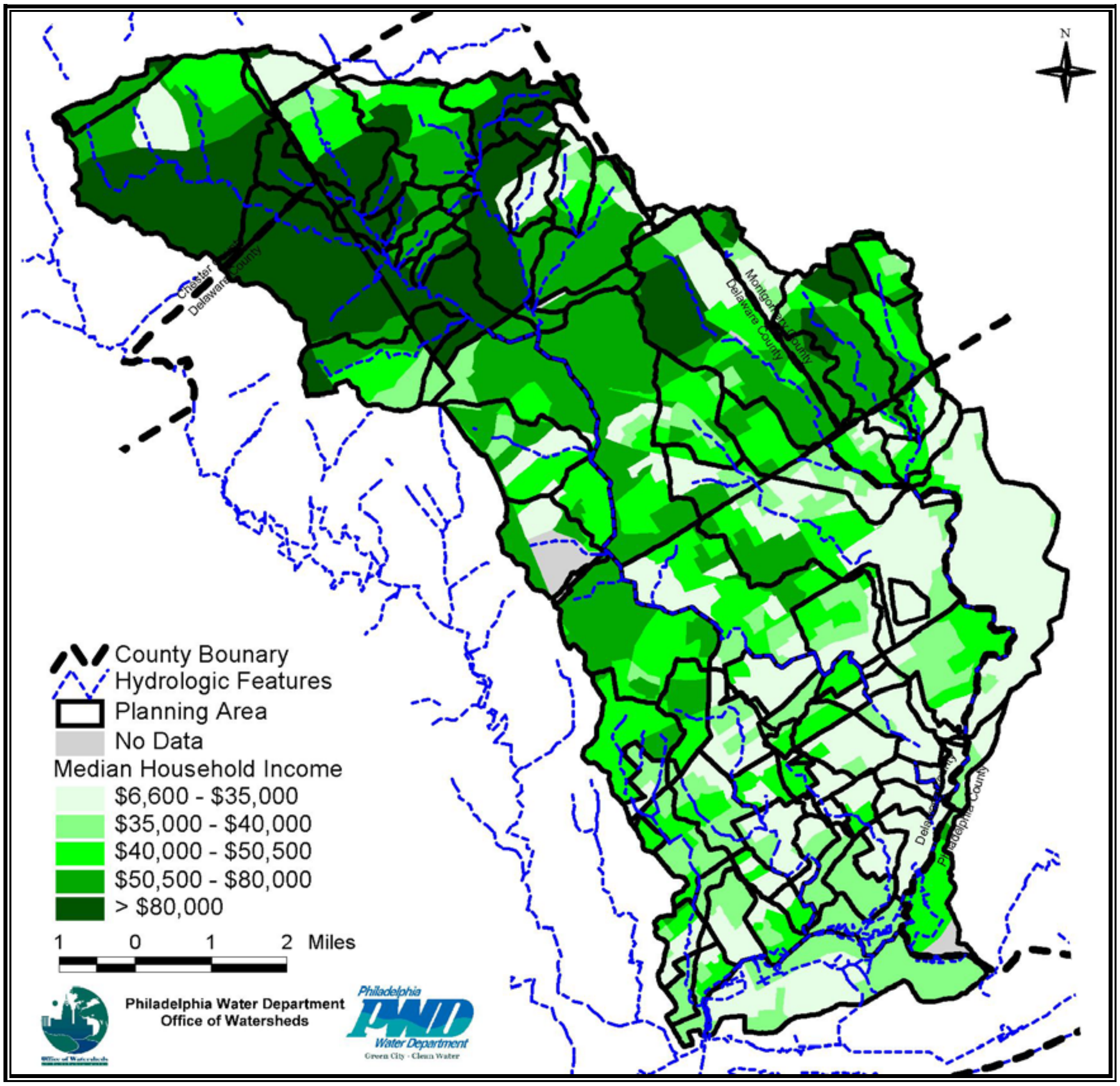


Figure 2-8 Mean Household Income

2.2 Land Use

Land use information for the Darby and Cobbs Creeks Watershed was obtained from the Delaware Valley Regional Planning Commission (DVRPC). Figure 2-9 is the current land use map for the study area. The upper reaches and headwaters of the Cobbs Creek watershed are characterized primarily by a mix of multiple-family and detached single-family residential areas. The lower portions of the Cobbs Creek watershed are primarily high-density residential areas in the City of Philadelphia and a mix of high- and low-density residential areas in the Delaware County portion, with commercial areas along highway corridors. Riparian lands within the City consist mainly of relatively undisturbed parkland.

Land uses in the Darby Creek watershed consist primarily of single- and multiple-family residential areas in the lower portions and a combination of single-family residential, commercial, park land, and golf course uses in the upper reaches. A large commercial area is located along the northern edge of the watershed in Chester and Delaware Counties. The Tinicum watershed consists of residential and commercial development to the northwest and undeveloped wetlands and marshes to the southeast.

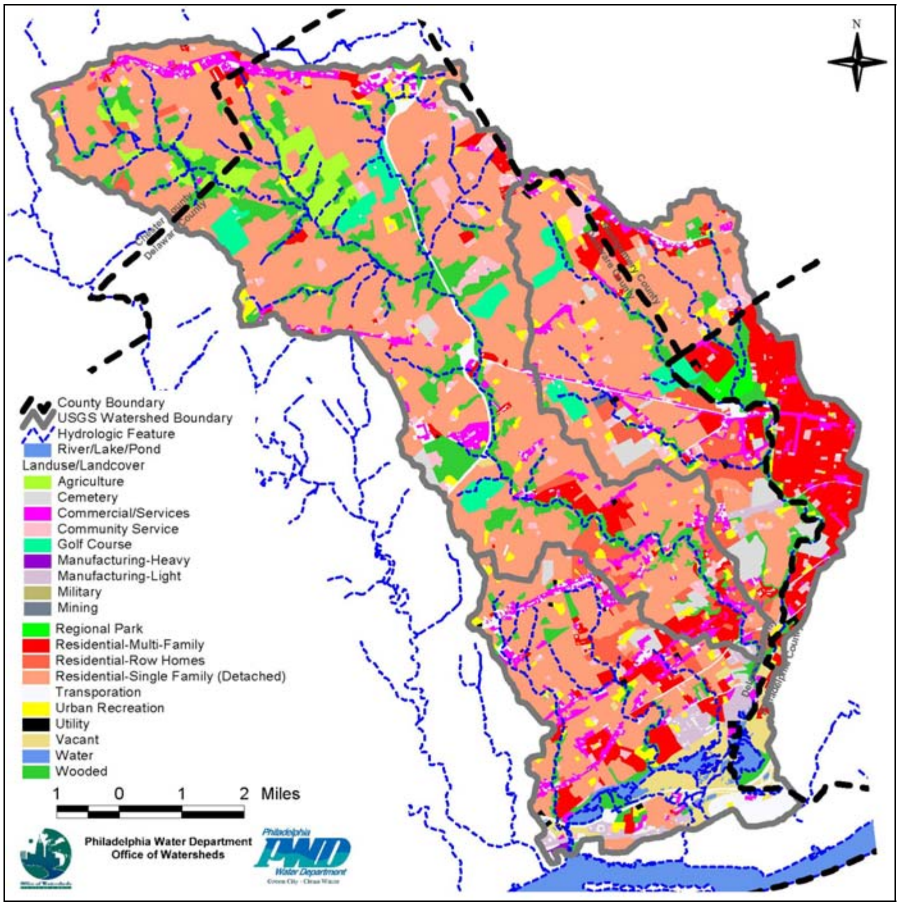


Figure 2-9 Land Use

One of the primary indicators of watershed "health" is the percent of impervious cover in the watershed. Based on numerous research efforts, studies and observations, a general categorization of watersheds has been widely applied to watershed management based on percent impervious cover (Schueler 1995). These are summarized in Table 2-1. Table 2-2 shows that the entire watershed is above 25% impervious cover, placing it in the "Non-Supporting" category of stream health.

Table 2-1 Impervious Cover as an Indicator of Stream Health (Schueler 1995)

Characteristic	Sensitive	Degrading	Non-Supporting
Percent Impervious Cover	0% to 10%	11% to 25%	26% to 100%
Channel Stability	Stable	Unstable	Highly Unstable
Water Quality	Good to Excellent	Fair to Good	Fair to Poor
Stream Biodiversity	Good to Excellent	Fair to Good	Poor
Pollutants of Concern	Sediment and temperature only	Also nutrients and metals	Also bacteria

Table 2-2 Estimated Total Impervious Cover

Watershed	County	Area (ac)	% Impervious
Cobbs	Delaware	8,041	46.7%
Cobbs	Montgomery	2,644	40.6%
Cobbs	Philadelphia	3,562	60.2%
Darby	Chester	4,217	25.7%
Darby	Delaware	24,503	38.7%
Darby	Montgomery	70	44.2%
Darby	Philadelphia	558	66.7%
Tinicum	Delaware	5,811	49.4%

Table 2-3 summarizes several of the impacts of traditional development on streams and watersheds, most of which are created by the addition of impervious cover across the portions of the land surface. Figures 2-10 and 2-11 illustrate the changes to the volume and duration of runoff as well as the physical stream channel before and after development. Figure 2-10 also illustrates the benefits of using various BMP's and low impervious techniques to manage stormwater. As Figure 2-11 depicts, traditional development within a watershed may raise the elevation of the floodplain limit and reduce summer low flows when compared to predevelopment conditions.

Table 2-3 Impacts of Traditional Development on Watershed Resources (Schueler 1995)

Changes in Stream Hydrology	Changes in Stream Morphology
▪ Increased magnitude/frequency of severe floods ▪ Increased frequency of erosive bankfull and sub-bankfull floods ▪ Reduced ground water recharge ▪ Higher flow velocities during storm events	▪ Channel widening and downcutting ▪ Streambank erosion ▪ Channel scour ▪ Shifting bars of coarse sediments ▪ Imbedding of stream substrate ▪ Loss of pool/riffle structure ▪ Stream enclosure or channelization

Changes in Stream Water Quality	**Changes in Stream Ecology**
▪ Instream pulse of sediment during construction ▪ Nutrient loads promote stream and lake algae growth ▪ Bacteria contamination during dry and wet weather ▪ Higher loads of organic matter ▪ Higher concentrations of metals, hydrocarbons, and priority pollutants ▪ Stream warming ▪ Trash and debris jams	▪ Reduced or eliminated riparian buffer ▪ Shift in external production to internal production ▪ Reduced diversity of aquatic insects ▪ Reduced diversity of fish ▪ Creation of barriers to fish migration ▪ Degradation of wetlands, riparian zones and springs ▪ Decline in amphibian populations

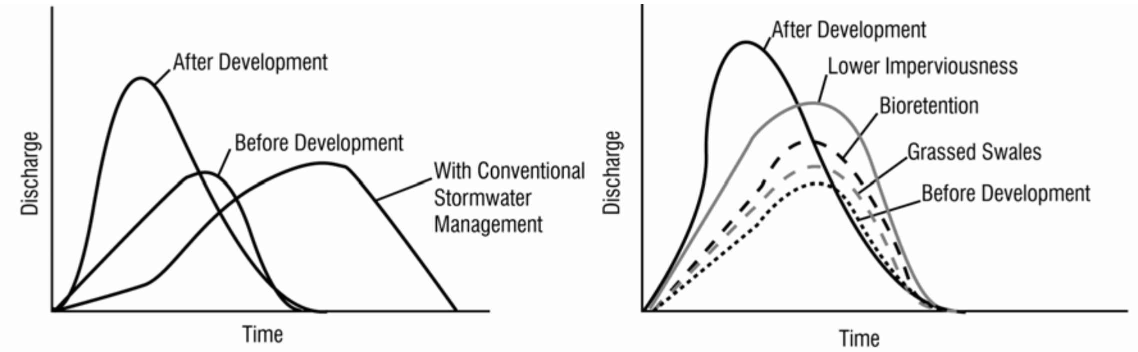


Figure 2-10: Comparison of volume and duration of stormwater runoff before and after land development, and reductions in runoff from BMP’s. (Prince George’s County Department of Environmental Resources et. al., undated)

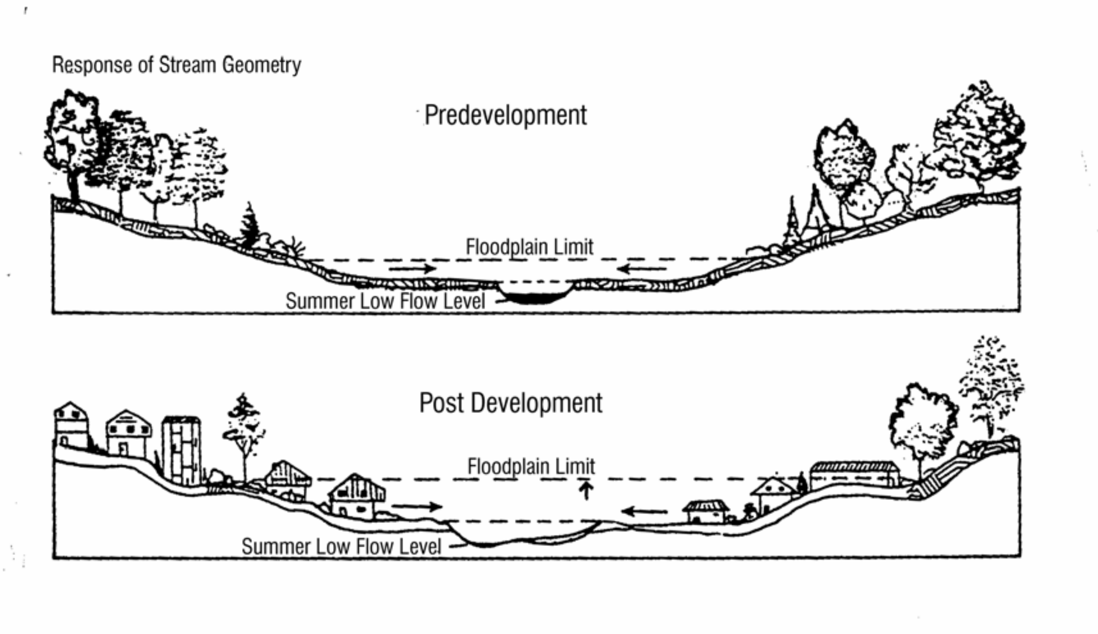


Figure 2-11: Potential impacts of development on stream flow and flooding. (Schueler 1995(a), and Schueler 1987)

Section 3 Sampling and Monitoring Program

Background

PWD's Office of Watersheds (OOW) has carried out an extensive sampling and monitoring program to characterize conditions in the Darby and Cobbs Creeks watershed. The program is designed to document the condition of aquatic resources and to provide information for the planning process needed to meet regulatory requirements imposed by EPA and PADEP. The program includes hydrologic, water quality, biological, habitat, and fluvial geomorphological aspects. OOW is well suited to carry out the program because it merges the goals of the city's stormwater, combined sewer overflow, and source water protection programs into a single unit dedicated to watershed-wide characterization and planning.

Under the provisions of the Clean Water Act, the National Pollutant Discharge Elimination System (NPDES) program requires permits for point sources that discharge to waters of the United States. In the Darby and Cobbs Creeks watershed, stormwater outfalls, wet weather sewer overflow points, and wastewater treatment plant discharges to surface waters are classified as point sources and are regulated by NPDES.

EPA's Combined Sewer Overflow Control Policy, published in 1994, provides the national framework for regulation of CSOs under NPDES. The Policy guides municipalities and state and Federal permitting agencies in meeting the pollution control goals of the CWA in as flexible and cost-effective a manner as possible. As part of the program, communities serviced by combined sewer systems are required to develop long-term CSO control plans (LTCPs) that will result in full compliance with the CWA in the long term, including attainment of water quality standards. PWD completed its LTCP in 1997 and is currently implementing its provisions. The strong focus of the National CSO Policy on meeting water quality standards is a main driver behind PWD's water quality sampling and monitoring program.

Regulation of stormwater outfalls under the NPDES program requires operators of medium and large municipal stormwater systems or MS4s, such as the separate-sewered portions of the Darby and Cobbs Creeks watershed, to obtain a permit for discharges and to develop a stormwater management plan to minimize pollution loads in runoff over the long term. Partially in administration of this program, PADEP assigns designated uses to water bodies in the state and performs ongoing assessment of the condition of the water bodies to determine whether the uses are met and to document any improvement or degradation. These assessments are performed primarily with biological assessments based on the EPA's Rapid Biomonitoring Protocols (RBPs) for benthic invertebrates and fish. Water bodies that do not meet their designated uses are classified as unattained and are included on the state listing of impaired waters under section 303(d) of the CWA.

Cobbs Creek and its tributaries are designated warm water fisheries. Darby Creek is designated a cold water fishery above PA Route 3 and a trout stocking fishery below Route 3. Muckinipattis and Stony Creeks in the Tinicum subwatershed are designated warm water fisheries. All of the Cobbs watershed and the lower portions of the Darby watershed are classified as unattained by PADEP. For this reason, the stormwater permit for the City of Philadelphia specifies that the state of the aquatic resource must be evaluated periodically. Because PADEP has endorsed biomonitoring as a means of determining attainment of uses, PWD periodically performs RBPs in the Cobbs watershed and has assisted PADEP on assessments in the Darby watershed.

OOW is responsible for characterization and analysis of existing conditions in local watersheds to provide a basis for long-term watershed planning and management. The extensive sampling and monitoring program described in this section is designed to provide the data needed for the long-term planning process.

Summary of Sampling and Monitoring

PWD's Office of Watersheds (OOW) and Bureau of Laboratory Services (BLS) have planned and carried out an extensive sampling and monitoring program to characterize conditions in the Darby and Cobbs Creeks watershed. The program includes hydrologic, water quality, biological, habitat, and fluvial geomorphological aspects. OOW is well suited to administer the program because it merges the goals of the city's stormwater, combined sewer overflow, and source water protection in a single unit dedicated to watershed-wide characterization and planning.

Sampling and monitoring follow the Quality Assurance Project Plan (QAPP) and Standard Operating Protocols (SOPs) prepared by BLS. These documents cover the elements of quality assurance, including field and laboratory procedures, chain of custody, holding times, collection of blanks and duplicates, and health and safety. They are intended to help the program achieve a level of quality assurance and control that is acceptable to regulatory agencies.

Tables 3-1 and 3-2 summarize the types, amounts, and dates of recent sampling and monitoring performed by PWD, PADEP, and USGS. A river mile-based naming convention is followed for sampling and monitoring sites located along waterways in the watershed. The naming convention includes three letters and three or more numbers which denote the watershed, stream, and distance from the mouth of the stream. For example, site DCC-110 is located as follows:

- "DC" stands for the Darby-Cobbs watershed.
- "C" stands for Cobbs Creek.
- "110" places the site 1.10 miles upstream of the mouth of Cobbs Creek, where it flows into Darby Creek.

Table 3-1 Summary of Physical and Biological Sampling and Monitoring

		Physical			Biology			
					PWD			
Site Name	USGS Gauge	PWD Geomorph.	USGS Daily Flow	USGS Annual Peak Flow	RBP III	RBP V	Habitat	PADEP
DCC-110	01475550	Assessments were performed at cross-sections located throughout the system.	1964-1990	1964-1990	December 1999		December 1999	
DCC-175						April 2000		
DCC-455					December 1999		December 1999	
DCC-505						April 2000		
	01475540		1964-1973	1965-1971				
DCC-770	01475530		1964-1981	1964-1980			December 1999	
DCC-820						April 2000		
DCC-865					December 1999		December 1999	
DCD-765	01475510		1964-1990	1964-1990				
	01475545		1972-1978	1972-1978				
DCD-1170								
DCD-1570								
DCD-1660								
	01475300		1972-1997*	1972-1996				
STA01 - STA12								1995-1996
DCI-010								
DCI-135					December 1999		December 1999	
DCIW-010					December 1999		December 1999	
DCIW-100						April 2000		
DCIW-185					December 1999		December 1999	
DCM-300								
DCN-010								
DCN-185					December 1999		December 1999	
DCN-215						April 2000		
DCS-170								

* Provisional data are available up to the present.

Table 3-2 Summary of Water Quality Sampling and Monitoring

		Chemical		
	USGS	PWD		
Site Name	Gauge	Discrete	Continuous	Wet Weather
DCC-110	01475550	14 samples 5/11/99-6/29/00	3379 hrs	3 periods 5/23/00-7/28/00
DCC-115			951 hrs	
DCC-175				
DCC-455		10 samples 5/11/99-7/20/99	3176 hrs	
DCC-505				
	01475540			
DCC-770	01475530	10 samples 5/11/99-7/20/99	2486 hrs	
DCC-820				
DCC-865				
DCD-765	01475510	12 samples 5/11/99-6/12/00	1854 hrs	3 periods 5/23/00-7/28/00
	01475545			
DCD-1170		10 samples 5/11/99-7/20/99		
DCD-1570		10 samples 5/11/99-7/20/99		
DCD-1660		4 samples 6/1/00-7/13/00	2645 hrs	1 period 7/27/00-7/28/00
	01475300			
STA01 - STA12				
DCI-010		10 samples 5/11/99-7/20/99		
DCI-135				
DCIW-010				
DCIW-100				
DCIW-185				
DCM-300		10 samples 5/11/99-7/20/99		
DCN-010		10 samples 5/11/99-7/20/99	167 hrs	
DCN-185				
DCN-215				
DCS-170		10 samples 5/11/99-7/20/99		

Hydrologic and Outfall Monitoring

Hydrologic monitoring includes a system of precipitation gauges and measurement of flows at outfall points. Characterization of hydrologic and hydraulic data is presented in Section 4.

Precipitation data are available from the National Oceanography and Atmospheric Administration (NOAA) and from local gauges operated by PWD and other organizations. NOAA's gauge at the Philadelphia International Airport, located in southeastern Philadelphia, has over 100 years of hourly precipitation data; the period of record runs from January 3, 1902 through the present. Additional precipitation data can be obtained from PWD's network of 23 rain gauges throughout the city; these data are available in 15-minute increments from the early 1990's to the present. Five of the City gauges are located in or near the Darby and Cobbs Creeks watershed, as shown in Figure 3-1.

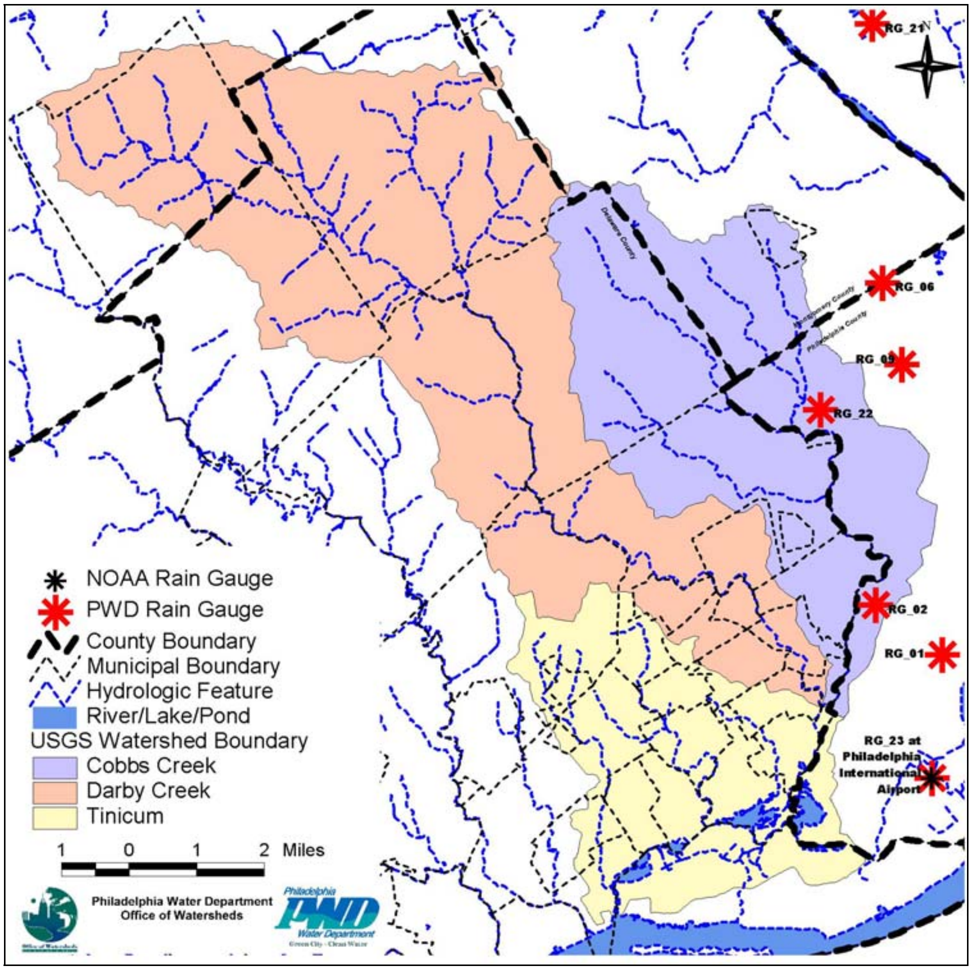


Figure 3-1 City Rain Gauges In or Near the Watershed

PWD maintains real-time sewer monitors in the Cobbs Creek system. At these points, monitors are typically present in the trunk sewer just above the regulator and in the outfall pipe itself. The magnitude and quality of discharges from the city's CSO outfalls are determined by a combination of this monitored data and calibrated computer models.

Water Quality Sampling and Monitoring

A range of water quality samples were collected between 1999 and 2001 at eleven sites in the watershed. The sites are listed in Table 3-3 and are shown on Figure 3-2. Three different types of sampling were performed as discussed below. Parameters were chosen because state water quality criteria apply to them or because they are known or suspected to be important in urban watersheds. The parameters sampled during each type of sampling are listed in Table 3-4. Water quality in each reach and section of the watershed is characterized in Section 5.

The sampling and analysis program meets AMSA (2002) et al. recommendations for the minimum criteria that should form the basis for impairment listings:

- Data collected during the previous five years may be considered to represent current conditions.
- At least ten temporally independent samples should be collected and analyzed for a given parameter.
- "A two-year minimum data set is recommended to account for inter-year variation, and the sample set should be distributed over a minimum of two seasons to account for inter-seasonal variation."
- "No more than two-thirds of the samples should be collected in any one year."
- "Samples collected fewer than four days apart at the same riverine location should be considered one sample event."
- "Samples collected within 200 meters [about 0.1 miles] of each other will be considered the same station or location." This convention was followed except where two sampling sites were chosen to represent conditions upstream and downstream of a modification such as a dam.

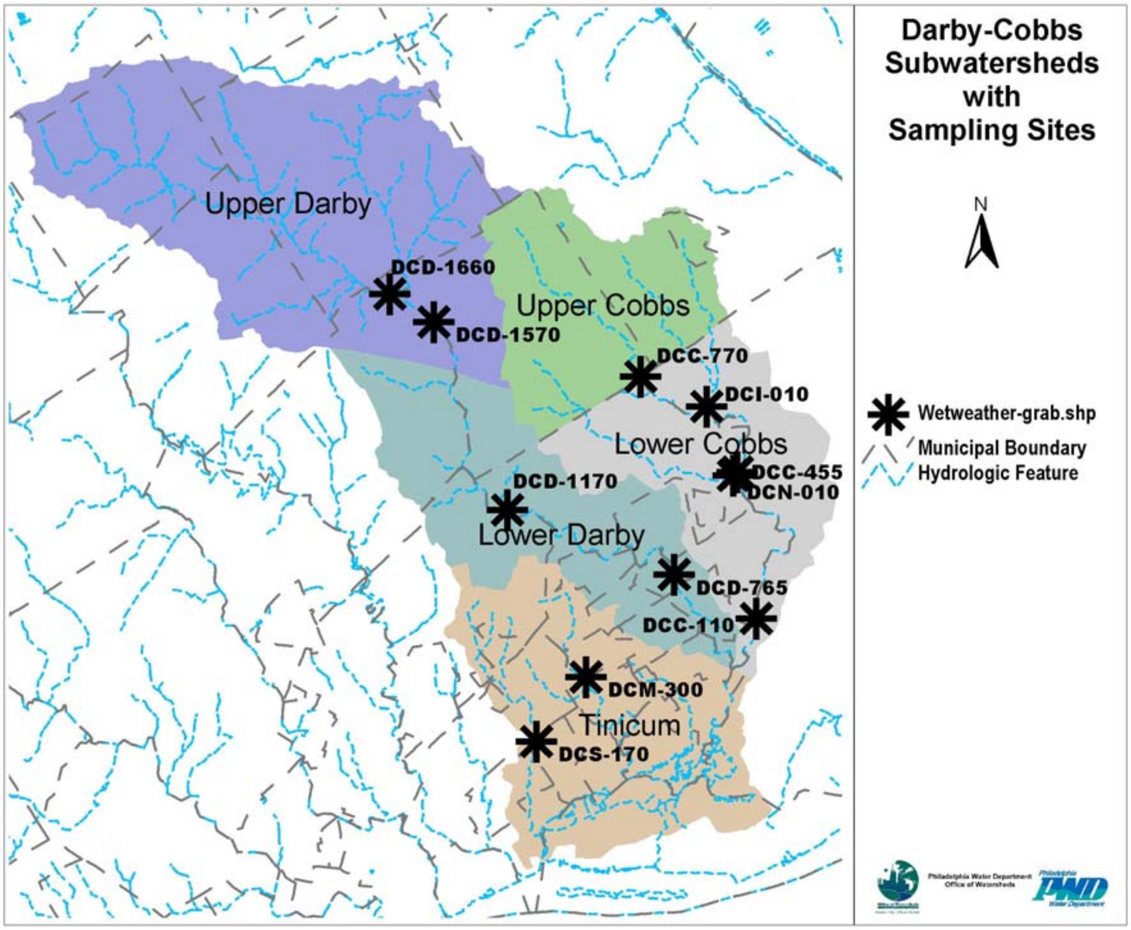


Figure 3-2 Water Quality Sampling Sites

Table 3-3 Water Quality Sampling Sites

Cobbs Creek	**Darby Creek**	**Tinicum**
Mainstem DCC110 DCC455 DCC770 Naylors DCN010 Indian Creek DCI010	Mainstem DCD765 DCD1570 DCD1660	Muckinpates Creek DCM300 Stony Creek DCS170

Table 3-4 Water Quality Parameters Sampled

Parameter	Units	Discrete	Wet Weather	Continuous
PHYSICAL PARAMETERS				
Temperature	deg. C	X	X	X
pH	none	X	X	X
Specific Conductance	uS/cm	X	X	X
Alkalinity	mg/L as CaCO3	X	X	
Turbidity	NTU	X	X	X
TSS	mg/L	X	X	
TDS	mg/L	X	X	
OXYGEN AND OXYGEN DEMAND				
DO	mg/L	X	X	X
BOD5	mg/L	X	X	
BOD30	mg/L	X	X	
CBOD5	mg/L	X		
NUTRIENTS				
Total Ammonia	mg/L as N	X	X	X*
Nitrate	mg/L as N	X	X	X*
Nitrite	mg/L as N	X	X	X*
TKN	mg/L as N	X	X	
Phosphate	mg/L as P	X	X	
Total Phosphorus	mg/L	X	X	
METALS				
Aluminum	mg/L	X	X	
Calcium	mg/L	X	X	
Cadmium	mg/L	X	X	
Chromium	mg/L	X	X	
Copper	mg/L	X	X	
Fluoride	mg/L	X	X	
Iron	mg/L	X	X	
Dissolved Iron	mg/L	X		
Magnesium	mg/L	X	X	
Manganese	mg/L	X	X	
Lead	mg/L	X	X	
Zinc	mg/L	X	X	
BIOLOGICAL				
Chlorophyll A	ug/L	X	X	
Total Chlorophyll	ug/L	X	X	
Fecal Coliform	/100 mL	X	X	
E. coli	/100 mL	X	X	
Osmotic Pressure	mosm	X	X	
MISCELLANEOUS				
Phenolics	mg/L	X	X	

* Results did not pass quality assurance but may have some value as a relative measure.

Discrete Sampling. Discrete samples were collected at 11 sites in both wet and dry weather at an interval of two weeks to one month. During discrete sampling, each sampling site along a stream is sampled once during the course of a few hours. The purpose of discrete sampling is initial characterization of water quality under both dry and wet conditions and identification of parameters of possible concern. Discrete sampling follows the Standard Operating Protocol "Field Procedures for Grab Sampling".

Wet Weather Event Sampling. At three sites, a series of samples was collected over the course of several wet weather events. During wet weather sampling, several discrete samples are collected just before and during the course of a wet weather event. The data allow characterization of water quality responses to stormwater runoff and wet weather sewer overflows.

Continuous Measurement. Continuous data were collected at six sites for a total of over 12,900 hours. During continuous sampling, data for selected parameters are collected at 15-minute increments by a submerged instrument (YSI Sonde 6600) over approximately two weeks. The instrument measures parameters using voltage and diffusion-based probes rather than physically collecting samples. Parameters measured include stage, dissolved oxygen, temperature, pH, turbidity. To the author's knowledge, this type of equipment has not been employed extensively in urban streams in the past. This method produces 96 measurements per parameter every 24 hours, but cost and quality control are more challenging compared to discrete sampling. The SOP for continuous sampling describes the extensive quality control and assurance procedures applied to the data.

Biological and Habitat Monitoring

Benthic invertebrate, fish, and habitat assessments were carried out by PWD in the Cobbs Creek watershed between December 1999 and April 2000. Bioassessment procedures are summarized below. The results of the bioassessments are presented in Section 6.

Fish Sampling. Five sampling stations were chosen on Cobbs Creek; three on the main stem and two sites on the smaller tributaries, West Branch Indian Creek and Naylor's Run. Prior to the main stem analysis, the Academy of Natural Sciences (ANS) completed their assessment on the three tributaries and were interested in completing a watershed analysis on Cobbs Creek. Data from these sites were provided to the Philadelphia Water Department and the Pennsylvania Department Of Environmental Protection (PADEP). Using EPA protocols for rapid bioassessment, a reach was measured using a graduated tape and both upstream and downstream portions were blocked off using standard seining nets. Two Coffelt backpack electro-shockers were operated at 50-75 watts direct current (DC). Fish were collected using D-frame dip nets, identified to species and total length of each individual was obtained.

Benthic Invertebrate Sampling. On December 6th-7th, 1999, the Pennsylvania Department of Environmental Protection (PADEP), Office of Watersheds and the Bureau of Laboratory Services conducted Rapid Bioassessment Protocols (RBP III) on seven sites (Figure 3.2) in the Cobbs Creek watershed. Using EPA guidelines, macroinvertebrates were collected by placing a standard D-frame dipnet at the downstream portion of a riffle. The substrate was then kicked and scraped manually one meter from the net aperture to remove all benthic species. This procedure was repeated at another riffle location with less flow. Specimens were then preserved in 95% ETOH (ethyl alcohol) and returned to the laboratory in polyethylene containers. In the laboratory, samples were placed in a 11″ x 14″ gridded (numbered) pan and random "plugs" were examined until 100 individuals were collected. Macroinvertebrates were identified to genus and population estimates were calculated.

Habitat Assessment. Prior to the benthic procedures, habitat assessments at the seven sites were completed based on the Stream Classification Guidelines for Wisconsin (Ball, 1982) and Methods of Evaluating Stream, Riparian, and Biotic Conditions (Platts et al., 1983). Reference conditions were used to normalize the assessment to the "best attainable" situation. Habitat parameters are separated into primary, secondary, and tertiary parameters. Primary parameters are those that characterize the stream "microscale" habitat and have the greatest direct influence on the structure of the indigenous communities. Secondary parameters measure the "macroscale" habitat such as channel morphology characteristics. Tertiary parameters evaluate riparian and bank structure and comprise three categories: (1) bank vegetative protection, (2) grazing or other disruptive pressure, and (3) and riparian vegetative zone width. Additional habitat assessment was also carried out by the fluvial geomorphological study team using customized parameters from the Rapid Steam Assessment Technique (RSAT, Washington Metropolitan council of Governments) and the Qualitative Habitat Evaluation Index (Ohio).

Fluvial Geomorphological Monitoring

Assessment of fluvial geomorphological conditions in the watershed was performed to support future stream channel, streambank, and habitat restoration initiatives. The results of the assessments are presented in Section 8.

Approximately eleven miles of stream cross sections and banks were assessed within the study area. A team of three environmental scientists walked the length of Cobbs Creek and Indian Creek and characterized channel morphology, disturbance, stability, and habitat parameters. The team surveyed cross sections of Cobbs Creek and Indian Creek to characterize the morphological features of the channel, provide a template for hydrologic and hydraulic modeling, and serve as a baseline for assessing channel bank and bed changes (erosion and sediment accretion). Features surveyed included breaks in slope, bankfull stage, water surface and thalweg. A permanent bench mark was established on one side of the cross section to mark the location and relative elevation.

The assessment team installed bank pins and scour chains, providing PWD the opportunity to measure and quantify stream bank erosion and streambed degradation/aggradation. As the bank begins to erode, the pins protrude further and further into the steam. After a storm event, technicians can locate the pins and measure the distance they protrude and compare that to the previous distance. This 'depth' of erosion can then by multiplied by the length and height of the eroded bank to quantify the cubic yards of sediment being deposited into the channel. Over time these measurements can be correlated to different storm events to estimate the rate and quantity of sediment being deposited into the system. Similarly, scour chains are placed into the bed of the stream and allow one to measure the amount of bed scour or sediment accretion occurring during each storm event. Both the bank erosion pins and the bed scour chains are easy to maintain and measure and provide solid data that can be used to estimate degradation and prioritize capital improvement projects.

Section 4 Characterization of Hydrology

This section examines the components of the hydrologic cycle for the Darby-Cobbs watershed.   The hydrologic cycle includes precipitation, evaporation, infiltration into soil, stormwater runoff over the land surface and in the sewer system, surface water flow in streams, and groundwater. The different types of sewer systems that serve the area are discussed in this section because they are an important part of the hydrologic cycle in the urban environment.

4.1 Components of the Urban Hydrologic Cycle

One way to develop an understanding of the hydrologic cycle is to develop a water balance. The balance tries to characterize the flow of water into and out of the "system" by assigning estimated rates of flow for all of the components of the cycle. It is also important to understand that the natural water cycle components of precipitation, evapotranspiration (ET), infiltration, stream baseflow, and stormwater runoff must be supplemented by the many artificial interventions related to urban water, wastewater, and stormwater systems.

The first step in developing a water balance for the urban hydrologic cycle is to identify the system boundaries and the pathways that allow water to cross those boundaries. For the Darby and Cobbs Creeks watershed, the system includes the land surface within the watershed boundaries, structures and vegetation on the surface, and the subsurface beneath the watershed. Inputs to the system are precipitation and outside sources of potable water. Outflows from the system include streamflow through the system outlet, evaporation and transpiration losses to the atmosphere, and flows of wastewater to the system outlet. In addition, it is possible for subsurface exchanges to occur across the boundary.

Precipitation that falls on the land surface may evaporate, be taken up by plants and lost through transpiration, flow directly to a water body over land or through a storm sewer system, or enter a combined sewer system. In combined sewer systems, a portion of flow is captured by the sanitary sewer system and a portion reaches surface water. Flow in streams consists of stormwater runoff, combined sewer overflow, delayed wet weather inputs through shallow groundwater, and a baseflow component due to the discharge of groundwater to the creek during dry weather. A portion of potable water pumped in from outside the watershed enters the sanitary sewer system and is sent to outside treatment plants, and a portion is lost to consumptive uses.

The system inflows and outflows can be split into a number of components. These are shown below as a simple, input equals output water balance with the many natural and anthropogenic components of a typical urban water cycle.

Inflows: P + OPW + WW/IND Rech + EDR + WW Disch

Outflows: RO + SWW+ GWW + EDW + BF + OWD + ET where:

P is the average precipitation at the Philadelphia gage

OPW is the outside potable water brought in

WW/IND Rech is the wastewater and industrial discharge back to groundwater

EDR is the estimated domestic recharge from private septic systems

WW Disch is the discharge of water to creeks from larger wastewater plants or industrial facilities

RO is the surface water runoff component of precipitation

SWW is the withdrawal of water from creek, primarily for public water supply and industrial use

GWW is the groundwater withdrawal from public water supply or industrial wells

EDW is the estimated domestic withdrawal of groundwater from private wells

BF is the median baseflow of streams

OWD is the discharge of wastewater to outside plant

ET is the evaporation and transpiration of water (including error)

4.1.1 Precipitation

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

Precipitation is the primary, natural inflow to the hydrologic system. Precipitation data used to estimate this component are available from the National Oceanography and Atmospheric Administration (NOAA) and from local gauges operated by PWD and other organizations. NOAA's gauge at the Philadelphia International Airport, located in southeastern Philadelphia, has over 100 years of hourly precipitation data covering a period of record from January 3, 1902 through the present. The average annual rainfall in the Philadelphia area based upon the airport gauge is 41 inches. Most months have average precipitation totals of 3-4 inches. The driest season is late fall, and the wettest is late summer when thunderstorms are common (Table 4-1). Average temperatures during the winter months are above the freezing point during the day and below the freezing point at night. Snow and snowmelt events occur, but it is rare for a snow pack to accumulate and last through the season.

Additional precipitation data can be obtained from PWD's network of 23 rain gauges throughout the city; these data are available in 15-minute increments from the early 1990's to the present. Five of the City gauges are located in or near the Darby and Cobbs Creeks watershed, as shown in Figure 4-1. Data from these gauges provide precipitation at a higher level of spatial and temporal detail.

Table 4-1 Average Monthly Precipitation, Temperature, and Potential Evaporation

		Average Temperature		
Month	Average Precipitation (in)	High (°F)	Low (°F)	Potential Evaporation (in/month)
January	3.3	39.2	24.4	2.1*
February	2.9	42.1	26.1	2.1*
March	3.6	50.9	33.1	2.1
April	3.4	63	42.6	4.5
May	3.5	73.2	52.9	5.4
June	3.6	81.9	61.7	6.3
July	4.1	86.4	67.5	6.6
August	4.3	84.6	66.2	5.7
September	3.4	77.4	58.6	4.2
October	2.8	66.6	46.9	2.7
November	3.0	55	37.6	2.1
December	3.3	43.5	28.6	2.1*

* estimated

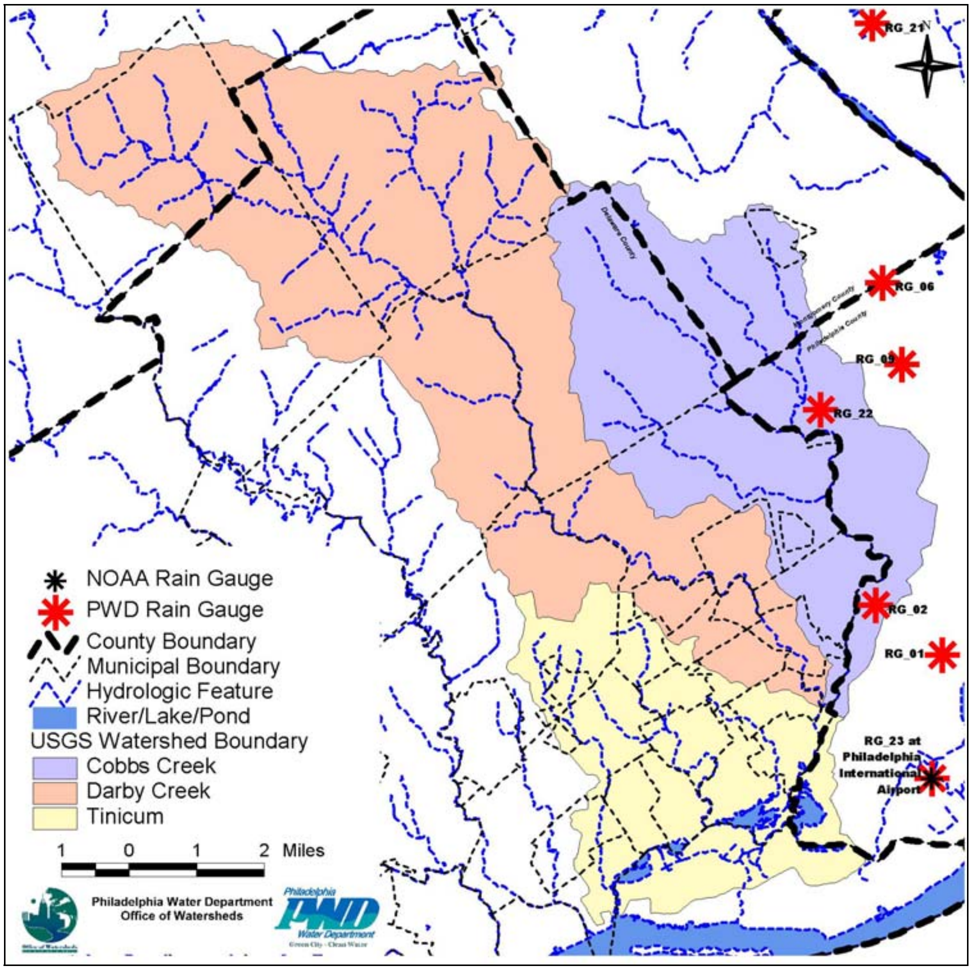


Figure 4-1 City Rain Gauges In or Near the Watershed

4.1.2 Outside Potable Water

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

The watershed is generally supplied with drinking water from sources of water outside the watershed. For the Philadelphia portion of the watershed, water is "imported" into the watershed through the drinking water distribution system from raw water drawn from the Schuylkill and Delaware Rivers. For the outside communities, most of the water is supplied by Aqua America (formerly Philadelphia Suburban) and Pennsylvania American from Crum and Ridley Creeks.

For the Darby-Cobbs watershed, most of this water never leaves the urban infrastructure used to transmit drinking water to and convey wastewater from homes to wastewater treatment plants outside the watershed. In this sense, this component of the watershed water balance is not critical to the development of the watershed management plan.

4.1.3 Wastewater and Industrial Recharge to Groundwater

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

This component represents water that has been used in homes or industry, has been treated, and is subsequently discharged back to the groundwater, thus making it an "inflow" component. Available data suggest that there are no such discharges within the watershed. For this reason, this component is not included in the table of estimated flows for components of the hydrologic cycle.

4.1.4 Estimated Domestic Recharge

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

This component represents water that has been used in homes and is subsequently discharged to septic systems. In this way, it represents an inflow component to the groundwater portion of the hydrologic cycle. Although there are some septic system areas in the watershed, most of the population is served by sanitary sewers, making this a very small component of the water cycle. Counts of septic systems are based on 1990 U.S. census data and are highly uncertain. Based on this information and an estimate of 50 gallons of sewage per person per day discharged to septic systems, this component represents 56,000 gallons per day in the Cobbs watershed and 205,000 gallons per day in the Darby watershed upstream of the confluence. These flows may also be expressed as 0.05 inches per year for the Cobbs and 0.11 inches per year for the Darby.

4.1.5 Wastewater Discharges to the Stream

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

This component represents water that has been used in homes or industry, has been treated, and is subsequently discharged back into the stream, thus making it an "inflow" component. Available data suggest that there are no discharges to Cobbs Creek, and only a few, very small permitted discharges on the Darby Creek. For this reason, this component can be considered insignificantly small in comparison to the main inflow components and is not included in the table of estimated flows for components of the hydrologic cycle.

4.1.6 Runoff

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

Precipitation is the primary natural inflow component of the water cycle. This inflow component generally results in three, natural outflow components: evapotranspiration (ET), runoff, and infiltration into the groundwater. Thus runoff is one of the major, natural outflow components to be estimated.

The amount of stormwater runoff depends on a variety of factors, including rainfall intensity, surface ponding of rain, ground slope, and, most importantly, the imperviousness of the ground surface. The amount of impervious cover follows patterns of land use and population density because manmade structures and pavement are the cause of impervious surface. Estimates of imperviousness can be further refined by examining the relative proportion of impervious surfaces on the USGS quadrangles and in aerial photos. Because of the urbanized nature of the watershed, runoff is almost always collected into a sewer system. Depending on the location within the watershed, it can either be discharged through storm sewers or through combined sewers. Therefore, this component is further discussed under the Runoff/Outside Wastewater Discharge component below.

4.1.7 Surface Water Withdrawals

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

This outflow component represents intakes for water withdrawal for drinking water or industrial use. For the Darby-Cobbs watershed, no permitted withdrawals exist on either river, and this component can be left out of the water balance table.

4.1.8 Groundwater Withdrawals

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

This outflow component represents groundwater pumping for industrial use or public water supply. There are no public supply or industrial wells of significance in the watershed, and this component can be left out of the water balance table.

4.1.9 Estimated Domestic Withdrawals

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

The entire watershed is served by a public water supply distribution system. There are no areas where domestic wells form a significant source of supply, and groundwater pumping can be ignored as a significant component of the water balance.

4.1.10 Baseflow

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

Precipitation results in three, natural outflow components: evapotranspiration (ET), runoff, and infiltration into the groundwater. In most shallow groundwater systems, the surface watershed generally corresponds to the recharge and discharge area of the groundwater system. This means that infiltration enters the groundwater aquifer, and flows underground to the stream for eventual discharge as stream baseflow. This allows us to equate infiltration with stream baseflow, making it possible to estimate infiltration through baseflow separation techniques at stream gauges.

In pervious areas, the amount of water that infiltrates the soil, and thus reappears as stream baseflow, depends on soil properties. At the beginning of a storm, when soil pores are usually not saturated, the moisture content of the soil determines the amount of infiltration that can occur. Capillary suction forces caused by surface tension in the pores also affect the infiltration rate. The size, shape, and distribution of soil pores determine the rate at which a soil can transmit flow in both the unsaturated and saturated states. The infiltration rate decreases as soil pores become filled with water during the course of the storm. When the pores become completely saturated, the water transmission rate reaches an equilibrium and is referred to as the saturated hydraulic conductivity or soil permeability. Sandy soils allow the highest infiltration rates, while soils with high clay content allow very slow infiltration; loams and mixtures of different soil types fall between the two extremes. Table 4-2 lists typical values for saturated hydraulic conductivity, capillary suction, and initial moisture deficit for a range of NRCS soil textures (Handbook of Hydrology, D.R. Maidment, Editor in Chief, McGraw-Hill, Inc., 1993, pp 5.1-5.39.) Soil textures found in the watershed were discussed in Section 1. It is important to remember that in urbanized areas, the original soils have often been disturbed, compacted, or replaced by fill material that may have different hydraulic characteristics from the undisturbed state.

Table 4-2 Typical Hydraulic Properties of Different NRCS Soil Textures

	Saturated Hydraulic Conductivity (in/hr)	Capillary Suction (in)	Initial Moisture Deficit (fraction)
Sand	9.3	2.0	0.35
Loamy Sand	2.4	2.4	0.31
Sandy Loam	0.86	4.3	0.25
Loam	0.52	3.5	0.19
Silt Loam	0.27	6.6	0.17
Sandy Clay Loam	0.12	8.6	0.14
Clay Loam	0.08	8.2	0.15
Silty Clay Loam	0.08	10.8	0.11
Sandy Clay	0.05	9.4	0.091
Silty Clay	0.04	11.5	0.092
Clay	0.02	12.5	0.079

The simplest way to compute infiltration, which is generally difficult to measure and/or model, is to perform baseflow separation on streamflow. In this way, if baseflow is assumed to equal infiltration, then the infiltration component can be directly balanced by the baseflow component. For the Darby-Cobbs watershed, this approach results in an annual infiltration/baseflow component of 8.1 inches per year in Cobbs Creek and 14.4 inches per year Darby. This difference is a good indication of the more impervious nature of the Cobbs Creek watershed when compared to the Darby Creek watershed.

Table 4-3 Summary of Hydrograph Separation Results Over the Period of Record

Gauge	Mean Total Flow (in/yr)	Mean Baseflow (in/yr)	Mean Runoff (in/yr)	Baseflow (% of Total Flow)	Runoff (% of Rainfall)
French Creek 01475127	20.3	12.9	7.4	64	18
Cobbs Creek 01475550	18.8	8.1	10.7	43	26
Darby Creek D/S 01475510	23.3	14.5	8.9	62	21
Darby Creek U/S 01475300	23.7	15.6	8.1	66	20

4.1.11 Runoff and Outside Wastewater Discharges

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

Almost the entire watershed is served by sewers. Depending on the area of the watershed, stormwater may either enter surface water directly, enter a combined sewer, or enter a separate storm sewer system. Unsewered areas, where runoff flows overland to the stream system, make up approximately 5-10% of the Darby and Cobbs Creeks watershed. These areas serve mainly natural areas located along the stream corridor, such as Cobbs Creek Park, where storm sewers are not necessary. Some areas in western Delaware County are also unsewered.

Sewered areas within the watershed are served by two types of sewer systems. In areas served by combined sanitary and storm sewers, the sewer system conveys flows to an interceptor sewer and later to a wastewater treatment plant under dry weather conditions. During larger wet weather events, a combined flow regulator structure diverts a portion of the flow to a receiving stream. Portions of Philadelphia County, including 20% of the Cobbs Creek subwatershed, are serviced by combined sewers. The City of Philadelphia has 38 regulator structures within the watershed, as shown in Figure 4-2. 25 of these structures are instrumented with continuous flow monitors.

Except for park lands (about 5% of the Cobbs watershed), the rest of the watershed area is serviced by separate sanitary and storm sewer systems. In these areas, the storm sewer system conveys most surface runoff directly to a receiving stream. A portion of stormwater, known as infiltration and inflow, enters the sanitary sewer system during wet weather. The occurrence of CSO and the categorization of sampling periods as wet or dry are discussed later in the section.

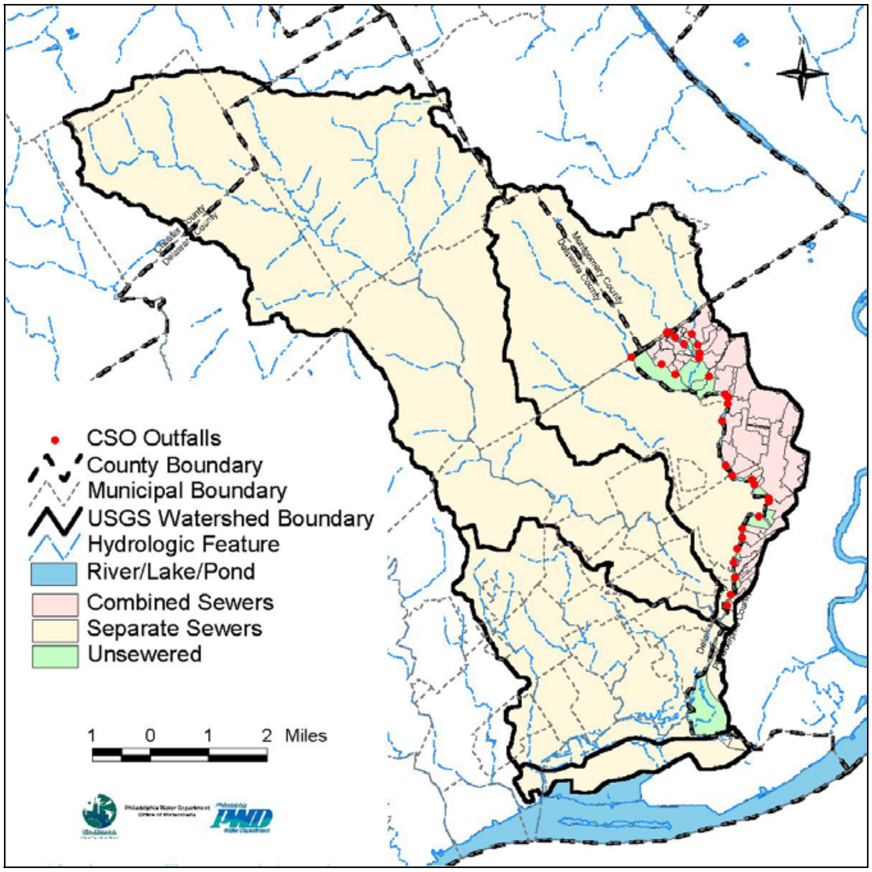


Figure 4-2 Types of Sewer Service and Locations of Regulator Structures

Hydrologic and Hydraulic Modeling

Estimates of the volume, frequency, and duration of combined sewer overflows are based on results from calibrated hydrologic and hydraulic models. Model calibration depends on data from PWD's extensive rainfall gauge network and sewer monitoring program.

The hydraulic and hydrologic model development process focused the greatest detail on the interceptor sewer system, using the USEPA Storm Water Management Model (SWMM) Extended Transport (EXTRAN) module. The EXTRAN module of SWMM was chosen as the most appropriate tool for the interceptor model. This model is the most widely used and accepted model for interceptor and CSO modeling (Roesner et al., 1988). It accurately simulates complex hydraulic conditions that occur in combined sewer interceptors, including unsteady flow, surcharging, branched and looped pipe networks, pumps, orifices, and weirs.

To estimate the treatment rates of the combined sewer regulator structures, or the maximum flow that can pass through the regulator's connector pipe to the interceptor in wet weather, the initial sewershed hydrologic representation is in the form of ramp-function hydrographs loaded directly to EXTRAN. Later in the process, the combined sewersheds are modeled in the United States Army Corps of Engineers (USACOE)

Storage, Treatment, Overflow, Runoff Model (STORM), providing a more detailed characterization of the hydrologic response of the system with an algorithm for the computation of rainfall excess. STORM thereby provides a wet weather characterization that is useful for assessment of impacts and for planning-level alternatives screening used to establish the direction for detailed facility planning and design.

STORM is run in continuous simulation mode using a long-term rainfall record. There is general agreement in the modeling community that single event or design storm simulations are not sufficient for the generation of long-term CSO statistics, including average annual frequency and volume (EPA, 1993). Continuous simulation more thoroughly accounts for antecedent conditions and inter-event conditions within the system.

Discharge Monitoring Report and Annual Report Generation

The EXTRAN model is used for the hydraulic characterization of interceptors and regulators to a fine level of detail. The model supports estimates of sewer system overflow characteristics using STORM. This characterization of the combined sewersheds and trunk sewer system is at the correct level of detail for the hydrologic and hydraulic characterization requirements of NPDES permits for CSO and sanitary sewer facilities and for the alternatives analyses required for long term CSO control planning.

Quarterly discharge monitoring reports (DMR's) are required under the NPDES permit system. In addition, the results of the SWMM/NetSTORM model are used to prepare the CSO Annual Report required under Philadelphia's LTCP and Chapter 94 of the Pennsylvania Code. This report details progress on the three phases of the LTCP: implementation of the Nine Minimum Controls, construction of capital projects, and watershed-based planning. The report also summarizes CSO volume, frequency, and capture statistics for the year.

Annual CSO Frequency and Volume Stats

Table 4-4 lists estimated capture percentages for regulator structures in the Cobbs Creek watershed, based on the modeling results listed in the CSO Annual Reports. A capture percentage is defined as the percentage of combined sewage (mixed sanitary sewage and stormwater) that is "captured" and sent to a treatment plant during rainfall events over the course of a year. 85% capture is considered to be an ultimate goal for many communities as they implement CSO long term control plans. Based on Table 4-4, capture percentages are generally in the range 50-60% for the Cobbs Creek High Level sewer system (32 regulator structures draining 2180 acres) and 70-80% for the Cobbs Creek Low Level sewer system (12 regulator structures draining 390 acres). It is important to note that percent capture for a given year is strongly dependent on the frequency and magnitude of rainfall events during that year. The seven years of data listed in Table 4-4 are not sufficient to determine whether an increasing or decreasing trend has taken place. However, as the amount of data increases throughout implementation of the Long Term Control Plan, it will ultimately be possible to evaluate the effectiveness of the control measures.

Table 4-4 Estimated Annual Combined Sewage Capture Percentages

Year	Precipitation (in)	Capture (%) – Lowest and Highest Structure	
		Cobbs Creek High Level	Cobbs Creek Low Level
2001	31.1	61 – 62	84 – 85
2000	43.2	51 – 52	74 – 75
1999	48.6	49 – 50	73 – 74
1998	30.7	65 - 67	87 - 88
1997	32.0	59 – 63	88 – 92
1996	53.2	30 – 31	63 – 65
1995	31.6	74 – 75	76 – 78

4.1.12 Evapo-Transpiration

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

Once precipitation reaches the earth’s surface, it may take a variety of paths. Typically, a portion enters soil pores through infiltration, a portion returns to the atmosphere through evaporation, and a portion runs off over the land surface (or often into a sewer in urbanized areas). A portion may also be stored temporarily in puddles, in plant parts, through freezing, or in manmade structures designed to detain stormwater; this portion then infiltrates, evaporates, or runs off at a later time.

One of the largest “outflows” of water from the system is evaporation and transpiration. Evapotranspiration includes evaporation, or loss of water to the atmosphere as water vapor, and transpiration, or loss of water to the atmosphere through plants. Evapotranspiration rates depend on temperature, wind speed, solar radiation, type of surface, type and abundance of plant species, and the growing season. Because of these factors, estimated evapotranspiration rates for the Philadelphia region vary seasonally. Neither the Philadelphia Airport nor the Wilmington Airport records evaporation data. One site in New Castle County, Delaware was located which has recorded daily evaporation data from 1956 through 1994. Average daily evaporation rates from this site were developed and are listed in Table 4-1 (City of Philadelphia Combined Sewer Overflow Program: System Hydraulic Characterization).

4.2 Cobbs Creek Water Cycle Component Tables

The relevant components of the urban water cycle have been estimated for the Darby-Cobbs watershed. Outside Potable Water is assumed to balance Outside Wastewater Discharges, with stormwater and CSO’s considered as part of the Runoff component of the water cylde. Tables 4-5 and 4-6 show the results of the analysis, first in inches per year, then in million of gallons per day. The inches per year figure simply takes all the flows over an average year, and divides by the area of the watershed. The million gallons per day table takes all the flows over an average year, and divides by 365 days to get an "average" day value.

Table 4-5 Water Budget Components (in/yr)

	Period of Record	Inflow		Outflow		
		P	EDR	RO	BF	ET+Error
Cobbs Creek	1964 - 1990	42.1	0.05	10.6	8.1	23.4
Darby Creek	1964 - 1990	42.1	0.11	8.9	14.4	18.9

Table 4-6 Water Budget Components (MGD)

	Period of Record	Inflow		Outflow		
		P	EDR	RO	BF	ET+Error
Cobbs Creek	1964 - 1990	44.4	0.06	11.2	8.6	24.7
Darby Creek	1964 - 1990	79.6	0.2	16.8	27.3	35.7

4.3 Surface Water Characteristics

The above component tables contain values for runoff, ET, and baseflow. These values, however, are complicated by the fact that much of the water is collected in both separate and combined sewers. This section describes, in more detail, the surface water portion of the cycle.

Stormwater runoff ultimately reaches Darby and Cobbs Creeks and their tributaries through surface runoff, a combined or separate storm sewer, or a treated water discharge. An understanding of the range and frequency of flows, the stage-velocity-discharge relationship, and trends over time is important to a more complete watershed characterization. This information is useful in water quality management, habitat restoration and management, and potable water and flood control applications.

During the USGS/PWD cooperative program in the 1970's, the USGS established streamflow gauging stations at six locations in the Darby and Cobbs Creeks Watershed. These locations are presented in Figure 4-3. Table 4-7 contains summary information at each of the gauging stations for their respective periods of record. Historical rating curves are available for four of the stations and are shown in Figure 4-4.

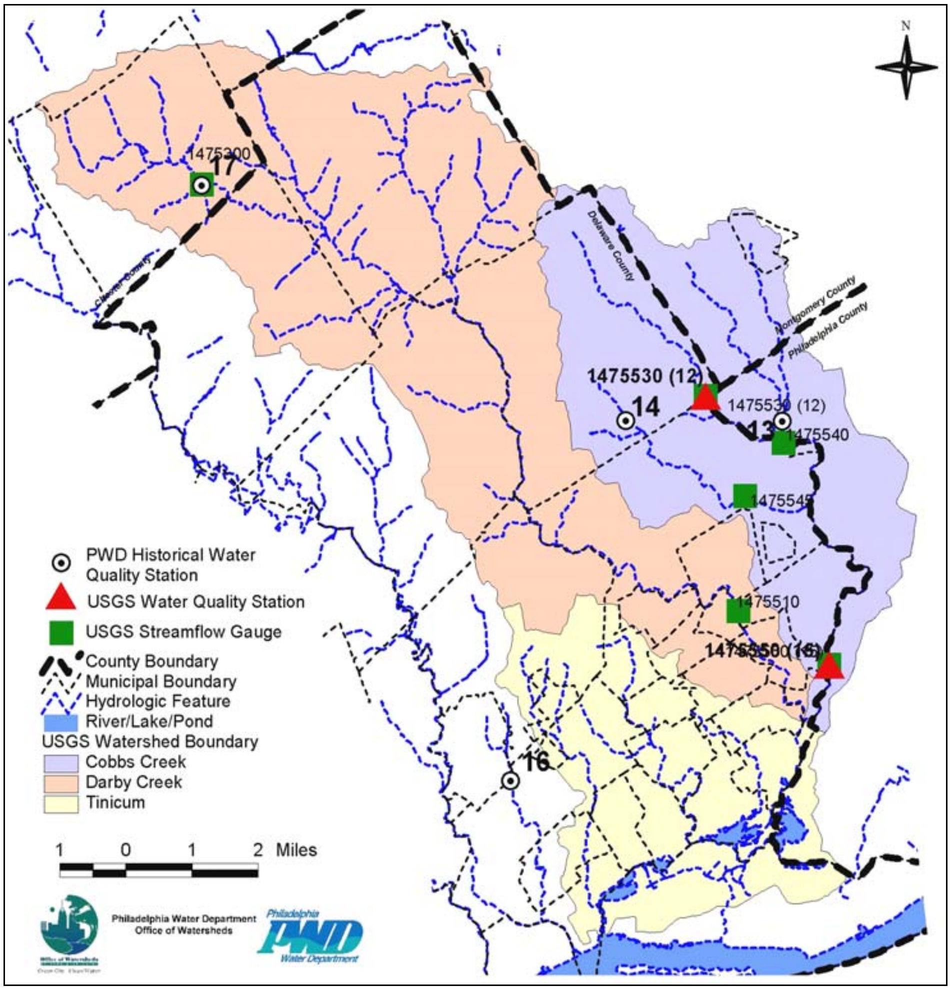


Figure 4-3 USGS Streamflow and Water Quality Gauges

Table 4-7 USGS Gauges and Periods of Record

Station ID	Location	Quality Data (Period)	Streamflow Data (Period)
01475300	Darby Creek At Waterloo Mills Near Devon, Pa.		4/28/1972-9/30/1994 6/28/1996-9/30/1997
01475530	Cobbs Creek At U.S. Highway No. 1 At Phila., Pa.	1/1/1965-3/3/1980	10/1/1964-9/30/1981
01475510	Darby Creek Near Darby, Pa.		2/1/1964-10/3/1990
01475550	Cobbs Creek At Darby, Pa.	11/9/70-3/3/80	1/1/1964-10/3/1990
01475545	Naylor Creek At West Chester Pike Near Phila., Pa.		6/1/1972-10/20/1978
01475540	Cobbs Creek Below Indian Creek Near Upper Darby, Pa.	10/10/1967-2/7/1973	10/1/1964-6/30/1973

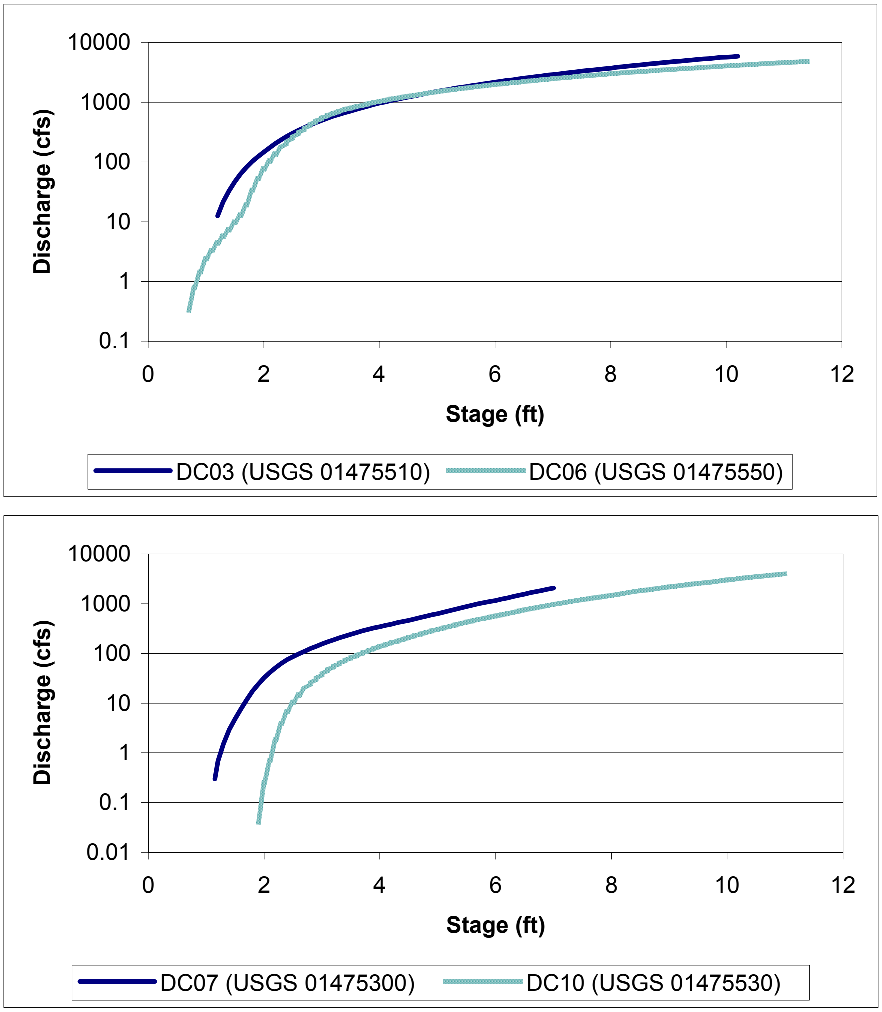


Figure 4-4 Historical Rating Curves for Four USGS Stations

4.3.1 Evaluation of Total Flow for Trends

Magnitude and Frequency of Flow

Cumulative distribution plots for each of the six gauges listed in Table 4-7 are presented in Figure 4-17. A cumulative distribution plot is a plot of discharge versus the percentage of time that a particular flow is not exceeded. These curves are not strictly probability curves because discharge is correlated to successive time intervals and is dependent upon season of the year. However, cumulative distribution plots provide a compact graphical summary of streamflow variability at the different gauging stations.

Trends in Total Flow

Modified Tukey box plots were used to identify seasonal discharge characteristics for both the upstream and downstream monitoring stations on Cobbs Creek. Tukey plots display statistical information including median, mean, minimum/maximum values, and selected percentile values as shown in Figure 4-5. Seasonal discharge characteristics are observed for an annual flow cycle using this approach. The discharge plots, discussed above, were used to delineate wet and dry flow regimes. A high flow season earlier in the year and a low flow season occurring later in the year are identified by the peak and trough locations on the plot. Discharges were plotted by weekly time segments, Figures 4-6 and 4-7, and monthly time segments, Figures 8-7 and 4-9.

Figures 4-10 and 4-11 present an analysis of the streamflow gauge data from USGS Gauge 01475300, Darby Creek at Waterloo Mills. This gauge is the only USGS gauge that remained operational through both the PWD/USGS Cooperative Program and the 1990s. Figure 4-10 shows an annual modified Tukey box plot of daily flow observations. This plot indicates that although average daily flow varies from year to year, generally, the flow regime has remained constant throughout the decades of the 1970s, 1980s, and 1990s. This observation holds even though some years the flows were statistically different from other years. Figure 4-11 shows the decade modified Tukey box plots. This plot indicated that although daily flows in the 1980s and 1990s are somewhat lower than flows in the 1970s, the differences are statistically insignificant.

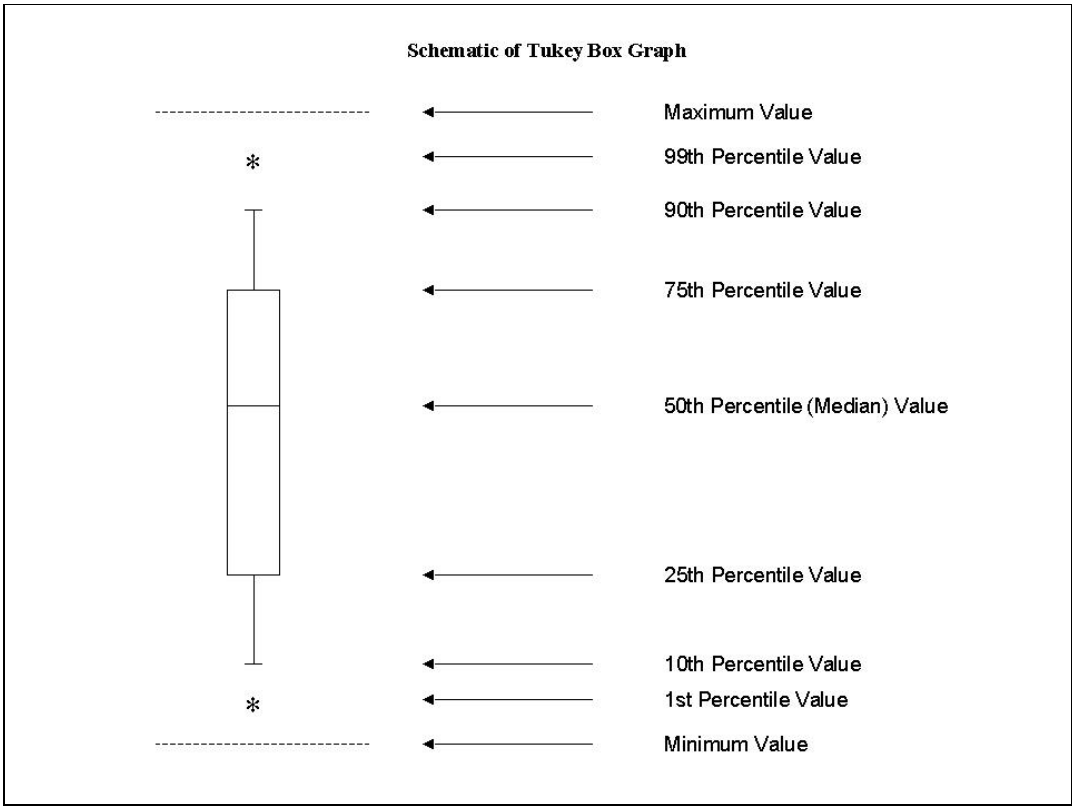


Figure 4-5 Explanation of Modified Tukey Box Plots

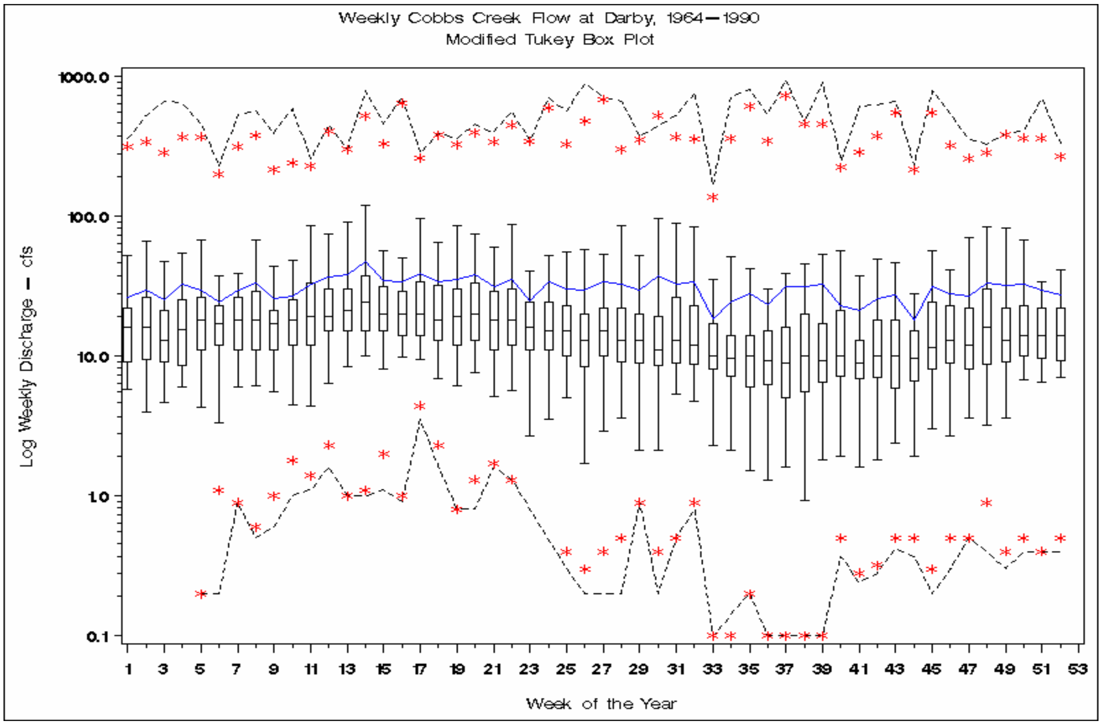


Figure 4-6

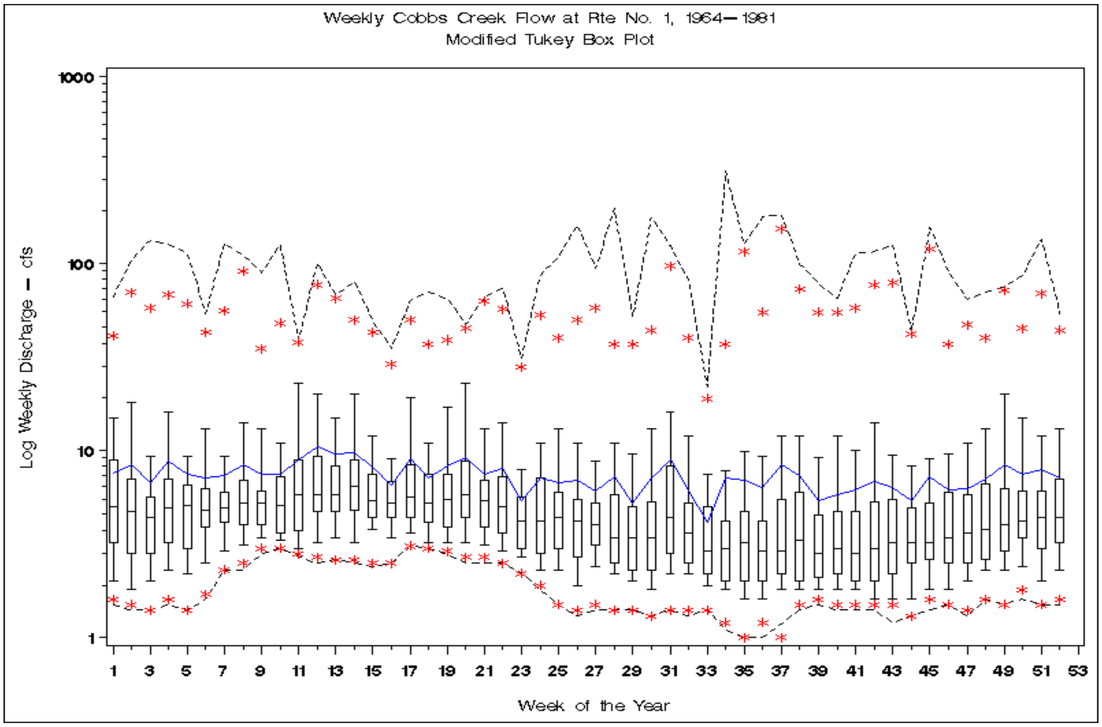


Figure 4-7

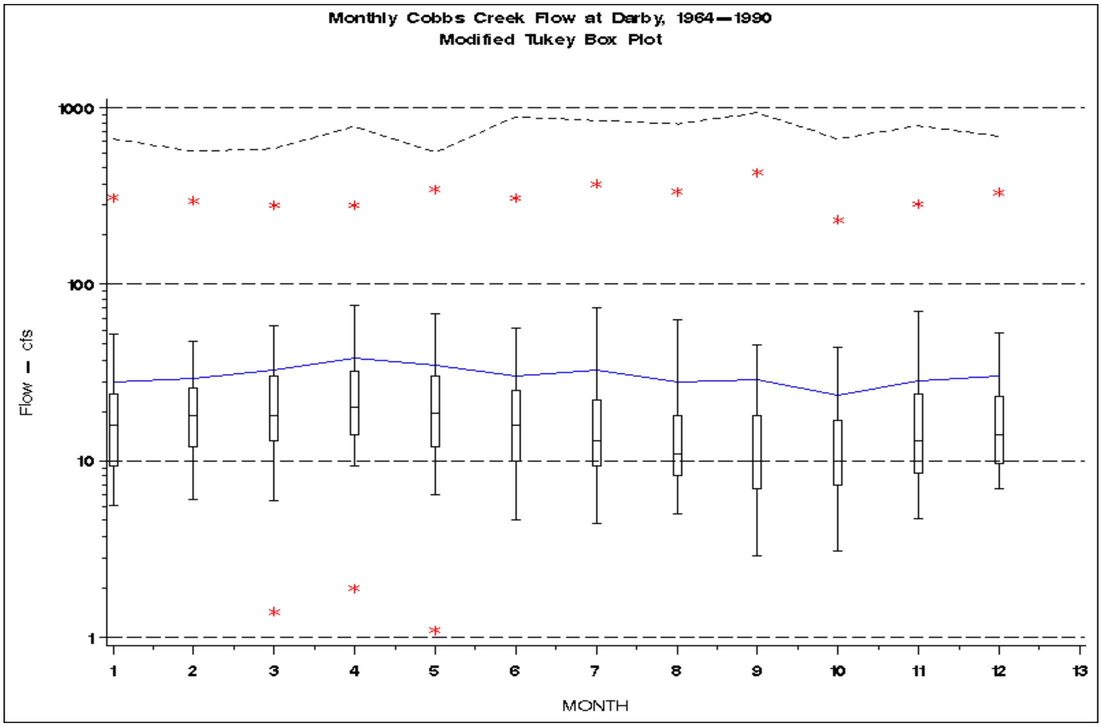


Figure 4-8

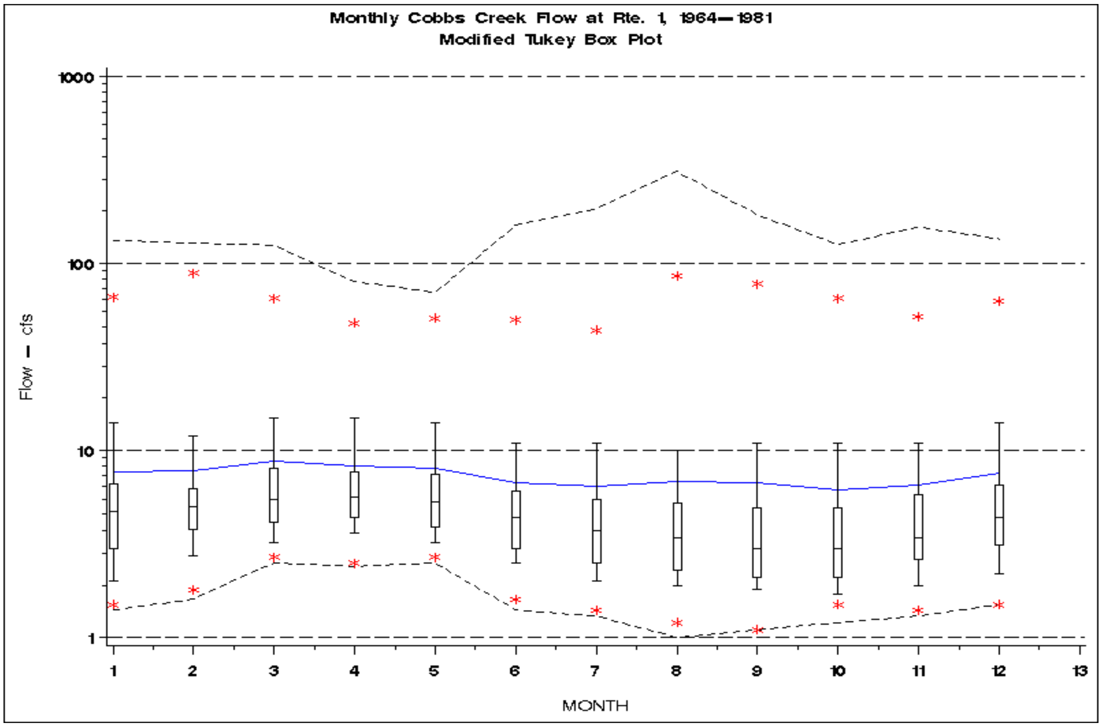


Figure 4-9

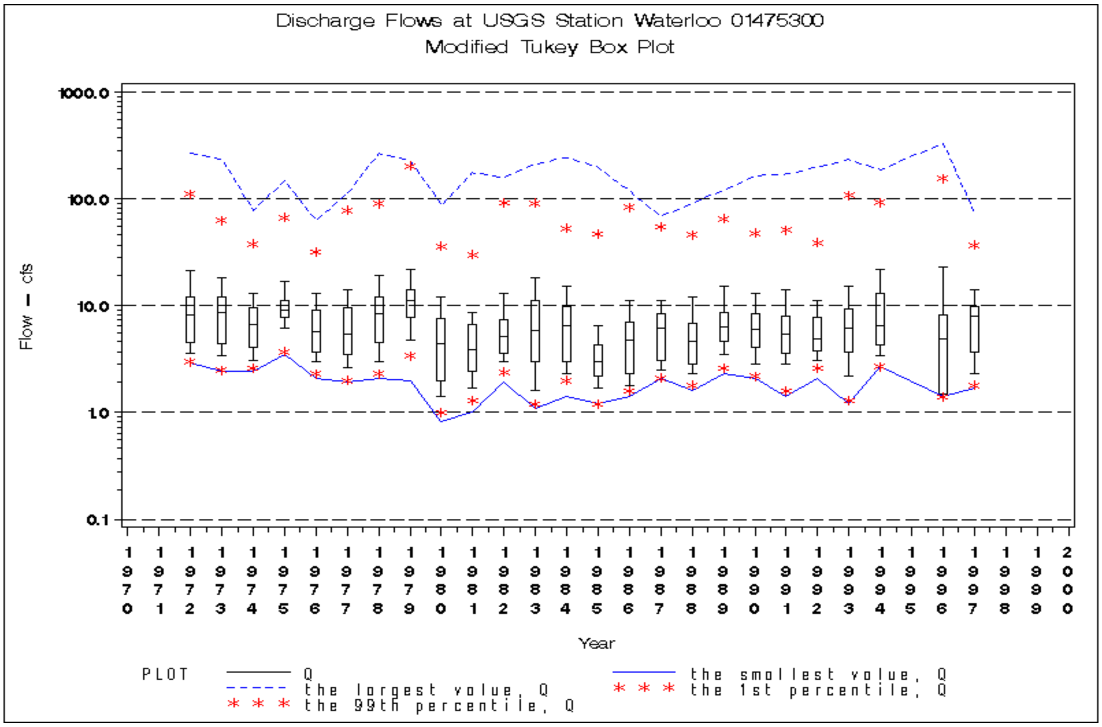


Figure 4-10

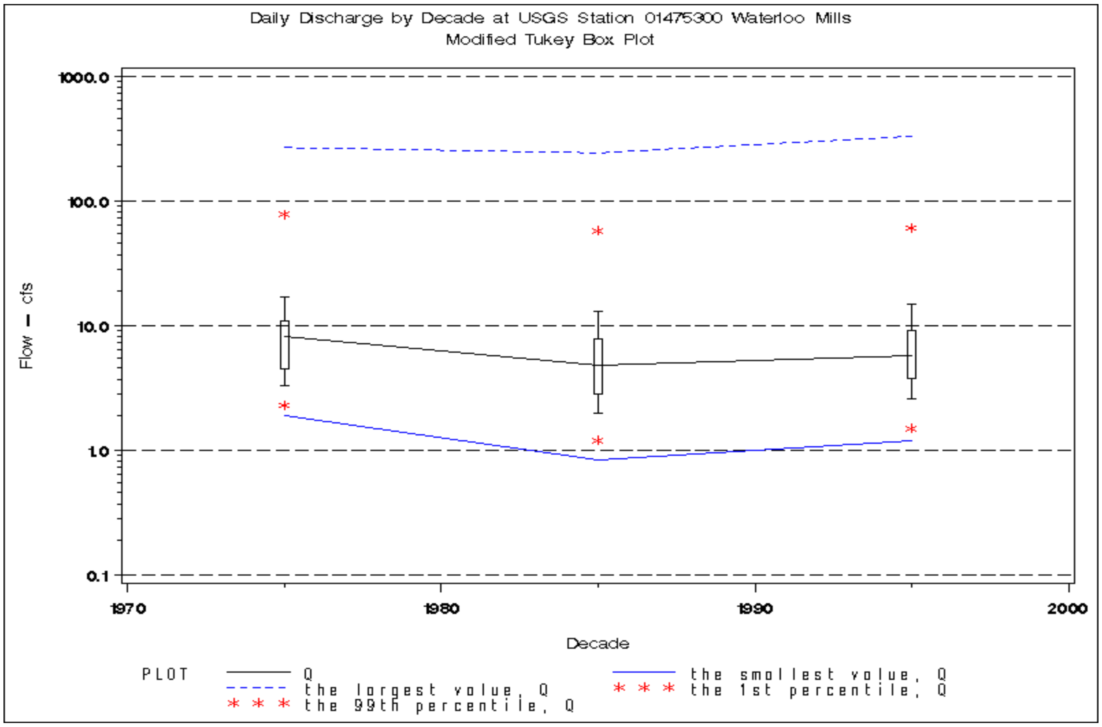


Figure 4-11

4.3.2 Hydrograph Decomposition Analysis

Areas and Gauges Studied

As discussed in Section 2, the Cobbs Creek watershed and the lower portions of the Darby Creek watershed are highly urbanized and contain a large proportion of impervious cover. The hydrologic impact of urbanization can be observed through analysis of streamflow data taken from USGS gauges on Darby and Cobbs Creeks. In addition, data from French Creek in Chester County provide a picture of a nearby, less-developed watershed. Table 4-8 lists four gauges with available data, including their locations, periods of record, and drainage areas.

Table 4-8 Data Used for Baseflow Separation

Gauge	Name	Period of Record (yrs)	Drainage Area (sq.mi.)	N (days)	2N* (days)
01472157	French Creek near Phoenixville Pa.	33.0	59.1	2.26	5
01475550	Cobbs Creek at Darby Pa.	26.7	22.0	1.86	3
01475510	Darby Creek near Darby Pa.	26.7	37.4	2.06	5
01475300	Darby Creek at Waterloo Mills Pa.	25.4	5.15	1.39	3

The interval 2N* used for hydrograph separations is the odd integer between 3 and 11 nearest to 2N. N is calculated based on watershed area.

Baseflow Separation

Baseflow due to groundwater inflow is the main component of most streams in dry weather. Baseflow slowly increases and decreases with the elevation of the shallow aquifer water table. In wet weather, a stormwater runoff component is added to the baseflow. Estimation and comparison of these two components can provide insights into the relationship between land use and hydrology in urbanized and more natural systems.

Baseflow separation was carried out following procedures similar to those found in the USGS "HYSEP" program. The following text is taken from "HYSEP: A COMPUTER PROGRAM FOR STREAMFLOW HYDROGRAPH SEPARATION AND ANALYSIS U.S. GEOLOGICAL SURVEY Water-Resources Investigations Report 96-4040":

"Hydrograph analysis is a useful technique in a variety of water-resource investigations. Separation of streamflow hydrographs into base-flow and surface-runoff components is used to estimate the ground-water contribution to streamflow. Hydrograph-separation techniques also have been used to quantify the ground-water component of hydrologic budgets and to aid in the estimation of recharge rates. In addition, base-flow characteristics determined by hydrograph separation of hydrographs from streams draining different geologic terrains have been used to show the effect of geology on base flow (Sloto and others, 1991, p. 29-33).

"The HYSEP program uses three methods to separate the base-flow and surface-runoff components of a streamflow hydrograph—fixed interval, sliding interval, and local minimum. These methods can be described conceptually as three different algorithms to systematically draw connecting lines between the low points of the streamflow hydrograph. The sequence of these connecting lines defines the base-flow hydrograph. The techniques were developed by Pettyjohn and Henning (1979). Hydrograph separations were performed for the streamflow-measurement station French Creek near Phoenixville, Pa., using three methods. Each method is described below.

The duration of surface runoff is calculated from the empirical relation:

$N=A^{0.2}$

where N is the number of days after which surface runoff ceases, and A is the drainage area in square miles (Linsley and others, 1982, p. 210).

"The interval 2N* used for hydrograph separations is the odd integer between 3 and 11 nearest to 2N (Pettyjohn and Henning, 1979, p. 31). For example, the drainage area at the streamflow-measurement station French Creek near Phoenixville, Pa. (USGS station number 01472157), is 59.1 mi2. The interval 2N* is equal to 5, which is the nearest odd integer to 2N, where N is equal to 2.26. The N and 2N* values used for the four gauges in this analysis were listed in Table 4-8.

"The hydrograph separation begins one interval (2N* days) prior to the start of the date selected for the start of the separation and ends one interval (2N* days) after the end of the selected date to improve accuracy at the beginning and end of the separation. If the selected beginning and (or) ending date coincides with the start and (or) end of the period of record, then the start of the separation coincides with the start of the period of record, and (or) the end of the separation coincides with the end of the period of record.

"The sliding-interval method finds the lowest discharge in one half the interval minus 1 day [0.5(2N*-1) days] before and after the day being considered and assigns it to that day. The method can be visualized as moving a bar 2N* wide upward until it intersects the hydrograph. The discharge at that point is assigned to the median day in the interval. The bar then slides over to the next day, and the process is repeated."

Summary Statistics

The results of the hydrograph decomposition exercise support the relationships between land use and hydrology discussed above. For convenience, the flows in Tables 4-9 and 4-10 are expressed as a mean depth (flow per unit area) over a one-year time period. Based on the French Creek gauge and the two Darby Creek gauges, the hydrologic behavior of these two systems is similar. Effective impervious cover allows sufficient groundwater recharge to give streamflow relatively natural characteristics; a mean of approximately 20% of annual rainfall contributes to the stormwater component of streamflow, and baseflow represents approximately 65% of total annual streamflow. This is fairly typical of streams in the Piedmont Province. Cobbs Creek exhibits behavior typical of a highly urbanized stream, with over 25% of rainfall contributing to stormwater runoff in a mean year and with mean baseflow comprising only 43% of mean annual streamflow.

Table 4-9 Summary of Hydrograph Separation Results Over the Period of Record

Gauge	Mean Total Flow (in/yr)	Mean Baseflow (in/yr)	Mean Runoff (in/yr)	Baseflow (% of Total Flow)	Runoff (% of Rainfall)
French Creek 01475127	20.3	12.9	7.4	64	18
Cobbs Creek 01475550	18.8	8.1	10.7	43	26
Darby Creek D/S 01475510	23.3	14.5	8.9	62	21
Darby Creek U/S 01475300	23.7	15.6	8.1	66	20

Table 4-10 Annual Summary Statistics for Baseflow and Stormwater Runoff

	Baseflow (in/yr)				Runoff (in/yr)			
	Mean	Max	Min	St.Dev.	Mean	Max	Min	St.Dev.
French Creek 01475127	12.9	20.8	5.8	3.8	7.4	15.4	2.9	3.1
Cobbs Creek 01475550	8.1	16.1	1.8	3.6	10.7	15.6	5.2	2.7
Darby Creek D/S 01475510	14.5	21.4	7.6	4.0	8.9	15.6	3.6	2.9
Darby Creek U/S 01475300	15.6	26.0	8.0	4.3	8.1	16.7	3.8	2.9

	Baseflow (% of Annual Rainfall)				Runoff (% of Annual Rainfall)			
	Mean	Max	Min	St.Dev.	Mean	Max	Min	St.Dev.
French Creek 01475127	31%	44%	15%	7%	17%	30%	7%	5%
Cobbs Creek 01475550	19%	31%	5%	7%	25%	33%	18%	3%
Darby Creek D/S 01475510	34%	44%	20%	8%	21%	31%	12%	4%
Darby Creek U/S 01475300	37%	51%	18%	9%	19%	32%	10%	5%

	Baseflow (% of Annual Total Flow)				Runoff (% of Annual Total Flow)			
	Mean	Max	Min	St.Dev.	Mean	Max	Min	St.Dev.
French Creek 01475127	64%	75%	53%	5%	36%	47%	25%	5%
Cobbs Creek 01475550	42%	54%	16%	10%	58%	84%	46%	10%
Darby Creek D/S 01475510	62%	75%	54%	6%	38%	46%	25%	6%
Darby Creek U/S 01475300	66%	78%	50%	6%	34%	50%	22%	6%

As expected, the quantity of stormwater runoff on a unit-area basis follows patterns of impervious cover in the drainage area. The French Creek watershed, the least developed, has the smallest amount of stormwater runoff both as an annual mean quantity (7.4 in) and as an annual mean percent of rainfall (17%). As expected, the highly-developed Cobbs Creek watershed has the most runoff both as an annual mean quantity (10.7 in) and as an annual mean percent of rainfall (25%). Further highlighting the effects of development, mean runoff from the Cobbs basin is almost 50% greater than mean runoff in the French Creek basin. The two Darby Creek gauges have an intermediate quantity of stormwater runoff; the downstream gauge, representing most of the Darby basin, has slightly more runoff (8.9 in) on a unit-area basis than the gauge representing the less-developed headwaters (8.1 in).

The summary statistics for stormwater runoff in Table 4-10 present some interesting results. The standard deviation of annual stormwater flows for Cobbs Creek, both in inches (2.7 in) and as a percentage of rainfall (3%), is the lowest of the four gauges studied, indicating that these flows are less variable from year to year. A possible explanation for this pattern is that the capture of some stormwater as part of combined sewage reduces the variability of runoff reaching streams.

Another interesting statistic is that the maximum annual amount of stormwater runoff as a percent of annual rainfall is between 30% and 33% for all four gauges. This result suggests that the maximum amount of runoff that can occur is dependent on the way the rainfall is distributed during the year. In a very wet year characterized by a significant number of larger (greater than 1 inch) storm events, saturated pervious cover responds more like impervious cover during the larger storms. If much of the total annual rainfall occurs in these larger storms (an unusual event), the annual runoff as a percent of total rainfall becomes similar for urbanized and less developed watersheds.

Expressing runoff as a percent of annual rainfall as in Table 4-10 provides an estimate of the upper bound of directly connected impervious area (DCIA), that portion of impervious surfaces that are hydraulically connected to the drainage system. In other words, percent DCIA may be less than this number but is no greater. Runoff from impervious surfaces that are not directly connected may ultimately infiltrate or evaporate rather than contributing to stormwater runoff. It is interesting to note that compared to the land use-derived estimates of total impervious cover presented in Section 4, estimated DCIA is no more than 55% of total impervious area in the Darby watershed and 51% in the Cobbs watershed. These estimates are calculated as the long-term mean runoff, as a percentage of rainfall, divided by the impervious cover estimate listed in Section 4. For example, runoff in the Cobbs watershed is 25% of rainfall on an annual mean basis, and impervious cover is estimated at 49% on an area-weighted basis. Therefore 25/49 = 51% is one estimate of DCIA.

The magnitude of groundwater-derived stream baseflow also depends on impervious cover because pervious areas are necessary for groundwater to recharge. As expected, the unit-area Cobbs Creek baseflows (8.1 inches) shown in Table 4-10 are smaller than those in either Darby Creek (15.6 inches upstream, 14.5 inches downstream) or French Creek (12.9 inches). Baseflow is between 62% and 66% of mean annual streamflow in Darby and French Creeks and only 43% of mean baseflow in Cobbs Creek. Although the Darby Creek watershed contains more impervious cover than the French Creek watershed, it has higher mean baseflows on a unit-area basis. The most likely explanation for this behavior is a difference in the groundwater yield of the geologic formations underlying each basin.

Example Time Series Graphs

Figures 4-12 through 4-14 provide some idea of trends in unit-area flow, baseflow, and runoff from year to year. Although there is considerable variability between years, flows at the four gauges generally follow the same patterns. For example, the Cobbs Creek gauge has the lowest unit-area baseflow and the highest stormwater runoff almost every year of the period of record. This agreement between gauges suggests that the conclusions drawn from long-term mean flows in the previous section are valid for most individual years.

The annual baseflow time series also demonstrates the effects of an extended drought period on stream baseflow in urbanized watersheds. During the drought years 1964-1965, rainfall was less than 30 inches compared to the annual mean of 41.5 inches. Baseflow was below average at the Darby and French Creek gauges, but it was extremely low at the Cobbs Creek gauge. When rainfall recovered to more typical levels in the ensuing years, baseflow at the Cobbs Creek gauge recovered more slowly than baseflow in the less urbanized basins. The data support the assertion that impervious cover increases a watershed's sensitivity to both extreme flood and extreme drought events.

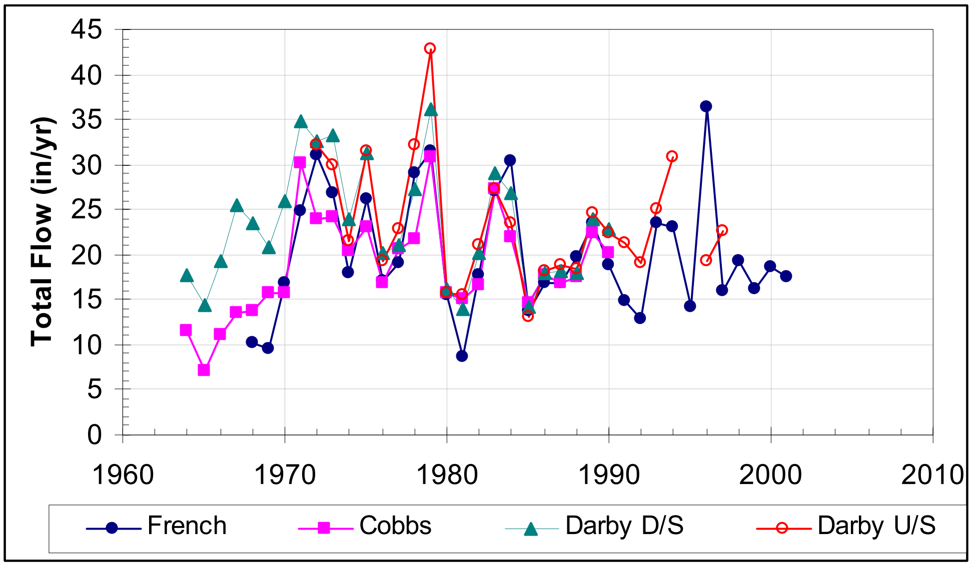


Figure 4-12

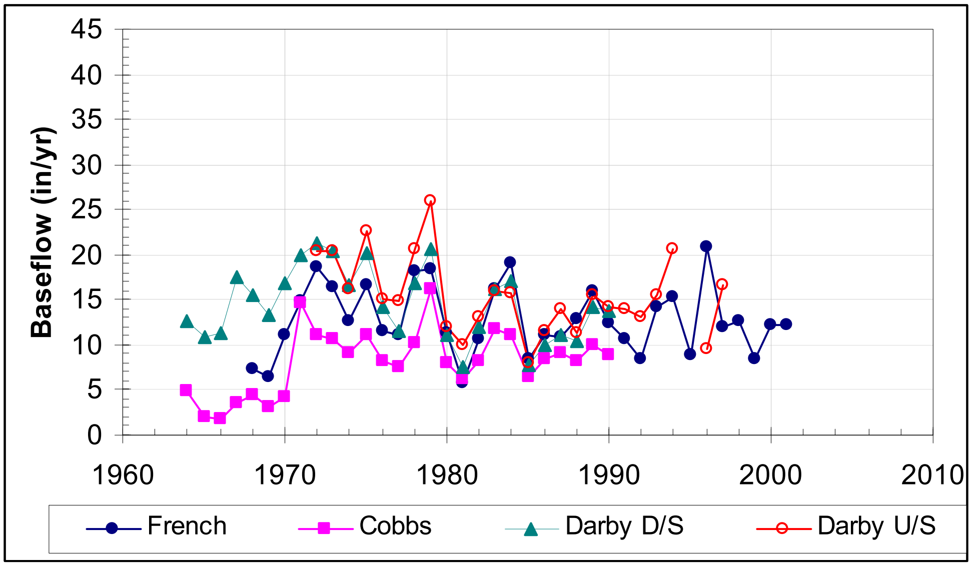


Figure 4-13

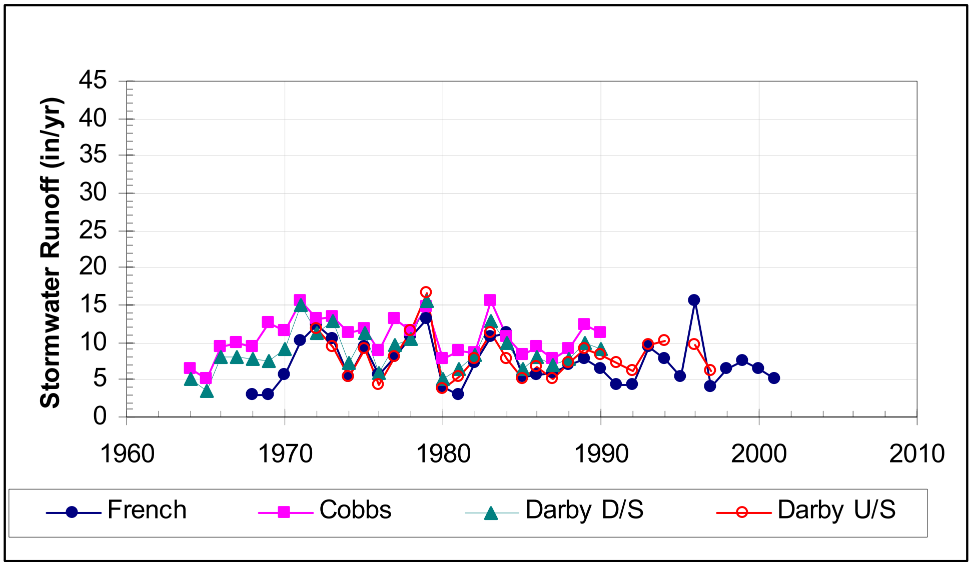


Figure 4-14

Cumulative Distribution

The cumulative distribution of average daily flow at the Cobbs and Darby gauges provides more evidence that the Cobbs gauge experiences greater extremes of flow. The graph shows the percent of daily flow observations (horizontal axis) that are equal to or less than a given value (on the vertical axis). For example, Figure 4-15 indicates that average daily flow at the Darby Creek gauge was less than 0.1 inches on about 90% of days observed. Cobbs Creek experiences greater extremes of flow than Darby Creek. On approximately 92% of days, flow in Cobbs Creek is less than flow in Darby Creek on a unit-area basis. On the driest 20% of days, flow in Cobbs Creek drops toward zero at a greater rate than flow in Darby Creek. On the wettest 8% of days, flow in Cobbs Creek is greater than flow in Darby Creek on a unit-area basis. These observations strengthen the evidence that Cobbs Creek is more prone to flash flooding than Darby Creek.

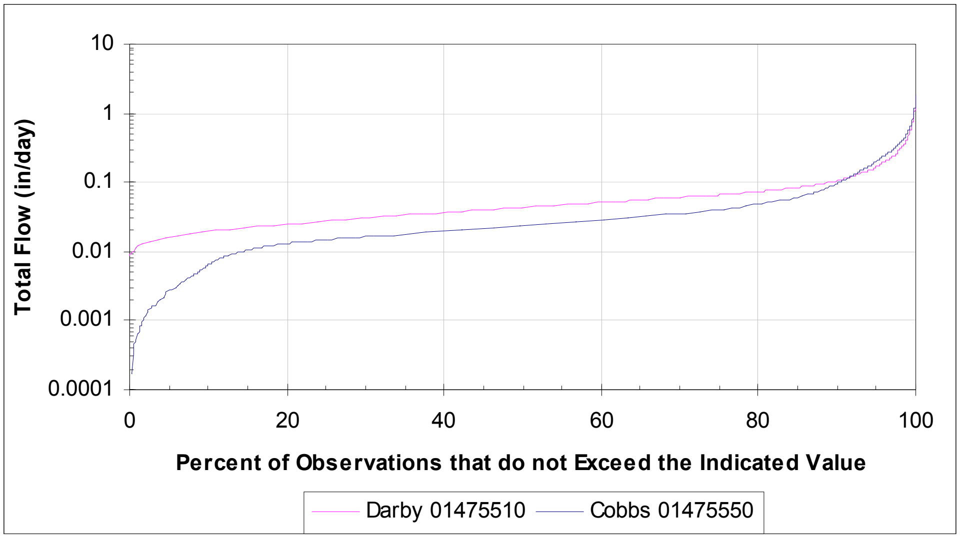


Figure 4-15 Cumulative Distribution of Total Flow

Another possible indicator of the degree of urbanization that was explored was a series of linear least-squares regressions of baseflow and runoff vs. seasonal rainfall. If the regression results were consistently strong (r^2 >= 0.90), then differences in slope and intersect between gauges might provide meaningful insights. However, regression results for baseflow vs. rainfall were poor, with r^2 values ranging from 0.11 to 0.40. Regression results for stormwater were better (Table 4-11) but still do not indicate a relationship strong enough to provide meaningful comparisons of different gauges over short periods of time. It is interesting to note that runoff and rainfall appear to be more closely correlated in more impervious basins.

Table 4-11 Correlation Coefficient of Stormwater Runoff and Rainfall

	Cobbs	Darby
Fall	0.73	0.66
Winter	0.76	0.67
Spring	0.90	0.82
Summer	0.63	0.54

A final indicator that was explored compared runoff as a percent of rainfall in one system to runoff as a percent of rainfall in a reference system. If this relationship were relatively constant from year to year, then it might provide a way to track changes in watershed conditions over a relatively short period of time. However, Figure 4-16 demonstrates that while runoff as a percent of rainfall is almost always greater in the Cobbs Creek watershed than in the French Creek watershed, the ratio between the two systems varies substantially from year to year. For this reason, this ratio is not likely to be a good indicator of hydrologic trends over time.

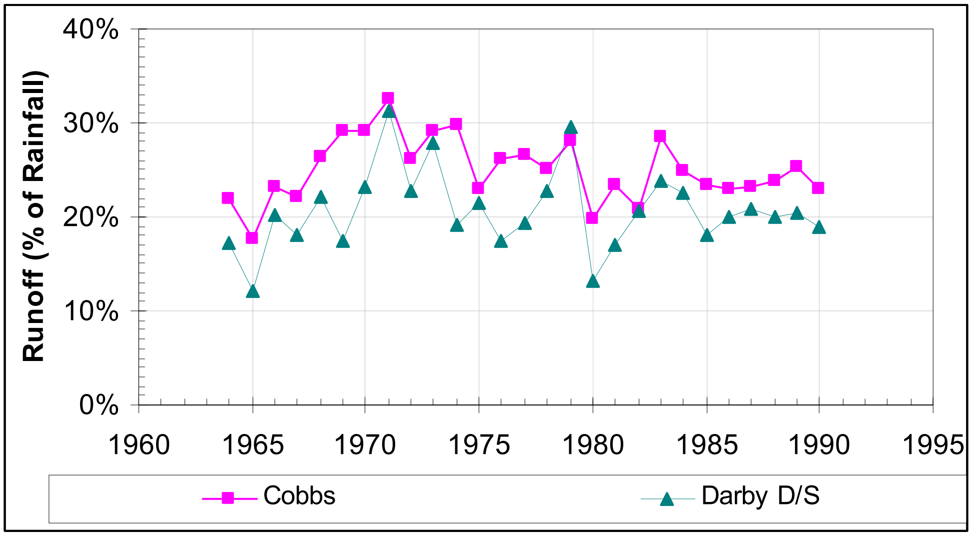


Figure 4-16 Runoff as a Percent of Rainfall in Two Systems

Characterization of Wet and Dry Weather Sampling Periods

The evaluation of water quality data begins with the segregation of water quality observations into wet and dry weather periods. This classification is based upon a combination of the following three factors: streamflow data when available, rainfall, and CSO occurrence data. To characterize the streamflow, cumulative distribution plots based on average daily USGS streamflow are plotted. Figure 4-17 shows the cumulative distribution for the six historical gauges on an annual basis. Because approximately 100 days per year are impacted by wet weather in the Philadelphia region, the 75th percentile flow for a particular stream is taken as a rough estimation of baseflow on a seasonal basis. This forms one basis for classification of wet and dry sampling periods. However, the lack of streamflow data and the fact that precipitation is spatially variable shifts focus towards the CSO occurrence data. Hence the evidence of CSO occurrence anywhere in the system becomes the main basis for characterizing the sampling periods as wet or dry.

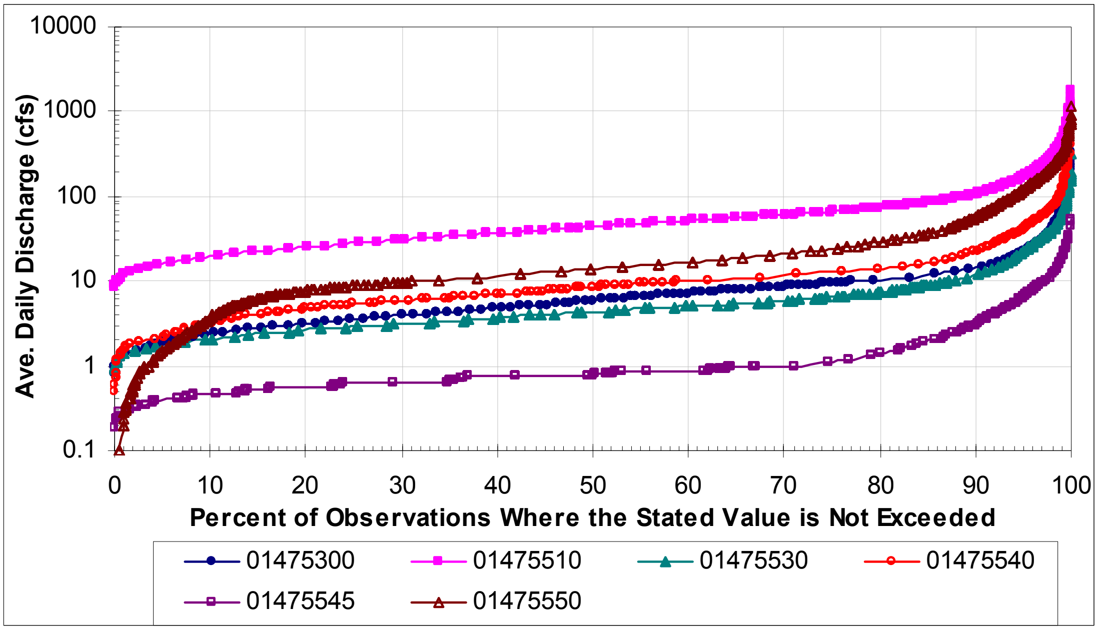


Figure 4-17 Cumulative Distribution of Historical USGS Gauge Data

Table 4-12 Wet Weather/Dry Weather Flow Estimates for Historical USGS Gauge Data

Gauge Name	Gauge Number	Season	Q3 (75%) (cfs)
Darby Creek at Waterloo Mills Near Devon	01475300	Annual	9.6
Darby Creek at Waterloo Mills Near Devon	01475300	Winter	11
Darby Creek at Waterloo Mills Near Devon	01475300	Spring	11
Darby Creek at Waterloo Mills Near Devon	01475300	Summer	5.4
Darby Creek at Waterloo Mills Near Devon	01475300	Fall	6.3
Darby Creek Near Darby	01475510	Annual	67
Darby Creek Near Darby	01475510	Winter	75
Darby Creek Near Darby	01475510	Spring	78
Darby Creek Near Darby	01475510	Summer	48
Darby Creek Near Darby	01475510	Fall	47
Cobbs Creek at US Hwy 1 At Philadelphia	01475530	Annual	6.5
Cobbs Creek at US Hwy 1 At Philadelphia	01475530	Winter	6.9
Cobbs Creek at US Hwy 1 At Philadelphia	01475530	Spring	7.3
Cobbs Creek at US Hwy 1 At Philadelphia	01475530	Summer	5.2
Cobbs Creek at US Hwy 1 At Philadelphia	01475530	Fall	5.5
Cobbs Creek Below Indian Creek Near Upper Darby	01475540	Annual	13
Cobbs Creek Below Indian Creek Near Upper Darby	01475540	Winter	15
Cobbs Creek Below Indian Creek Near Upper Darby	01475540	Spring	13
Cobbs Creek Below Indian Creek Near Upper Darby	01475540	Summer	10
Cobbs Creek Below Indian Creek Near Upper Darby	01475540	Fall	11
Naylor Creek at West Chester Near Philadelphia	01475545	Annual	1.2
Naylor Creek at West Chester Near Philadelphia	01475545	Winter	1.3
Naylor Creek at West Chester Near Philadelphia	01475545	Spring	1.3
Naylor Creek at West Chester Near Philadelphia	01475545	Summer	1.0
Naylor Creek at West Chester Near Philadelphia	01475545	Fall	1.0
Cobbs Creek at Darby	01475550	Annual	24
Cobbs Creek at Darby	01475550	Winter	25
Cobbs Creek at Darby	01475550	Spring	29
Cobbs Creek at Darby	01475550	Summer	19
Cobbs Creek at Darby	01475550	Fall	20

An example of trends in rainfall and corresponding CSOs can be observed in Figures 4-18 and 4-19. Figure 4-17 shows rainfall and CSO data for three CSO outfalls for the period May 23 to 27, 1999. A total of 2.75 inches of rain occurs during the period and CSOs are active. Because CSOs are observed at multiple points in the system, it can be inferred that sampling sites throughout the system are impacted by CSO and stormwater. The discrete sampling done on May 25, 1999 was thus called a wet day. Figure 4-19 shows rainfall and CSO data for the period May 31 to June 4, 1999. This period is classified as dry because neither rainfall nor CSO occurs. Table 4-13 shows the wet or dry categorization of sampling periods when discrete samples were collected. Table 4-14 lists the wet dates in the continuous monitoring or Sonde deployment periods.

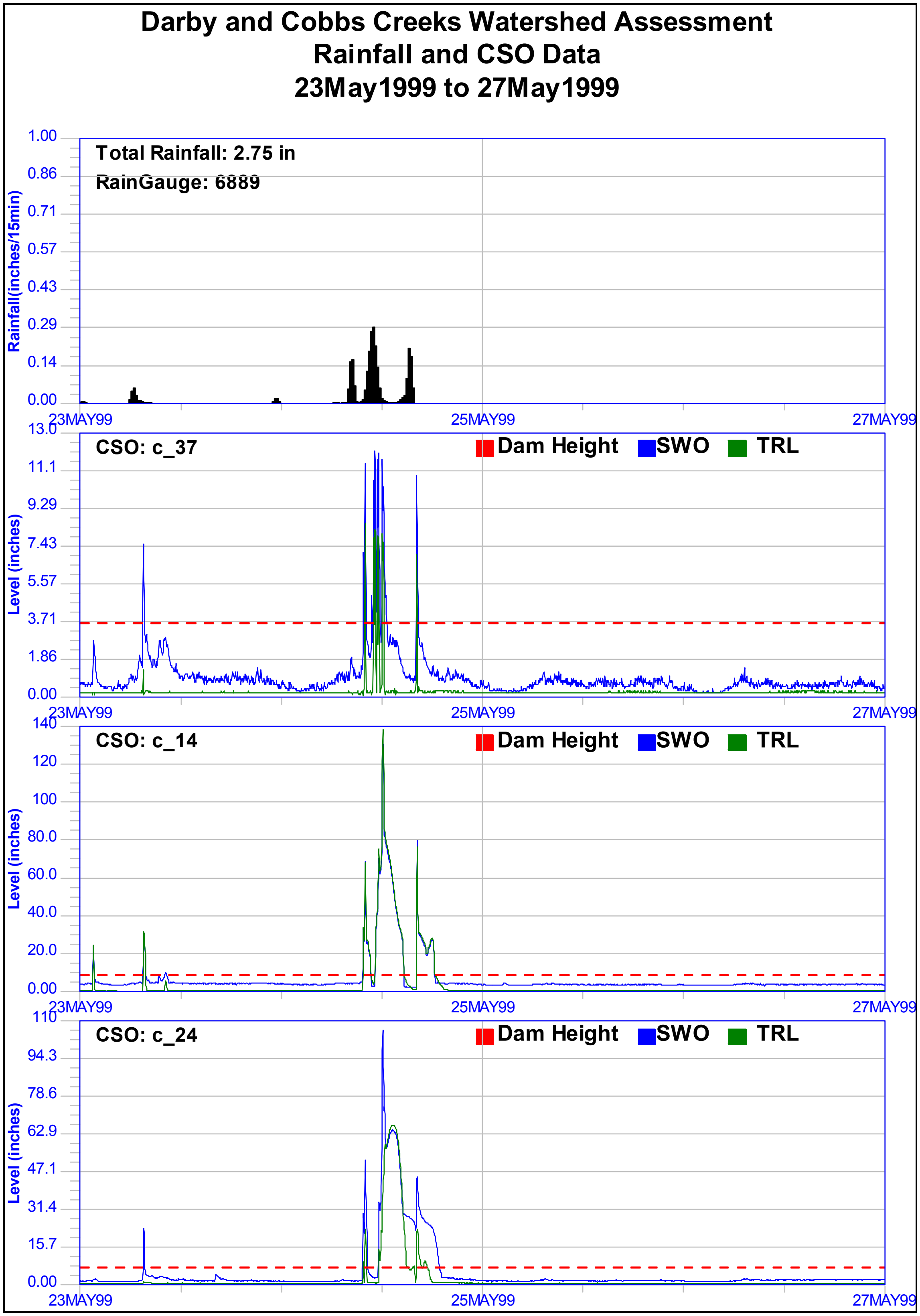


Figure 4-18 Rainfall and CSO plot for a wet period

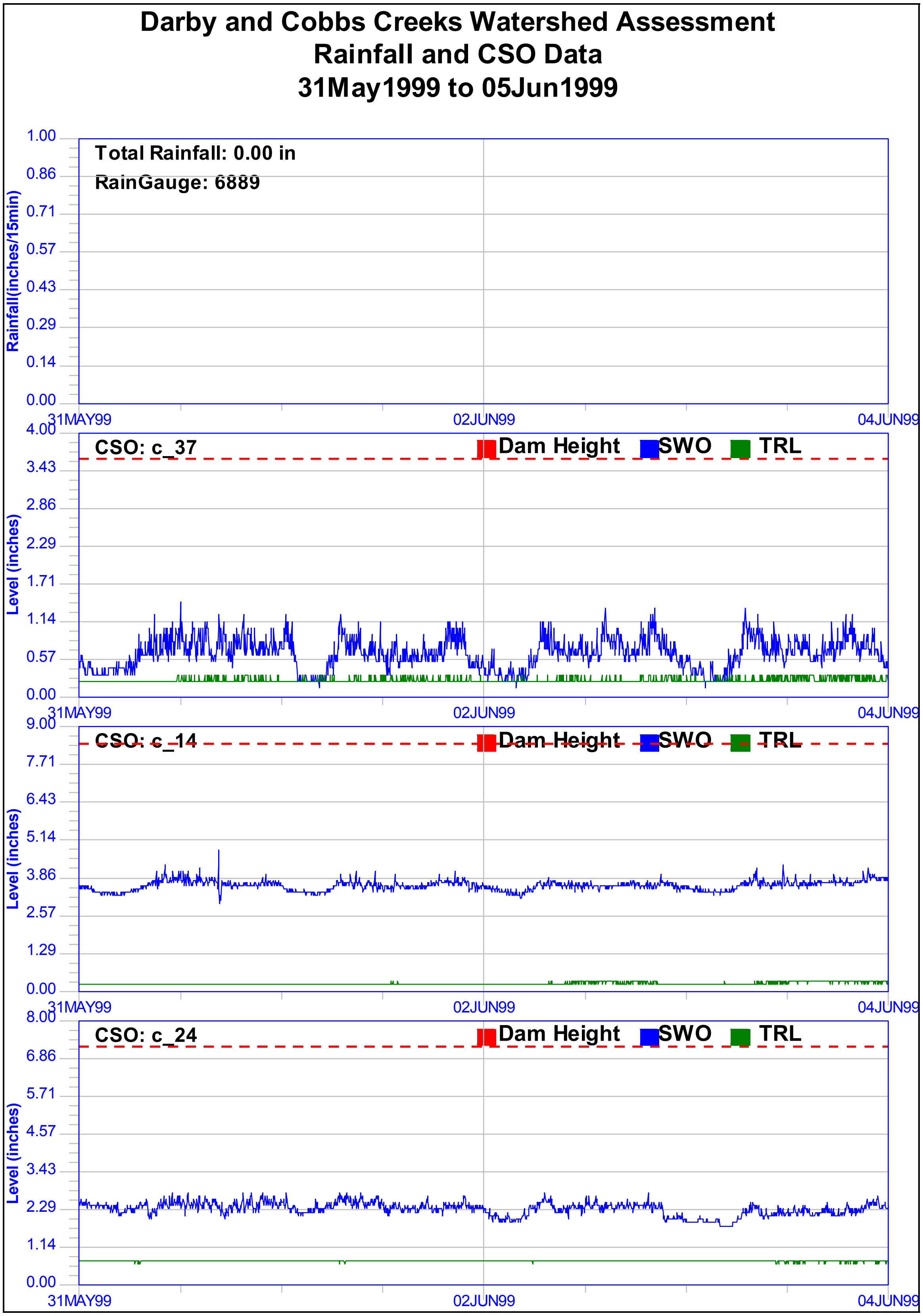


Figure 4-19 Rainfall and CSO plot for a Dry period

Table 4-13 Wet and Dry Period Characterization

Date/Period	Weather Status	Sampling Type
5/11/1999	DRY	Discrete
5/18/1999	DRY	Discrete
5/25/1999	WET	Discrete
6/2/1999	DRY	Discrete
6/8/1999	DRY	Discrete
6/15/1999	WET	Discrete
6/22/1999	WET	Discrete
6/29/1999	WET	Discrete
7/13/1999	DRY	Discrete
7/20/1999	WET	Discrete
6/1/2000	DRY	Discrete
6/12/2000	WET	Discrete
6/15/2000	WET	Discrete
6/29/2000	WET	Discrete
7/13/2000	DRY	Discrete
5/23-26/2000	WET	WETW
6/6-8/2000	WET	WETW
7/24-28/2000	WET	WETW

WETW = Series of samples taken during a wet weather hydrograph, but the first sample is taken in dry weather before the forecast storm.

Table 4-14 Wet Weather Days of Continuous Sampling Periods

Date/Period	Wet Weather Dates
07/09/99 To 07/13/99	--
07/14/99 To 07/22/99	07/20
08/14/99 To 08/20/99	08/14, 08/15, 08/16
08/26/99 To 09/03/99	08/26, 08/27
09/09/99 To 09/17/99	09/10, 09/16
09/15/99 To 09/21/99	09/16
02/11/00 To 02/27/00	02/13, 02/19
02/25/00 To 03/10/00	02/27
03/03/00 To 03/19/00	03/11, 03/17
04/28/00 To 05/06/00	--
05/18/00 To 06/03/00	05/19, 05/20, 05/24
06/02/00 To 06/16/00	06/06, 06/12, 06/14
06/16/00 To 06/30/00	06/18, 06/22, 06/29
07/14/00 To 08/05/00	07/14, 07/16, 07/19, 0727, 07/31, 08/03
08/09/00 To 08/25/00	08/11, 08/14
08/24/00 To 09/09/00	08/27, 08/31, 09/01, 09/03
09/01/00 To 09/09/00	09/01, 09/03
09/12/00 To 09/24/00	09/13, 09/15, 09/19
09/27/00 To 10/07/00	10/05
10/13/00 To 10/27/00	10/18
11/06/00 To 11/18/00	11/10, 11/14
05/11/01 To 05/25/01	05/21, 05/22, 05/23
07/26/01 To 08/11/01	07/26, 07/29, 08/03, 8/10
09/07/01 To 09/21/01	09/14
11/14/01 To 11/28/01	11/25
12/05/01 To 12/19/01	12/08
01/15/02 To 02/02/02	01/24

4.4 Flooding

Introduction

A stormwater management plan has been prepared for the watershed by Delaware County under Pennsylvania's Act 167, the Storm Water Management Act of 1968. The Act 167 report contains a more detailed listing of flooding "trouble spots" and floodplain obstructions.

The Darby Creek Watershed River Conservation Plan discusses the role of floodplains and riparian areas in flood control: "Floodplains and the riparian areas buffering streams, rivers, lakes, and other water bodies are especially sensitive watershed zones. In their naturally vegetated and undisturbed state, floodplains and riparian areas provide critical stormwater management and flood control functions, both in terms of water quantity and water quality. For example, floodplains intercept and reduce unmanaged sheet flow runoff and absorb/contain out-of-bank flows as storms increase in intensity. Flood flows are stored, detained, and infiltrated into the vegetated floodplain zone."

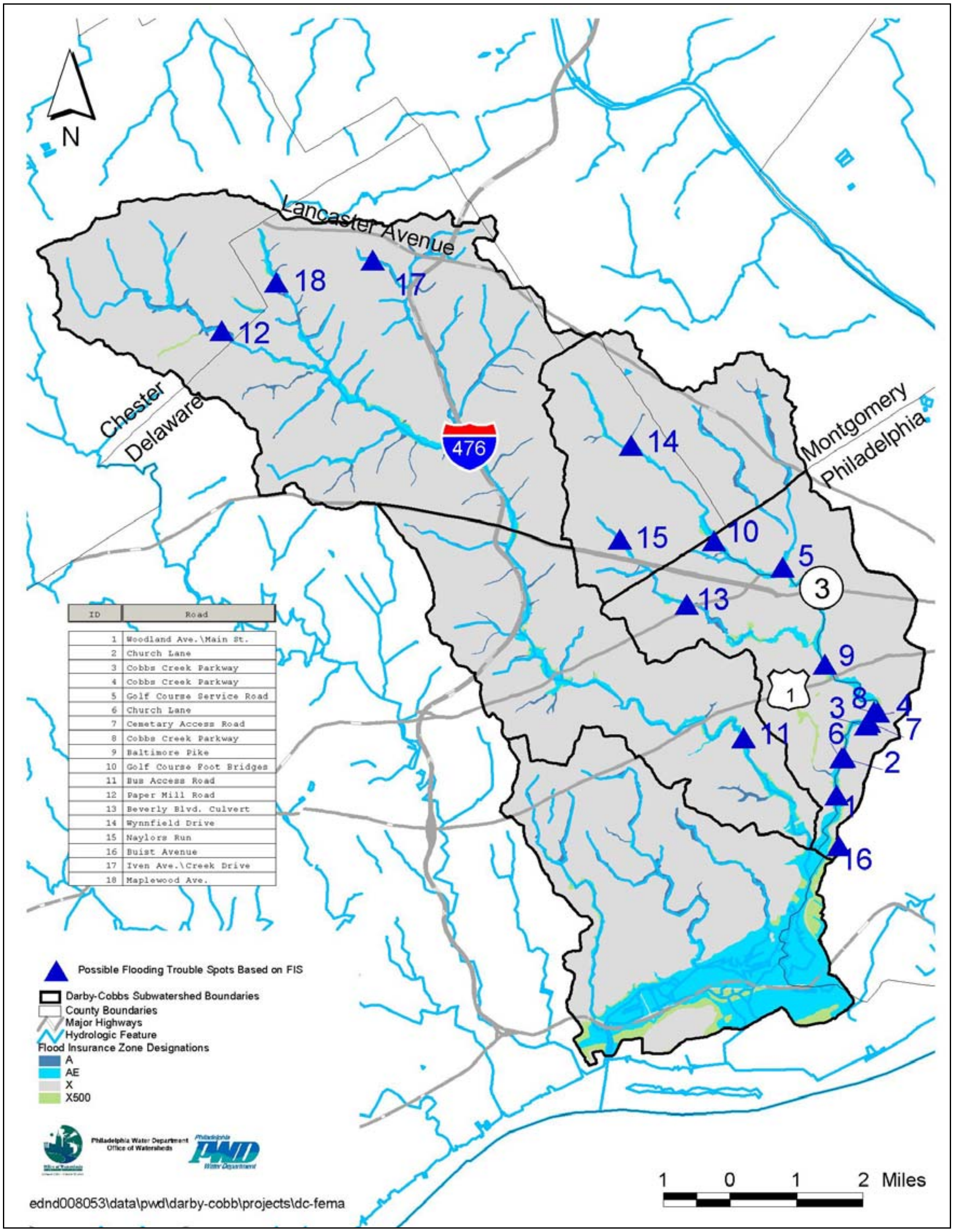
Frequent damaging flooding does not appear to be a major concern within the study area. However, frequent smaller events of flooding occur in some locations, and damaging flooding has occurred during very large storms.

FEMA Floodplains and Flood Insurance Rate Maps

Information on floodplain extents, historical flooding events, and flood insurance rates is available from FEMA and provides an idea of flood hazards in the study area. The flood insurance rate map (Figure 4-20) provides a quick idea of the areas in the watershed that may experience flooding. As summarized in Table 4-15, Zones A and AE are areas where flooding is likely (1% or greater annual chance of occurrence) and zones X and X500 are areas where flooding is unlikely (less than an annual 1% chance due to elevation or flood protection structures). Conditions within the individual subwatersheds (i.e. Cobbs Creek, Darby Creek, and Tinicum) are discussed below.

Table 4-15 National Flood Insurance Program Zone Designations

Zone	Description
A	Zone A is the flood insurance rate zone that corresponds to the 100-year floodplains that are determined in the FIS by approximate methods. Because detailed hydraulic analyses are not performed for such areas, no base flood elevations or depths are shown within this zone. Flood insurance is generally mandatory in these zones.
AE	Zone AE is the flood insurance rate zone that corresponds to the 100-year floodplains that are determined in the FIS by detailed methods. In most instances, whole-foot base flood elevations derived from detailed hydraulic analyses are shown at selected intervals within this zone. Flood insurance is generally mandatory in these zones.
X and X500	Zone X is the flood insurance rate zone that corresponds to areas outside the 500-year floodplain, areas within the 500-year floodplain but not the 100-year floodplain (X500), and to areas of 100-year flooding where average depths are less than 1 foot, areas of 100-year flooding where the contributing drainage area is less than 1 square mile, and areas protected from the 100-year flood by levees. No base flood elevations or depths are shown within this zone. Flood insurance is generally not mandatory in these zones.



ID	Road
1	Woodland Ave.\Main St.
2	Church Lane
3	Cobbs Creek Parkway
4	Cobbs Creek Parkway
5	Golf Course Service Road
6	Church Lane
7	Cemetary Access Road
8	Cobbs Creek Parkway
9	Baltimore Pike
10	Golf Course Foot Bridges
11	Bus Access Road
12	Paper Mill Road
13	Beverly Blvd. Culvert
14	Wynnfield Drive
15	Naylors Run
16	Buist Avenue
17	Iven Ave.\Creek Drive
18	Maplewood Ave.

Figure 4-20 FEMA Flood Insurance Rates and Possible Flooding Areas

Table 4-16 Potential Flooding Locations Identified by County FEMA Studies

County	Sheet	Creek	River Mile (ft)	Road Crown/Bridge Deck Below 50-Yr Flood Elevation
Philadelphia	07P	Cobbs	5,750	Woodland Ave./Main Street (just above 10-yr)
Philadelphia	07P	Cobbs	9,000	Church Lane
Philadelphia	08P	Cobbs	13,150	Cobbs Creek Parkway (below 10-yr)
Philadelphia	09P	Cobbs	14,500	Cobbs Creek Parkway
Philadelphia	17P	Indian	400	golf course service road
Delaware	29P	Cobbs	8,850	Church Lane
Delaware	30P	Cobbs	13,550	cemetery access road (below 10-yr)
Delaware	30P	Cobbs	14,350	Cobbs Creek Parkway (below 10-yr)
Delaware	31P	Cobbs	21,550	Baltimore Pike (just below 50-yr)
Delaware	35P	Cobbs	40,000	golf course foot bridges
Delaware	58P	Darby	40,700	bus access road, MacDade Blvd.
Delaware	64P	Darby	110,800	Paper Mill Road
Delaware	100P	Naylors	6,864	Beverly Blvd. culvert inlet / Beverly Blvd.

Floodplains and Flooding in the Cobbs Creek Subwatershed

Indian Creek and the upper and middle reaches of Cobbs Creek flow through Morris Park and Cobbs Creek Park, moderately sloped parkland where floodplain development is limited. This extensive undisturbed riparian area provides a hydrologic, aesthetic, and recreational benefit to the surrounding neighborhoods. The floodplain along the lower reaches of Cobbs Creek is relatively flat, and the original floodplain has been covered with fill material.

FEMA's Flood Insurance Study for Philadelphia (FEMA, 1996) indicates that low-lying portions of the greater Philadelphia area have experienced damaging flooding in the past during major tropical events, including Hurricanes Connie and Dianne in August 1955 and Hurricane Agnes in June 1972.

The FIS mentions that in 1974, Haverford Township experienced flooding problems along Cobbs Creek due to flow restrictions caused by a box culvert under Wynnfield Drive. This culvert may flood to a depth of four feet or more during intense rain events. Flooding is also known to occur along Naylors Run in Haverford Township.

The extreme southern reaches of Cobbs Creek, including portions of the Eastwick neighborhood, have experienced flooding during these events. On August 19, 1955, the Philadelphia Evening Bulletin noted "flooding of a portion of Eastwick near Buist Avenue to depth of ten feet over Cobbs Creek's banks and 400 evacuated by boat." Portions of the Eastwick neighborhood were also flooded in September 1999 as the remnants of Hurricane Floyd passed over the east coast. This area has existing flood protection measures, and future enhancement of these measures is under consideration by the Philadelphia Redevelopment Authority.

Flood profiles based on HEC-1/HEC-2 modeling from FEMA's Flood Insurance Study identify a few points where the crowns of roads may lie within the 50-year floodplain. Along Cobbs Creek, these include Cobbs Creek Parkway, Woodland Ave., and Church Lane. The crown of Beverly Boulevard is below the 50-year flood level where it crosses Naylors Run.

Floodplains and Flooding in the Darby Creek Subwatershed

The following text is taken from the Darby Creek Watershed River Conservation Plan:

"Over the years, development has encroached substantially into floodplains of the Darby Creek Watershed. In many places, this development has resulted in total stream enclosure/burial with virtual elimination of any semblance of the floodplain. Elsewhere, streams have been substantially channelized with structures that are built into and on the floodplain. Fill has been placed within floodplain areas to accommodate parking, roads, and other development elements, resulting in a broad array of impacts on natural floodplain functions. Even the relatively inoffensive clearing of floodplain areas with replacement as lawn and other landscaped areas takes its toll on the important water quality and water quantity functions of the natural floodplain.

"A major problem, as the data indicate, is that so much of the Darby Creek Watershed has been developed before the emergence of any floodplain regulations, the most notable of which are the Federal Emergency Management Agency (FEMA) set of minimum floodplain standards, which were modified and made more rigorous in the mid-1990's. At this time, virtually all of the 31 municipalities of the Darby Creek Watershed participate in the FEMA floodplain program; East Lansdowne is the one municipality in Delaware County which is not required to participate in the FEMA program. Most municipalities have incorporated minimum FEMA standards into their respective codes and ordinances, although some municipalities in Delaware County may not be in strict compliance with the FEMA program, especially given the FEMA program changes which occurred in the mid 1990's. (According to William Gothier at the Delaware County Conservation District, several municipalities may be in violation of FEMA program requirements; in cases of non-compliance with elements of the National Flood Insurance Program, municipalities could be suspended from the FEMA program and held responsible if flooding damages were to occur; in these cases, homeowners would be deprived of flood protection as part of the NFIP). In any case, a cursory review of the municipal ordinances requested from and made available by the municipalities for this RCP indicates that most municipalities have not gone beyond FEMA minimum requirements, although they are constitutionally enabled to enact more rigorous floodplain and riparian zone controls."

The FEMA Flood Insurance Study for Delaware County (1993) compiled flooding information from a number of anecdotal sources. It describes widespread flooding during Tropical Storms Diana in 1955, Hurricane Donna in 1960, a stationary front in September 1971, and Hurricane Agnes in 1972. In addition, it describes periodic flooding along Darby and Little Darby Creeks in Radnor Township due to undersized culverts; flooding occurs along Little Darby Creek behind Maplewood Avenue at the Mill Dam Club approximately once a year according to residents. Also in Radnor, flooding occurs along Ithan Creek due to undersized culverts in the vicinity of Iven Avenue and Creek Drive near the Township Building. The FEMA study mentions a flood control dam in Naylors Run Park and a detention basin on Naylors Run between Garrett Road and Sherbrook Boulevard, but states that the effectiveness of these measures has not been thoroughly tested. There are four dams in Upper Darby Township and one in Clifton Heights Borough, but these are not thought to perform significant flood control functions.

Low-lying points on roads identified from FEMA flood profiles are shown on Figure 4-20. These are defined as having a crown elevation below the 50-year flood elevation at the point of stream crossing, and include points on Church Lane, Cobbs Creek Parkway, and Baltimore Pike.

Floodplains and Flooding in the Tinicum Subwatershed

Darby Creek discharges to the Delaware River through the wetlands of the Tinicum Wildlife Refuge. In addition, developed areas within Tinicum Township drain directly to the wetlands. Virtually all of the watershed within the Tinicum area lies within the 100-year floodplain and is flood-prone, although flood protection and tidal control structures are in place along portions of Darby Creek, Long Hook Creek, and along many roads. Interstate 95 is built on fill material and forms a barrier to flood waters south of the highway. Development is prohibited within the Tinicum Wildlife Preserve itself (FEMA, 1996).

Section 5 Characterization of Water Quality

The purpose of this section is to characterize existing water quality in the surface waters of the Darby and Cobbs Creeks watershed. The watershed is divided into five sections: upper and lower Cobbs Creek, upper and lower Darby Creek, and the Tinicum area. Each section is represented by two to three sampling sites. Detailed information on the sampling sites is available in Section 3.

5.1 Historical Water Quality

5.1.1 PWD/USGS Cooperative Program (Water Quality and Flow Data)

In the early 1970's, the Philadelphia Water Department began a study in cooperation with the U.S. Geological Survey titled, "Urbanization of the Philadelphia Area Streams." The purpose of this study was to quantify the pollutant loads in some of Philadelphia's streams and possibly relate the degradation in water quality to urbanization. Two of the stations sampled for the study were in the Darby and Cobbs Creeks Watershed: Station 12, Cobbs Creek at U.S. Route 1, and Station 15, Cobbs Creek at Darby. Monthly "snapshot" water quality samples were collected at each site and analyzed for conductivity, BOD_5, total phosphate, ammonia, nitrite, nitrate, and fecal coliform. The program collected about 10 years of monthly samples. The water quality data collected for the Cobbs Creek stations showed a significant increase in BOD_5, ammonia, total phosphate, and fecal coliform between the upstream (12) and downstream (15) stations. These increases were attributed to malfunctioning regulators and higher pollutant loading rates during storm events. The loading rates were compared with estimates based on sampling data collected during the Phase I Reconnaissance Survey. The comparison is in Section 9 of the Comprehensive Characterization Report. Figure 5.1 shows the locations of the two monitoring stations from the PWD/USGS Cooperative Program. Also indicated on Figure 5.1 are the two locations where water quality samples were obtained during the 10 year study.

Partially through the cooperative program, the USGS also established streamflow gauging stations at six locations in the Darby and Cobbs Creeks Watershed. These locations are shown on Figure 5.1 and listed in Table 5.1. Table 5.2 contains summary information at each of the gauging stations for their respective periods of record. Historical rating curves are available for four of the stations and are shown in Figure 5.2.

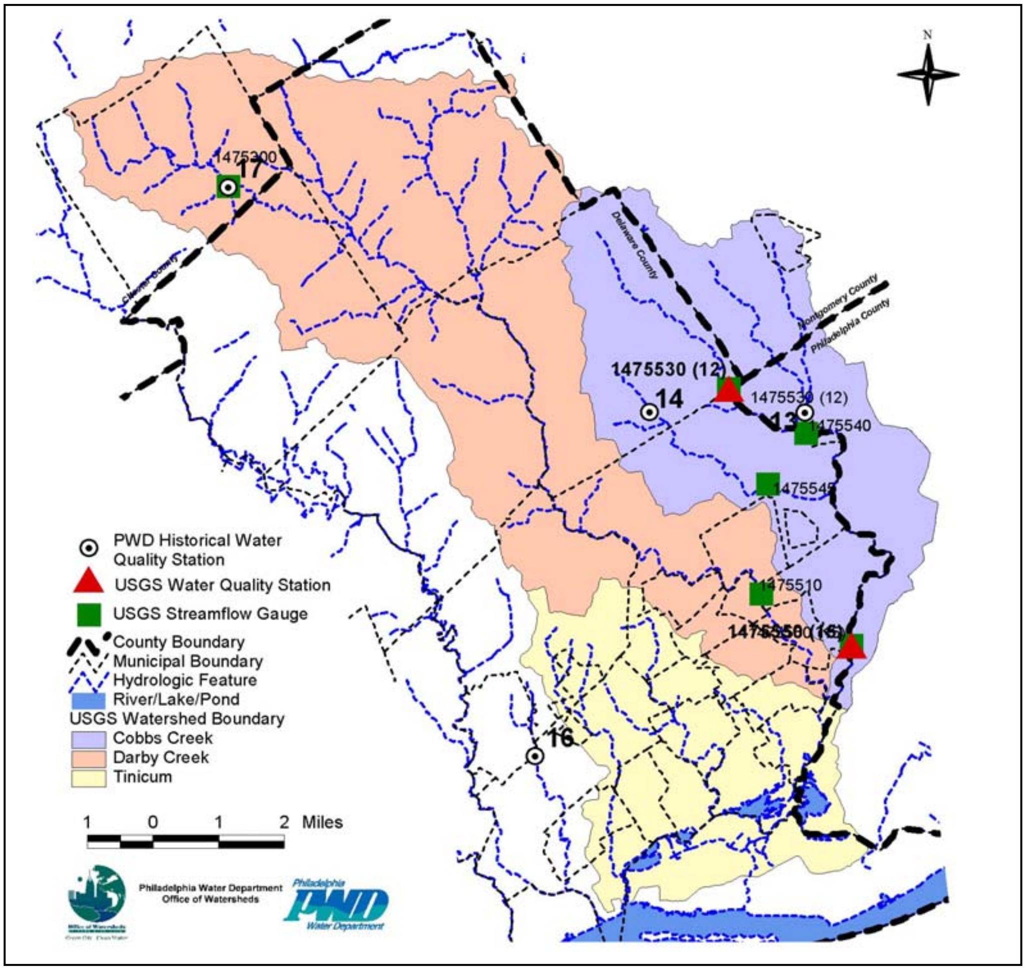


Figure 5.1 PWD/USGS Cooperative Program Water Quality Stations

Table 5.1 Periods of Record for Flow and Quality Data

Station ID	Location	Quality Data (Period)	Streamflow Data (Period)
01475300	Darby Creek At Waterloo Mills Near Devon, Pa.		4/28/1972-9/30/1994 6/28/1996-9/30/1997
01475530	Cobbs Creek At U.S. Highway No. 1 At Phila., Pa.	1/1/1965-3/3/1980	10/1/1964-9/30/1981
01475510	Darby Creek Near Darby, Pa.		2/1/1964-10/3/1990
01475550	Cobbs Creek At Darby, Pa.	11/9/70-3/3/80	1/1/1964-10/3/1990
01475545	Naylor Creek At West Chester Pike Near Phila., Pa.		6/1/1972-10/20/1978
01475540	Cobbs Creek Below Indian Creek Near Upper Darby, Pa.	10/10/1967-2/7/1973	10/1/1964-6/30/1973

Table 5.2 Summary Statistics for Six Gauge Stations

Station ID	Average Daily Flow Statistics (cfs)		
	Minimum	Mean	Maximum
01475300	0.83	9.0	330
01475530	0.90	7.3	310
01475510	8.6	64	1770
01475550	0	30	1150
01475545	0.18	1.7	54
01475540	0.50	14	480

5.1.2 STORET

The majority of the data available from STORET, USEPA's water quality database, for the Darby and Cobbs Creeks Watershed were from the PWD/USGS Cooperative Program, "Urbanization of the Philadelphia Area Streams." The STORET inventory of water quality data within the Darby and Cobbs Creeks Watershed is attached as Appendix B.

5.1.3 Evaluation of Water Quality Data

Analysis of the Philadelphia Water Department's water quality data from the "Urbanization of Philadelphia Stream Sites" report (1970-1980) was performed to assess the impact of the City (including its CSOs) on Cobbs Creek using two of the program's monitoring sites, as well as to provide a baseline for this watershed study. The upstream site is Cobbs at U.S. Highway No.1 (Station 12) and the downstream site is Cobbs at Darby (Station 15). The City's contribution to the pollution in Cobbs Creek is the difference in mass flux between the two stations. The water quality samples were collected monthly at each site by the U.S. Geological Survey and analyzed for conductivity, BOD_5, total phosphate, ammonia, nitrite, nitrate, and fecal coliform at the Water Department's laboratories. For the first three years, samples of metals also were collected and analyzed.

5.1.4 Baseline Water Quality

Tukey plots also were used to characterize water quality parameters by comparing total nitrogen, total phosphate, and fecal coliform load changes as Cobbs Creek passes through the city. Using the wet/dry flow splits determined during the lognormal probability analysis, paired box plots were compared over the 10-year period of water quality data collected. The total phosphate and fecal coliform plots, Figures 5.2 and 5.3, display an increased concentration from the upstream location at U.S. No. 1 to the downstream location at Darby. Malfunctioning regulators and higher loading rates during storm events are the most likely cause according to the study's report. However, other sources of fecal coliforms not previously considered include urban runoff, broken or leaking sewers, failing septic systems, and unanticipated pump station discharges from non-gravity separate sewer systems. In addition, total nitrogen concentrations, Figure 5.4, are higher within the upstream site and decrease after passing through the city. Some level of nitrification within the downstream portion of the stream may result in reduced levels of ammonia and nitrite.

Time series plots were developed for both monitoring sites from 1970-1980 for conventional water quality parameters and metals data and are available on the Partnership web site. These plots allow for visual identification and correlation to recorded storm events. Peak water quality measurements were identified with some recorded large storm events (i.e., hurricanes). Table 5.3 presents a quantitative summary of the water quality data from the PWD/USGS Cooperative Program. Table 5.4 qualitatively summarizes the data from the PWD/USGS Cooperative Program.

Table 5.3 Site Specific Statistics from Water Quality Samples

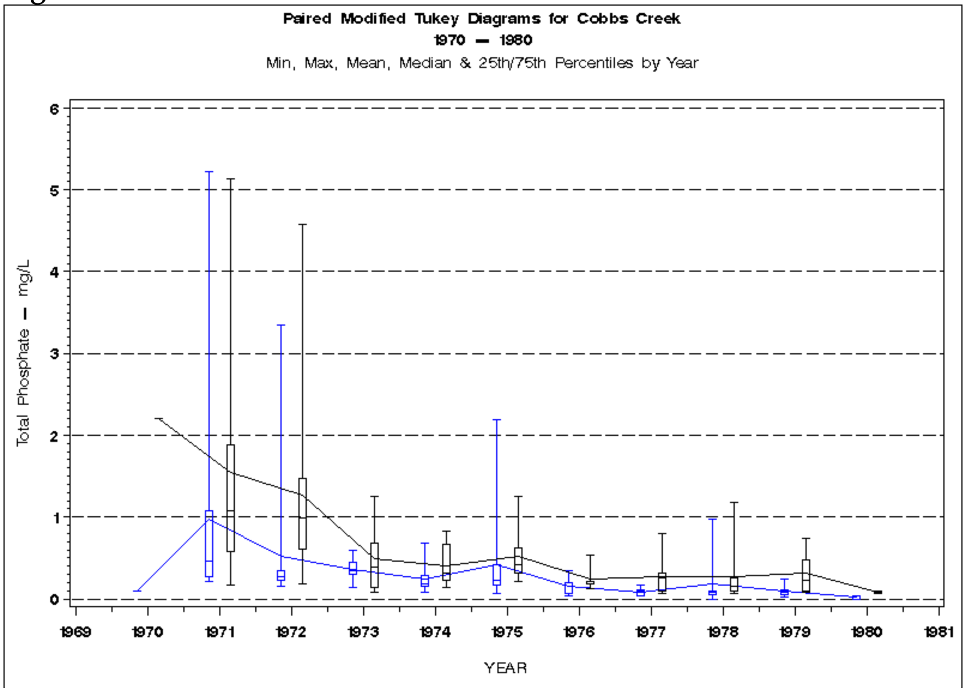
METALS 11/9/70 - 10/3/73

Site	Statistic	Zn (mg/L)	Ca (mg/L)	Mg (mg/L)	Fe (mg/L)	Ni (mg/L)	Cd (mg/L)	Cu (mg/L)	Cr (mg/L)	Co (mg/L)	Mn (mg/L)	Pb (mg/L)	Be (mg/L)	Al (mg/L)	Ag (mg/L)
12	N	27	11	11	27	10	27	27	27	12	27	27	4	10	4
	MIN	0.01	16	8	0.03	0.01	0.001	0.01	0.01	0.01	0.01	0.001	0.01	0.03	0.001
	MAX	0.18	32	13	1.64	0.04	0.004	0.06	1.66	0.01	0.48	0.51	0.01	0.44	0.001
	MEAN	0.0578	24	9.8182	0.2796	0.013	0.0011	0.0152	0.0722	0.01	0.07	0.0267	0.01	0.136	0.001
	STD	0.0393	4.5387	1.4013	0.3316	0.0095	0.0006	0.0122	0.3174	0	0.0965	0.0972	0	0.1525	0
15	N	27	12	12	27	11	27	27	27	13	27	27	5	11	5
	MIN	0.02	16	5	0.06	0.01	0.001	0.01	0.01	0.01	0.01	0.001	0.01	0.02	0.001
	MAX	0.15	38	13	1.41	0.05	0.006	0.02	0.48	0.01	0.27	0.11	0.01	0.63	0.001
	MEAN	0.07	29.6667	9.5833	0.6093	0.0136	0.0012	0.0119	0.0644	0.01	0.1359	0.019	0.01	0.1373	0.001
	STD	0.0344	7.9468	2.7122	0.3034	0.0121	0.001	0.004	0.1191	0	0.0686	0.0231	0	0.1714	0

CHEMICAL/Physical/Fecal
11/9/70 - 3/3/80

Site	Statistic	Discharge (cfs)	Temp deg C	DO (mg/L)	BOD (mg/L)	COD (mg/L)	TOC (mg/L)	COND. (umhos/cm)	TDS (mg/L)	TSS (mg/L)	pH stnd. units	TP (mg/L)	Org. N (mg/L)	NH3 (mg/L)	NO3 (mg/L)	NO2 (mg/L)	Fecal Col. (/100mL)
12	N	127	125	129	109	36	30	127	68	35	31	128	3	125	129	129	124
	MIN	0.3	0	0	0.1	0	3	118	2	1	6.5	0.01	0.18	0.02	0	0	50
	MAX	1150	26	15	14.3	47.2	12	920	736	29	9.1	14.3	0.3	4.93	0.7	6.11	170000
	MEAN	34.76	12.063	9.216	3.751	10.417	5.1333	350.29	241.82	7.314	7.4258	1.07	0.25333	0.573	0.071	2.595	15127.68
	STD	113.14	7.453	2.845	2.764	9.322	2.193	139.04	113.45	6.927	0.5228	1.843	0.06429	0.798	0.095	1.165	26415.6
15	N	107	108	109	93	36	31	109	64	35	30	109	3	107	110	110	94
	MIN	0.2	0	0	0	0	0	106	88	1	6.6	0.05	0.19	0.01	0	0.15	500
	MAX	463	29	16.3	26	60.4	13	1740	512	121	8.4	9.9	0.46	9.8	0.61	6.74	660000
	MEAN	29.641	12.163	8.515	5.1387	13.5056	5.8387	367.22	254.047	16.8	7.4067	1.447	0.32333	0.897	0.08	2.312	68218.04
	STD	59.561	7.727	3.049	4.8551	10.6941	3.3075	200.3	86.234	24.741	0.4842	1.915	0.13503	1.15	0.096	1.201	124606.99

Figure 5.2



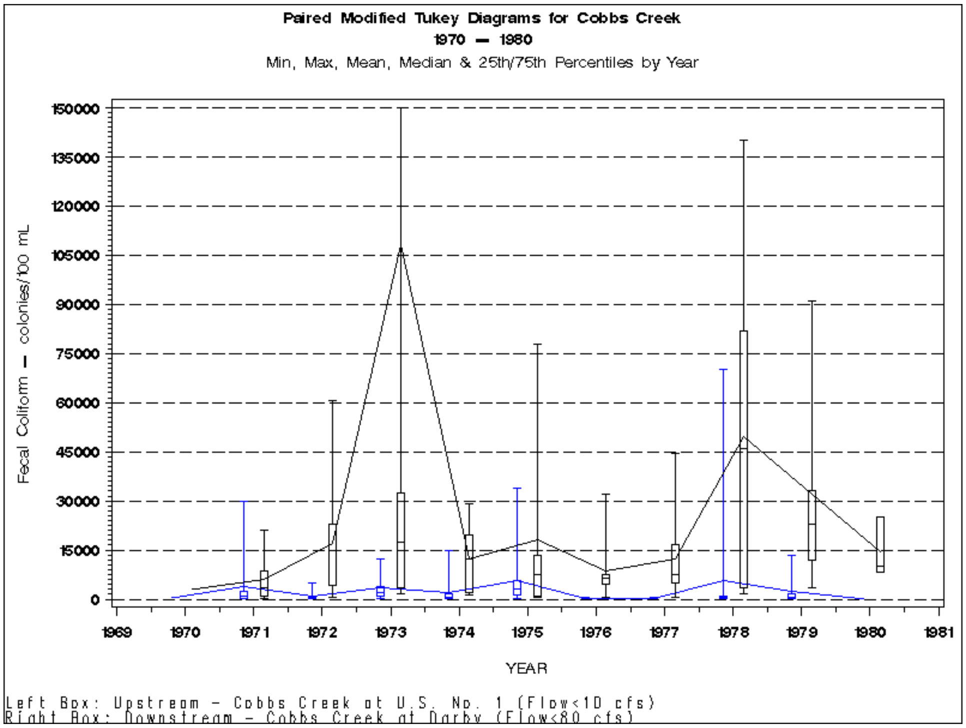


Figure 5.3

Figure 5.4

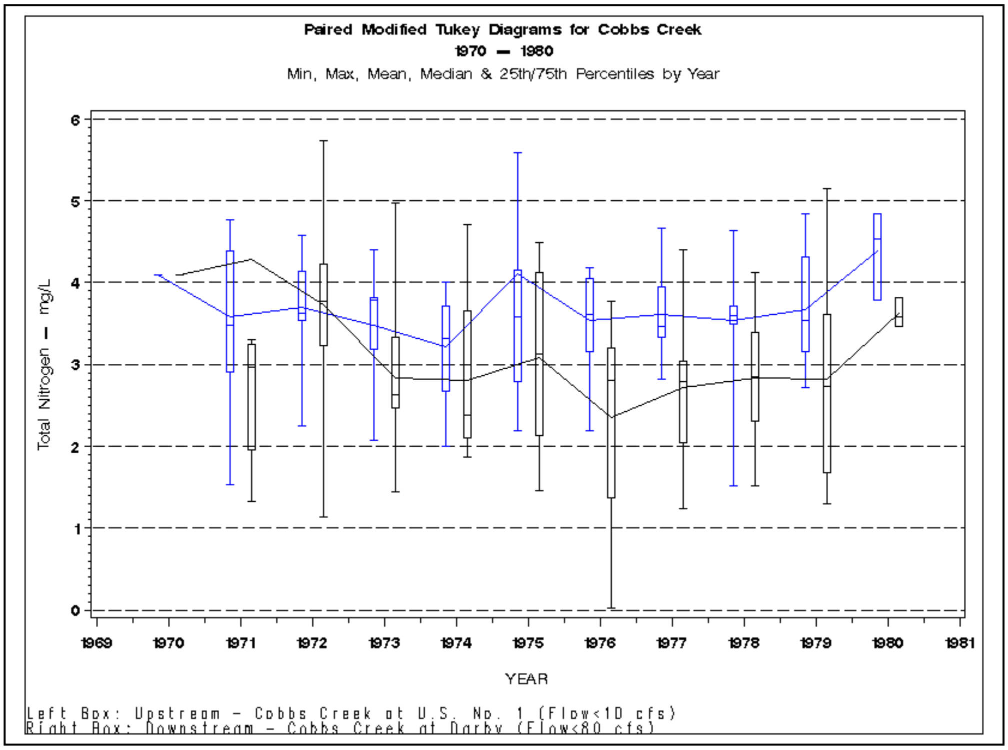


Table 5.4 Qualitative Summary of Water Quality Data Collected 1970-1980

Parameter	**Period of Observation**	**Comments**
Discharge	1970-1980	Discharge at the upstream and downstream sites follow the same pattern, with discharge increasing downstream.
Temperature	1970-1980	Water temperature goes through a seasonal cycle and differs very little between cross-sections.
pH	1970-1973	pH is lower at the downstream location for most of the samples. All the pH values fall between 6.5 and 8.5.
Specific Conductance	1970-1980	For most measurements, specific conductance was greatest at the downstream cross-section.
Dissolved Oxygen	1970-1980	DO concentrations at the upstream range seasonally from about 8 mg/L to 14 mg/L. DO concentrations at the downstream location are almost always lower and drop as low as 0 mg/L during some summers.
BOD	1970-1980	Upstream BOD loads are mostly less than 5 mg/L. Downstream BOD is higher but is usually still under 10 mg/L except for some peaks in mid-1971.
COD	1970-1973	COD concentrations range from about 0 to 30 mg/L at the downstream site and from about 5 to 45 mg/L at the upstream site. COD concentrations are greatest at the downstream site with the exception of three upstream peaks.
TOC	1970-1973	TOC concentrations range from about 0 to 10 mg/L at the upstream site and from about 0 to 25 mg/L at the downstream site. TOC concentrations are greatest at the downstream site with the exception of three upstream peaks.
Suspended Solids	1970-1973	Suspended solids are greatest in the downstream location, ranging as high as 60 mg/L, except for two peaks in the upstream concentration. Other than the peaks, upstream suspended solids are less than 10 mg/L.
Total Dissolved Solids	1970 – 1980	TDS was greatest at the downstream site for most samplings.

Table 5-4, continued

Organic Nitrogen	1972	The small number of data points for organic nitrogen concentrations show relatively constant values at the upstream site and values ranging between 0 and 2.25 mg/L at the downstream site.
Ammonia as Nitrogen	1970-1980	Other than downstream peaks as high as 20 mg/L in late 1971, most ammonia measurements are less than 2 mg/L. Downstream values are greater than upstream values for almost all measurements.
Nitrite an Nitrogen	1970-1980	Except for a few peaks, nitrite concentrations were less than 0.05 mg/L at the upstream location. Concentrations at the upstream location were higher and reached a maximum of 0.7 mg/L.
Nitrate as Nitrogen	1970-1980	Nitrate concentrations were greatest at the upstream location with very few exceptions.
Total Phosphate	1970-1980	The total phosphate concentration was greater at the downstream location for most measurements, reaching a maximum of 11 mg/L in late 1972.
Fecal Coliform	1970-1980	Fecal coliform counts appear to increase by a factor of approximately ten from the upstream to downstream locations.
Aluminum	1970-1973	The upstream and downstream concentrations follow the same shape. The downstream concentration is greater for two of the peaks, while the upstream concentration is greater for two other peaks.
Beryllium	1970-1973	All of the beryllium concentrations measured were less than 0.01 mg/L. These values were not graphed.
Cadmium	1970-1973	Most cadmium concentrations at the upstream and downstream locations are less than 0.001 mg/L. In 1971, the upstream peaks were earlier and greater than the downstream peaks. In 1972 and 1973, the downstream peaks are greater than the upstream peaks. The largest downstream peak is not reflected at the upstream location.
Calcium	1970-1973	The upstream and downstream concentrations follow the same shape. The downstream concentration is greater except for two times in late 1971 and mid-1972.
Chromium	1970-1973	Upstream concentrations are all less than 0.1 mg/L with the exception of one peak of about 1.7 mg/L in April 1972. Downstream concentrations range between 0 and 0.5 mg/L.
Cobalt	1970-1973	All upstream cobalt concentrations are less than 0.001 mg/L. All downstream concentrations are less than 0.001 mg/L except for one peak of 0.01 mg/L.
Copper	1970-1973	Many of the copper concentrations are less than 0.01 mg/L and plotted as zero. The downstream concentration reached five peaks of about 0.02 mg/L, and the upstream concentration reached three peaks of 0.03 to 0.06 mg/L.
Iron	1970-1973	The downstream iron concentration is greater than the upstream concentration except for one downstream peak in May 1973.
Lead	1970-1973	All the measured lead concentrations except for two are less than 0.05 mg/L. The downstream concentrations are greater than the upstream concentrations.
Magnesium	1970-1972	The upstream concentration varies between approximately 8 mg/L and 10 mg/L. The downstream concentration pattern follows a similar shape but has more extreme maximum and minimum values.
Manganese	1970-1973	The downstream concentration of manganese is greater than the upstream concentration except for three upstream peaks and the final reading.
Nickel	1970-1972	Measured nickel concentrations are less than 0.01 mg/L (plotted as zero) during the study period except for one peak that occurs both upstream and downstream. The downstream peak is larger in concentration and occurs about two months later than the upstream peak.
Silver	1970-1973	All of the silver concentrations measured were less than 0.001 mg/L. These values were not graphed.
Zinc	1970-1973	Other than four peaks in the upstream concentration, downstream concentrations of zinc are greater.

5.2 Summary of Water Quality Data Collected 1999-2002

PWD carried out a comprehensive sampling and monitoring program in the Darby-Cobbs watershed between 1999 and 2002 (see Section 3 of the Comprehensive Characterization Report). The first step in water quality analysis is to identify constituents of possible concern. Tables 5.5 and 5.6 list constituents monitored, applicable state water quality standards, number of samples, and number of samples that exceed the standards.

For dissolved oxygen, discrete sampling is not sufficient to characterize the condition of the stream. The magnitude of the diurnal pattern exhibited by DO is an indicator of the amount of algal activity in the steram, and the minimum DO occurs in darkness when sampling is impractical. For this reason, PWD has monitored dissolved oxygen on a continuous basis at several sites in the Cobbs Creek system (Figure 5.5). At sites DCC110 and DCC455, concentrations are occasionally (less than 5% of observations) below the average daily limit of 5 mg/L. The only site where concentrations are often below the average standard (20% of observations) and the instantaneous standard (5% of observations) is site DCC115. This site is just above the low dam at Woodland Ave.

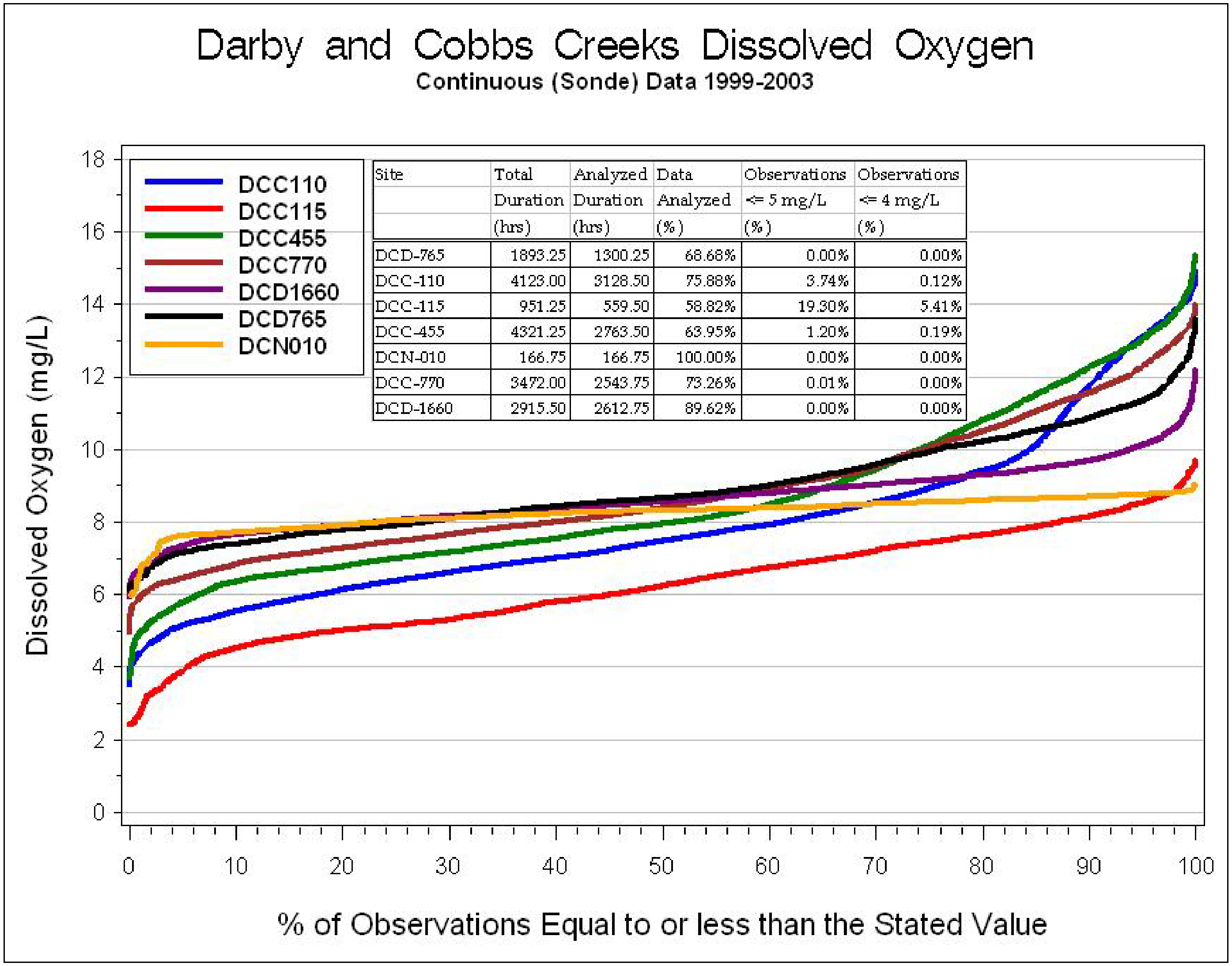
Following the determination of parameters of possible concern, sites were identified where exceedance of these parameters has occurred. Table 5.7 lists the parameters of possible concern and sites where they have been identified. Locations of sampling sites are shown in Figure 5.6.

Table 5.5 Dry Weather Water Quality Summary – Parameters with Standards

Parameter	Standard	Units	No. Observations	Percentiles					No. Exceeding	% Exceeding
				0	25	50	75	100		
Alkalinity	Minimum	mg/L	59	58.0	66.0	74.0	79.0	98.0	0	0.0
Cadmium	Aquatic Life Acute Maximum	mg/L	59	ND	ND	ND	ND	ND	0	0.0
Cadmium	Aquatic Life Chronic Maximum	mg/L	59	ND	ND	ND	ND	ND	0	0.0
Cadmium	Human Health Maximum	mg/L	60	ND	ND	ND	ND	ND	0	0.0
Chromium	Aquatic Life Acute Maximum	mg/L	59	ND	ND	ND	ND	0.00247	0	0.0
Chromium	Aquatic Life Chronic Maximum	mg/L	59	ND	ND	ND	ND	0.00247	0	0.0
Copper	Aquatic Life Acute Maximum	mg/L	59	0.00107	0.00236	0.00330	0.00409	0.0101	0	0.0
Copper	Aquatic Life Chronic Maximum	mg/L	59	0.00107	0.00236	0.00330	0.00409	0.0101	0	0.0
Copper	Human Health Maximum	mg/L	59	0.00107	0.00236	0.00330	0.00409	0.0101	0	0.0
Dissolved Iron	Maximum	mg/L	59	0.0545	0.136	0.173	0.209	0.436	4	6.8
DO	Average Daily Minimum	mg/L	58	4.88	6.98	7.96	8.80	10.7	1	1.7
DO	Instantaneous Minimum	mg/L	58	4.88	6.98	7.96	8.80	10.7	0	0.0
Fluoride	Maximum	mg/L	59	ND	ND	ND	0.108	0.142	0	0.0
Iron	Maximum	mg/L	59	0.152	0.231	0.286	0.399	0.918	0	0.0
Fecal	Maximum	/100mL	60	90	290	410	620	23000	51	85.0
Manganese	Maximum	mg/L	59	0.0137	0.0251	0.0330	0.0460	0.0972	0	0.0
NH3T	Maximum	mg/L	58	ND	ND	ND	ND	0.186	0	0.0
NO23	Maximum	mg/L	60	2.90	2.90	2.90	2.90	2.90	0	0.0
Osmotic Pressure	Maximum	mOsm/kg	20	3.00	4.00	5.00	6.00	6.00	0	0.0
pH	Maximum	dimensionless	58	7.09	7.39	7.57	7.73	8.18	0	0.0
Lead	Aquatic Life Acute Maximum	mg/L	59	ND	ND	ND	0.00102	0.00433	0	0.0
Lead	Aquatic Life Chronic Maximum	mg/L	59	ND	ND	ND	0.00102	0.00433	0	0.0
Lead	Human Health Maximum	mg/L	59	ND	ND	ND	0.00102	0.00433	0	0.0
Phenolics	Maximum	mg/L	56	ND	ND	ND	ND	0.17	3	5.4
TDS	Maximum	mg/L	59	148	210	234	289	420	0	0.0
Temperature	Instantaneous Maximum	degree C	58	13.7	15.7	18.9	20.3	24.1	7	12.1
Zinc	Aquatic Life Acute Maximum	mg/L	59	ND	0.00640	0.00947	0.0138	0.0582	0	0.0
Zinc	Aquatic Life Chronic Maximum	mg/L	59	ND	0.00640	0.00947	0.0138	0.0582	0	0.0
Zinc	Human Health Maximum	mg/L	59	ND	0.00640	0.00947	0.0138	0.0582	0	0.0

Table 5.6 Wet Weather Water Quality Summary – Parameters with Standards

Parameter	Standard	Units	No. Observations	Percentiles					No. Exceeding	% Exceeding
				0	25	50	75	100		
Alkalinity	Minimum	mg/L	96	24.0	42.0	58.5	68.0	85.0	0	0.0
Cadmium	Aquatic Life Acute Maximum	mg/L	93	ND	ND	ND	ND	ND	0	0.0
Cadmium	Aquatic Life Chronic Maximum	mg/L	93	ND	ND	ND	ND	ND	0	0.0
Cadmium	Human Health Maximum	mg/L	93	ND	ND	ND	ND	ND	0	0.0
Chromium	Aquatic Life Acute Maximum	mg/L	93	ND	ND	0.00151	0.0036	0.014	0	0.0
Chromium	Aquatic Life Chronic Maximum	mg/L	93	ND	ND	0.00151	0.0036	0.014	6	6.5
Copper	Aquatic Life Acute Maximum	mg/L	93	0.00183	0.00428	0.00625	0.0096	0.034	11	11.8
Copper	Aquatic Life Chronic Maximum	mg/L	93	0.00183	0.00428	0.00625	0.0096	0.034	23	24.7
Copper	Human Health Maximum	mg/L	93	0.00183	0.00428	0.00625	0.0096	0.034	0	0.0
Dissolved Iron	Maximum	mg/L	93	0.0739	0.129	0.155	0.2143	0.3924	5	5.4
DO	Average Daily Minimum	mg/L	94	1.73	5.27	6.52	8.07	10.25	22	23.4
DO	Instantaneous Minimum	mg/L	94	1.73	5.27	6.52	8.07	10.25	9	9.6
Fluoride	Maximum	mg/L	96	ND	ND	0.101	0.1145	0.194	0	0.0
Iron	Maximum	mg/L	93	0.181	0.317	0.550	0.747	6.456	13	14.0
Fecal Coliform	Maximum	/100mL	95	100	2100	7900	31000	200000	94	98.9
Manganese	Maximum	mg/L	93	0.0170	0.0385	0.0553	0.07443	0.2118	0	0.0
NH3T	Maximum	mg/L	93	ND	ND	0.100	0.198	1.62	0	0.0
NO23	Maximum	mg/L	102	2.90	2.90	2.90	2.9	2.9	0	0.0
Osmotic Pressure	Maximum	mOsm/kg	10	2.00	2.00	3.00	3.00	4.00	0	0.0
pH	Maximum	dimensionless	94	6.82	7.21	7.33	7.54	7.83	0	0.0
Lead	Aquatic Life Acute Maximum	mg/L	93	ND	0.00144	0.00246	0.00577	0.0571	1	1.1
Lead	Aquatic Life Chronic Maximum	mg/L	93	ND	0.00144	0.00246	0.00577	0.0571	40	43.0
Lead	Human Health Maximum	mg/L	93	ND	0.00144	0.00246	0.00577	0.0571	1	1.1
Phenolics	Maximum	mg/L	94	ND	ND	ND	ND	0.116	5	5.3
TDS	Maximum	mg/L	96	20.0	128	185	235	391	0	0.0
Temperature	Instantaneous Maximum	degree C	94	14.2	16.5	19.8	21.5	25.3	9	9.6
Zinc	Aquatic Life Acute Maximum	mg/L	93	ND	0.0110	0.0180	0.0295	0.111	3	3.2
Zinc	Aquatic Life Chronic Maximum	mg/L	93	ND	0.0110	0.0180	0.0295	0.111	6	6.5
Zinc	Human Health Maximum	mg/L	93	ND	0.0110	0.0180	0.0295	0.111	0	0.0



Site	Total Duration (hrs)	Analyzed Duration (hrs)	Data Analyzed (%)	Observations <= 5 mg/L (%)	Observations <= 4 mg/L (%)
DCD-765	1893.25	1300.25	68.68%	0.00%	0.00%
DCC-110	4123.00	3128.50	75.88%	3.74%	0.12%
DCC-115	951.25	559.50	58.82%	19.30%	5.41%
DCC-455	4321.25	2763.50	63.95%	1.20%	0.19%
DCN-010	166.75	166.75	100.00%	0.00%	0.00%
DCC-770	3472.00	2543.75	73.26%	0.01%	0.00%
DCD-1660	2915.50	2612.75	89.62%	0.00%	0.00%

Figure 5.5 Continuous DO Monitoring Results

Table 5.7 Sites with at least one Observed Exceedance of Water Quality Criteria

	Dry											
Parameter	DCC110	DCC115	DCC455	DCC770	DCN010	DCI010	DCD765	DCD1170	DCD1570	DCD1660	DCM300	DCS170
Chromium												
Copper												
Dissolved Iron	X				X						X	X
DO		X										
Iron												
Fecal Coliform	X		X	X	X	X	X	X	X		X	X
Lead												
Phenolics					X						X	
Temperature							X		X	X		
Zinc												

	Wet											
Parameter	DCC110	DCC115	DCC455	DCC770	DCN010	DCI010	DCD765	DCD1170	DCD1570	DCD1660	DCM300	DCS170
Chromium	X					X	X		X			
Copper	X		X			X	X					X
Dissolved Iron	X						X					X
DO	X	X					X			X		
Iron	X											
Fecal Coliform	X		X	X	X	X	X	X	X	X	X	X
Lead	X		X	X		X	X			X		X
Phenolics			X	X			X			X	X	
Temperature							X	X	X	X		
Zinc	X						X					

Note: DCC115 was sampled for DO only on a continuous basis.

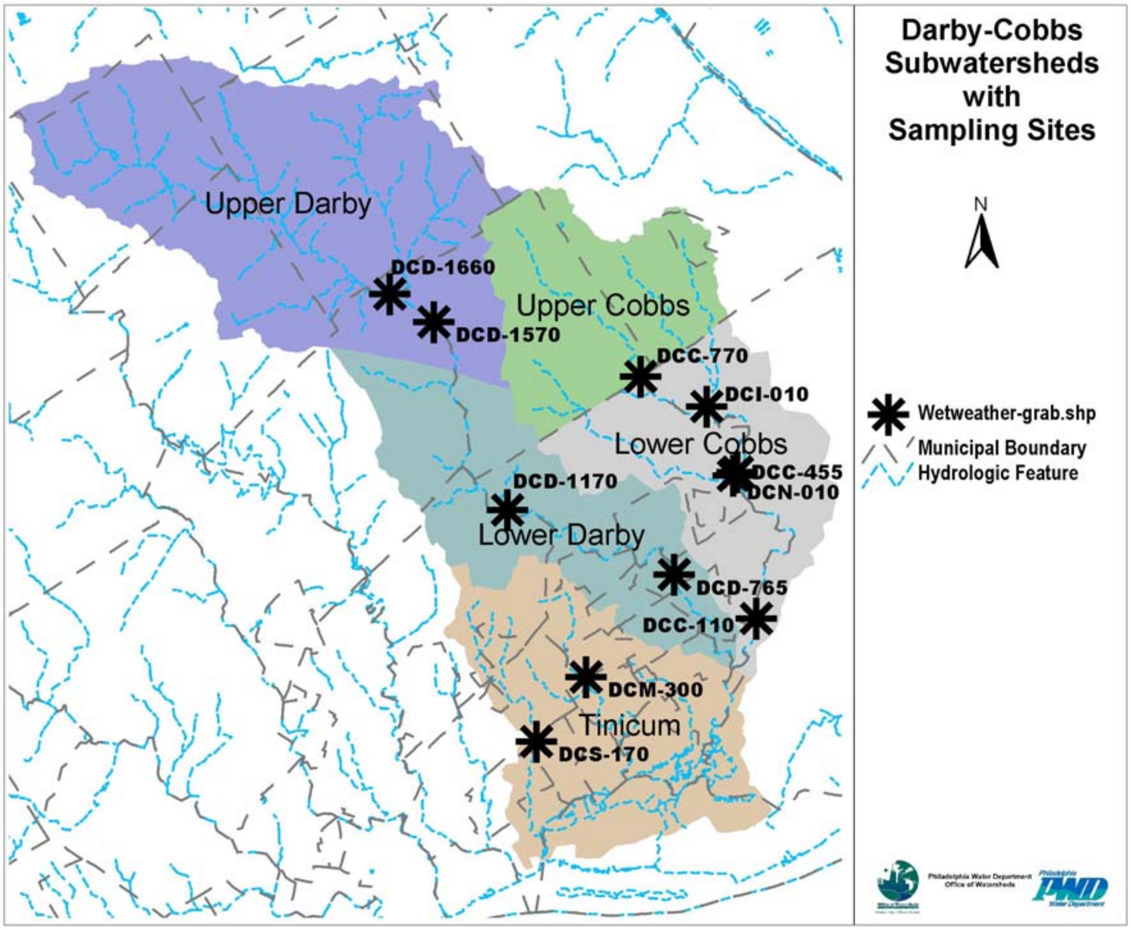


Figure 5.6 Subwatersheds and Sampling Sites

5.3 Detailed Discussion of Data Collected 1999-2000

5.3.1 Upper Cobbs Creek

Two sampling sites represent the headwaters and upper reaches of Cobbs Creek. Site DCC-770 is on the main stem of Cobbs Creek near the Philadelphia/ Montgomery County line, and DCI-010 is on Indian Creek just above the confluence with the main stem. These sites do not receive CSO inputs. Table 5.8 summarizes the mean concentrations of water quality constituents collected at the two sites.

Table 5.8 Summary of Upper Cobbs Mean Water Quality

		DCC-770		DCI-010	
Parameter	Units	Dry	Wet	Dry	Wet
Al	mg/L	0.066	0.216	0.018	0.102
Alk	mg/L	60.8	57.4	79.8	68.2
BOD30	mg/L	2.28	3.61	1.72	2.73
BOD5	mg/L	1.00	1.50	1.00	1.71
CBOD5	mg/L	1.00	1.43	1.00	1.69
Ca	mg/L	31.7	24.3	45.6	33.0
Cd	mg/L	5.00E-04	5.00E-04	5.00E-04	5.00E-04
Chla	ug/L				
Cr	mg/L	0.004	0.005	0.004	0.006
Cu	mg/L	0.004	0.007	0.004	0.007
DO	mg/L	7.72	7.30	8.13	7.18
DissCd	mg/L				
DissFe	mg/L	0.142	0.110	0.166	0.142
Ecoli	/100 mL	578	6800	350	9840
F	mg/L	0.050	0.070	0.060	0.082
Fe	mg/L	0.242	0.414	0.224	0.288
Fecal	/100 mL	440	1.64E+04	386	3.15E+04
Mg	mg/L	15.6	11.5	18.1	12.9
Mn	mg/L	0.028	0.032	0.018	0.028
NH3T	mg/L	0.050	0.110	0.050	0.114
NO2	mg/L	0.007	0.022	0.005	0.033
NO3	mg/L	2.29	1.86	1.66	1.39
OsPress	mosm	4.00	3.00	6.00	4.00
PO4	mg/L	0.020	0.028	0.020	0.032
Pb	mg/L	0.002	0.003	5.00E-04	0.002
Phen	mg/L	0.015	0.022	0.015	0.015
SpCond	uS/cm	349	294	447	354
TChl	ug/L				
TDS	mg/L	216	200	274	243
TKN	mg/L	0.614	1.09	0.536	1.09
TP	mg/L	0.036	0.074	0.056	0.098
TSS	mg/L	10.4	12.4	2.10	6.90

Table 5-8, cont'd

TempC	degrees C	17.4	19.0	17.4	19.3
Turb	NTU	3.24	11.3	3.03	2.98
Zn	mg/L	0.009	0.012	0.008	0.010
pH		7.38	7.32	7.70	7.50

Notes on tables in this section

- The individual data points used in calculation of these means are listed by site and date on the web site.
- For concentrations at or below the detection limit, half the detection limit is used in the calculation of the means listed above.
- For multiple observations during a wet weather event, a single value was chosen to represent the event as follows: for DO, the minimum; for pH, specific conductance, temperature, alkalinity, and turbidity, the mean; for all other parameters, the maximum. This single value was used in the calculation of means listed in the table above.

Upper Cobbs Physical Conditions: Temperature, pH, Solids, Conductivity, Turbidity

Figure 5.7 and 5.8 includes graphs of eutrophication related physical/chemical parameters and nutrients over the 1999 discrete sampling period at DCC-770. Other than the increase in temperature over the course of the summer, there are no obvious trends over time or between wet and dry dates.

Upper Cobbs Dissolved Oxygen

1335.5 hours of quality-assured continuous DO data are available for site DCC-770. Figure 5.9 includes graphs from four of these deployments. The data from July 9 to 12, 1999 (upper left) represent an uninterrupted dry weather period. Between July 26 and August 9, 2001 (upper right), several small wet weather events occurred. CSOs do not affect upper Cobbs sites, but they can be used to identified wet weather periods. Small quantities of CSO occur downstream on July 26 and 30. On Aug 10 and 12, larger CSOs occur throughout the system, including outfalls C_31, C_32 and C_33. Stormwater runoff and CSOs cause the noise or random variation in the measurements to increase slightly but have only a small effect on the overall magnitude or pattern of DO.

Similar effects are observed when a larger storm occurs on December 9-10, 2001 (lower left and lower right representing two instruments deployed concurrently). All data points are shown, but data that do not meet quality assurance criteria are shown with a thinner gray line. Quality assurance and control procedures developed to assess data from the urban environment are described in detail in the Appendix. Data points taken with a calibrated handheld instrument show that the lower right plot represents actual conditions more accurately except for a period during the runoff event. There does not appear to be a major difference in DO between dry and wet weather. In dry weather, the amplitude of the diurnal pattern is approximately 1.5-2.0 mg/L. The water column is often supersaturated in the afternoon.

The amplitude of the diurnal pattern at DCC-110 ranges from approximately 1.5 to 2.5 mg/L with an average of approximately 2.0 mg/L. The greatest amplitudes were observed during the autumn deployments and the least during summer deployments.

Figure 5.10 summarizes the range and cumulative distribution of DO in the Upper Cobbs and throughout the system. The plot shows the percentage of samples (on the horizontal axis) that are less than or equal to a range of DO concentrations (on the vertical axis). For example, DO at DCC-770 ranges from approximately 4 to 15 mg/L and is less than or equal to 6 mg/L for approximately 2% of quality-assured observations.

Upper Cobbs Nutrients

Mean inorganic nitrogen at DCC-770, including nitrate, nitrite, and ammonia, is 2.35 mg/L in dry weather and 2.00 mg/L in wet weather. Mean ammonia increases from approximately 2% of total nitrogen in dry weather to 4% in wet weather. Figure 5-8 shows the temporal trends at DCC-770 in nitrogen species, phosphorus species, and other parameters related to the trophic state of the site. DCC-770 generally has higher nitrate concentrations than those found further downstream.

Upper Cobbs Bacteria

Observed fecal coliform and *E. coli* concentrations at DCC-770 are on the order of 10^2/100 mL in dry weather and range higher than 10^4/100 mL in wet weather conditions. Similar trends are observed at DCI-010.

Upper Cobbs Metals

At both Upper Cobbs sites, mean concentrations of most metals are greater in wet weather. These metals include aluminum, chromium, copper, total iron, manganese, lead, and zinc. Cadmium samples are below the detection limit for all samples at both sites. For concentrations at or below the detection limit, half the detection limit is used in the calculation of mean and in temporal and spatial plots. Mean dissolved iron is lower in wet weather at both sites.

Upper Cobbs Fish Advisories

AMSA et al. (2002) recommend against using fish advisories alone as the basis for impairment listings, but they can provide a basis for further study and for establishment of water quality standards. Fish advisories are most often due to metals or organic chemicals. The April 2001 fish advisory for this watershed advises to limit consumption of White Perch, Striped Bass, and Carp to one meal a month, and to limit consumption of Channel Catfish to one meal every two months. American eel should not be eaten at all. This is all due to PCB pollution.

5.3.2 Lower Cobbs Creek

Three sampling sites represent lower Cobbs Creek. Site DCC-455 is on the main stem at Cobbs Creek Environmental Center, and DCN-010 is on Naylors Run just above the confluence with Cobbs Creek. Site DCC-110 is on the main stem about one mile above the confluence with Darby Creek. The two sites on the mainstem receive stormwater and CSO inputs, while the Naylors Run site receives only stormwater. Additional monitoring was conducted just upstream of the dam at DCC-110. Table 5.9 summarizes the mean concentrations of water quality constituents collected at the three sites.

Table 5.9 Summary of Lower Cobbs Mean Water Quality

		DCC-110		DCC-455		DCN-010	
Parameter	Units	Dry	Wet	Dry	Wet	Dry	Wet
Al	mg/L	0.058	0.623	0.026	0.152	0.044	0.058
Alk	mg/L	76.0	53.1	71.8	62.6	79.4	64.0
BOD30	mg/L	3.81	20.6	2.12	6.71	2.93	3.34
BOD5	mg/L	1.00	4.37	1.00	3.22	1.00	1.54
CBOD5	mg/L	1.00	3.39	1.00	2.72	1.00	1.48
Ca	mg/L	37.2	24.5	37.8	27.7	49.3	35.3
Cd	mg/L	5.00E-04	5.00E-04	5.00E-04	5.00E-04	5.00E-04	5.00E-04
Chla	ug/L	1.69	39.8				
Cr	mg/L	0.003	0.005	0.004	0.006	0.004	0.005
Cu	mg/L	0.004	0.009	0.003	0.006	0.003	0.006
DO	mg/L	6.57	4.15	7.40	5.64	8.34	8.06
DissCd	mg/L	5.00E-04	5.00E-04				
DissFe	mg/L	0.217	0.226	0.184	0.166	0.220	0.168
Ecoli	/100 mL	292	4.40E+04	850	4.37E+04	475	8980
F	mg/L	0.086	0.116	0.060	0.098	0.084	0.130
Fe	mg/L	0.456	0.954	0.310	0.414	0.272	0.252
Fecal	/100 mL	415	7.68E+04	972	4.68E+04	564	2.59E+04
Mg	mg/L	15.1	9.89	16.1	11.3	17.8	13.3
Mn	mg/L	0.054	0.110	0.026	0.060	0.034	0.036
NH3T	mg/L	0.089	0.463	0.050	0.270	0.050	0.120
NO2	mg/L	0.029	0.055	0.020	0.066	0.019	0.035
NO3	mg/L	1.56	1.21	1.89	1.49	2.45	2.13
OsPress	Mosm	5.00	2.00	5.00	3.00	6.00	4.00
PO4	mg/L	0.020	0.031	0.020	0.040	0.020	0.026
Pb	mg/L	0.002	0.008	5.00E-04	0.003	5.00E-04	5.00E-04
Phen	mg/L	0.015	0.015	0.015	0.020	0.018	0.042
SpCond	uS/cm	409	269	416	321	506	403
TChl	ug/L	2.75	47.2				
TDS	mg/L	244	195	247	224	304	280
TKN	mg/L	0.657	1.52	0.660	1.04	0.582	1.14
TP	mg/L	0.076	0.196	0.052	0.132	0.038	0.080
TSS	mg/L	2.25	23.0	1.70	8.00	3.60	3.30
TempC	degrees C	19.6	20.7	19.0	20.3	18.1	20.0
Turb	NTU	2.79	13.8	2.10	7.48	2.75	2.94
Zn	mg/L	0.016	0.026	0.008	0.012	0.010	0.014
PH		7.51	7.16	7.58	7.26	7.78	7.64

Lower Cobbs Physical Conditions: Temperature, pH, Solids, Conductivity, Turbidity

The continuous data collected by the Sonde instruments provides a picture of how various water quality constituents interact in the urban environment during dry and wet weather. In a highly impervious environment, the streamflow hydrograph responds to wet weather with a sudden, high peak flow followed by a rapid recession back to baseflow. In the warmer months, stormwater runoff from hot pavement can increase water temperature by several degrees during a runoff event. Suspended solids and turbidity in the water column both increase during the course of a storm because of stormwater inputs. In addition, high velocity flows may re-suspend bed sediments and cause bank erosion, further increasing solids in the water column. Conductivity, an indirect measure of dissolved solids, typically decreases during a storm as stormwater runoff dilutes the ambient water.

Figure 5.11 displays the results of one Sonde deployment at DCC-110 during November 2000. The effects of urban runoff and high velocity on depth, turbidity, and conductivity are all apparent. Although warm pavement may cause sudden increases in stream temperature during wet weather, the temperature trend observed during this deployment is most likely the result of a front passing through and affecting air temperature. The average daily water temperature mirrors air temperature, but its changes are less pronounced due to the higher specific heat of water (Figure 5.11.1). When the storm front raises air temperatures to a high of 19 ^{o}C on November 10, instream water temperature increases approximately 2.5^{o}C to just under 15 ^{o}C over a period of six hours. Both air and water temperature drop after the passage of the storm front.

Lower Cobbs Dissolved Oxygen

A total of 2597 and 1337.75 hours of quality-assured continuous DO data were collected at the two mainstem lower Cobbs sites: DCC-110 and DCC-455 respectively. Figure 5.12 includes time series plots of DO measured during four deployments at DCC-110. July 9 to 12, 1999 (upper left) is an example of dry weather conditions at the site. A total of 0.96 inches of rain was produced by wet weather events during the period from June 2 to 15, 2000 (upper right). The event, on June 6, 2000, depresses observed DO for a brief period; however, it is difficult to tell whether this effect is due to instrument error or actual conditions. The second event causes what appears to be a random fluctuation in the data.

The deployment from May 11 to 24, 2001 (lower left) includes a larger wet weather event that triggers multiple CSOs. The signal becomes extremely erratic during the event and does not recover. The data from May 21 to the end of the period do not meet quality assurance criteria and are not included in analyses. During the late summer deployment from July 26 to August 6, 2001 (upper right), the trough of the observed diurnal pattern at DCC-110 is between 4 and 5 mg/L. The gradually decreasing saturation DO indicates that air temperature increased during this period.

Figure 5.13 includes four time series plots of continuous DO measured at site DCC-455. After the DO probe readings stabilize, the September 27 to October 5, 2000 deployment (upper left) is a good example of dry weather conditions at this site. During the period from July 27 to August 10, 2001 (upper right), there is some noise or random fluctuation in the data, but this deployment provides another good example of dry weather conditions with one small wet weather event of 0.49 inches.

The December 5 to 17, 2001 deployment at DCC-455 (lower left) begins with a dry weather period with an observed diurnal amplitude of approximately 4 mg/L. Concentrations measured by the Sonde are verified by two readings taken with hand-held meters. A wet weather event of 0.72 inches occurs on December 8 and causes the instrument to cease functioning until maintenance is performed on December 10. Data taken after the wet weather event, while they do not match the hand-held data points exactly, provide more evidence that the diurnal amplitude was large during this period. The deployment period from January 15 to 31, 2002 displays similar conditions including low water temperatures, high DO, and a large difference between daily maxima and minima.

The observed dry weather diurnal DO amplitude at site DCC-110 is between 1.5 and 2.5 mg/L for quality-assured data. At site DCC-455, the diurnal amplitude of the DO signal ranged from approximately 1.5 to over 4 mg/L for quality-assured data. The average amplitude was approximately 2.5 mg/L. Thus, there is some evidence that the amplitude is greater at DCC-455. Pronounced differences between the amplitude in different seasons were not observed.

Figure 5.10 includes the cumulative distribution of DO at four sites in the lower Cobbs. At DCC-110, DO ranges from between 4 and 15 mg/L, with 95% of measurements greater than 5 mg/L. At DCC-455, DO ranges from just below 4 to greater than 15 mg/L. DO at DCC-455 is generally greater than DO at DCC-110, but the range in measurements is greater at DCC-455. The two main stem Darby Creek sites have the greatest range of all monitored sites in the Darby and Cobbs Creeks watershed.

Figure 5.10 also includes 560 hours of data at site DCC-115, just above the dam at DCC-110. This site has the lowest DO of any monitored site in the system, with nearly 20% of observations below 5 mg/L. The monitor is located just upstream of the dam in a deep pool of very low velocity, poorly mixed water.

Lower Cobbs BOD

Observed mean BOD at the lower Cobbs sites is greater in wet weather than in dry weather. Figure 5-14 shows multiple BOD_{30} observations during a single event at DCC-110 between June 1 and 8, 2000. The concentration is lowest during the dry weather sample before the storm, reaches a peak during the storm, and recedes to its dry weather level after the storm.

BOD measured under idealized laboratory conditions does not always represent the amount of oxygen demand exerted in the field. Figure 5-15 includes four graphs of laboratory 30-day BOD data sheets for wet weather samples taken at DCC-110. Very little oxygen demand is exerted during the first 2 to 3 days of the test. Because travel time in Cobbs Creek is thought to be on the order of 1-2 days, it is unlikely that BOD will have a significant effect on instream DO except in poorly mixed pools.

Lower Cobbs Nutrients

Figures 5.16 through 5.23 compare concentrations of nitrogen and phosphorus species along the length of Cobbs Creek and throughout the Darby and Cobbs Creeks system. The plots show the mean and range of measurements, river miles, and wet weather status. Figures 5.24 through 5.27 display temporal trends for a variety of eutrophication-related parameters at sites DCC-110 and DCC-455.

Compared to upstream sites, observed mean inorganic nitrogen in the water column (nitrate, nitrite, and ammonia) under dry conditions decreases from 2.35 mg/L at DCC-770 and 1.96 mg/L at DCC-455 to 1.68 mg/L at DCC-110. Under dry weather conditions, ammonia makes up approximately 2% of total nitrogen at sites DCC-770 and 4% at site DCC-110. Under wet conditions, ammonia makes up approximately 4% of total nitrogen at DCC-770, 10% at DCC-455, and 17% at DCC-110. The mean and range of ammonia concentrations at DCC-455 and DCC-110 are roughly equal but are double those seen at DCC-770.

Inorganic phosphorus under dry weather conditions is below the detection limit of 0.04 mg/L at all three sites. Maximum wet weather phosphate concentrations are similar at the three Cobbs sites, although dry weather concentrations appear to increase from upper to lower Cobbs. It is difficult to estimate ratios of nitrogen to phosphorus due to the detection limit samples. If the phosphate concentration is taken as half the detection limit, the ratio of inorganic nitrogen to inorganic phosphorus in dry weather decreases from 117:1 at DCC-770 to 98:1 at DCC-455 to 83:1 at DCC-110. However, any unknown trend in the phosphorus concentration could significantly change these ratios.

Lower Cobbs Bacteria

Bacteria are present at Lower Cobbs sites at high concentrations under both dry and wet conditions. Mean dry weather fecal coliform at DCC-110 is 2.3 x 10^4 /100 mL. Under wet weather conditions when CSOs are active, fecal coliform may peak at 10^5/100 mL or higher as shown in wet weather sampling results (Figure 5-28). Similar trends are seen in *E. coli* (Figure 5.29).

At DCC-455, fecal coliform observations range from 460/100 mL in dry weather to 2x10^5/100 mL in wet weather. At DCN-010, observations range from 8x10^2/100 mL in dry weather to 3x10^5/100 mL in wet weather.

Figures 5.30 and 5.31 compare fecal coliform and *E. Coli* along the length of Cobbs Creek and throughout the Darby and Cobbs Creeks system. The plots show the mean and range of measurements, river miles, and dry or wet weather status. Mean and maximum bacteria counts increase from upper Cobbs to Lower Cobbs.

Lower Cobbs Metals

In most cases, metals concentrations are greater in wet weather than in dry. At DCC-110, mean concentrations of all sampled metals except cadmium are greater in wet weather. At DCC-455, the following mean metals concentrations are greater in wet weather: aluminum, chromium, copper, manganese, lead, and zinc. At DCN-010, the following mean metals concentrations are greater in wet weather: aluminum, chromium, copper, manganese, and zinc. All lead samples were below the detection limit at this site. Observed concentrations of Cd are at or below the detection limit in both dry and wet weather for the three sites representing the lower Cobbs.

When multiple wet weather samples are collected during a storm, there is a greater chance that the peak concentration will be measured. During wet weather sampling at DCC-110 , the concentrations of metals follow a pattern similar to the runoff hydrograph (Figures 5.32 through 5.35).

Dissolved iron clearly increases from upstream to downstream along the length of the Cobbs. Concentrations of iron and dissolved iron do not always follow the trend of increasing in wet weather. Compared to the dry weather mean, mean total iron increases in wet weather in both of the main stem sites but decreases slightly at the Naylors Run site. At DCC-110, dissolved iron has a mean of 0.217 mg/L under dry conditions and 0.226 mg/L under wet conditions. Wet weather sampling at DCC-110 indicates that both species increase during a June 2000 runoff event of 0.3 inches (Figures 5.32 and 5.33). At DCC-455, dissolved iron has a mean of 0.184 mg/L under dry conditions and 0.166 mg/L under wet conditions. At DCN-010, the mean dry weather concentration is 0.220 mg/L and the mean wet weather concentration is 0.168.

Lower Cobbs Fish Advisories

AMSA et al. (2002) recommend against using fish advisories alone as bases for impairment listings, but they can provide a basis for further study and for establishment of water quality standards. Fish advisories are most often due to metals or organic chemicals. The April 2001 fish advisory for this watershed advises to limit consumption of White Perch, Striped Bass, and Carp to one meal a month, and to limit consumption of Channel Catfish to one meal every two months. American eel should not be eaten at all. This is all due to PCB pollution.

5.3.3 Upper Darby Creek

The headwaters of Darby Creek are represented by data taken from site DCD-1570 and by a limited amount of data from DCD-1660. These sites are not impacted by known CSOs. Table 5.10 lists the mean dry and wet weather concentrations of water quality constituents at the two sites.

Table 5.10 Summary of Upper Darby Mean Water Quality

		DCD-1570		DCD-1660	
Parameter	Units	Dry	Wet	Dry	Wet
Al	Mg/L	0.054	0.246	0.170	0.195
Alk	Mg/L	71.2	68.2	69.0	60.0
BOD30	Mg/L	1.81	6.81	3.66	2.71
BOD5	Mg/L	1.00	1.70	1.00	1.00
CBOD5	Mg/L	1.00	1.32		
Ca	Mg/L	31.2	25.0	24.4	26.1
Cd	Mg/L	5.00E-04	5.00E-04	5.00E-04	5.00E-04
Chla	ug/L			3.03	2.95
Cr	Mg/L	0.004	0.006	0.001	7.50E-04
Cu	Mg/L	0.002	0.003	0.002	0.003
DO	Mg/L	8.81	7.86	9.41	7.06
DissCd	Mg/L			5.00E-04	5.00E-04
DissFe	Mg/L	0.146	0.130	0.070	0.090
Ecoli	/100 mL	375	7700	175	6000
F	Mg/L	0.050	0.080	0.075	0.050
Fe	Mg/L	0.242	0.466	0.305	0.395
Fecal	/100 mL	404	6730	185	10000
Mg	Mg/L	15.6	12.2	12.1	13.0
Mn	Mg/L	0.024	0.030	0.025	0.040
NH3T	Mg/L	0.050	0.066	0.050	0.050
NO2	Mg/L	0.009	0.017		
NO3	Mg/L	1.67	1.33		
OsPress	mosm	3.50	2.00		5.00
PO4	Mg/L	0.020	0.026	0.030	0.323
Pb	Mg/L	5.00E-04	0.001	5.00E-04	5.00E-04
Phen	Mg/L	0.015	0.015	0.015	0.027
SpCond	uS/cm	338	271	237	197
TChl	ug/L			3.76	3.89
TDS	Mg/L	200	193	225	141
TKN	Mg/L	0.546	0.710		
TP	Mg/L	0.034	0.064	0.050	0.075
TSS	Mg/L	2.70	10.8	74.0	26.5
TempC	degrees C	17.2	19.3	17.5	19.0
Turb	NTU	4.19	8.88	2.66	23.6
Zn	Mg/L	0.009	0.009	0.010	0.015
pH		7.60	7.54	7.35	7.25

Upper Darby Physical Conditions: Temperature, pH, Solids, Conductivity, Turbidity

The continuous data collected by the Sonde instruments provides a picture of how various water quality constituents interact in the urban environment during dry and wet weather. Figure 5-36 includes graphs of multiple parameters for DCD-1660 between September 12 and September 24, 2000. Three wet weather events occurred during this period. The flood peaks are high, occur over short durations, and are followed by a rapid return to baseflow. Each flood peak is accompanied by a large increase in turbidity and a decrease in specific conductance. Temperature, DO, and pH all display characteristic diurnal patterns in dry weather.

Upper Darby Dissolved Oxygen

Continuous DO samples were collected during 8 periods at site DCD-1660. Data from the period October 13 to 27, 2000 (Figure 5.37 upper left) represent a dry weather pattern with the exception of one wet weather event of 0.41 inches on October 18. The period from June 2 to 15, 2000 (upper right) is similar to the previous period. Stormwater runoff appears to mute the diurnal pattern, but the pattern returns to its previous amplitude after less than 24 hours. Data reliability may have decreased after the second wet weather period, but the data still meet quality assurance criteria. Data from the periods June 2 to 15, 2000 (lower left) and July 14 to August 4, 2000 (lower right) display similar trends.

The amplitude of the diurnal variation at DCD-1660 is approximately 1 to 1.5 mg/L, the smallest of the sites studied. The amplitude is greatest during the summer deployments and smaller during the spring and fall.

Upper Darby BOD

At DCD-1570, mean BOD in the water column is greater in wet weather than in dry. At DCD-1660, there is not enough evidence to conclude that it is greater. Figure 5.38 shows the laboratory BOD measured over time for a sample taken at DCD-1660 on June 15, 2000, a wet weather day. The 30-day BOD is approximately 3 to 4 mg/L, but there is virtually no BOD exertion for the first 3 to 5 days.

Upper Darby Nutrients

Figures 5.16 through 5.23 display the means, ranges, and weather status of samples of nitrogen and phosphorus species taken along the length of Darby Creek and throughout the Darby and Cobbs Creeks system. Mean nitrate and ammonia concentrations increase slightly along the length of Darby Creek. Mean total phosphorus is greater at DCD-1660 than at DCD-1570.

Upper Darby Bacteria

Figures 5.30 and 5.31 display the means, ranges, and weather status of samples of fecal coliform and *E. coli* taken along the length of Darby Creek and throughout the Darby and Cobbs Creeks system. Mean and maximum counts both increase along the length of Darby Creek.

Upper Darby Metals

At the two Upper Darby sites, mean concentrations of aluminum, copper, iron, and manganese are greater in wet weather than in dry weather. Cadmium is at or below the detection limit for all samples. Dissolved iron is lower in wet weather than in dry at DCD-1570.

Upper Darby Fish Advisories

AMSA et al. (2002) recommend against using fish advisories alone as bases for impairment listings, but they can provide a basis for further study and for establishment of water quality standards. Fish advisories are most often due to metals or organic chemicals. The April 2001 fish advisory for this watershed advises to limit consumption of White Perch, Striped Bass, and Carp to one meal a month, and to limit consumption of Channel Catfish to one meal every two months. American eel should not be eaten at all. This is all due to PCB pollution.

5.3.4 Lower Darby Creek

Lower Darby Creek is represented by two sampling sites. DCD-1170 is in the northwest part of Upper Darby Township,and DCD-765 is upstream of the confluence with Cobbs Creek. These sites are impacted by stormwater but not by known CSOs. Table 5.11 lists the mean dry and wet weather concentrations of water quality constituents at the two sites.

Table 5.11 Summary of Lower Darby Mean Water Quality

		DCD-765		DCD-1170	
Parameter	Units	Dry	Wet	Dry	Wet
Al	Mg/L	0.033	0.635	0.034	0.178
Alk	Mg/L	68.4	57.4	70.2	67.6
BOD30	Mg/L	2.79	9.04	2.36	5.42
BOD5	Mg/L	4.00	2.32	1.00	1.82
CBOD5	Mg/L	1.00	1.75	1.00	1.45
Ca	Mg/L	29.4	22.9	31.2	25.7
Cd	Mg/L	5.00E-04	5.00E-04	5.00E-04	5.00E-04
Chla	Ug/L	1.85	12.0		
Cr	Mg/L	0.003	0.006	0.004	0.005
Cu	Mg/L	0.003	0.007	0.002	0.003
DO	Mg/L	9.24	7.30	8.38	7.65
DissCd	Mg/L	5.00E-04	5.00E-04		
DissFe	Mg/L	0.133	0.157	0.162	0.146
Ecoli	/100 mL	768	1.54E+04	400	3340
F	Mg/L	0.069	0.105	0.050	0.060
Fe	Mg/L	0.214	0.869	0.254	0.404
Fecal	/100 mL	964	3.30E+04	516	6940
Mg	Mg/L	14.5	11.0	15.3	12.3
Mn	Mg/L	0.018	0.060	0.046	0.048
NH3T	Mg/L	0.060	0.171	0.050	0.066
NO2	Mg/L	0.012	0.024	0.009	0.017
NO3	Mg/L	1.81	1.53	1.70	1.38
OsPress	mosm	5.00	3.00	4.00	3.00
PO4	Mg/L	0.020	0.033	0.020	0.024
Pb	Mg/L	5.00E-04	0.005	5.00E-04	0.001
Phen	Mg/L	0.015	0.031	0.015	0.015
SpCond	US/cm	334	254	373	297
TChl	Ug/L	2.18	14.1		
TDS	Mg/L	219	187	219	211
TKN	Mg/L	0.442	0.831	0.492	0.738
TP	Mg/L	0.059	0.118	0.032	0.068
TSS	Mg/L	1.69	32.4	2.30	8.40
TempC	degrees C	19.0	20.0	17.9	19.6
Turb	NTU	1.28	30.2	2.46	6.93
Zn	Mg/L	0.009	0.023	0.005	0.028
PH		7.92	7.57	7.58	7.54

Lower Darby Physical Conditions: Temperature, pH, Solids, Conductivity, Turbidity

The continuous data collected by the Sonde instruments provides a picture of how various water quality constituents interact in the urban environment during dry and wet weather. Figure 5.39 shows two dry weather periods separated by a wet weather event. During the initial dry weather period, temperature, pH, and DO all show a relatively constant diurnal pattern. The urban wet weather hydrograph is characterized by a high, short duration storm peak followed by a rapid return to baseflow in less than 24 hours. During the storm peak, a large increase in turbidity and a decrease in specific conductance are observed. The decrease in water temperature following the storm most likely corresponds to a decrease in air temperature. pH and DO data taken after the peak do not meet quality assurance criteria, as described in the Appendix.

Lower Darby Dissolved Oxygen

Continuous DO data were collected at DCD-765 during 8 periods between September 1999 and August 2001. The period from September 27 to October 5, 2000 (upper left, Figure 5-40), is an example of a dry weather DO pattern with an amplitude of approximately 1-2 mg/L. The period from October 13 to 26, 2000 (upper right) is an example of a mostly dry period with one small wet weather event. Runoff mutes the diurnal pattern, but it recovers within 24 hours of the storm passing. The muted effect can be explained by the diluting effect of stormwater runoff, although it is difficult to determine the role of instrument error in these readings. The amplitude of the signal in this case is approximately 2 to 2.5 mg/L. The period from July 26 to August 9, 2001 (lower left) is similar but includes several wet weather events. The deployment between September 1 and September 7, 2000 (lower right) begins with a dry weather period displaying an amplitude of 2 mg/L. Following the wet weather event, the data do not meet quality assurance criteria.

Overall, the amplitude of the diurnal DO variation at DCD-765 is approximately 2 mg/L. There are insufficient data to determine whether this amplitude varies between seasons.

Lower Darby BOD

Laboratory BOD tests conducted on wet weather samples at DCD-765 show that 5-day and 30-day BOD are greater in wet weather than in dry weather. When the samples are incubated in the laboratory for five days, the total oxygen demand generated is in the range of 2 mg/L. BOD exertion over 2-3 days, coupled with a high estimate of travel time in the stream, would mean that in-stream BOD is much less than 1 mg/L.

Lower Darby Nutrients

Inorganic nitrogen at DCD-765 has a mean concentration of 1.88 mg/L in dry weather and 1.73 mg/L in wet weather. Ammonia makes up approximately 3% of total nitrogen in dry weather and 7% in wet weather. Mean inorganic nitrogen at DCD-

1170 has a concentration of 2.20 mg/L in dry weather and 2.13 mg/L in wet weather. Ammonia makes up approximately 2% of total nitrogen in dry weather and 3% in wet weather.

At both DCD-765 and DCD-1170, phosphate is equal to or less than the detection limit for all samples except one wet weather sample on 7/20/99. At DCD-765, phosphate makes up approximately one-third of total phosphorus in both dry and wet weather. At DCD-1170, total phosphorus makes up approximately 62% of total phosphorus in dry weather and 35% in wet weather.

Figures 5.41 and 5.42 show the temporal relationships between discrete nitrogen and phosphorus species collected at DCD-765. Figures 5.16 through 5.23 display the means, ranges, and weather status of samples of nitrogen and phosphorus species taken along the length of Darby Creek and throughout the Darby and Cobbs Creeks system. Nitrate and ammonia concentrations increase along the length of Darby Creek. Total phosphorus is highest at the most upstream and most downstream sites.

Lower Darby Bacteria

Fecal coliform at the two Lower Darby sites ranges from a minimum of 190/100 mL in dry weather to greater than 10^5/100 mL in wet weather. *E. coli* ranges from a minimum of 100/100 mL in dry weather to a maximum of 2.6×10^4 in wet weather. Figures 5.30 and 5.31 show how these concentrations compare to observations at other points in the system. Counts generally increase with distance downstream. At DCD-765, the mean and range of counts are similar to those in the combined-sewered areas of the Cobbs watershed.

Lower Darby Metals

Trends in metals between wet and dry weather are similar to those observed at other sites. Mean aluminum, chromium, copper, iron, manganese, lead, and zinc are all higher in wet weather for both sites. Cadmium is at or below the detection limit for all samples. Dissolved iron is greater in wet weather at DCD-765 but lower in wet weather upstream at DCD-1170. Figures 5.43 through 5.50 compare means, ranges, and weather status of metals concentrations observed along the length of Darby Creek and throughout the Darby and Cobbs Creeks system.

Lower Darby Fish Advisories

AMSA et al. (2002) recommend against using fish advisories alone as bases for impairment listings, but they can provide a basis for further study and for establishment of water quality standards. Fish advisories are most often due to metals or organic chemicals. The April 2001 fish advisory for this watershed advises to limit consumption of White Perch, Striped Bass, and Carp to one meal a month, and to limit consumption of Channel Catfish to one meal every two months. American eel should not be eaten at all. This is all due to PCB pollution.

5.3.5 Tinicum Area

Two sampling sites represent conditions in the Tinicum area. These include DCM-300 on Muckinipattis Creek and DCS-170 on Stony Creek.

Table 5.12 Summary of Tinicum Mean Water Quality

		DCM-300		DCS-170	
Parameter	Units	Dry	Wet	Dry	Wet
Al	Mg/L	0.013	0.054	0.044	0.142
Alk	Mg/L	72.4	62.6	76.2	60.2
BOD30	Mg/L	2.76	3.57	2.52	4.47
BOD5	Mg/L	1.57	1.84	1.53	2.23
CBOD5	Mg/L	1.00	1.45	1.00	2.05
Ca	Mg/L	28.9	20.5	39.7	25.2
Cd	Mg/L	5.00E-04	5.00E-04	5.00E-04	5.00E-04
Chla	ug/L				
Cr	Mg/L	0.004	0.004	0.004	0.005
Cu	Mg/L	0.003	0.006	0.007	0.009
DO	Mg/L	6.94	6.03	7.42	6.08
DissCd	Mg/L				
DissFe	Mg/L	0.258	0.184	0.248	0.246
Ecoli	/100 mL	1400	9840	600	8160
F	Mg/L	0.102	0.122	0.100	0.118
Fe	Mg/L	0.462	0.292	0.464	0.494
Fecal	/100 mL	1010	3.51E+04	970	3.43E+04
Mg	Mg/L	13.0	8.01	14.3	8.51
Mn	Mg/L	0.036	0.020	0.046	0.046
NH3T	Mg/L	0.050	0.064	0.062	0.086
NO2	Mg/L	0.008	0.006	0.007	0.020
NO3	Mg/L	0.834	0.836	1.42	1.17
OsPress	mosm	4.50	2.00	6.00	2.00
PO4	Mg/L	0.020	0.024	0.020	0.024
Pb	Mg/L	5.00E-04	8.00E-04	5.00E-04	0.002
Phen	Mg/L	0.046	0.015	0.015	0.015
SpCond	uS/cm	363	210	470	319
TChl	ug/L				
TDS	Mg/L	210	156	263	231
TKN	Mg/L	0.596	0.740	0.798	0.908
TP	Mg/L	0.030	0.066	0.036	0.088
TSS	Mg/L	2.10	1.90	4.80	6.10
TempC	degrees C	18.3	19.9	18.5	20.1
Turb	NTU	3.85	3.92	5.13	6.87
Zn	Mg/L	0.010	0.012	0.010	0.016
PH		7.28	7.22	7.36	7.16

Tinicum Dissolved Oxygen

Discrete samples of DO at DCS-170 range from 4.75 mg/L measured on 6/15/99 to 9.54 mg/L measured on 5/11/99. Observed DO at DCM-300 ranges from 4.36 mg/L measured on 6/29/99 to 9.90 mg/L measured on 5/11/99. Figures 5.51 and 5.53 display the temporal trend in dissolved oxygen and physical parameters for discrete samples collected in 1999.

Tinicum Nutrients

Mean total inorganic nitrogen (nitrate, nitrite, and ammonia) at site is 1.73 mg/L in dry weather and 1.41 mg/L in wet weather. Ammonia represents approximately 2% of total nitrogen in dry weather and 3% in wet weather. Figures 5.51 through 5.54 show the temporal trends in nitrogen and phosphorus species over the duration of the 1999 discrete sampling period. Nitrate concentrations are generally lower than those observed in other parts of the system, while ammonia concentrations are similar.

Tinicum Bacteria

Observed bacteria concentrations are similar at the two Tinicum sites, ranging from a minimum of 200/100 mL fecal coliform in dry weather to a maximum of 76,000/100 mL in wet weather. Figures 5.30 and 5.31 are visual representations of the range of concentrations found throughout the system in dry and wet weather. Mean and maximum counts are similar to those found at Upper Cobbs and Lower Darby sites.

Tinicum Metals

Mean concentrations of most metals increase from dry to wet weather at both sites, including aluminum, copper, lead, and zinc. Mean manganese concentrations are lower or unchanged in wet weather, and mean dissolved iron concentrations decrease at both sites in wet weather. Figures 5.43 through 5.50 compare means, ranges, and weather status of bacteria concentrations at the two Tinicum sites and throughout the Darby and Cobbs Creeks system.

Tinicum Fish Advisories

AMSA et al. (2002) recommend against using fish advisories alone as bases for impairment listings, but they can provide a basis for further study and for establishment of water quality standards. Fish advisories are most often due to metals or organic chemicals. The April 2001 fish advisory for this watershed advises to limit consumption of White Perch, Striped Bass, and Carp to one meal a month, and to limit consumption of Channel Catfish to one meal every two months. American eel should not be eaten at all. This is all due to PCB pollution.

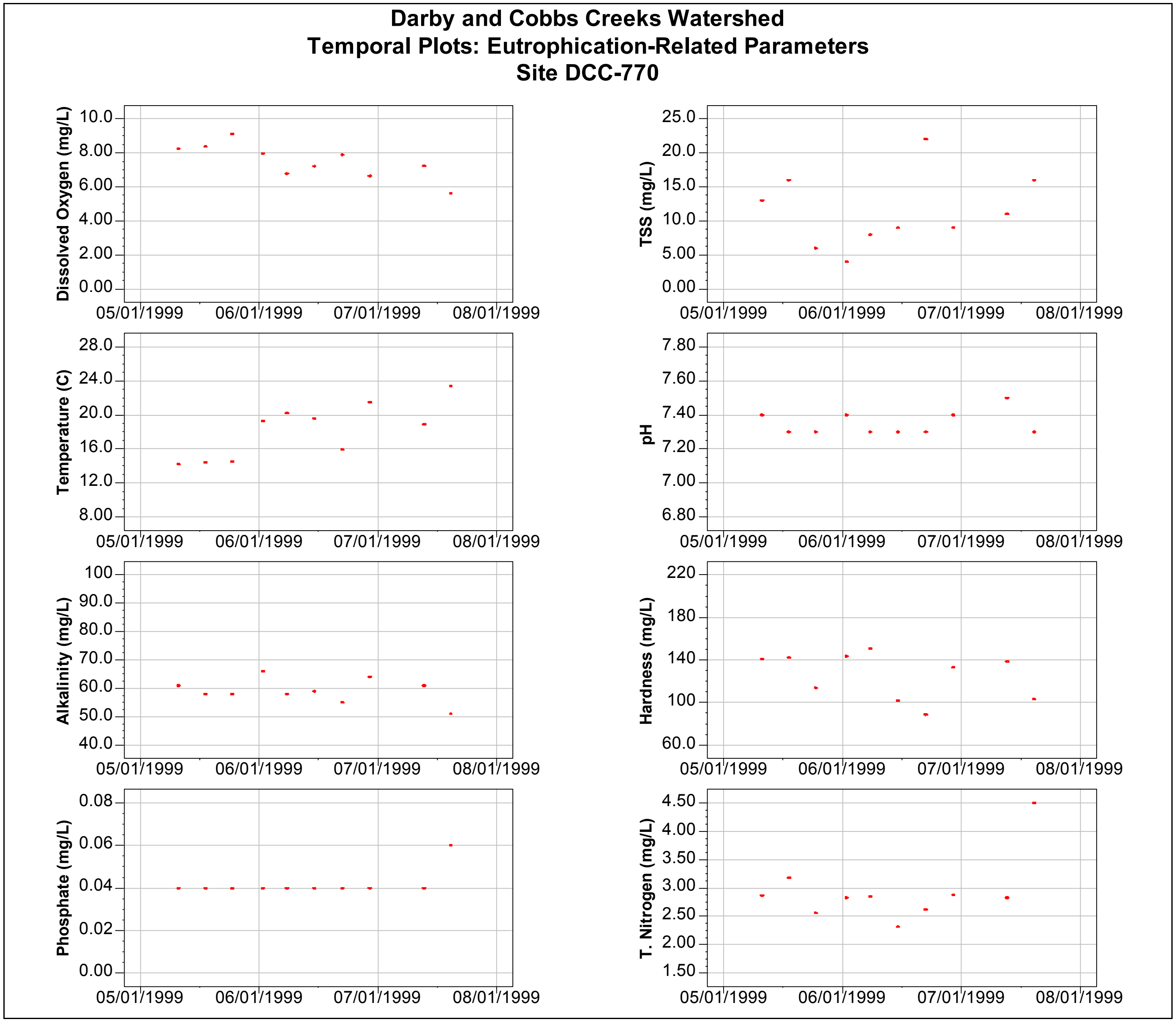


Figure 5.7 Eutrophication-Related Physical Parameters Temporal Plots at DCC-770

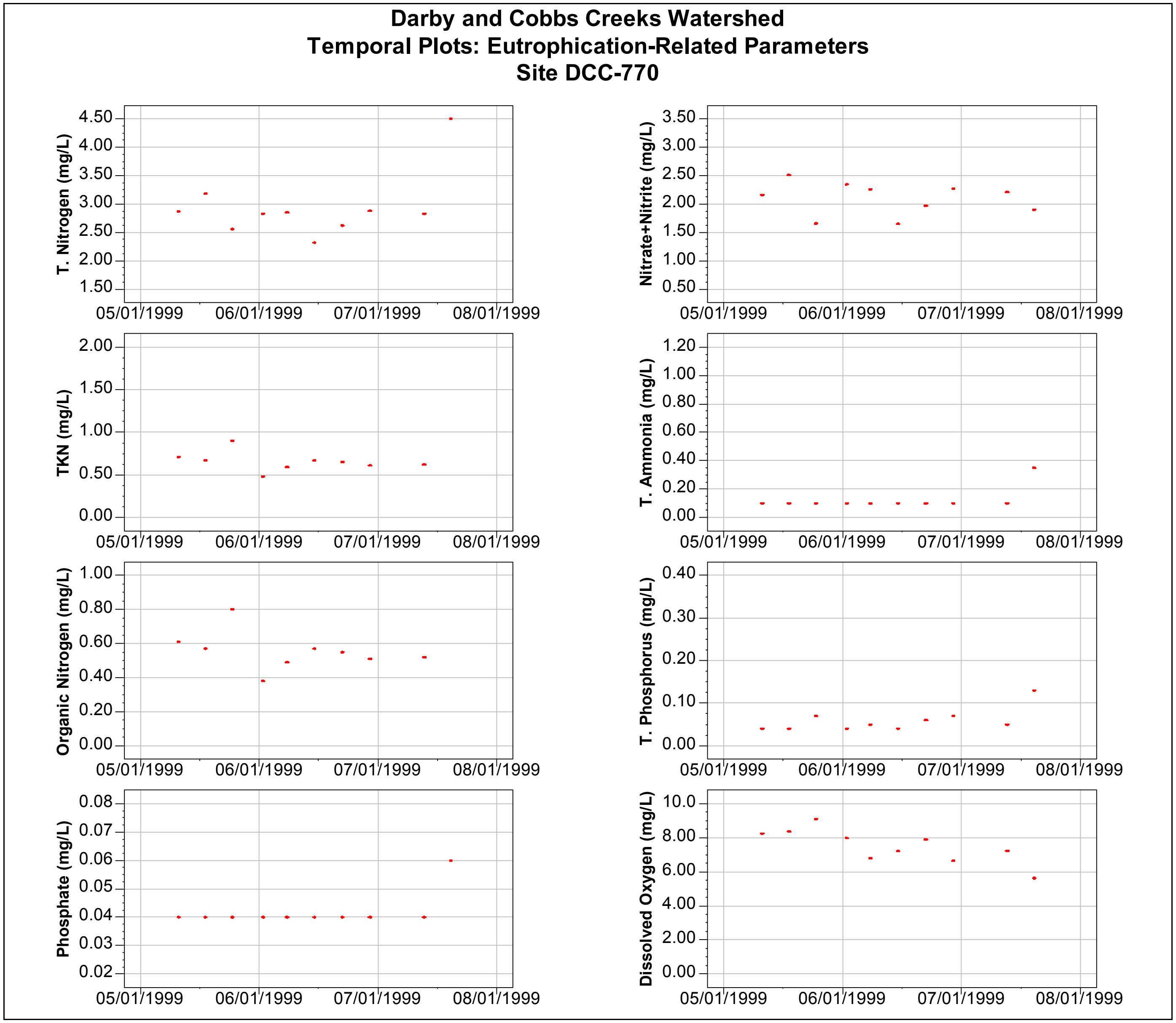
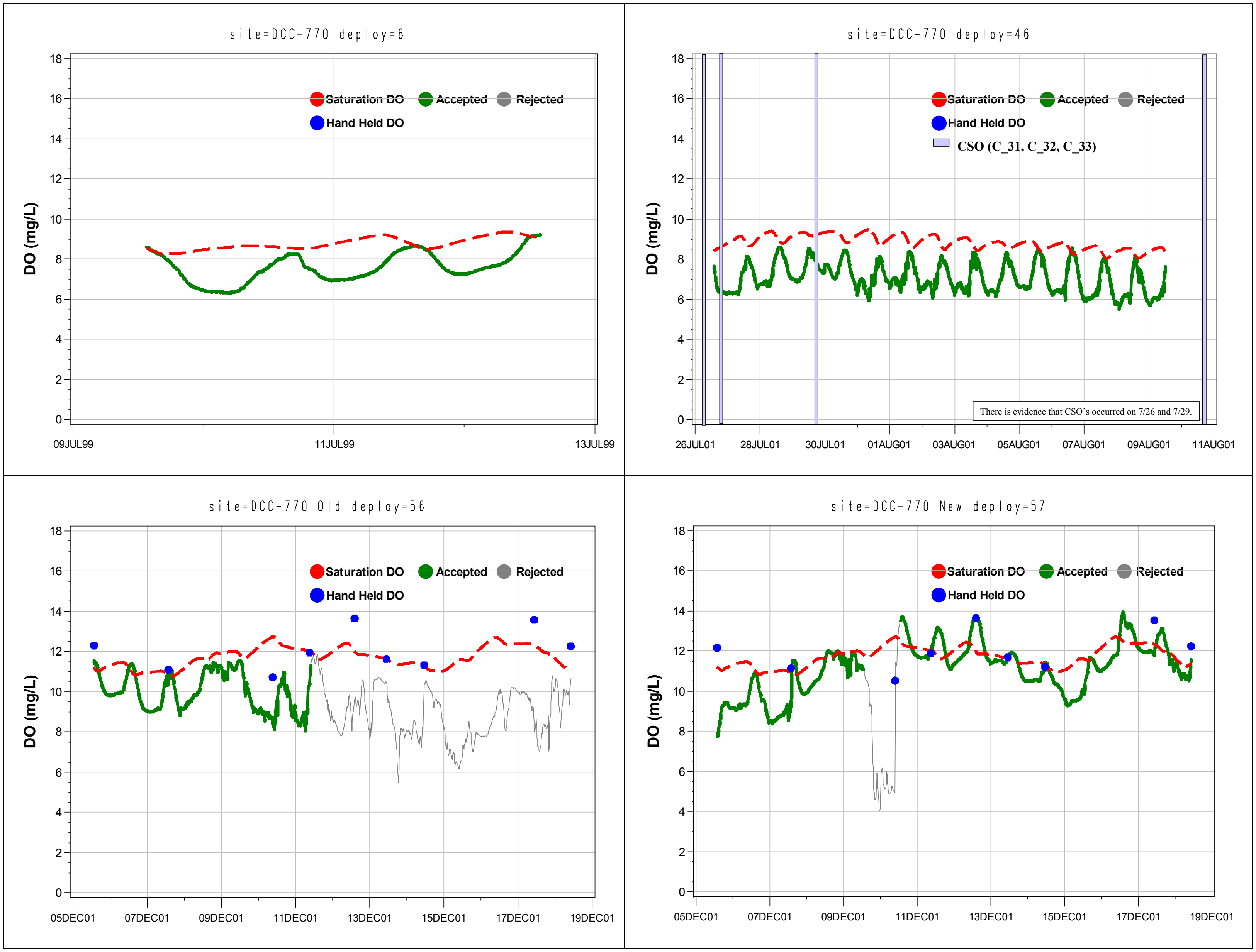
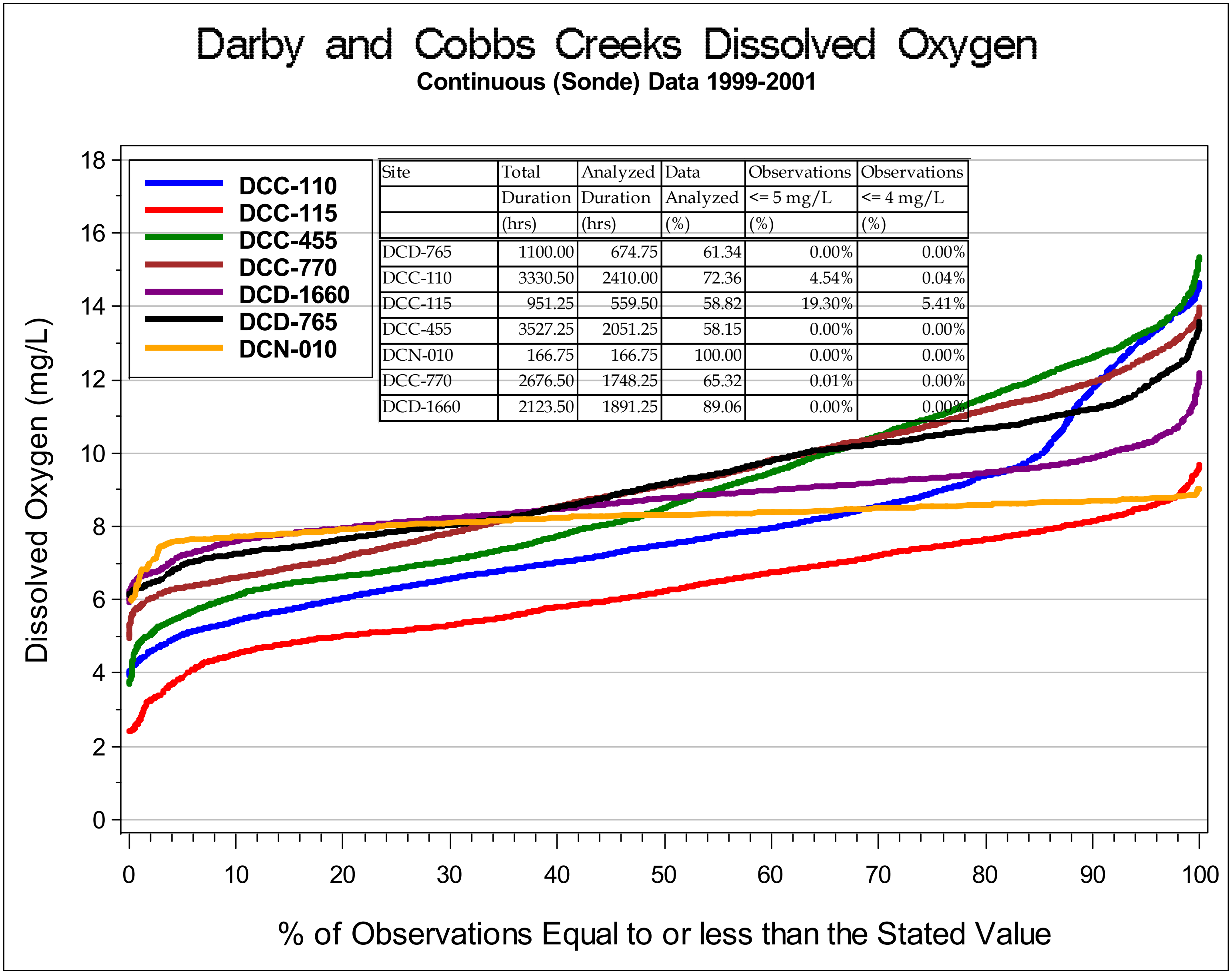


Figure 5.8 Eutrophication-Related Nutrient Parameters Temporal Plots at DCC-770



There is evidence that CSO's occurred on 7/26 and 7/29.

Figure 5.9 Sonde Continuous DO Temporal Plots at DCC-770



Site	Total Duration (hrs)	Analyzed Duration (hrs)	Data Analyzed (%)	Observations <= 5 mg/L (%)	Observations <= 4 mg/L (%)
DCD-765	1100.00	674.75	61.34	0.00%	0.00%
DCC-110	3330.50	2410.00	72.36	4.54%	0.04%
DCC-115	951.25	559.50	58.82	19.30%	5.41%
DCC-455	3527.25	2051.25	58.15	0.00%	0.00%
DCN-010	166.75	166.75	100.00	0.00%	0.00%
DCC-770	2676.50	1748.25	65.32	0.01%	0.00%
DCD-1660	2123.50	1891.25	89.06	0.00%	0.00%

Figure 5.10 Sonde DO CDF plots of All Sites for 1999-2001

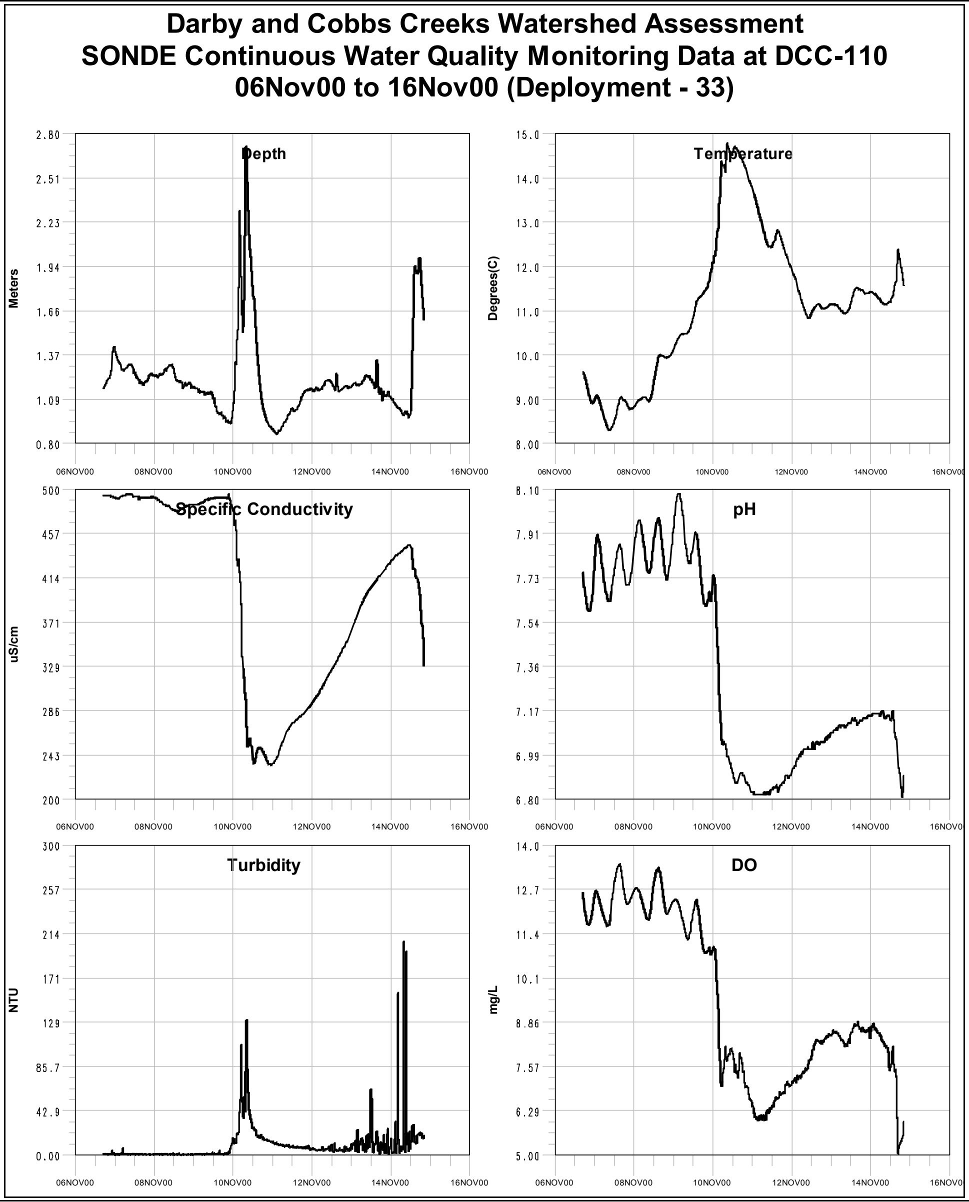


Figure 5.11 Sonde Continuous Multi Parameter Temporal Plots at DCC-110

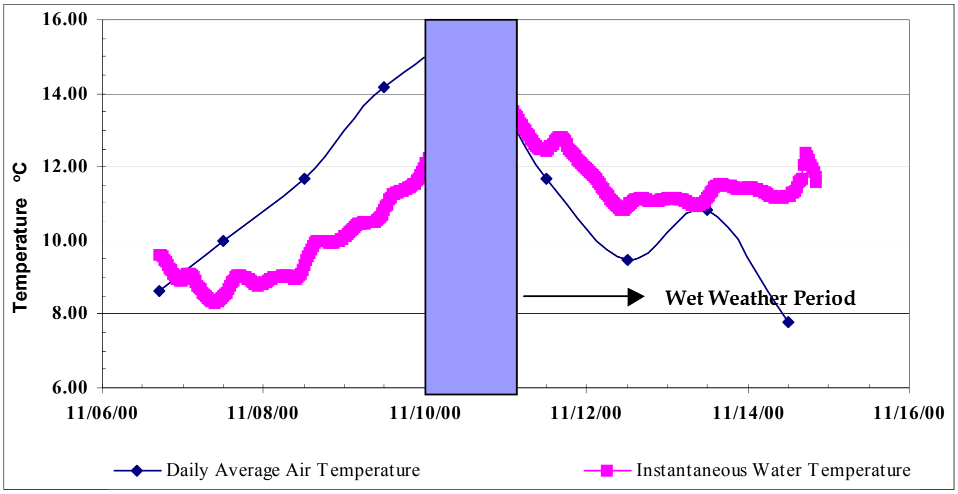
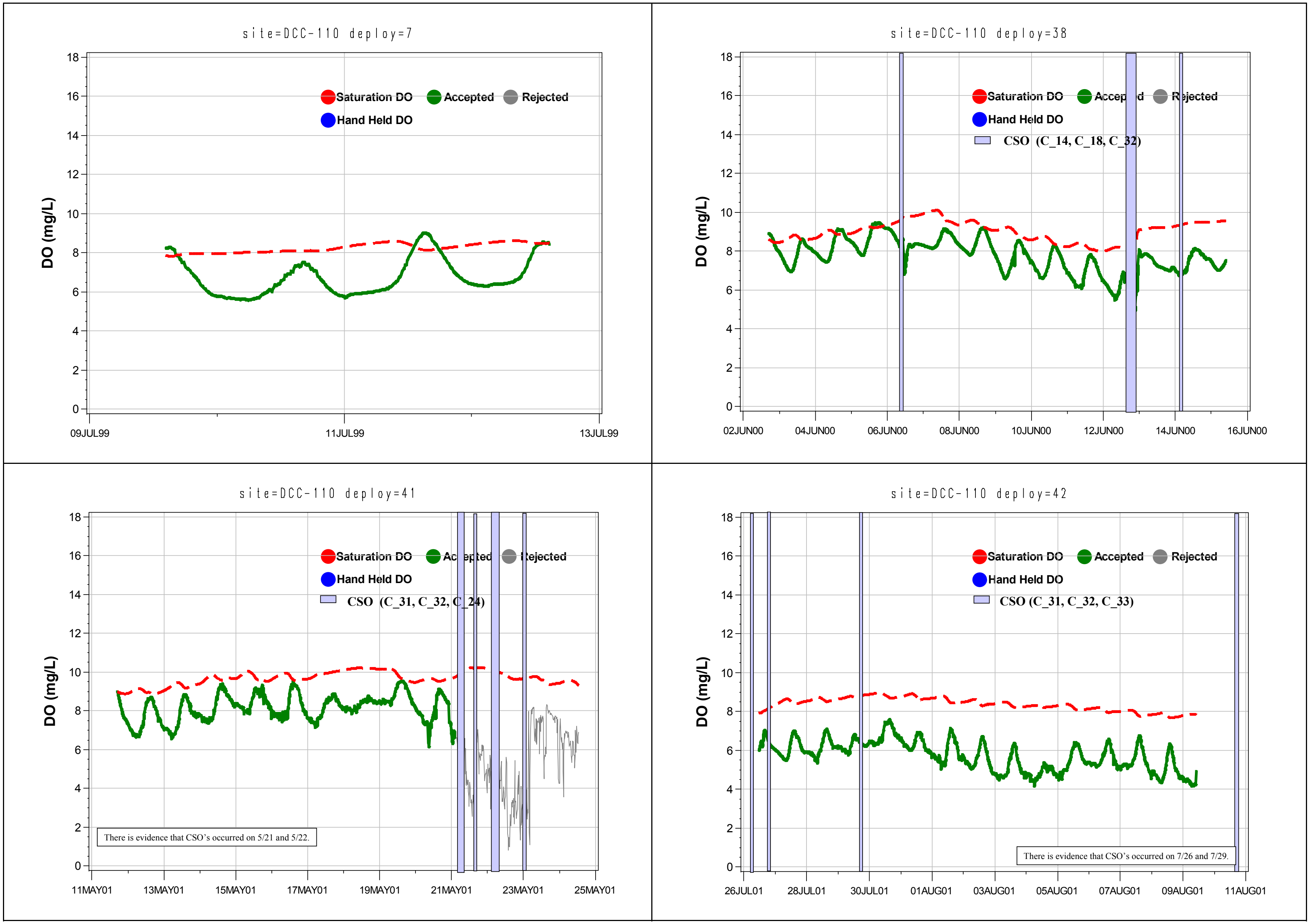


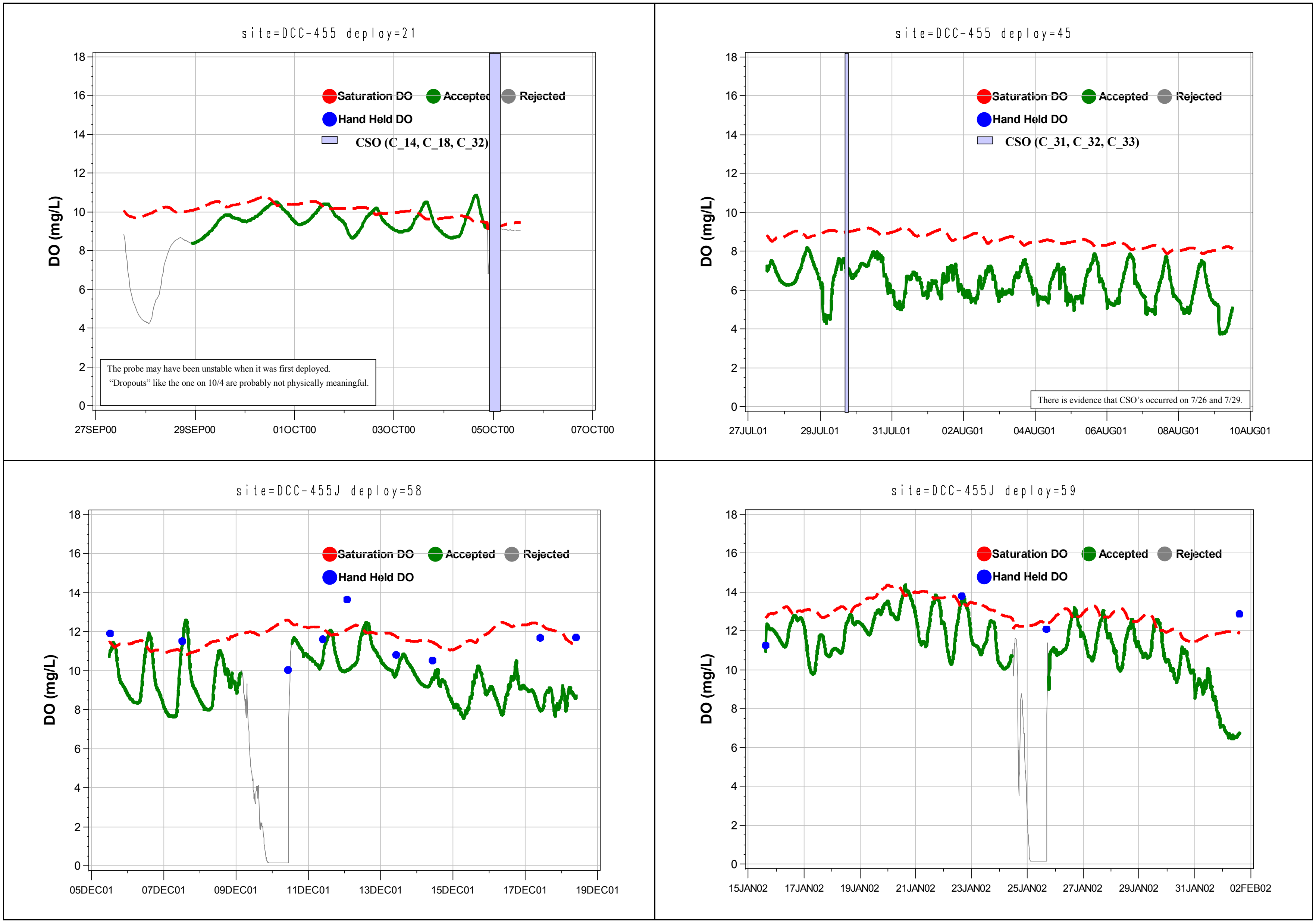
Figure 5.11.1 Comparison of Air and Water temperature Trend with a storm



There is evidence that CSO's occurred on 5/21 and 5/22.

There is evidence that CSO's occurred on 7/26 and 7/29.

Figure 5.12 Sonde Continuous DO Temporal Plots at DCC-110



site=DCC-455 deploy=21

The probe may have been unstable when it was first deployed.
"Dropouts" like the one on 10/4 are probably not physically meaningful.

site=DCC-455 deploy=45

There is evidence that CSO's occurred on 7/26 and 7/29.

site=DCC-455J deploy=58

site=DCC-455J deploy=59

Figure 5.13 Sonde Continuous DO Temporal Plots at DCC-455

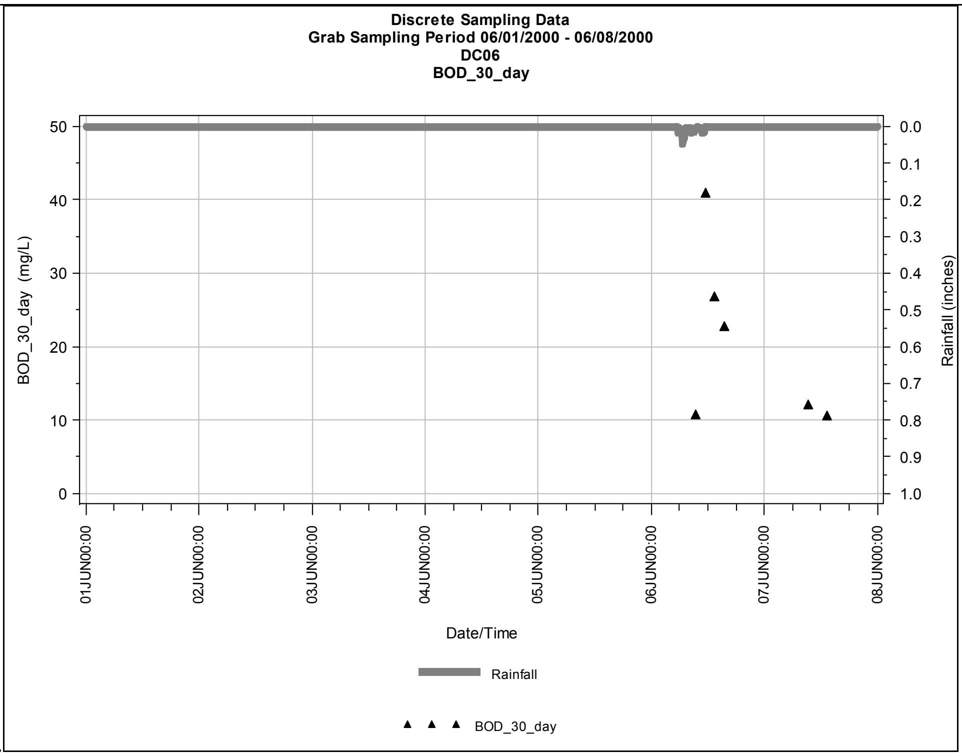


Figure 5.14 Wet Weather Plot for BOD30 at DCC-110

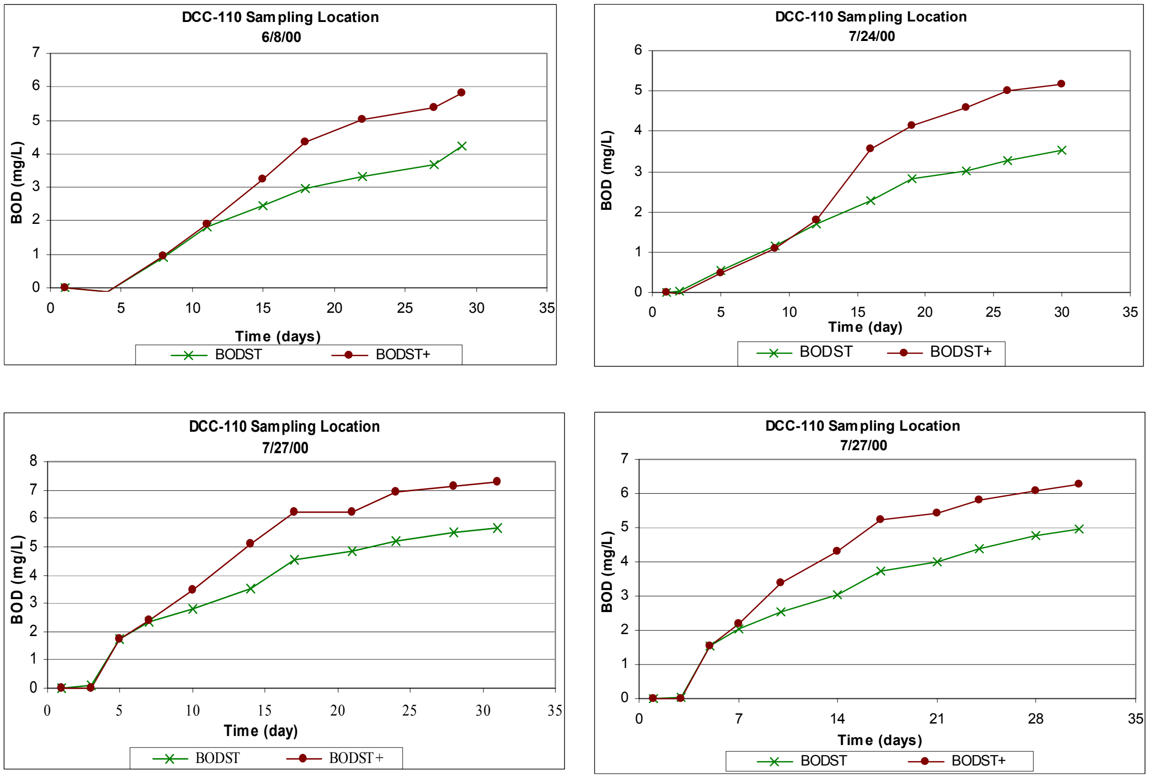


Figure 5.15 BOD Plots for DCC-110

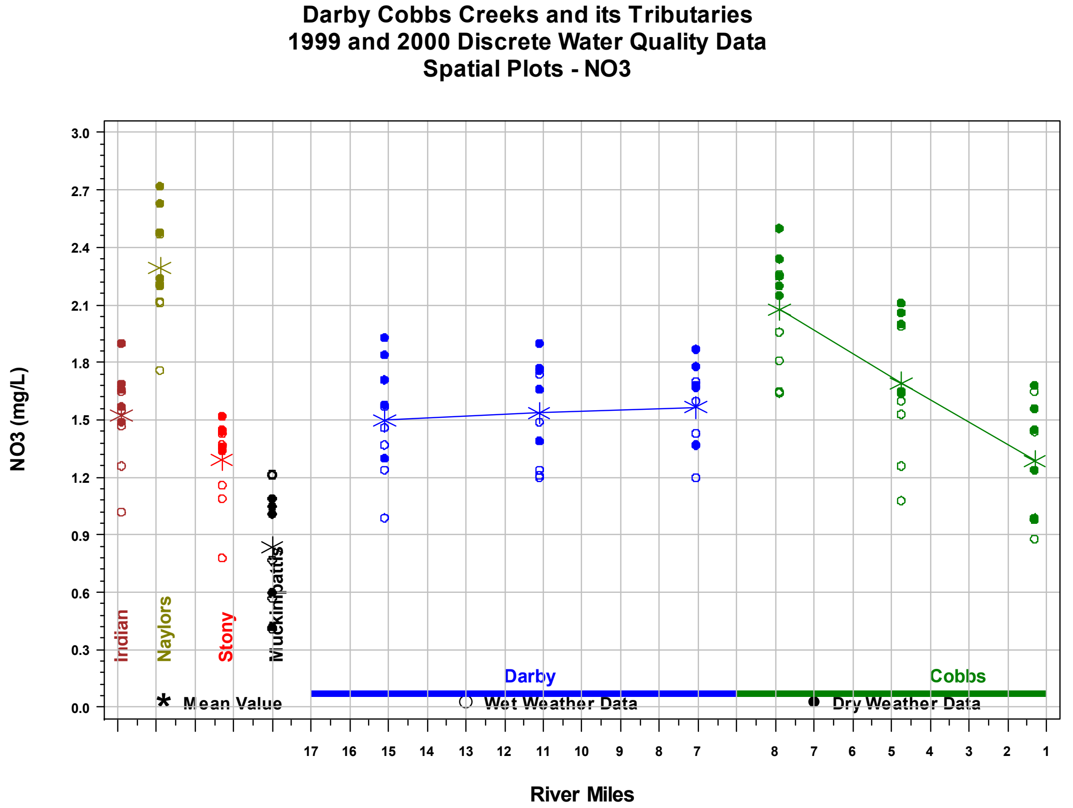


Figure 5.16 Spatial Plot for Nitrate

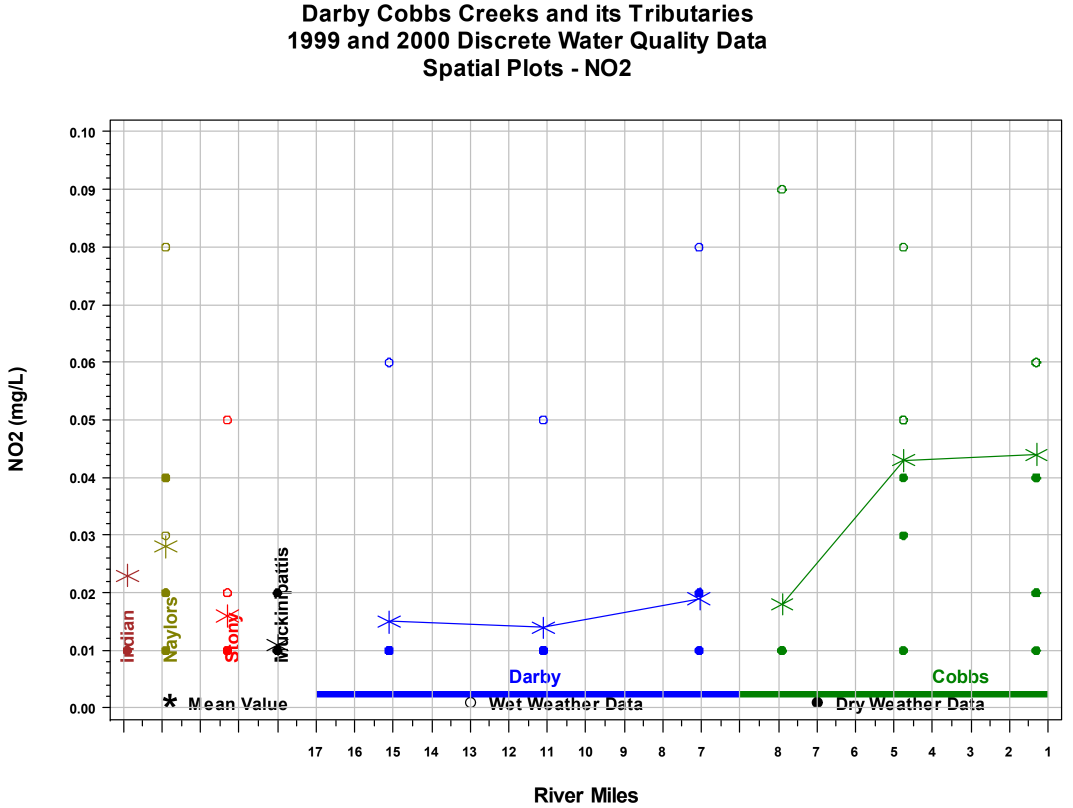


Figure 5.17 Spatial Plot for Nitrite

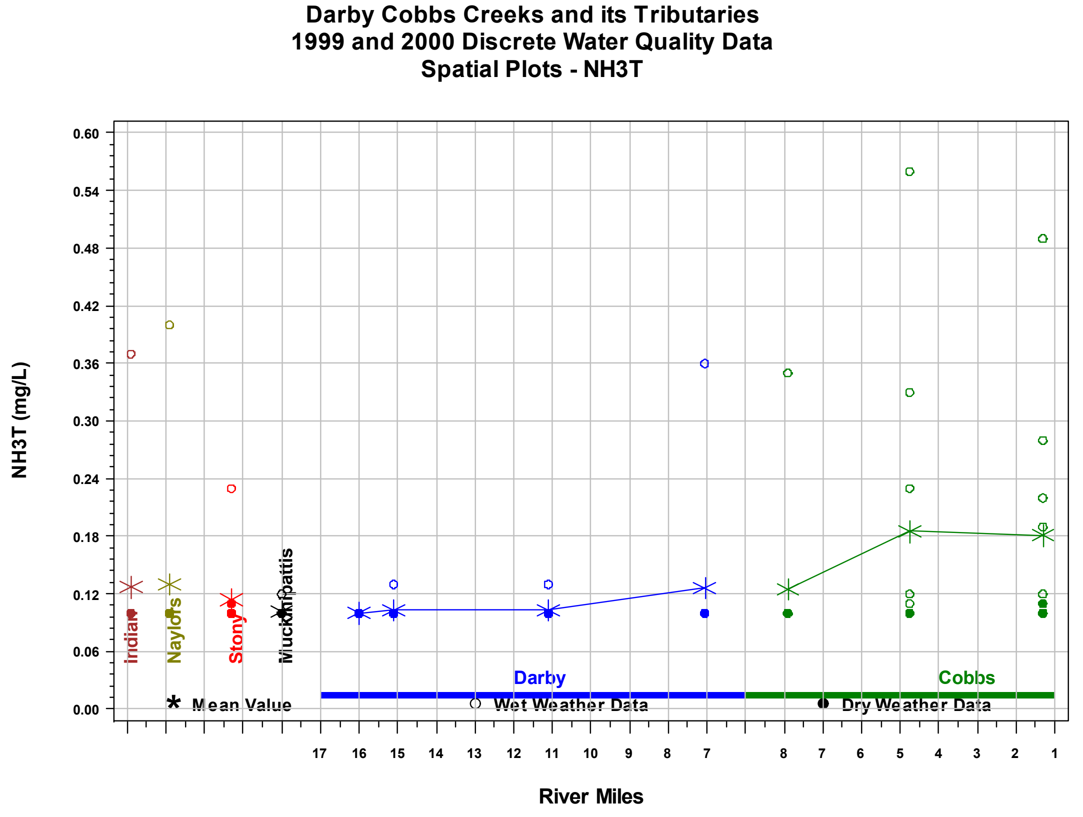


Figure 5.18 Spatial Plot for Total Ammonia

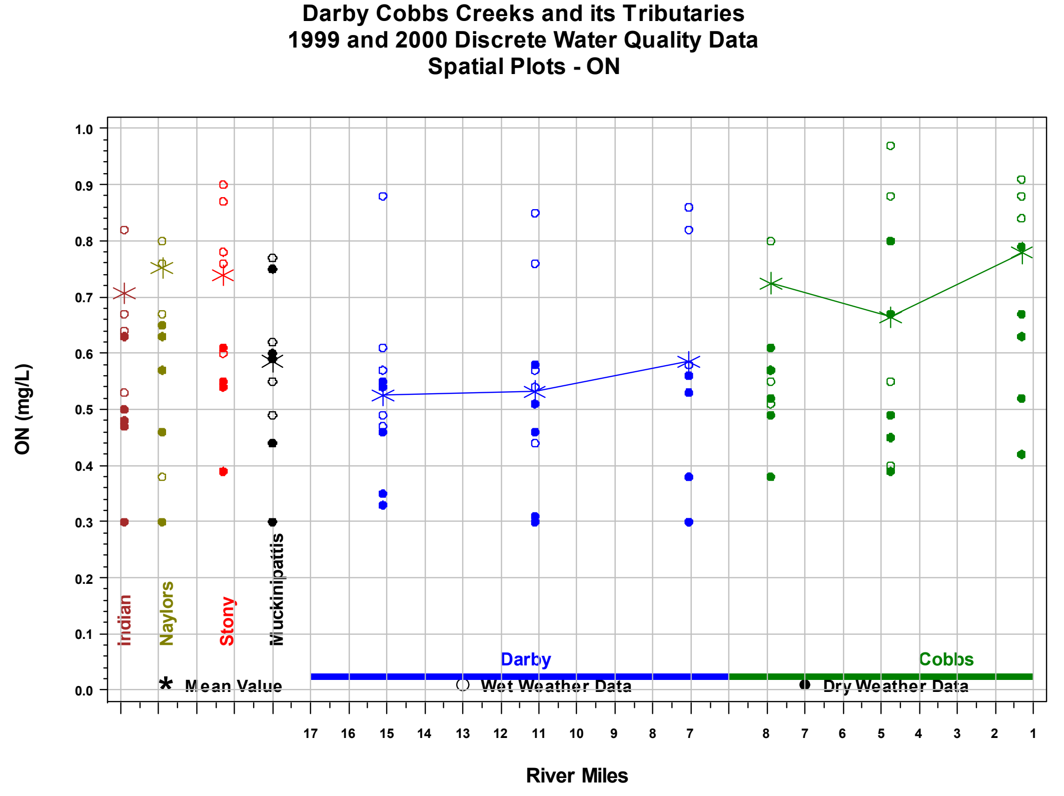


Figure 5.19 Spatial Plot for Organic Nitrogen

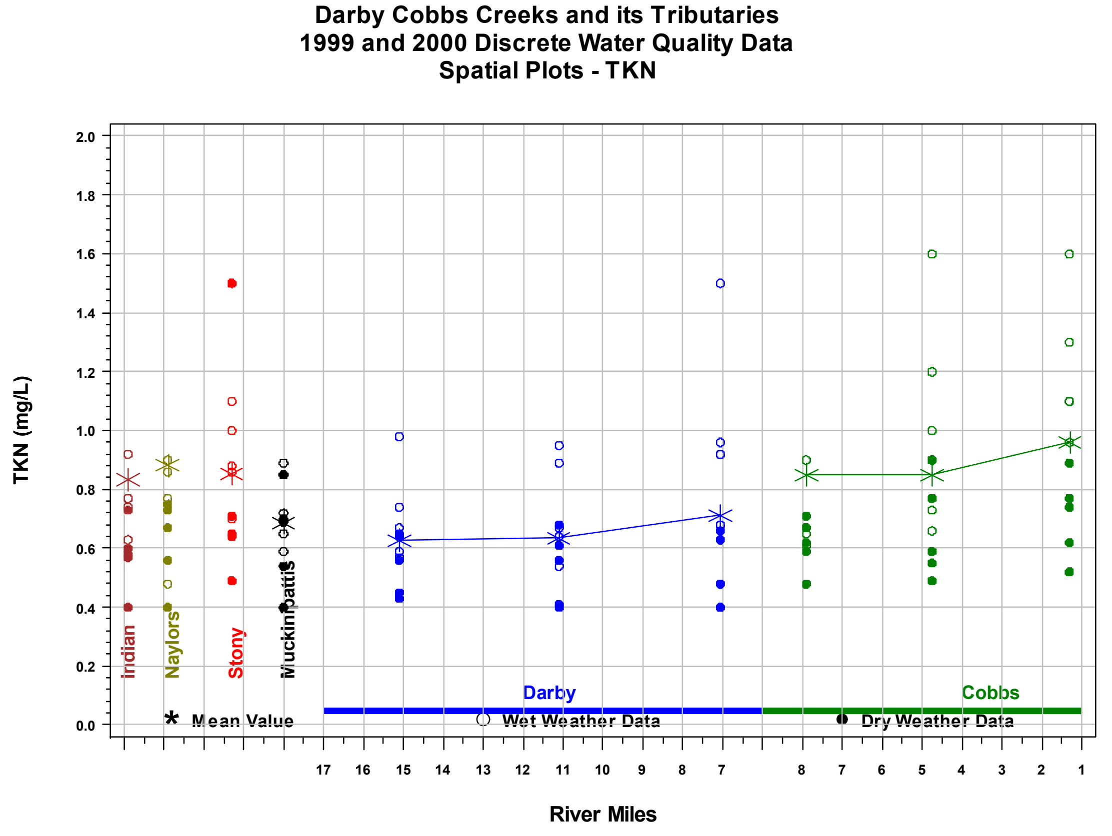


Figure 5.20 Spatial Plot for TKN

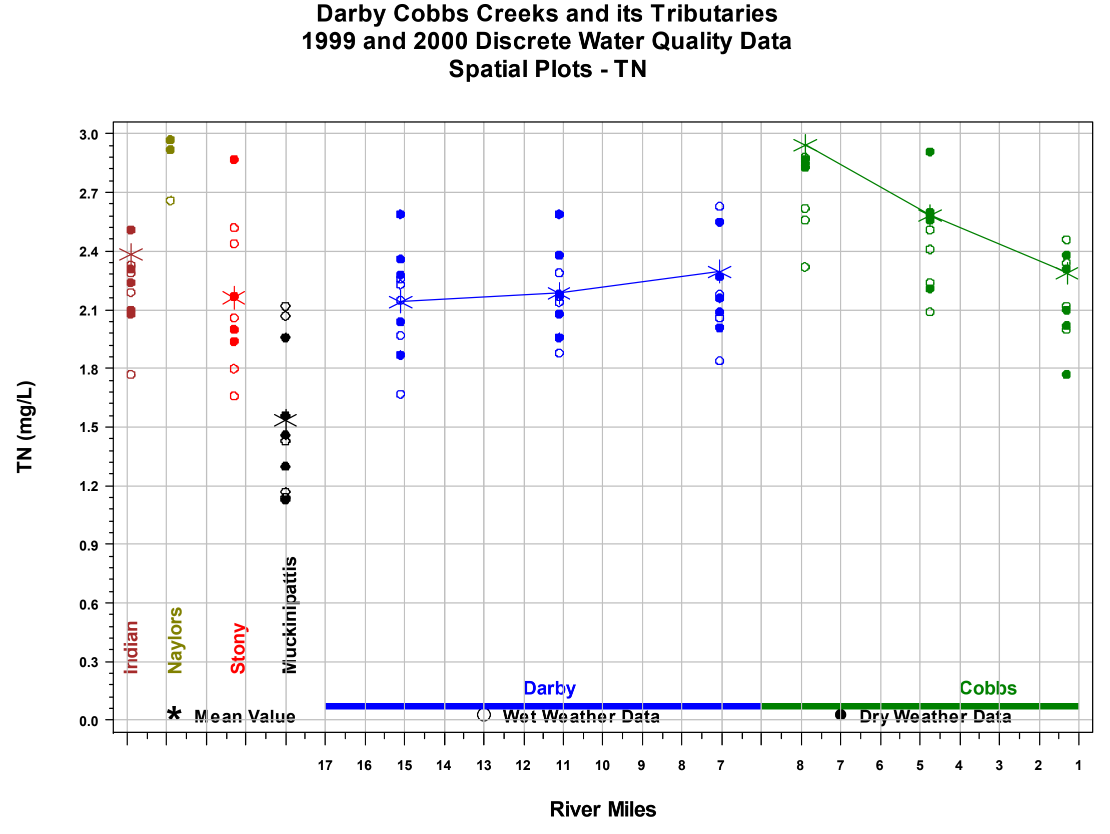


Figure 5.21 Spatial Plot for Total Nitrogen

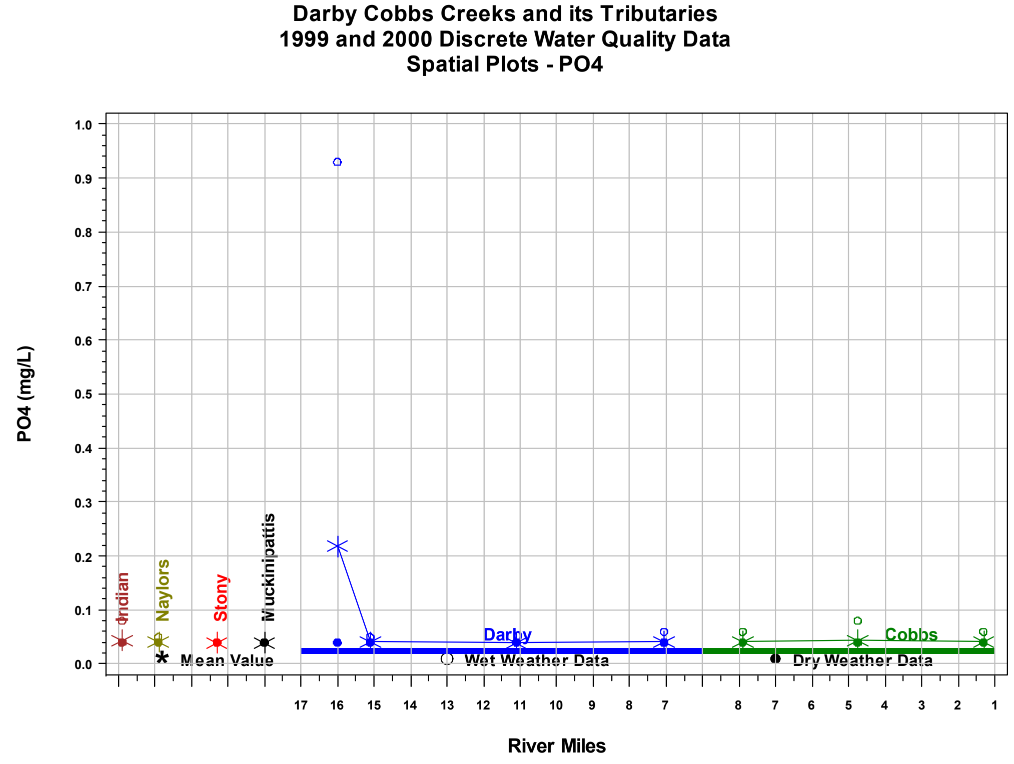


Figure 5.22 Spatial Plot for Ortho Phosphate

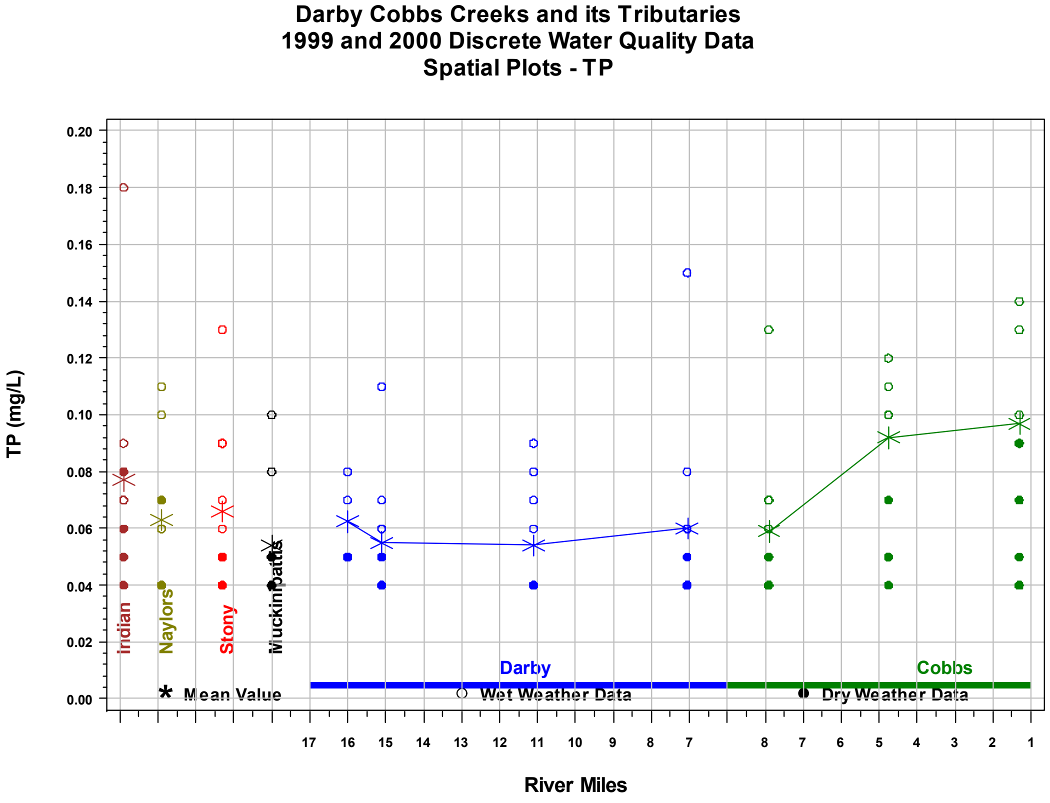


Figure 5.23 Spatial Plot for Total Phosphate

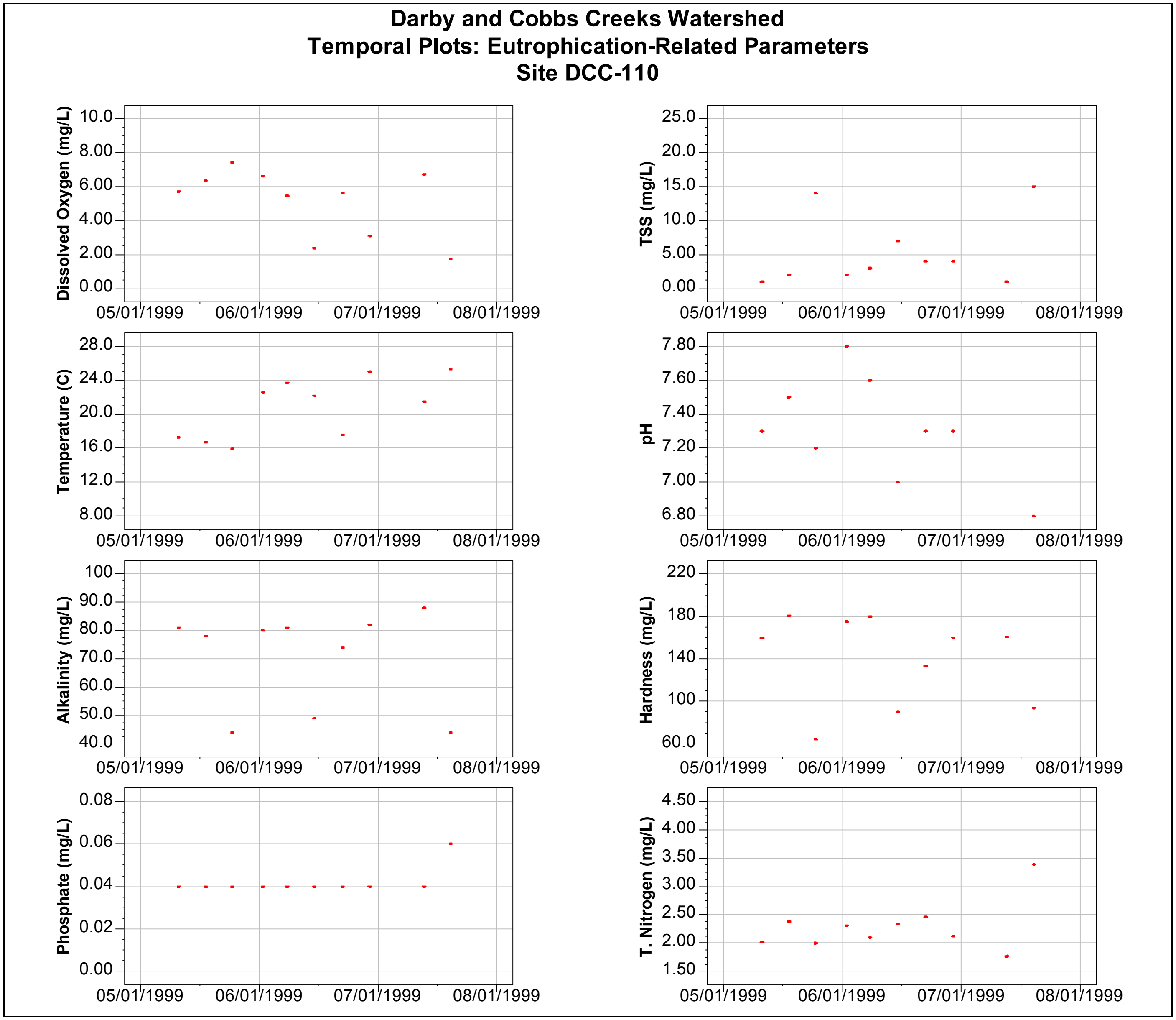
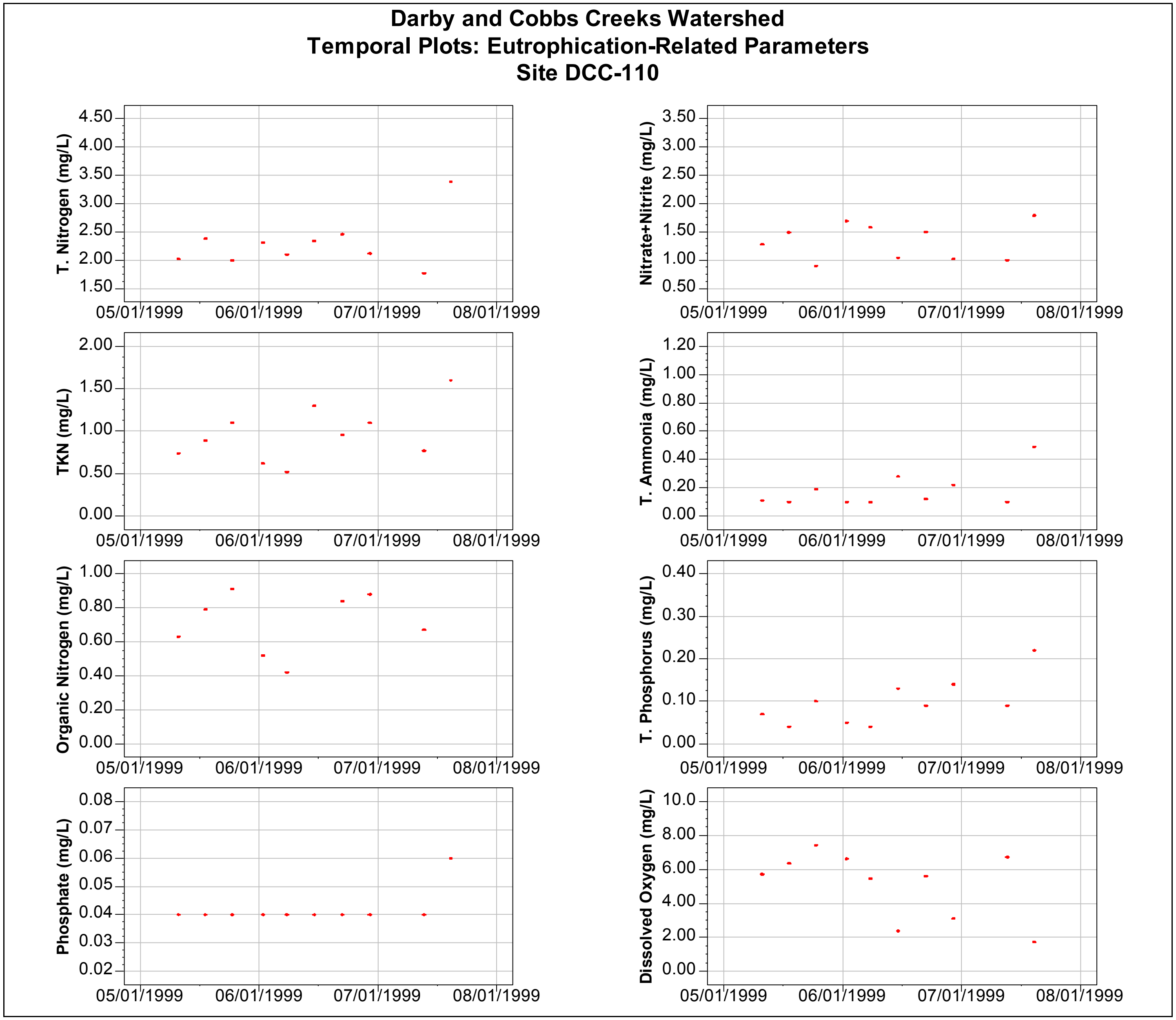


Figure 5.24 Eutrophication-Related Physical Parameters Temporal Plots at DCC-110



Darby and Cobbs Creeks Watershed
Temporal Plots: Eutrophication-Related Parameters
Site DCC-110

Figure 5.25 Eutrophication-Related Nutrient Parameters Temporal Plots at DCC-110

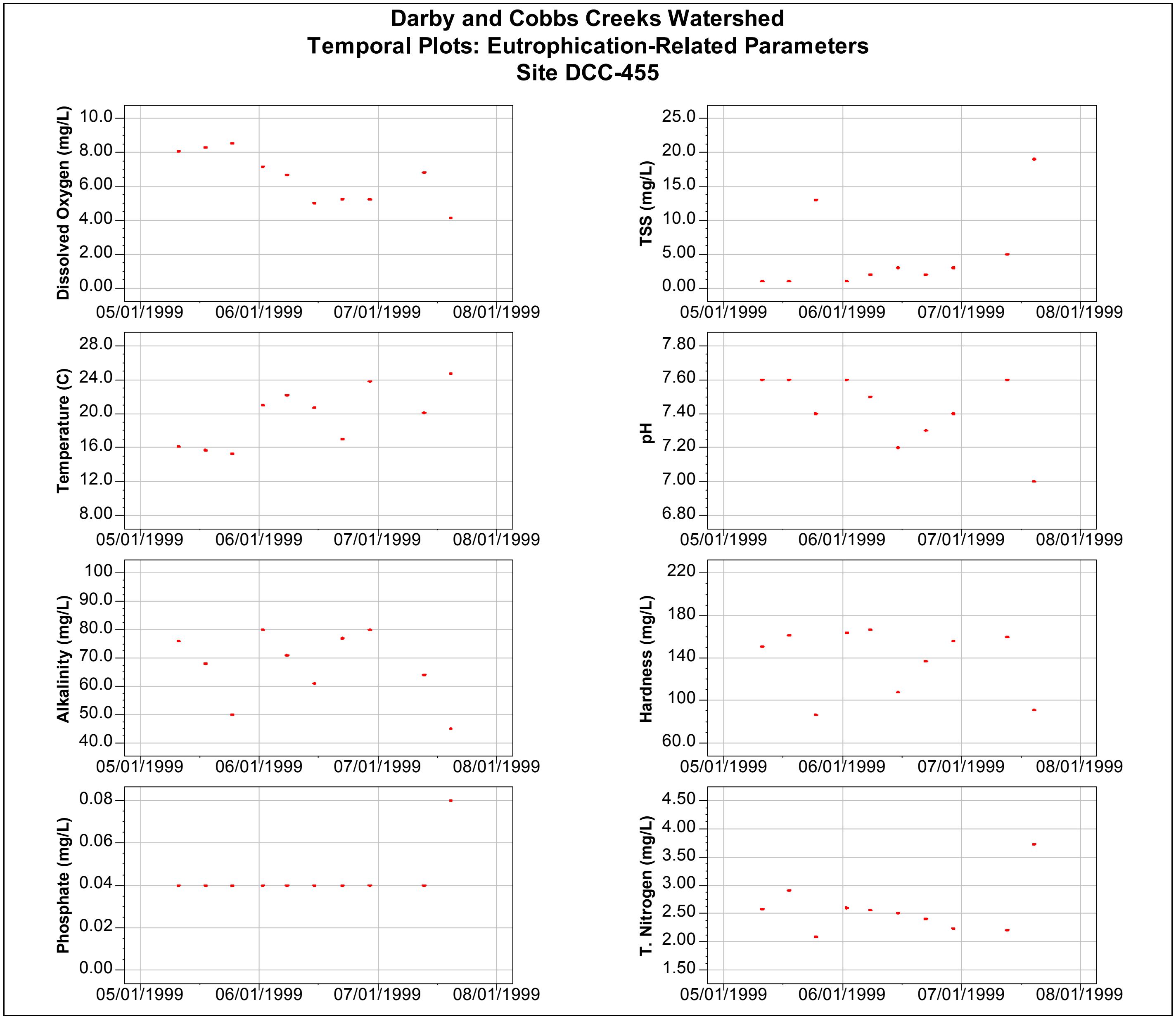


Figure 5.26 Eutrophication-Related Physical Parameters Temporal Plots at DCC-455

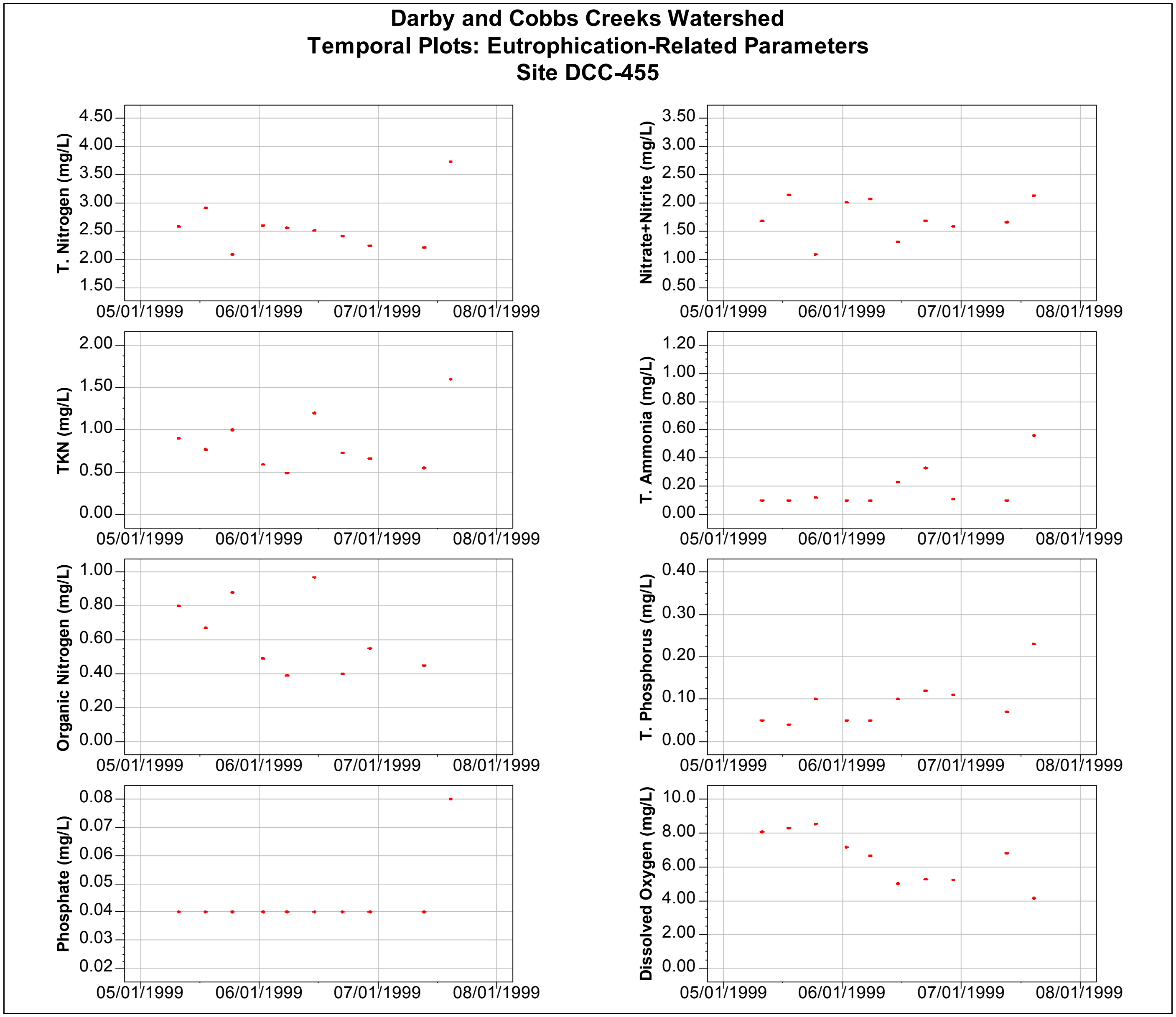


Figure 5.27 Eutrophication-Related Nutrient Parameters Temporal Plots at DCC-455

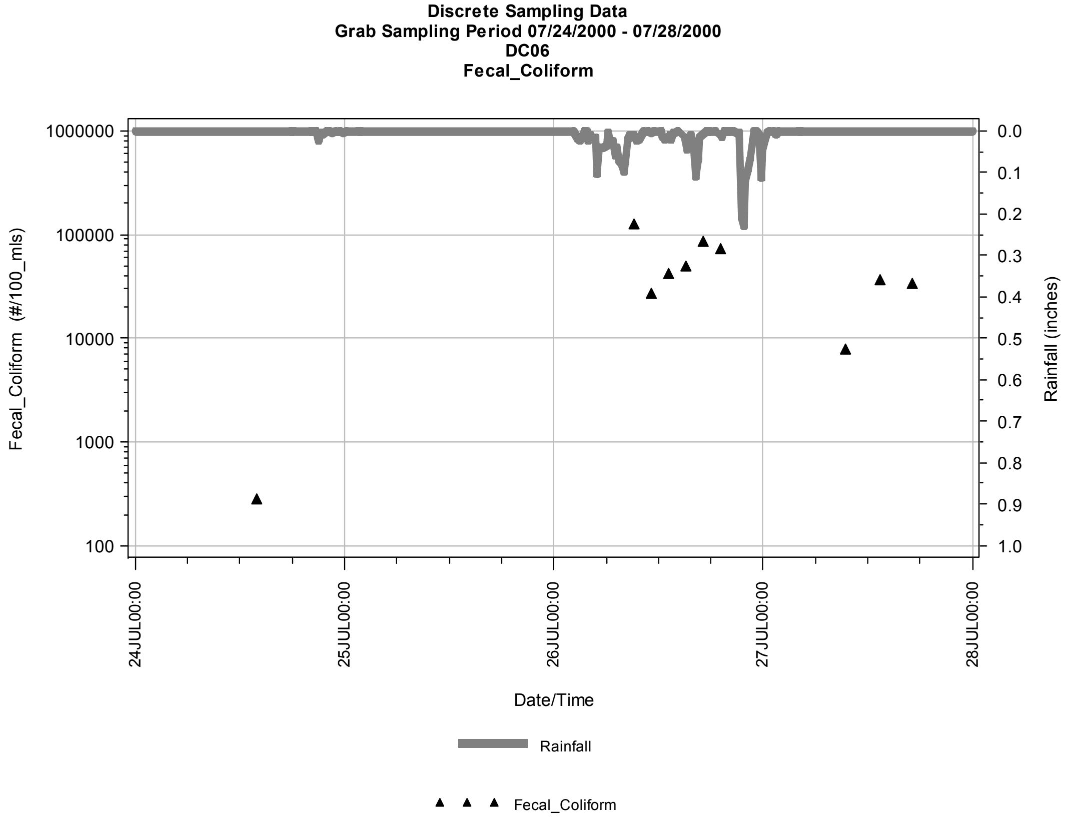


Figure 5.28 Wet Weather Plot for Fecal Coliform at DCC-110

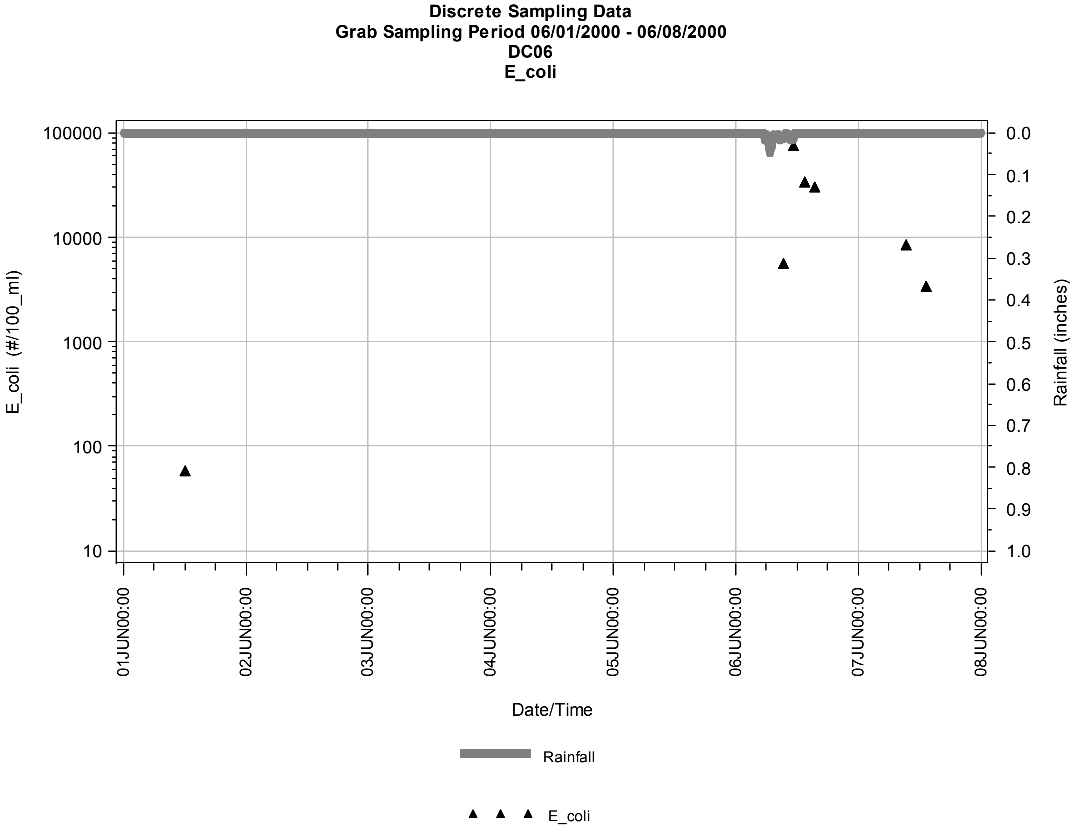


Figure 5.29 Wet Weather Plot for E. Coli at DCC-110

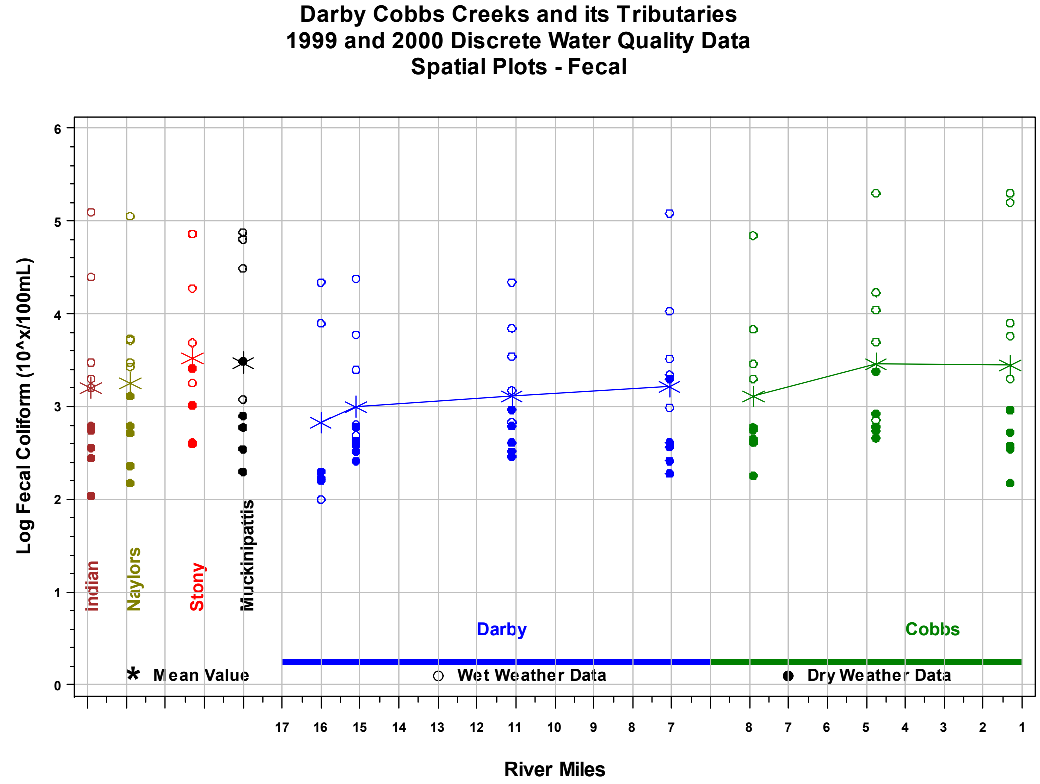


Figure 5.30 Spatial Plot for Fecal Coliform

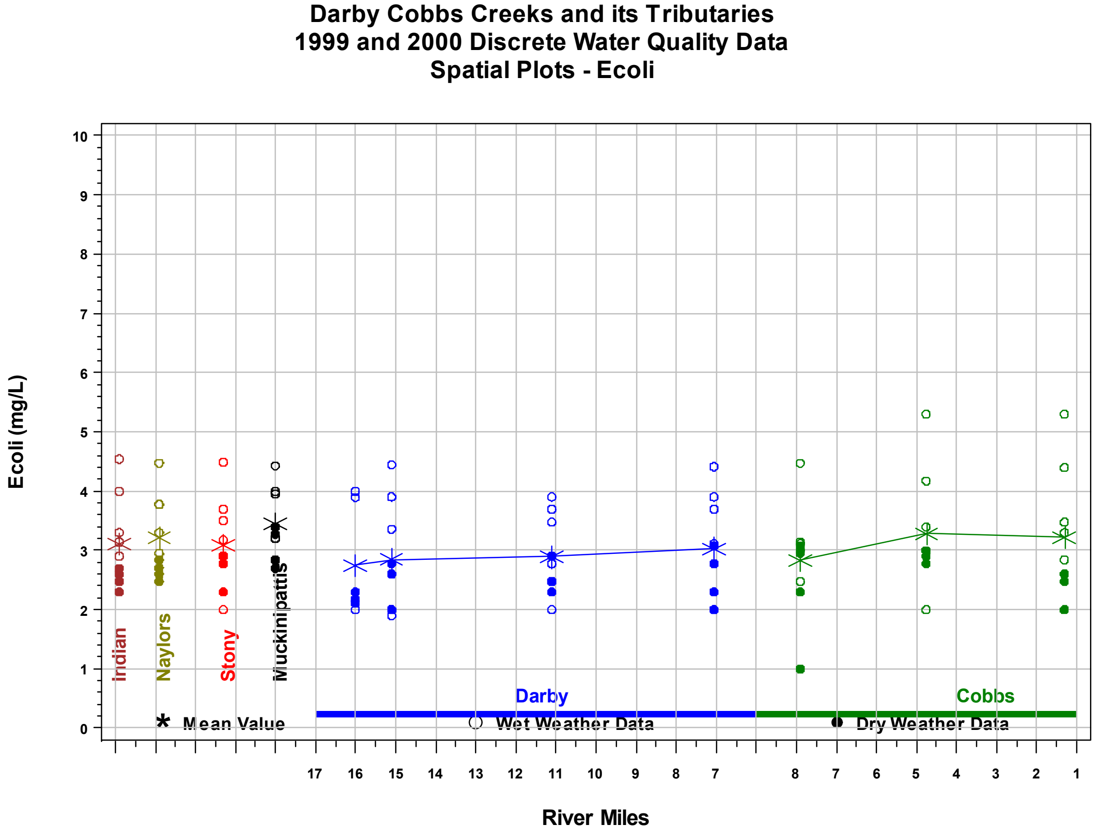


Figure 5.31 Spatial Plot for E. Coli

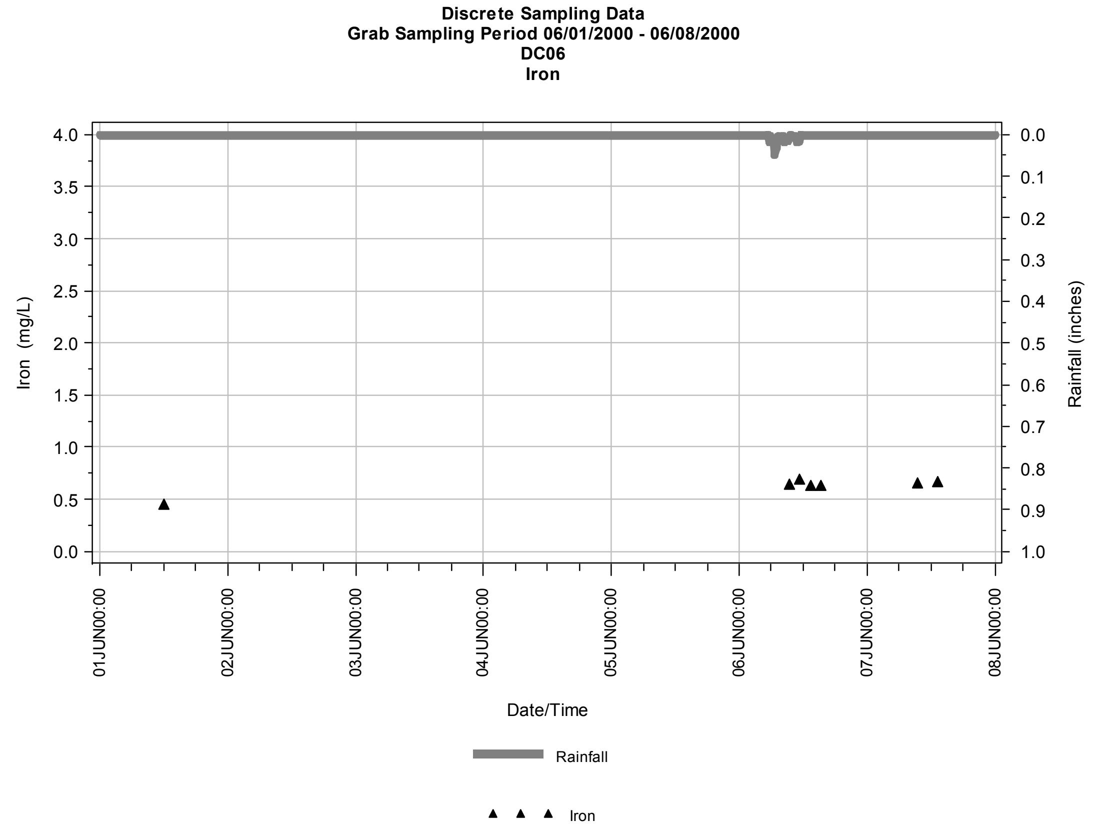


Figure 5.32 Wet Weather Plot for Iron at DCC-110

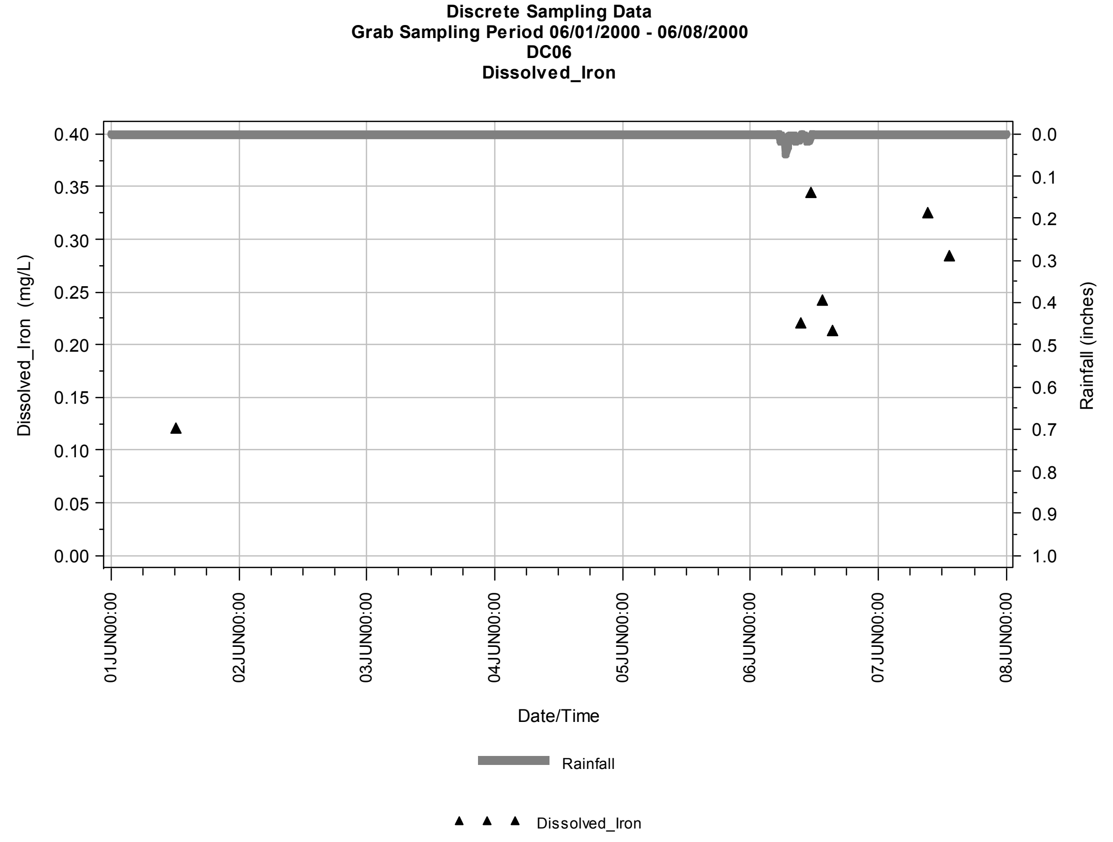


Figure 5.33 Wet Weather Plot for Dissolved Iron at DCC-110

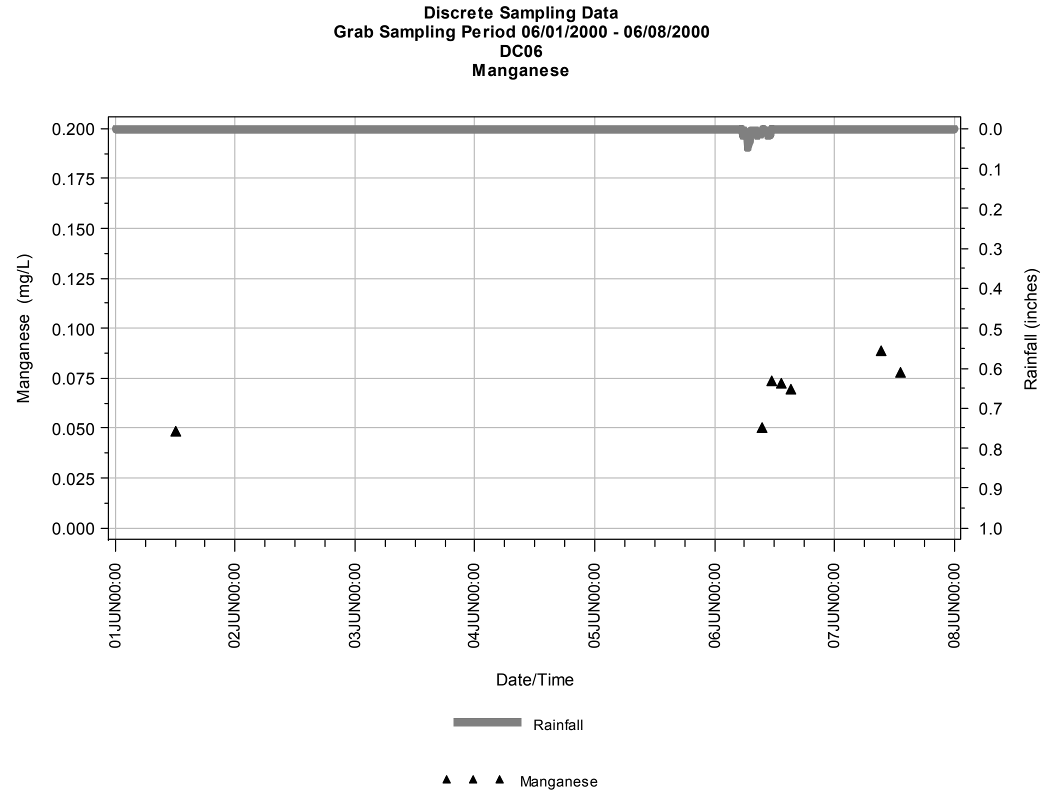


Figure 5.34 Wet Weather Plot for Manganese at DCC-110

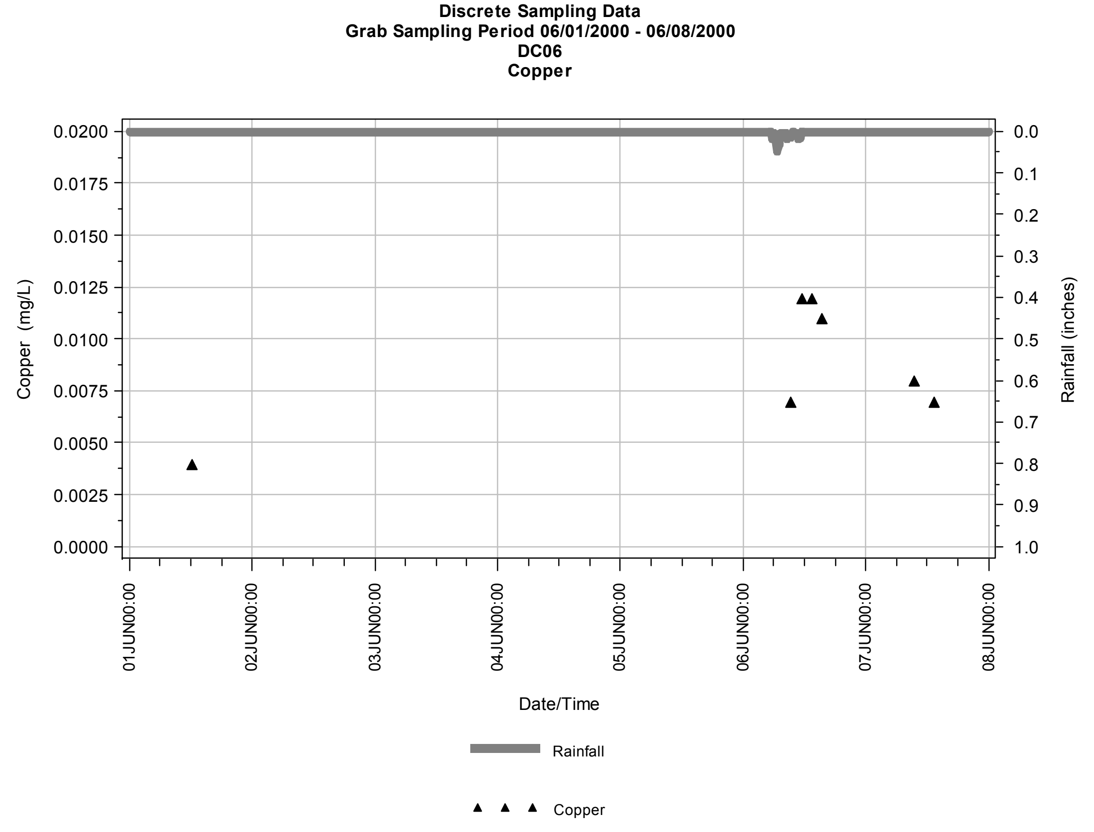
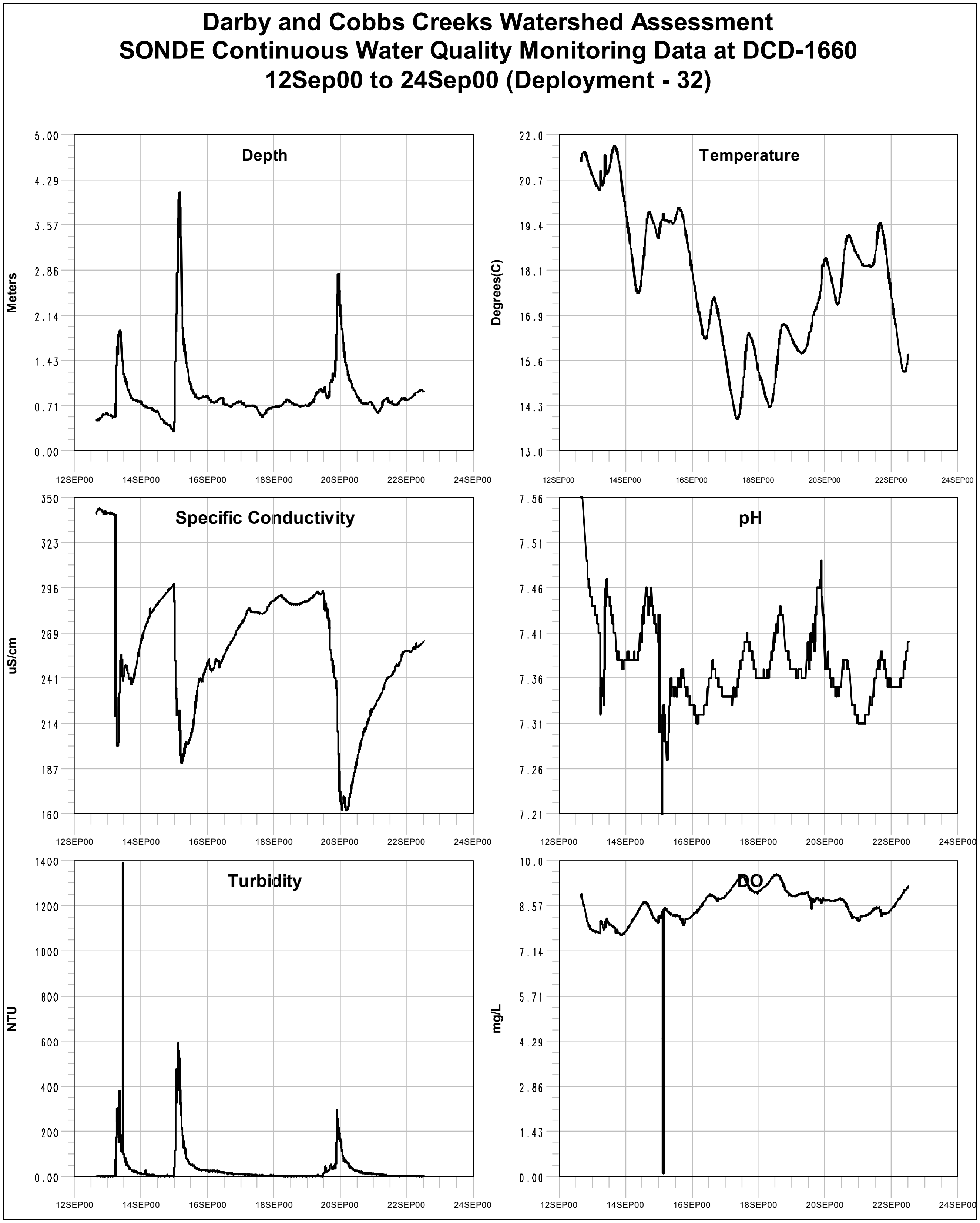


Figure 5.35 Wet Weather Plot for Copper at DCC-110



Darby and Cobbs Creeks Watershed Assessment
SONDE Continuous Water Quality Monitoring Data at DCD-1660
12Sep00 to 24Sep00 (Deployment - 32)

Depth

Temperature

Specific Conductivity

pH

Turbidity

DO

Figure 5.36 Sonde Continuous Multi Parameter Temporal Plots at DCD-1660

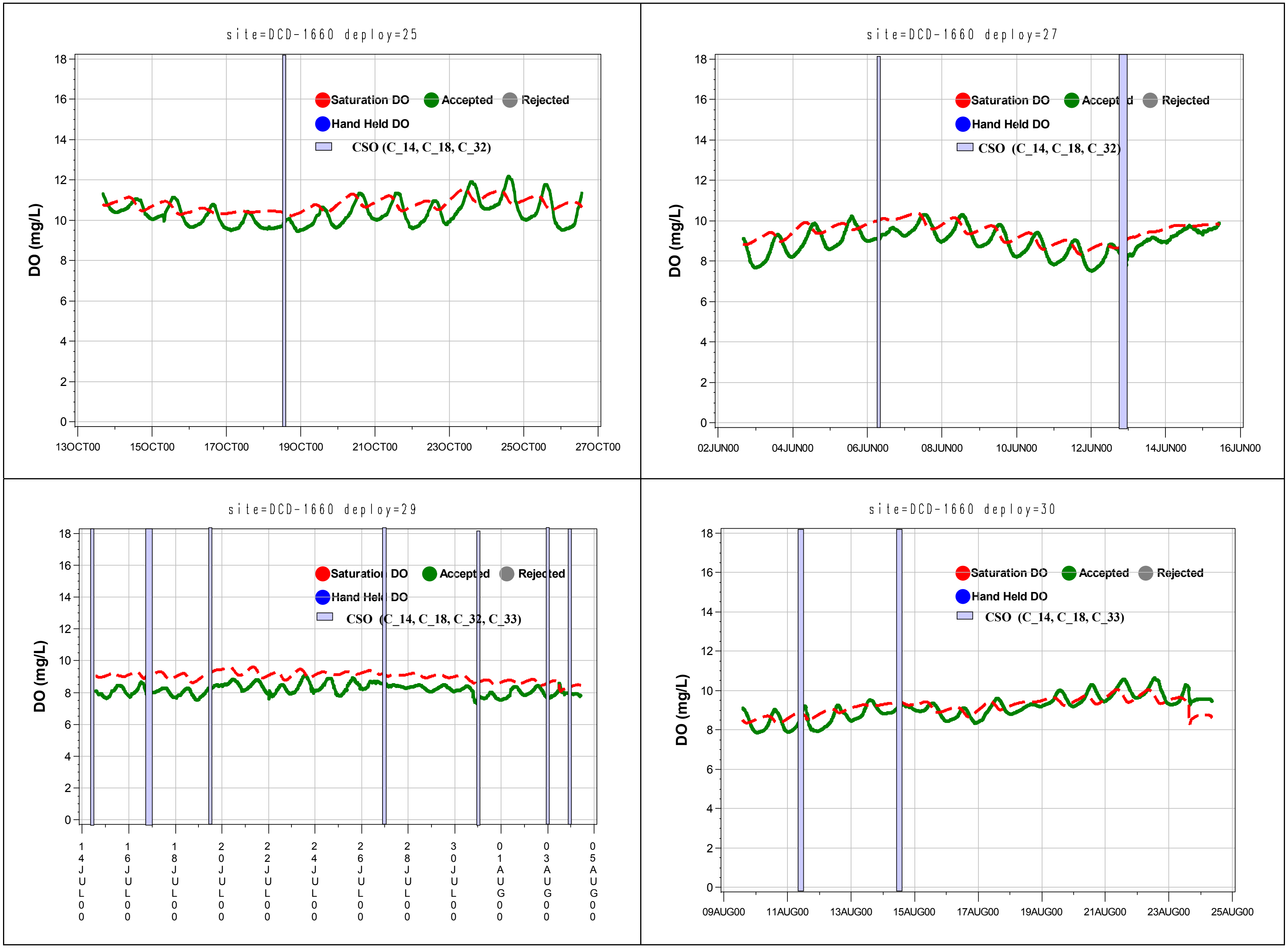


Figure 5.37 Sonde Continuous DO Temporal Plots at DCD-1660

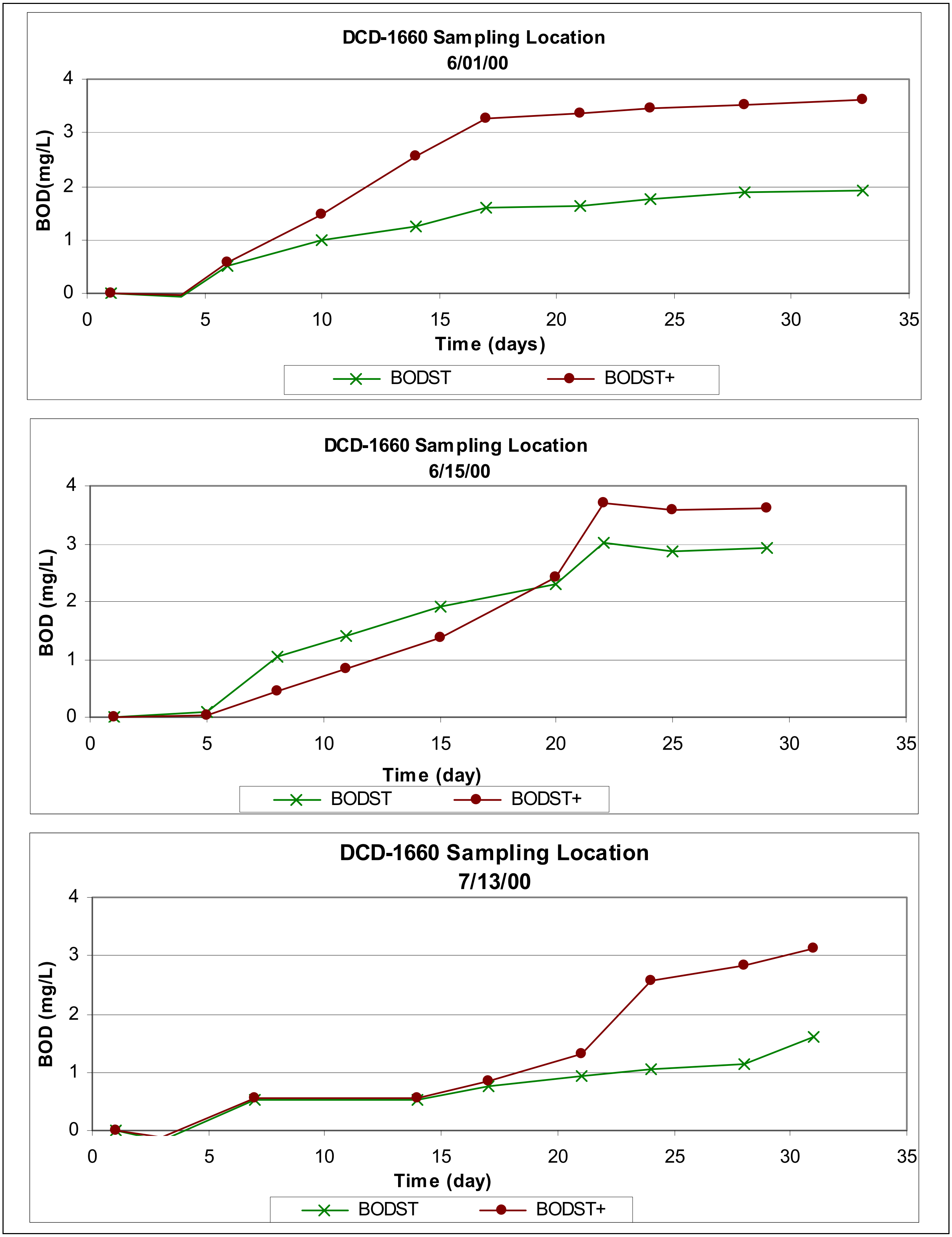


Figure 5.38 BOD Plots for DCD-1660

Darby and Cobbs Creeks Watershed Assessment
SONDE Continuous Water Quality Monitoring Data at DCD-765
01Sep00 to 09Sep00 (Deployment - 14)

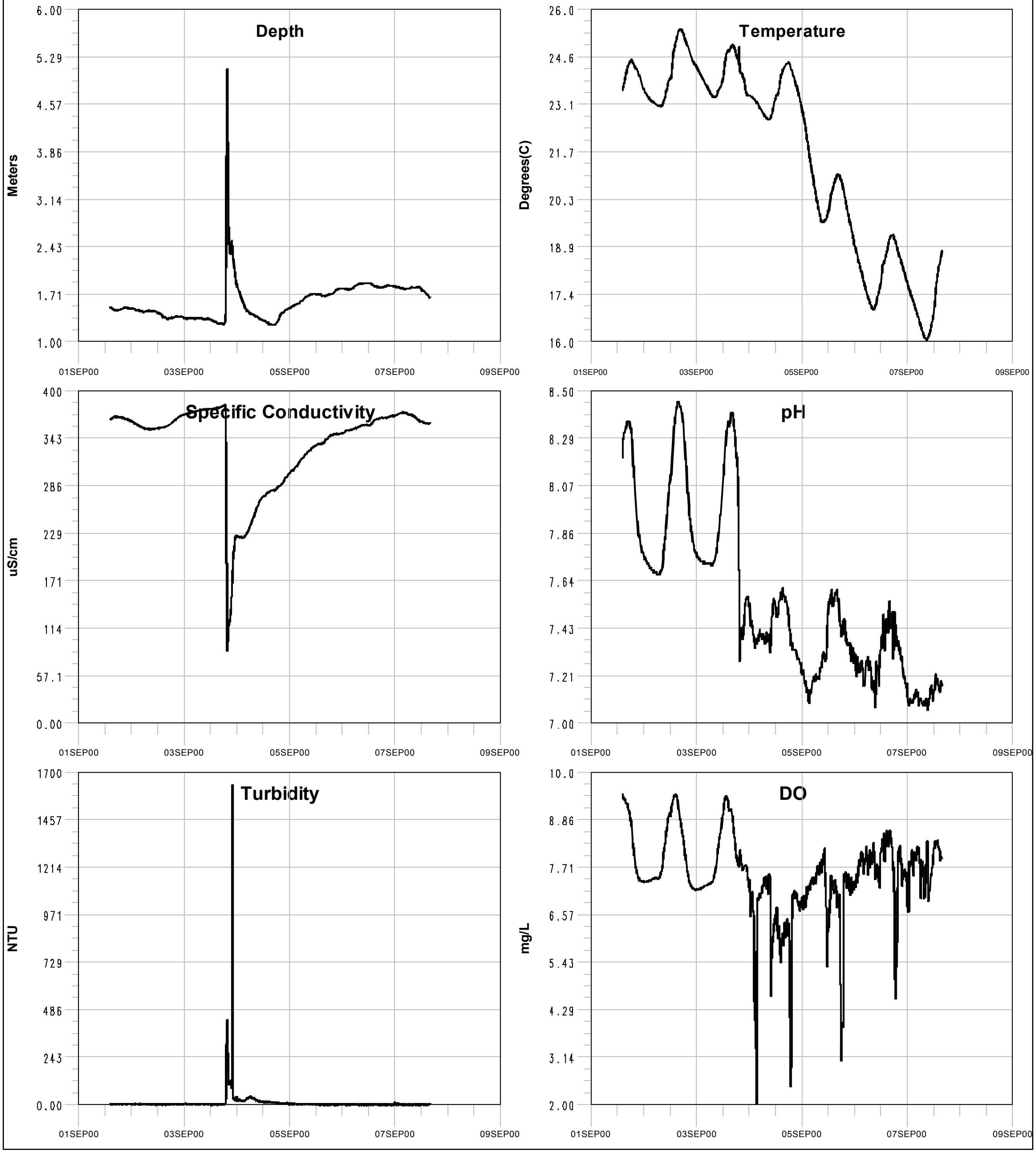
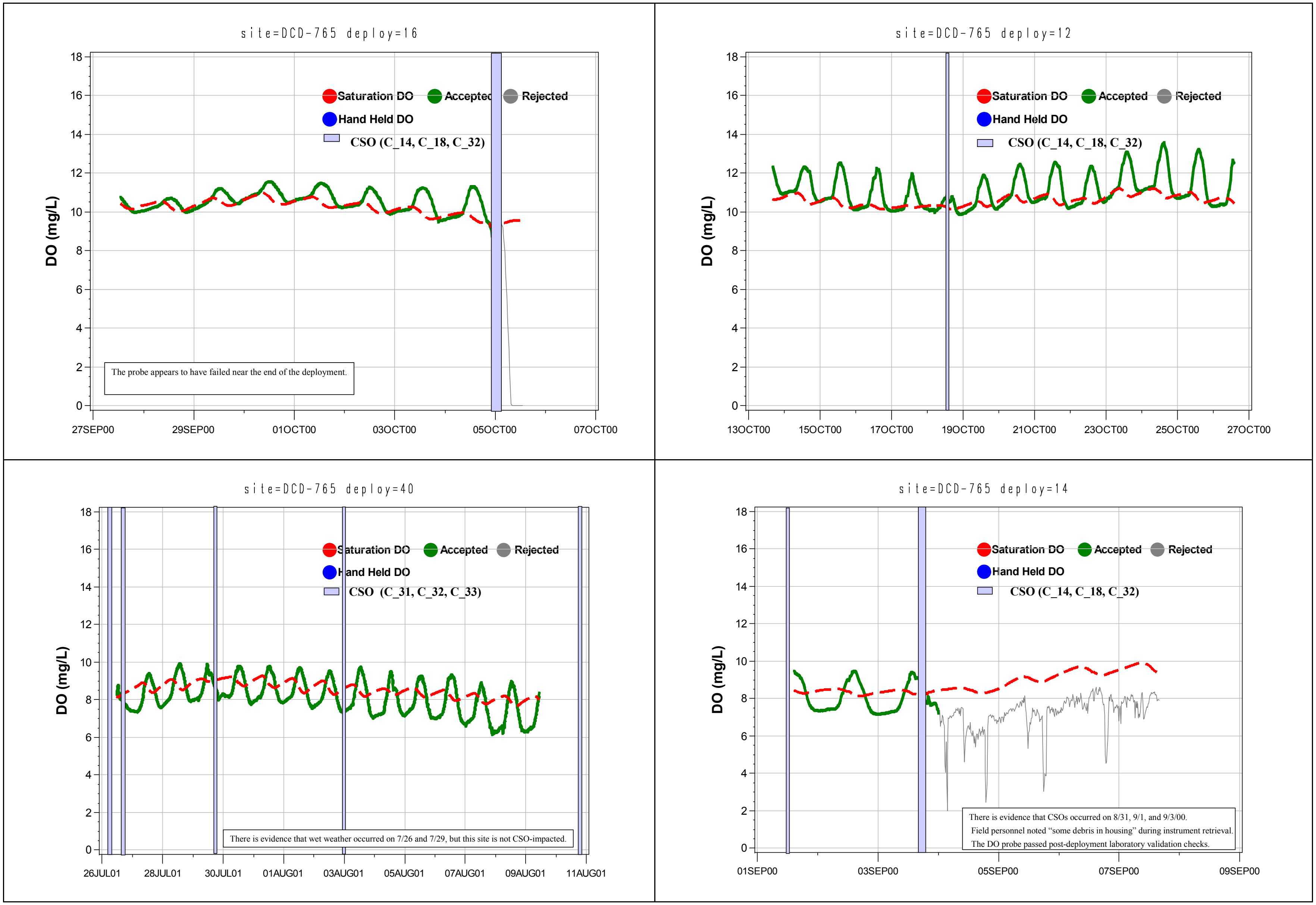


Figure 5.39 Sonde Continuous Multi Parameter Temporal Plots at DCD-765



The probe appears to have failed near the end of the deployment.

There is evidence that wet weather occurred on 7/26 and 7/29, but this site is not CSO-impacted.

There is evidence that CSOs occurred on 8/31, 9/1, and 9/3/00.
Field personnel noted "some debris in housing" during instrument retrieval.
The DO probe passed post-deployment laboratory validation checks.

Figure 5.40 Sonde Continuous DO Temporal Plots at DCD-765

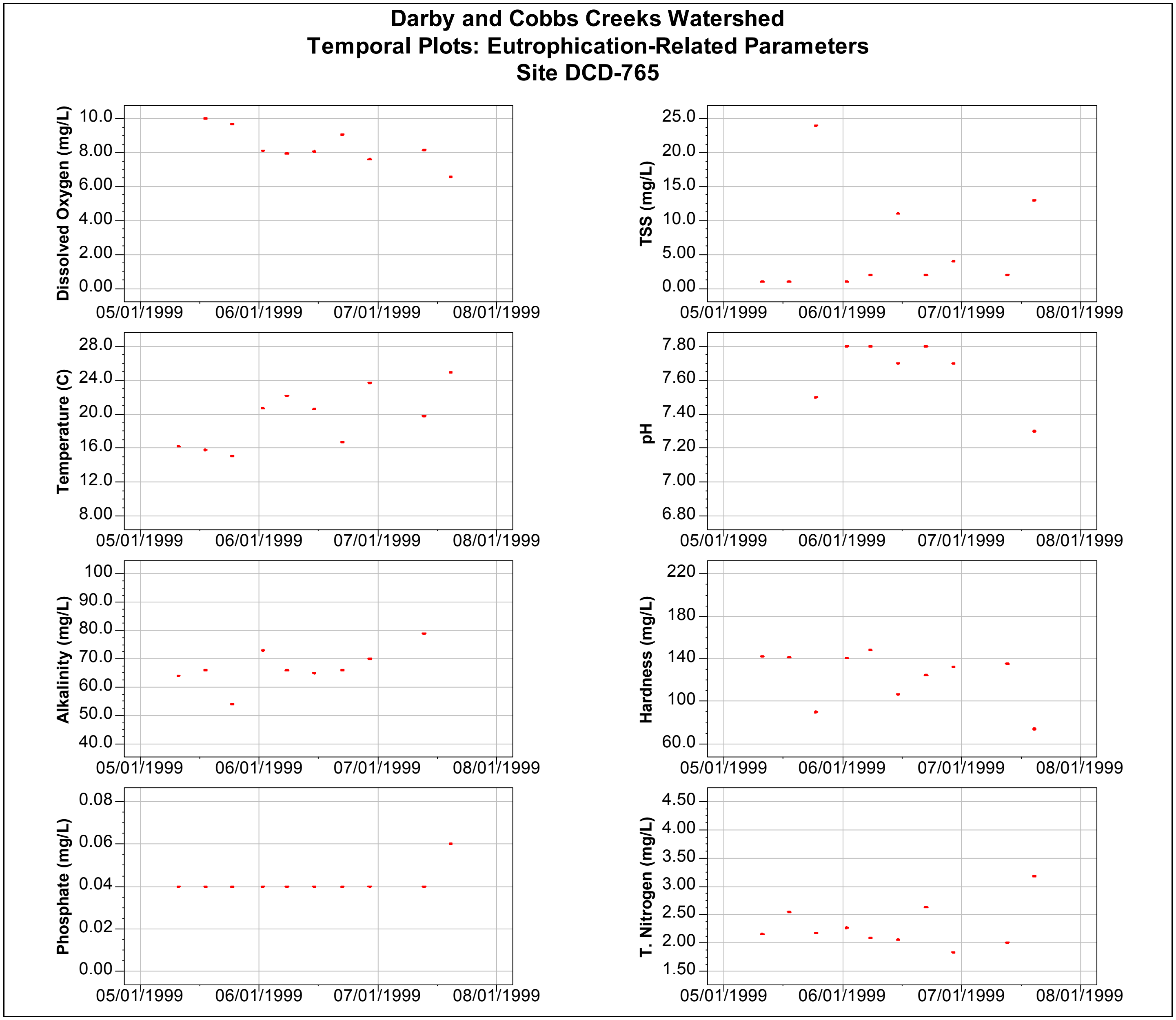


Figure 5.41 Eutrophication-Related Physical Parameters Temporal Plots at DCD-765

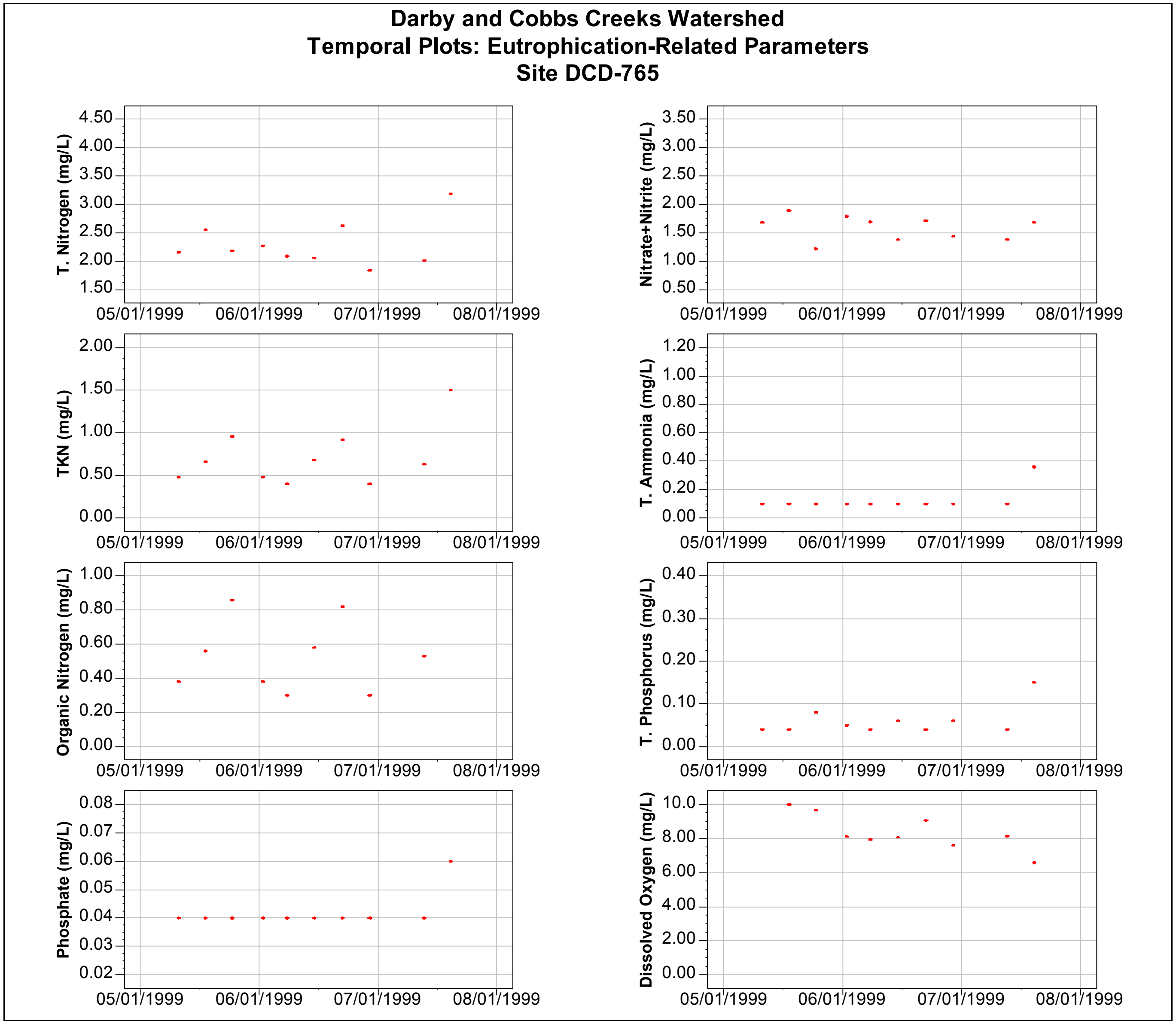


Figure 5.42 Eutrophication-Related Nutrient Parameters Temporal Plots at DCD-765

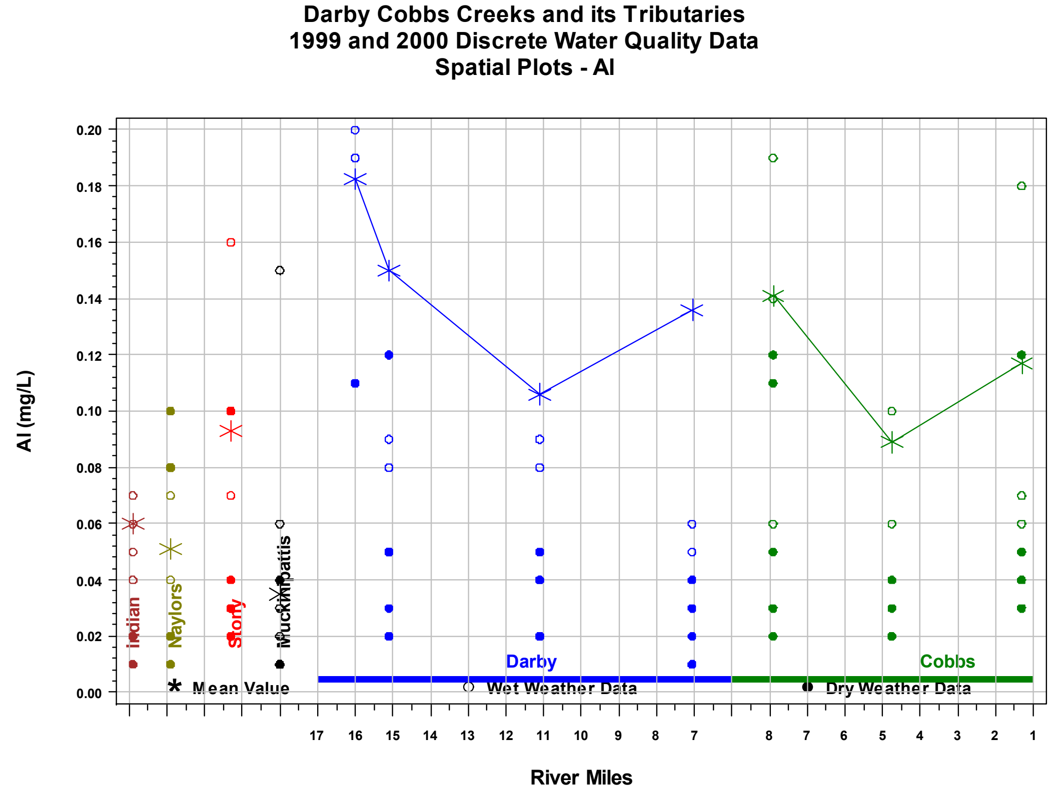


Figure 5.43 Spatial Plot for Aluminum

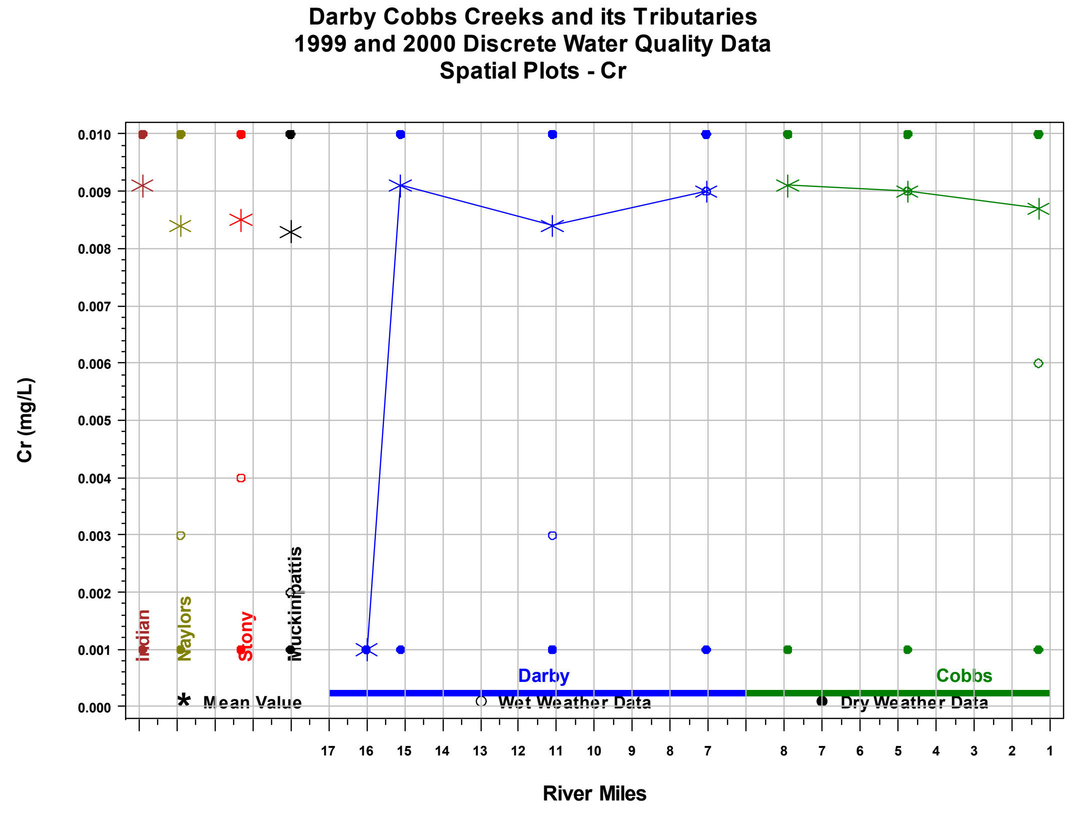


Figure 5.44 Spatial Plot for Chromium

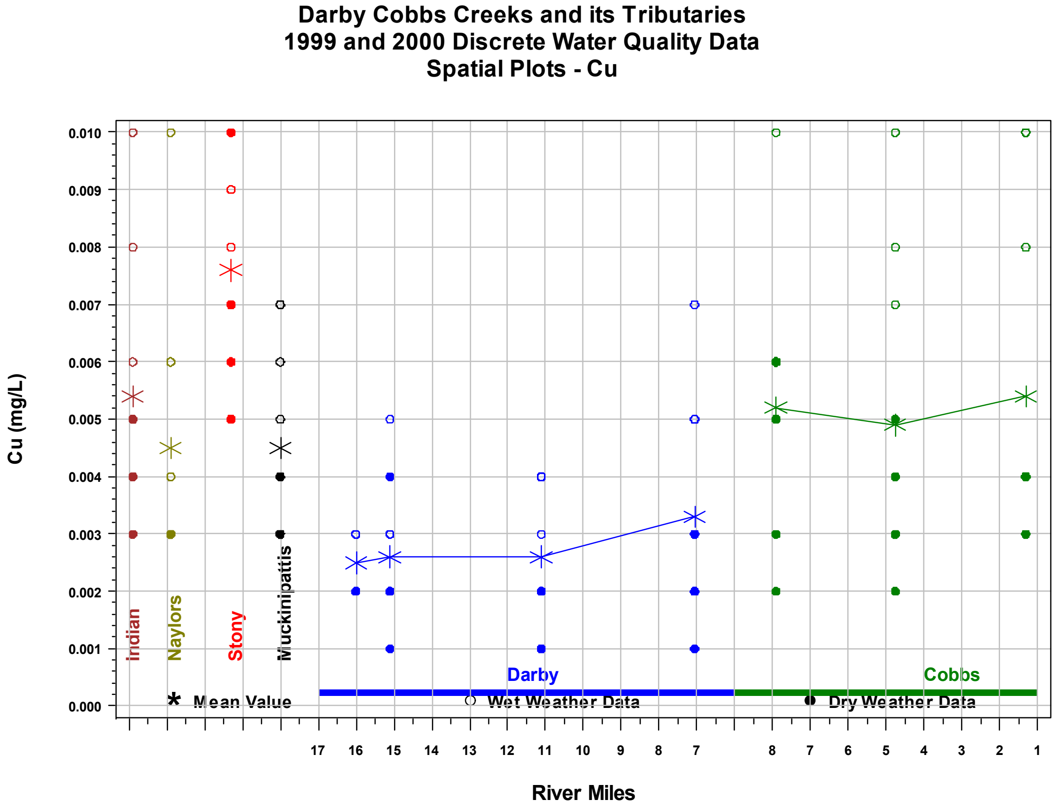


Figure 5.45 Spatial Plot for Copper

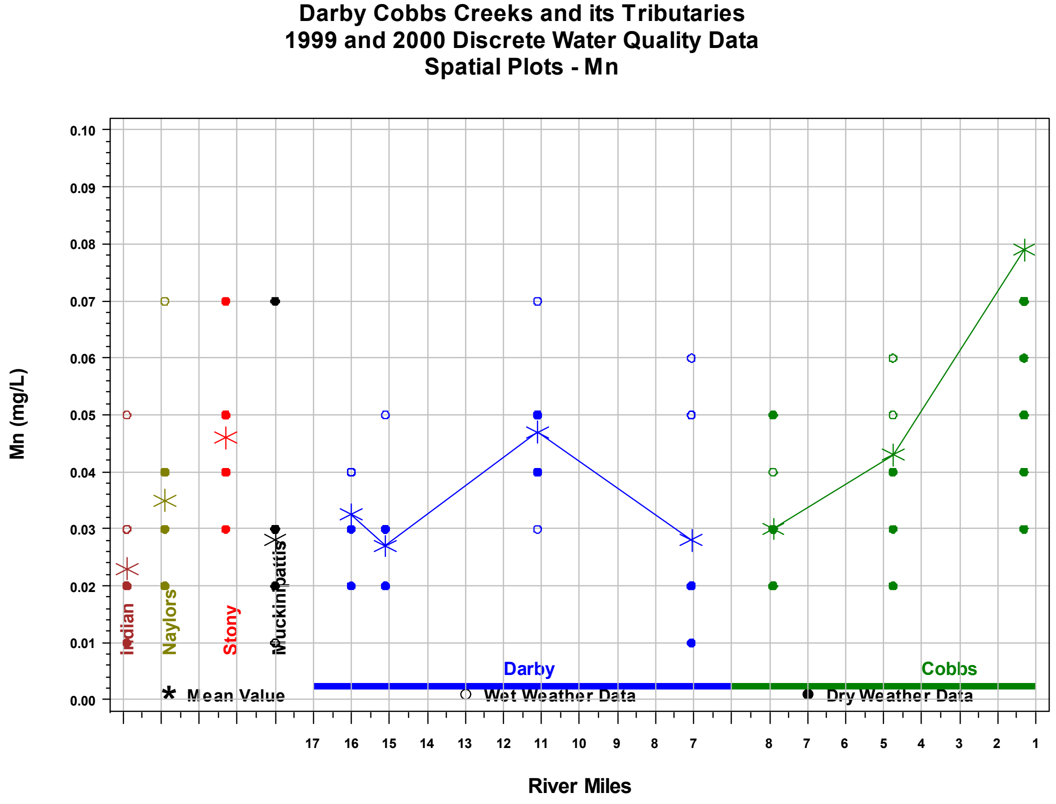


Figure 5.46 Spatial Plot for Manganese

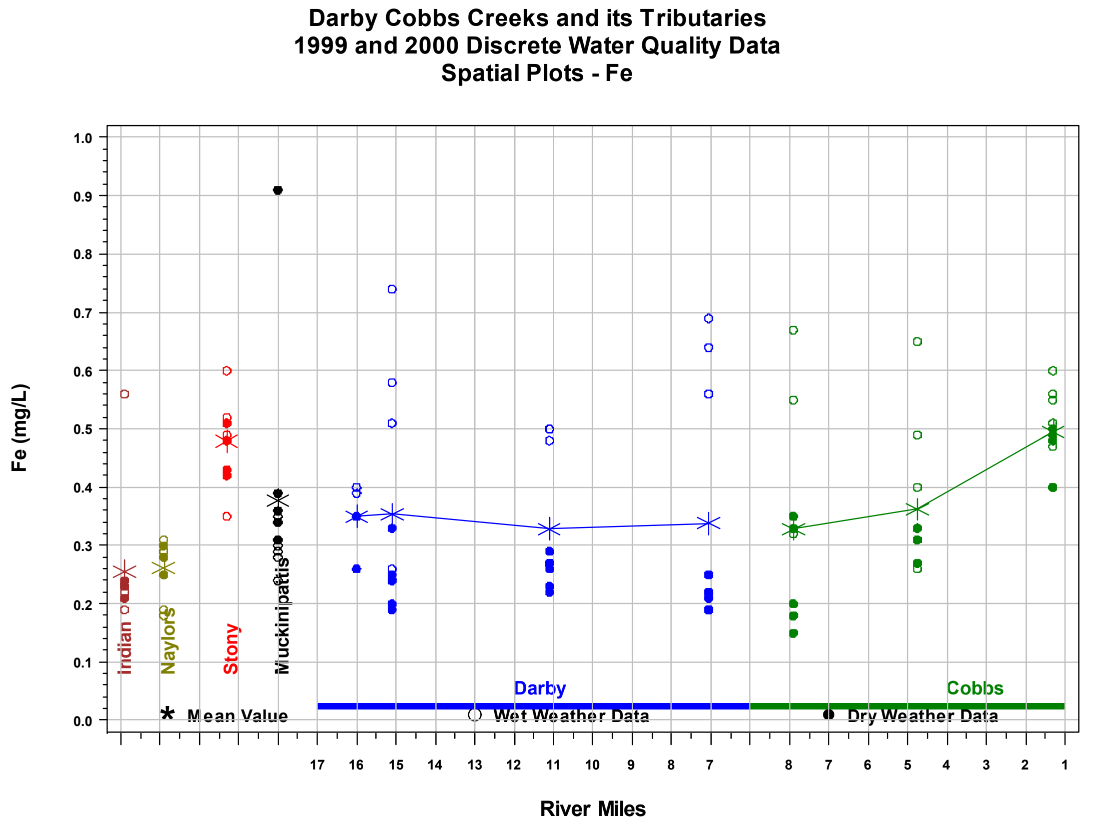


Figure 5.47 Spatial Plot for Iron

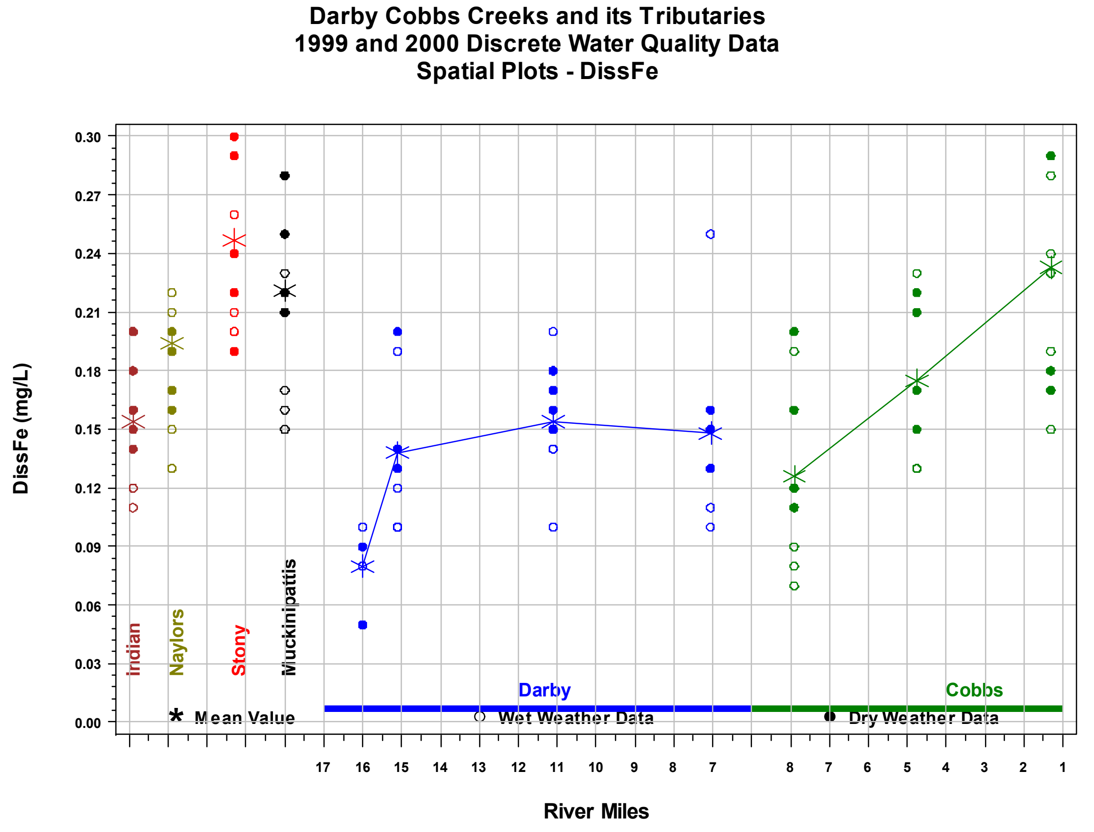


Figure 5.48 Spatial Plot for Dissolved Iron

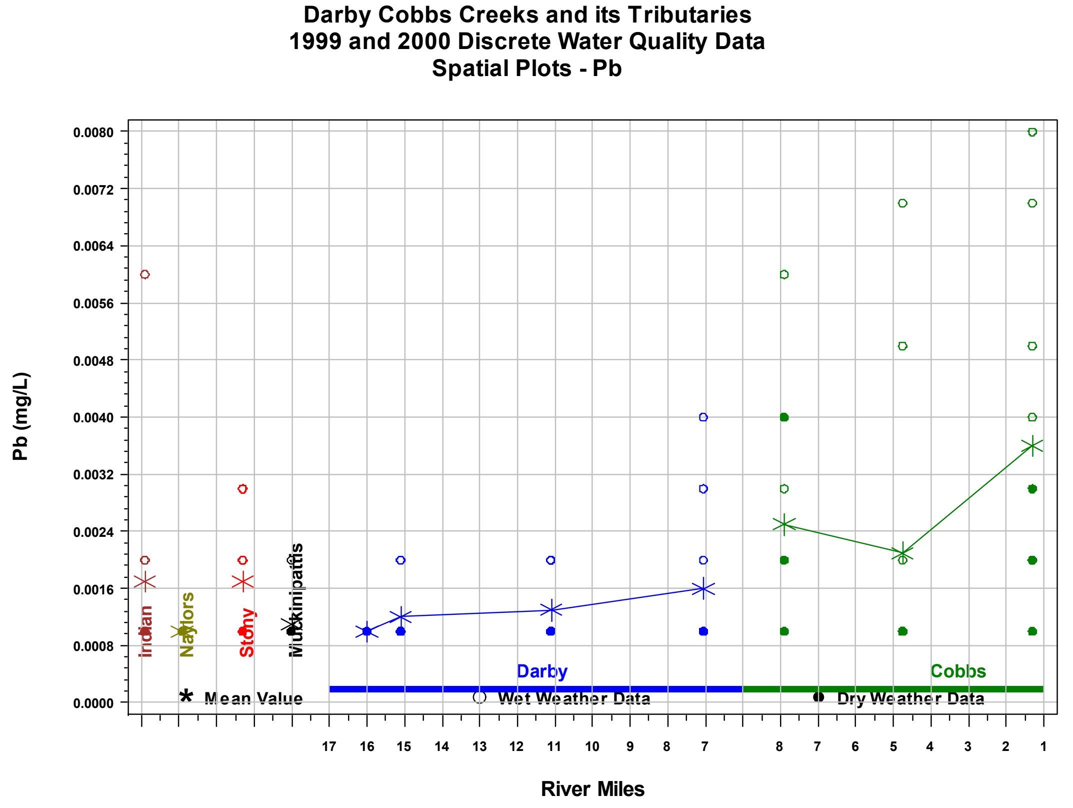


Figure 5.49 Spatial Plot for Lead

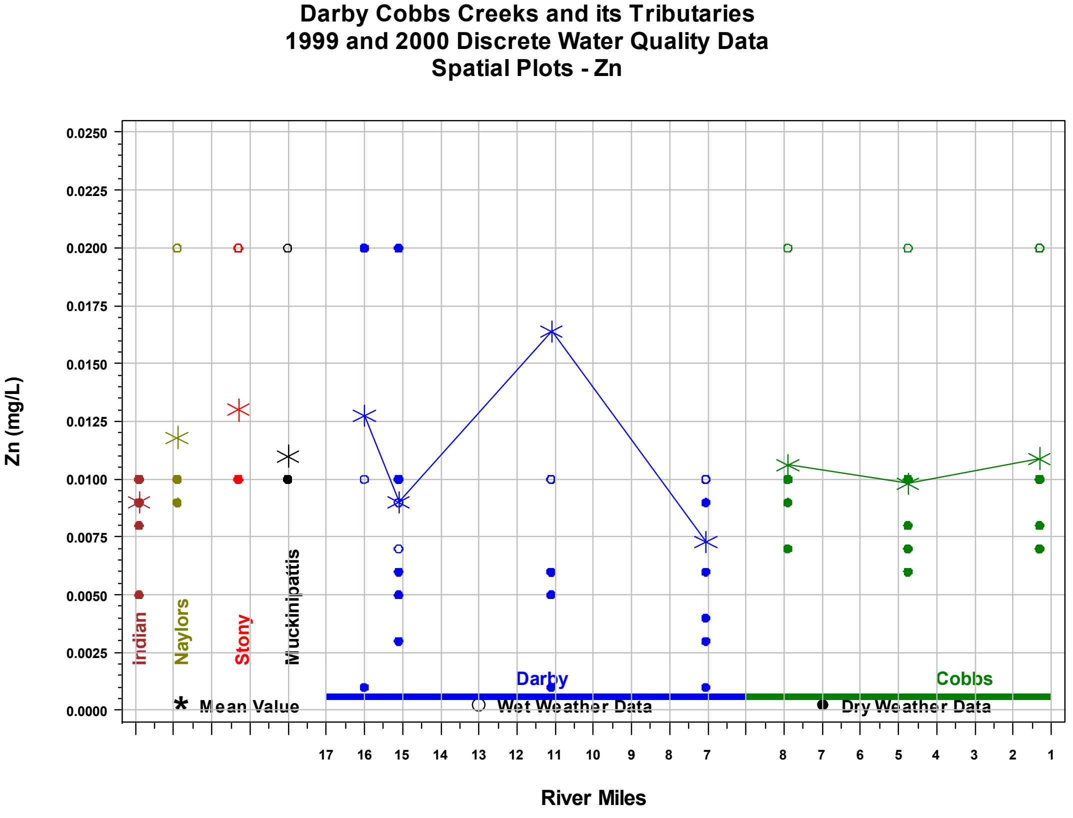


Figure 5.50 Spatial Plot for Zinc

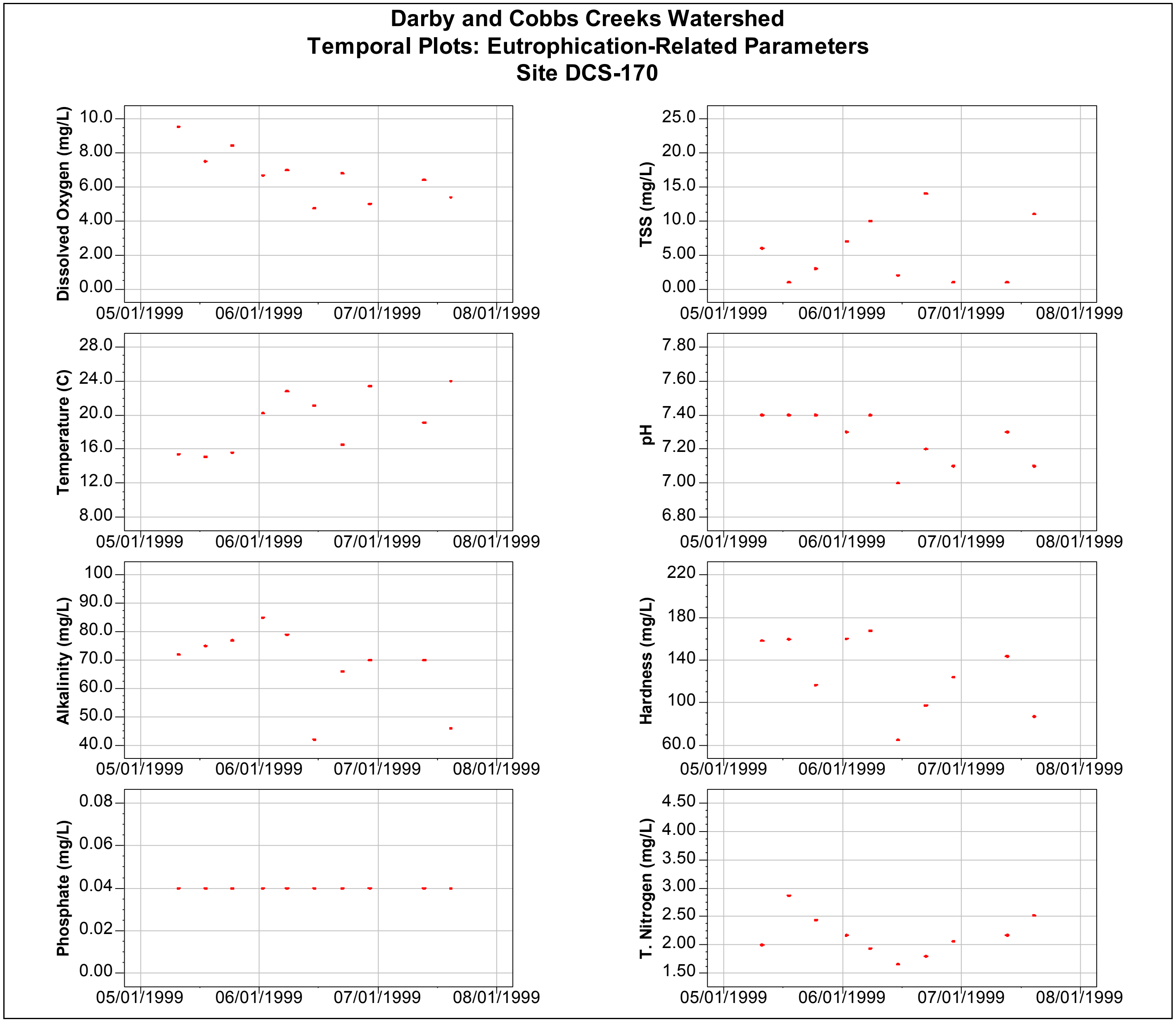
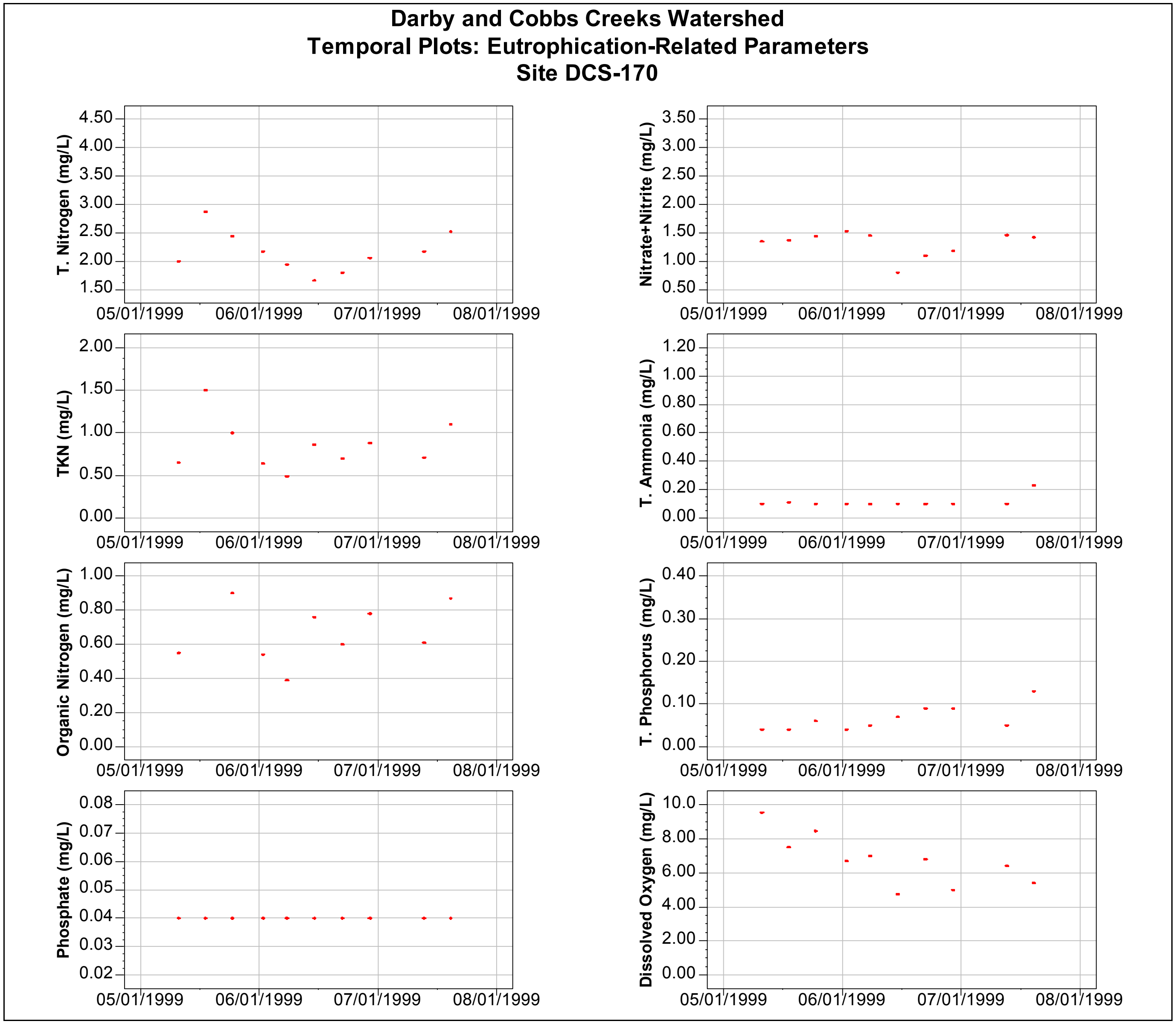


Figure 5.51 Eutrophication-Related Physical Parameters Temporal Plots at DCS-170



Darby and Cobbs Creeks Watershed
Temporal Plots: Eutrophication-Related Parameters
Site DCS-170

Figure 5.52 Eutrophication-Related Nutrient Parameters Temporal Plots at DCS-170

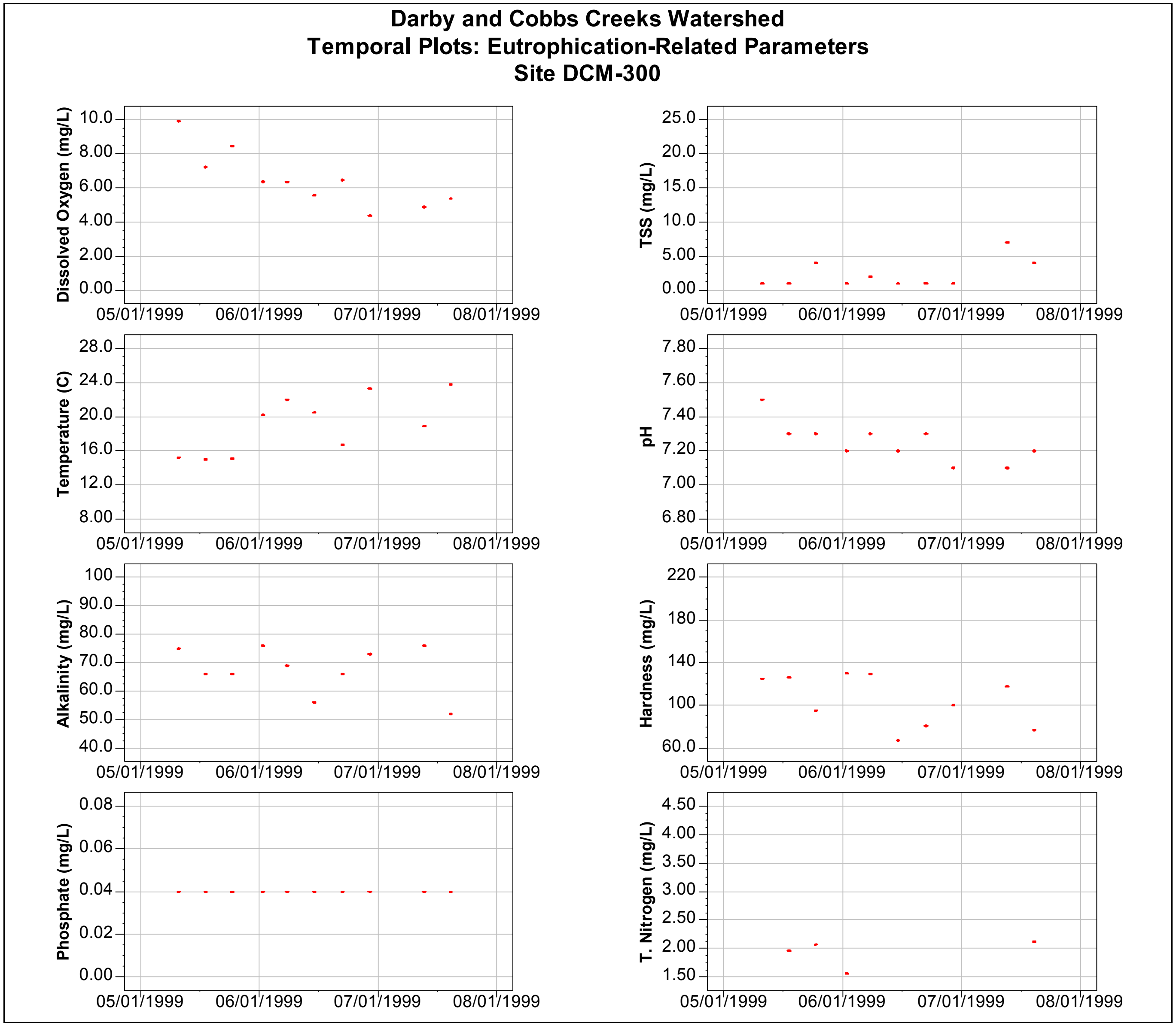


Figure 5.53 Eutrophication-Related Physical Parameters Temporal Plots at DCM-300

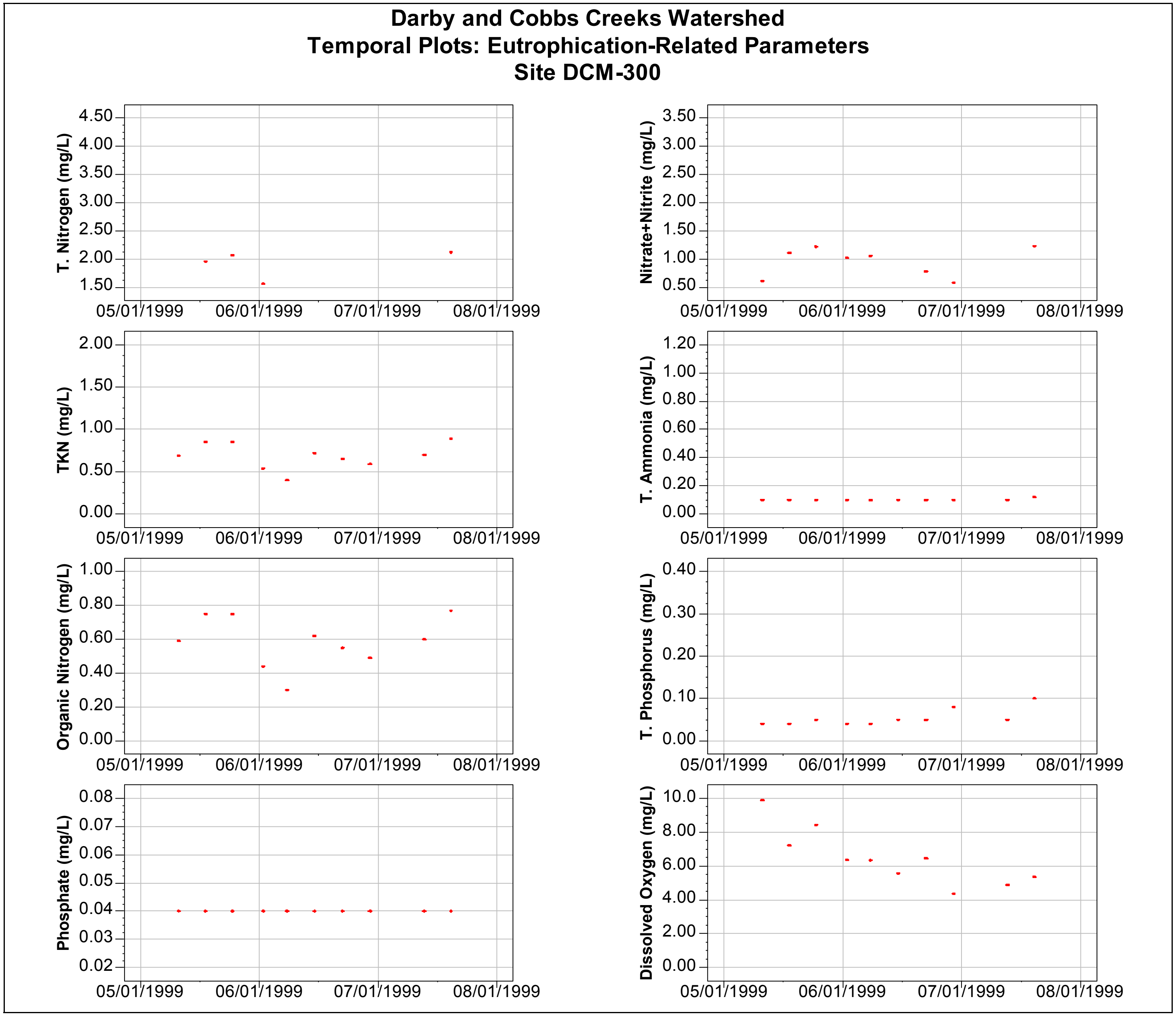


Figure 5.54 Eutrophication-Related Nutrient Parameters Temporal Plots at DCM-300

Section 6 Characterization of Biology and Habitat

6.1 Historical and Existing Information

ANS Geomorphology Study

The Philadelphia Academy of Natural Sciences collected stream morphology data for four streams in the Darby and Cobbs Creeks watershed in August 1998. The data were collected in Fairmount Park for Indian Run, Indian Creek, Bocce Tributary, and Cobbs Tributary 3. The geographic data showing the location of the stream morphology study was not available at time of publication. The data provide information about streambed slope, cross-sectional properties, and sediment grain size distribution.

The thalweg (channel bottom elevation) plot for Indian Run shows that the stream has a slope of approximately 2.6% in the area studied. The channel is approximately 15 m wide and 1 m deep at the cross-sections measured. Based on the grain size distribution, the sediment is poorly sorted, with most particle diameters ranging from 10 mm (medium gravel) to 200 mm (small boulders).

The thalweg of the Indian Creek channel varies more than the elevation of the other three creeks studied, with several deeper pools along the length of the channel. The average slope of the creek in the area studied is 1.6%. The five cross-sections measured all have widths of approximately 15 m and depths of approximately 1 m. The sediment is poorly sorted, with most particles ranging between 1 mm (coarse sand) and 100 mm (cobbles) in diameter.

The Bocce Tributary has a relatively constant bottom slope of approximately 2.5%. The channel is narrower than the others studied, with a width between 4 m and 8 m. The sediment grain size distribution is similar to the distribution for Indian Creek, with most particle diameters ranging from 1 to 100 mm.

Cobbs Tributary 3 has an average slope of 2.5% along the section studied. The channel has a width of approximately 6 to 8 m and a depth of approximately 1.5 m. Most of the sediment particles range in diameter from 1 to 200 mm.

PADEP Aquatic Biological Investigation

The Pennsylvania Department of Environmental Protection, with assistance from the Philadelphia Academy of Natural Sciences, conducted an aquatic biological investigation in the Darby Creek Watershed in June of 1995 and May of 1996. They investigated the general biological health of the watershed and assessed the damage from improper pesticide use in May of 1996. Figure 6-1 presents the locations where investigations were conducted. Only one of the stations, Station 12, was located on Cobbs Creek.

Table 6-1 summarizes the general assessment information available from the study, including information on shading, erosion, stream bed material, vegetation, land use, and biological quality.

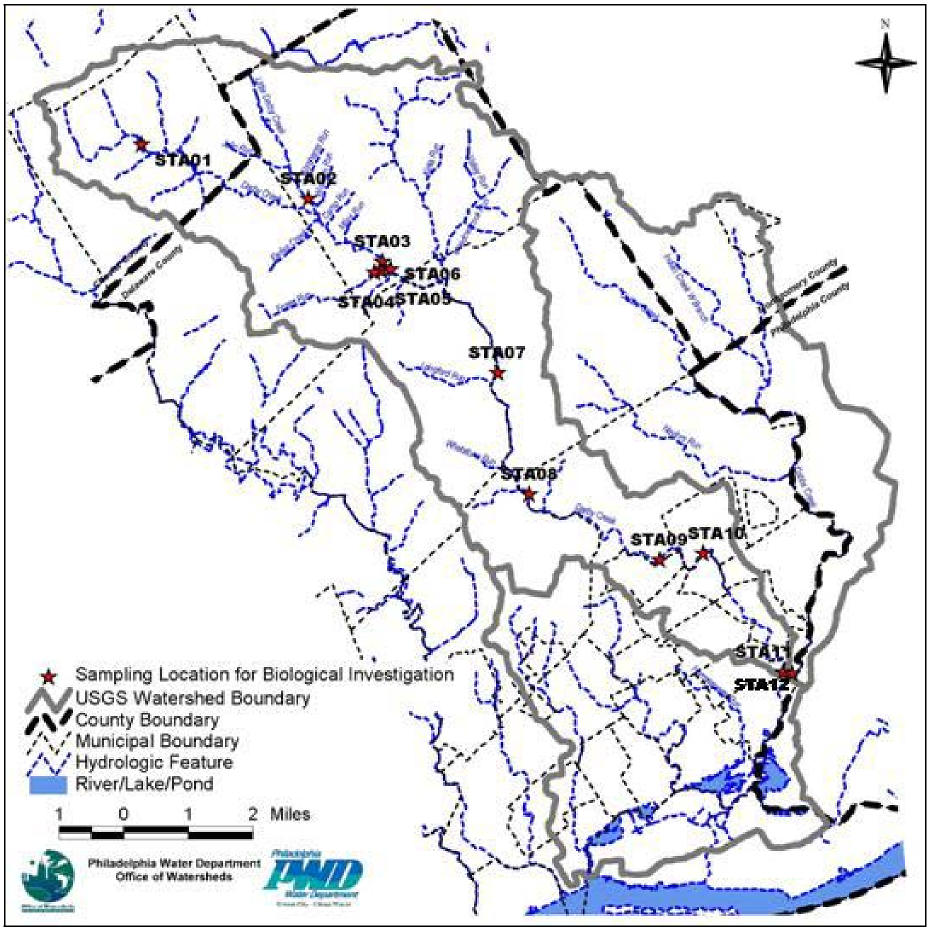


Figure 6-1 PaDEP/ANS Aquatic Biology Investigation 1995-1996

Water quality sampling indicated that the overall water quality in Darby Creek was good. The few parameters sampled above the detection limit but not threatening to fish were iron, aluminum, total suspended solids, and fecal coliform. Fecal coliform concentrations were only notable because they exceeded the Chapter 94 standards. In Cobbs Creek, low dissolved oxygen and elevated levels of ammonia, phosphorus, iron, lead and manganese were observed. The low dissolved oxygen and elevated nutrient levels led researchers to conclude that nutrient enrichment and associated plant growth were possibly affecting this part of Cobbs Creek adversely. Additional studies on Cobbs Creek were recommended to determine the level of impairment from nutrient enrichment and metals toxicity.

Benthic invertebrate data indicated fair conditions in the headwaters and Little Darby Creek and good conditions in some of the headwater tributaries. At other sampled stations, the benthic communities were considered poor. Fisheries data indicated fair conditions throughout the Darby Creek Watershed except for good conditions where the benthic community also was rated good. The fish habitat was thought to be better than indicated by the fisheries data.

Table 6-1 PaDEP/ANS Aquatic Biology Investigation

Station	Width (m)	Shading (%)	Erosion (%)	Silt (%)	Clay (%)	Sand (%)	Gravel (%)	Cobble (%)	Boulder (%)	Bedrock (%)	Veg-etation	Land Use	Biological Quality	
													Benthic	Fish
1	2	25	10	40	20			40			trees shrubs	residential	fair	not reported
2	5	85	20	25	25	10		10	30		trees shrubs	not reported	fair	not reported
3	6	90	60	10		40	20	30			trees lawn	residential woodlot	very good	good
4	2	80	60	10		30	20	30	10		shrubs lawn	residential	very good	good
5	2	80	60	5		10	20	60	5		trees shrubs lawn	residential	poor	fair
6	11	60	40	10		30	15	40	5		shrubs trees	residential woodlot	good	fair
7	6	50	70	15		40	30	30	5		trees shrubs lawn	residential	poor	fair
8	8	60	50	10		20	20	40	10		shrubs trees	woodlot residential	poor	fair
9	13	70	30	10		25	10	15	30	10	trees shrubs	not reported	poor	fair
10	15	40	50	40	10	30	10	5	5		trees shrubs	residential	not reported	not reported
11	10	30	70	40	30	30					trees shrubs	residential	not reported	not reported
12	10	40	80	20		60	20				shrubs	residential	not reported	not reported

Philadelphia Suburban Water Company

In May of 1997, Normandeau Associates conducted an ecological assessment of Cobbs Creek at the request of Philadelphia Suburban Water Company, eight months after observed fish mortality associated with a chlorinated drinking water main break. While the study concluded that the effects of the break were short term and that the recovery of the communities studied was complete, information from this biological assessment can be used for the Darby and Cobbs Creeks Watershed Study. The study area for the Normandeau Associates biological assessment runs from 500 feet above Manoa Road and extends 250 feet below City Line Avenue. All sampling occurred from within Cobbs Creek Park. Figure 6-2 shows the study area for the biological assessment.

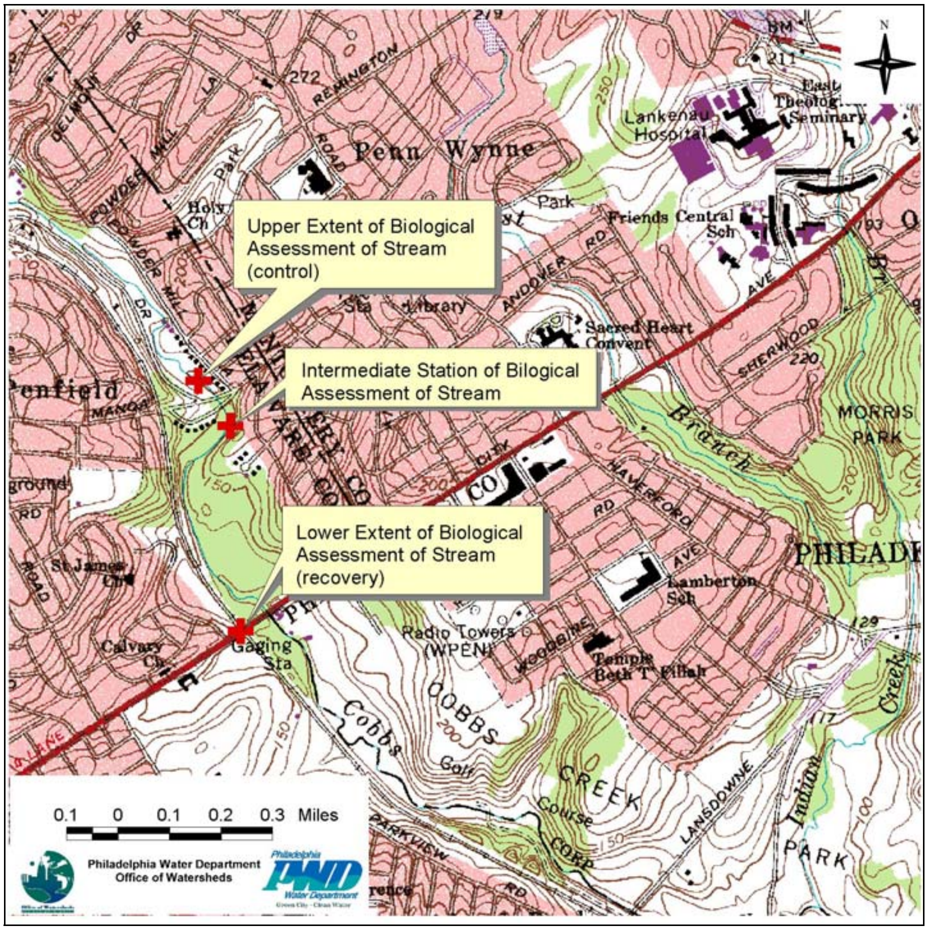


Figure 6-2 Biological Assessment for Philadelphia Suburban Water Company

During the biological assessment, the water temperature was unseasonably cool with temperatures in the range of 52 to 57 degrees F. Specific conductance ranged between 363 and 370 uS/cm.

Based upon USEPA's criteria for habitat assessment, the habitat in Cobbs Creek was rated as "good" to "excellent" in the study area. In the study area, habitat types of riffles, pools and backwater were present, but not throughout the study area. The invertebrate data, collected for the assessment, indicated poor taxonomy, domination by pollution tolerant species, and low diversity. The fisheries data indicated that although numerically dense, the fish community was species poor, containing a preponderance of blacknose dace and white suckers.

Pennsylvania Unassessed Waters Program

At the request of PWD, the Pennsylvania DEP (PaDEP) performed a biological assessment of the non-tidal portions of the Darby and Cobbs Creeks Watershed. For the assessment, 28 stations were chosen to represent the watershed based upon land use and stream order. Each station was evaluated using the Rapid Bio-assessment Protocol and EPA's habitat assessment methods. The assessments occurred between June and late October in 1998. The decisions to consider a station impaired or unimpaired were based upon the quality and quantity of habitat and macroinvertebrates.

The assessments indicated that 52 percent of the stations evaluated were impaired. Generally, impaired stations in the Darby and Cobbs Creeks Watershed were located below Route 3. Figure 6-3 presents the assessment locations and the State's delineation of impaired waters. The State listed the impaired stream segments below Route 3 in the Year 2000 303d list. Stormwater, CSOs, and habitat modification were surmised as the primary and secondary causes of impairment. As a result, TMDLs will need to be developed for pollutants causing stream impairment, once those pollutants are determined.

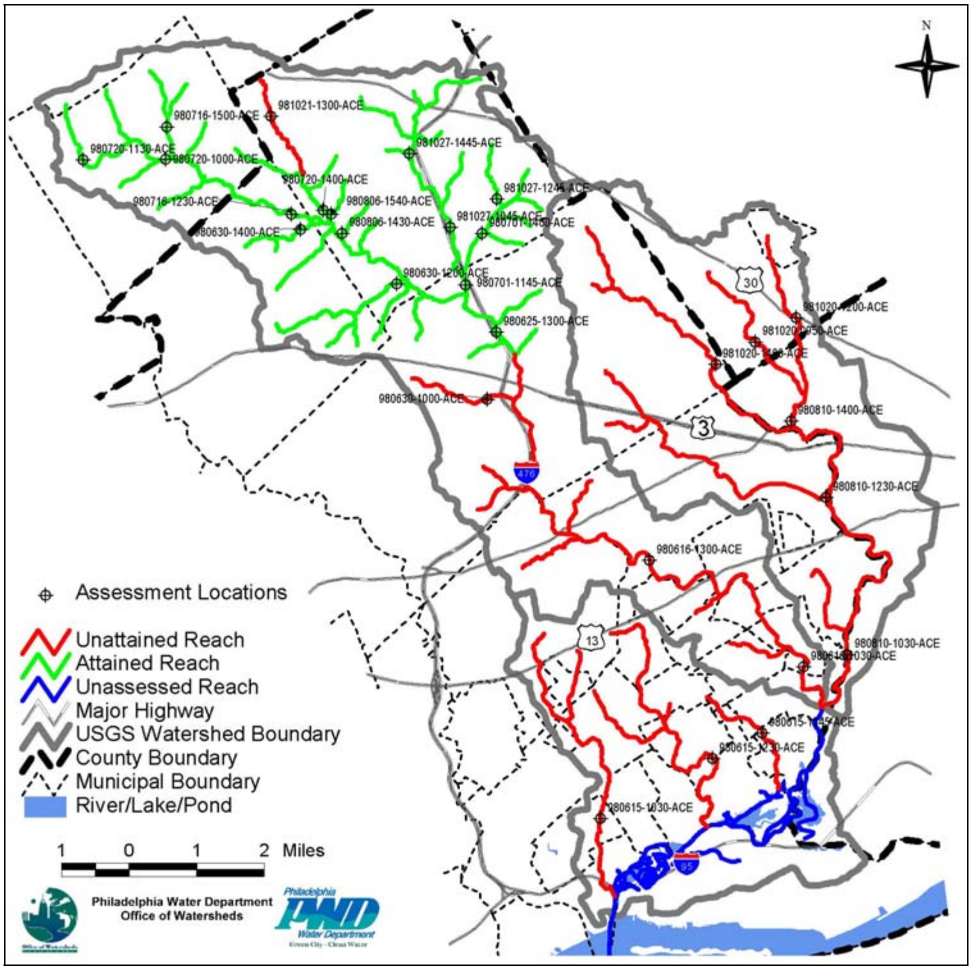


Figure 6-3 PaDEP Delineation of Impaired Reaches 1998

Darby Creek Valley Association

The Darby Creek Valley Association, a non-profit citizen's group, undertook a program to monitor aquatic ecosystem health at eleven sites in the Darby Creek watershed. These sites are shown on Figure 6-4. The program focused on monitoring of aquatic macroinvertebrate communities. The diversity of species and specific species present provide information about the degree of pollution in the stream. The data have not yet been published but will be made available on the internet at a future time.

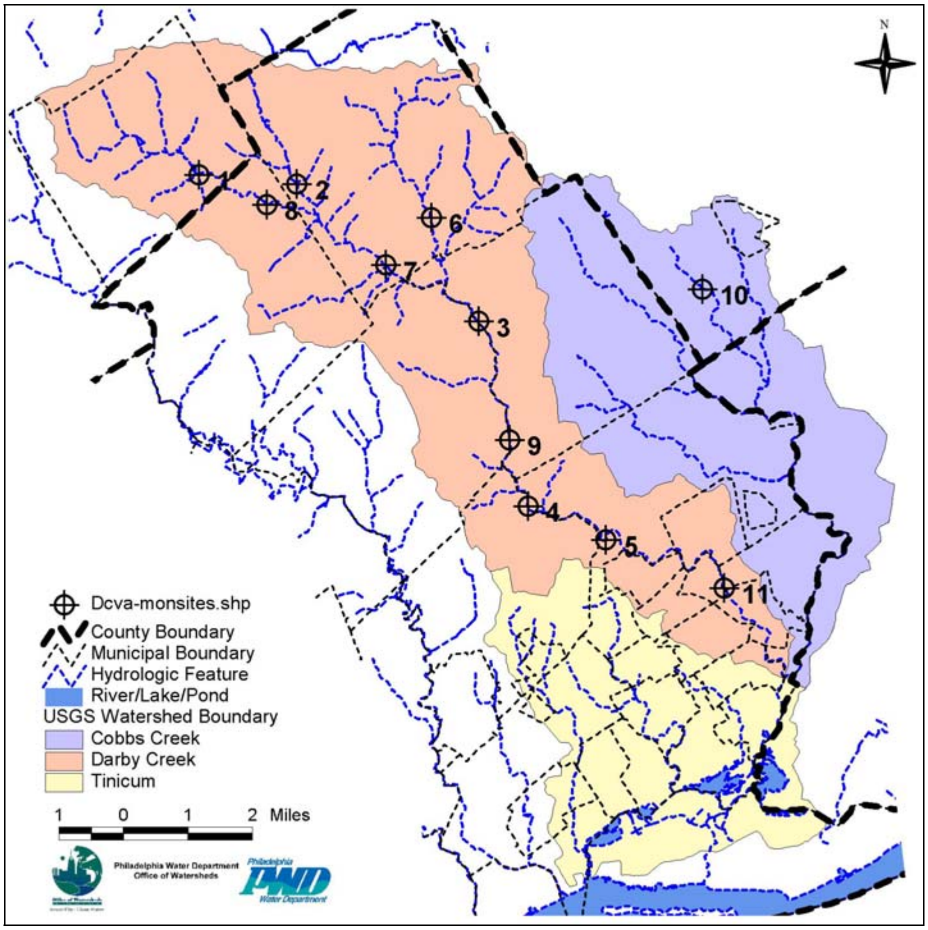


Figure 6-4 DCVA Stream Watch Macroinvertebrate Monitoring Sites

6.2 Preliminary Documentation on the Biological Assessment of the Cobbs Creek Watershed

6.2.1 Introduction

Biological monitoring is a useful means of detecting anthropogenic impacts to the aquatic community. Resident biota (e.g. benthic macroinvertebrates, fish, periphyton) in a water body are natural monitors of environmental quality and can reveal the effects of episodic and cumulative pollution and habitat alteration (Plafkin et. al. 1989, Barbour et al. 1995). Biological surveys and assessments are the primary approaches to biomonitoring.

The Philadelphia Water Department's Office of Watersheds and Bureau of Laboratory Services, along with the Academy of Natural Sciences and the Pennsylvania Department of Environmental Protection have been working together to develop a preliminary biological database to assess the aquatic integrity of the Darby-Cobbs watershed. Although each agency has different objectives for the data (e.g. rapid biological protocol assessments (RBPs), research and presentation, storm water permit compliance (NPDES), Phase II of Darby-Cobbs assessment), the main goal of this project was to avoid redundancy in data collection and to gather as much expertise in the field as possible. During this period, macroinvertebrate, ichthyfauna and habitat assessments were conducted at specified locations within Cobbs Creek watershed. Geographical Information Systems (GIS) databases and watershed maps were also constructed to provide accurate locations of the sampling sites. The Office of Watersheds and the Bureau of Laboratory Services then analyzed compiled data to provide both a quantitative and qualitative assessment of the biological integrity of Cobbs Creek and to provide insight on the current problems associated with this urban stream system. In addition, this report also addresses future assessments and potential solutions for the restoration of the Darby-Cobbs watershed.

6.2.2 Methodology

Fish Sampling

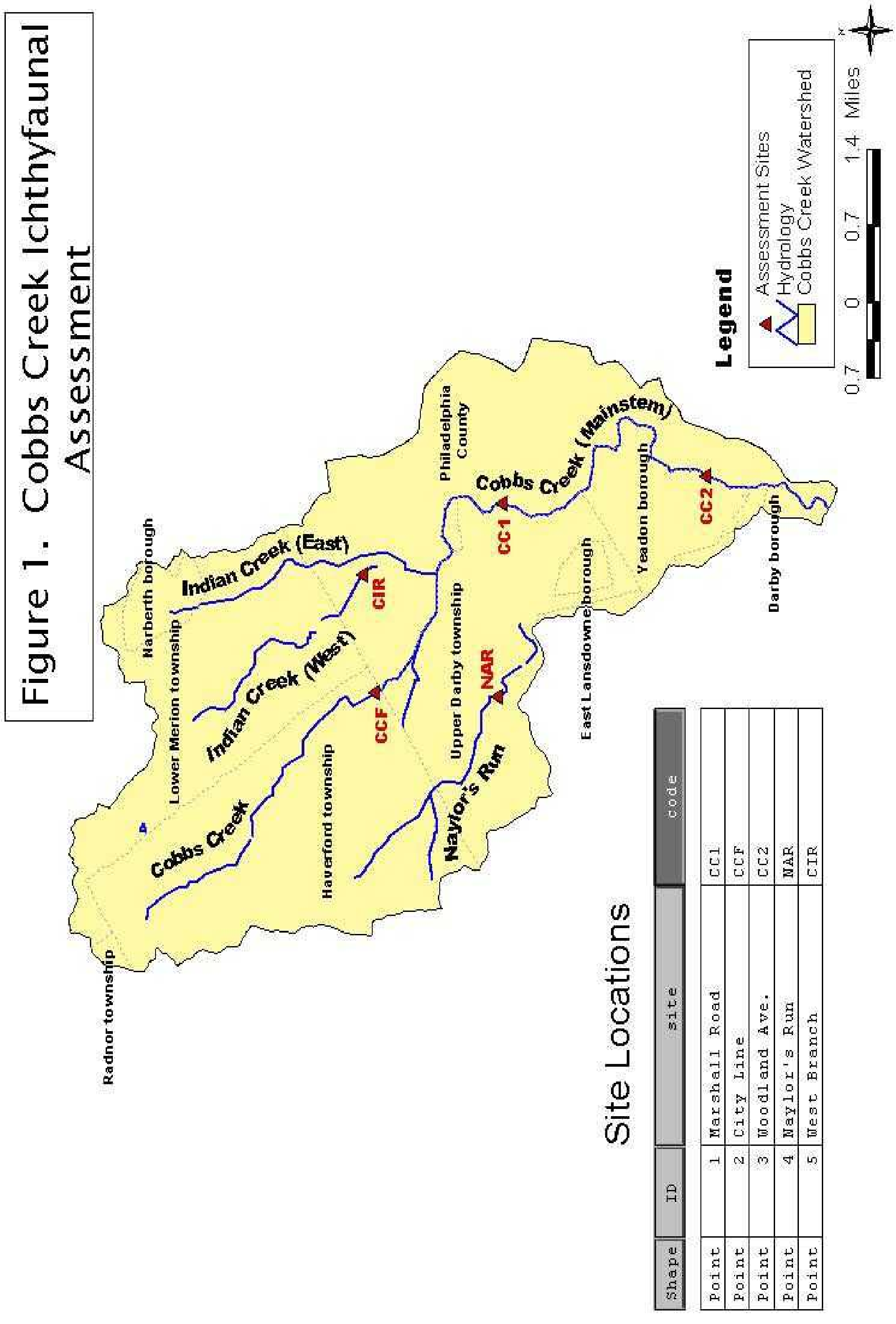
Five sampling stations were chosen on Cobbs Creek; three on the main stem and two sites on the smaller tributaries, West Branch Indian Creek and Naylor's Run. Prior to the main stem analysis, the Academy of Natural Sciences (ANS) completed their assessment on the three tributaries and were interested in completing a watershed analysis on Cobbs Creek. Data from these sites was provided to the Philadelphia Water Department and the Pennsylvania Department Of Environmental Protection (PADEP).

DCC-820: Main Stem (Cobbs Creek, Montgomery County): CCF

Sampling occurred on the main stem of the Cobbs Creek approximately 50 meters above City Line Avenue, Montgomery County (Latitude: 39°58'30.72" Longitude: 75°16'51.60", Figure 6-5). Using EPA protocols for rapid bioassessment, a 150 meter reach was measured using a graduated tape and both upstream and downstream portions were blocked off using standard seining nets. Two Coffelt backpack electro-shockers were operated at 50-75 watts direct current (DC). Fish were collected using D-frame dip nets, and identified to species and total length of each individual. Upon completion, an additional pass without replacement was completed.

The site name conventions in some graphics, including Figure 6-5 correspond to the current convention as follows:

Old Site Name Conventions	New Site Name Convention
CC1 / Site 1	DCC455
CCF / Site 2	DCC770
CC2 / Site 3	DCC110
NAR / Site 4	DCN215
CIR / Site 5	DCIW100



Shape	ID	site	code
Point	1	Marshall Road	CC1
Point	2	City Line	CCF
Point	3	Woodland Ave.	CC2
Point	4	Naylor's Run	NAR
Point	5	West Branch	CIR

Figure 6-5 Cobbs Creek Ichthyfaunal Assessment

DCC-175: Mainstem (Cobbs Creek, Philadelphia County): CC2

Sampling procedures occurred on the mainstem Cobbs Creek near Mt. Moriah Cemetery (Latitude: 39°56′4.92″ Longitude: 75°14′12.84″, Figure 6-5). Using EPA guidelines for ichthyfaunal assessment, a 200 meter reach was blocked off using standard seining nets. Fish collection, identification and health assessment at this location were similar to the DCC-820 collection. For more information on the methodology concerning fish assessment, refer to Barbour et. al. (1999).

DCN-215 and DCIW-100: (Tributaries To The Main Stem)

Prior to field sampling on Cobbs Creek main stem, the Academy of Natural Sciences conducted a field analysis on two tributaries, Naylor's Run (DCN-215) and West Branch Indian Creek (DCIW-100), and an additional site on the main stem of Cobbs Creek (DCC-505) (Figure 6-5).

3.3.2 Biological Assessment (Fish Biosurvey And Data Analysis)

Six metrics were used to assess the quality of the fish assemblages in Cobbs Creek (Table 6-2).

Table 6-2 Quantitative and Qualitative Analyses of Cobbs Creek Ichthyfaunal Community

1. **Species Richness**
2. **Species Diversity**
3. **Trophic Composition Relationships**
4. **Pollution Tolerance Levels**
5. **Disease and Parasite Abundance/Severity**
6. **Introduced (exotic) Species**
7. **Species descriptions***
   *Not used as a metric

Species Richness:

The first metric, species richness, addresses the total number of native fish species and generally signifies increased stream degradation as the number of species decreases. Number of native species, however, is strongly correlated to stream size at small stream sites and thus, it is important to develop species/waterbody size relationships for future assessments in the Darby-Cobbs watershed (Karr et al, 1986).

Species Diversity:

Species diversity, a characteristic unique to the community level of biological organization, is an expression of community structure (Brower et al., 1990). In general, high species diversity indicates a highly complex community. Thus, population interactions involving energy transfer (e.g. food webs), predation, competition and niche distribution are more complex and varied in a community of high species diversity. In addition, many ecologists support species diversity as a measure of community stability (i.e. the ability of community structure to be unaffected by perturbations). Using the Shannon-Weiner (H') index, the following formulas were used to calculate species diversity at each sampling location:

$$H' = -\sum(Pi)(\ln Pi), \qquad \text{(eq. 1)}$$

$$Pi = \frac{ni}{N}; \qquad \text{(eq. 2)}$$

where pi is the proportion of the total number of individuals n occurring in species I to the total number of species counted N.

Trophic Composition and Tolerance Designations:

Trophic composition metrics were used to assess the quality of the energy base and trophic dynamics of the fish assemblages (Plafkin et al., 1989). The trophic composition metrics offer a means to evaluate the shift toward more generalized foraging that typically occurs with increased degradation of the physiochemical habitat (Barbour et al., 1999). Pollution tolerance metrics were also used to distinguish low and moderate quality sites by assessing tolerance values of each species identified at the sampling locations. For a more detailed description of metrics used to evaluate the trophic and pollution designations of fish assemblages see Barbour et. al. (1999).

Disease and Parasite Abundance/Severity:

Two species, Rhinichthys atratulus and Catastomus commersoni, were used to assess the severity of parasite infestation on two fish populations. Using a sub-sample of individuals (n=15) located at Cobbs Creek at City Line (DCC-820) and Cobbs Creek near Woodland Avenue (DCC-175), the ranking of parasite infestation was based on the severity of trematode cysts, ranging from 0 (no infestation) to 3 (heavily infested). A one-way analysis of variance (ANOVA) was used to determine the significance of trematode cyst infestation on R. atratulus and C. commersoni between sites. While trematode cysts are generally not pathenogenic to fish species, the presence and severity of infestation represents a stressed and weakened community. Trematode cysts can cause damage to gill function (e.g. respiration) and skin defects (e.g. peeling and loss of proteins and fluids).

Proportion of Introduced/Exotic Species:

This metric was used as a qualitative approach to determine direct anthropogenic (e.g. human) effects on the stream ecosystem through introduction of non-native species. Generally, as environmental degradation increases, the percent of introduced species also increases. In addition, invasive species are also capable of shifting community dynamics by eliminating native species.

Species Descriptions:

Descriptions of habitat, functional feeding groups, reproduction and migratory processes of individual species were also created in this report to serve as an educational component for future work with community organizations, neighboring municipalities and educational systems within Philadelphia and surrounding school systems.

Benthic (Macroinvertebrate) Sampling

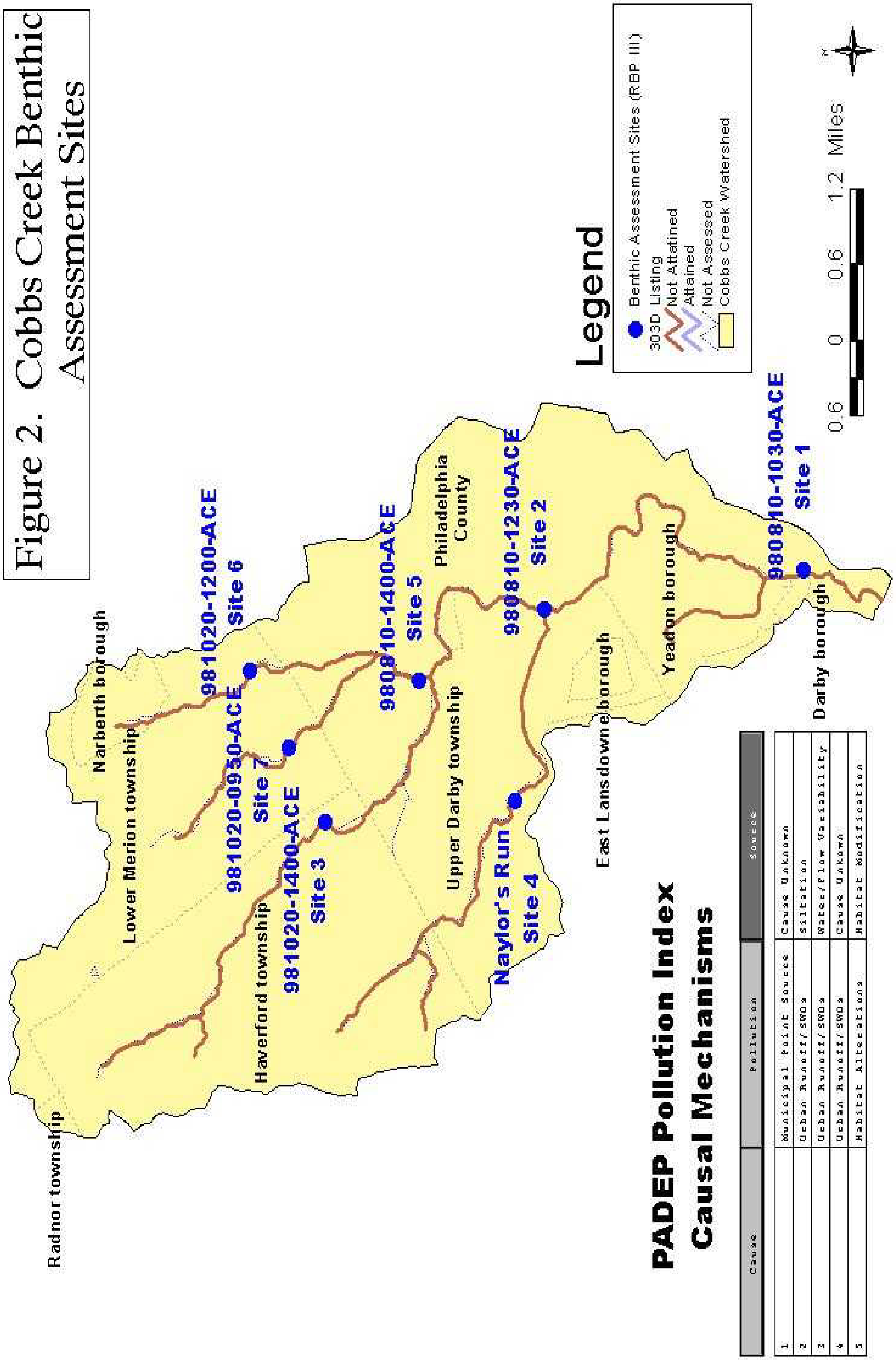
On December 6th-7th, 1999, the Pennsylvania Department of Environmental Protection (PADEP), Office of Watersheds and the Bureau of Laboratory Services conducted Rapid Bioassessment Protocols (RBP III) on seven sites (Figure6-6) in the Cobbs Creek watershed. Using EPA guidelines, macroinvertebrates were collected by placing a standard D-frame dipnet at the downstream portion of a riffle.

The substrate was then kicked and scraped manually one meter from the net aperture to remove all benthic species. This procedure was repeated at another riffle location with less flow. Specimens were then preserved in 95% ETOH (ethyl alcohol) and returned to the laboratory in polyethylene containers. In laboratory, samples were placed in a 11” x14” gridded (numbered) pan and random “plugs” were examined until 100 individuals were collected. Macroinvertebrates were identified to genus and population estimates were calculated. Using the following flowchart, the biological integrity and benthic community composition was determined (EPA guidelines for RBP III and PADEP Modified Rapid Biological Assessments) (Table 6-3):

Table 6-3: Biological Condition Scoring Criteria For RBP III

Metric	Biological Condition Scoring Criteria			
	6	4	2	0
Taxa Richness (a)	>80%	79-70%	69-60%	<60%
Hilsenhoff Biotic Index (Modified) (a)	<0.71	0.72-1.11	1.12-1.31	>1.31
Modified EPT Index (a)	>80%	79-60%	59-50%	<50%
%Contribution of Dominant Taxon (a)	<10	11-16	17-22	>22
%Modified Mayflies (a)	<12	13-20	21-40	>40
Ratio of Scrapers/Filter (b) Collectors	>50%	35-50%	20-35%	<20%
Community Loss Index (b)	<0.5%	0.5-1.5	1.5-4.0	>4.0
Ratio of Shredders/Total (b)	>50%	35-50%	20-35%	<20%

(a) Metrics used to quantify scoring criteria (PADEP)
Additional metrics used for qualitative descriptions of sampling locations (EPA)



Cause	Pollution	Source
1	Municipal Point Sources	Cause Unknown
2	Urban Runoff/SWOs	Siltation
3	Urban Runoff/SWOs	Water/Flow Variability
4	Urban Runoff/SWOs	Cause Unkown
5	Habitat Alterations	Habitat Modification

Figure 6-6 Cobbs Creek Ichthyfaunal Assessment

Upon completion of the total biological scoring criteria, each site was compared to a reference site according to its drainage area and geomorphological attributes. The two reference sites chosen were Broad Run (located at the intersection of Chestnut Lane and Broad Run Road, West Bradford Township, Chester County) and French Creek (located at Coventry Road Bridge, South Coventry Township, Chester County). Using the following chart, a biological assessment of each site was established in attempt to create a baseline for monitoring trends in benthic community structure that might be attributable to improvement or worsening of conditions over time (Table 6-4):

Table 6-4 Bioassessment of Benthic Community Structure (RBPIII)

% Comparison to Reference Score (a)	Biological Condition Category	Attributes
>83%	Nonimpaired	Comparable to the best situation within an ecoregion. Balanced trophic structure. Optimum community structure for stream size and habitat quality.
54-79%	Slightly impaired	Community structure less than expected. Composition (species and dominance lower than expected due to loss of some intolerant forms. Percent contribution of tolerant forms increases.
21-50%	Moderately impaired	Fewer species due to loss of most intolerant forms. Reduction in EPT index.
<17%	Severely impaired	Few species present. If high densities of organisms, then dominated by one or two taxa.

(a)Percentage values obtained that are intermediate to the above ranges will require subjective judgment as to the correct placement. Use of the habitat assessment and physiochemical data may be necessary to aid in the decision process.

Habitat Assessment

Prior to the benthic procedures, habitat assessments at the seven sites were completed based on the Stream Classification Guidelines for Wisconsin (Ball, 1982) and Methods of Evaluating Stream, Riparian, and Biotic Conditions (Platts et al., 1983). Reference conditions were used to normalize the assessment to the “best attainable” situation. Habitat parameters are separated into three principal categories:

(1) primary, (2) secondary, and (3) tertiary parameters.

Primary parameters are those that characterize the stream "microscale" habitat and have the greatest direct influence on the structure of the indigenous communities.

Secondary parameters measure the "macroscale" habitat such as channel morphology characteristics. Tertiary parameters evaluate riparian and bank structure and comprise three categories: (1) bank vegetative protection, (2) grazing or other disruptive pressure, and (3) and riparian vegetative zone width. The following chart (Table 6-5) describes the analysis that was completed:

Table6-5: Habitat Assessment Criteria Used at Benthic Monitoring Stations*

Condition/Parameter	Condition			
	Optimal	**Suboptimal**	**Marginal**	**Poor**
Primary-Substrate And Instream Cover				
Instream Cover	**16-20**	**11-15**	**6-10**	**0-5**
Epifaunal Substrate	**16-20**	**11-15**	**6-10**	**0-5**
Velocity/Depth regimes	**16-20**	**11-15**	**6-10**	**0-5**
Secondary-Channel Morphology				
Channel alteration	**16-20**	**11-15**	**6-10**	**0-5**
Sediment Deposition	**16-20**	**11-15**	**6-10**	**0-5**
Frequency of Riffles	**16-20**	**11-15**	**6-10**	**0-5**
Channel Flow Status	**16-20**	**11-15**	**6-10**	**0-5**
Tertiary-Riparian and Bank Structure				
Bank Vegetative Protection	**16-20**	**11-15**	**6-10**	**0-5**
Grazing or Other Disruptive Pressure	**16-20**	**11-15**	**6-10**	**0-5**
Riparian Vegetative Zone Width	**16-20**	**11-15**	**6-10**	**0-5**

*Habitat assessment parameters used were in agreement with Pennsylvania Department Of Environmental Protection's Unassessed Waters Program.

6.2.3 Results

Fish Analysis:

Rapid Bioassessment Protocol V (RBP V) (Plafkin et al. 1989) is perhaps the most common method for assessing fish communities by using an established Index of Biotic Integrity (IBI) similar to that described by Karr et al. (1986). Due to temporal differences in fish collection on Cobbs Creek by the Academy of Natural Sciences and the Office of Watersheds, the data provided by this sampling effort were used to assess the general condition of the resident fish population as a function of abundance and diversity. Trophic relationships, tolerance values and percent infestation were also used as a means to quantify the overall health of the fish assemblage. The taxonomic list and common names of fish collected in Cobbs Creek watershed are displayed as an attached appendix (Table 6-6). In addition, an identification list of fish species comprising habitat preference, reproductive strategies and feeding behaviors is also included in the appendix (Figure 6-7).

Species Richness And Diversity

Fish abundance, richness and diversity varied greatly among the five sampling locations (Table6-6).

Table 6-6 Species abundance, richness and diversity (H′) at the five sampling locations on Cobb Creek.

Species	DCIW-100	DCC-820	DCN-215	DCC-505	DCC-175
American Eel	0	15	19	6	8
Brown Bullhead	0	0	0	0	2
White Sucker	10	190	0	19	20
Banded Killifish	0	0	0	0	74
Mummichog	0	0	17	16	171
Redbreast Sunfish	0	0	3	0	31
Pumpkinseed	0	14	6	1	2
Common Shiner	0	415	21	52	1
Spottail Shiner	0	0	0	3	1
Swallowtail Shiner	0	5	549	145	49
Fathead Minnow	0	0	0	0	48
Green Sunfish	0	0	1	0	0
Blacknose Dace	86	651	333	59	48
Creek Chub	7	48	0	0	1
Total Number	**103**	**1338**	**949**	**301**	**456**
Total Taxa	**3**	**7**	**8**	**8**	**13**
Shannon-Weiner Diversity Index (H')	**0.56**	**1.23**	**0.97**	**1.44**	**1.85**

Cobbs Creek at Indian Run (DCIW-100) displayed the lowest fish density and species richness (n=3) (Figure 6-7). The dominant taxon at this location was Blacknose Dace, *Rhinichthys atratulus*, (83.0%), a generalist/insectivore feeder with the ability to withstand high levels of pollution. The Shannon Diversity Index (H') value at this location was 0.56, also indicating low species richness as well as low relative diversity (evenness).

Cobbs Creek at City Line Avenue (DCC-820) possessed the highest number of individuals, dominated by white sucker (*Catastomus commersoni*) (14.2%), and two cyprinid species, common shiner (*Luxilus cornutus*) (31.0%) and blacknose dace (*Rhinichthys atratulus*) (48.7%). In addition, the catadromous species, *Anguilla rostrata*, was also present at this location although means of migration from into the Cobbs Creek watershed appear to be impeded due to dam structures (e.g. Woodland Avenue).

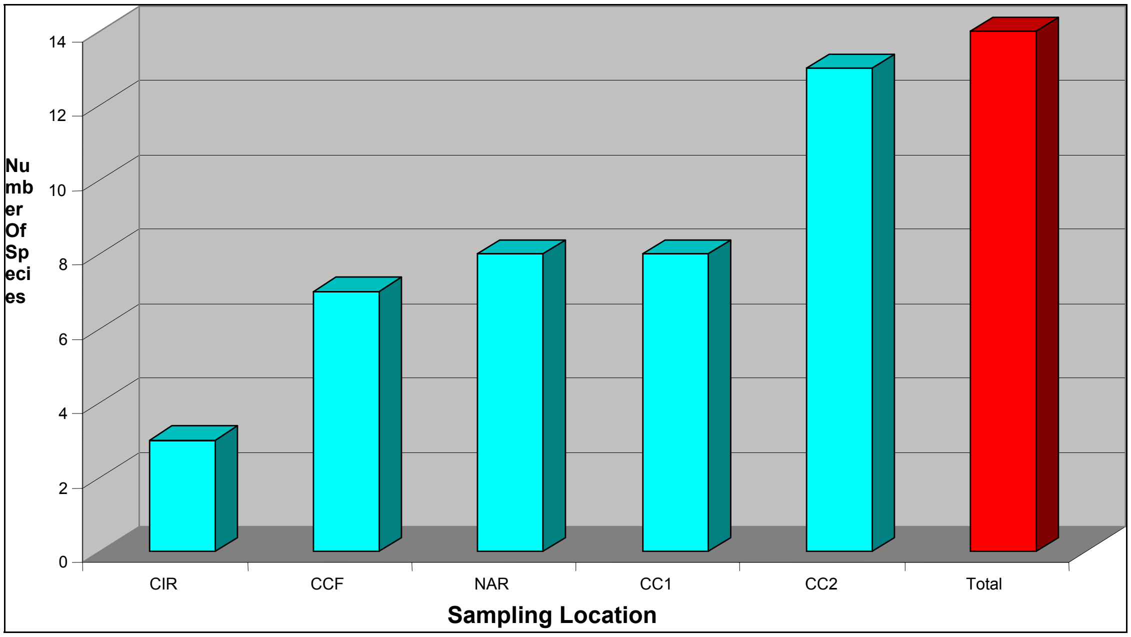


Figure 6-7 Number of species at each sampling location in Cobbs Creek.

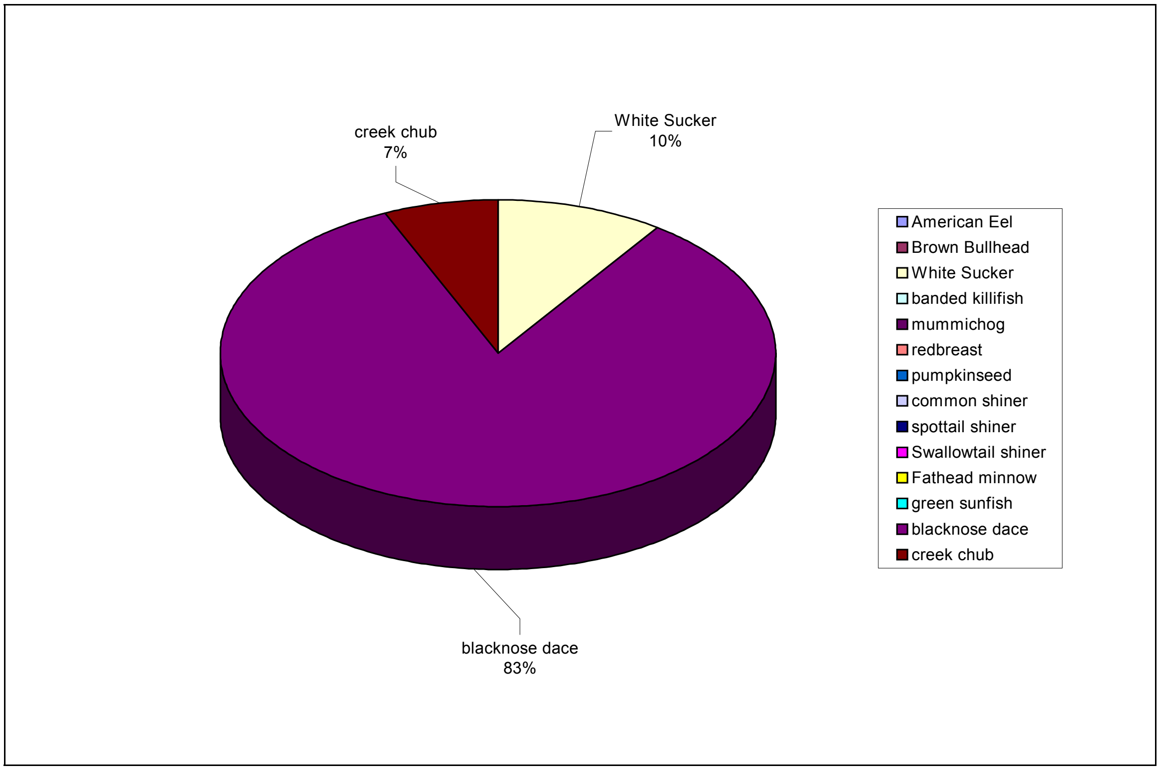


Figure 6-8 Species distribution (%) at West Branch Indian Run (DCIW-100)

Naylor's Run (DCN-215) and Cobbs Creek at Marshall Road (DCC-505) both contained a similar number of taxa (n=8) with dominant species being swallowtail shiner, *Notropis procne*, (57.9% and 48.2%, respectively) and blacknose dace, *R. atratulus* (35.1% and 19.6%, respectively). Common shiner, *Luxilus cornutus*, and mummichog, *Fundulus heteroclitus*, were also common species at these locations. Although Naylor's Run (DCN-215) station was higher in fish abundance (N=949) than Marshall Road (DCC-505) (N=301), the species diversity (H') value at DCC-505 was greater (1.44), indicating a more evenly distributed community.

Cobbs Creek at Woodland Avenue (DCC-175) displayed the highest species richness (n=13) and species diversity value (H'=1.855) of all the five monitoring locations. Dominant species at DCC-175 were *Fundulus diaphanus* (16.2%), *F. heteroclitus* (37.5%), *N. procne* (10.7%), *Pimephales promales* (10.5%) and *R. atratulus* (10.5%). While these metrics indicate a relatively diverse and evenly distributed community, four of the dominant species are classified as "pollution tolerant", capable of low oxygen concentrations and able to persist in physically and chemically degraded habitats.

Table 6-7 Species distribution (%) at all sites

SITES SPECIES	DCC-505	DCC-820	DCC-175	DCN-215	DCIW-100
American Eel	2.0	1.1	1.8	2.0	
Brown Bullhead			0.4		
White Sucker	6.3	14.2	4.4		
Banded Killish			16.2		10.0
Mummichog	5.3		37.5	1.8	
Redbreast			6.8	0.3	
Pumpkinseed	0.3	1.0	0.4	0.6	
Common shiner	17.3	31.0	0.2	2.2	
Swallowtail shinner	48.2	0.4	10.7	57.9	
Fathead minnow			10.5		
Green sunfish				0.1	
Blacknose dace	19.6	48.7	10.5	35.1	83.0
Creek chub		3.6	0.2		7.0
Spottail shinner	1.0				

Trophic Composition And Tolerance Designations

Functional feeding guilds for all five assessment sites are displayed in Table 6-8. Trophic designations (e.g. piscivore, invertivore, omnivore) of each taxon compiled in this report were obtained from literature by Barbour et al. (1999) and Halliwell et al. (1999). Results show that all sites are dominated by insectivores (80%-95%) with the exception of Cobbs Creek at Woodland Avenue (DCC-175) where the dominant functional feeding group is primarily generalist feeders (55.9%). In addition, the percent of piscivorous species at all locations is moderately low (1.1%-2.0%), with Indian Run (DCIW-100) containing no piscivorous species. This condition may be due to the lack of adequate habitat for large predatory species (e.g. deep pool systems).

Table 6-8 . Functional feeding guilds (%) at all sites

Functional Feeding Species	DCC-505	DCC-820	DCC-175	DCN-215	DCIW-100
Generalist Feeder	5.6	4.6	55.9	2.7	7
Insectivore	86.0	80.0	37.9	95.2	83.0
Omnivore	6.3	14.2	44.0	0.1	10.0
Piscivore	2.0	1.1	1.8	2.7	-

Tolerance values, expressed as the percentage of tolerant, intermediate and intolerant taxa, are shown in Figure 6-9. Fish assemblage at Indian Run (DCIW-100) showed the highest percentage (100%) of pollution tolerant species, consisting of three taxa (*Semotilus atromaculatus*, *Rhinichthys atratulus*, and *Catastomus commersoni*). Sites on Naylor's Run (DCN-215), Cobbs Creek at Marshall Avenue (DCC-505) and Cobbs Creek at Woodland Avenue (DCC-175) had similar percentages of moderately tolerant (58%-74%) and tolerant individuals (26%-42%). The percentage of pollution tolerant taxa at Cobbs Creek City Line (DCC-820) was substantially higher (66%) than the previously mentioned sites. More importantly, no sampling sites contained individuals classified as "pollution intolerant", indicating the probability of episodic periods of impaired water quality or habitat degradation.

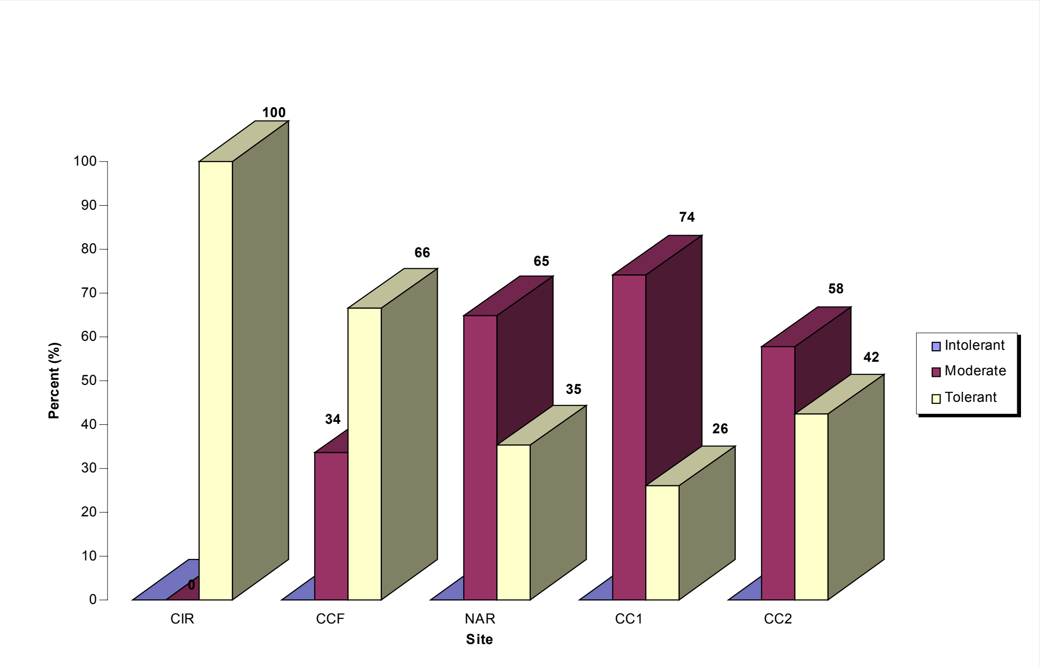


Figure 6-9 Fish tolerance levels at the five biomonitoring stations. Numbers indicate percentages in each tolerance category.

Disease and Parasite Abundance/Severity

Results from the study show significant differences in the amount of trematode infestation in both blacknose dace (R. atratulus) and white sucker (C. commersoni) between Cobbs Creek at City Line Avenue (DCC-820) and Cobbs Creek at Marshall Road (DCC-175) (p=0.0007 and p=0.0168, respectively) (Table6-9).

Table 6-9 ANOVA analysis of locational effects on trematode infestion in R. atratulus and C. commersoni shown as F statistics. Significance: *p<0.05, **p<0.01, and ***p<0.001.

Species	MS Effect	MS Error	F statistic
Blacknose Dace	8.533	0.581	14.688***
White Sucker	4.033	0.623	6.465*

Blacknose dace showed a higher abundance of trematode cysts at site DCC-175 (x=2.33 ± 0.72) when compared to site DCC-820 (x=1.27 ± 0.80) (Figure 3.15.). Similarly, severities of trematode cysts on white sucker at site DCC-175 were significantly higher than infestation rates at DCC-820 (x=1.87 ± 0.83 and x=1.13 ± 0.74, respectively).

Proportion of Introduced Species

Of the five sampling sites, Naylor's Run (DCN-215) and Cobbs Creek at Woodland Avenue (DCC-175) were the only sites that contained introduced/exotic species. These species were identified as green sunfish, *Lepomis cyanellus*, and fathead minnows, P*imephales promelas*. Although present, *L. cyanellus* and *P. promelas* at sites DCN-215 and DCC-175 were not dominant species within the community (0.001% and 0.105%, respectively).

Benthos

Scientific names and functional feeding groups of macroinvertebrates collected in Cobbs Creek watershed (11/10/99) are attached as an appendix. A master identification list of the macroinvertebrate community describing species specific attributes (e.g. life-history traits) and graphic representations of trophic designations are included in the appendix. Biological metrics calculated for the seven monitoring locations as well as the reference stations, French Creek and Broad Run, are also displayed in the Appendix .

DCC-110: (Cobbs Creek Mainstem, Philadelphia County):

The macroinvertebrate assemblage at DCC-110 received a total metric score of 6, representing 20.0% comparability to the reference conditions at French Creek and placing the benthos in the "moderately impaired" category (Tables 6-10 and 6-11). Samples collected in the 1999 survey were dominated by the filter-feeding caddisfly, Hydropsychidae. This dense filter-feeding assemblage appears to reflect the effects of moderate organic enrichment, and is indicative of an unbalanced community responding to an overabundance of a food resource---in this case Fine Particulate

Organic Matter (FPOM). The low abundance of scrapers relative to filtering collectors also corroborates that the FPOM has displaced periphyton as a food resource at DCC-110. Low taxa richness (56.3% comparability), an elevated Hilsenhoff metric (5.46) and the absence of modified EPT taxa (Hilsenhoff ≤ 3) indicate potentially episodic periods of poor water quality and/or habitat degradation.

DCC-110 received a total habitat assessment score of 109/240 and was the lowest habitat score received by a biomonitoring station during the 1999 survey. Total score reduction was mostly affected by low scores for epifaunal substrate, channel alteration, sediment deposition, frequency of riffles and riparian vegetative zone width. Stream reach characteristics included embedded riffle systems where 50%-75% of the gravel, cobble and boulder particles are surrounded by fine sediment. Well-defined pool systems were absent due to substantial sediment deposition throughout the stream reach.

Table 6-10 Metrics Used in Comparison of Cobbs Creek Stations to the Reference Sites.

Metric	DCC-110	DCC-455	DCC-865	DCN-185	DCIW-010	DCI-135	DCIW-185
Taxa Richness (%)(a)	56.3	100.0	93.8	72.2	72.2	88.9	55.6
Modified EPT Index (%) (a)	0	0	0	0	0	0	0
Modified Hilsenhoff (b)	2.93	3.78	4.02	3.64	3.04	3.44	3.42
Percent Dominant Taxa (b)	4.99	39.2	28.8	2.2	0.2	15.4	11.5
Percent Modified Mayflies ©	100	100	100	66.7	66.7	66.7	66.7

(a) Assessment Site/Reference Site.

(b) Assessment Site-Reference Site.

© Reference Site-Assessment Site.

Table 6-11 Biological Scoring and Condition Category of Each Assessment Site

Metric	DCC-110	DCC-455	DCC-865	DCN-185	DCIW-010	DCI-135	DCIW-185
Taxa Richness	**0**	**6**	**6**	**4**	**4**	**6**	**0**
Modified EPT Index	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Modified Hilsenhoff	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Percent Dominant Taxa	**6**	**0**	**0**	**6**	**6**	**4**	**4**
Percent Modified Mayflies	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Total	**6**	**6**	**6**	**10**	**10**	**10**	**4**
Percent Comparison	**20.0%**	**20.0%**	**20.0%**	**33.3%**	**33.3%**	**33.3%**	**13.3%**
Scoring Criteria	**Moderately Impaired**	**Moderately Impaired**	**Moderately Impaired**	**Moderately Impaired**	**Moderately Impaired**	**Moderately Impaired**	**Severely Impaired**

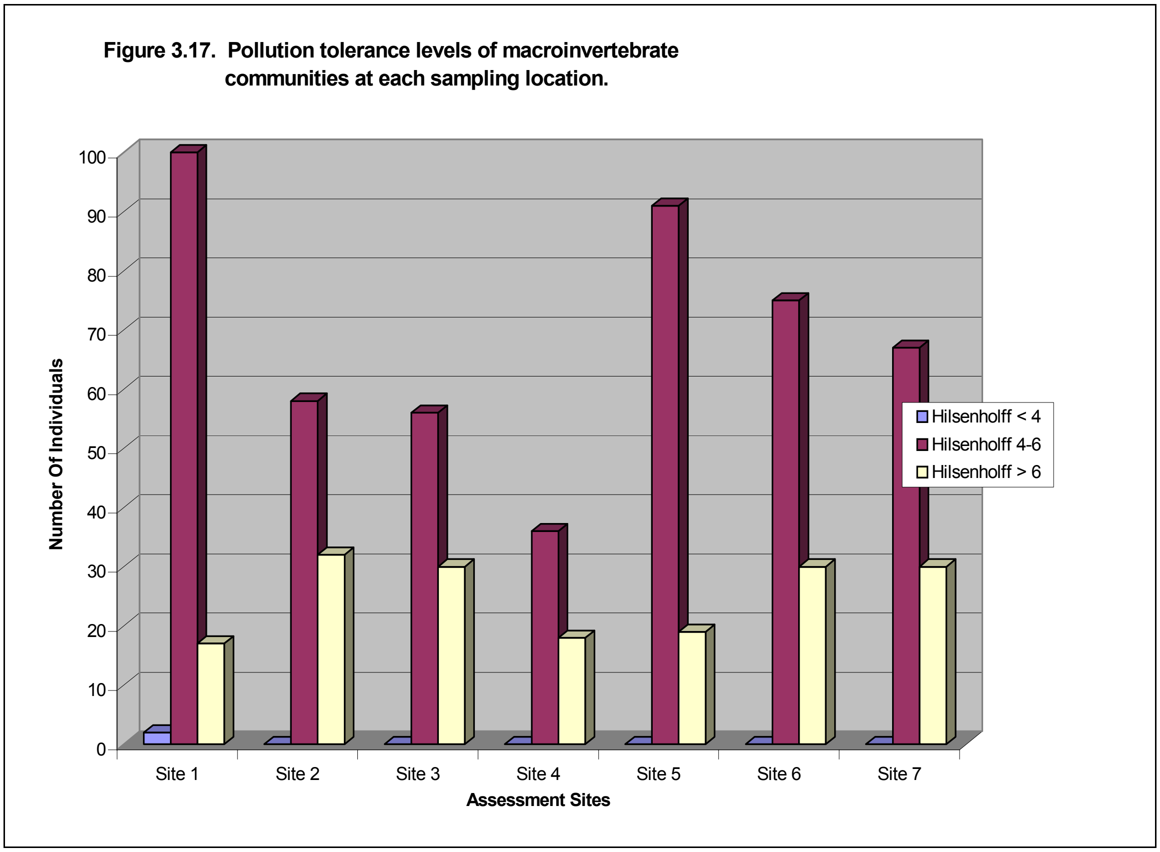


Figure 6.10 Pollution Tolerance Levels of Macroinvertebrate Communities

Table 6-12 Habitat Assessments of Each Biological Monitoring Station and Percent of Comparability to the Reference Sites.

Habitat Parameter	DCC-110	DCC-455	DCC-865	DCN-185	DCIW-010	DCI-135	DCIW-185
Instream Cover	10	11	15	11	12	14	11
Epifaunal Substrate	5	11	11	15	16	12	11
Embeddedness	8	9	12	5	10	11	9
Velocity/Depth	13	10	14	11	12	12	9
Channel Alteration	4	8	14	11	13	11	13
Sediment Deposition	5	16	15	11	7	15	13
Frequency Of Riffles	4	16	17	16	11	16	11
Channel Flow Status	14	6	12	10	15	6	14
Condition Of Banks	16	12	13	13	11	12	7
Bank Vegetation Protection	14	9	15	14	11	13	11
Grazing/Disruptive Pressure	12	6	16	8	10	6	7
Riparian Zone Width	4	2	12	5	5	2	2
Total	109	116	166	130	133	130	118
Percent Of Comparability (%)	60.22	64.09	91.71	74.71	76.44	74.71	67.82
Assessment Category	Partially Supporting	Partially Supporting	Comparable To Reference	Partially Supporting	Supporting	Partially Supporting	Partially Supporting

DCC-455: Cobbs Creek Mainstem and Naylor's Run Confluence (Philadelphia County):

DCC-455 received a biological scoring metric of 6 (20% comparability), placing the stream reach in the "moderately impaired" category, similar to that of DCC-110. Despite scoring high on the taxa richness metric (score: 6), all additional metrics received the lowest scores possible (score: 0). *Hydropsyche* sp. (n=20), *Cricotopus* sp. (n=14) and *Caecidotae* sp. (n=19) represented the three dominant taxa, all possessing Hilsenholff tolerance values ≥ 5. Similarly, the modified Hilsenholff score for DCC-455 was 6.31, indicating a tolerant macroinvertebrate assemblage. Functional feeding designations show a diverse trophic assemblage with filtering collectors and gathering collectors comprising a majority of the benthic community (34% and 31%, respectively). The absence of sensitive EPT taxa and modified mayflies also corresponds to the potential problems described at DCC-110.

The habitat assessment score at DCC-455 was 116/200, designating the site as "partially supporting" when compared to the reference station, French Creek (181/224). Reduction in habitat score at DCC-455 was due to low values for channel flow status, grazing or other disruptive pressure and riparian vegetative zone width. Riffle substrates were mostly exposed along with the decreased amount of water filling the stream channel. All additional scores, excluding sediment deposition (score: 16/20), ranged in the suboptimal to marginal categories.

DCC-865: Cobbs Creek Mainstem (Haverford Township, Delaware County):

The benthos assemblage at DCC-865 received a total metric score of 6, representing 20% comparability to "best attainable" conditions at French Creek. Dominant taxon at this sampling site was the net spinning caddisflies (*Hydropsyche* sp. and *Cheumatopsyche* sp.). The preponderance of hydropsychids (38% relative abundance) along with absence of a scraper population is similar to that of both DCC-110 and DCC-455, indicating the possibility of organic enrichment at this location. Also, the abundance of both filtering collectors (42%) and generalist feeders (16%) corroborates that FPOM is the dominant food resource in this area. DCC-865 received the highest Hilsenholff score (6.55) of all sites, indicating a moderately high pollution tolerant benthic community.

Despite being placed in the "moderately impaired" category for biological integrity, DCC-865 received the highest habitat assessment score (166/224) of all the seven sampling locations. High values were attributed to adequate instream cover, a well-defined channel with little evidence of accelerated sedimentation processes, ample vegetative cover along the banks and a substantial riparian buffer along the stream reach.

DCN-185: Naylor's Run (Upper Darby Township, Delaware County):

The macroinvertebrate assemblage at DCN-185 received a biological score of 10, representing 33.3% comparability to the reference station, Broad Run, and placing the benthic community in the "moderately impaired" category. Perhaps the most obvious problem associated with DCN-185 is the low abundance of macroinvertebrates collected and sorted at this location (n=54). The dominance of the hydropsychid caddisflies, categorized as filtering collectors (44%), high HBI score (6.28) and the lack of genera belonging to the Families Plecoptera, Trichoptera and Ephemeroptera are all indicators that Naylor's Run is biological impaired by physiochemical degradation along this reach.

In addition to benthic impairment, Naylor's Run received a total habitat score of 130/224, designating the site as "partially supporting" when compared to Broad Run. The reduction in habitat score is attributed to a heavily embedded substrate (score: 5/20) and the lack of riparian vegetation (score: 5/20). Despite having multiple riffle systems, all other metrics ranged in the suboptimal (11-15) and marginal (6-10) categories.

DCIW-010: Confluence of West Branch Indian Creek and East Branch Indian Creek (Philadelphia County):

DCIW-010 received a total biological score of 10 (33% comparability), placing the site in the "moderately impaired" category. The preponderance of Hydropsyche sp. and Cheumatopsyche sp. (48% relative abundance) at DCIW-010 is characteristic of a reach dominated by filtering collectors, indicating organic enrichment as a possible reason for the skewed community structure. Additional attributes of DCIW-010 are the absence of modified mayflies (Hilsenholff ≤ 3) and modified EPT taxa (Hilsenholff ≤ 3) and decreased ratio of shredder taxa to total taxa, all indicators of a biologically impaired stream reach.

The total habitat assessment score of DCIW-010 was 133/224, placing the stream reach in the "supporting" category. A decreased habitat score can be attributed to sediment deposition (score: 7) and riparian zone width (score: 5).

DCI-135: East Branch Indian Run (Lower Merion Township, Montgomery County):

DCI-135 benthos assemblage received a total metric score of 10, representing 33.3% comparability to "best attainable" conditions at Broad Run. In addition to the absence of modified mayflies and sensitive EPT taxa, the site is dominated by filtering collectors and gathering collectors (27% and 35%, respectively). A large proportion of shredder feeders (23%) represented by the genera *Cricotopus* sp. were present at the sampling site. Dominant taxa at the East Branch Indian Creek monitoring location were *Caecidotea* sp. (n=27), *Cricotopus* sp. (n=22) and Hydropsyche sp. (n=17).

East Branch of Indian Creek received a total habitat assessment score of 130/224, designating the site as "partially supporting" when compared to Broad Run. The decrease in overall habitat score can be attributed to channel flow status (score: 6) where a majority of flow composed approximately 50% of the channel, and the lack of a riparian zone (score: 2) where vegetation had been disturbed through anthropogenic influence (e.g. grass cutting, tree clearing).

DCIW-185: West Branch Indian Creek (Lower Merion Township, Montgomery County):

The total biological score at DCIW-185 was 4, representing 13.3% comparability to the reference site and designating the site as "severely impaired". All metrics scored poorly (score: 0) with the exception of percent dominant taxa (score: 4). Of the total amount of individuals collected (n=97), 66% belonged to the family *Hydropsychidae*, a pollution tolerant taxa indicative of possible organic enrichment. Similar to the other monitoring locations, West Branch of Indian Creek did not contain any modified mayflies, nor did the site include any modified EPT taxa. The ratio of scrapers to filtering collectors was also low, indicating an unbalanced community represented by pollution tolerant taxa (modified HBI=6.06).

When compared to the reference site, Broad Run, DCIW-185 received a total habitat score of 118/224 (67.82% comparability). Overall score reduction was attributed to the degraded condition of both banks and the lack of a riparian buffer. Habitat scores corroborated with the biological criteria, indicating an impaired stream reach due to anthropogenic stressors (e.g. bank erosion due to clear cutting).

6.2.3 Summary of Biology and Habitat by Reach

Upper Cobbs Creek

Seven sampling sites represent the headwaters and upper reaches of Cobbs Creek. Site DCI-135 is on Indian Creek main stem, 1.35 miles upstream of the confluence with Cobbs Creek. DCIW-185, DCIW-100, and DCIW-010 are located along Indian Creek West Branch. DCC-865, DCC-820, and DCC-770 are on the main stem of Cobbs Creek. These sites are all above the CSO-impacted area.

All of the Cobbs Creek subwatershed is considered unattained by PADEP, indicating that current conditions do not support designated uses. Additional RBP III benthic assessments at three sites score between 20% and 33% of the reference stream score and are classified as moderately impaired. The results of RBP V assessments indicate that fish species richness and diversity at DCIW-100 are the lowest of the sites studied in the Cobbs Creek subwatershed; however, it is important to consider the effect of stream size when evaluating these parameters. In addition, no piscivores were found at this site. Species richness and diversity at DCC-820 were similar to conditions found farther downstream on Cobbs Creek. All species found at DCIW-100 are considered pollution tolerant, while 66% of species found at DCC-820 are considered pollution tolerant and the remainder are considered moderately tolerant. Habitat scores ranged from 68% (DCIW-185, classified as partially supporting) to 92% (DCC-865, classified as comparable to the reference stream) of reference stream conditions.

Lower Cobbs Creek

Five sampling sites represent lower Cobbs Creek. DCN-215 is on Naylors Creek, 2.15 miles upstream of the confluence with Cobbs Creek. The remaining sites are on Cobbs Creek: DCC-505, DCC-455, DCC-175, and DCC-110. These sites receive both stormwater and CSO discharges.

All portions of the Cobbs Creek subwatershed are considered unattained by PADEP. Additional RBP III benthic assessments at two sites score only 20% of the reference stream score and are classified as moderately to severely impaired. The results of RBP V assessments indicate that fish species richness and diversity are greater in Lower Cobbs than higher in the watershed; however, the increase in stream size should be considered when comparing these numbers. A smaller percentage of highly pollution-tolerant species are found at lower Cobbs sites compared to sites located further upstream; however, no pollution-intolerant species are found. Habitat scores at the two lower Cobbs study sites are between 60% and 64% of the reference stream score and are classified as partially supporting.

Upper Darby Creek

The headwaters of Darby Creek are represented by data taken by PADEP and ANS at six sites upstream of PA Route 3 and numbered STA01 (farthest upstream) through STA06 (farthest downstream). These sites are not impacted by known CSOs.

Darby Creek and its tributaries north of Route 3 are classified as attained by PADEP. The health of the benthic ecosystem includes the full range from poor to very good depending on the site. Criteria based on fish range from fair to good. Some erosion was observed at all sites, and erosion generally increases with distance downstream.

Lower Darby Creek

PADEP/ANS sampling sites were STA07, just downstream of PA Route 3 in Delaware County, through STA10, near PWD sampling site DCD-765. These sites are classified as unattained by PADEP. The health of the benthic ecosystem is rated as poor at the three sites studied, and the health of the fishery is rated fair at the three sites studied. Observed erosion is generally greater at these sites than at the sites located in the upper portions of Darby Creek and its headwaters.

Tinicum Area

Data availability is limited in the Tinicum area. The non-tidal portions of this subwatershed are considered unattained by PADEP.

Section 7 Characterization of Wetlands

The locations and condition of existing wetlands have been extensively characterized in the Cobbs Creek watershed. Opportunities for enhancement of existing wetlands have been identified. Opportunities for creation of new wetlands, for both treatment and habitat, have been identified. The "Cobbs Creek Watershed Wetland Analysis", scheduled for release in 2004, documents the results of these studies.

Section 8 Characterization of Fluvial Geomorphology

The fluvial geomorphology (shape and condition of stream channels and banks) of Cobbs Creek has been extensively studied. The results of the study are documented in "Geomorphologic Survey – Level II: Guiding Principles for Fluvial Geomorphologic Restoration", released in 2003.

Section 9 Active and Potential Sources of Water Quality Constituents

9.1 Model Description and Data Sources

Introduction

This subsection summarizes the results of a preliminary estimate of loading rates of various pollutants to Darby Creek, Cobbs Creek, and tributaries. The waters in the drainage area receive point source discharges including municipal wastewater, CSO and other urban and suburban stormwater, sanitary sewer overflows, and limited industrial storm, process, and cooling waters. Combined sewers service approximately 6% of the watershed. Nonpoint sources in the basin include atmospheric deposition, overland runoff from urban and suburban areas, and individual on-lot domestic sewage systems discharging through shallow groundwater. The results were obtained using the detailed Storm Water Management Model (SWMM) in the Cobbs Creek subwatershed and the simpler Watershed Management Model (WMM) in the Darby and Tinicum subwatersheds.

The Storm Water Management Model (SWMM)

The U.S. EPA's Storm Water Management Model (SWMM) was used to develop the watershed-scale model for Cobbs Creek. The major components of the SWMM model used in the development of the Cobbs Creek watershed model were the RUNOFF and EXTRAN modules.

The RUNOFF module was developed to simulate both the quantity and quality of runoff in a drainage basin and the routing of flows and contaminants to sewers or receiving body. The program can accept an arbitrary precipitation (rainfall or snowfall) hyetograph and performs a step by step accounting of snowmelt, infiltration losses in pervious areas, surface detention, overland flow, channel flow, and water quality constituents leading to the calculation of one or more hydrographs and/or pollutographs at a certain geographic point such as a sewer inlet. The driving force of the RUNOFF module is precipitation, which may be a continuous record, single measured event, or artificial design event.

The EXTRAN module was developed to simulate hydraulic flow routing for open channel and/or closed conduit systems. The EXTRAN module receives hydrograph inputs at specific nodal locations by interface file transfer from an upstream module (e.g. the RUNOFF module) and/or by direct user input. The module performs dynamic routing of stormwater flows through storm drainage systems and receiving streams.

The SWMM model development and calibration process is discussed in detail in the Cobbs Creek SWMM Model Report.

The Watershed Management Model (WMM)

The Watershed Management Model provides an overall framework for estimating pollutant loads within a watershed and can be used as a screening level model in the preliminary stages of total maximum daily load (TMDL) development. WMM was originally developed to assess watershed management plans but also works well as a screening level load estimator. WMM uses land use categories and associated event mean concentrations (EMCs) to determine the non-point source load contribution within individual watershed planning areas. The model also includes estimates for tabulated municipal and industrial process water discharges. WMM was used to develop screening-level loads for the Darby and Tinicum portions of the Darby-Cobbs watershed.

WMM uses land use type, imperviousness, and event mean concentrations to generate seasonal and annual runoff flows and pollutant loads. The model also includes annual loads for point sources, CSOs, baseflow, and septic systems. WMM was refined (version 4.3.1) through EPA's Rouge River Wet Weather Demonstration Project and by the City of Westminster, Colorado and includes a user-friendly graphical interface built on an EXCEL® data structure and macro program. Because EPA funded the development of WMM, the Rouge River version is available in the public domain. WMM 4.3.1 for EXCEL® was used for this application because of the greater flexibility in assigning geographically distributed baseflows and baseflow concentrations.

WMM's capabilities, appropriate to this phase of the Darby and Cobbs Creeks Watershed Study, include:

- Estimates stormwater runoff pollution loads for nutrients (total phosphorus; total kjeldahl nitrogen, including organic nitrogen and ammonia; and total nitrite and nitrate), metals (cadmium, copper, lead, and zinc), oxygen demand, and sediment based on EMCs, land use, percent imperviousness, and annual rainfall.
- Estimates pollutant loads from stream baseflow.
- Estimates pollution loads from failing septic system.
- Applies delivery ratio to account for reduction in runoff pollution load due to uptake or removal in stream courses.

Data Needs and Sources

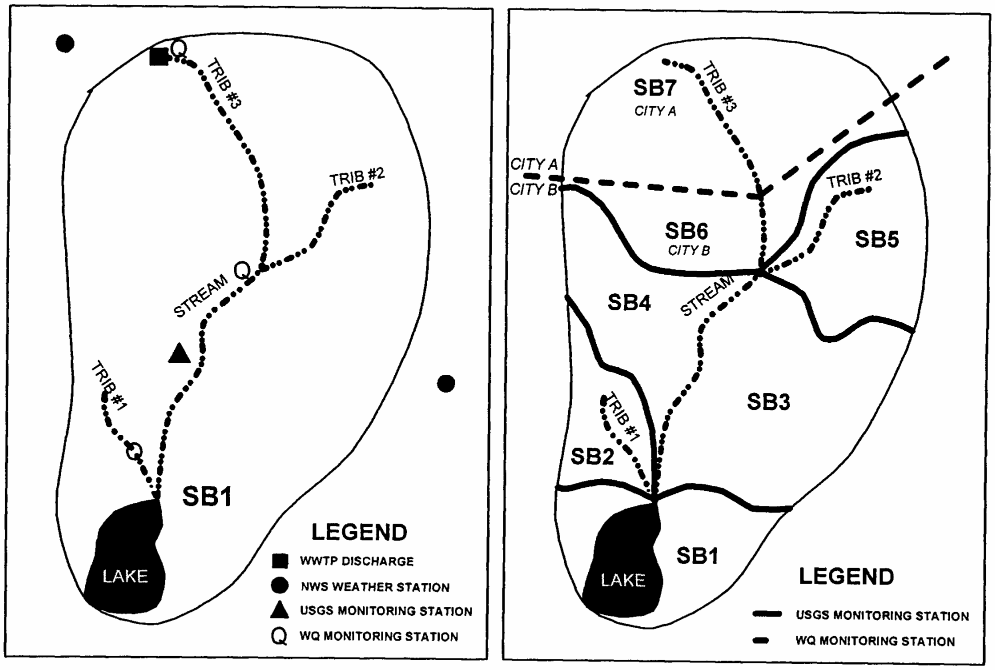
Table 9.1 presents the data requirements for screening-level applications of the Watershed Management Model and the sources of data used to develop the Darby and Cobbs Creeks Phase I load assessment model. A more detailed description of data used to build the SWMM model may be found in the associated report, "Watershed Scale Model Development".

Table 9.1 Data Requirements for WMM

Data Requirement	Use	Source for Darby-Cobbs
Subsheds	USGS topographic subwatersheds for Darby and Tinicum; topographic subwatersheds for separate-sewered areas in Cobbs; sewersheds for combined-sewered areas in Cobbs	Darby and Tinicum: USGS Cobbs separate-sewered areas: generated from elevation data Cobbs combined-sewered areas: PWD
Land Use	Used to define imperviousness and assign EMCs	Delaware Valley Regional Planning Commission
Imperviousness	Determines runoff volume in WMM; one factor affecting runoff volume in SWMM	Primarily Land Use. Population Density for Residential Land Uses (Manning, 1977 and Stankowski, 1974)
Event Mean Concentrations (EMCs)	Used to estimate pollutant loads from runoff	Literature values for stormwater concentrations; PWD treatment plant influent for sanitary concentrations
Baseflows	Used to estimate loads from background concentrations	USGS/PWD Cooperative Program
Other Loads	Point sources, CSOs, septic tanks	NPDES permits, CSO program, U.S. Census Bureau

Planning Areas/Units (Subsheds)

Delineation of subsheds in the SWMM model is discussed in detail in the associated report, "Watershed Scale Model Development". For WMM-based load estimates, the planning areas, or model units, for which WMM was compiled, are jurisdictional watersheds. Figure 9.1 presents WMM's conceptual framework for drainage area and sub-basin (model unit) delineation. USGS delineated sub-watersheds for streams tributary to Darby Creek were intersected with municipal jurisdictional boundaries to form the planning-level sub-areas. The USGS watersheds and the municipalities located wholly or partially within the watershed boundaries are shown in Figure 9.2.



A. Map of Watershed and Location of Potential Data Sources B. Delineation of Subbasins by Drainage and Jurisdiction

Figure 9.1 Conceptual Framework for Delineation of Model Units

The USGS delineated sub-basins and municipal boundaries were discussed in Section 2. The planning areas, also known as model units, are the intersection of the municipal boundaries and the watershed boundaries. These areas are identified by a sub-basin identifier, such as SB1, SB2, etc. The use of these planning units allows for loads to be summarized by sub-watershed and municipality and allows the city to determine its relative load contribution in comparison with other municipalities.

The planning areas or jurisdictional sub-watersheds range in size from less than 1 acre to greater than 3,000 acres. The mean size of the planning areas is about 430 acres with a median size of about 216 acres. The largest planning area is located in the Darby Creek Watershed on Darby Creek Branch D and Easttown Township, Chester County. The smallest basin is located in the southwestern most part of Sharon Hill Borough in Delaware County and drains a small portion of the Muckinipattis Creek A sub-basin. Eighty percent of the planning area is between 20 and 1000 acres.

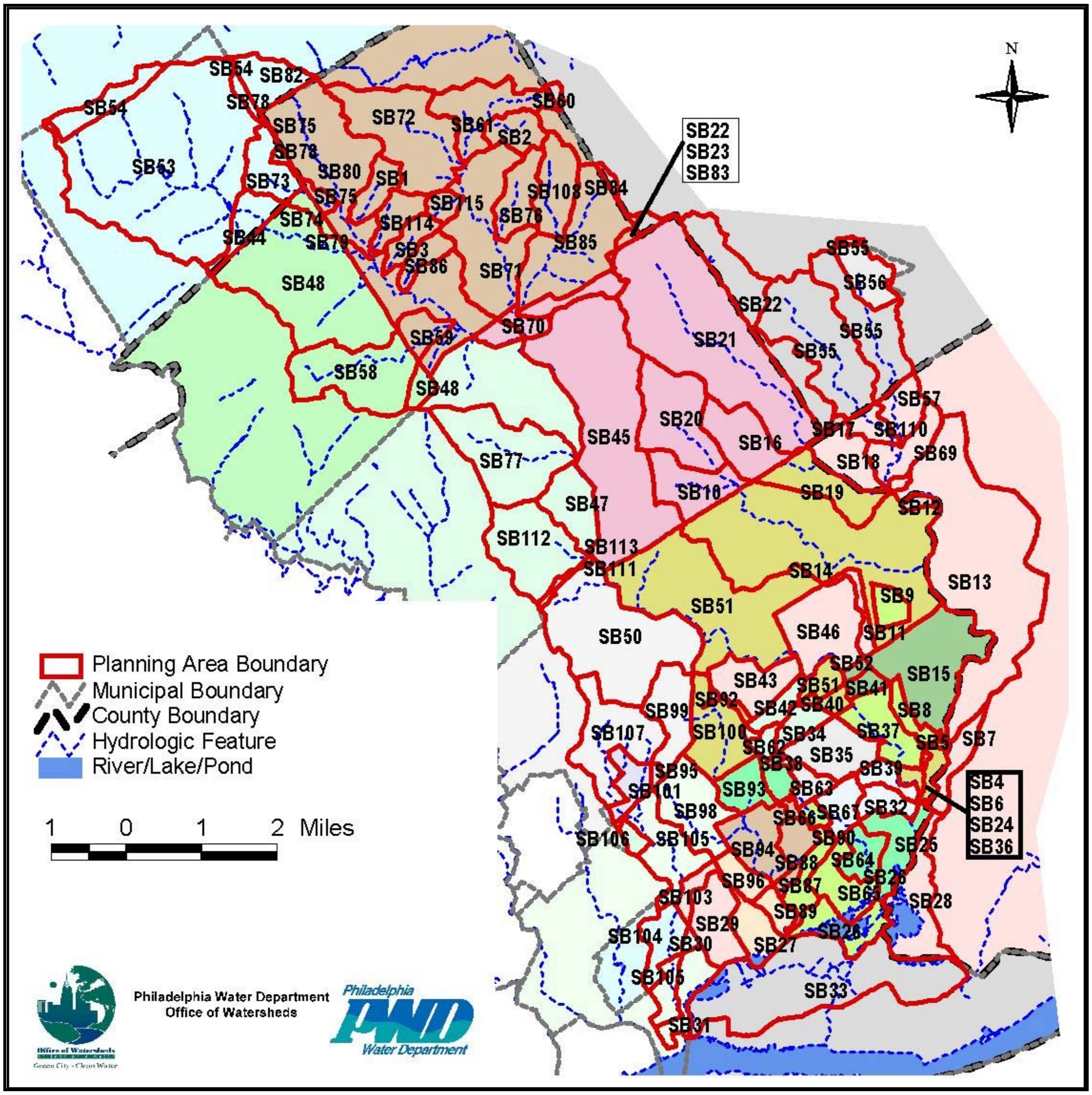


Figure 9.2 Planning Areas or Model Units

Land Use

Data used to define the land uses by planning area were compiled by the Delaware Valley Regional Planning Commission (DVRPC) and were discussed in detail in Section 2.

Land Surface Imperviousness and Runoff Volume

Estimated Imperviousness in the SWMM model is discussed in detail in the associated report, "Watershed Scale Model Development". For the WMM model, runoff coefficients used in the model were calculated from percent imperviousness values based on land use. Impervious area was determined for non-residential areas based on generally accepted percent imperviousness reported in the literature for various land use categories (Smullen, Hartigan, and Grizzard, 1978). For residential areas, percent imperviousness was based on population density. Generally, residential areas have much greater variability in percent imperviousness, which has been correlated with population density (Manning, 1987; Stankowski, 1974). Nine residential subcategories were developed from the DVRPC land use data, based on a histogram of block group population density. The histogram of percent imperviousness based upon population density is shown in Figure 9.3. The categories were distributed so that each contained approximately the same number of census blocks. Table 9.2 presents the percent imperviousness associated with each land use category. Note that the 100 percent "impervious" assigned to water/wetlands simply means that all the water that falls on the waterbody, enters the water body, a slightly different definition than the imperviousness related to other land use.

Table 9.2 WMM Imperviousness by Land Use Category

Land Use	Imperviousness (%)
Agricultural/Pasture	5.0
Cemetery	5.0
Commercial	80.0
Golf Course	5.0
Transportation	30.0
Industrial	80.0
Regional Park	5.0
Residential 1	18.2
Residential 2	25.9
Residential 3	33.8
Residential 4	39.3
Residential 5	44.1
Residential 6	49.6
Residential 7	57.9
Residential 8	75.4
Residential 9	90.1
Urban Recreation	60.0
Vacant	5.0
Water/Wetlands	100.0
Wooded	5.0

WMM calculates annual runoff volumes for pervious and impervious areas in each land use category by multiplying the average annual rainfall volume by a runoff coefficient. Runoff coefficients can be adjusted to reflect local conditions and land uses. For impervious surfaces, a runoff coefficient of 0.95 is typically used (thus, 95 percent of the rainfall over an impervious surface is directly converted to runoff). The pervious area runoff coefficient typically used is 0.20. An important distinction about impervious areas is that not all runoff from impervious areas flows directly to a drainage system or river and is often routed to lawns or dry wells. Runoff that enters a drainage system or river is from "directly connected impervious areas (DCIA)". The DCIA percentage typically is 50% or more of the total impervious area percentage.

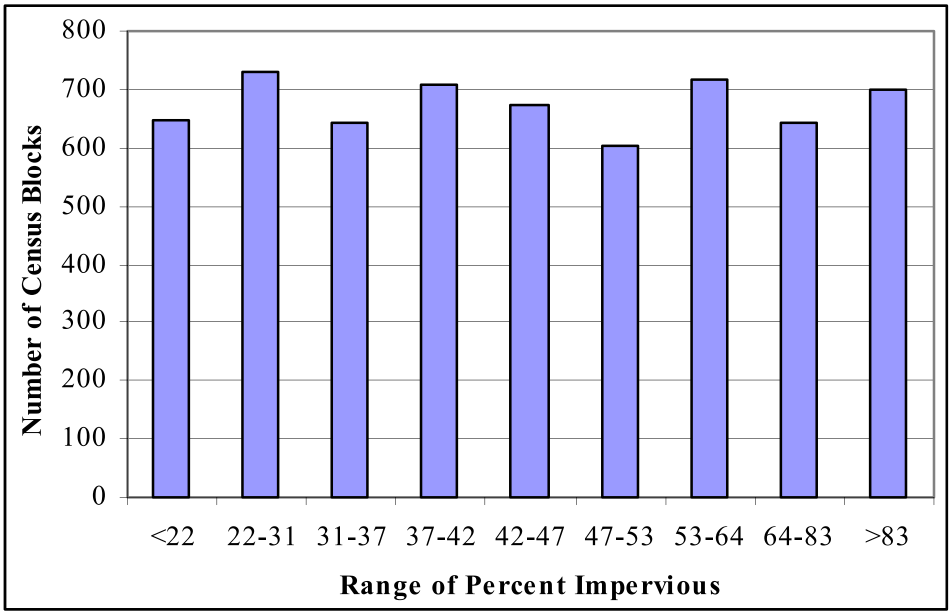


Figure 9.3 Distribution of Impervious Cover among Census Blocks

The total average annual surface runoff from land use, L, is calculated by weighting the impervious and pervious area runoff factors as follows:

$$R_L = [C_P + (C_I - C_P) * IMP_L] * I$$

where:

R_L = total average annual surface runoff from land use L (in/yr);
C_P = pervious area runoff coefficient;
C_I = impervious area runoff coefficient;
IMP_L = fractional imperviousness of land use L; and
I = long-term average annual precipitation (in/yr).

Total runoff from the watershed is the area-weighted sum of R_L for all land uses.

Event Mean Concentrations (EMCs)

Event Mean Concentrations (EMCs) are defined as the total mass load of a chemical parameter yielded from a site during a storm divided by the total runoff water volume discharged during the storm. The EMC is widely used as the primary statistic for evaluations of stormwater quality data and as the stormwater pollutant loading factor in analyses of pollutant loads to receiving waters.

Use of EMCs in Loading Analyses. Nonpoint source pollution loading analyses typically consist of applying land use- specific stormwater pollution loading factors to land use scenarios in the watershed under study. Loading rates of urban stormwater pollution (nutrients, metals, BOD, fecal coliform) are determined by the quantity of runoff from the land surface. Thus, they are closely related to the imperviousness of the land use type. Applying EMCs to calculated runoff volumes provides reasonable estimates of nonpoint source pollutant loadings, especially from urban areas.

Runoff volumes are computed for each land use category based on percent imperviousness of the land use and annual rainfall. These runoff volumes are multiplied by the land use specific EMC load factor (mg/L) to obtain nonpoint source pollutant loads by land use category. This analysis can be performed on a subarea or watershed-wide basis, and the results can be used to perform load allocation studies, to evaluate pollution control alternatives, or as input into a riverine water quality model.

The model calculates pollutant loads based upon nonpoint source pollution loading factors (expressed as lb/acre/year) that vary by land use and the percent imperviousness associated with each land use. The pollution loading factor M_L is computed for each land use L by the following equation:

$$M_L = EMC_L * R_L * K$$

where:

M_L = loading factor for land use L (lb/acre/year)

EMC_L = event mean concentration of runoff from land use L (mg/L); EMCs may vary by land use and pollutant

R_L = total average annual surface runoff from land use L (in/yr); and

K = 0.2266, a unit conversion constant.

By multiplying the pollutant loading factor by the acreage per land use and summing for all land uses, the total annual pollution load from a sub-basin can be computed. The EMC coverage is typically not changed for various land use scenarios within a given study watershed.

History and Sources of EMCs. Once point source discharges from treatment plants and industrial facilities were addressed in the 1970s and 1980s, more attention was focused on stormwater runoff from urban areas as a source of water quality degradation. As pollution from stormwater and urban drainage began to be investigated, studies focused on the types of pollution and methods to reduce the loads. However, these investigations did not consider the achievable level of improvement of receiving water bodies with the mitigation of stormwater pollution. In addition, many research studies concluded that additional and more comprehensive information was needed to make such assessments. This need led to the development of the Nationwide Urban Runoff Program, also known as NURP.

The goals of NURP were to develop and provide information to local decision makers, the States, EPA, and other parties for use in assessing the impacts of stormwater and urban runoff on water quality. The information collected also was intended to aid in the development of water quality management plans and provide a foundation for local, State and Federal policy decision making about water quality issues.

The NURP studies investigated 10 standard water quality constituents to characterize urban runoff. As a result of data collected through the NURP program, EMCs for these and other pollutants were developed from over 2,300 station-storms at more than 81 urban sites located in 28 different metropolitan areas. These studies greatly increased the knowledge of the characteristics of urban runoff, its effects upon the designated uses of receiving water bodies, and the performance efficiencies of various control measures. Pertinent conclusions from the NURP Program include:

- The variance of the EMCs, when data from sites are grouped by land use type or geographic region, is so great that differences in measures of central tendency among groups are not statistically significant.

- Statistically, the entire sample of EMCs and the medians of all EMCs among sites are log-normally distributed.

EMCs often are used in screening models such as WMM. The pollutant loads (L_i) are estimated as the product of the area of urban land (A_U), the rainfall-runoff depth as estimated by a modified rational formula approach (d_r), and a constant pollutant concentration (C_i), usually estimated from the EMCs reported by NURP (i.e., $L_i = C_i A_u d_r$).

Since the conclusion of the NURP Program in the 1980's, additional urban runoff quality monitoring data has been collected. One large effort conducted by the United States Geological Survey resulted in the collection of urban runoff data for over 1,100 station-storms at 97 urban sites in 21 metropolitan areas. Additionally, EPA required many major cities to collect urban runoff quality data as part of the application requirements for stormwater discharge permits under the National Pollutant Discharge Elimination System (NPDES). Data from 800 station-storms from 30 cities was gathered and incorporated into a database by CDM. CDM analyzed the data collected from NURP, USGS, and NPDES to assess if additional EMC observations (more degrees of freedom) would uncover statistically significant differences in EMCs among various land uses. While the resulting EMCs from the combined data sets did not indicate statistical differences in water quality among land uses, the pooled EMCs were significantly different than the NURP EMCs for several parameters (e.g., TSS, Cu, and Pb) and would produce different loading rates for urban areas. Table 9.3 indicates the EMCs used in the Darby and Cobbs Creeks Watershed Study and the source of each EMC value.

Table 9.3 Event Mean Concentrations

	Mean EMCs, mg/L											**Source (Equivalent Category)**
Land Use	**BOD**	**COD**	**TSS**	**TP**	**DP**	**TKN**	**NO2+NO3**	**Pb**	**Cu**	**Zn**	**Fecal**	
Agriculture	14.1	40.0	70.0	0.121	0.026	0.965	0.543	0.0300	0.0135	0.195	30000	EPA 1982 Chesapeake Bay Program
Commercial	14.1	52.8	78.4	0.315	0.129	1.73	0.658	0.0675	0.0135	0.162	30000	Smullen, J. T., et al. 1999
Industrial	14.1	52.8	78.4	0.315	0.129	1.73	0.658	0.0675	0.0135	0.162	30000	Smullen, J. T., et al. 1999
Transportation	24.0	103	141	0.430	0.129	1.82	0.830	0.5270	0.052	0.367	30000	FHA, 1990.
Water (Atmospheric Input)	1	1	1	0.064	0.02	1.022	0.571	0.00266	0.0022	0.0652	1	EPA 1982 Chesapeake Bay Program
Residential 1	14.1	52.8	78.4	0.315	0.129	1.73	0.658	0.0675	0.0135	0.162	30000	Smullen, J. T., et al. 1999
Residential 2	14.1	52.8	78.4	0.315	0.129	1.73	0.658	0.0675	0.0135	0.162	30000	Smullen, J. T., et al. 1999
Residential 3	14.1	52.8	78.4	0.315	0.129	1.73	0.658	0.0675	0.0135	0.162	30000	Smullen, J. T., et al. 1999
Residential 4	14.1	52.8	78.4	0.315	0.129	1.73	0.658	0.0675	0.0135	0.162	30000	Smullen, J. T., et al. 1999
Residential 5	14.1	52.8	78.4	0.315	0.129	1.73	0.658	0.0675	0.0135	0.162	30000	Smullen, J. T., et al. 1999
Residential 6	14.1	52.8	78.4	0.315	0.129	1.73	0.658	0.0675	0.0135	0.162	30000	Smullen, J. T., et al. 1999
Residential 7	14.1	52.8	78.4	0.315	0.129	1.73	0.658	0.0675	0.0135	0.162	30000	Smullen, J. T., et al. 1999
Residential 8	14.1	52.8	78.4	0.315	0.129	1.73	0.658	0.0675	0.0135	0.162	30000	Smullen, J. T., et al. 1999
Residential 9	14.1	52.8	78.4	0.315	0.129	1.73	0.658	0.0675	0.0135	0.162	30000	Smullen, J. T., et al. 1999
Wooded	14.1	52.8	40.5	0.145	0.129	0.505	0.245	0.0675	0.0135	0.162	30000	EPA 1982 Chesapeake Bay Program
Parks	14.1	52.8	78.4	0.145	0.129	3.19	1.0100	0.0675	0.0135	0.162	30000	EPA 1982 Chesapeake Bay Program
Cemetery	14.1	52.8	407	0.75	0.100	3.19	1.0100	0.0675	0.0135	0.162	30000	EPA 1982 Chesapeake Bay Program
Urban Recreation	2.00	52.8	60	0.188	0.100	3.19	1.0100	0.0675	0.0135	0.162	30000	EPA 1982 Chesapeake Bay Program
Vacant	2.00	52.8	60	0.188	0.100	3.19	1.0100	0.0675	0.0135	0.162	30000	EPA 1982 Chesapeake Bay Program
Golf Courses	14.1	52.8	407	0.75	0.100	3.19	1.0100	0.0675	0.0135	0.162	30000	EPA 1982 Chesapeake Bay Program

Note: All metals data are from Smullen (1999), except Highway. Atmospheric contributions are included in these values. The EMC for fecal coliform is based on NURP data as reported in NOAA (1987).

Baseflows

Most streams exhibit dry weather flow due to groundwater infiltration. As discussed in Section 4, baseflows for the individual planning areas were determined using USGS streamflow gauging data. To account for baseflow discharges as part of the average annual flow volume discharged from a watershed, an estimate of baseflow rate and quality is included in WMM. Concentrations of various constituents in baseflow are based on dry weather monitoring data.

Baseflow due to groundwater inflow is the main component of most streams in dry weather. Baseflow slowly increases and decreases with the elevation of the shallow aquifer water table. In wet weather, a stormwater runoff component is added to the baseflow. Estimation and comparison of these two components can provide insights into the relationship between land use and hydrology in urbanized and more natural systems. For a more detailed explanation of the baseflow separation techniques used see Section 4.3.

Constituent Source Types

For a watershed or TMDL study, an inventory of pollutant sources to the receiving water bodies must be compiled. The various types of sources usually considered are listed below. Note that urban stormwater runoff has some attributes of both point and nonpoint sources.

- Point (industrial and municipal dischargers, CSOs, SSOs);
- Nonpoint (stormwater, urban drainage, leaking septic systems);
- Background (instream, baseflow); and
- Atmospheric.

Municipal and Industrial Process Water Discharges. A file review of NPDES permits and Discharge Monitoring Reports (DMRs) for permitted dischargers within the Darby-Cobbs Creeks Watershed was performed at the Pennsylvania Department of Environment Protection in Conshohocken, PA. Information regarding site location, flow rates, and pollutant concentrations was gathered. Table 9.4 presents the list of dischargers and the information found for each point source.

Combined Sewer Overflows (CSOs). In many cities throughout the United States, stormwater runoff and sanitary wastewater are collected in the same sewer (a combined sewer). In dry-weather conditions, all flows are conveyed to and treated at a local or regional wastewater treatment plant. In wet-weather conditions, the capacity of the combined sewer system can be exceeded and discharges of mixed sanitary and stormwater then occur to receiving waters. The fraction of sanitary sewage in discharges varies from storm to storm, but is typically on the order of 10% over the long term, while the remaining 90% is untreated stormwater. For constituents where sanitary sewage and untreated stormwater concentrations are the same order of magnitude (e.g., TSS, nutrients), concentrations in CSO are similar or slightly higher compared to stormwater. For constituents where sanitary concentrations are typically lower (e.g., metals such as Pb, Cu, Zn), concentrations in CSO are slightly lower than in untreated stormwater. For bacteria and other pathogens, concentrations in CSO are an order of magnitude or higher than those found in stormwater.

Sanitary Sewer Overflows (SSOs). SSOs result in discharges of untreated wastewater that can affect stream quality and occasionally basements and city streets. The USEPA. has found that SSOs represent a significant health and environmental threat in areas where they occur frequently. Frequent SSOs may indicate that the capacity of the collection system is insufficient to convey the flows introduced or that the system is in need of maintenance or repair. Potential causes of excess flow include infiltration and inflow, illegal connections, population growth, and under-design. Problems requiring maintenance or repair may include broken or cracked pipes, tree roots, poor connections, and settling. Proper maintenance can help prevent problems or identify them before they become extremely costly to repair (USEPA, 2000).

Sanitary Sewer Overflows (SSOs) are a known source of bacterial and other pollution to the Darby and Cobbs Creeks watershed. Currently, no inventory of SSOs exists for the area within the four counties that contain the Darby and Cobbs Creeks Watershed. Since the data collection effort required to obtain SSO load information was beyond the scope of this screening-level study, SSO loads were not considered part of this study. An SSO assessment methodology will be implemented as part of the Phase II efforts.

Stormwater and Urban Drainage. Stormwater from areas with separate storm sewers contributes to water body impairment in highly urbanized, impervious catchments. Pollutants most frequently associated with stormwater include sediment, nutrients, bacteria, oxygen demanding substances, oil and grease, heavy metals, other toxic chemicals, and floatables. The primary sources of these pollutants include automobiles, roadways (pavement, bridges), housekeeping and landscaping practices, industrial activities, construction, non-storm connections to drainage systems, accidental spills and illegal dumping.

Septic Tanks. The number of septic tanks in Darby and Cobbs Creeks Watershed planning areas was estimated using 1990 Census data on population and housing. Comparison of water-only billed accounts with septic tank counts for the City of Philadelphia indicated a large discrepancy in the number of housing units with septic tanks. The 1990 census data estimated that 205 households were served by septic tanks in the Philadelphia portion of the watershed. However, a review of water-only accounts by the Water Department indicated that only 3 households within the City and the Cobbs watershed have septic tank or on-lot sewage disposal systems.

County agencies for Delaware, Montgomery, and Chester Counties were consulted about septic tank inventories/information in their areas. However, compilations of septic tank and on-lot sewer systems have not been completed to date. Detailed assessment of individual municipalities for septic tank and on-lot sewage disposal inventories and/or permits was beyond the scope of the current phase of this study.

Atmospheric Sources. Pollutants from atmospheric deposition on land surfaces are considered to be included in the calculations for the stormwater runoff. Direct deposition on water surfaces also is included in these calculations by the use of a water surface land use type. Specifically, precipitation falling on the water surface land use was assigned EMCs of nutrients and metals derived from rainfall data. For this study, the water surface EMCs were taken from the Chesapeake Bay Program literature (EPA, 1982).

Table 9.4 Active Point Sources Permitted Under NPDES

PA NPDES ID.	Site Name	Available Data
PA0056839	Sun Oil Company	Benzene, Total BTEX, Ethylbenzene, Toluene, Total Xylene, flow volume, and pH.
PA0011541	Sun Oil Company	Oil, Grease, Total Organic Carbon, flow volume, and pH.
PA0056685	SEPTA Victory Terminal	No water quality or flow data available.
PA0056642	Meenan Oil Company	Permitted discharge levels.
PA0052752	Mobil Oil Company	Benzene, Toluene, Xylene, and flow. Source removed in 1996.
PA0013323	Boeing Defense and Space Group	TDS, TSS, Oil and Grease, CN, Ag, Cd, Cr, Cu, Ni, Pb, Zn, and flow.
PA0028380	Tinicum Township Sewerage Authority	Settled solids, suspended solids, BOD, Chlorine residual, Fecal Coliform, pH and flow.
PA0057002	Township of Haverford Public Works	TSS, TDS, Mn, Mg, Color, Total Fe, Dissolved Fe, Barium, Specific Conductance, pH and flow.

9.2 Results: Estimated Annual Constituent Loads for the Cobbs Creek Subwatershed

Figures 9.4 through 9.12 show estimated loading rates for stormwater runoff and CSO. Table 9.5 breaks load estimates into two geographic regions, upper and lower Cobbs. The loads are estimates of the total input to the stream system. For example, the surface runoff listed for lower Cobbs (an area serviced partially by combined sewers) is relatively low because it does not include the volume that is captured, treated, and discharged outside the system. With some exceptions, higher pollutant loading rates are found in the lower Cobbs watershed, in and near the densely populated areas of Philadelphia. These results were obtained by using the SWMM model developed for Cobbs Creek. The specific components of the model that were utilized were the RUNOFF and EXTRAN modules.

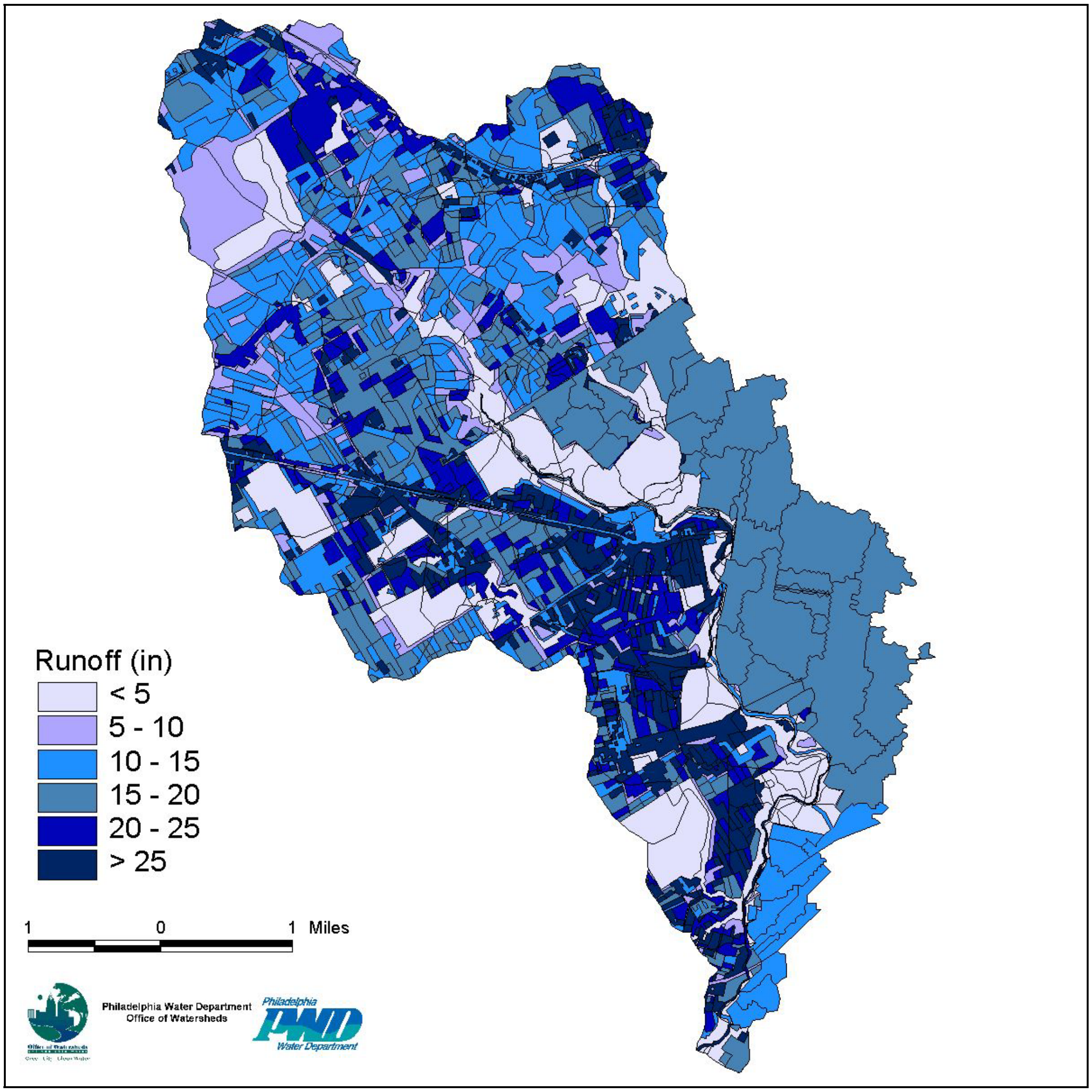


Figure 9.4 Estimated Annual Runoff for Cobbs Creek

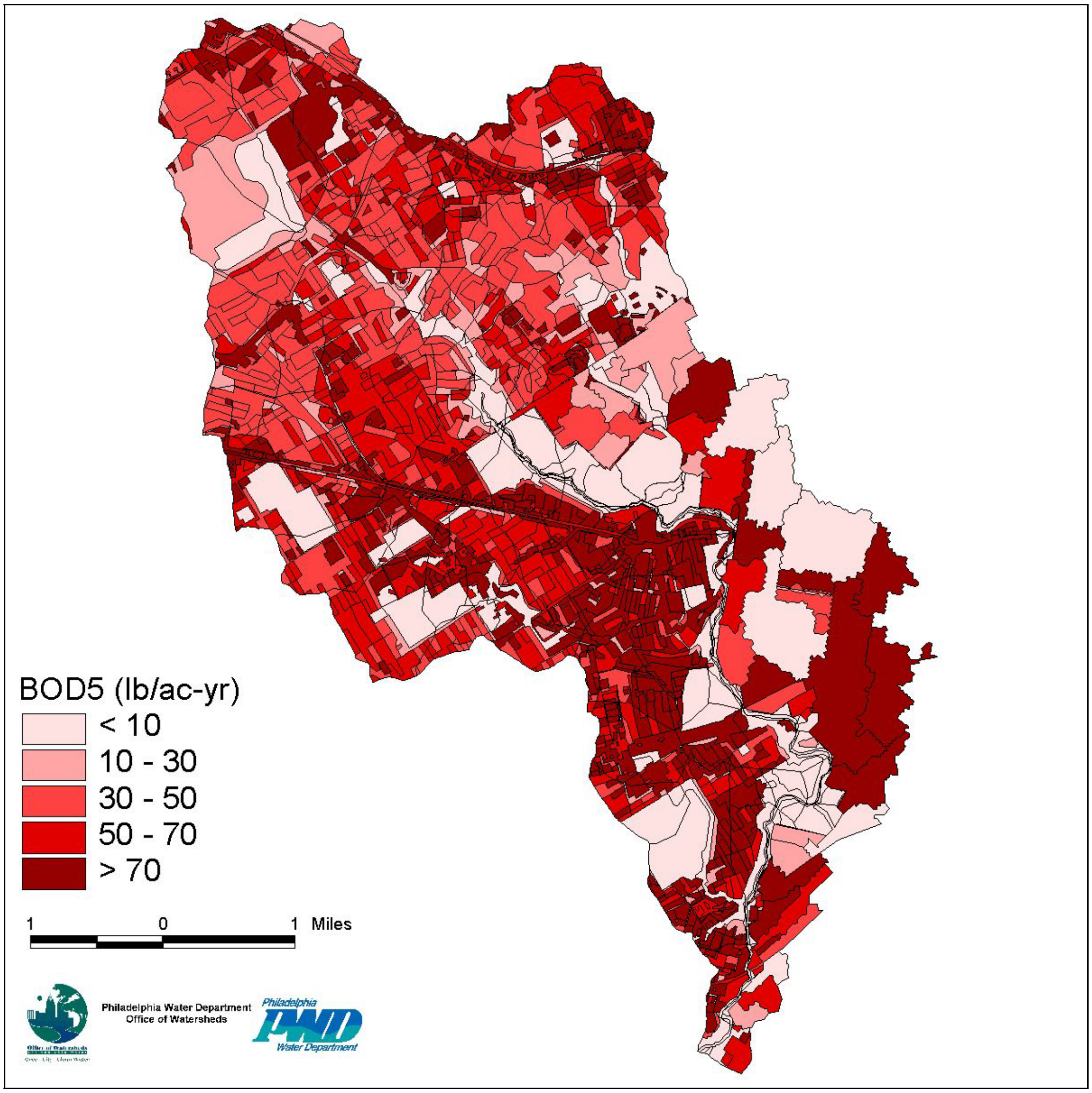


Figure 9.5 Estimated Annual Loading Rate for BOD for Cobbs Creek

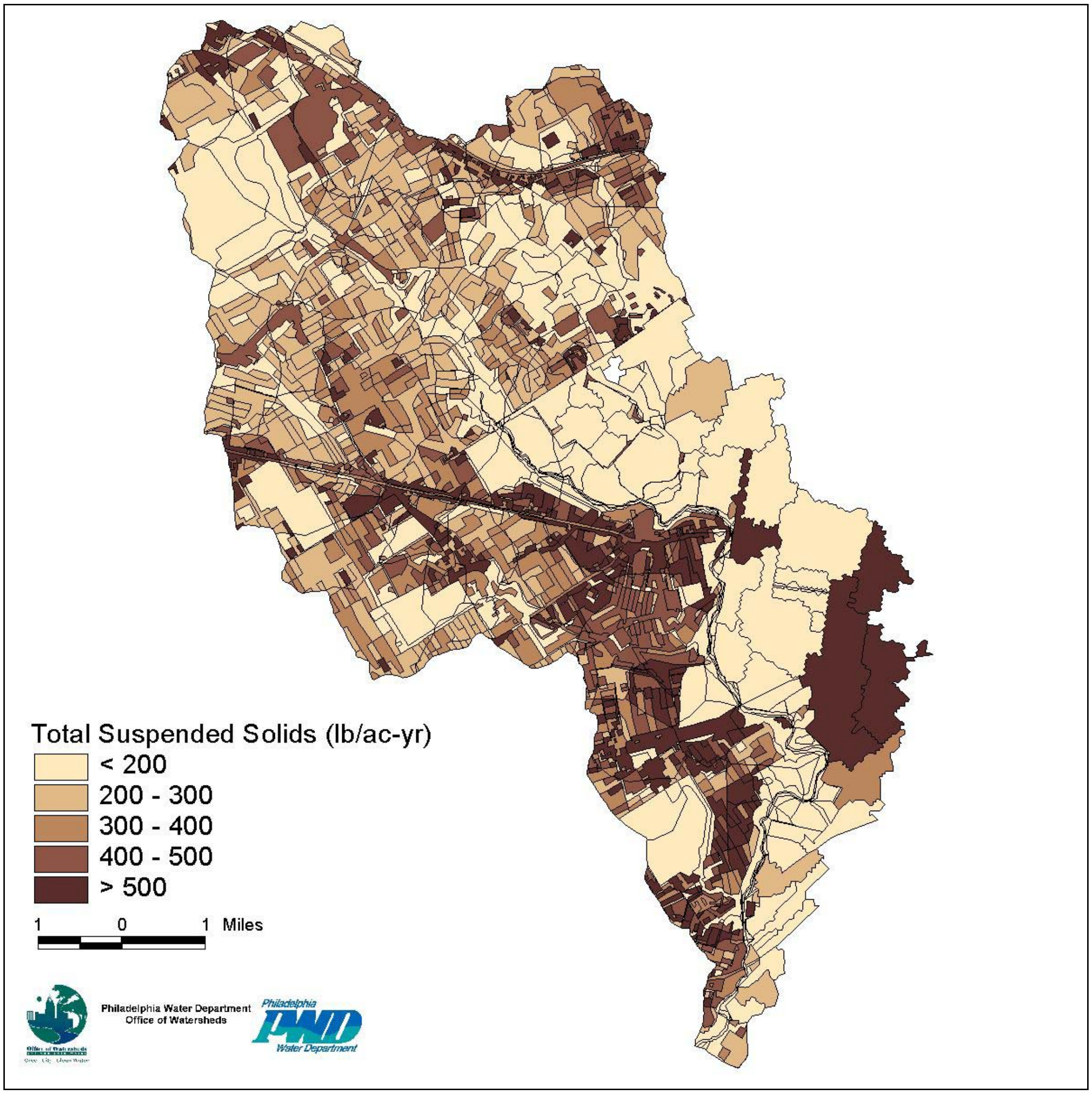


Figure 9.6 Estimated Annual Loading Rate for TSS for Cobbs Creek

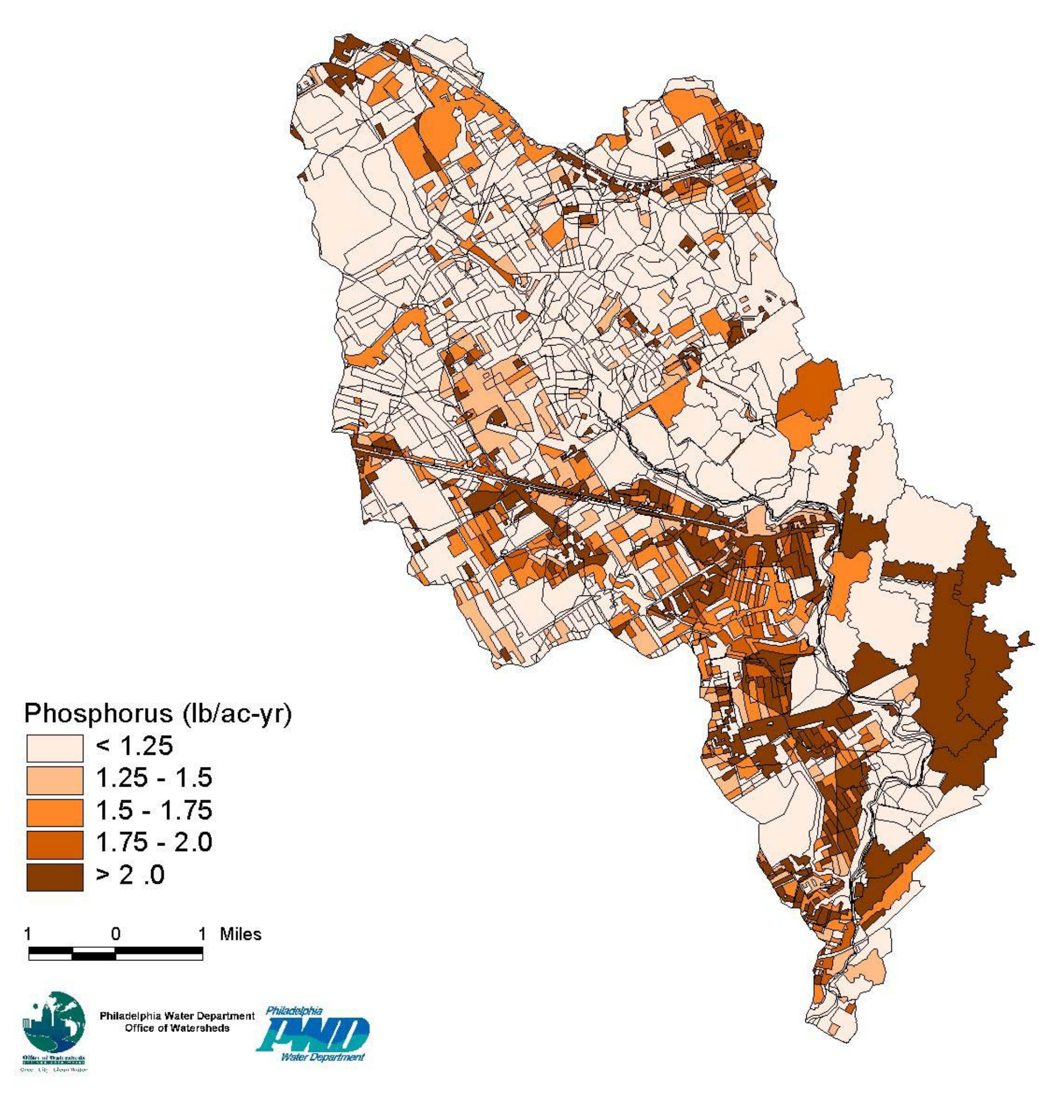


Figure 9.7 Estimated Annual Loading Rate for Total Phosphorous for Cobbs Creek

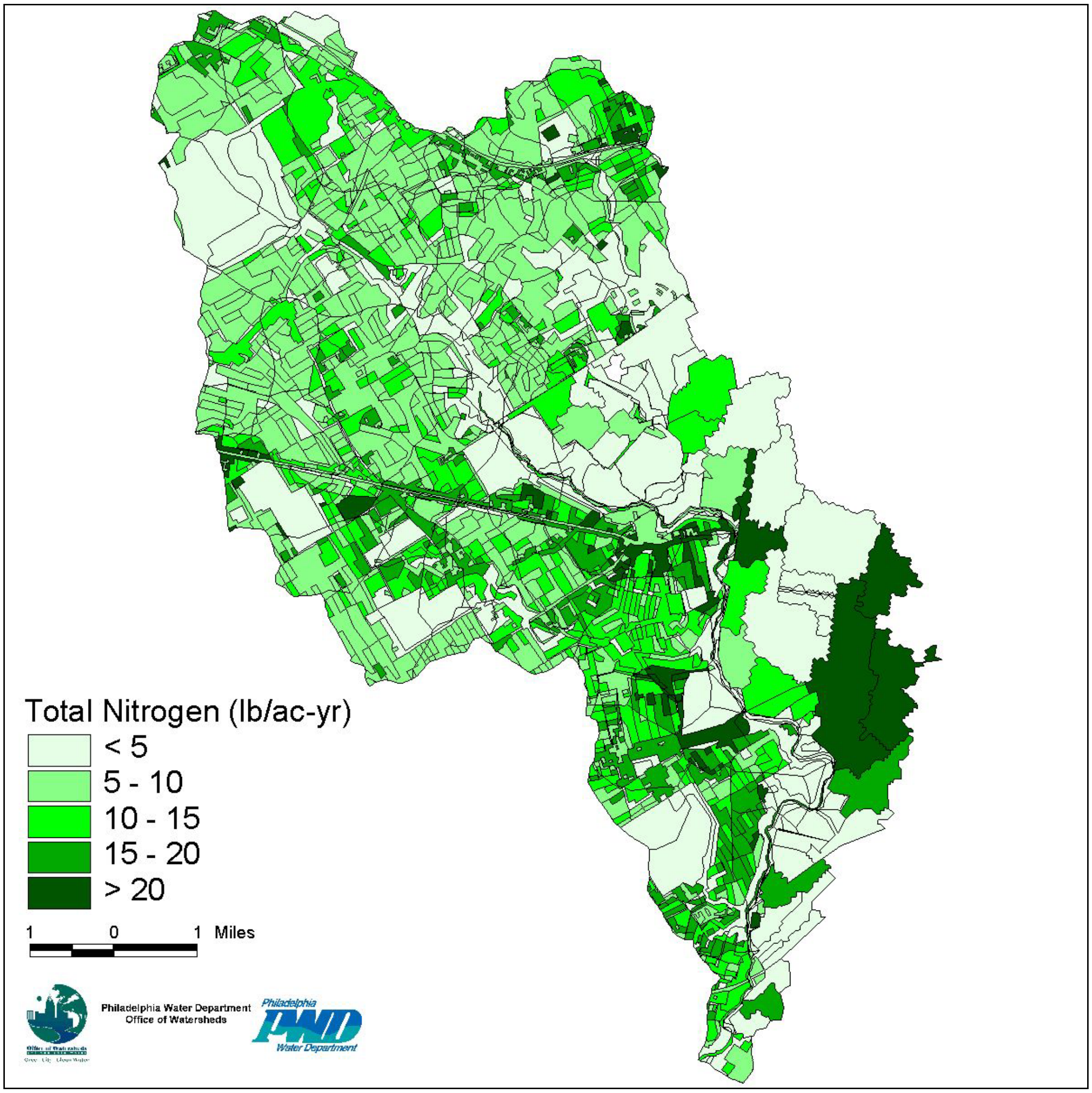


Figure 9.8 Estimated Annual Loading Rate for Total Nitrogen for Cobbs Creek

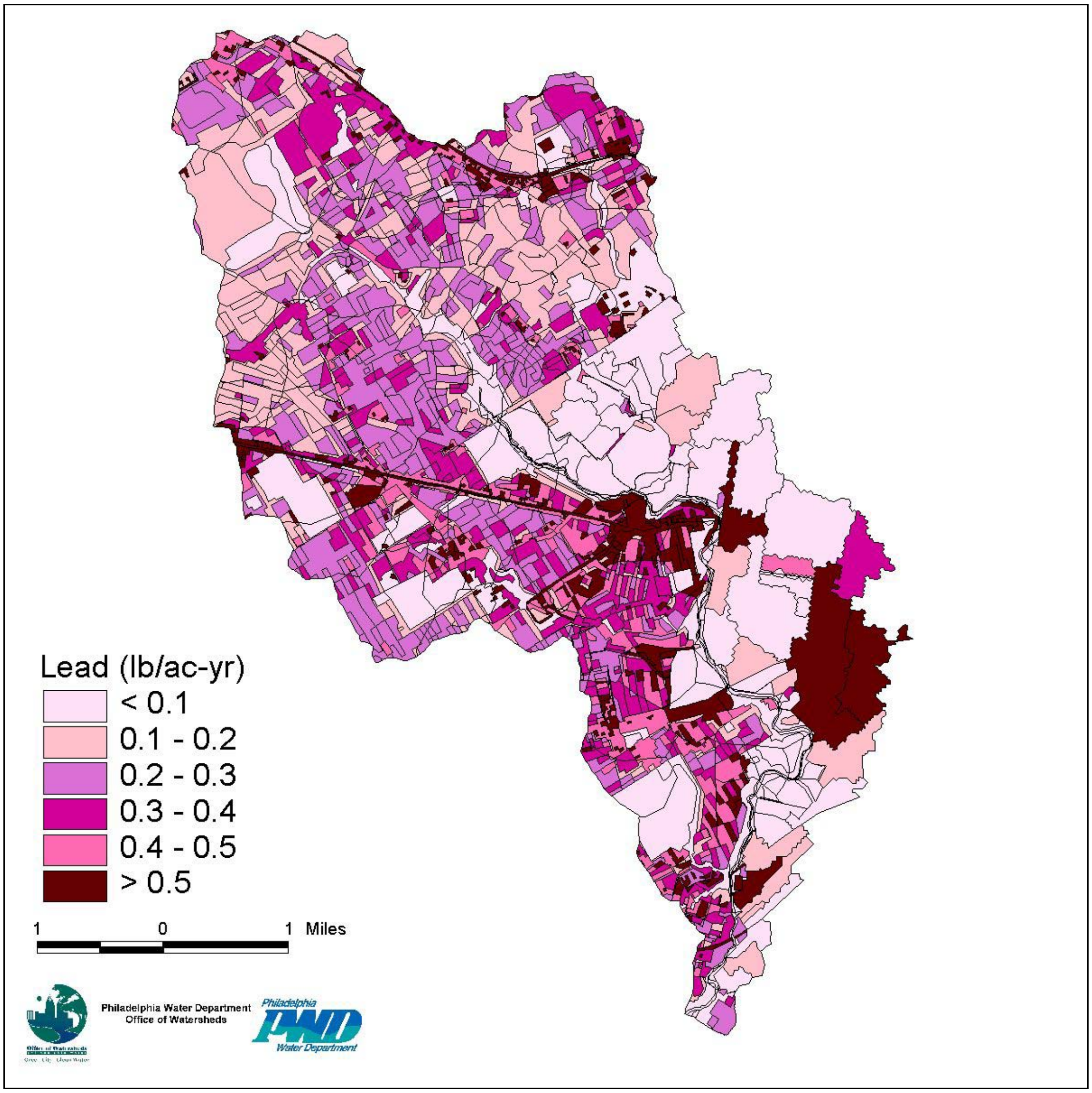


Figure 9.9 Estimated Annual Loading Rate for Lead for Cobbs Creek

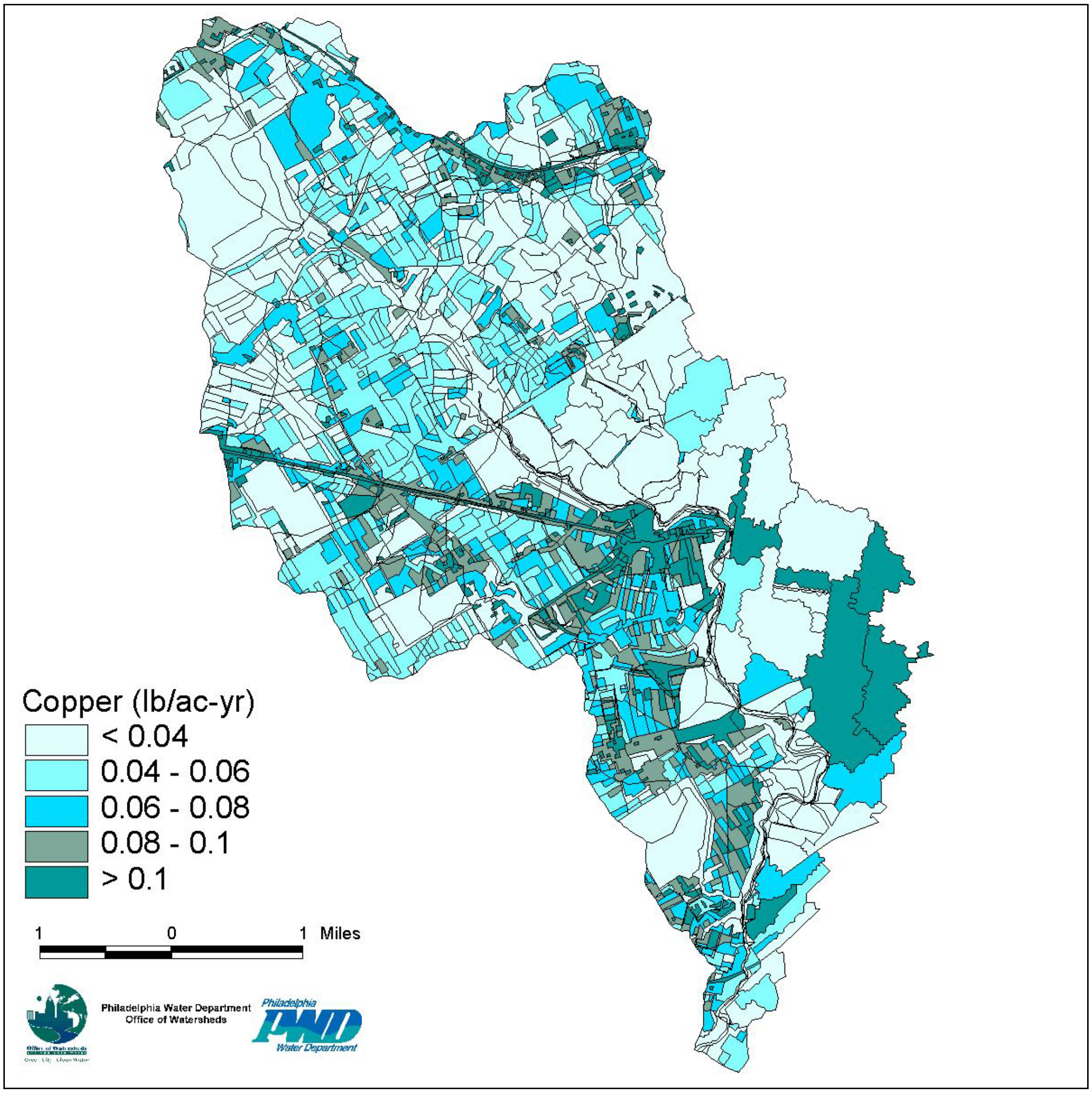


Figure 9.10 Estimated Annual Loading Rate for Copper for Cobbs Creek

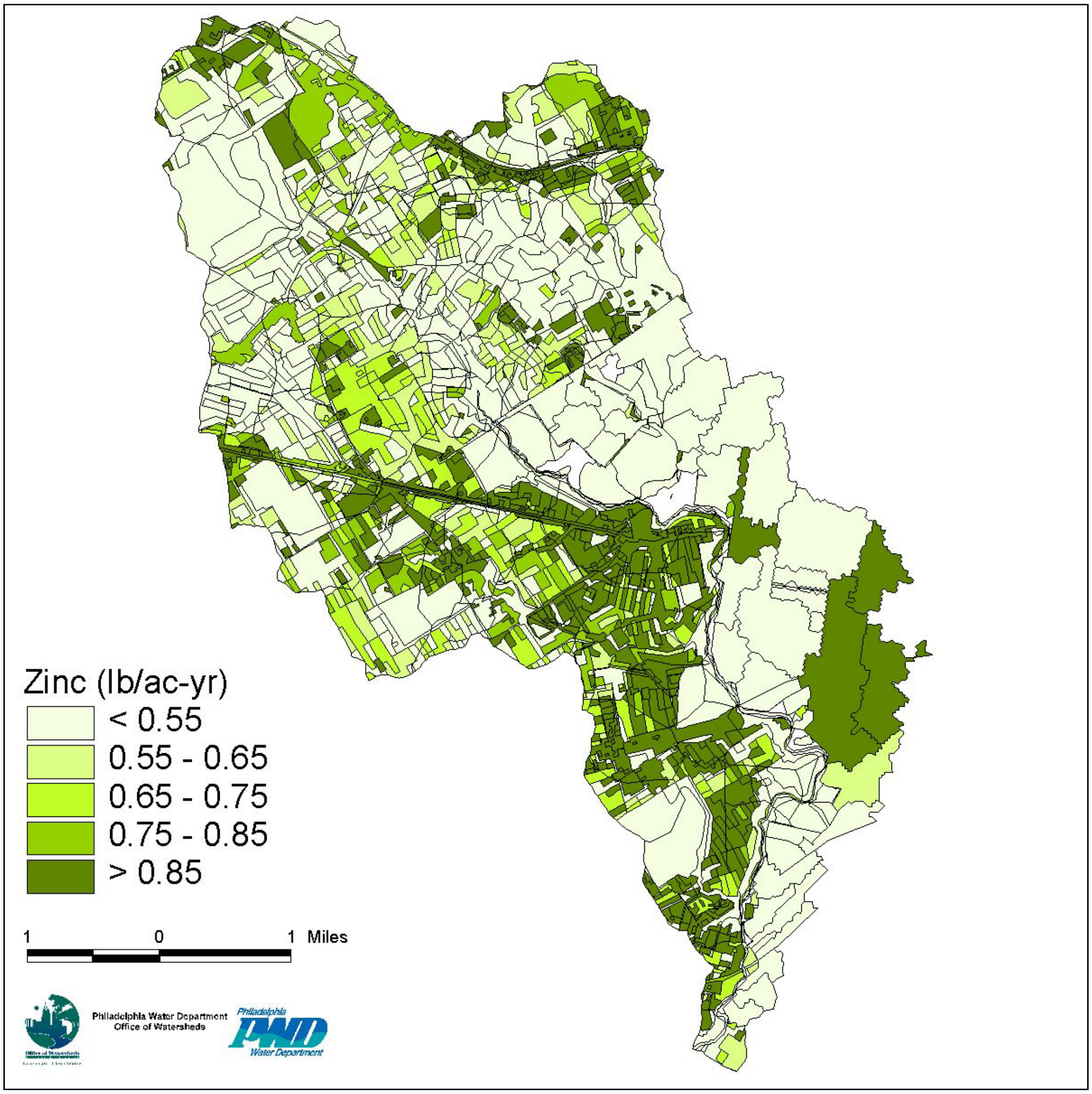


Figure 9.11 Estimated Annual Loading Rate for Zinc for Cobbs Creek

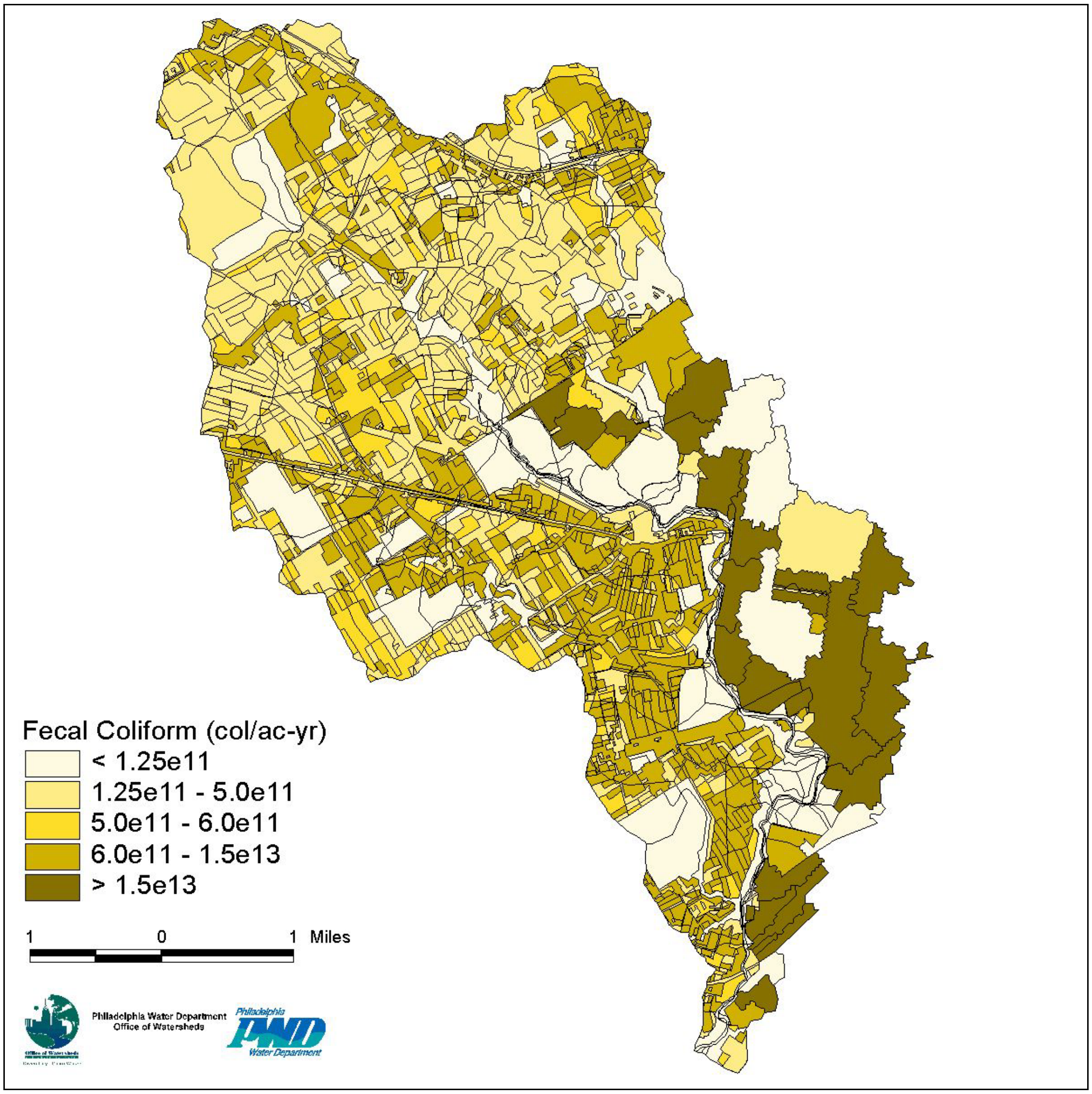


Figure 9.12 Annual Loading Rate for Fecal Coliform for Cobbs Creek

Table 9.5 Mean SWMM-Estimated Loads by Basins

Watershed	Area (ac)	Surface Runoff (in/yr)	Surface Runoff (MG)	BOD (ton/yr)	TSS (ton/yr)	Fecal (col/yr)	TN (ton/yr)	TP (ton/yr)	Cu (ton/yr)	Pb (ton/yr)	Zn (ton/yr)
Upper Cobbs	6,482	13.94	2046	145.5	813.2	2.76E+15	24.51	3.24	0.15	0.79	1.70
Lower Cobbs	4,202	17.93	2455	119.6	669.5	2.26E+15	20.30	2.67	0.12	0.68	1.41

9.2.2 Relative Contribution of Source Types

Figure 9.13 presents the approximate relative contribution each source (stormwater runoff from separate sanitary areas, baseflow, CSOs, industrial and municipal point sources, septic tanks, and atmospheric sources) contributes to the total potential load to the Delaware River from the Cobbs Creek watershed area. As expected in highly urbanized settings, runoff from separate sanitary areas is the dominant source of water pollution for most pollutant types except fecal coliform. Baseflow contributes a significant amount of total nitrogen. Separate sanitary overflows (SSOs) may be a significant source of pollutants, but information concerning these sources was insufficient to include in the current analysis. The results indicate that CSOs represent no more than 10% of the total load for any parameter except fecal coliform. The model indicates that over two-thirds of the fecal coliform introduced to the system is the result of CSOs; however, this portion may change when future work accounts for the contribution of SSOs. Industrial and municipal point sources are a relatively small source of pollutants. Septic tank loads are significant only for phosphorus and nitrogen. However, the reliability of the data available on septic tanks in the watershed is questionable. Atmospheric inputs, based on wetfall or concentrations within rainfall, are included in the EMCs for all land use types except for wetlands and open water. Atmospheric loads to wetlands and water were small (1% or less) but measurable.

Table 9.6 presents the average areal loads contributed by runoff from separate and combined sewer areas. Areal loads show the intensity of loading rather than total loads. The loads for all the parameters fall within the ranges shown on Figures 9.4 through 9.12. The areal loadings for most parameters are similar for the two sources, but the fecal coliform loads introduced by combined sewer areas are approximately 100 times greater per acre than those introduced by runoff from separate sewer areas. For comparison, the table includes loads for the other sources.

Sources of Uncertainty

Baseflow water quality information is based upon water quality sampling data obtained between 1999 and 2000. The data represents background conditions; if significant dry weather pollutant inputs are present, these will be reflected in the baseflow concentrations.

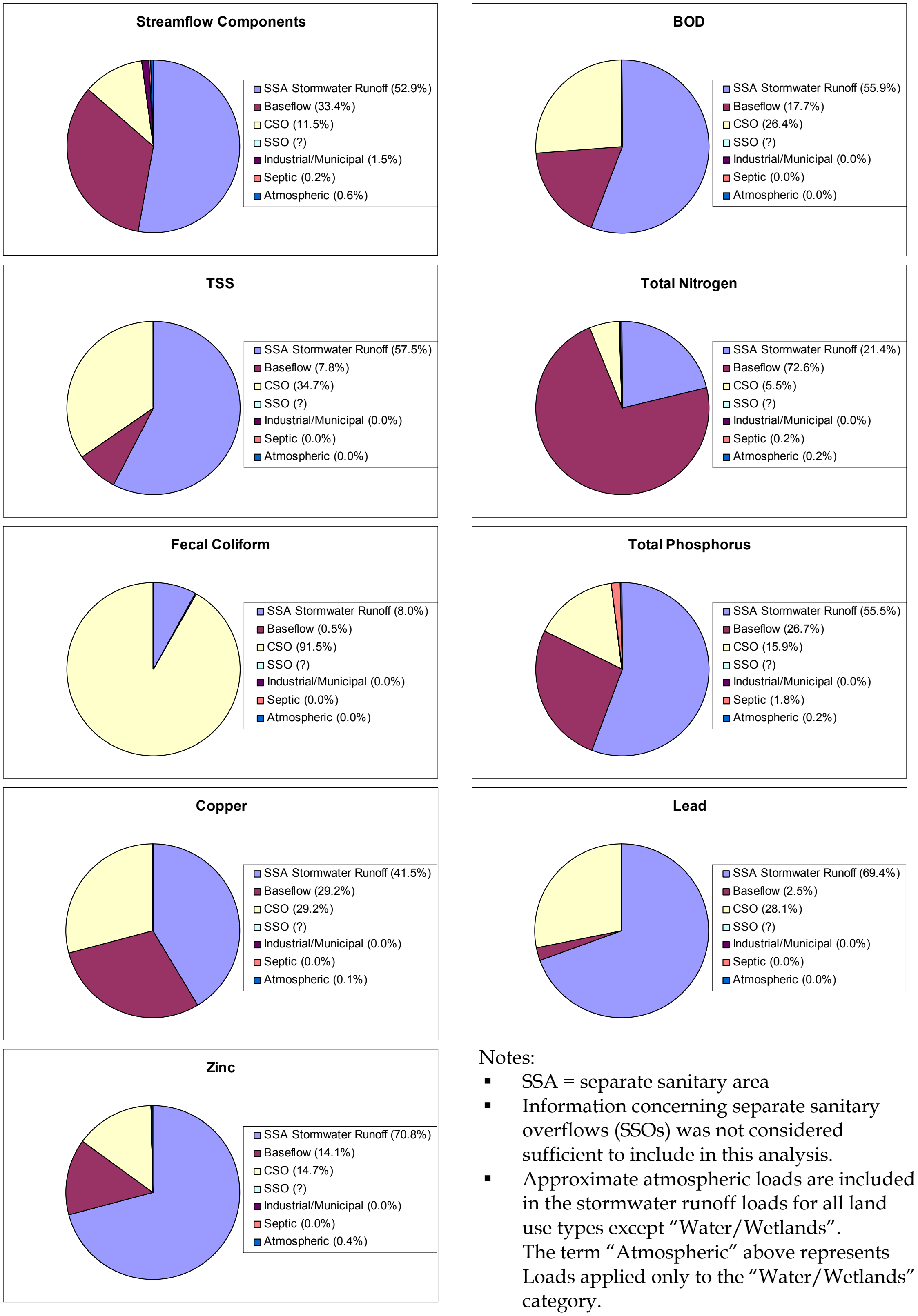
EMCs are based on literature values. The EMCs used for this study for urban land uses are from Smullen, Shallcross, and Cave (1999). These values represent a compilation of stormwater monitoring data from NURP, the USGS, and NPDES Phase I Municipal Stormwater Monitoring Requirements.

Sanitary sewer overflows (SSOs) are believed to be a significant potential source of bacterial and other pollution in the watershed. For the watershed study, estimates of SSO flows and pollutant loads were not calculated due to lack of readily available information on municipal sewer systems. Future studies may include a more thorough investigation of these sources.

Failures of septic tanks can contribute nutrient and bacterial loads to receiving waters. For this screening level study, the 1990 census data for on-lot septic systems was used to determine the number of septic systems in each drainage area. Although the census data indicated that over 200 septic systems were located within the Philadelphia portion of the Darby-Cobbs Creek watershed, water-only accounts indicated that three or fewer septic systems were located in this part of the watershed. Since extensive research into on-lot systems and Act 537 plans for Delaware and Chester Counties will be required, the 1990 census counts of septic systems were used for all portions of the Darby-Cobbs watershed study except Philadelphia.

Table 9.6 Cobbs Estimated Annual Areal Loads by Source (lb/ac except as noted)

Parameter	SSA Stormwater Runoff (lb/ac)	Baseflow	CSO	Industrial/ Municipal	Septic	Atmospheric
BOD	47.2	12.0	88	0	0	0
TSS	264	28.6	634	0	0	0
Fecal Coliform (col/ac)	4.47E+11	2.3E+10	2.04E+13	0	0	0
Total Nitrogen	8.00	21.7	8.22	0	0.072	0.062
Total Phosphorous	1.052	0.404	1.194	0	0.027	0.002
Copper	0.048	0.027	0.133	0	0	8.5E-05
Lead	0.262	0.007	0.421	0	0	1.0E-04
Zinc	0.555	0.088	0.456	0	0	2.5E-03



Notes:

- SSA = separate sanitary area
- Information concerning separate sanitary overflows (SSOs) was not considered sufficient to include in this analysis.
- Approximate atmospheric loads are included in the stormwater runoff loads for all land use types except “Water/Wetlands”. The term “Atmospheric” above represents Loads applied only to the “Water/Wetlands” category.

Figure 9.13 –Cobbs Estimated Annual Relative Contribution of Constituent Sources

9.2.3 Comparison of Load Estimates

Table 9.7 compares several loading rate estimates for Cobbs Creek. These estimates are based on historical water quality monitoring, 1999 water quality monitoring, and SWMM/WMM estimates. The loads from the monitoring data were calculated by applying wet weather and dry weather pollutant concentrations to USGS historical flow data. The resultant loads were averaged over the period of record to determine the average daily load.

Table 9.7 compares the loads of some conventional water quality parameters calculated from the results of the first 50 months of sampling of the PWD/USGS Cooperative Program "Effects of Non-Point Discharge on Urban Stream Quality," reported by Radzuil, with loads calculated based on wet and dry flow regimes. Loads for metals and suspended solids were not reported. The calculated loads were developed by assigning wet and dry flow regimes and wet and dry concentrations, then accumulating the load over the discharge record. The estimated historical downstream load can be compared with Radzuil's load for Cobbs Creek. The comparison suggests that the biochemical oxygen demand load increased for the duration of the cooperative program study. The phosphorus load may have been significantly reduced. Ammonia and nitrate loads were not calculated for the estimate. The loading rates estimated by SWMM/WMM are much larger than the instream mass load estimated from the current monitoring data. This difference is not a mistake but a result of the modeling philosophy:

- SWMM/WMM loads represent the total potential load to be delivered downstream and do not specifically account for the instream processes that reduce the total load.

- For the screening level study, the loads were used to estimate an overall delivery ratio for each pollutant, rather than estimate delivery ratios for various land uses by pollutant.

- The instream mass loads were based on limited, discrete, wet and dry weather monitoring data in addition to streamflow data from the 1970s.

- Loading is based on national EMCs which are measures of central tendency with significant variance. Local conditions may not be reflected by the national EMCs.

9.2.4 Delivery Ratios

The delivery ratio represents the fraction of the original pollutant load remaining after a particular pollutant travels downstream and is affected by instream processes. Data available in the literature indicate that the delivery ratio varies with drainage-area size. Some representative values calculated by the USDA for sediment are:

Drainage Area (sq. miles)	Delivery Ratio
0.5	0.33
10	0.18
100	0.10

However, the delivery ratios may vary substantially for any given size of drainage area. Other important factors affecting pollutant delivery include soil texture, relief (slope), types of erosion, sediment transport system, and deposition areas. For instance, a watershed with fine soil texture, high channel density, and high stream gradients would generally have a higher than average delivery ratio for watersheds of similar drainage area. Also, edge-of-field delivery ratios can approach 1.0 while delivery ratios for larger study areas can be less than 0.05. Instream processes also affect the delivery ratio. Such processes include deposition, sediment and water column diagenesis, remineralization, and volatilization. These processes are discussed in the next section.

Table 9.7 presents the calculated delivery ratios for two sites along Cobbs Creek (DC10 and DC06). Although delivery ratios might be expected to decrease with distance downstream, the Cobbs Creek data do not display such behavior. The delivery ratio for most pollutants increases from the upstream to the downstream cross-sections; the delivery ratios for total suspended solids, fecal coliform, and lead stay about the same. This trend may be largely explained by greater urbanization in the downstream reaches of Cobbs Creek; much of the loading occurs downstream where less time and distance are available for degradation processes to take place.

Table 9.7 Comparisons of Load Estimates for Cobbs Creek

	Historic Data		1999 Monitoring Data		1999 vs. Historical		Radzuil Loads	SWMM Estimate		Calculated Delivery Ratio	
	Upstr.	Downstr.	Upstr.	Downstr.	Upstr.	Downstr.	Downstream	Upstr.	Downstr.	Upstr.	Downstr.
Drainage Area (sq. mi)	4.5	22	4.5	22							
Arithmetic Mean Discharge (cfs)	7.3	30.4	7.3	30.4							
BOD$_5$ (lb/day)	412	1240	84.2	478	20%	39%	1280	797	1,717	11%	28%
TSS (lb/day)	8490	40,200	450	922	5%	2%		4,456	6,430	10%	14%
Total N (lb/day)			115	374				134	287.90	86%	130%
NH$_3$ (lb/day)	9.49	225	4.87	31.2	51%	14%	356				
NO$_2$ (lb/day)	7.71	136	0.73	8.15	9%	6%	16.1				
NO$_3$ (lb/day)	0.98	15.3	81.3	202	8290%	1320%	337				
Total P (lb/day)	295	1190	2.5	17.6	1%	2%	514	17.7	40.0	14%	44%
Fecal Coliform (col/day)	5.59E+08	1.55E+09	2.53E+11	4.83E+12	45300%	311000%		7.57E+12	4.55E+13	3%	11%
Cu (lb/day)	0.9	2.37	0.21	1.01	24%	43%		0.8	1.45	26%	69%
Cd (lb/day)	0.034	0.4	0.039	0.16	116%	41%					
Cr (lb/day)	29.3	30.3	0.36	1.48	1%	5%					
Fe (lb/day)	16	103	13.1	82.8	82%	80%					
Pb (lb/day)	4.22	4.74	0.098	0.63	2%	13%		4.4	5.7	2%	11%
Zn (lb/day)	2.35	12.1	0.49	2.34	21%	19%		9.3	13.6	5%	9%

Note: "Upstream" corresponds to station 12 for the historical and Radzuil data, station DC10 for the 1999 monitoring data and USGS station 01475530 (Cobbs Creek near Philadelphia). "Downstream" corresponds to station 15 for the Historical and Radzuil data, station DC06 for the 1999 monitoring data, and USGS station 01475550 (Cobbs Creek at Darby).

9.3 Results: Estimated Annual Constituent Loads for the Darby Creek and Tinicum Subwatersheds

Figures 9.14 through 9.22 show estimated loading rates for stormwater runoff and CSO. Table 9.8 presents the estimates summarized by watershed. The loads are estimates of the total input to the stream system. Higher pollutant loading rates are found in the lower Darby and Tinicum subwatersheds, in and near the densely populated areas of Philadelphia. Lower loading rates occur in the upper Darby watershed, where there is more open space and less densely populated residential areas. Pollutant loadings, population density, and runoff all follow the same general trends. WMM was used to develop screening-level loads for the Darby and Tinicum portions of the Darby-Cobbs watershed.

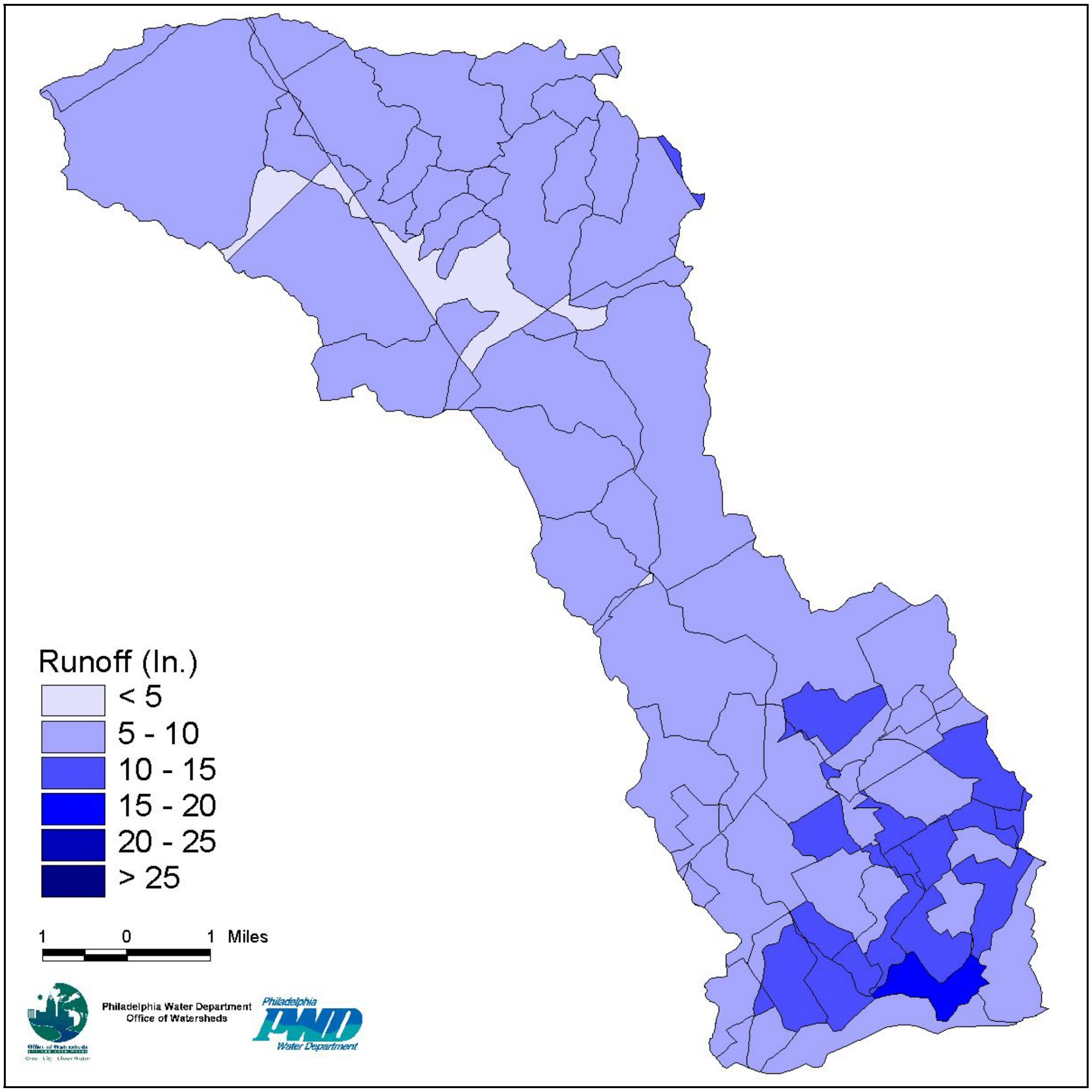


Figure 9.14 Estimated Annual Runoff Rate for Darby Creek and Tinicum

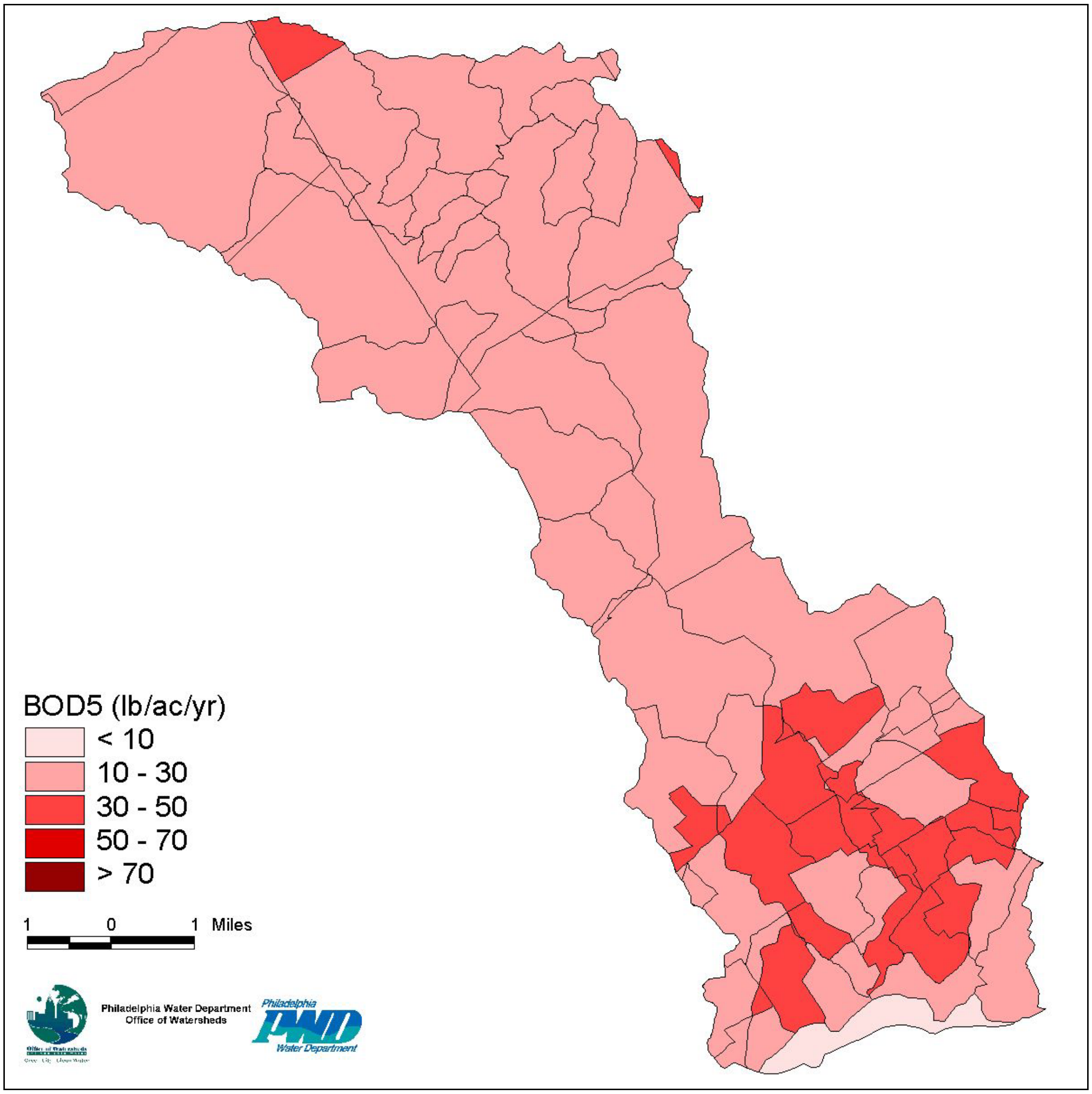


Figure 9.15 Estimated Annual Loading Rate for BOD for Darby Creek and Tinicum

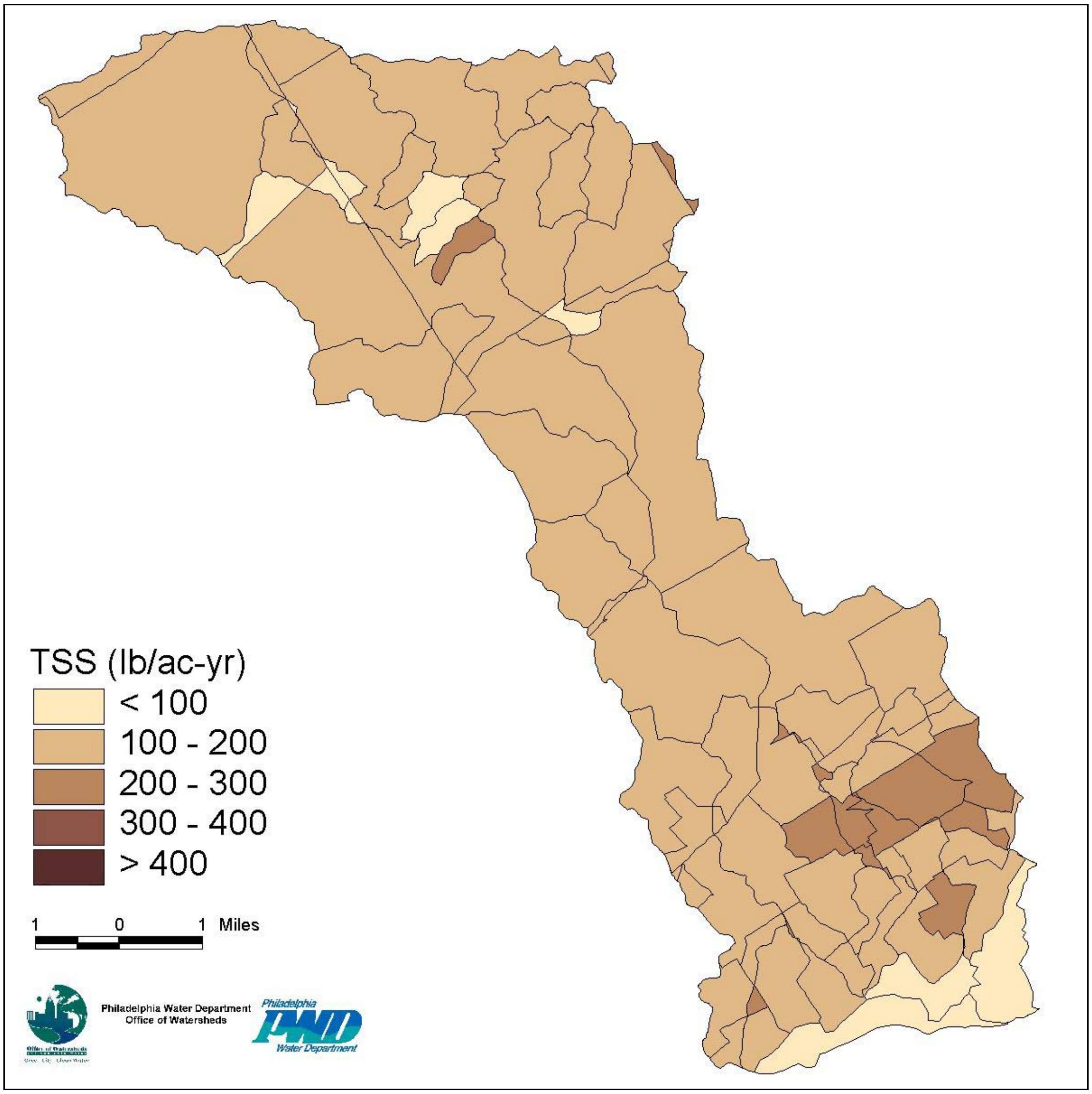


Figure 9.16 Estimated Annual Loading Rate for TSS for Darby Creek and Tinicum

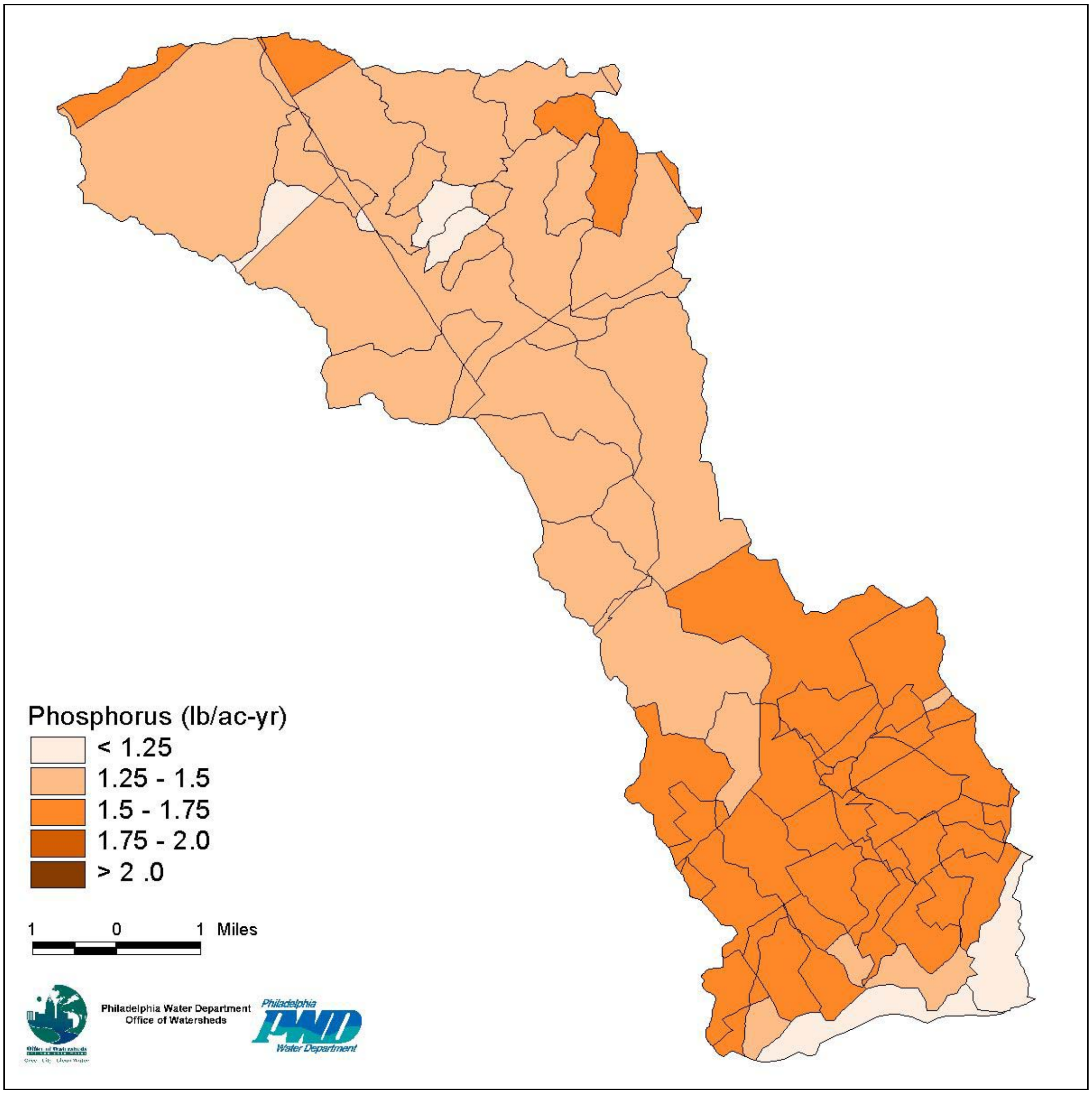


Figure 9.17 Estimated Annual Loading Rate for Total Phosphorous for Darby Creek and Tinicum

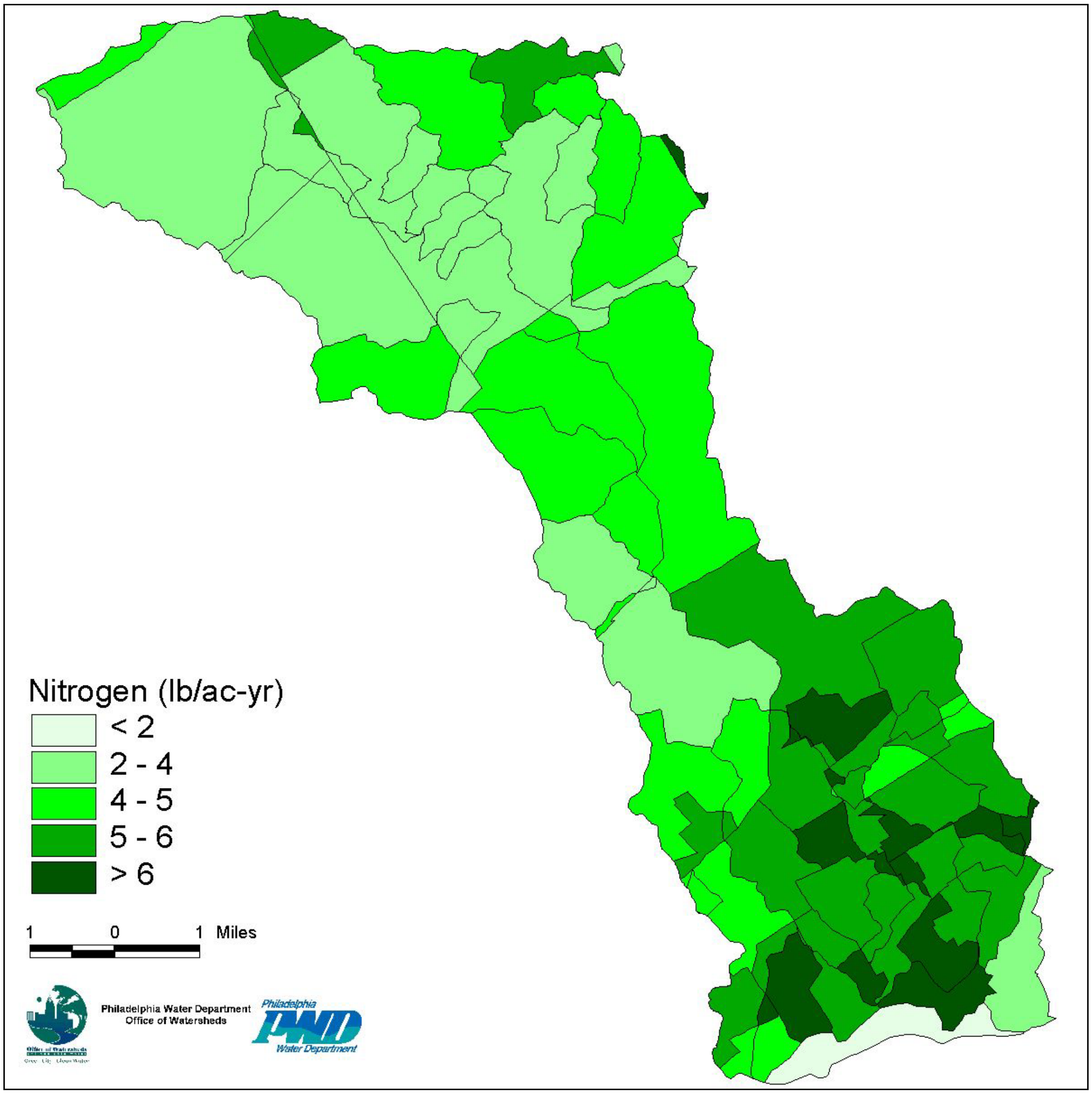


Figure 9.18 Estimated Annual Loading Rate for Total Nitrogen for Darby Creek and Tinicum

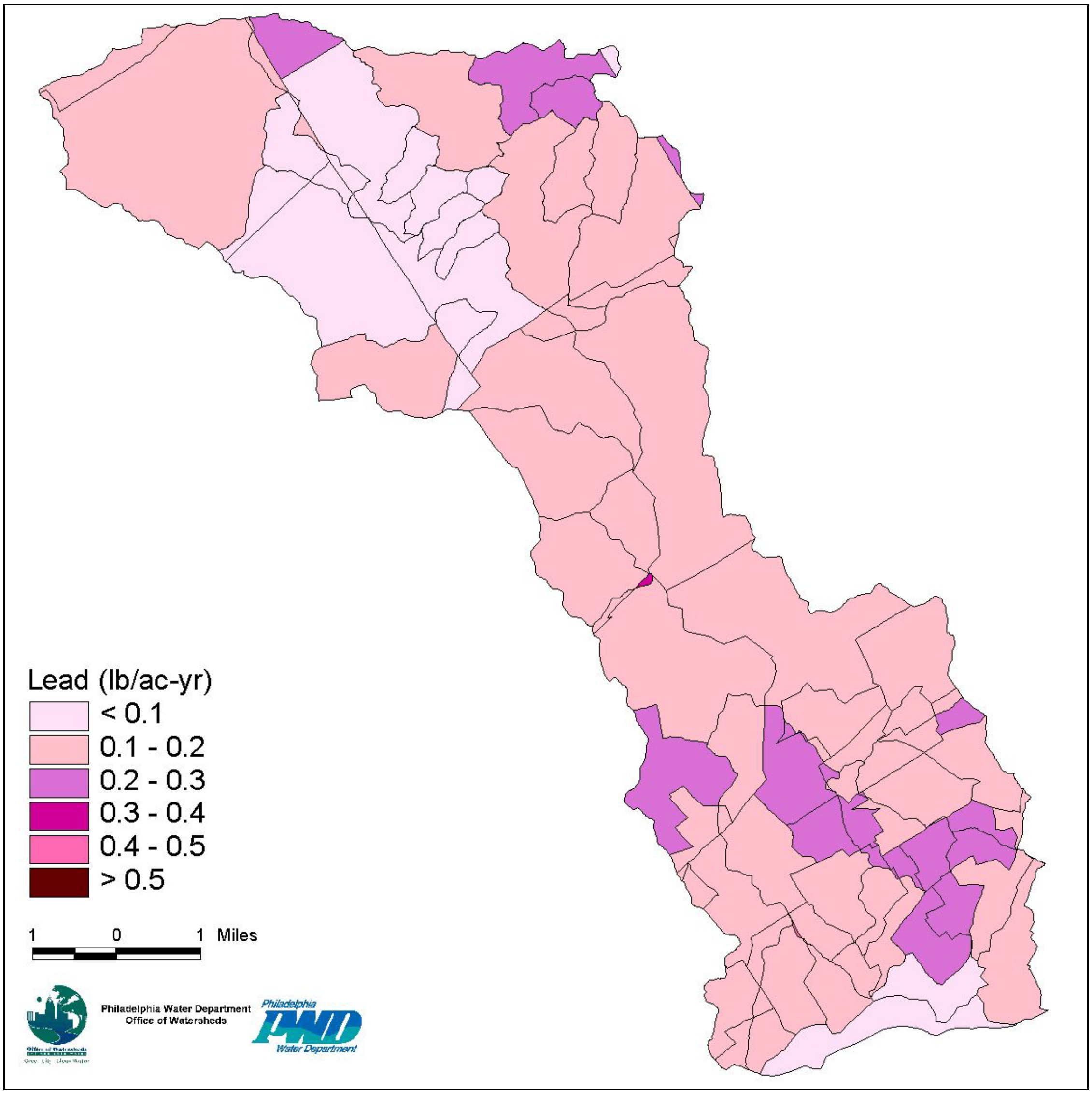


Figure 9.19 Estimated Annual Loading Rate for Lead for Darby Creek and Tinicum

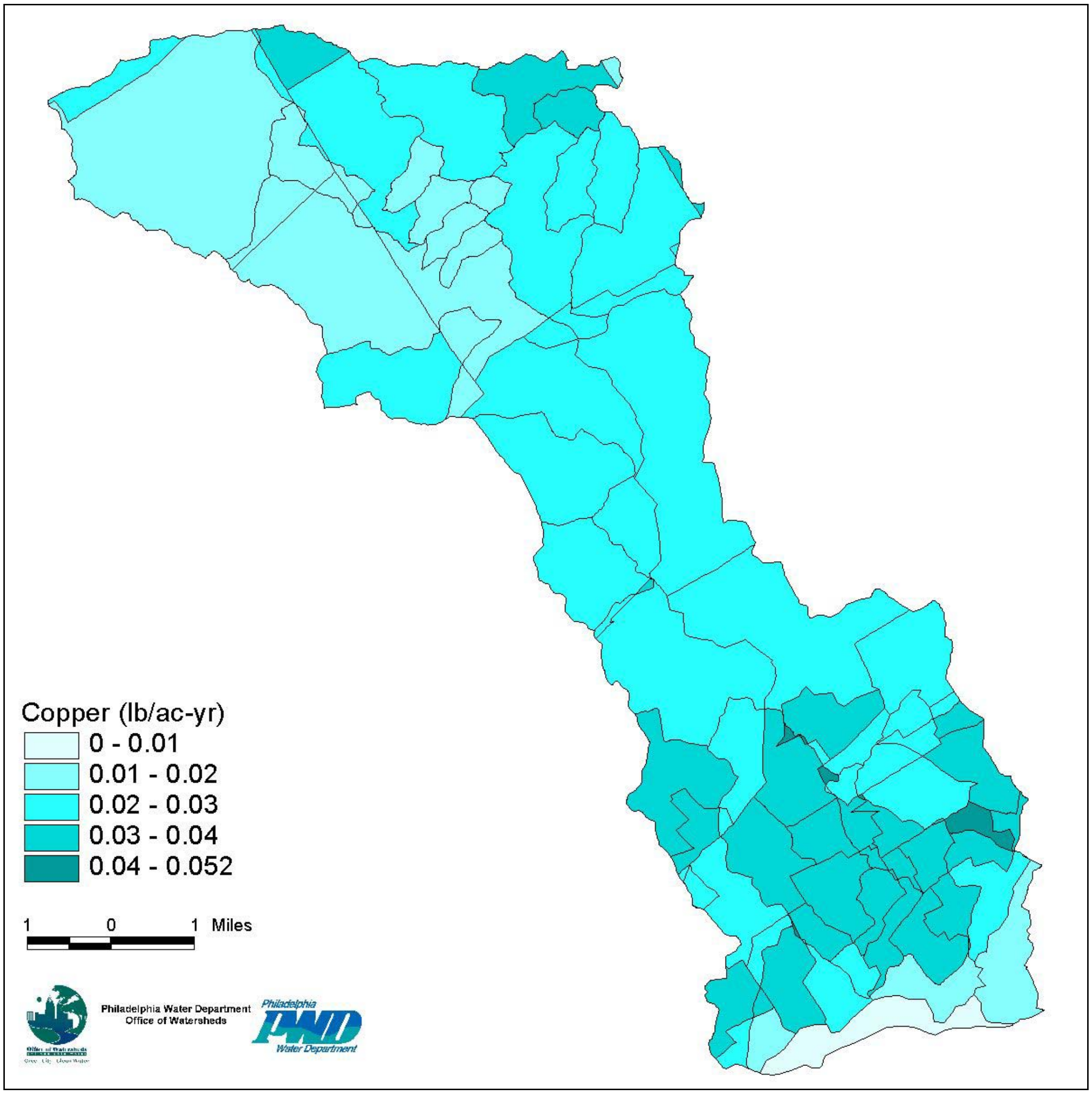


Figure 9.20 Estimated Annual Loading Rate for Copper for Darby Creek and Tinicum

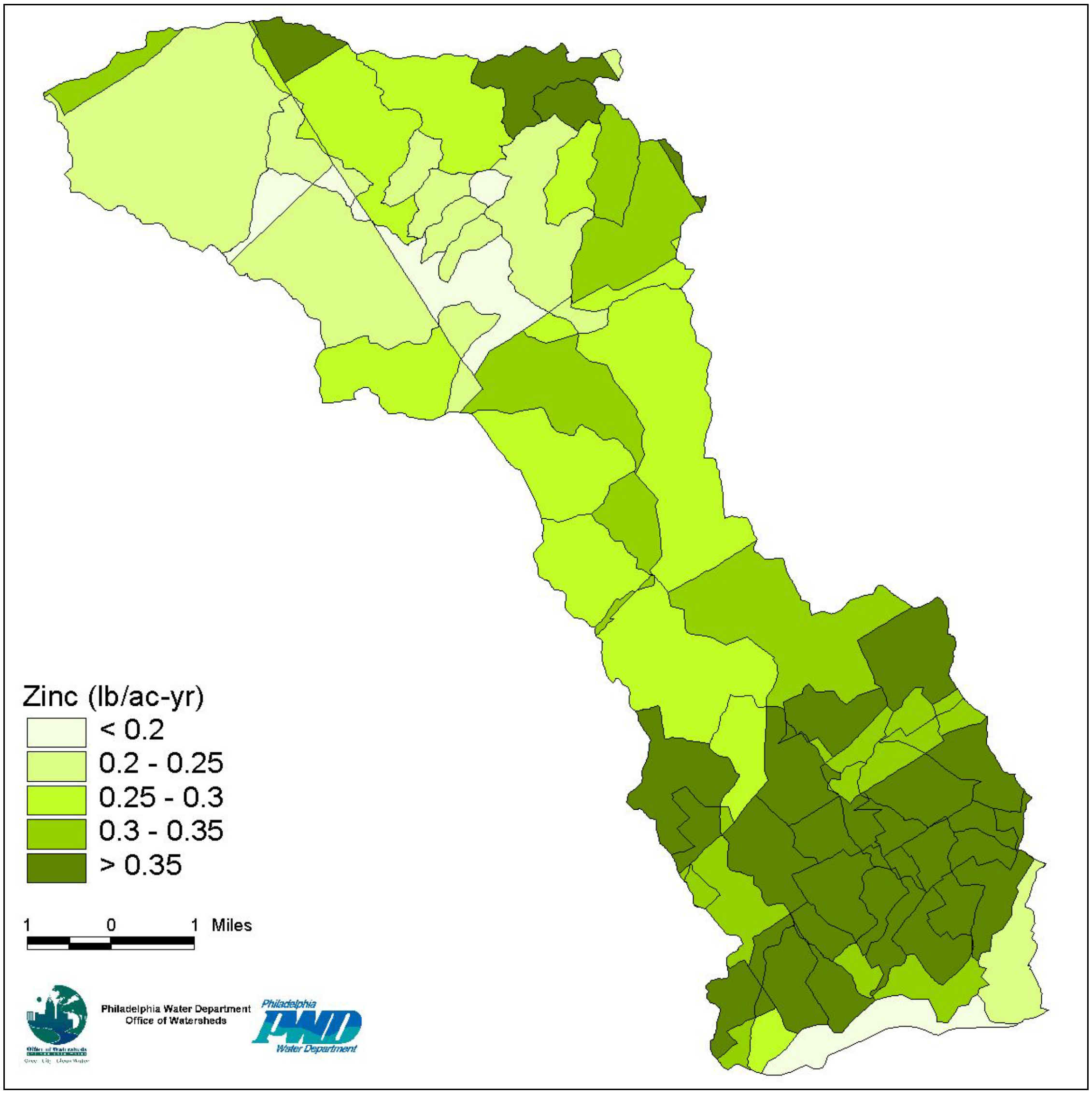


Figure 9.21 Estimated Annual Loading Rate for Zinc for Darby Creek and Tinicum

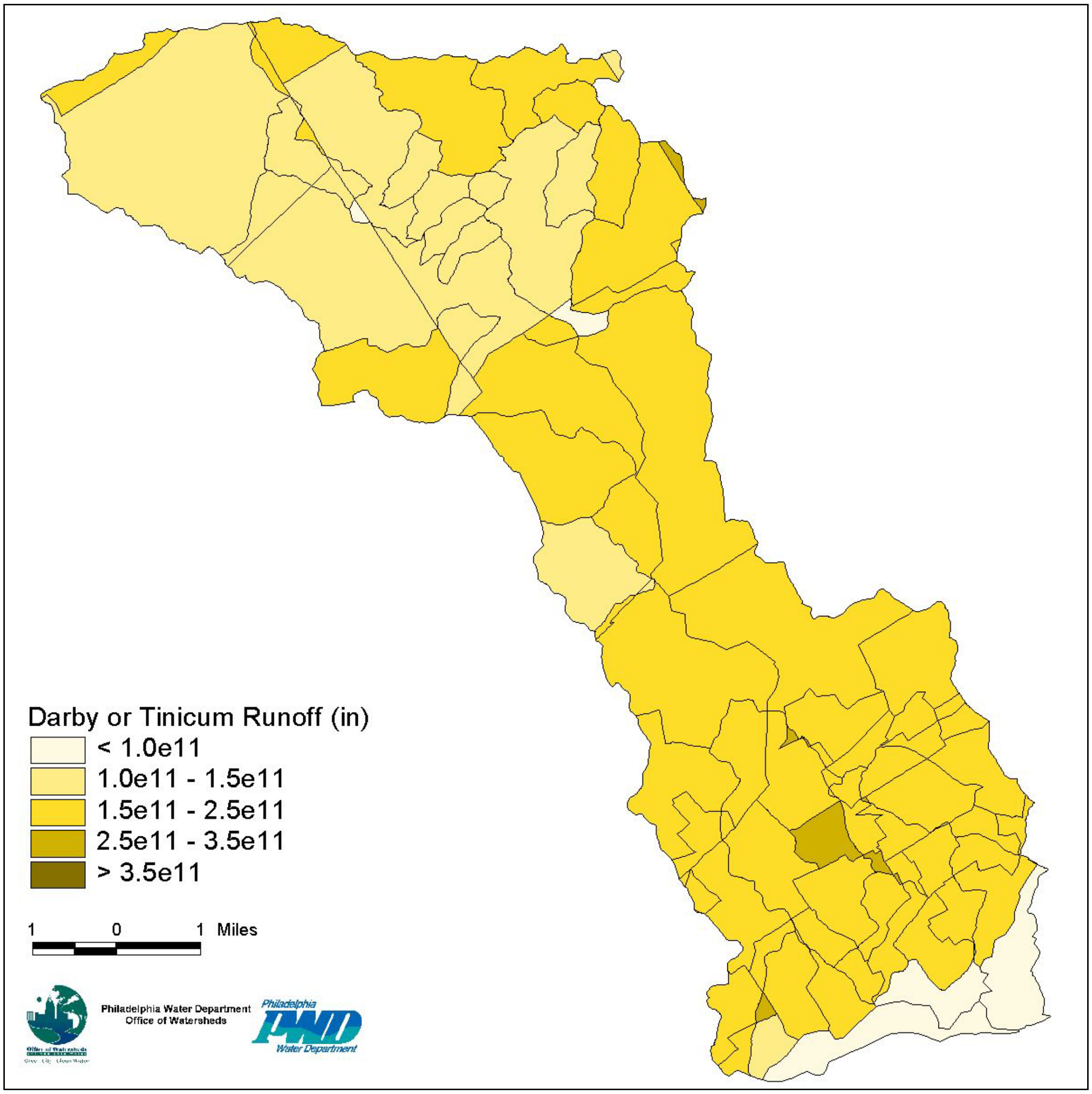


Figure 9.22 Annual Loading Rate for Fecal Coliform for Darby Creek and Tinicum

Table 9.8 Mean WMM-Estimated Loads by Basins

Watershed	Area (ac)	Surface Runoff (in)	Surface Runoff (MG)	BOD (ton/yr)	TSS (ton/yr)	Fecal (col/yr)	TN (ton/yr)	TP (ton/yr)	Cu (ton/yr)	Pb (ton/yr)	Zn (ton/yr)
Upper Darby	14,051	6.71	2,561	147.9	902	2.08E+15		3.28	0.15	0.82	1.81
Lower Darby	11,305	8.23	2,528	147	901	2.04E+15	26.1	3.38	0.15	0.85	1.76
Tinicum	5,811	9.76	1,540	86.4	512	1.21E+15	15.8	1.98	0.09	0.54	1.07

9.3.2 Relative Contribution of Source Types

Figures 9.23 and 9.24 present the approximate relative contribution each source (stormwater runoff from separate sanitary areas, baseflow, CSOs, industrial and municipal point sources, septic tanks, and atmospheric sources) contributes to the total potential load to the Delaware River from the Darby and Tinicum subwatershed areas. As expected in highly urbanized settings, runoff from separate sanitary areas is the dominant source of water pollution for most pollutant types. Baseflow contributes a significant amount of total nitrogen. Separate sanitary overflows (SSOs) may be a significant source of pollutants, but information concerning these sources was insufficient to include in the current analysis. There are no combined sewer systems in the Darby and Tinicum subwatersheds. Industrial and municipal point sources are a relatively small source of pollutants. Septic tank loads are significant only for phosphorus and nitrogen. However, the reliability of the data available on septic tanks in the watershed is questionable. Atmospheric loads were not considered in the Darby and Tinicum subwatersheds.

Tables 9.9 and 9.10 present the average areal loads contributed by runoff from separate sewer areas (there are no CSOs). Areal loads show the intensity of loading rather than total loads. The loads for all the parameters fall within the ranges shown on Figures 9.14 through 9.22. For comparison, the table includes loads for the other sources.

Sources of Uncertainty

Baseflow water quality information is based upon water quality sampling data obtained between 1999 and 2000. The data represent background conditions; if significant dry weather pollutant inputs are present, these will be reflected in the baseflow concentrations.

EMCs are based on literature values. The EMCs used for this study for urban land uses are from Smullen, Shallcross, and Cave (1999). These values represent a compilation of stormwater monitoring data from NURP, the USGS, and NPDES Phase I Municipal Stormwater Monitoring Requirements.

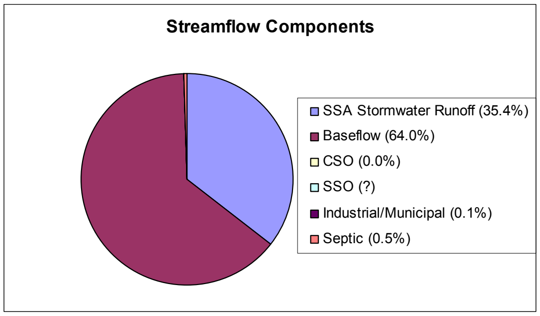
Separate Sanitary Overflows (SSOs) are believed to be a significant potential source of bacterial and other pollution in the watershed. For the watershed study, estimates of SSO flows and pollutant loads were not calculated due to lack of readily available information on municipal sewer systems. Future studies may include a more thorough investigation of these sources.

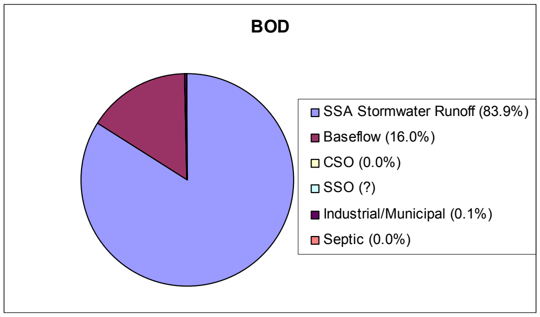
Failures of septic tanks can contribute nutrient and bacterial loads to receiving waters. For this screening level study, the 1990 census data for on-lot septic systems was used to determine the number of septic systems in each drainage area. Although the census data indicated that over 200 septic systems were located within the Philadelphia portion of the Darby-Cobbs Creek Watershed, water-only accounts indicated that three or fewer septic systems were located in this part of the watershed. Since extensive research into on-lot systems and Act 537 plans for Delaware and

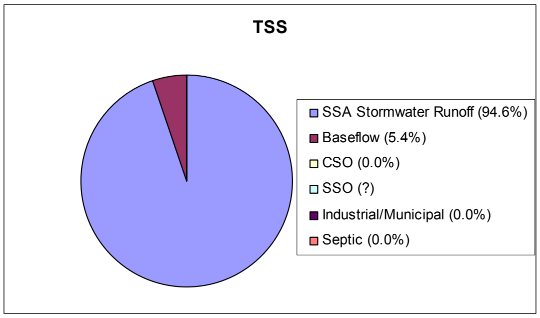
Chester Counties will be required, the 1990 census counts of septic systems were used for all portions of the Darby-Cobbs watershed study except Philadelphia.

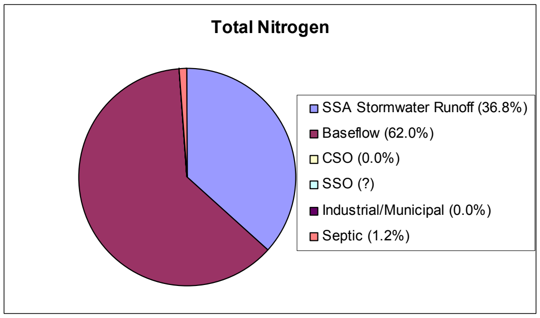
Table 9.9 Darby Estimated Annual Areal Loads by Source (lb/ac except as noted)

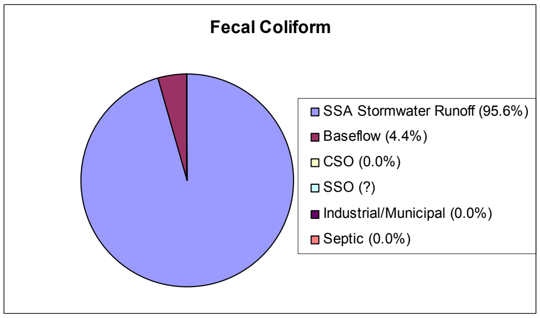
Parameter	SSA Stormwater Runoff (lb/ac)	Baseflow	CSO	Industrial/ Municipal	Septic
BOD	54.6	8.32	0	0.073	0
TSS	333	15.1	0	0.035	0
Fecal Coliform (col/ac)	3.8E+11	1.4E+10	0	0	0
Total Nitrogen	10.2	13.7	0	0.005	0.264
Total Phosphorous	1.25	0.251	0	0	0.099
Copper	0.058	0.014	0	0	0
Lead	0.319	0.004	0	0	0
Zinc	0.684	0.054	0	0.0002	0

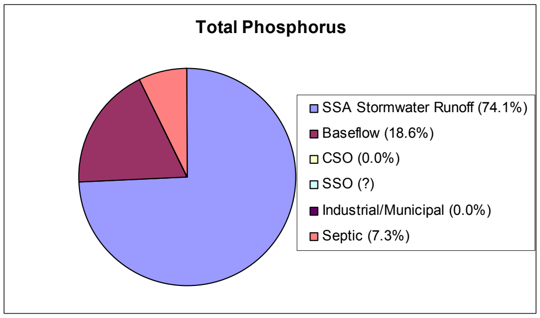

Streamflow Components

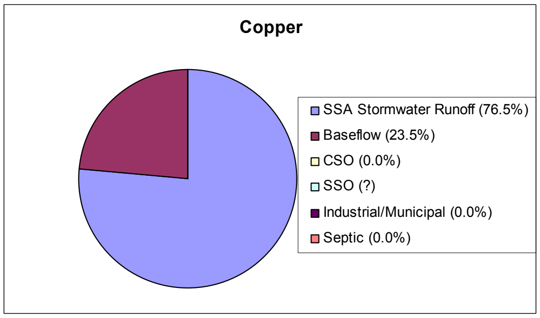

BOD

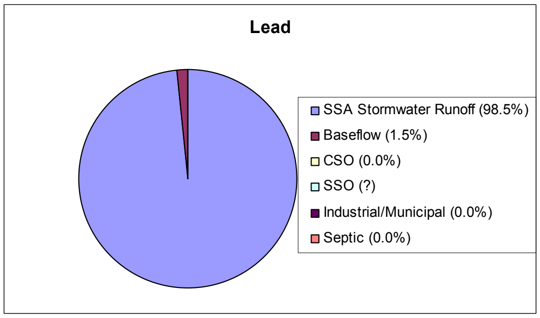

TSS

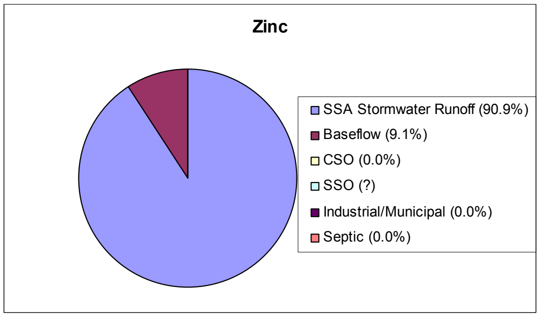

Total Nitrogen


Fecal Coliform


Total Phosphorus


Copper


Lead


Zinc

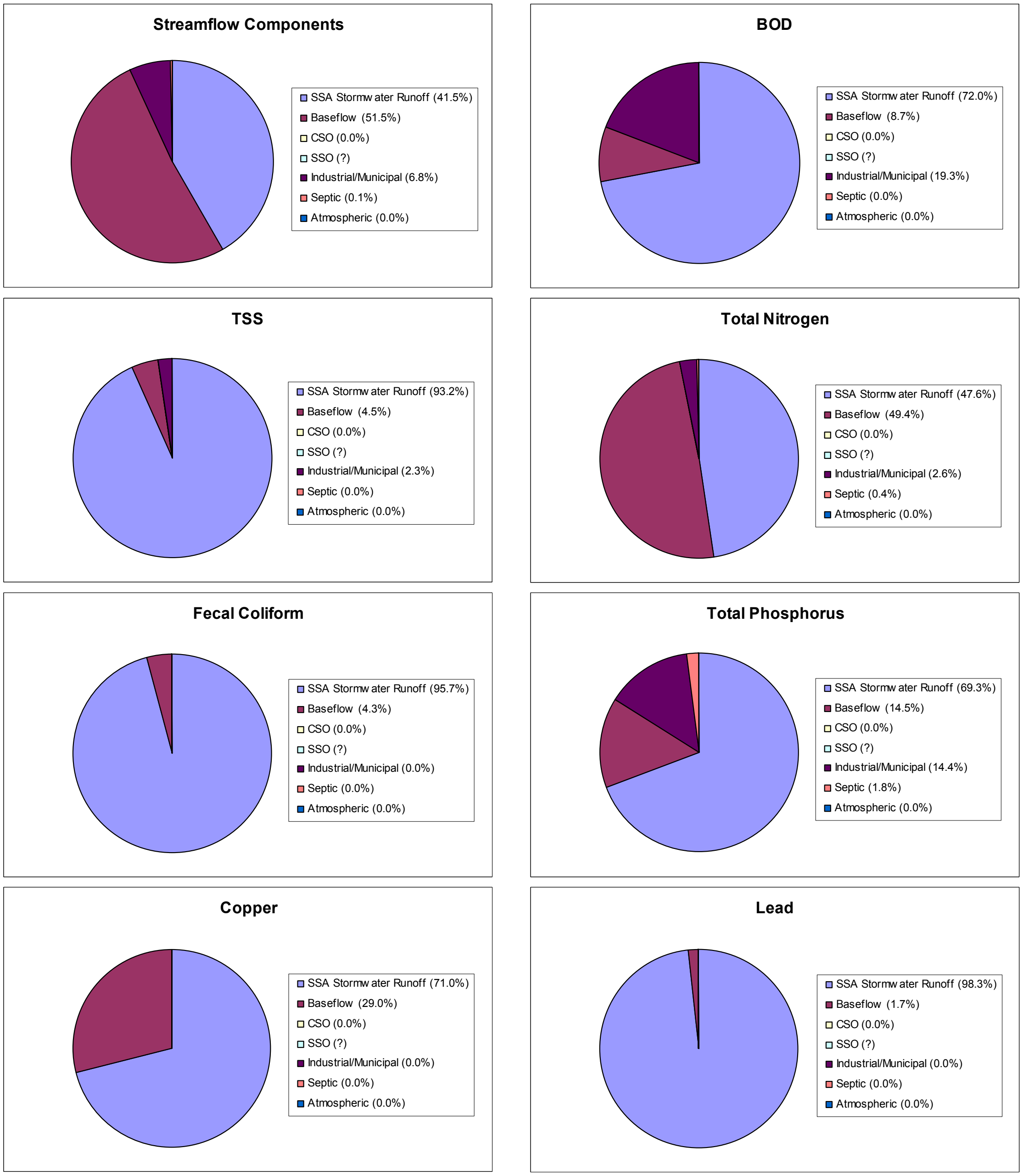
Notes:

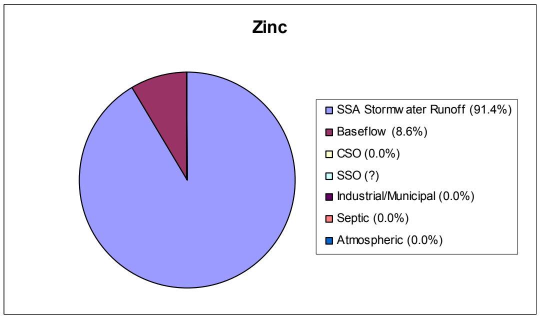
- SSA = separate sanitary area
- Information concerning separate sanitary overflows (SSOs) was not considered sufficient to include in this analysis.
- Approximate atmospheric loads are included in the stormwater runoff loads for all land use types except "Water/Wetlands". The term "Atmospheric" above represents Loads applied only to the "Water/Wetlands" category.

Figure 9.23 Darby Estimated Annual Relative Contribution of Constituent Sources

Table 9.10 Tinicum Estimated Annual Areal Loads by Source (lb/ac except as noted)

Parameter	SSA Stormwater Runoff (lb/ac)	Baseflow	CSO	Industrial/ Municipal	Septic
BOD	15.3	1.48	0	3.27	0
TSS	90.5	3.48	0	1.78	0
Fecal Coliform (col/ac)	1.1E+11	3.8E+09	0	9.6E+06	0
Total Nitrogen	2.79	2.32	0	0.123	0.02
Total Phosphorous	0.349	0.058	0	0.058	0.007
Copper	0.017	0.005	0	0	0
Lead	0.095	0.001	0	0	0
Zinc	0.189	0.014	0	0	0





Notes:

- SSA = separate sanitary area
- Information concerning separate sanitary overflows (SSOs) was not considered sufficient to include in this analysis.
- Approximate atmospheric loads are included in the stormwater runoff loads for all land use types except "Water/Wetlands". The term "Atmospheric" above represents Loads applied only to the "Water/Wetlands" category.

Figure 9.24 Tinicum Estimated Annual Relative Contribution of Constituent Sources

9.3.3 Comparison of Load Estimates

Separate loading rates were not estimated for upper Darby for two reasons. First, only one Cooperative Program site was located on Darby Creek, and its location (at Waterloo Mills, in the headwaters) does not represent a large enough portion of the watershed to compare to the 1999 monitoring and WMM-estimated loads. Second, the lack of USGS gauge data in the vicinity of DC05 causes difficulty producing a baseflow estimate.

Table 9.11 compares the loads of some conventional water quality parameters calculated from the results of the first 50 months of sampling of the PWD/USGS Cooperative Program "Effects of Non-Point Discharge on Urban Stream Quality," reported by Radzuil, with loads calculated based on wet and dry flow regimes. Loads for metals and suspended solids were not reported. The calculated loads were developed by assigning wet and dry flow regimes and wet and dry concentrations, then accumulating the load over the discharge record.

The loading rates estimated by WMM for some constituents are much larger than the instream mass load estimated from the current monitoring data. This difference is not a mistake but a result of the modeling philosophy:

- WMM loads represent the total potential load to be delivered downstream and do not specifically account for the instream processes that reduce the total load.
- For the screening level study, the loads were used to estimate an overall delivery ratio for each pollutant, rather than estimate delivery ratios for various land uses by pollutant.
- The instream mass loads were based on limited, discrete, wet and dry weather monitoring data in addition to streamflow data from the 1970s.
- Loading is based on national EMCs which are measures of central tendency with significant variance. Local conditions may not be reflected by the national EMCs.

9.3.4 Delivery Ratios

The delivery ratio represents the fraction of the original pollutant load remaining after a particular pollutant travels downstream and is affected by instream processes. Data available in the literature indicate that the delivery ratio varies with drainage-area size. Some representative values calculated by the USDA for sediment are:

Drainage Area (sq. miles)	Delivery Ratio
0.5	0.33
10	0.18
100	0.10

However, the delivery ratios may vary substantially for any given size of drainage area. Other important factors affecting pollutant delivery include soil texture, relief (slope), types of erosion, sediment transport system, and deposition areas. For instance, a watershed with fine soil texture, high channel density, and high stream gradients would generally have a higher than average delivery ratio for watersheds of similar drainage area. Also, edge-of-field delivery ratios can approach 1.0 while delivery ratios for larger study areas can be less than 0.05. Instream processes also affect the delivery ratio. Such processes include deposition, sediment and water column diagenesis, remineralization, and volatilization. These processes are discussed in the next section. Table 9.11 presents the calculated delivery ratios for one site near the outlet of Darby Creek (PWD sampling site DCD765).

Table 9.11 Comparisons of Load Estimates for Darby Creek

	1999 Monitoring Data	WMM Estimate	Delivery Ratio
Drainage Area (ac)	25,600	28,276	
Surface Runoff (in)	15.7	7.55	
BOD_5 (lb/day)	1,560	1,693	92%
TSS (lb/day)	1,940	10,332	19%
Total N (lb/day)	799	316	253%
Total P (lb/day)	22	38.83	57%
Fecal Coliform (col/day)	2.81E+12	1.17E+13	24%
Cu (lb/day)	1.13	1.81	63%
Pb (lb/day)	0.55	9.88	6%
Zn (lb/day)	2.66	21.22	13%

Note: Loading estimates based on monitoring data require a baseflow estimate. Unlike data for Cobbs Creek, USGS historical streamflow data for the Darby Creek watershed are insufficient to calculate separate loading rates for the upper portion of the watershed. Monitoring loads are based on data from DCD765 and USGS station 01475510, (Darby Creek near Darby).

Section 10 Discussion and Analysis

Sections 1 through 8 provide a wide range of information characterizing the geography, hydrology, water quality, biology, habitat, and fluvial geomorphology of the Darby and Cobbs Creeks watershed. The purpose of Section 10 is to examine the wide range of information presented in this report and to draw conclusions about the current state of the watershed. This analysis will provide a basis for future planning and management of the watershed.

10.1 Water Quality, Biology, and FGM Discussion

As part of the CCIWMP, the highest priority problems in the Cobbs Creek system were identified. With the exception of CSO-related issues, these same problems apply to some degree in the Darby and Tinicum subwatersheds. Given that the Cobbs Creek watershed is a highly urbanized watershed with both CSOs and significant stormwater flows, some of the highest priority problems include:

Dry Weather Water Quality and Aesthetics

- Water quality concerns including high fecal coliform during dry weather
- Dry weather sewage flows in separate sewered areas
- Trash-filled, unsightly streams that discourage residential use.
- Safety concerns along streams and stream corridors

Healthy Living Resources

- Degraded aquatic and riparian habitats
- Limited diversity of fish and benthic life
- Periodic, localized occurrences of low dissolved oxygen primarily associated with plunge pools and areas of stagnant water behind dams
- Utility infrastructure threatened by bank and streambed erosion
- Limited public awareness and sense of stewardship for Cobbs Creek

Wet Weather Water Quality and Quantity

- Water quality concerns including high fecal coliform during wet weather, and nutrients and metals during wet weather flows
- CSO impacts on water quality and stream channels
- Little volume control and treatment of stormwater flows in separate sewered areas

This section presents a brief summary of the analyses behind the watershed indicators presented in the CCIWMP. The data and analyses used to derive these results are documented in more detail in the Technical Memoranda and Comprehensive Characterization Report. The discussion covers each of five geographic areas as shown in Figure 10-1.

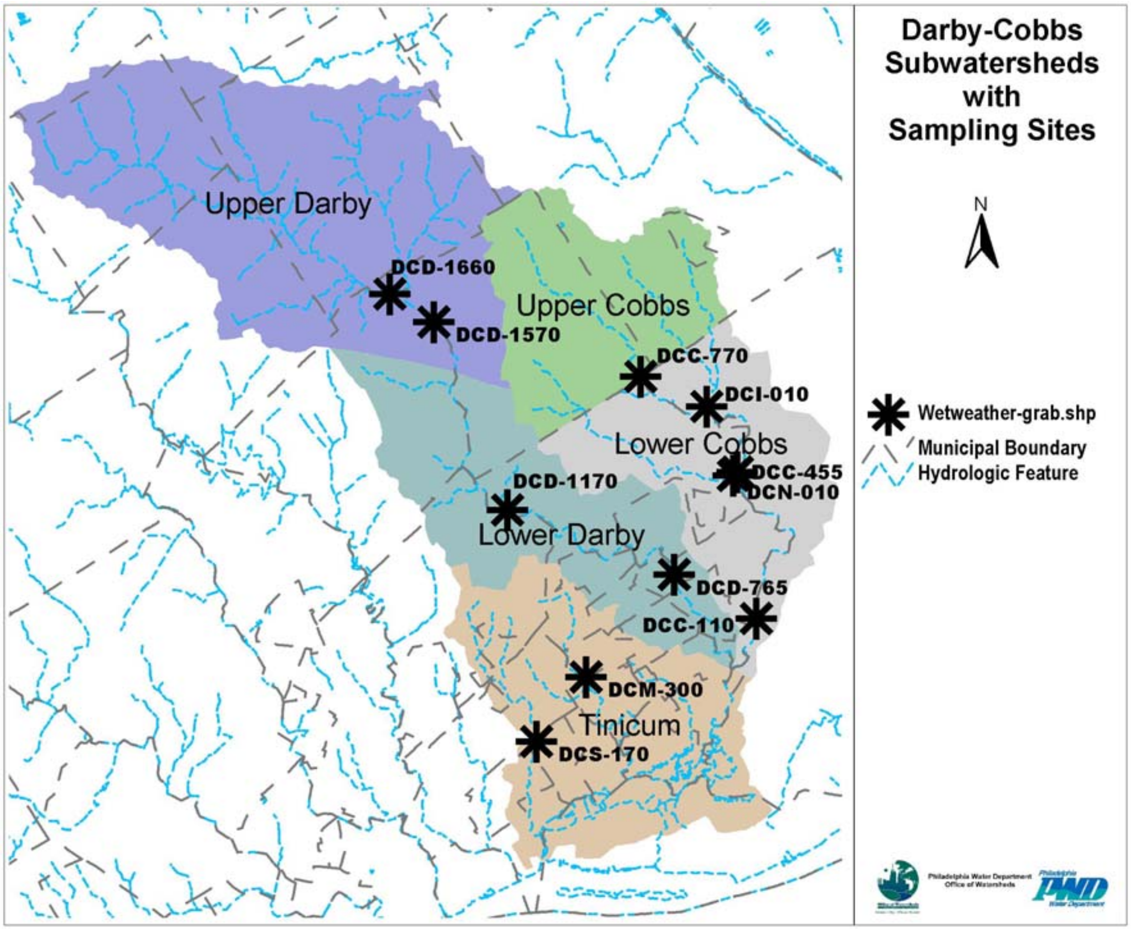


Figure 10-1 Subwatersheds and Sampling Sites

Upper Cobbs Creek

Two sampling sites represent the headwaters and upper reaches of Cobbs Creek. Site DCC-770 is on the main stem of Cobbs Creek near the Philadelphia/ Montgomery County line, and DCI-010 is on Indian Creek just above the confluence with the main stem. These sites do not receive CSO inputs.

Table 10-1 Status of parameters for Upper Cobbs

	Upper Cobbs Indicator Summary							
Site	1 Impervious Cover	2 Baseflow	3 Channel Type	5 Fish	6 Benthos	7 Bacteria	8 Metals	9 DO
DCC770	○	○	○	◗	○	○	●	●
DCI010	○	○	○		○	○	●	●
● Good ◗ Fair ○ Poor								

Land Use, Impervious Cover, and Stream Baseflow

The upper portion of Cobbs Creek consists of a mix of mainly residential land uses with disturbed urban soils, and significant natural park land along the stream corridor inside the City. Based on hydrograph separation analysis (documented in the Comprehensive Characterization Report), baseflow is approximately 43% of average annual rainfall for the Cobbs watershed as a whole. For French Creek, a reference stream with similar soils and geology, baseflow is 64% of average annual runoff. This difference is attributed to reduced groundwater recharge caused by urbanization.

Stream Channel Type and Trends

The headwaters of Cobbs Creek include East Indian Creek, West Indian Creek, and the upstream-most reaches of the main stem in Delaware County. Cross section surveys of East Indian Creek resulted in mostly B Rosgen channel types and a small number of F Rosgen channel types (Figure 10-2). A Rosgen channel type B is moderately entrenched, has a width/depth ratio greater than 12, and has moderate sinuosity. B channel types differ from F channel types since they generally have less steep, tall banks, and a deeper, more varied channel bed rather than being consistently flat. Sediment supply and bank erosion are usually high since they are actively changing through bed and bank erosion. Those East Indian Creek reaches classified as F channel types have completed downcutting and have undergone enough bank erosion to create a wide, flat bottom channel.

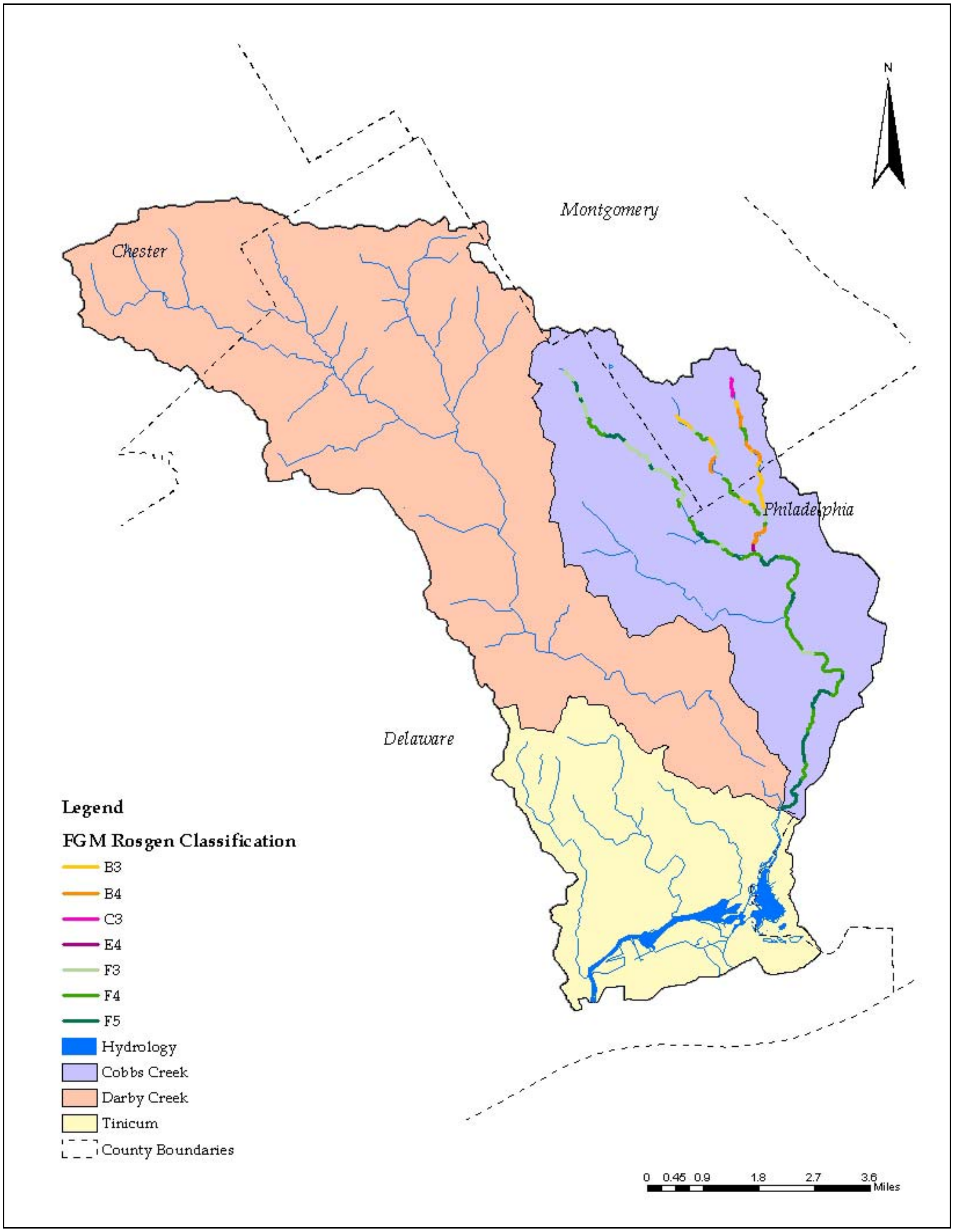


Figure 10-2 Fluvial Geomorphology Study - Rosgen Classification of Cobbs Reaches 2003

Bank conditions throughout East Indian Creek range from relatively stable in undisturbed areas to moderately eroded upstream of Lansdowne Avenue. Residential land use and regular mowing have limited the development of forested buffer, increased sediment supply, and facilitated bank erosion. Channel banks are the most degraded downstream of City Line Avenue where banks and adjacent slopes are the steepest within the subwatershed. These reaches are uncharacteristic of the remainder of the East Indian Creek subwatershed and are most similar to topography and valley types within the Cobbs Creek watershed.

Measured cross sections resulting in an F Rosgen channel type are located nearest the confluence with Cobbs Creek. These reaches have completed downcutting and possibly over-widening more quickly than the upstream reaches classified as B channel types. Existing channel geometry for the East Indian Creek suggests that the downstream end of East Indian Creek is further ahead in the channel migration process than the upstream portion. Over time, all reaches within East Indian Creek are expected to become F channel types and follow the same channel migration pattern over geologic time to transition to a stable C channel type.

West Indian Creek reaches are classified as B and F channel types. Overall, the upstream most portion of the channel is a B channel type and the downstream portion is an F channel type. The mid-section of West Indian Creek contains a transitional area where short overwidened F sections alternate with sections of entrenched, actively degrading B portions. West Indian Creek contains a greater percentage of F channel type than East Indian Creek, although both are still actively adjusting.

Most of West Indian Creek is surrounded by residential development where private homeowners have cleared forested buffers, reducing the buffer width to create additional lawn space or landscape their yards. Reaches downstream of City Line Avenue are the only ones within the subwatershed where a minimum of a 100-foot forested buffer remains. Additionally, 10 of the 15 reaches assessed are disturbed by in-stream structures, utilities, or road crossings.

Overall, bank erosion and sediment supply within the West Indian subwatershed were low and only a few isolated occurrences of more degraded banks were observed. None of the reaches assessed were determined to have high bank erosion or sediment supply ratings. Banks throughout this subwatershed are an average of 5 feet tall, although there are a few instances of banks that are higher than 6 feet tall. Additionally, existing conditions of West Indian Creek provide few indications of whether the channel is aggrading or degrading. Therefore, the reach bed stability was indeterminate throughout West Indian Creek.

The stream condition and stability of West Indian Creek are also influenced by a dam and pond located just downstream of Remington Road. West Indian Creek appears to have been redirected to the dam and away from the original channel located to the west of the pond. The original channel is approximately 5-8 feet wide, which is considerably smaller than the creek both upstream and downstream of the pond, and appears stable. Although the dam and associated structures appear to be in good condition, water in the pond was stagnant at the time of the field assessment. Because the dam and pond outfall downstream of Remington Road interrupt flow through the West Indian Creek, they are influencing the stability of the channel downstream.

West Indian Creek is also expected to follow the same channel migration pattern as Cobbs and East Indian Creek. West Indian Creek most likely was a stable B or C channel that began downcutting when development increased and has continued to adjust since that time. Since a greater percentage of West Indian Creek has migrated to an F channel type than in East Indian Creek, existing conditions suggest that West Indian Creek is further ahead in the channel migration process. Stream reaches within the West Indian Creek that are currently classified as B channel types are expected to over-widen and become F channel types over geologic time. Should no additional land use changes occur within the watershed, West Indian Creek will most likely begin forming depositional features and creating a more narrow, meandering channel within the old channel banks.

Channel cross section measurements and calculations show that the entire Cobbs Creek classifies as a Rosgen type F channel. A Rosgen type F channel is entrenched, has a width/depth ratio greater than 12, and has a low sinuosity. A low entrenchment ratio (less than 1.4 = a highly entrenched channel), allows for very high bank erosion, sediment supply and lateral over-widening in an effort to create a new floodplain within the channel. Lateral bars and moderated riffle/pool sequences are often present. F channel types generally have low slopes, ranging from less than 1 to 1%.

Bank conditions in Cobbs Creek vary throughout the watershed, and generally worsen as the Creek progresses downstream. Channel banks within the headwaters are no taller than 5 feet and are at least 60% vegetated. Bankfull width of the Creek in the headwaters is an average of 25 feet wide.

Currently, the majority of Cobbs has ceased downcutting and is continuing to over-widen. Evidence of over-widening is exhibited as undercutting and vertical banks. The majority of Cobbs Creek is expected to continue widening through bank erosion. The upstream-most portion is expected to begin downcutting and become more entrenched prior to beginning the over-widening stage that the remainder of the Creek is currently undergoing. The rate of channel over-widening will slow, or cease, when deposition is initiated in the channel.

Stream Biology

Indicators based on species abundance and diversity are poor in this portion of the system. Designated uses are considered unattained by PADEP, and both benthic and fish-based indicators indicate a moderately- to severely-impaired system. The sampling site on Indian Creek West Branch receives the lowest scores of any sampling site. However, habitat assessments are generally more positive. Site DCC-865, on Cobbs Creek main stem, scores the highest with respect to the reference stream of any sampling site in the system.

Pollutant Loads and Water Quality

Estimated loadings of water quality constituents, including nutrients, metals, and bacteria, are moderate compared to other portions of the watershed. However, mean nitrate concentrations measured at DCC-770 were some of the highest in the system. Observed DO concentrations meet state standards and are adequate to support aquatic life. The magnitude of the daily DO fluctuation is moderate at upper Cobbs sites, suggesting that excessive algal biomass is not present. Dry and wet weather bacteria counts are not as high as those found in the combined-sewered portion of the watershed, but they still rarely meet standards. With the exception of a small number of lead samples, concentrations of metals are low in dry and wet weather.

Lower Cobbs Creek

Three sampling sites represent lower Cobbs Creek. Site DCC-455 is on the main stem at Cobbs Creek Environmental Center, and DCN-010 is on Naylors Run just above the confluence with Cobbs Creek. Site DCC-110 is on the main stem about one mile above the confluence with Darby Creek. The two sites on the mainstem receive stormwater and CSO inputs, while the Naylors site receives only stormwater. Additional monitoring was conducted at DCC-115, just upstream of the dam at DCC-110.

Table 10-2 Status of parameters for Lower Cobbs

	Lower Cobbs Indicator Summary							
Site	1 Impervious Cover	2 Baseflow	3 Channel Type	5 Fish	6 Benthos	7 Bacteria	8 Metals	9 DO
DCC455	○	○	○	○	○	○	●	●
DCC110	○	○	○	○	○	○	◗	◗
DCN010/DCN208	○	○		○	○	○	●	●
	● Good	◗ Fair	○ Poor					

Land Use, Impervious Cover, and Stream Baseflow

The lower portion of the Cobbs Creek watershed is highly urbanized and highly impervious, with high-density residential areas in the City, a mix of high- and lower-density residential areas in Montgomery County, commercial land uses along highway corridors, and park land along riparian corridors. Combined sewers serve the Philadelphia portion of the watershed. Based on hydrograph separation analysis (documented in the Comprehensive Characterization Report), baseflow is approximately 43% of average annual rainfall for the Cobbs watershed as a whole. For French Creek, a reference stream, baseflow is 64% of average annual runoff.

Stream Channel Type and Trends

Bank conditions throughout Cobbs Creek vary throughout the watershed and generally worsen as the Creek progresses downstream. As the Creek progresses downstream, banks transition to greater than 6 feet tall and less than 50% vegetated. Bankfull width varies from 25 feet to approximately 60 feet wide.

Existing sediment supply and reach bed stability also worsen as the Creek continues downstream. Reaches in the headwaters are an average of 25 feet wide at bankfull and increase to an average width of 60 feet near the confluence with Darby Creek.

Generally, it is the goal of an F channel type to cease downcutting and begin depositing bed materials as alternating lateral bars. Deposition forming lateral bars in turn continues the over-widening process. Alternating lateral bars will slowly build over time through exchange of sediment during bankfull events to effectively decrease the width of the channel accessible by base flow. Limiting the width of the channel through the creation of alternating lateral bars will yield a greater sinuosity and a new, lower floodplain. Although an F channel type is not considered stable, it will generally migrate to a stable C channel type over geological time.

Currently, the majority of Cobbs has ceased downcutting and is continuing to over-widen. Evidence of over-widening is exhibited as undercutting and vertical banks. The majority of Cobbs Creek is expected to continue widening through bank erosion. The rate of channel over-widening will slow, or cease, when deposition is initiated in the channel.

Stream Biology

As has historically been the case in many urban stream ecosystems, the moderately impaired benthic community and pollution tolerant fish assemblages in Cobbs Creek are an apparent result of habitat deterioration and episodic water quality degradation throughout the watershed. All of the Cobbs watershed is classified as unattained by PADEP. Sampling sites are moderately to severely impaired based on benthic criteria. Habitat is classified as partially supporting aquatic life uses at approximately 60% of the reference stream condition.

Cobbs Creek watershed is a highly urbanized region where traditional methods of stream bank "reconstruction" and storm water management have significantly channelized the stream, creating a system which is not in dynamic equilibrium (i.e. the amount of erosion and sedimentation is not equal to the amount of sediment transport out of the system). Furthermore, this aquatic ecosystem has lost much of its link magnitude (e.g. small first order streams) and wetland systems due to development and increased impervious surfaces. By changing the "natural" state of the stream, development has altered the hydrologic profile, decreasing the time to peak flow and increasing the peak flow itself. In doing so, events reaching or exceeding bankfull stage are no longer managed by the stream channel and flood plain. Typical events scour stream banks, fill pool systems and cover riffle structures with sediment at an accelerated rate. As a result, a highly ephemeral (short-lived) system with increased sediment deposition, decreased habitat heterogeneity (e.g. pool-riffle-run systems) and unstable stream banks has been created. Biologically, these processes have had a deleterious effect on the benthic and ichthyfaunal communities inhabiting Cobbs Creek. Three of the most important attributes of streams for macroinvertebrate and fish persistence are oxygen, food, and habitat. Although the first two attributes are equally important, habitat modifications and loss of habitat appear to be the primary reasons for decreases in species diversity and fecundity, skewed population dynamics and increases in "pollution tolerant" species in Cobbs Creek.

Benthic invertebrates rely heavily on riffle systems as primary habitat to carry out most or all of their life cycles. Morphologically, many species have evolved and adapted to handle increased flow over riffle systems (e.g. dorsally flattened bodies, claws for clinging). However, increases in flow, sediment deposition and scouring in Cobbs Creek have impeded reproductive and feeding strategies of many species of macroinvertebrates. Those individuals not adapted to extreme hydrologic fluctuations have been extirpated from this area. Also, sediment deposition has created embedded riffle systems where eggs are either scoured downstream or covered by layers of fine and course sediment. By decreasing the species richness and evenness of the benthic community, functional feeding groups have also been modified. Many species responsible for conditioning course particulate organic matter (CPOM), are no longer present in this watershed (e.g. Order: *Plecoptera*). Organisms well adapted to hydrologic extremes and pollution, such as blackflies (Family: *Simuliidae*), *Hydropsychid* caddisflies (Family: *Hydropsychidae*) and midges (Family: *Chironomidae*) currently dominate the assessed areas. In addition to the community dynamics, the fluvial geomorphological profile in Cobbs Creek has created temporary riffles where spates may virtually change the "aqua-scape" in a period of days.

Like the benthic invertebrate community, fish communities rely heavily on various habitats within a stream reach. Many species (e.g., *Etheostoma olmstedi*) have adapted to shallow riffles systems for food acquisition. Other species (e.g. *Micropterus* sp.) rely on large pools for foraging and reproduction. Stream runs with vegetated areas are also important habitat components for many species of fish. Extremes in the hydrologic profile of Cobbs Creek have also contributed to decreased species diversity and offspring of fish within this area. Many species rely on vegetation or rocks to deposit their eggs, while other species build nests that are closely guarded by the parent or parents. Extreme flow conditions contribute to the deposition of sediment in pool systems and scouring regions where offspring have been deposited, thus increasing mortality rates in eggs and fry populations. In addition, pool systems in this area are highly dynamic (e.g., a moderately sized pool can be covered within a few days).

Pollutant Loads and Water Quality

Pollutant loading estimates generally correspond to degree of development, as represented by population density, in the separate-sewered areas, and are some of the highest in the system. BOD, TSS, and bacteria loading estimates are relatively high in the combined-sewered areas, while nutrient loading estimates are relatively low due to the proportion of captured flows. Estimates of metals loadings are mixed compared to other portions of the system.

Storm hydrographs at DCC-455 and DCC-110 in this portion of the system display the high intensity, low-duration behavior typical of highly urbanized, highly impervious systems; these high-velocity flows are erosive and can present a problem for aquatic life. Turbidity also increases sharply in wet weather and may indicate a combination of fine sediment in stormwater runoff, and streambed and bank erosion.

There is evidence to indicate that lower Cobbs sites, and DCC-455 in particular, may be eutrophic. Observed nitrate generally decreases along Cobbs Creek main stem; mean nitrate at DCC-455 is greater than mean nitrate at DCC-110, and observed nitrate concentrations at DCN-010 are among the highest in the system. The large daily range in DO and qualitative observations at DCC-455 suggest that this site is the most biologically active among the sites sampled. Continuous data suggest that DO at DCC-110 is below the level needed to support aquatic ecosystems approximately 5% of the time. DCC-115, located just above a low dam, experiences the lowest DO of any site due to poor mixing.

Bacteria counts in the lower Cobbs exceed standards in both dry and wet weather and in both combined- and separate-sewered areas. Copper, lead, and zinc exceed standards in wet weather at DCC-110. Stormwater outfalls and combined sewer overflows (CSOs) have also exacerbated the problems of sedimentation and erosion as well as contributed to episodic periods of reduced water quality.

Upper Darby Creek

The headwaters of Darby Creek are represented by data taken from site DCD-1570 and by a limited amount of data from DCD-1660. These sites are not impacted by known CSOs.

Table 10-3 Status of parameters for Upper Darby

	Upper Darby Indicator Summary							
Site	1 Impervious Cover	2 Baseflow	3 Channel Type	5 Fish	6 Benthos	7 Bacteria	8 Metals	9 DO
DCD1660	○	●			●	◗	●	◗
DCD1570	○	●			●	●	●	●
● Good ◗ Fair ○ Poor								

Land Use, Impervious Cover, and Stream Baseflow

The upper portion of the Darby Creek watershed is the least urbanized portion of the system and consists of mixed residential, commercial, park land, and golf course land uses. Estimates of pollutant loads are relatively low with the exception of commercial areas in the northern-most portion of the watershed. Hydrograph separation analysis of a USGS gauge in the headwaters (01475300) indicates that baseflow comprises approximately 66% of mean annual flow, similar to an undeveloped system.

Stream Biology

The upper portion of the Darby Creek watershed is listed by PADEP as attaining its designated uses. Benthic indicators range from poor to very good at different sites, and fish indicators range from fair to good. Habitat assessment data are limited. Although the area is less urbanized than other portions of the Darby and Cobbs Creeks watershed, continuous monitoring data of depth and turbidity still display the high flood peaks and short durations typical of urban flows. Qualitative assessments by ANS and PADEP indicate that some erosion has occurred, and the amount of erosion generally increases from upstream to downstream along the length of the Darby.

Pollutant Loads and Water Quality

Although many estimated pollutant loads are low in the area, estimated nitrogen and phosphorus loads are moderate, as expected from landscaped areas. DO is generally adequate to support aquatic life, although water temperatures occasionally exceed standards for designated cold water fisheries. DO fluctuations are smaller than those observed in other parts of the system, suggesting less algal activity and a less-enriched system. Bacteria counts are lower than those found downstream, but most samples still do not meet standards. Concentrations of metals increase in wet weather but do not exceed standards for protection of aquatic life.

Lower Darby Creek

Lower Darby Creek is represented by two sampling sites. DCD-1170 is on the main stem downstream of PA Route 3, and DCD-765 is upstream of the confluence with Cobbs Creek. These sites are impacted by stormwater but not by known CSOs.

Table 10-4 Status of parameters for Lower Darby

	Lower Darby Indicator Summary							
	1	2	3	5	6	7	8	9
Site	Impervious Cover	Baseflow	Channel Type	Fish	Benthos	Bacteria	Metals	DO
DCD1170	○	○			○	○	●	●
DCD765	○	○			○	○	●	●

● Good ◐ Fair ○ Poor

Land Use, Impervious Cover, and Stream Baseflow

The lower portion of the Darby Creek watershed consists primarily of a mix of single and multiple-family residential land uses. The estimated average annual runoff is 17.8 inches or 43% of average annual rainfall; this level of imperviousness is similar to upper Cobbs, less than lower Cobbs, and greater than upper Darby. As in other separate-sewered areas, estimated constituent loadings generally follow trends in imperviousness and population density. Continuous monitoring data indicate high-intensity, short-duration runoff events occur that are likely to cause erosion of streambeds and banks.

Stream Biology

PADEP lists lower Darby Creek, defined as the area below PA Route 3, as unattained for designated uses. ANS and PADEP list benthic quality as poor and fish quality as fair. Habitat data are limited, but observed erosion is generally greater than that observed further upstream. These conditions suggest that in addition to some instances of degraded water quality in wet weather, urban flow modifications are degrading habitat.

Pollutant Loads and Water Quality

There is some evidence that DCD-765 may be nutrient-enriched. Nitrate and ammonia concentrations increase slightly over the length of Darby Creek, although they are generally lower than those found in the Cobbs Creek system. DO is less than the state standard during some wet weather events.

Bacteria counts are lower in dry weather than those found in Cobbs Creek; however, wet weather bacteria counts are similar to those found in the combined-sewered areas of Cobbs Creek. Metals concentrations increase in wet weather as they do throughout the system and sometimes exceed state standards at DCD-765.

Tinicum

Two sampling sites represent conditions in the Tinicum area. These include DCM-300 on Muckinipattis Creek and DCS-170 on Stony Creek.

Table 10-5 Status of parameters for Tinicum

	Tinicum Indicator Summary							
	1	2	3	5	6	7	8	9
Site	Impervious Cover	Baseflow	Channel Type	Fish	Benthos	Bacteria	Metals	DO
DCM300	○				○	○	●	●
DCS170	○				○	○	●	●
		● Good	◐ Fair	○ Poor				

Land Use, Impervious Cover, and Stream Baseflow

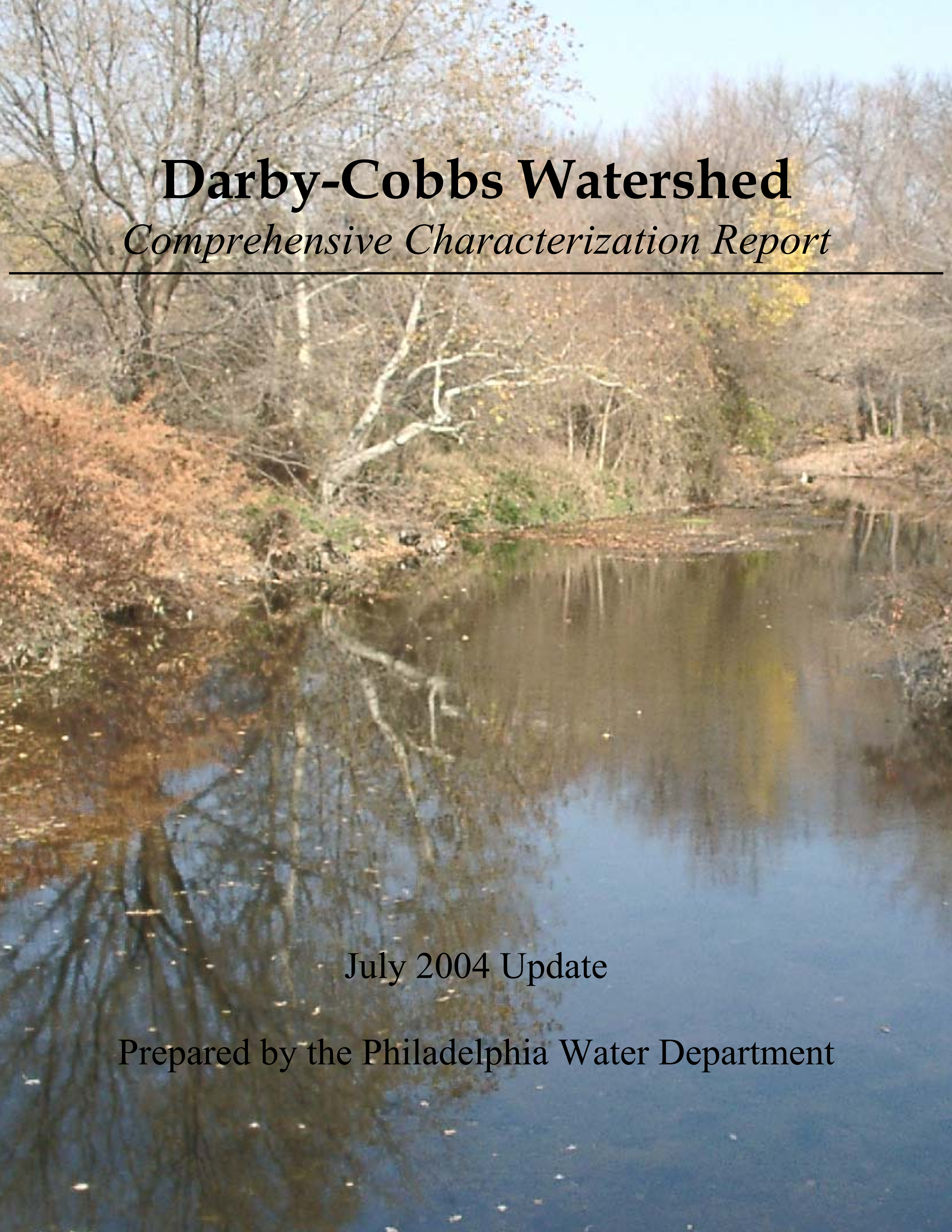
The Tinicum watershed consists of residential and commercial development to the northwest and undeveloped wetlands and marshes to the southeast. The more developed portion of the watershed results in moderate pollutant load estimates relative to other portions of the watershed.

Stream Biology

PADEP lists the area as unattained based on benthic macroinvertebrate species diversity.

Pollutant Loads and Water Quality

Discrete DO samples sometimes were less than state standards in dry and wet weather. Nitrate is generally lower in Tinicum than in other parts of the system, but ammonia is generally greater. Metals concentrations are elevated and sometimes exceed state standards in wet weather.



Darby-Cobbs Watershed

Comprehensive Characterization Report

July 2004 Update

Prepared by the Philadelphia Water Department

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CONTACT INFORMATION

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ACKNOWLEDGEMENTS

Philadelphia Water Department (PWD) would like to thank those individuals who devoted their time and energy to assist water department personnel in completing the comprehensive assessment of Darby-Cobbs Watershed. In particular, Mike Boyer and Alan Everett of the Pennsylvania Department of Environmental Protection (Southeast Regional Office) were instrumental in field assistance and quality control/quality assurance oversight. Paula Conolly (D.S. Winokur), Virginia Ranly (D.S. Winokur) and Gary Martens (Camp, Dresser & McKee) provided support with field work, database management and Geographic Information Systems (GIS).

PWD would also like to thank Drexel University's Cooperative Program for providing highly qualified students to assist in various monitoring programs. More specifically, Kelly Anderson, Rick Howley and Jim Pagana contributed to the fieldwork effort and assisted in data organization.

In addition to the aforementioned individuals and agencies, scientists from the Office of Watersheds (OOW) and Bureau of Laboratory Services (BLS) would like to extend their gratitude to individuals within the Water Department for their involvement in the assessment. Maureen Jaroszewski, Marla Johnson, Steve Ostrowski, Joe Roman, Cindy Rettig and staff, and the staff of the Central Receiving Unit were actively involved with fieldwork activities and/or laboratory analyses.

SECTION 1: INTRODUCTION

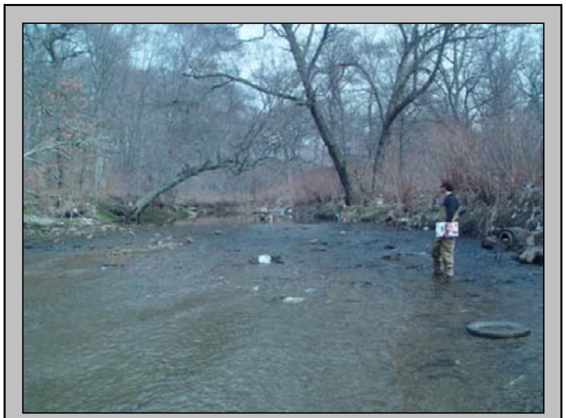
This report summarizes the Philadelphia Water Department's (PWD) Watershed Sciences Group 2003 comprehensive assessment of Darby-Cobbs Watershed. Since the last comprehensive assessment, conducted in 1999, the understanding of the watershed has been advanced by numerous studies and modeling exercises, funded largely by the Commonwealth of Pennsylvania (e.g., Acts 167, 104b3 and 537). These investigations, combined with considerable urban planning and community stewardship efforts, have culminated in the Cobbs Creek Integrated Watershed Management Plan (CCIWMP). Comprehensive watershed assessments conducted in 1999 and 2003 informed the decision-making and prioritization processes of the plan, and future assessments will complement state water quality criteria in providing a scientific means to measure improvements once restoration activities are implemented.

While improvements to the watershed are interrelated and will happen concurrently, the CCIWMP presents the overall goal of watershed restoration as a series of targets: A) dry weather water quality, B) healthy living resources, and C) wet weather water quality. Management plan targets are addressed by various components of this comprehensive watershed assessment, including physical habitat assessments, water quality monitoring, and algae, benthic macroinvertebrate, and fish surveys. Since components of an aquatic ecosystem are interrelated, this integrative approach allows for a greater understanding of factors affecting the aquatic ecosystem that would not be possible if individual elements were studied alone. Of primary importance is understanding how the physical and chemical attributes of streams affect algae, invertebrate, and fish communities, because healthy aquatic communities cannot survive in the absence of healthy habitats.

As impairments are identified and corrected, the Watershed Sciences Group is responsible for measuring improvements quantitatively. If improvements are unsatisfactory or absent, PWD and its CCIWMP partners must identify remaining causes of impairment. Many tools available to aquatic biologists were developed to identify impairments due to organic pollution from point sources and runoff. Traditional bioassessment tools may not be useful for monitoring BMPs. Reference site conditions may not be replicable due simply to differences in climate and geography. Interpretation of bioassessment data must integrate results of other data collection efforts so as not to misattribute impairment to less important, or even unrelated, causes. Lastly, our investigations suggest that biogeography and dispersal ability of sensitive indicator organisms may play an important role in how quickly improvements, as measured by bioassessment techniques, manifest themselves following stream restoration or improvements in water quality.

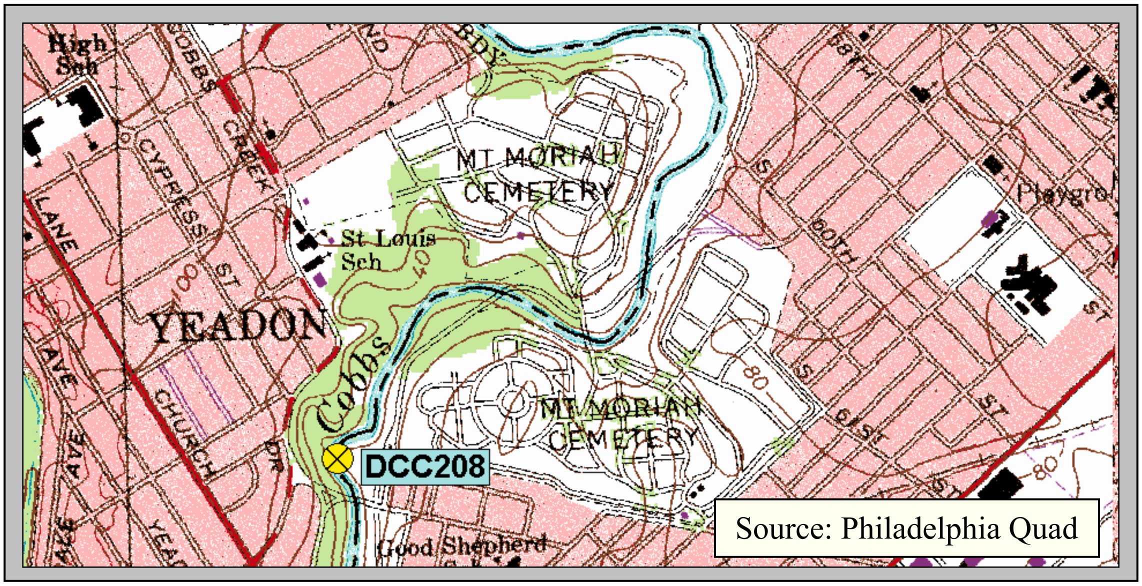
SECTION 2: SITE LOCATIONS AND DESCRIPTIONS

2.1. DCC 208: Darby-Cobbs Study Area **Philadelphia County**



Upstream view of DCC208

Downstream view of DCC208



Source: Philadelphia Quad

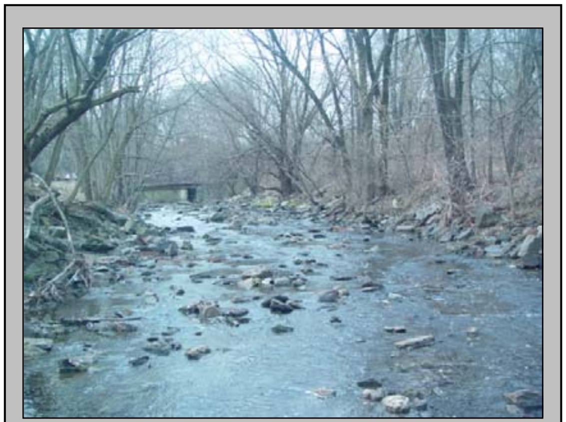
Location:

Access gained from 65th Street and the Cobbs Creek Parkway. (Latitude: -75.24459, Longitude: 39.93046)

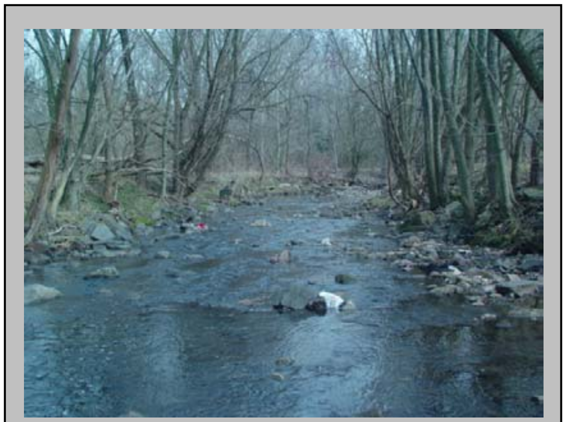
Description:

DCC208 is located upstream of a bridge near 65th Street and Cobbs Creek Parkway. The surrounding land use consists of a residential area and a cemetery. Cobbs Creek Parkway runs along the left bank of the creek at this location.

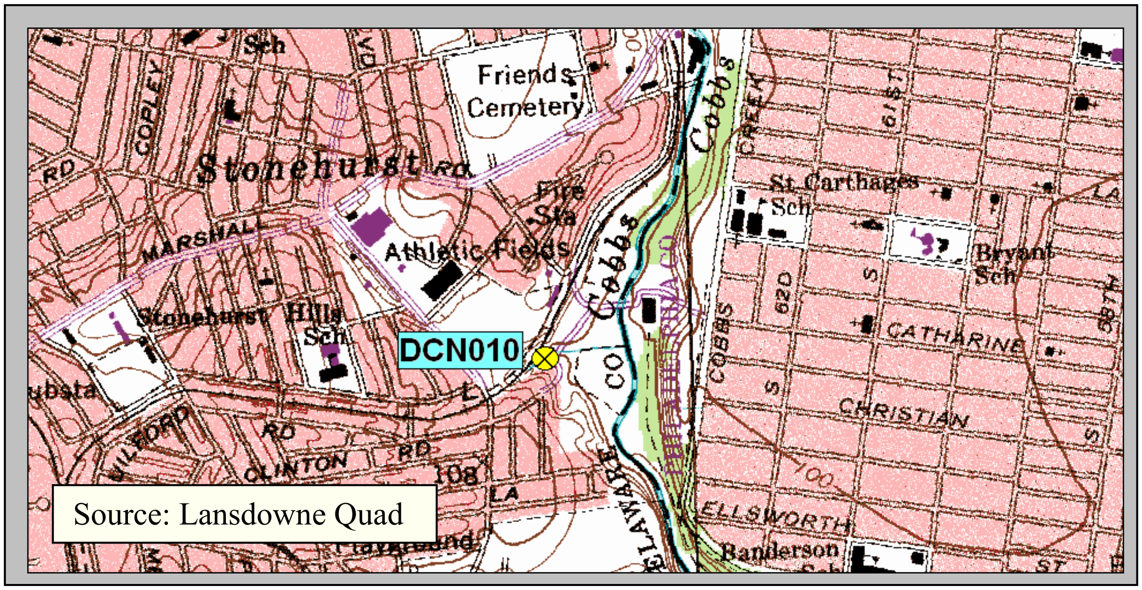
2.2. DCN 010: Darby-Cobbs Study Area Delaware County



Upstream view of DCN010



Downstream view of DCN010



Source: Lansdowne Quad

Location:

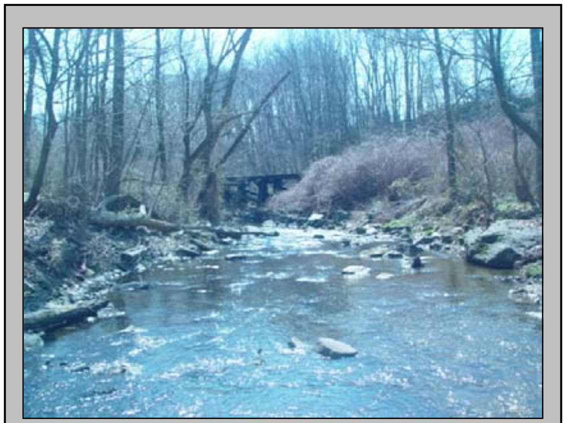
Access gained from Walnut Park Road off of 69th Street. (Latitude: -75.25336, Longitude: 39.95100)

Description:

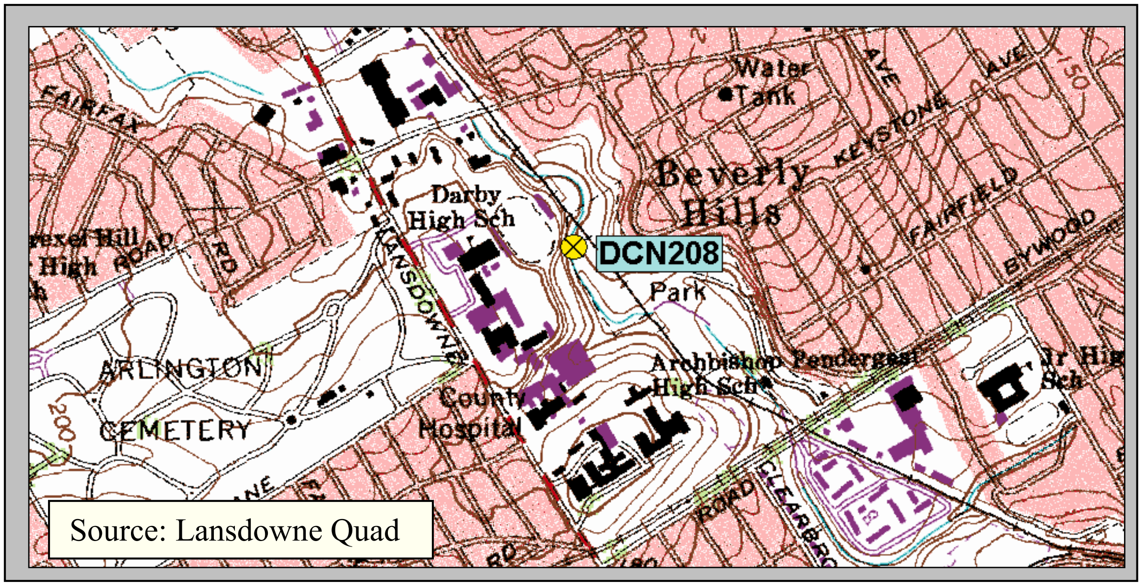
Site DCN010 is located on Naylors Run, just upstream of the confluence with Cobbs Creek. The site contains a lot of artificial substrate (concrete, bricks, etc.). The surrounding land use is field/pasture and residential.

2.3. DCN 208: Darby-Cobbs Study Area Delaware County

Upstream view of DCN208



Downstream view of DCN208



Source: Lansdowne Quad

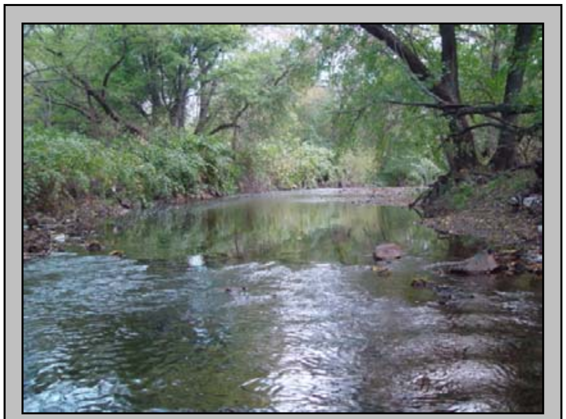
Location:

Access gained off of Garrett Road across from Barclay Square. (Latitude: -75.28287, Longitude: 39.95743)

Description:

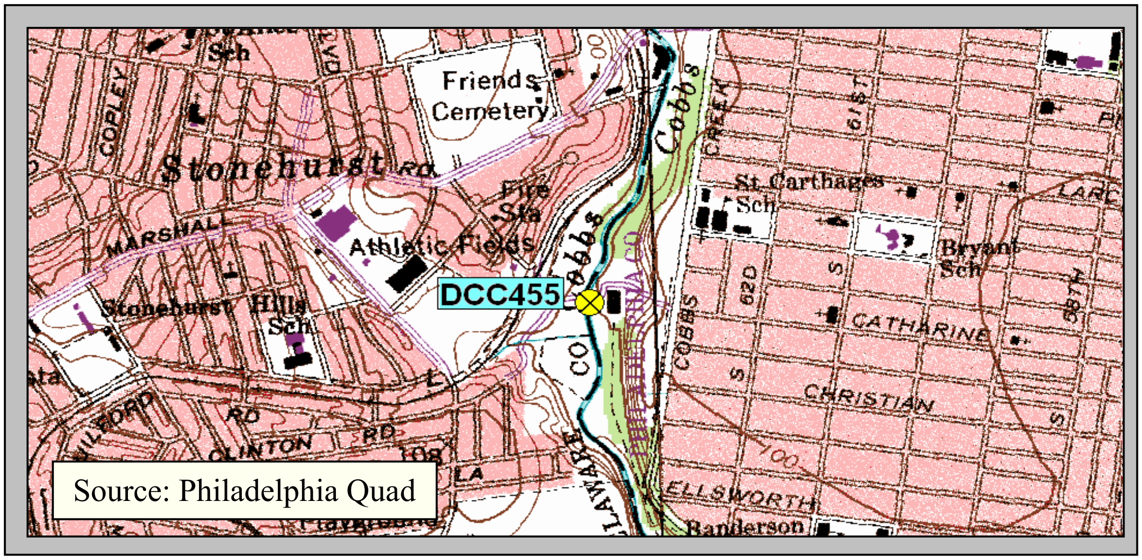
DCN208 is located on Naylors Run near Upper Darby High School. The surrounding land use is residential, and obvious sources of nonpoint source pollution exist near the site. A dam is present 250 meters downstream from the site, at which point the stream is also channelized.

2.4. *DCC 455: Darby-Cobbs Study Area* ***Philadelphia County***



Upstream view of DCC455

Downstream view of DCC455



Source: Philadelphia Quad

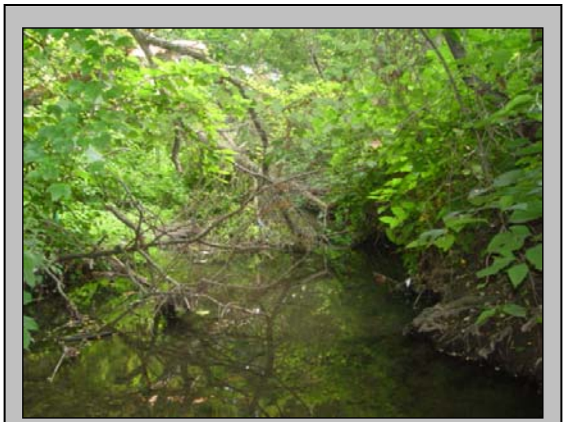
Location:

Access gained from the Cobbs Creek Community Environmental Education Center. (Latitude: -75.25203, Longitude: 39.95178)

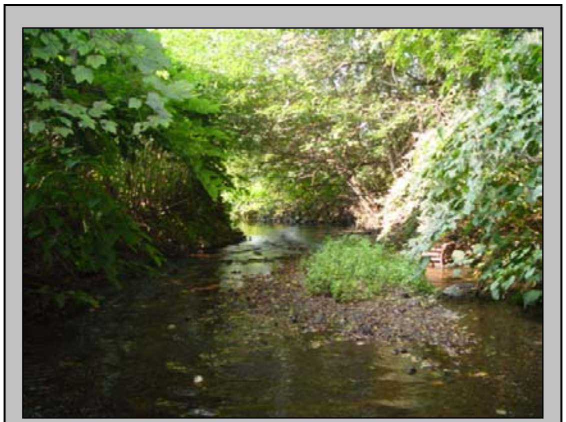
Description:

Site DCC455 is located 200 meters upstream of the footbridge behind the Cobbs Creek Community Environmental Education Center. The site is within the Cobbs Creek portion of Philadelphia's Fairmount Park. The surrounding land use is parkland and residential.

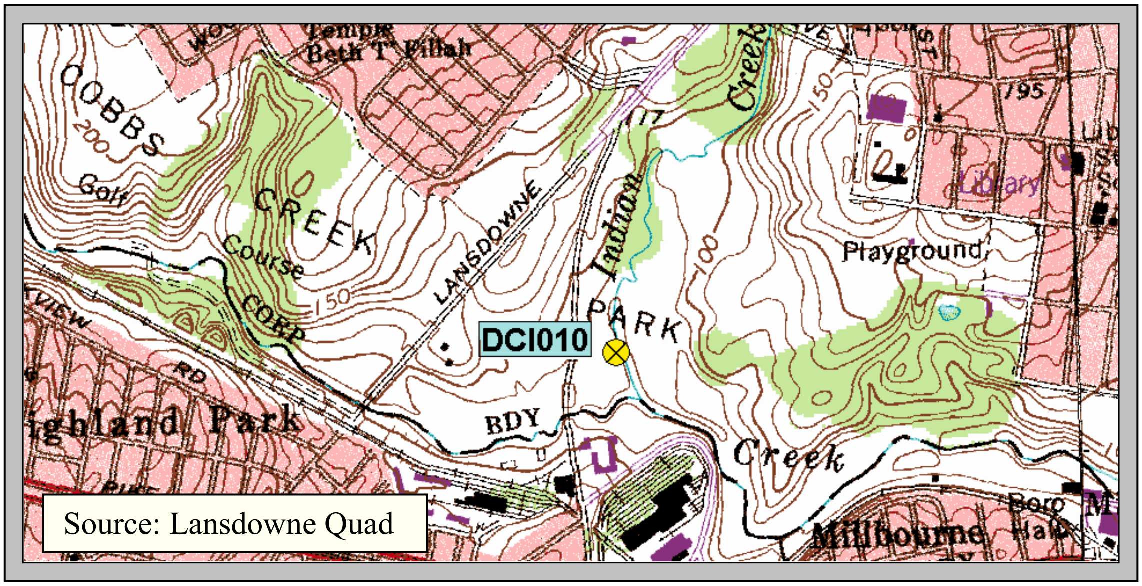
2.5. *DCI 010: Darby-Cobbs Study Area* Montgomery County



Upstream view of DCI010



Downstream view of DCI010



Source: Lansdowne Quad

Location:

Access gained from Cobbs Creek Golf Course near Haverford Avenue. (Latitude: -75.26084, Longitude: 39.96726)

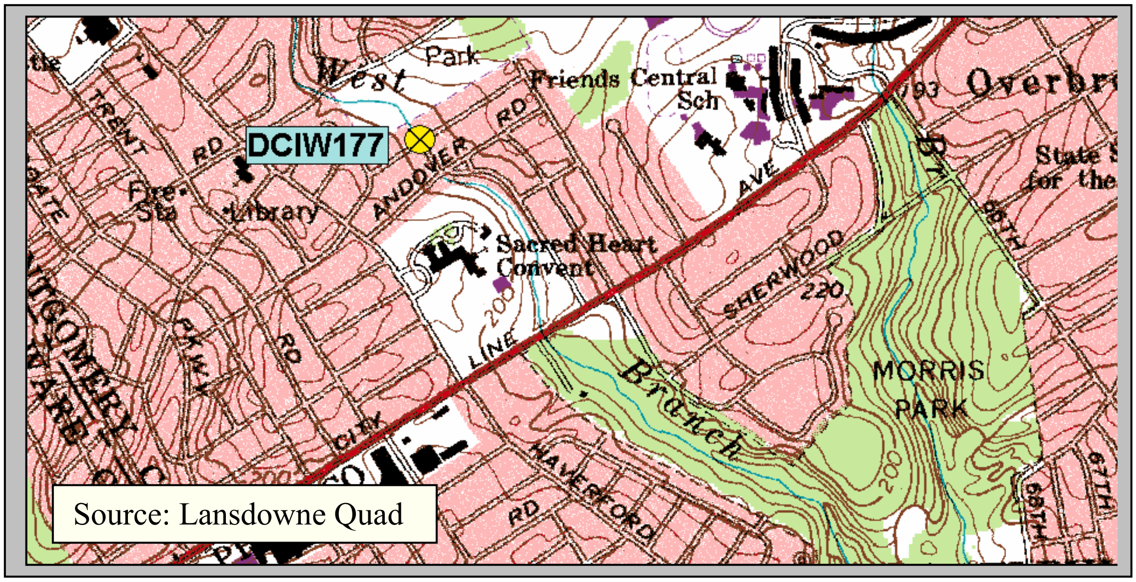
Description:

Site DCI010 is located within the Cobbs Creek Golf Course on Indian Creek. The site is positioned 100 meters upstream up a golf cart crossing. The surrounding land use is Cobbs Creek Golf Course.

2.6. DCIW 177: Darby-Cobbs Study Area Montgomery County

Upstream view of DCIW177

Downstream view of DCIW177



Source: Lansdowne Quad

Location:

Access gained at Manoa and Wiltshire Roads. The site is adjacent to Penn Wynne Playground. (Latitude: -75.27062, Longitude: 39.98483)

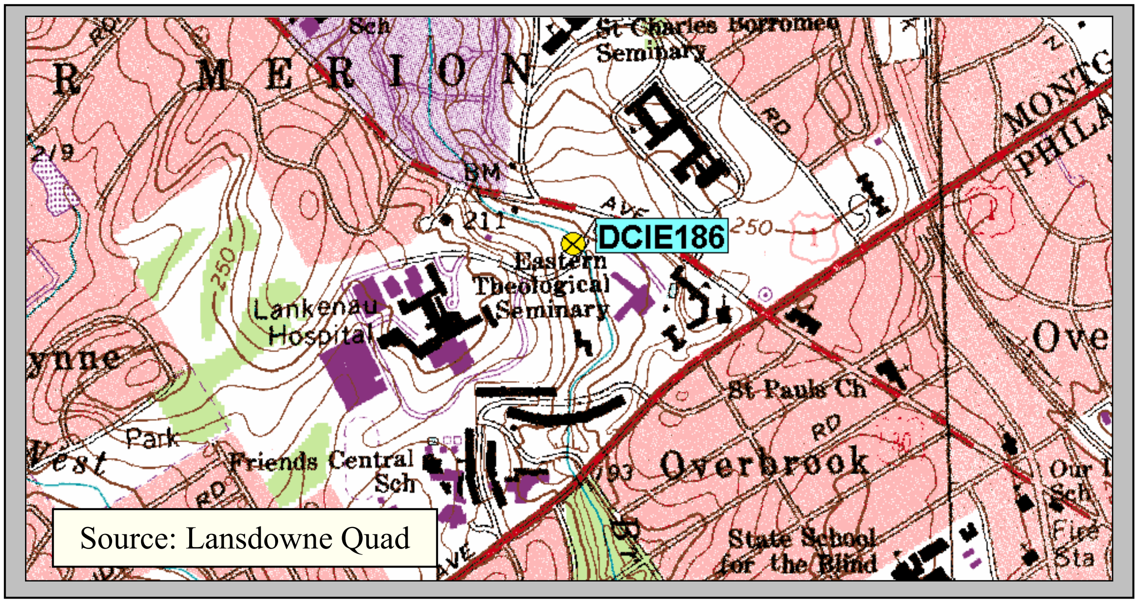
Description:

Site DCIW177 is located on the west branch of Indian Creek near City Line Avenue. The stream is channelized at this portion with vegetation established on the banks. The surrounding land use is a mowed grass ballfield.

2.7. DCIE 186: Darby-Cobbs Study Area Montgomery County

Upstream view of DCIE186

Downstream view of DCIE186



Source: Lansdowne Quad

Location:

Access gained from Lankenau Hospital parking area. (Latitude: -75.25912, Longitude: 39.98964)

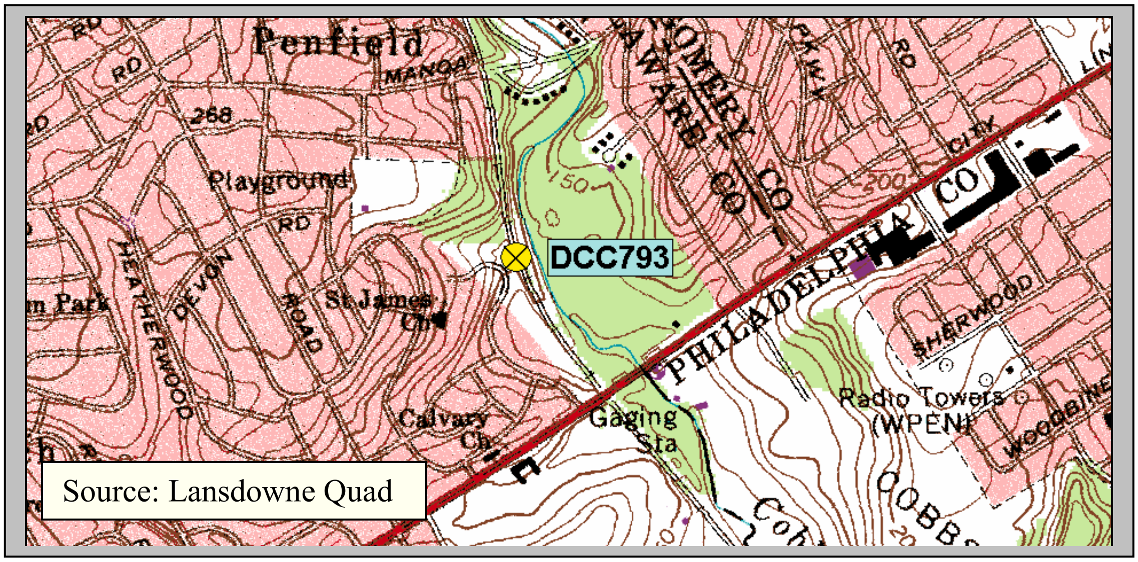
Description:

DCIE186 is located on the East Branch of Indian Creek near the Lankenau Hospital. The surrounding land use consists of the hospital as well as other commercial facilities and residential areas.

2.8. DCC 793: Darby-Cobbs Study Area Delaware County

Upstream view of DCC793

Downstream view of DCC793



Source: Lansdowne Quad

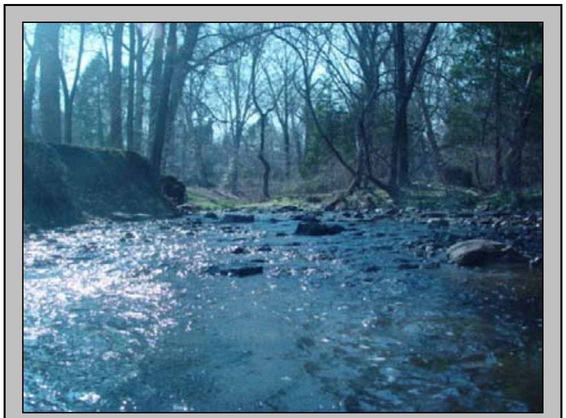
Location:

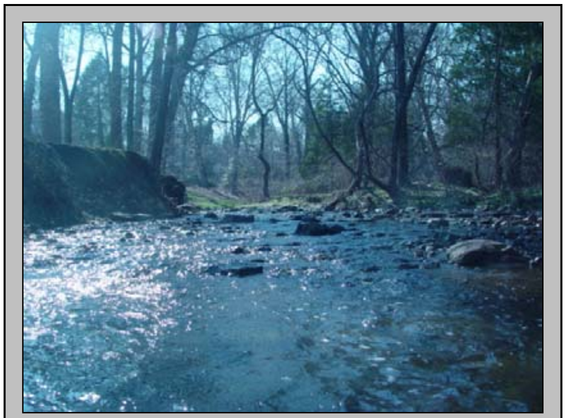
Access gained by a private road on the Grange Estate Property near City Line Avenue (official entrance off of Myrtle Street). (Latitude: -75.28322, Longitude: 39.97710)

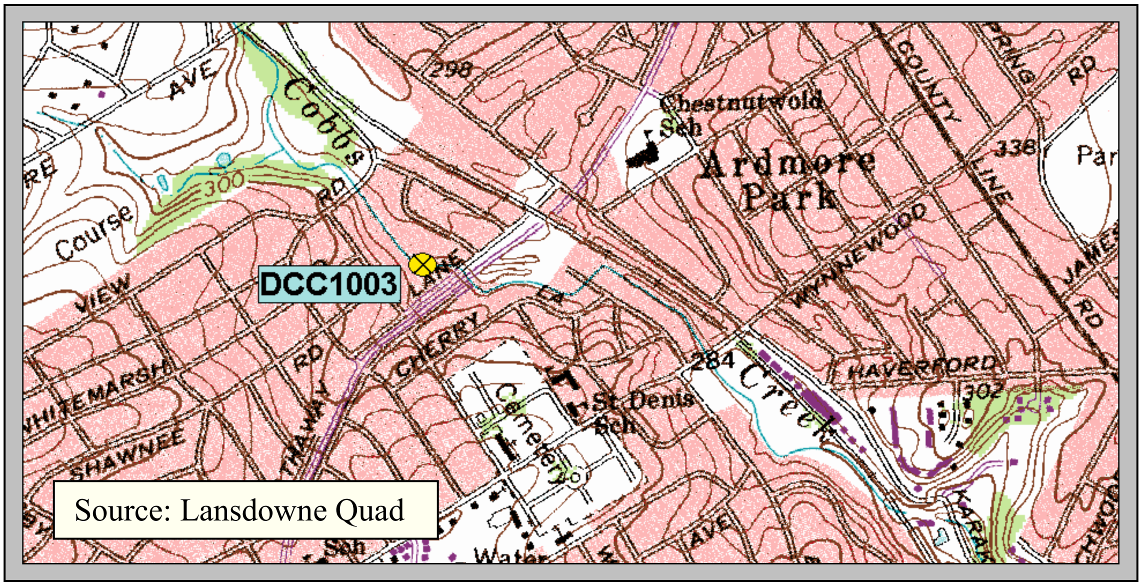
Description:

DCC793 is located on the edge of a private estate. The surrounding land use is residential and field/pasture land. The Creek passes underneath a railroad track close to the site.

2.9. DCC 1003: Darby-Cobbs Study Area Delaware County


Upstream view of DCC1003


Downstream view of DCC1003



Source: Lansdowne Quad

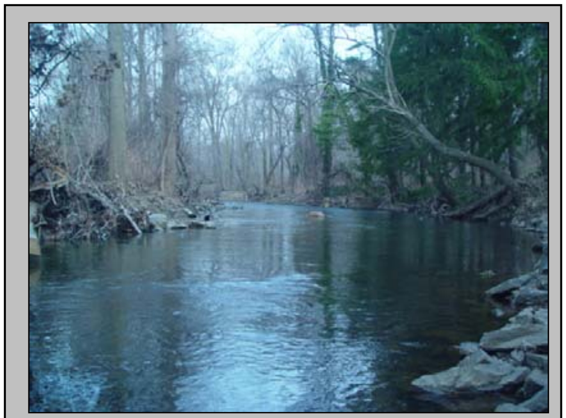
Location:

Access gained from Hathaway Bridge on Hathaway Lane off of Haverford Road. (Latitude: -75.30657, Longitude: 39.99499)

Description:

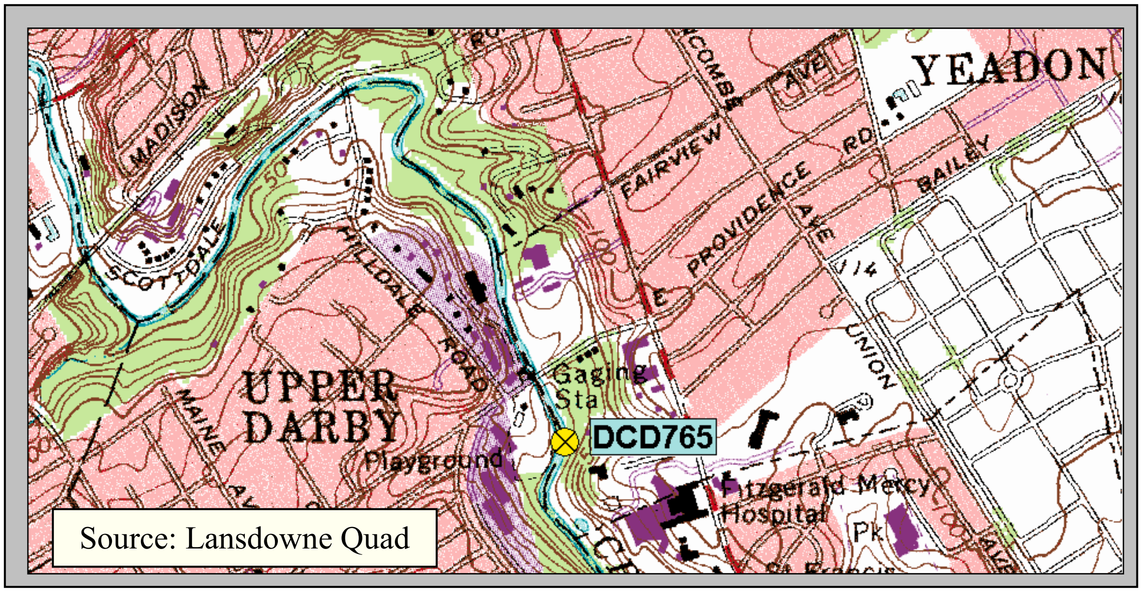
DCC1003 is the most upstream site on Cobbs Creek. It is located just upstream of the bridge on Hathaway Lane. The surrounding land use is single-family residential housing.

2.10. *DCD 765: Darby-Cobbs Study Area* **Delaware County**



Upstream view of DCD765

Downstream view of DCD765



Source: Lansdowne Quad

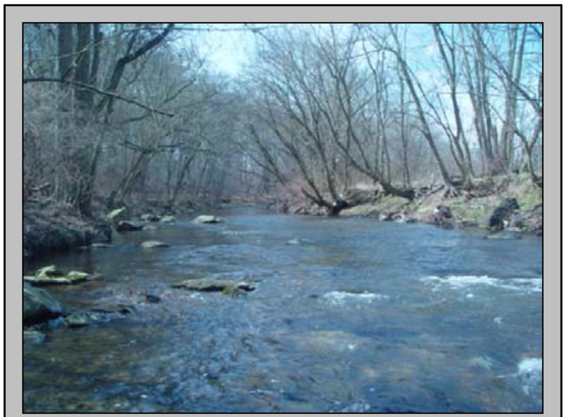
Location:

Access gained from the ballpark and playground located on Providence Road. The site is 100 meters downstream of Providence Road. (Latitude: -75.27214, Longitude: 39.92807)

Description:

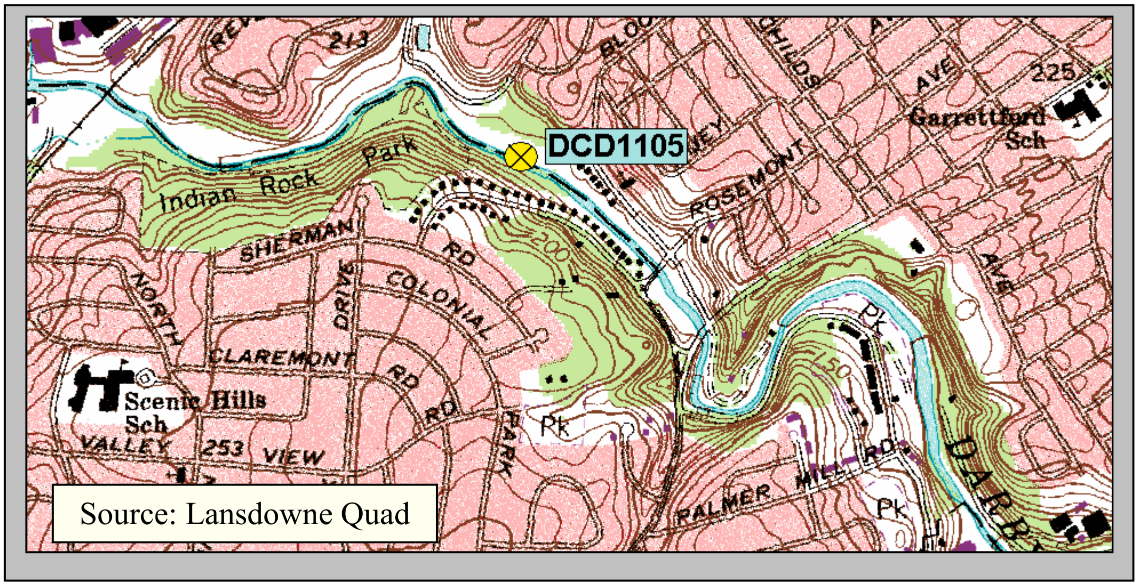
The general land use surrounding DCD765 is residential and commercial. The area immediately surrounding the site includes a baseball field and playground. The left bank of the stream reach has been modified with riprap.

2.11. DCD 1105: Darby-Cobbs Study Area Delaware County



Upstream view of DCD1105

Downstream view of DCD1105



Source: Lansdowne Quad

Location:

Access gained through the delivery entrance at Drexelbrook Apartments on Bloomfield Ave. The stream segment is reached by driving through the parking lot past a large white banquet facility and is 250 meters past a yellow gate. (Latitude: -75.31195, Longitude: 39.94261)

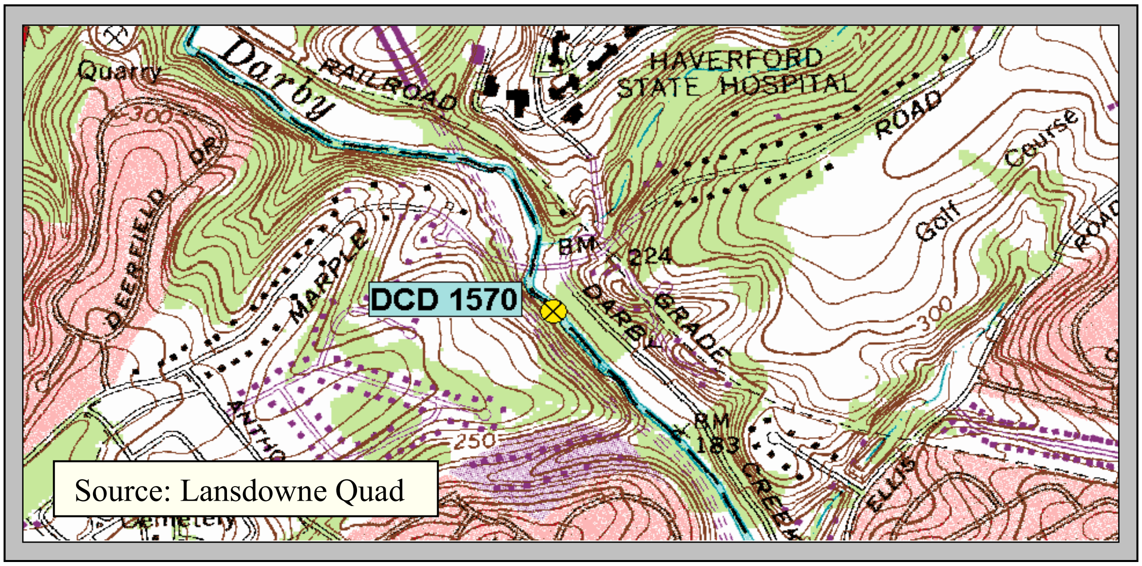
Description:

DCD1105 is located off of Bloomfield Avenue near Indian Rock Park. Forest and residential land use surround the site. Riprap has been placed on the left bank of the reach.

2.12. DCD 1570: Darby-Cobbs Study Area **Delaware County**

Upstream view of DCD1570

Downstream view of DCD1570



Source: Lansdowne Quad

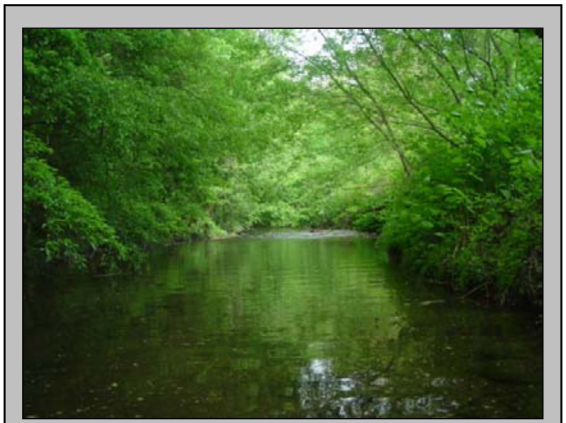
Location:

Access gained from Darby Creek Road. The creek was reached by use of an access road typically chained off by RHM Sewer Authority. (Latitude: -75.34313, Longitude: 39.98887)

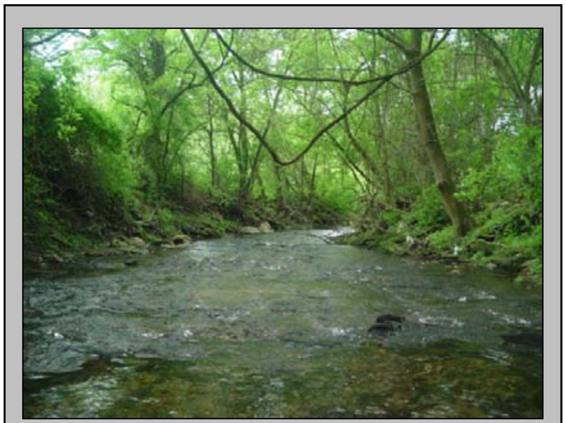
Description:

Site DCD1570 is located off of Darby Creek Road near the Marple Road overpass of Interstate 476. The site is situated alongside Interstate 476. The predominant land use surrounding the site is forest and the interstate highway.

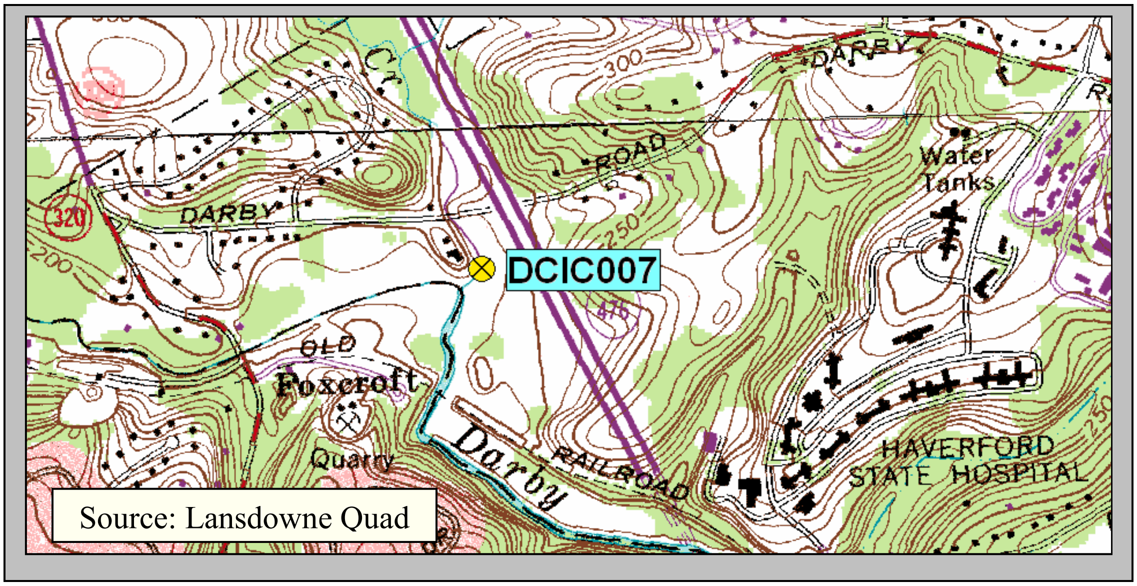
2.13. *DCIC 007: Darby-Cobbs Study Area* Delaware County



Upstream view of DCIC007



Downstream view of DCIC007



Source: Lansdowne Quad

Location:

Access gained from Darby Road in Radnor Township. Site is located 75 meters downstream of Darby Road. (Latitude: -75.35076, Longitude: 39.99756)

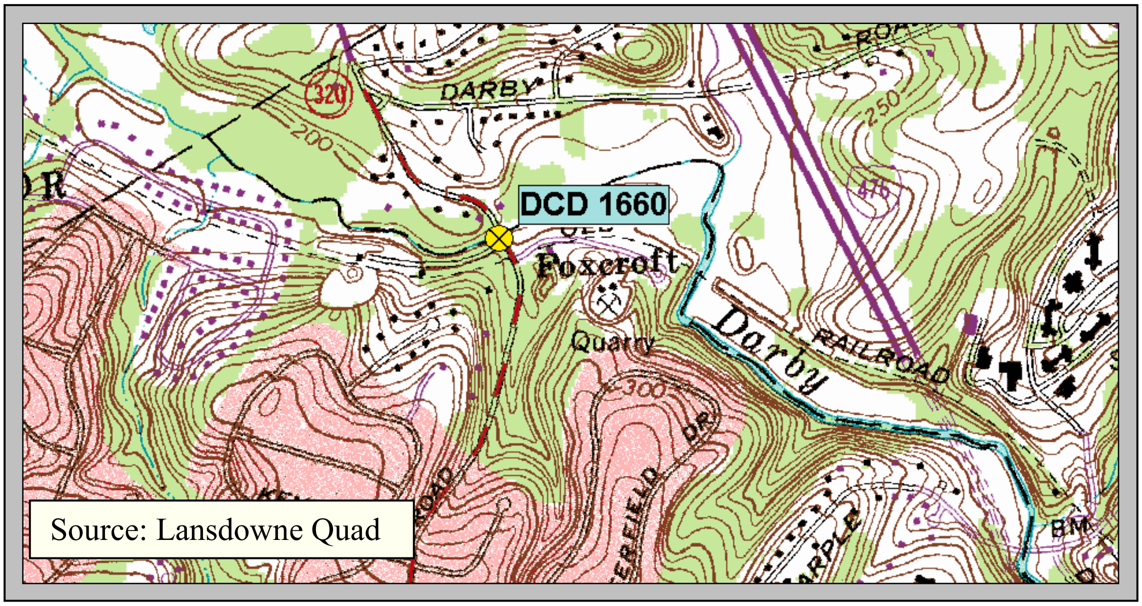
Description:

Site DCIC007 is located on Ithan Creek just downstream of Darby Road near the confluence of Ithan and Darby Creeks. The site is close to Interstate 476 and the Darby Creek Valley Park. The land use surrounding the site is field/pasture and residential.

2.14. DCD 1660: Darby-Cobbs Study Area **Delaware County**

Upstream view of DCD1660

Downstream view of DCD1660



Source: Lansdowne Quad

Location:

Access gained from Sproul Road (Route 320) near the intersection with Darby Road. (Latitude: -75.35633, Longitude: 39.99574)

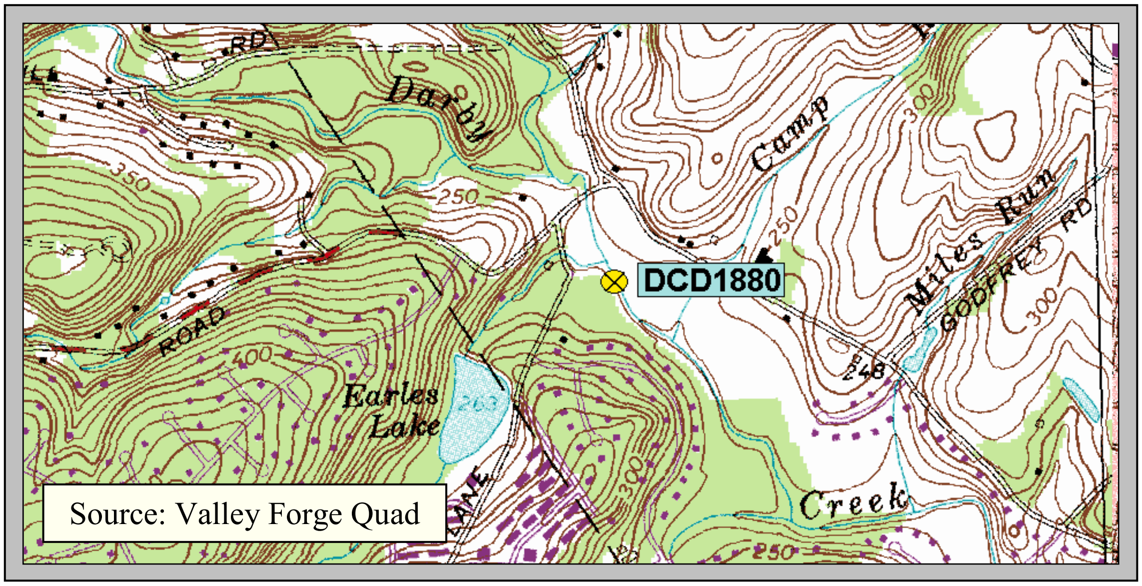
Description:

Site DCD1660 is located just downstream of Sproul Road near its intersection with Darby Road. The surrounding land use is residential.

2.15. DCD 1880: Darby-Cobbs Study Area Delaware County

Upstream view of DCD1880

Downstream view of DCD1880



Source: Valley Forge Quad

Location:

Access gained from Saw Mill Road near the intersection with Earles Lane.
(Latitude: -75.38683, Longitude: 40.01051)

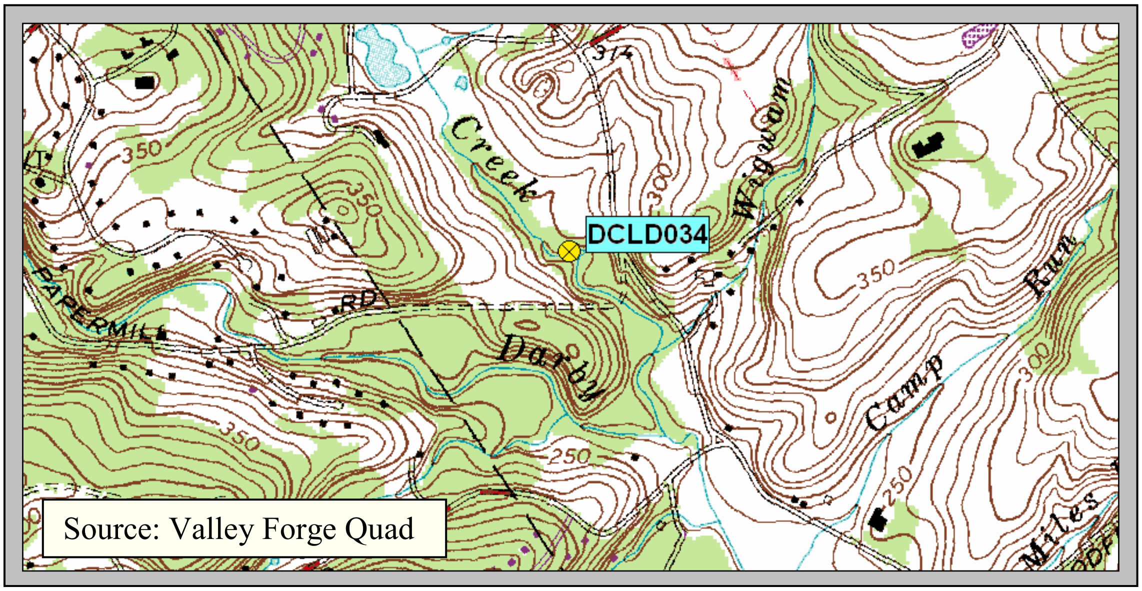
Description:

DCD1880 is located in Sawmill Park in Radnor Township, near the intersection of Saw Mill Road and Earles Lane. The site is just downstream of the confluence with Little Darby Creek. The surrounding land use is predominantly agricultural.

2.16. DCLD 034: Darby-Cobbs Study Area Delaware County


Upstream view of DCLD034


Downstream view of DCLD034



Source: Valley Forge Quad

Location:

Access gained from Darby-Paoli Road. The site is within The Willows Park in Radnor Township. (Latitude: -75.39029, Longitude: 40.01636)

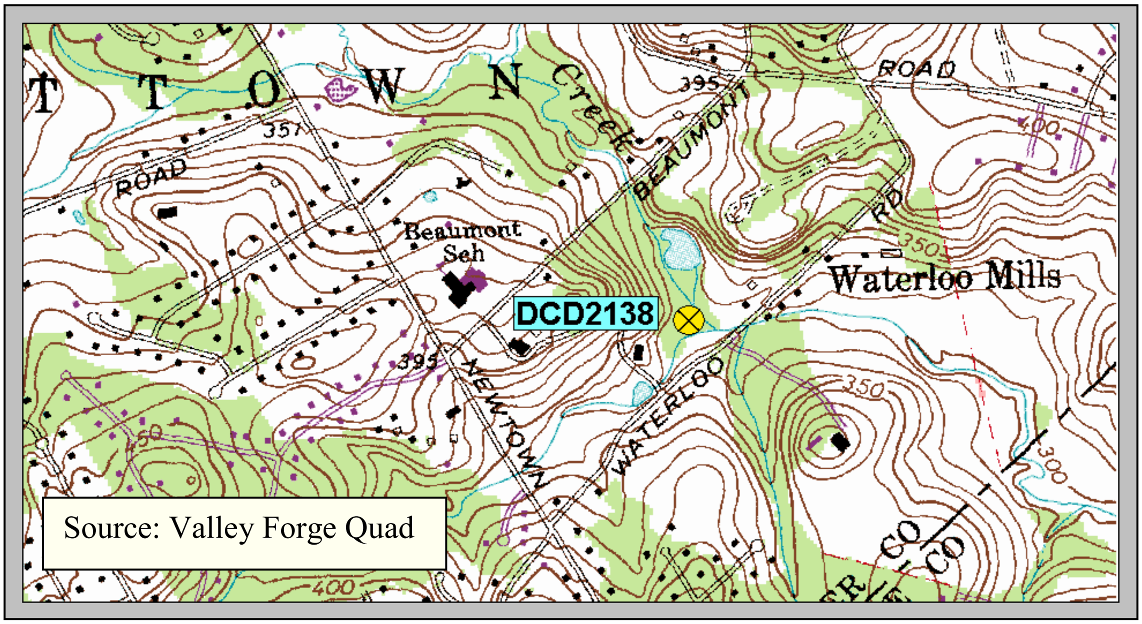
Description:

DCLD034 is located on Little Darby Creek in Radnor Township, Delaware County. The site is off of Darby-Paoli Road in The Willows Park. The surrounding area is field and pasture. A dam is located upstream of the sampled stream reach.

2.17. DCD 2138: Darby-Cobbs Study Area Chester County

Upstream view of DCD2138

Downstream view of DCD2138



Source: Valley Forge Quad

Location:

Access gained from Waterloo Road, east of Darby-Paoli Road. (Latitude: -75.42304, Longitude: 40.02276)

Description:

DCD2138 is the most upstream sampling site on Darby Creek. The site is located within an area managed by the Brandywine Conservancy on Waterloo Road in Chester County. The site is forested, and there is no evidence of nonpoint source pollution.

SECTION 3: WATERSHED DELINEATIONS AND MONITORING LOCATIONS

3.1. Watershed Location

The Darby-Cobbs Watershed is defined as the land area that drains to the mouth of Darby Creek at the Delaware Estuary, encompassing approximately 80 square miles of southeast Pennsylvania (Figure 1). This area includes portions of Chester, Delaware, Montgomery, and Philadelphia Counties. Cobbs Creek drains approximately 14,500 acres or 27% of the total watershed area, and discharges into Darby Creek. The Darby Creek Watershed drains approximately 29,000 acres or 55% of the total study area, and discharges to the Delaware River. Designated uses of Darby-Cobbs Watershed include warmwater fishery, trout stocked fishery, and migratory fishes (25 PA§ 93.9e).

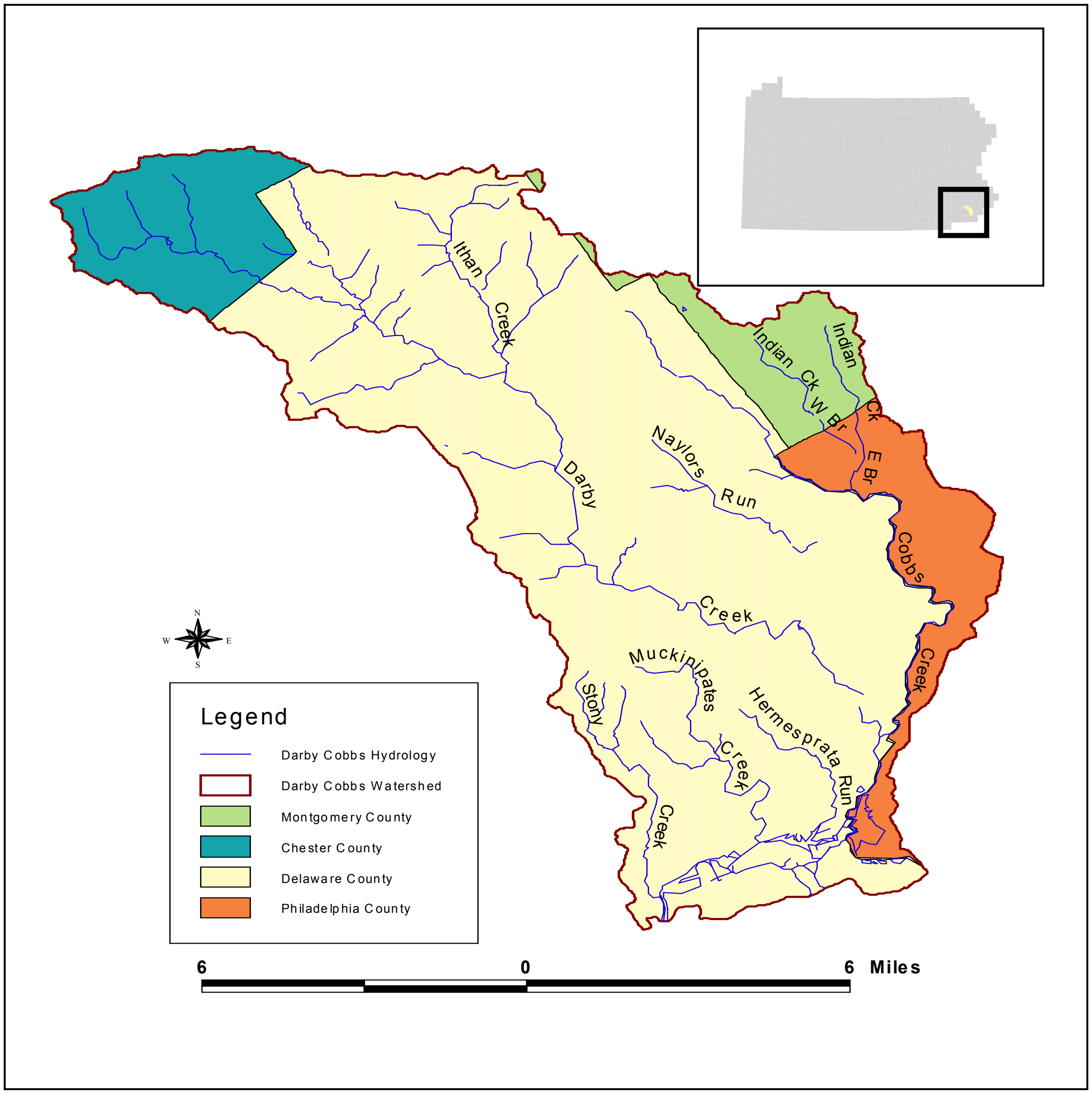


Figure 1. Darby-Cobbs Watershed and associated tributaries.

3.2. *Watershed Land Use*

Figure 2 shows land use patterns in the Darby-Cobbs Watershed consist primarily of single family residential areas (78.3%). Parklands (wooded and recreational areas), represent approximately three percent of land usage in the watershed, but make up a significant portion of land adjacent to Darby-Cobbs Watershed, providing buffer zones around the creek and its tributaries.

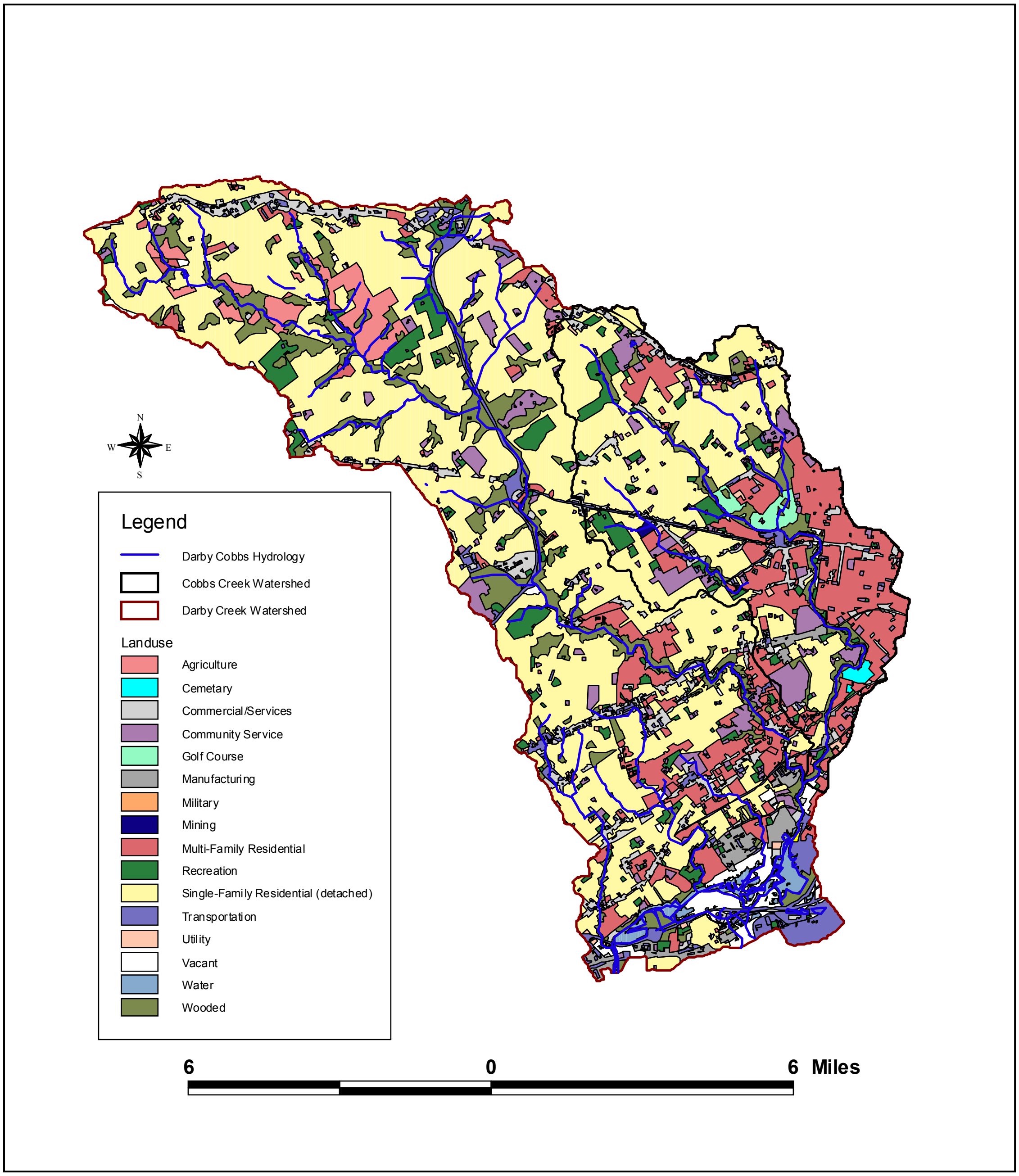


Figure 2. Darby-Cobbs Watershed land use patterns.

3.3. PWD Monitoring Locations (2003)

PWD has 27 monitoring locations in Darby-Cobbs Watershed, six of which are located on the main stem of Cobbs Creek, and 14 of which are located on the main stem of Darby Creek. The remaining seven are located on tributaries, namely the east and west branches of Indian Creek, Ithan Creek, Little Darby, and Naylor's Run. Figure 3 displays locations of these monitoring sites, as well as the type of assessments performed (i.e., discrete chemical, RBP III, habitat, RBP V, or tidal assessments).

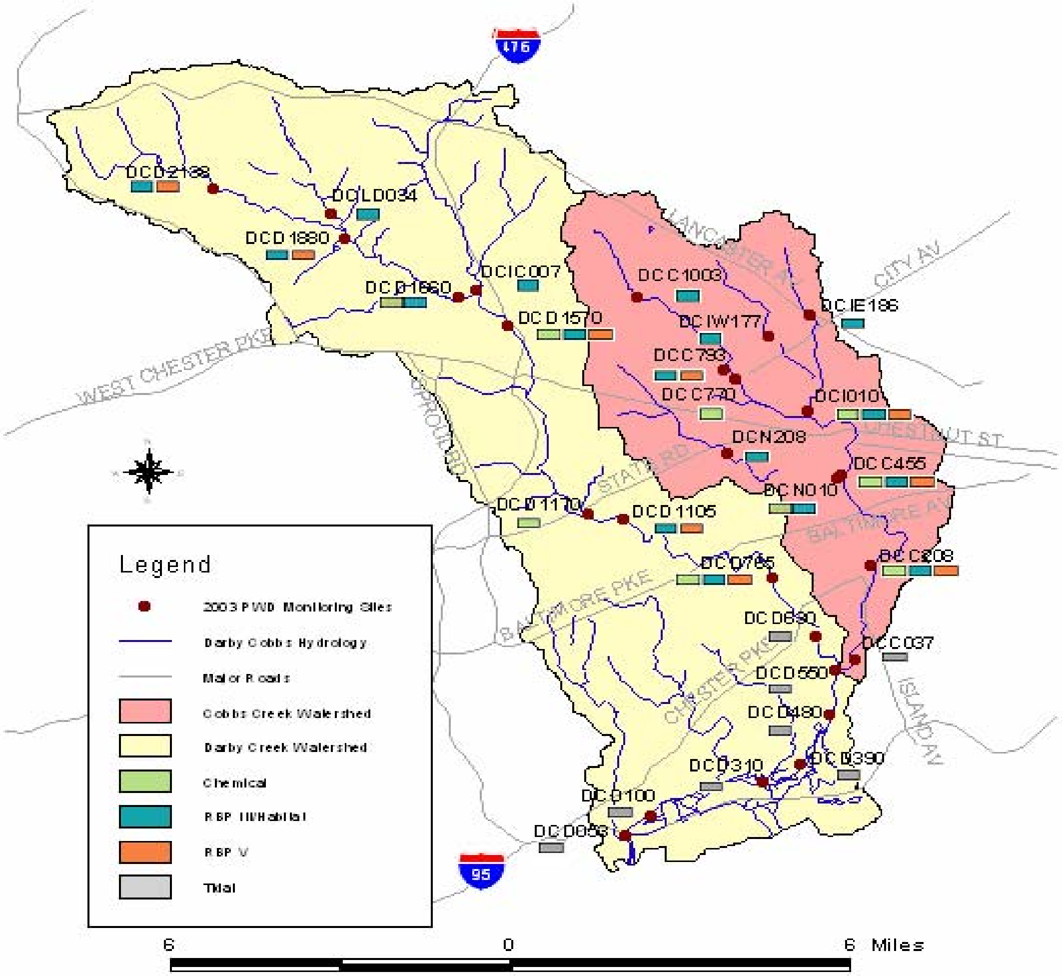


Figure 3. PWD monitoring locations in the Darby-Cobbs Watershed.

3.4. PWD Continuous and Wet Weather Monitoring Locations

Of 27 PWD monitoring locations in Darby-Cobbs Watershed, five sites were designated as continuous and wet weather monitoring locations in 2003 (Figure 4). More specifically, each location was a deployment site for an automated sampler (i.e., Sonde), which continuously measures dissolved oxygen, specific conductance, pH, depth, turbidity, and temperature, or an Isco automated sampler, which collects samples later analyzed in the laboratory for ammonia, fecal coliform, BOD_5, metals, and other relevant parameters at scheduled times during wet weather events.

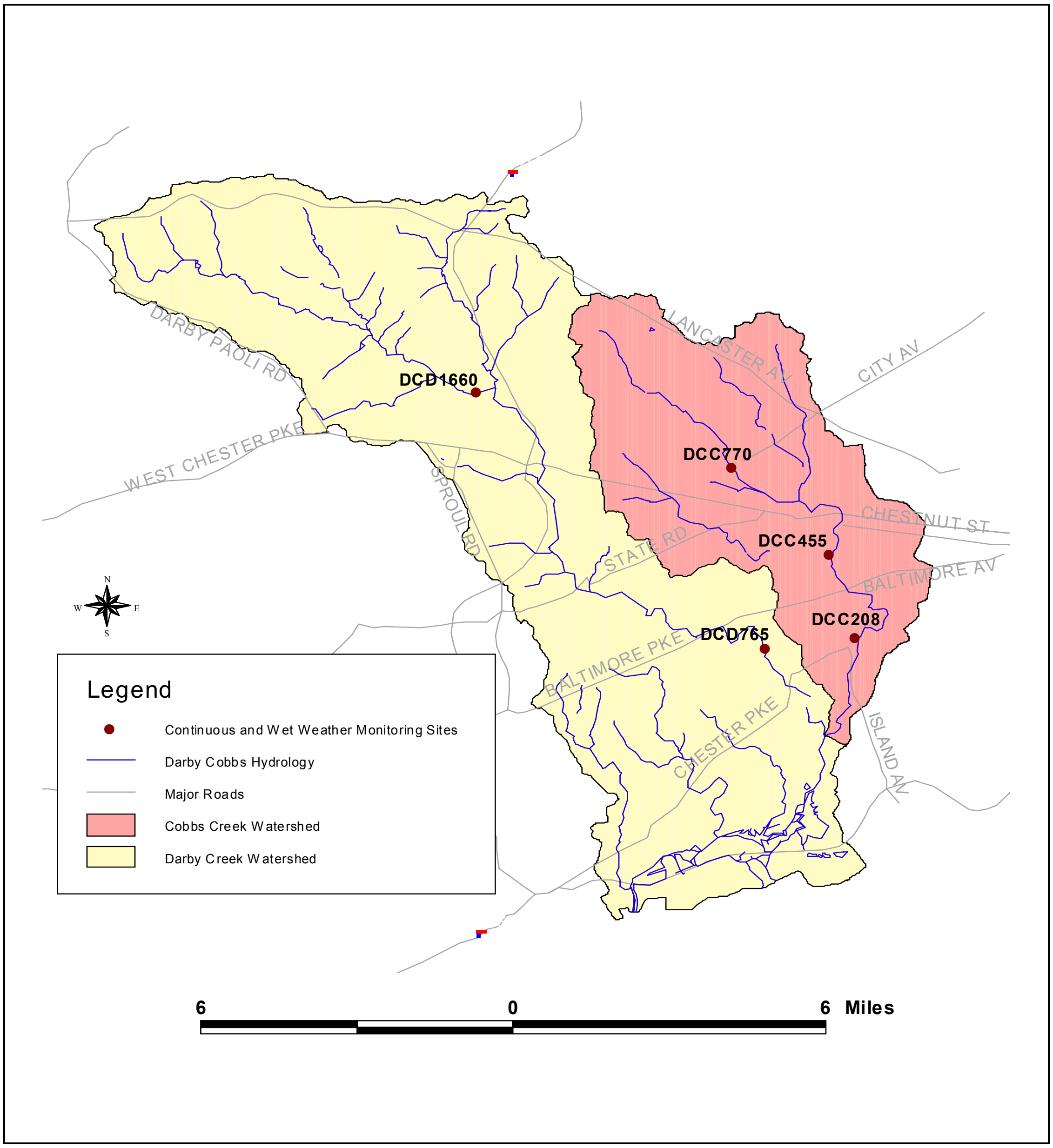


Figure 4. PWD continuous and wet-weather monitoring locations in Darby-Cobbs Watershed

3.5. PWD Tidal Assessment Monitoring Locations

Six of 27 PWD monitoring locations in Darby-Cobbs Watershed are tidal assessment sites (Figure 5). The tidal assessment area extends approximately 6.6 miles upstream from Darby Creek's confluence with the Delaware River. Tidal assessments also extended approximately 0.8 miles into the Darby main stem and approximately 0.4 miles into the Cobbs Creek main stem from the confluence of the two creeks.

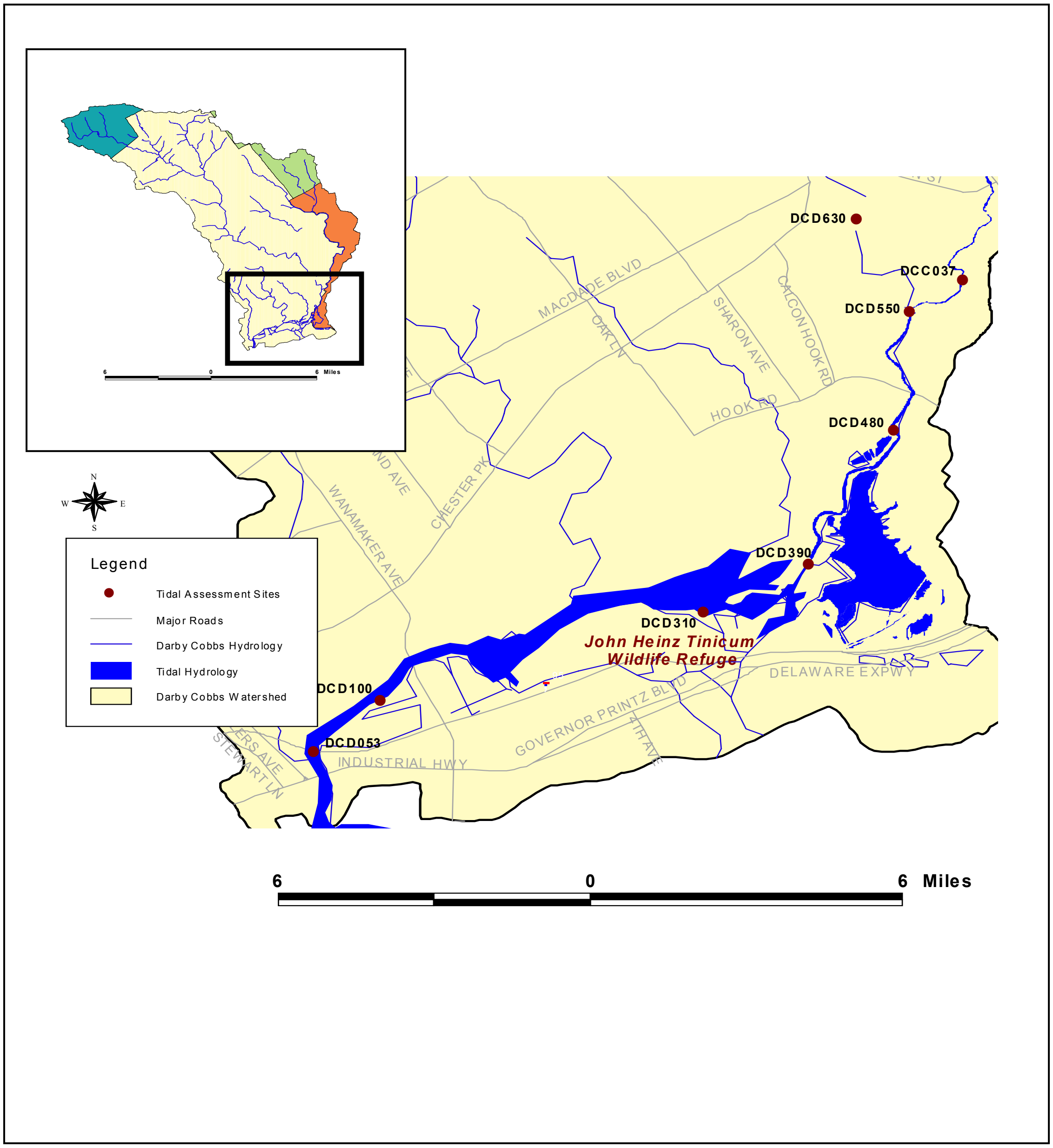


Figure 5. Tidal assessment locations in lower Darby Creek.

3.6. PADEP Monitoring Locations and Attainment Status

As part of its Statewide Surface Water Assessment Program, formerly the Unassessed Waters Program, PADEP conducted modified rapid bioassessment protocols at 28 locations in Darby-Cobbs Watershed. PADEP used benthic macroinvertebrate and habitat data collected during the assessments to determine the health of Darby-Cobbs Watershed and to identify potential stressors on stream segments determined to be impaired, or "not attaining" their designated uses. Figure 6 depicts PADEP's 28 monitoring locations as well as designations made by PADEP for stream segments in Darby-Cobbs Watershed.

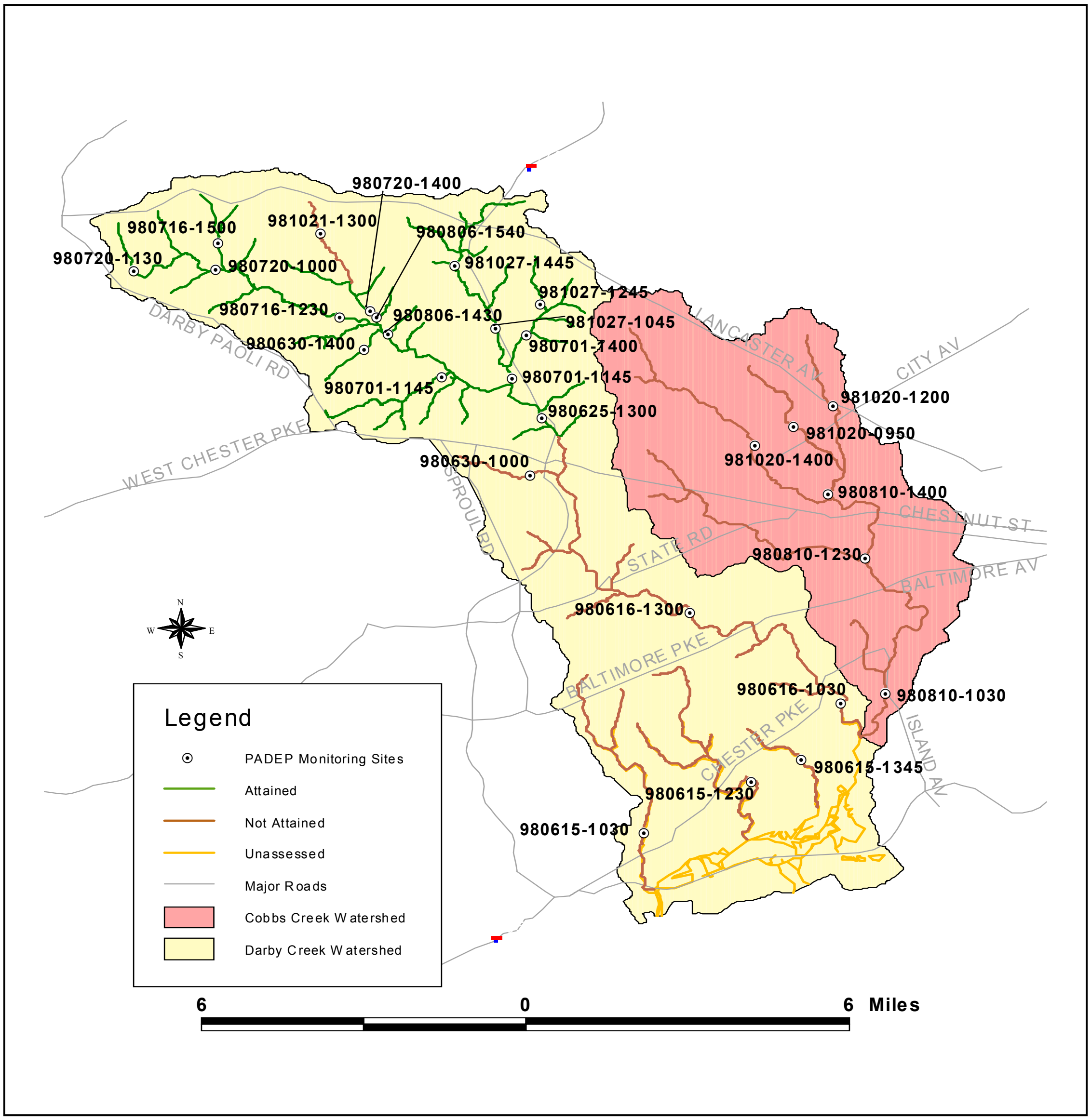


Figure 6. PADEP surface water assessment locations (1998-1999)

3.7. Historical United States Geological Survey (USGS) Monitoring Locations (1964-1990)

The United States Geological Survey (USGS) has historically monitored water quantity and quality at four locations in Darby-Cobbs Watershed (Figure 7). Water quality monitoring at the four stations in Cobbs Creek began in 1967, but was eventually terminated by 1983. Similarly, measurements of stream flow (Q) commenced in 1964 and were discontinued at all locations by 1990.

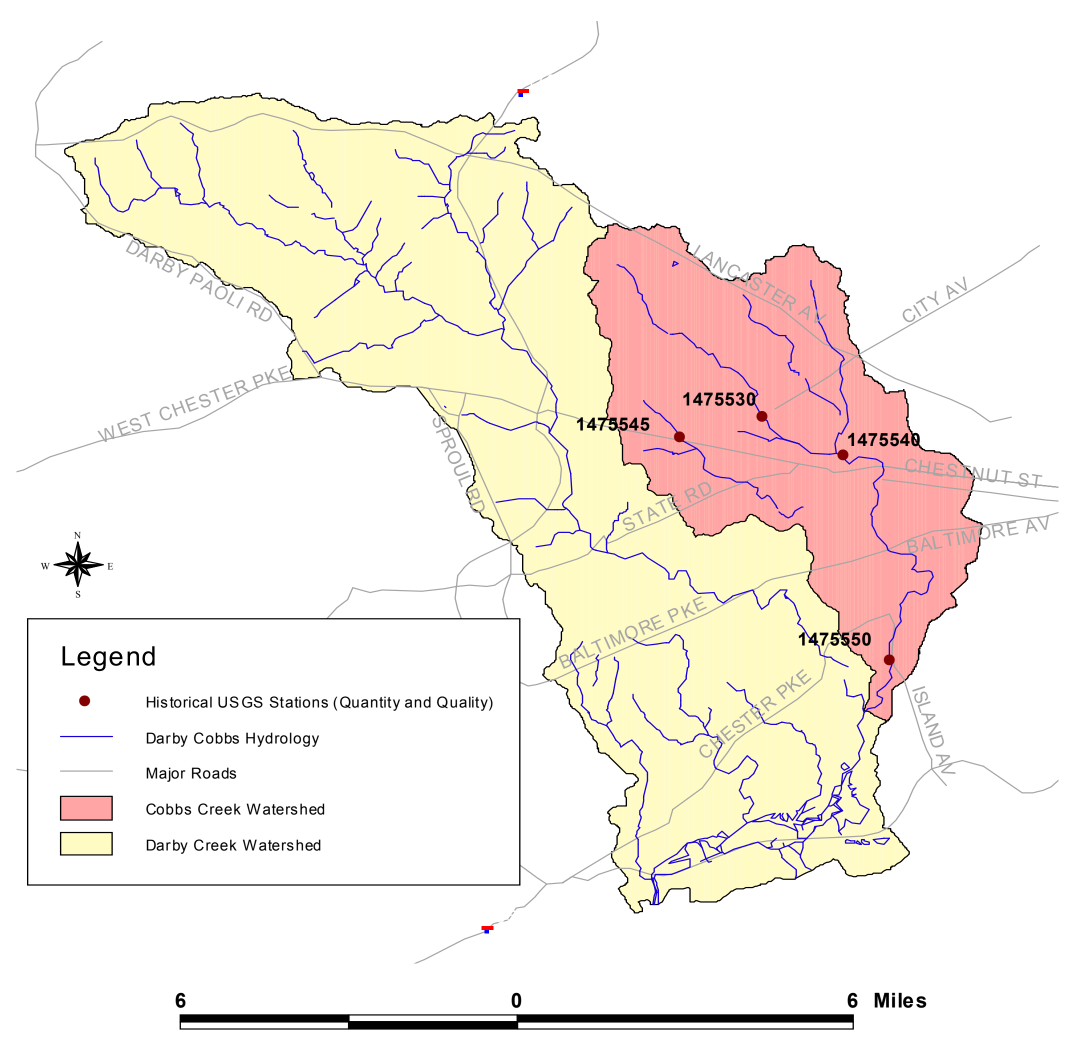


Figure 7. Historical USGS monitoring locations in Darby-Cobbs Watershed.

SECTION 4: METHODS

Standard Operating Procedures for Philadelphia Water Department's Watershed Assessment Program are available on the world-wide web at the following URL: http\\: phillywater.org

4.1. Benthic Macroinvertebrate Sampling

During 3/1/03 to 3/27/03, the Philadelphia Water Department conducted Rapid Bioassessment Protocols (RBP III) at seventeen (n=17) locations within Darby-Cobbs Watershed. Using EPA guidelines, macroinvertebrates were collected by placing a standard ($1m^2$) kicknet at the downstream portion of a riffle. The substrate was then kicked and scraped manually one meter from the net aperture to remove benthic invertebrates. Four rocks of varying size were randomly chosen within the sampling sites and manually scraped to remove benthic invertebrates. This procedure was repeated at another riffle location with less flow. Specimens were then preserved in 70% ETOH (ethyl alcohol) and returned to the laboratory in polyethylene containers. In the laboratory, samples were placed in an 11" x 14" gridded (numbered) pan and random "plugs" were examined until 100 individuals were collected. Macroinvertebrates were identified to genus, and population estimates were calculated.

4.1.1. Metrics:

Using the following chart, the biological integrity and benthic community composition was determined (EPA guidelines for RBP III and PADEP Modified Rapid Biological Assessments) (Table 1).

Table 1. Biological condition scoring criteria for RBP III.

Metric	Biological Condition Scoring Criteria			
	6	4	2	0
Taxa Richness (a)	>80%	79-70%	69-60%	<60%
Hilsenhoff Biotic Index (Modified) (a)	<0.71	0.72-1.11	1.12-1.31	>1.31
Modified EPT Index (a)	>80%	79-60%	59-50%	<50%
%Contribution of Dominant Taxon (a)	<10	11-16	17-22	>22
%Modified Mayflies (a)	<12	13-20	21-40	>40
Ratio of Scrapers/Filter (b) Collectors	>50%	35-50%	20-35%	<20%
Community Loss Index (b)	<0.5%	0.5-1.5	1.5-4.0	>4.0
Ratio of Shredders/Total (b)	>50%	35-50%	20-35%	<20%

[a] Metrics used to quantify scoring criteria (PADEP)

[b] Additional metrics used for qualitative descriptions of sampling locations (EPA)

Upon completion of the total biological scoring criteria, each site was compared to a reference site according to its drainage area and geomorphologic attributes. The reference sites chosen were French Creek, located at Coventry Road Bridge, South Coventry Township, Chester County and Rock Run, a tributary of French Creek (Appendix A). Using the following chart, benthic quality of each site was established to identify spatial trends of impairment along the river continuum (Table 2).

Table 2. Biological condition categories for RBP III.

% Comparison to Reference Score [(a)]	Biological Condition Category	Attributes
>83%	Nonimpaired	Comparable to the best situation within an ecoregion. Balanced trophic structure. Optimum community structure for stream size and habitat quality.
54-79%	Slightly impaired	Community structure less than expected. Species composition and dominance lower than expected due to loss of some intolerant forms. Percent contribution of tolerant forms increases.
21-50%	Moderately impaired	Fewer species due to loss of most intolerant forms. Reduction in EPT index.
<17%	Severely impaired	Few species present. If high densities of organisms, then dominated by one or two taxa.

(a) Percentage values obtained that are intermediate to the above ranges will require subjective judgment as to the correct placement. Use of the habitat assessment and chemical data may be necessary to aid in the decision process.

4.2. Ichthyofaunal (Fish) Sampling

4.2.1. Fish Collection in Non-Tidal Portions

Between 6/16/03-7/8/03, PWD biologists conducted fish assessments at nine (n = 9) locations within Darby-Cobbs Watershed (Figure 3). Fish were collected by electrofishing as described in EPA's Rapid Bioassessment Protocol V (RBP V) (Barbour et al., 1999). Depending on stream conditions, Smith-Root backpack or tote barge electrofishers were used to stun fish. A 100m reach of the stream was blocked at the upstream and downstream limits with nets to prevent immigration or emigration from the study site. Each reach was uniformly sampled, and all fish captured were placed in buckets for identification and counting. An additional pass without replacement was completed along the reach to insure maximum likelihood population and biomass estimates.

4.2.2. Fish Collection in Tidal Portions

Between 7/10/03-8/25/03, staff biologists completed fish assessments at eight (n=8) tidal locations in the Darby-Cobbs Watershed (Figure 5). Tote-barge electrofishers were used at the two most upstream tidal reaches of Darby and Cobbs Creeks (DCD 630 and DCC 037, respectively). Fish inhabiting nonwadeable tidal portions of the Darby-Cobbs Watershed were collected with Smith-Root electrofishing apparatus mounted aboard a small aluminum-hulled jonboat. Electrofishing was conducted for ten-minute intervals in a downstream direction, targeting areas with suitable fish habitat. It was not feasible to install block nets or otherwise prevent net movement of fish into or out of the sampling area.

4.2.3. Sample Processing

Fish were identified to species, weighed (± 0.01 g) with a digital scale (Model Ohaus Scout II) and measured to the nearest 0.1 cm using a Wildco fish measuring board. Large fish that exceeded the digital scale's capacity were weighed using spring scales (Pesola). Any external deformations, lesions, tumors, cysts, or disease were noted during processing. Species that could not be identified in the field (e.g., small or juvenile cyprinids) were preserved with 10% formalin solution and stored in polyethylene bottles for laboratory identification.

To facilitate the process of acquiring total fish biomass and to reduce field time, a simple linear regression was developed between weight (g) and length (cm). Approximately 20 individuals of each species were weighed, and total lengths were measured. Once 20 individuals of each species were measured (both weight and length), biomass (g) for each fish was calculated using the regression analysis. Results of the regression analysis on individual fish species can be found in Appendix B. Similar procedures were conducted at the reference locations (i.e., French Creek and Rock Run) to obtain a discrete measure of the condition of the fish assemblages at each assessment location.

4.2.4. Fish IBI Metrics:

The health of fish communities in Darby-Cobbs Watershed were based on the technical framework of the Index of Biological Integrity (IBI) developed by Karr (1981). The analysis entailed the definition of "ecoregional-specific" metrics pertinent to the fish assemblages located in the lower Schuylkill River Drainage. Standardized metrics (i.e., indices) were then integrated to provide an overall indication of the condition of fish assemblages at each assessment location. Individual metrics within the fish IBI framework were also used to provide quantitative information regarding a specific attribute of the respective assessment location (e.g., pollution tolerance values). In addition to IBI metrics, other metrics were incorporated into the design to evaluate the overall ecological health of fish assemblages and as a means of comparison of each assessment site. Tables 3 and 4 describe the various indices and scoring criteria used for the IBI metrics in the Darby-Cobbs Watershed. Additional metrics used in the analysis are displayed in Table 5.

Table 3. Metrics used to evaluate the Index of Biological Integrity (IBI) at representative sites. *

Metric	**Scoring Criteria**		
	5	3	1
1. Number Of Native Species	>67%	33-67%	<33%
2. Number Of Benthic Insectivore Species	>67%	33-67%	<33%
3. Number Of Water Column Species	>67%	33-67%	<33%
4. Percent White Sucker	<10%	10-25%	>25%
5. Number Of Sensitive Species	>67%	33-67%	<33%
6. Percent Generalists	<20%	20-45%	>45%
7. Percent Insectivores	>45%	20-45%	<20%
8. Percent Top Carnivores	>5%	1-5%	<1%
9. Proportion of diseased/anomalies	<1%	1-5%	>5%
10. Percent Dominant Species [a]	<40%	40-55%	>55%

*Metrics used are based on modifications as described in Barbour, *et al.*, 1999.

[a] Metric based on USGS NAWQA study (2002).

Table 4. Index Of Biological Integrity (IBI) score interpretation.*

IBI	Integrity Class	Characteristics
45-50	**Excellent**	Comparable to pristine conditions, exceptional assemblage of species
37-44	**Good**	Decreased species richness, intolerant species in particular
29-36	**Fair**	Intolerant and sensitive species absent; skewed trophic structure
10-28	**Poor**	Top carnivores absent or rare; omnivores and tolerant species dominant
<10	**Very Poor**	Few species and individuals present; tolerant species dominant; diseased fish frequent

* IBI score interpretation based on Halliwell, *et al.*, 1999.

Table 5. Additional metrics used to evaluate fish assemblage condition.

Metric	Assessment Type
Species Diversity	Shannon (H') Diversity Index
Trophic Composition	Percentage of Functional Feeding Groups
Tolerance Designations	Percentage of Pollution Tolerant, Moderate And Intolerant Species
Modified Index Of Well-Being	MIwb Index

4.2.5. Species Diversity:

Species diversity, a characteristic unique to the community level of biological organization, is an expression of community structure (Brower, *et al.*, 1990). In general, high species diversity indicates a highly complex community. Thus, population interactions involving energy transfer (e.g. food webs), predation, competition and niche distribution are more complex and varied in a community of high species diversity. In addition, many ecologists support species diversity as a measure of community stability (i.e., the ability of community structure to be unaffected by, or recover quickly from perturbations). Using the Shannon (H') Diversity Index formula, species diversity was calculated at each sampling location:

$$H' = -\Sigma\, n_i/N * \ln(n_i/N): \qquad \text{(eq. 1)}$$

where n_i is the relative number of the *i*th taxon.

4.2.6 Trophic Composition and Tolerance Designations:

Trophic composition metrics were used to assess the quality of the energy base and trophic dynamics of the fish assemblages (Plafkin *et al*., 1989). The trophic composition metrics offer a means to evaluate the shift toward more generalized foraging that typically occurs with increased degradation of the physiochemical habitat (Barbour et al., 1999). Pollution tolerance metrics were also used to distinguish low and moderate quality sites by assessing tolerance values of each species identified at the sampling locations. This metric identifies the abundance of tolerant, moderately tolerant and pollution intolerant individuals at the study site. Generally, intolerant species are first to disappear following a disturbance. Species designated as intolerant or sensitive should only represent 5-10% of the community; otherwise the metric becomes less discriminating. Conversely, study sites with fewer pollution intolerant individuals may represent areas of degraded water quality or physical disturbance. For a more detailed description of metrics used to evaluate the trophic and pollution designations of fish assemblages, see Barbour, *et al*., (1999).

4.2.7. Modified Index of Well-Being (MIwb):

Modified Index of Well-Being (MIwb) is a metric that incorporates two abundance and two diversity measurements. Modifications from the Ohio EPA (1987), which eliminate pollution tolerant species, hybrids and exotic species, were incorporated into the study in order to increase the sensitivity of the index to a wider array of environmental disturbances. MIwb is calculated using the following formula (equation 2):

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

where;

N = relative numbers of all species
B = relative weight of all species
H_N = Shannon index based on relative numbers
H_B = Shannon index based on relative weight

4.2.8. Biomass Per Unit Area:

This metric evaluates the relative biomass of fish within a given site relative to the area sampled. In general, as streams increase in width, the biomass of fish tends to increase in areas of suitable habitat, physical stability and appropriate water quality. Decreases in biomass per unit area may be attributed to episodic or chronic periods of degraded water quality and/or poor habitat heterogeneity.

4.3. Habitat Assessment

4.3.1. EPA Habitat Assessment

Prior to benthic macroinvertebrate sampling procedures, habitat assessments at 17 sites were completed based on the *Stream Classification Guidelines for Wisconsin* (Ball, 1982) and *Methods of Evaluating Stream, Riparian, and Biotic Conditions* (Platts et al., 1983). Reference conditions were used to normalize the assessment to the "best attainable" situation. Habitat parameters are separated into three principal categories: (1) primary, (2) secondary, and (3) tertiary parameters. Primary parameters are those that characterize the stream "microscale" habitat and have greatest direct influence on the structure of indigenous communities. Secondary parameters measure "macroscale" habitat such as channel morphology characteristics. Tertiary parameters evaluate riparian and bank structure and comprise three categories: (1) bank vegetative protection, (2) grazing or other disruptive pressure, and (3) riparian vegetative zone width. The following chart lists the various parameters addressed during habitat assessments (Table 6):

Table 6. Habitat assessment criteria used at benthic monitoring stations.

Condition/Parameter	Condition			
	Optimal	Suboptimal	Marginal	Poor
Epifaunal Substrate/Available Cover	16-20	11-15	6-10	0-5
Pool Substrate Characterization	16-20	11-15	6-10	0-5
Pool Variability	16-20	11-15	6-10	0-5
Sediment Deposition	16-20	11-15	6-10	0-5
Embeddedness	16-20	11-15	6-10	0-5
Velocity/Depth Regime	16-20	11-15	6-10	0-5
Frequency of Riffles (or bends)	16-20	11-15	6-10	0-5
Channel Flow Status	16-20	11-15	6-10	0-5
Channel Alteration	16-20	11-15	6-10	0-5
Channel Sinuosity	16-20	11-15	6-10	0-5
Bank Stability**	10-9	8-6	5-3	2-0
Vegetative Protection**	10-9	8-6	5-3	2-0
Riparian Vegetative Zone Width**	10-9	8-6	5-3	2-0

**Both right and left banks are assessed separately.

4.3.2. Habitat Suitability Index (HSI) Model Methods

4.3.2.1. Model History and Assumptions

Prior to the development of Instream Flow Incremental Methodology (IFIM), a number of Habitat Suitability Index (HSI) models were developed by the U.S. Fish and Wildlife Service (USFWS). Based on empirical data and supported by years of research and comprehensive review of scientific literature, these models present numerical relationships between various habitat parameters and biological resources, particularly gamefish species and species of special environmental concern. Through evaluation of various input parameters, models arrive at a final index value between 0 and 1, a score of 1 corresponding to the ideal habitat condition, and zero indicating that some aspect of the habitat is unsuitable for supporting a naturally reproducing population of the species of interest.

Numerous assumptions are inherent with use and interpretation of the models. First and foremost is the assumption that habitat features alone are responsible for determining abundance or biomass of the species of interest at the study site. Clearly, no species exists in a vacuum; aside from habitat variables, other ecological and environmental interactions can strongly influence biological communities. HSI indices assume that users will use good professional judgment, consult with regional experts when necessary, and consider the possible effects of other factors (e.g., competition, predation, toxic substances and other anthropogenic factors) when interpreting model output.

4.3.2.2. Model Data Requirements

Most types of data required by HSI models were available for all sites within Darby-Cobbs Watershed. However, a number of habitat parameters were not directly measured in a fashion best suited for use with HSI models and required additional interpretation or normalization. Few water quality parameters were measured with equal sampling effort across all sites; some parameters were measured with continuous monitoring instruments at some sites and grab samples or hand-held meters at other sites. Some variables were not directly measured at some sites; to facilitate HSI analysis at these sites, (conservative) values were substituted based on sampling conducted at nearby sites and reference sites in neighboring watersheds. Turbidity data were excluded from the analyses entirely because all HSI were developed using Jackson Turbidity Units (JTU), which cannot be converted to/from modern Nephelometric Turbdity Unit (NTU) data. Any other significant modifications to the variables or the modeling approach are explained in Section 5.3.5. (Habitat Suitability Indices). A list of all HSI input variables for the seven HSI models applied to Darby-Cobbs watershed appears in Table 7.

Table 7. Habitat Suitability Index (HSI) variable matrix.

HSI Model Variable Matrix	**Variable Type**	**Blacknose Dace**	**Common shiner**	**Creek Chub**	**Fallfish**	**Longnose Dace**	**Redbreast Sunfish**	**Smallmouth Bass**
Total number of HSI variables		**16***	**9**	**20**	**6**	**6**	**10**	**13***
Avg. Temperature during growing season (May-Oct.)	**temperature**	X						X
Average Temperature in spawning season**		X	X		X		X	X
Maximum temperature sustained for 1 week			X			X	X	
Average Summer Temperature (Jul-Sep)				X	X			
Average temperature during spring (May-Jun)				X				
Average Turbidity (JTU)***	**water quality**	X	X	X	X		X	X
Average yearly pH value			X					X
Least suitable pH value (instantaneous)							X	
pH fluctuation classification				X				
Minimum dissolved oxygen concentration				X			X	X
Minimum dissolved oxygen conc. During spring				X				
% instream cover during avgerage summer flow	**general stream characteristics**			X		X	X	X
Instream cover classification					X			
% shading of stream between 1000 and 1500 hrs.		X		X				
% vegetative cover							X	
Availability of thermal refugia (winter)				X				
Stream gradient (m/km)		X		X				X
Average stream velocity during average summer flow				X		X		
Dominant substrate characterization					X		X	
Stream width		X		X			X	
Mode of stream depth during average summer flow					X			
Water level fluctuations								X
Stream margin substrate characterization		X						
Average velocity along stream margins		X		X				
Stream margin vegetation characterization				X				
Substrate food production potential				X				
% riffles	**riffles**					X		
Riffle substrate characterization		X	X	X		X		
Average velocity in riffles		X	X	X				
Average depth of riffles		X						
Average maximum depth of riffles						X		
% pools	**pools**	X	X	X			X	X
Pool substrate characterization		X						X
Pool classification			X	X				
Average depth of pools				X				X
Average velocity at 0.6 depth in pools		X	X					

* some variables used more than once, applied to different life stages

**spawning season varies by species

*** Turbidity relationships developed using Jackson candle units; cannot be converted to NTU values

4.3.2.3. Suitability Index Expressions

HSI models use three major types of Suitability Index (SI) expressions or mathematical relationships to compute the suitability of a given habitat variable; they are (in increasing order of complexity): 1.) categorized relationships, 2.) linear equations (or more commonly, series of linear equations bounded by inflection points), and 3.) suitability curves. Categorized relationships are used for a limited number of HSI variables in which the relationship between the habitat feature and suitability for the species of interest is fairly simple. Substrate size categorization is one example; many HSI models use dominant substrate type categories (e.g., silt, sand, gravel, cobble, boulder, bedrock). Other SI variables that may be defined by simple categorization are temperature, dissolved oxygen, pH or, or in some cases, the variability of these measurements (Figure 8). Categorized data were processed directly within Microsoft Excel spreadsheet HSI models.

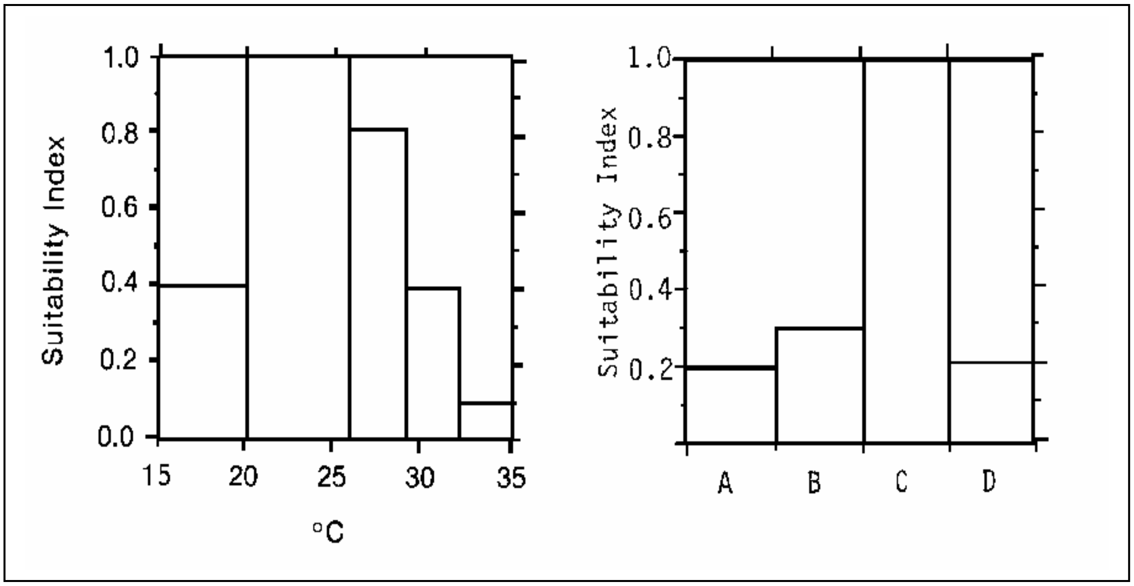


Figure 8. Categorized expressions in HSI models.

Many SI variables are defined by a series of linear relationships bounded by inflection points (i.e., a collection of linear relationships that roughly approximate a curve). Many of these relationships include a range of unsuitable (SI=0) values, a range of ideal (SI =1.0) values, or both. Although all types of SI variables were, in some cases, defined by series of linear relationships (Figure 9), these expressions were less likely to be employed as models increased in complexity. As models become more complex, there is a corresponding increased focus on development of SI curves. SI variables defined by linear relationships were processed using linear equations and boolean commands directly in Excel spreadsheet models.

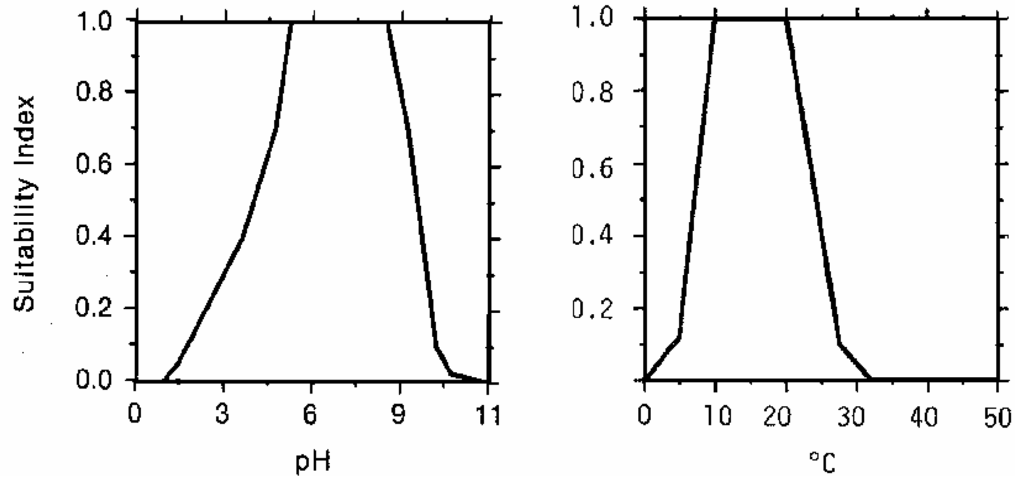


Figure 9. Linear expressions in HSI models.

SI curve relationships are considered the most precise and continuous of SI relationships, and therefore, appear more frequently in more complex HSI models. For example, curves allow models to accurately represent the non-linear, sub-asymptotic change in SI expected as a habitat variable approaches complete unsuitability or ideal suitability (SI score 0 or 1 respectively). Two general SI curve shapes were common, modified parabolae and "s-curves", though there was considerable variation in actual curve shape between different SI variables (Figure 10). As curve equations were not provided with HSI model documentation, lookup tables were generated by scanning curves with data extraction software (Data Thief). Subsequent data processing was handled in Excel.

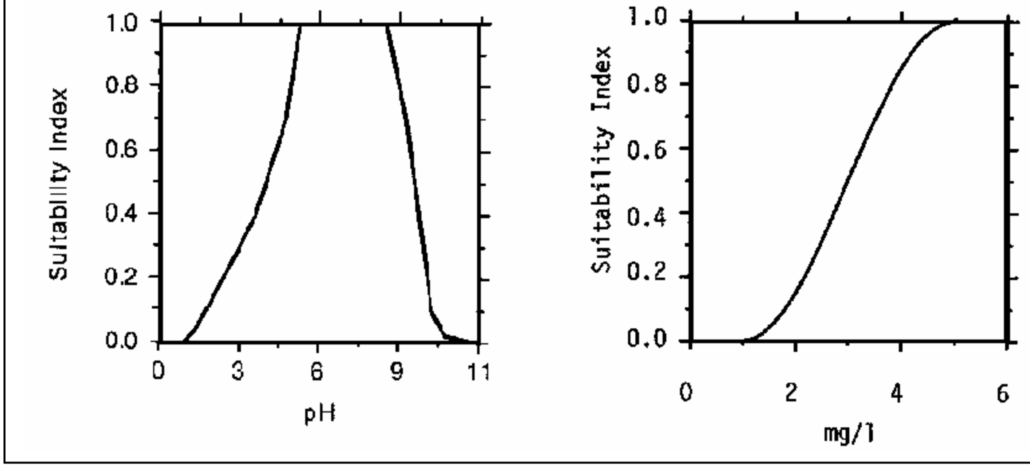


Figure 10. Curve relationships in HSI models.

4.3.2.4. Model Evaluation

HSI model output for each site was compared to EPA habitat data results. With the exception of Longnose dace HSI data, HSI model output was compared to observed fish abundance and biomass with correlation analyses. Several habitat models likely require modification in order to be useful in guiding or evaluating stream habitat improvement activities. While time constraints precluded the modification of models to better suit Darby-Cobbs Watershed, it is hoped that such modifications will increase the usefulness of these models in the future.

4.4. Chemical Assessment

4.4.1. Fixed Interval Chemical Sampling

Bureau of Laboratory Services staff collected surface water grab samples at nine locations within Darby-Cobbs Watershed for chemical and microbial analysis. Sampling events were planned to occur at each site at weekly intervals for one month during three separate seasons. Actual sampling dates were as follows: "winter" samples collected 2/13/03, 2/20/03, 2/27/03, and 3/20/03; “spring” samples collected 3/27/03, 5/22/03, 5/29/03, 6/05/03, and 6/12/03; “summer” samples collected 8/14/03, 8/21/03, 8/28/03, and 09/04/03. A total of 117 discrete, or “grab” samples were taken. To add statistical power, additional discrete water quality samples from PWD's wet-weather chemical sampling program were included in analyses when appropriate.

Locations of 2003 water quality sampling sites are depicted in Figure 3 of Section 3. Sites DCC770, DCC455, DCC208, DCD1570, DCD1170, DCD765, DCI010 and DCN010 were included in PWD's baseline chemical assessment of Darby-Cobbs Watershed in 1999. Sites in the Tinicum sub-basin (DCM300 and DCS170) were sampled in 1999 but not in 2003. A single new site (DCD1660), located on Darby Creek upstream of its confluence with Ithan Creek, was added for 2003.

Discrete sampling was conducted on a weekly basis and was not specifically designed to target wet or dry weather flow conditions. Depending on which definition of "dry weather" was used, six or seven sampling events occurred during dry weather. This data is most pertinent to Target A of the Watershed management Plan (Dry Weather water quality and aesthetics). Specifically addressed are indicators seven and eight- chemical and microbial constituents that are influential in shaping communities of aquatic systems or that are indicative of anthropogenic degradation of water quality in the watershed.

4.4.2. Wet-Weather Targeted Sampling

Target C of the Darby-Cobbs Integrated Watershed Management Plan addresses water quality in wet weather. Yet characterization of water quality at several widely spatially distributed sites simultaneously over the course of a storm event presents a unique challenge. Automated samplers (Isco, Inc. models 6712, 6700) were used to collect samples during two runoff-producing rain events in July and September 2003. The automated sampler system obviated the need for BLS team members to manually collect samples, thereby greatly increasing sampling efficiency. Automated samplers were equipped with vented instream pressure transducers that allowed sampling to commence beginning with a small (0.1ft.) increase in stage. Once sampling was initiated, a computer-controlled peristaltic pump and distribution system collected grab samples at 1 hr. intervals.

Use of automated samplers allows for a greater range of flexibility in sampling programs, including flow-weighted composite sampling based on a user defined rating curve, but stage discharge rating curves at these sites were poorly defined for larger flows. Furthermore, one automated sampler was an older model (model 6700) incapable of taking samples based on observed rate of change in stream stage. Though some difficulties were encountered due to a combination of mechanical failure, individual site characteristics, and/or vandalism, the one hour fixed interval was found to be generally satisfactory in collecting representative samples over a storm event (Appendix C). PWD continues to refine methods of sampling stormwater and experiment with alternative automated sampling programs.

4.4.3. Continuous Water Quality Monitoring

Physicochemical properties of surface waters are known to change over a variety of temporal scales, with broad implications for aquatic life. Several important, state-regulated parameters (e.g., dissolved oxygen, temperature, and pH) may change considerably over a short time interval, and therefore cannot be measured reliably or efficiently with grab samples. Self-contained data logging continuous water quality monitoring Sondes (YSI Inc. Models 6600, 600XLM) were deployed between 8/14/03-9/14/03 at five sites within Darby-Cobbs watershed in order to collect DO, pH, temperature, conductivity and depth data (Figure 4 in Section 3). Sondes continuously monitored conditions and discretized the data in 15 min increments.

Extended deployments of continuous water quality monitoring instruments in urban streams have presented many challenges: drastic increases in stream flow and velocity, probe fouling due to accumulation of debris and algae, manpower required for field deployment and maintenance, and the need to guard against theft or vandalism. With refinements to Sonde enclosures and increased attention to cleaning and maintenance, PWD's Bureau of Laboratory Services has made wide-reaching improvements in the quality and recoverability of continuous water quality data, particularly dissolved oxygen (DO) data.

4.4.4. RADAR Rainfall Data and Analysis

Because storm events are inherently variable and do not evenly distribute rainfall spatially or temporally, PWD contracted with Vieux and Associates to obtain discretized measurements of rainfall intensity during storm events targeted by wet weather sampling. For each 15 minute interval, RADAR tower-mounted equipment measured high frequency radio wave reflection in the atmosphere above Darby-Cobbs watershed. This information was provided to PWD as a series of relative reflectivity measurements for individual 1km^2 blocks. The resulting grid allowed for the summing of relative rainfall intensity within the sub-shed served by each sampling site over the course of each individual storm event (Figures 11 and 12). Individual intensity measurements were also graphed and arranged sequentially to produce animated time-series rainfall accumulation graphics. This analysis, combined with data from the PWD rain gauge network and stream stage measurements logged by the automated sampler, allowed for more thorough analysis of water quality data, particularly in determining whether some areas or subsheds may have contributed more runoff than others.

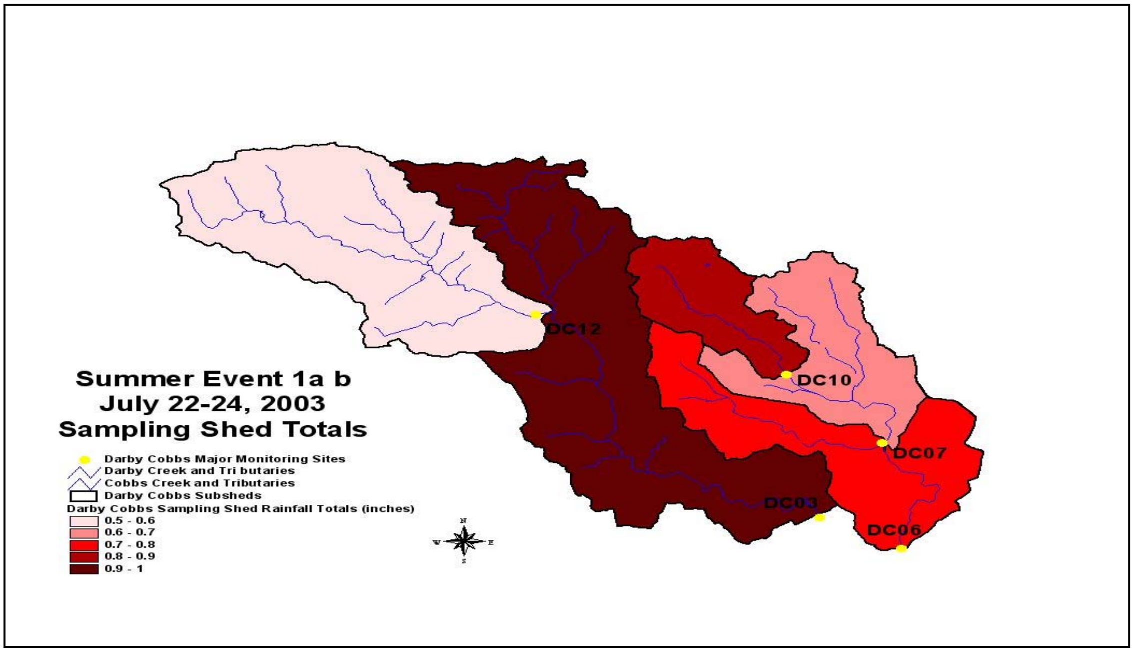


Figure 11. RADAR Rainfall totals by subshed (7/22/03-7/24/03).

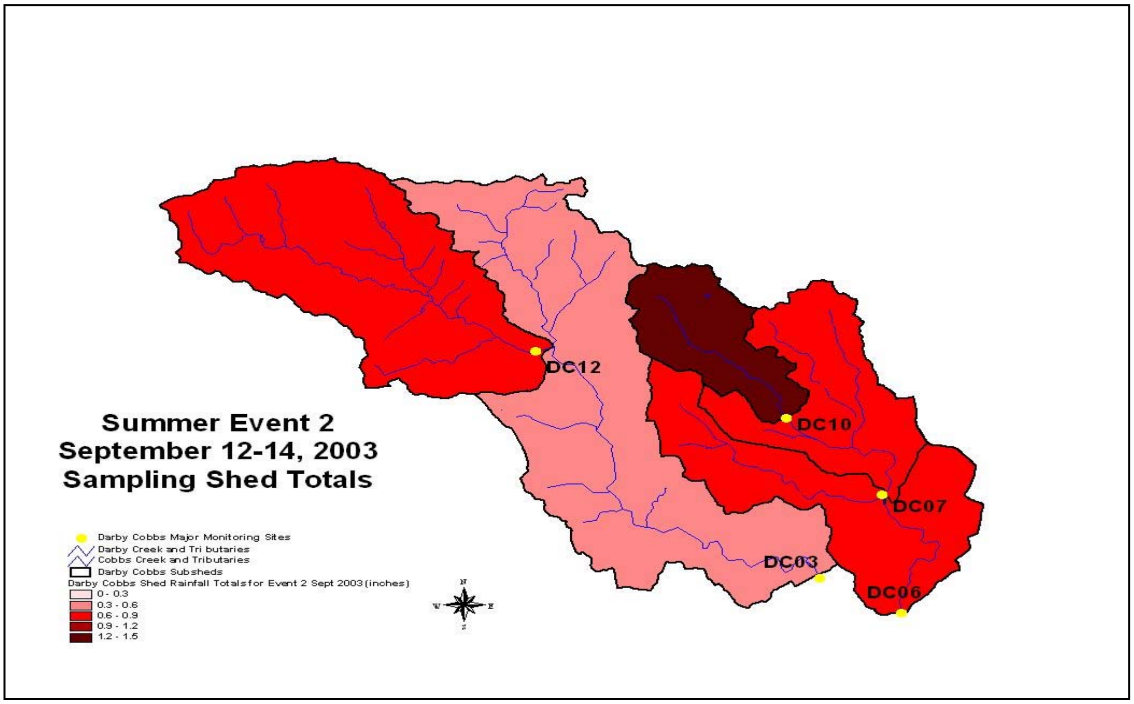


Figure 12. RADAR Rainfall totals by subshed (9/12/03-9/14/03).

SECTION 5: RESULTS AND DISCUSSION

5.1. Benthic Macroinvertebrate Assessment

Study of benthic macroinvertebrate communities has historically been one of the most important tools used in stream water quality assessment. While several key aspects of benthic macroinvertebrate ecology make them ideally suited as bioindicators, their widespread use as such is predicated upon practical concerns. Benthic macroinvertebrates are nearly cosmopolitan in distribution and can be collected by almost anyone in almost any wadeable stream without specialized skill or equipment. Furthermore, identification, to at least the family level, can usually be accomplished in the field without specialized equipment. Because of the ease of their collection and potential discriminatory power of sampling results, thousands of macroinvertebrate surveys are performed each year by governmental and tribal agencies, academic researchers, environmental organizations, volunteer groups, and students of all ages.

While some measures of macroinvertebrate community structure (e.g., diversity indices) may provide meaningful information alone, conclusions of most analyses and metrics are enhanced by, or require, comparison to an unimpaired reference site. However, unimpaired reference sites are often difficult to identify in southeastern Pennsylvania due to extensive development and agricultural land uses. The most logical application of the reference site approach is a pair of sites upstream and downstream of a suspected source of impairment. The downstream site in this scenario has a rather constant source of colonists, or "drift". In regions where impairments occur watershed-wide and first order streams have been eliminated, one cannot assume that study sites have a constant upstream source of immigrants. The most likely means of colonization of these sites is by winged adults. Life history attributes of many invertebrate taxa (e.g., short lifespan of adults, flight capability, and predilection to disperse over upland habitats) reduce the likelihood that impaired sites within a widely impaired region will be recolonized frequently.

Sites in Darby-Cobbs Watershed were compared to reference sites on French Creek and Rock Run, in Chester County, PA. Reference sites were chosen to reflect the range of stream drainage areas in Darby-Cobbs Watershed, yet extensive impervious cover in portions of Darby-Cobbs Watershed complicates this comparison. Due to exaggerated storm flows and concomitant erosion, many sites in Darby-Cobbs Watershed may be categorized as first or second order streams, yet exhibit geomorphological attributes (e.g., bankfull discharge area) similar to sites with much larger drainage areas. These details are addressed in greater detail in Section 5.3 Habitat Assessment

5.1.1. Watershed Overview

A total of 2,114 individuals of 40 taxa were collected and identified during the 2003 benthic macroinvertebrate survey of Darby-Cobbs Watershed. Mean taxa richness of all sites within the watershed was 14.3 (Table 8). Overall, moderately tolerant (89.74%) and generalist feeding taxa (75.72%) dominated the watershed. Mean Hilsenhoff Biotic Index (HBI) of all assessment sites was 5.63 (Figure 13). Overall, the watershed lacked

Table 8. Biological condition results for RBP III.

Watershed	Monitoring Site	Taxa Richness	Modified EPT Taxa	Hilsenhoff Biotic Index (modified)	Percent Dominant Taxon	Percent Modified Mayflies	Biological Quality (%)	Indicator Status
Cobbs	DCC208	12	0	7.06	42.42%	0.00	0.00	Severely Impaired
	DCC455	12	0	5.24	44.86%	0.00	26.67	Moderately Impaired
	DCC793	15	1	5.44	39.44%	0.00	40.00	Moderately Impaired
	DCC1003	13	0	5.88	57.80%	0.00	13.33	Severely Impaired
Darby	DCD765	11	1	5.69	68.70%	0.00	0.00	Severely Impaired
	DCD1105	17	1	5.38	32.08%	0.00	20.00	Moderately Impaired
	DCD1570	16	4	5.04	33.09%	100.00	46.67	Moderately Impaired
	DCD1660	14	1	5.45	61.42%	0.00	13.33	Severely Impaired
	DCD1880	17	3	4.81	23.14%	0.00	46.67	Moderately Impaired
	DCD2138	23	3	5.03	34.42%	100.00	73.33	Slightly Impaired
Tributaries	DCN010	16	1	6.13	15.04%	0.00	40.00	Moderately Impaired
	DCN208	13	0	6.02	23.97%	0.00	33.33	Moderately Impaired
	DCI010	12	0	5.97	60.29%	0.00	13.33	Severely Impaired
	DCIW177	12	1	5.83	37.82%	0.00	33.33	Moderately Impaired
	DCIE186	11	0	5.78	74.07%	0.00	6.67	Severely Impaired
	DCLD034	13	1	5.28	51.68%	0.00	13.33	Severely Impaired
	DCIC007	16	2	5.65	51.32%	0.00	6.67	Severely Impaired

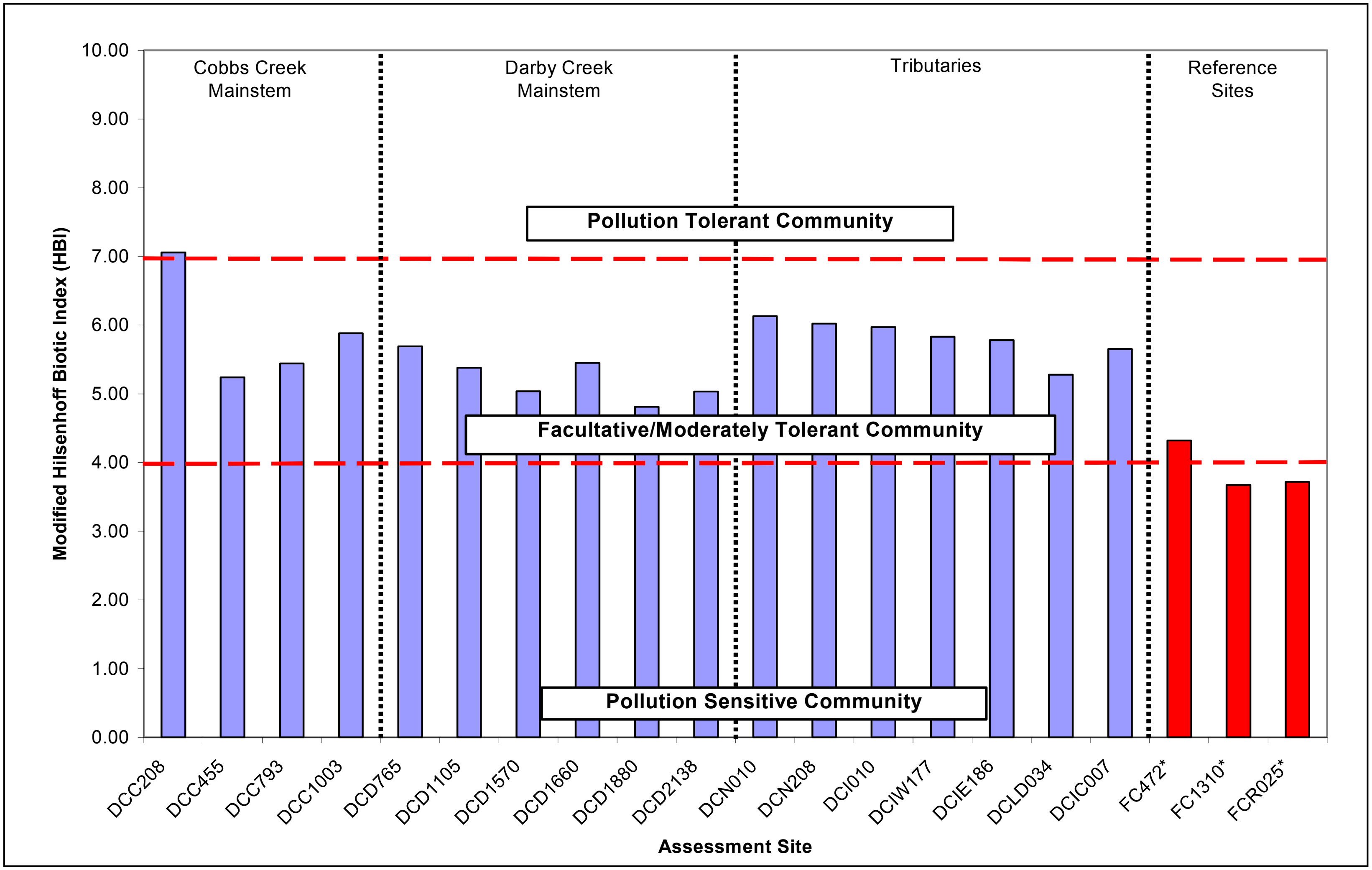


Figure 13. Modified Hilsenhoff Biotic Index (HBI) scores of assessment sites in Darby-Cobbs Watershed.

pollution sensitive Ephemeroptera, Plecoptera, and Trichoptera (EPT) taxa. While present at four upstream Darby Creek sites, abundance of EPT taxa was very low (Figure 14). Midges (family Chironomidae) and net-spinning hydropsychid caddisflies (*Hydropsyche* and *Cheumatopsyche*) dominated the benthic assemblage of most sites within the watershed (percent contribution ranged from 23.14% to 74.07%). Annelids, riffle beetles, isopods, amphipods, tipulids, gastropods, and oligochaetes were also present throughout the watershed.

Basic analysis of raw benthic macroinvertebrate abundance data yields a number of ecological community attributes, such as taxa richness, diversity and evenness, as well as metrics specific to the study of benthic macroinvertebrate communities: modified Ephemeroptera/Plecoptera/Trichoptera (EPT) and Mayfly indices; feeding categorizations; and tolerance measures, including the Hilsenhoff Biotic Index (HBI). While the sampling protocol (a modification of USEPA's RPBIII) was not designed as a quantitative method, the number of subsamples, or plugs, required to count the minimum number of organisms also provided some qualitative data.

The Hilsenhoff Biotic Index (HBI) is used to rate the overall pollution tolerance of a site’s benthic macroinvertebrate community. The HBI is reference site based and oriented toward the detection of organic pollution. HBI scores are unitless and can theoretically range from zero (very sensitive) to ten (very tolerant). Mean HBI score of sites within Darby-Cobbs Watershed was 5.63. The dominance of moderately tolerant individuals and general lack of pollution sensitive taxa contributed to the elevated HBI. Mean HBI score of reference sites was 3.90. Differences in HBI score between assessment and reference sites greater than 0.71 are considered an indicator of impairment. Mean HBI score of sites within Darby-Cobbs exceeded mean reference site score by 1.73, which suggests widespread impairment.

General Tolerance measures are intended to be representative of relative sensitivity to perturbation and may be expressed as numbers of pollution tolerant and intolerant taxa or percent composition (Barbour et al. 1999). Moderately tolerant individuals (89.72%) were collected with greatest frequency in Darby-Cobbs Watershed. Sensitive taxa were poorly represented (3.80%). Abundance of pollution-tolerant taxa may be a response to watershed-wide disturbances.

Feeding measures consider categorized functional feeding groups (e.g., scraper, shredder, collector-gatherer) and provide information regarding the balance of feeding strategies in the benthic community (Barbour et al. 1999). The trophic composition of benthic macroinvertebrate communities at most sites within Darby-Cobbs Watershed was skewed toward generalist-feeding filterers and collectors (75.72%) Generalist-dominated communities in the Cobbs and Indian Creek subsheds may be indicative of an unbalanced community responding to an overabundance of a food resource (i.e., fine particulate organic matter-FPOM) (Fiorentino, 2000). Limitation in food sources limits the competitive ability of specialized feeders.

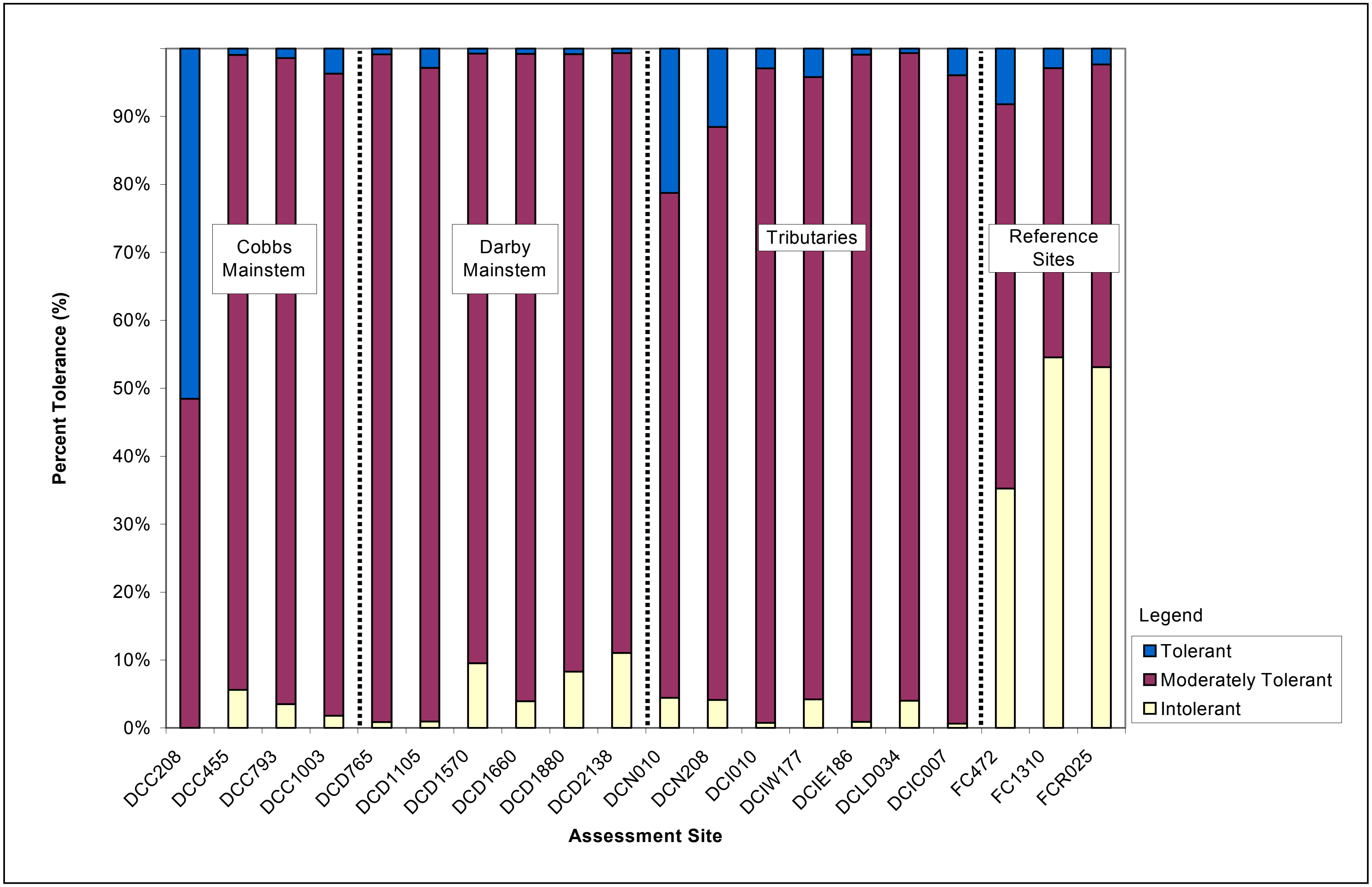


Figure 14. Pollution tolerance values (%) of macroinvertebrate assemblages at each assessment site in Darby-Cobbs Watershed.

However, specialized feeding groups are generally more sensitive to disturbance than generalist feeders. Generalist-dominated assemblages throughout the watershed, especially in Darby Creek watershed, may reflect effects of other environmental disturbances (e.g., flow modification) completely unrelated to organic enrichment. As most benthic macroinvertebrate metrics are aimed at detecting impairment due to organic enrichment, care must be taken not to misinterpret the findings of these tests, especially in light of potentially contradictory habitat and water chemistry data.

5.1.2. Cobbs Creek Mainstem Sites

5.1.2.1. DCC208

With a total biological score of four (4), DCC208 was designated “severely impaired” (13.3% comparison). Four plugs were sorted in order to obtain 100 individuals. DCC208 had low taxa richness (n=12) and no EPT taxa present. Physid snails dominated the benthic assemblage at the site (42.42%) which contributed to the highest HBI score (7.06) of all assessment sites. Due to the large snail population, scrapers (57.58%) and tolerant individuals (51.52%) dominated the assemblage.

5.1.2.2. DCC455

The total biological score at DCC455 was eight (8) out of 30. With a 26.67% comparison, the site was designated “moderately impaired”. The site had a slightly elevated HBI score (5.24) and was dominated by net-spinning caddisflies (66.35% total; 44.86% *Hydropsyche* and 21.50% *Cheumatopsyche*). The abundance of Hydropsychidae skewed the trophic feeding structure of the site toward filterers (66.36%). No EPT taxa were collected, and the site had low taxa richness (n=12). A broken sanitary sewer upstream of the assessment discovered shortly after benthic sampling may have contributed to the impaired macroinvertebrate community.

5.1.2.3. DCC793

DCC793 earned a biological score of 12. This score was a 40.0% comparison to the reference condition at FCR025, and the site was deemed “moderately impaired”. DCC793 had low taxa richness (n=15), although it was the highest of all assessment sites on Cobbs Creek. Only one EPT taxon was present (*Chimarra*), and the site had an elevated HBI score of 5.44. Similar to other downstream Cobbs Creek sites, DCC793 was dominated by filter feeding Hydropsychidae (*Hydropsyche* 39.44% and *Cheumatopsyche* 21.13%). Hydropsychids and chironomids comprised 83.10% of all individuals in the analyzed sample.

5.1.2.4. DCC1003

The assessment site at DCC1003 received a total biological score of four (4), which was a 13.3% comparison to FCR025. The relative density of macroinvertebrates was low at DCC1003. Three plugs were needed to acquire 100 individuals. There was low taxa richness (n=12) and an absence of EPT taxa at the site. The majority of individuals in the sample were midges (57.80% Chironomidae), and the trophic composition of the site was dominated by gatherers (61.47%). With most metrics scoring zero (0), DCC1003 was designated "severely impaired".

5.1.3. Darby Creek Mainstem Sites

5.1.3.1. DCD765

DCD765 received a total metric score of zero (0) out of a possible 30. The site was designated "severely impaired". To obtain 100 individuals, five sub-samples were sorted. DCD765 had the highest HBI score (5.69) and lowest taxa richness (n=11) of all mainstem Darby Creek assessment sites. The amphipod *Gammarus* dominated the benthic assemblage (68.70%), and the feeding structure at DCD765 consisted of mainly generalist collector-gatherers (75.65%). The low density of macroinvertebrates, dominance of moderately pollution tolerant taxa (98.26%) and high proportion of generalists contributed to the site's impairment designation.

5.1.3.2. DCD1105

The assessment at site DCD1105 received a biological score of eight (8). The site had a 20.0% comparison to FC472 and was designated "moderately impaired". DCD1105's metric comparison score fell between the moderate and severely impaired biological condition categories. A taxa richness of n=17 and relatively low percent dominant taxon (32.08% Chironomidae), lead to a "moderately impaired" status designation. Only one EPT taxon (*Chimarra*) was present, and the HBI score at DCD1105 was an elevated 5.38. All trophic levels were represented but generalist feeders dominated the sample (62.26% gatherers and 23.58% filterers). The site had a low relative density. Four sub-samples were sorted to obtain the necessary 100 individuals.

5.1.3.3. DCD1570

The total biological score at DCD1570 was 14—a 46.67% comparison to the reference condition at FC472. The site at DCD1570 was designated "moderately impaired". DCD1570 had one of the lowest HBI scores (5.04) and had the greatest number of EPT taxa (n=4) of all Darby-Cobbs assessment sites. The assemblage had relatively low percent dominant taxon (33.09% Chironomidae), but the trophic structure lacked shredders. The assemblage was dominated by gatherers (44.85) and scrapers (36.03%).

5.1.3.4. DCD1660

The macroinvertebrate assemblage at DCD1660 scored four (4) when compared to the reference conditions at FC1310. The site was designated “severely impaired”. Impairment was due to the dominance of midge larvae (61.42%) and an elevated HBI score (5.45). DCD1660 had low taxa richness (n=14) and only one EPT taxon (*Chimarra*) was identified in the sub-sample. All feeding groups were present, but specialized feeders (scrapers, shredders, and predators) were not well represented. Generalist feeding gatherers (67.7%) dominated the assemblage.

5.1.3.5. DCD1880

DCD1880 had a total biological score of 10 out of 30, which represents a 33.33% comparison to FC1310. DCD1880 had the lowest HBI score (4.81) of all 2003 assessment sites, and also had low percent dominant taxon (23.14% Chironomidae). Three EPT taxa were present in the analyzed sub-sample, and the taxa richness (n=17) was fair. DCD1880 was designated “moderately impaired”.

5.1.3.6. DCD2138

The assessment site at DCD2138 received a total biological score of 16, which was a 53.3% comparison to FC1310. The site was designated “slightly impaired”. DCD2138 was the only site in the 2003 survey to be deemed only slightly impaired. DCD2138 had the highest taxa richness (n=23) of all assessment sites, and received an HBI score of 5.03. Three EPT taxa were identified in the sub-sample from DCD2138, and it had low percent dominant taxon (34.42% Chironomidae). The trophic structure at DCD2138 was balanced, and the site had the highest proportion of intolerant macroinvertebrates of all sites.

5.1.4. Darby-Cobbs Tributary Sites

5.1.4.1. DCN010

DCN010 had a total biological score of 12, and the site was designated “moderately impaired”. The assemblage at the site had good percent dominant taxa, as the two major taxa (Lumbriculidae and *Hemerodromia*) each comprised 15.04% of all individuals, but Lumbriculidae and *Hemerodromia* are moderately tolerant and tolerant taxa, respectively. In addition, DCN010 had a balanced trophic structure. Despite the relatively favorable balance of the assemblage at DCN010, the sites had an overall lack of macroinvertebrates. Nine sub-samples were sorted in order to obtain the required 100 individuals for metrics. The site had an elevated HBI score (6.13) and a very high percentage of tolerant individuals (21.24%). The “moderately impaired” designation for DCN010 may not accurately reflect the biological condition at the site due to the low taxa richness of the reference site FCR025. This factor may have skewed the metric scores of DCN010.

5.1.4.2. DCN208

The total biological score at DCN208 was ten (10). The site was deemed "moderately impaired" based on a 33.33% comparison to the reference condition. Similar to other sites, DCN208 had an elevated HBI score (6.02) and an absence of EPT taxa. The community had low taxa richness, but good percent dominant taxa. Chironomid larvae and *Cheumatopsyche* each comprised 23.97% of the benthic assemblage. The total numbers of net-spinning caddisfly taxa (Hydropsyche and Cheumatopsyche) comprise 44.63% of all individuals. Generalist feeding gatherers and filterers composed 82.65% of the trophic structure of the site. The impaired biological conditions at DCN208 may be due in part to much of Naylors Run being encapsulated.

5.1.4.3. DCI010

The assessment site at DCI010 scored four (4) out of 30 when compared to FCR025. There was a 13.33% percent comparison to FCR025, and the site was designated "severely impaired". DCI010 had very high percent dominant taxon (Chironomidae 60.29%), and no EPT taxa were present. The site also had low taxa richness and an elevated HBI score (5.97). The abundance of chironomids caused gatherers (66.91%) to dominate the trophic structure of the site. Generalist feeding macroinvertebrates composed 95.59% of the total number of individuals. Upon visiting DCI010, field personnel were informed by golf course staff that water at the site was frequently an opaque gray color, possibly due to sewage in the creek.

5.1.4.4. DCIW177

The benthic assemblage at DCIW177 received a total biological score of ten (10), which represents a 33.33% comparison to FCR025. The site was designated "moderately impaired". One EPT taxon (*Glossosoma*) was identified in the sub-sample, but only one individual was found. The site had low taxa richness (n=12) and a high HBI score (5.83). All trophic levels were represented, but specialized feeders were almost absent. Generalist feeders comprised 94.96% of the macroinvertebrate community. The percent dominant taxon (37.82% Chironomidae) was fair.

5.1.4.5. DCIE186

DCIE186 scored only two (2) out of 30. With 13.33% comparison, the site was designated "severely impaired". DCIE186 had an elevated HBI score (5.75), and no EPT taxa. The site had the lowest taxa richness (n=11) and the highest percent dominant taxon (74.07% Chironomidae) of all the assessment sites. All trophic groups were present at the site, but gatherers (82.41%) dominated the community. 98.15% of all individuals at the site were moderately tolerant.

5.1.4.6. DCLD034

The macroinvertebrate assemblage at DCLD034 scored four (4) out of 30. DCLD034 had an elevated HBI score (5.28) and high percent dominant taxon (51.68% Chironomidae). The site had only one EPT taxa (*Chimarra*) and low taxa richness (n=13). Moderately tolerant taxa dominated the benthic assemblage. The metrics at DCLD034 had a 13.33% comparison to FCR025 deeming it "severely impaired".

5.1.4.7. DCIC007

The total biological score at DCIC007 was two (2). The score of two corresponded to a "severely impaired" designation (6.67% comparison). The site had an elevated HBI score (5.65) and a taxa richness of n=16. There were two EPT taxa (*Agraylea* and *Chimarra*) present in the sub-sample analyzed. The trophic composition was skewed toward generalist feeding gatherers (59.21%) due to the abundance of chironomids (51.32% of individuals). The benthic macroinvertebrates at DCIC007 were sampled approximately two months (5/12/03) after all other assessment sites were sampled. The observed biological integrity could be due to seasonal changes and not degraded water quality conditions.

5.2. Fish Assessment

5.2.1. Overview

A total of 12,882 individuals of 44 species representing 13 families were collected throughout Darby-Cobbs Watershed in the 2003 bioassessment (Table 9). Blacknose dace (*Rhinichthys atratulus*) and Banded killifish (*Fundulus diaphanus*), two taxa highly tolerant of poor stream conditions, were most abundant and comprised approximately 33% of all fish collected. Other common species were White sucker (*Catostomus commersoni*), Mummichog (*Fundulus heteroclitus*), Common shiner (*Luxilus cornutus*), and Swallowtail shiner (*Notropis procne*). Of 44 species collected, seven species comprised 78% of the entire fish assemblage. Similarly, four species made up nearly 70% of total biomass, with white sucker and American eel (*Anguilla rostrata*) contributing greater than 55%. In general, Darby Creek had greater species richness, but Cobbs Creek had higher abundance, density (individuals per unit area), and catch rates (catch per unit effort).

Trophic composition evaluates quality of the energy base and foraging dynamics of a fish assemblage. This is a means to evaluate the shift towards more generalized foraging that typically occurs with increased degradation of the physicochemical habitat (Barbour et al., 1999). Generalist feeders (54.7%) and insectivores (38.2%) dominated Darby-Cobbs Watershed, with 6.1% top carnivores and approximately 1% herbivores and filter feeders. Trophic composition was fair compared to reference sites. In Cobbs Creek, top carnivore and insectivore taxa abundance decreased while abundance of generalist feeders increased in an upstream direction (Figure 15). Also, percentage of White suckers (*C. commersoni*) increased in an upstream direction, as White suckers typically increase in abundance in degraded streams. In Darby Creek, abundance of generalist feeders increased, whereas the percentage of insectivore taxa decreased in an upstream direction.

Table 9. Species list and relative abundance of fish taxa collected in the Darby-Cobbs Watershed.

Scientific Name	Common Name	Number Of Individuals Identified
Alosa aestivalis	Blueback Herring	42
Alosa sapidissima	American Shad	1
Ameiurus catus	White Catfish	1
Ameiurus natalis	Yellow Bullhead Catfish	1
Ameiurus nebulosus	Brown Bullhead Catfish	60
Ambloplites rupestris	Rock Bass	76
Anguilla rostrata	American Eel	555
Carassius auratus	Goldfish	11
Catostomus commersoni	White Sucker	831
Cyprinella analostana	Satinfin Shiner	219
Cyprinus carpio	Common Carp	32
Cyprinella spiloptera	Spotfin Shiner	9
Dorosoma cepedianum	Gizzard Shad	3
Esox lucius x Esox masquinongy	Tiger Muskellunge	1
Etheostoma olmstedi	Tessellated Darter	237
Exoglossum maxillingua	Cutlips Minnow	442
Fundulus diaphanus	Banded Killifish	1917
Fundulus heteroclitus	Mummichog	1088
Gambusia affinis	Mosquitofish	3
Hybognathus regius	Eastern Silvery Minnow	117
Ictalurus punctatus	Channel Catfish	2
Lepomis auritus	Redbreast Sunfish	651
Lepomis cyanellus	Green Sunfish	8
Lepomis gibbosus	Pumpkinseed Sunfish	129
Lepomis auritus x Lepomis gibbosus	Sunfish Hybrid	1
Lepomis macrochirus	Bluegill Sunfish	52
Luxilus cornutus	Common Shiner	1018
Micropterus dolomieui	Smallmouth Bass	23
Micropterus salmoides	Largemouth Bass	6
Morone americana	White Perch	1
Morone saxatilis	Striped Bass	1
Notemigonus crysoleucas	Golden Shiner	11
Notropis hudsonius	Spottail Shiner	200
Notropis procne	Swallowtail Shiner	1465
Oncorhynchus mykiss	Rainbow Trout	26
Pimephales notatus	Bluntnose Minnow	65
Pimephales promelas	Fathead Minnow	148
Pomoxis nigromaculatus	Black Crappie	1
Rhinichthys atratulus	Blacknose Dace	2157
Salvelinus fontinalis	Brook Trout	1
Salmo trutta	Brown Trout	31
Semotilus atromaculatus	Creek Chub	143
Semotilus corporalis	Fallfish	24
Umbra pygmaea	Eastern Mudminnow	1

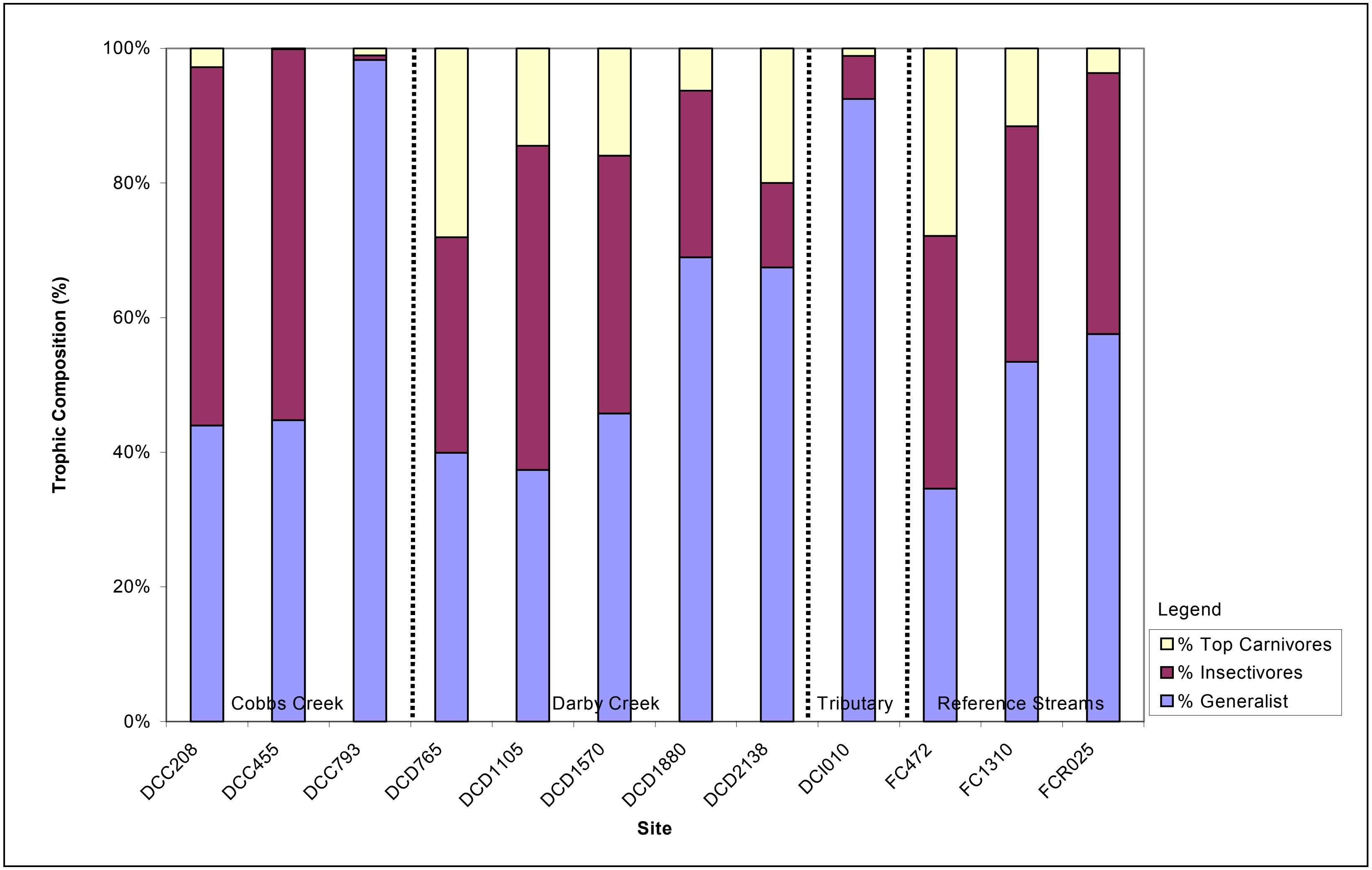


Figure 15. Trophic structure of fish assemblages in the Darby-Cobbs Watershed.

Relative abundance of insectivores decreases with degradation in response to availability of the insect supply, which reflects alterations of water quality and instream habitat (Daniels et al., 2002). Of particular concern was the absence of Longnose dace (*Rhinichthys cataractae*) in Darby-Cobbs Watershed. This benthic insectivore requires complex riffle systems of good quality and its complete absence in the watershed suggests impaired stream conditions. Though community composition varied between sites, the fish assemblage in Darby-Cobbs Watershed was skewed towards a tolerant, generalist feeding community.

Tolerance designations describe the susceptibility of a species to chemical and physical perturbations. Intolerant species are typically first to disappear following a disturbance (Barbour et al., 1999). Tolerant and moderately tolerant species composed 95% of the fish fauna in Darby-Cobbs Watershed (Figure 16). Cutlips minnow (*Exoglossum maxillingua*) and stocked trout (*Oncorhynchus mykiss, Salmo trutta, Salvelinus fontinalis*) were the only intolerant taxa found in the non-tidal sites. Eastern silvery minnow (*Hybognathus regiu*s) and Striped bass (*Morone saxatilis*) were additional intolerant species found in the tidal portions of the watershed. No more than one sensitive species was found at any given non-tidal site. Furthermore, all but two assessment sites were dominated by taxa tolerant of poor water quality. The non-tidal portion of Cobbs Creek was devoid of pollution-sensitive taxa. The relative low abundance of intolerant species implies a high level of disturbance that appears to increase upstream.

The Index of Biotic Integrity (IBI) is useful in determining long-term effects and coarse-scale habitat conditions because fish are relatively long-lived and mobile. A site with high integrity (i.e. high score) is associated with native communities that interact under natural community processes and functions (Karr 1981). Since biological integrity is closely related to environmental quality, assessments of integrity can serve as a surrogate measurement of health (Daniels et al., 2002). Mean IBI score for Darby-Cobbs Watershed was 31 (out of 50), placing it in the “fair” category (Figure 17). Skewed trophic structure and rare intolerant species are characteristics of a fish community in the “fair” category. The Modified Index of Well-Being and Shannon Diversity Index values, which are measures of diversity and abundance, decreased in an upstream direction. Overall, the more downstream sites had higher biological integrity than upstream sites.

5.2.2. Cobbs Creek Mainstem Sites

5.2.2.1. DCC208

In 1523.33 m^2 of stream surface area, a total of 1217 fish representing 13 species were collected during 80.95 minutes of electrofishing. DCC208 had the lowest abundance, biomass (9.50kg), density (0.8 fish/m^2), and standing crop (6.23g/m^2) in Cobbs Creek Watershed. Three species tolerant of poor stream conditions comprised over 80% of all fish collected, with Banded killifish (*F. diaphanus*) most abundant. Benthic insectivorous and intolerant species were absent from this monitoring location. Nearly

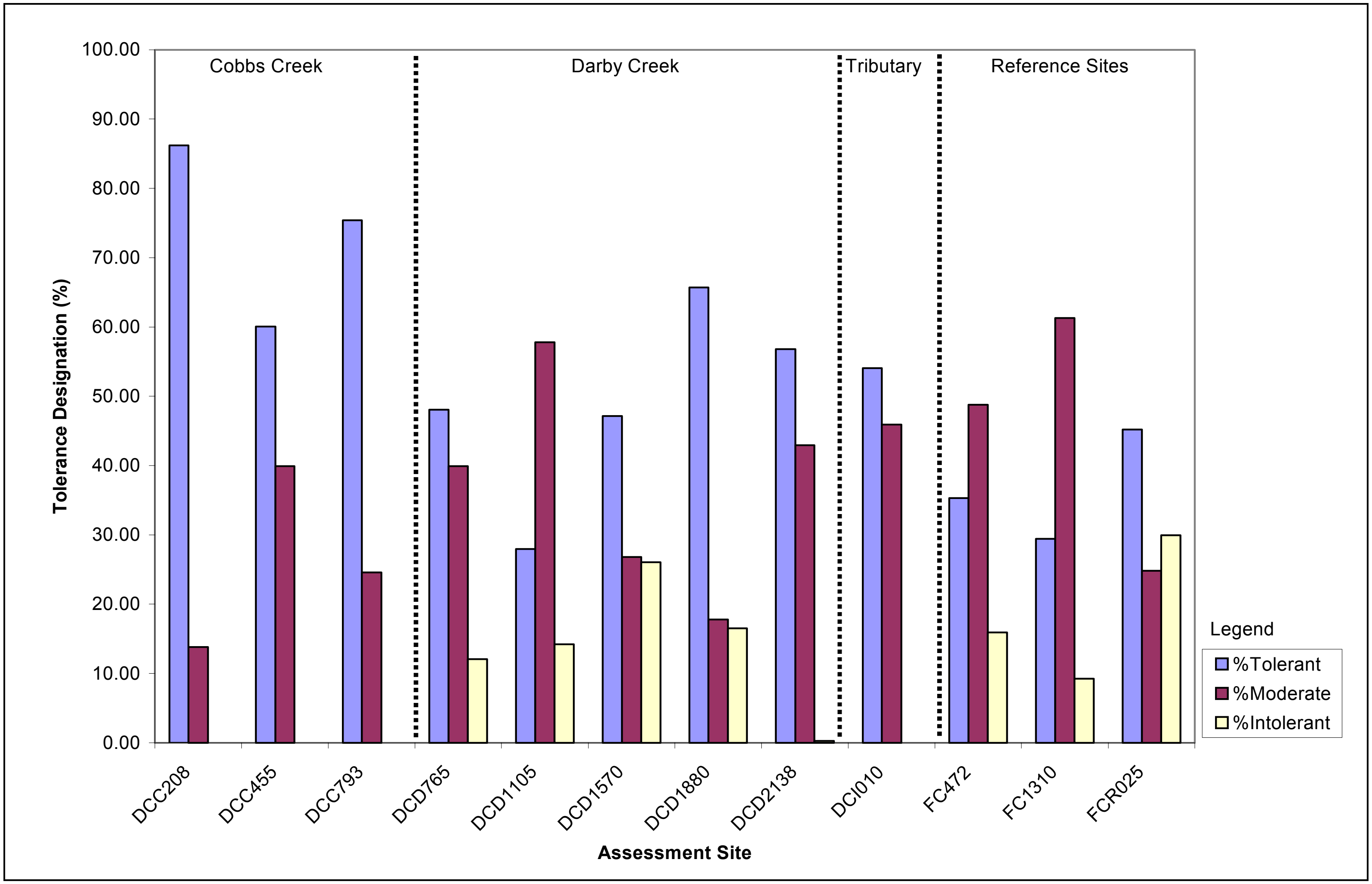


Figure 16. Pollution tolerance values at the monitoring sites in Darby-Cobbs Watershed.

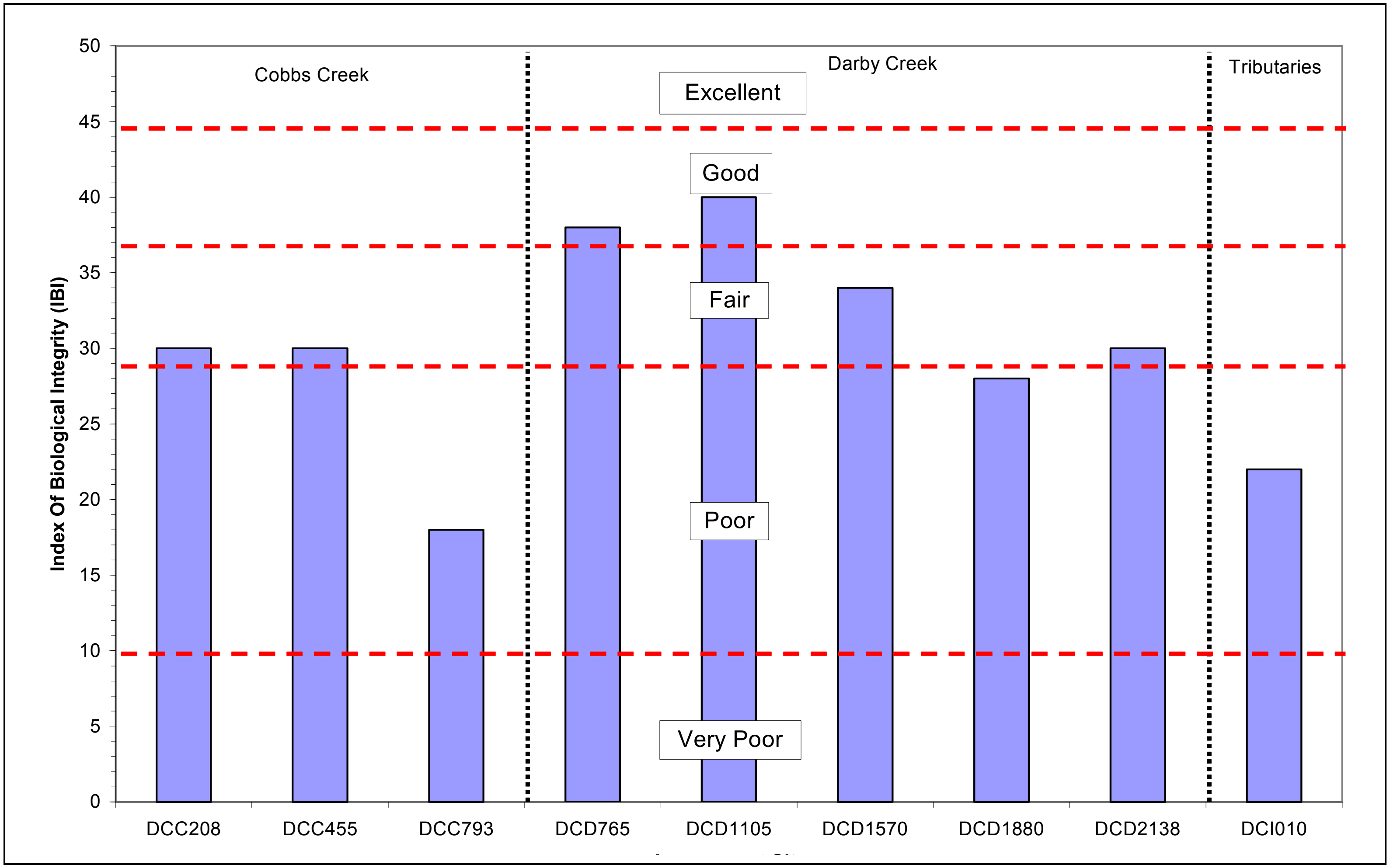


Figure 17. Index of Biological Integrity (IBI) scores at the nine assessment sites in Darby-Cobbs Watershed.

90% of the fish assemblage consisted of tolerant individuals and one single species accounted for 47% of all fish; three species contributed 68% of the total biomass at this location. The trophic composition was dominated by generalist feeders (44%) and insectivores (53%), with 3% top carnivores. The prevalence of tolerant taxa and unevenness of the assemblage indicated degraded stream conditions. The IBI score was 30 (out of 50), placing this site in the "fair" category. Absences of intolerant and sensitive species as well as a skewed trophic structure are characteristic of sites with fair biologic integrity. DCC208 had the lowest Modified Index of Well-Being value (9.51) of all main stem sites in the Darby-Cobbs Watershed and the Shannon Diversity Index (1.58) was well below reference condition values.

5.2.2.2. DCC455

A total of 1510 individuals of 17 species (including exotic and non-resident) yielded a biomass of 16 kg during 81 minutes of electrofishing. Based on a stream surface area of 1003 m^2, a density of 1.51 fish per m^2 and standing crop of 15.96 grams per m^2 were calculated. Of the 17 species collected at DCC455, four species accounted for 78% of the site's abundance and 86% of the total biomass. Banded killifish (*F. diaphanus*), a highly tolerant species, was most abundant (34%) and Brown bullhead (*Ameiuris nebulosus*) dominated the biomass (35%). Other common species were Mummichog (*F. heteroclitus*), Redbreast sunfish (*Lepomis auritus*), and Swallowtail shiner (*N. procne*). There were no intolerant taxa and benthic insectivorous species collected at this location; 60% of individuals were tolerant and 40% were moderately tolerant to pollution. The trophic composition was 55% insectivores, 45% generalist feeders, and less than 1% top carnivores.

The IBI score of 30 (out of 50) is characteristic of a "fair" quality fish assemblage. Since the IBI metric for total number of fish species excludes exotic and nonresident taxa, only 16 species were used to calculate the IBI score. This site had the highest Modified Index of Well-Being (11.13) and Shannon Diversity Index (1.94) for Cobbs Creek Watershed. However, these measures of abundance and diversity overestimate the quality of the assemblage because they do not account for the skewed trophic structure, lack of sensitive species, and elevated percentage of fish with disease and anomalies typically found in poor quality streams.

5.2.2.3. DCC793

DCC793 was the upstream-most fish assessment site within Cobbs Creek Watershed and located just upstream of the Philadelphia County line. This site had the greatest abundance and biomass, but the lowest diversity on the main stem of Cobbs Creek. The upstream site yielded 1907 individual fish of 12 species, accounting for 23.7 kg of biomass. Of 12 species collected at DCC793, 3 species comprised approximately 92% of all fish collected and 84% of the total biomass. Blacknose dace (*R. atratulus*), a tolerant species, was most abundant and accounted for more than half of the entire assemblage. Furthermore, no intolerant taxa were collected at DCC 793 and 98% of the assemblage was generalist feeders. Despite the highly skewed trophic structure (indicative of degraded stream conditions), this site had the greatest density (number of fish per unit area) and standing crop (biomass per unit area) in Cobbs Creek Watershed.

This site received an IBI score of 18 (out of 50), signifying a “poor” quality fish assemblage and therefore, poor environmental health. This was the lowest IBI score in Darby-Cobbs Watershed. In addition, nearly one third of assemblage had some type of disease or anomaly. The low values for the Modified Index of Well-Being (10.08) and Shannon Diversity Index (1.21) corroborate with the poor IBI score and represent an unhealthy stream reach.

5.2.3. Darby Creek Mainstem Sites

5.2.3.1. DCD765

Sampling at DCD765 took place several days following periods of rain. Discharge and stage height were slightly above normal, and may have accounted for reduced sampling efficiency. A total of 356 fish representing 18 species (including exotic and non-resident) were collected during 71.67 minutes of electrofishing in 1506.86 m^2 of stream surface area. This was the minimum number of fish collected at any site in Darby-Cobbs Watershed. Nevertheless, this site had good relative diversity and a balanced trophic structure. Trophic composition was evenly distributed, with 39% generalist feeders, 32% insectivores, and 28% top carnivores, representing the maximum percentage of top carnivores found at any site in the watershed. The most common fish were American eel (*Anguilla rostrata*), Cutlips minnow (*E. maxillingua*), and Redbreast sunfish (*L. auritus*), making up 58% of the fish assemblage. *A. rostrata* comprised 96% of the top carnivores and 41% of total biomass at DCD765. The presence of large American eels may have reduced the abundance of cyprinids and overall abundance through competitive exclusion or predation.

DCD765 received an IBI score of 38 (out of 50), placing it in the category of a “good” quality fish assemblage. The elevated percentage of intolerant individuals (12%) and low occurrence of DELT anomalies (5.9%) are characteristic of stream reaches with good biological integrity. The Modified Index of Well-Being (10.46) and Shannon Diversity Index (2.21), however, are relatively lower than expected in a “healthy” fish assemblage , and may be a result of decreased sampling efficiency due to high water velocities.

5.2.3.2. DCD1105

A total of 436 fish representing 17 species (including exotic, non-resident, stocked fishes) were collected during 75.33 minutes of electrofishing in 1450.67 m^2 of stream surface area. There were 2 benthic insectivorous species, 4 water column species, and only 1 intolerant taxa present at DCD1105. This site had the second lowest density and third lowest abundance of fish in Darby-Cobbs Watershed. Nonetheless, the small percentage of White suckers (3%) and a higher percentage of intolerant individuals (14%) are signs of a good quality fish assemblage. Also, this was one of only two sites with more moderately tolerant (58%) than tolerant (28%) fish. Functional feeding groups were well distributed between insectivores (48%), generalist feeders (37%) and top carnivores (15%).

The most common species included Swallowtail shiner (*N. procne*), Cutlips minnow (*E. maxillingua*), and Blacknose dace (*R. atratulus*), with American eel (*A. rostrata*) composing more than half of the biomass. This site had the highest IBI score in the Darby-Cobbs Watershed, with a value of 40 (out of 50). DCD1105 also received the highest Shannon Diversity Index value of 2.35. Based on the IBI score and Shannon Diversity Index, relative health of the fish assemblage at DCD1105 was the best in the watershed and characteristic of only slightly degraded streams.

5.2.3.3. DCD1570

The collection of 38 stocked trout (*Oncorhynchus mykiss* and *Salmo trutta*) from this site was the most in the watershed; however, the absence of juvenile trout suggests that there is no trout reproduction. Therefore, stocked trout were not included in several IBI metrics involving intolerant taxa and species richness. We collected 933 fish of 19 species (including exotic, non-resident, stocked fishes) during 87 minutes of electrofishing in 1208 m^2 of stream surface area. Of 19 species collected, six species accounted for 66% of all fish collected whereas four species comprised 87% of the total biomass. Blacknose dace (*R. atratulus*), a highly tolerant species, was most abundant (23%) and American eel (*A. rostrata*) was responsible for nearly half of the site's biomass. There were two benthic insectivorous species, four water column species, and only one intolerant species (*E. maxillingua*). DCD1570 had the greatest biomass (40.8 kg) and standing crop (biomass/m^2) of all Darby-Cobbs sites.

Biotic integrity of this site was "fair", receiving an IBI score of 34 (out of 50). Due to the high biomass and relative abundance, the Modified Index of Well-Being (10.46) and Shannon Diversity Index (2.27) overestimated the quality of the fish assemblage. This site was dominated by generalists feeders (46%) and had an elevated percentage of white suckers (12%), both signs of physical and chemical habitat deterioration (Barbour et al., 1999). Furthermore, this site had the greatest percentage of individual with DELT anomalies (43%) of all main stem sites in the watershed, suggesting possible subacute effects of chemical pollution.

5.2.3.4. DCD1880

The poor quality fish assemblage at this site was characterized by the high percentage of White suckers (15%), the dominance of generalist feeders (69%), lack of sensitive taxa, and high occurrence of individuals with DELT anomalies (25%). A total of 860 fish representing 22 species were collected at DCD1880; however, only 16 species were resident and non-stocked. Of 22 species collected, three species accounted for 72% of fish abundance and 74% of the total biomass (23.4 kg). Blacknose dace (*R. atratulus*), a highly tolerant species, comprised 41% of the fish assemblage and American eel (*A. rostrata*) was responsible for 37% of the site's biomass.

Tolerant taxa dominated this site and only one intolerant species (excluding stocked trout) was present. The Modified Index of Well-Being (11.21) and Shannon Diversity Index (1.91) values fell well below reference condition. The IBI score (28 out of 50) represented a fish assemblage of poor biological integrity. Local angler groups stock this portion of Darby Creek for an annual trout tournament and the potential effects of these introductions on native fish communities are uncertain.

5.2.3.5. DCD2138

Site DCD2138, positioned in a 2nd order reach of Darby Creek mainstem, was the uppermost site in Darby-Cobbs Watershed. This site had the lowest biomass and second lowest fish abundance in Darby Creek. A total of 375 individuals representing 12 species were collected during 70 minutes of electrofishing in 535.1 m^2 of stream surface area. Generalist feeders dominated this site (67%), but the percentage of top carnivores (20%) was much greater than expected for a stream this size. The piscivores, Rock bass (*Ambloplites rupestris*) and American eel (*Anguilla rostrata*), made up 78% of the biomass at this site. Furthermore, Blacknose dace (*R. atratulus*), a highly tolerant species, comprised 28% of the fish assemblage.

DCD2138 received an IBI score of 30 (out of 50), placing this site in the “fair” category. The Modified Index of Well-Being (10.26) value falls well below reference condition, but Shannon Diversity Index (2.12) is directly comparable to reference conditions. Over half of all individuals collected were tolerant and the fish assemblage was skewed towards a tolerant, generalist feeding community, suggesting a moderate level of chemical and/or physical perturbation.

5.2.4. Darby-Cobbs Tributary Sites

5.2.4.1. DCI010

This site was located on Indian Creek, a second order tributary to Cobbs Creek, and was the only tributary in which a fish assessment was conducted. Only six species were collected, compared to 18 species found at a second order reference stream. Species richness typically decreases with increased degradation. Common shiner (*L. cornutus*) and Blacknose dace (*R. atratulus*) were the most abundant species and White sucker (*C. commersoni*) constituted over half of the biomass. Intolerant taxa and benthic insectivorous species were absent. The trophic structure was biased towards generalist feeders (93%) and very few top carnivores were present. This site had the highest percentage of fish with disease and anomalies in Darby-Cobbs Watershed; more than half of all fish were affected. The extremely high incidence of DELT anomalies is symptomatic of a stressed community typically found downstream of point source pollution (Barbour et al., 1999).

Low species richness and composition scores combined with uneven trophic structure yielded an IBI score of 22 (out of 50), which is characteristic of a fish assemblage with “poor” biological integrity. To further support this point, DCI010 had the lowest

Modified Index of Well-Being (9.32) and second lowest Shannon Diversity Index (1.36) in the Darby-Cobbs Watershed. Also, this site had the maximum percentage of White suckers in the watershed (17%), indicative of degraded stream conditions.

5.2.5. Darby-Cobbs Tidal Sites

5.2.5.1. DCC037

Site DCC037 is located near the head of tide on the main stem of Cobbs Creek and was sampled at low to incoming tide. A total of 1710 individuals representing 25 species (including exotic and non-resident) were collected during 40.13 minutes of electrofishing in 1349.42 m^2 of stream surface area. This site had the greatest species richness, catch per unit effort (42.62 fish/min.) and second highest number of individuals collected in Darby-Cobbs Watershed. Despite the high diversity and abundance, two highly tolerant species, Banded killifish (*F. diaphanus*) and Mummichog (*F. hete*roclitus), comprised over 70% of the total fish assemblage. Furthermore, over 80% of all fish collected at DCC037 were tolerant of poor water quality, suggesting chemical and/or physical perturbation. It is important to note, however, that this is the only site in Cobbs Creek that contained an intolerant species (*Hybognathus regiu*s).

Due to the lack of tidal reference streams, an Index of Biotic Integrity (IBI) could not be determined. However, various metrics were used to estimate biological integrity. DCC037 had the highest percentage of top carnivores and the lowest percentage of individuals with disease, eroded fins, lesions, tumors, and anomalies (DELTA) in Cobbs Creek Watershed. Also, Modified Index of Well-Being (10.78) and Shannon Diversity Index (1.77) values indicate a fair quality fish assemblage.

5.2.5.2. DCD630

Site DCD630 is located near the head of tide on the main stem of Darby Creek and was sampled at low and incoming tide. A total of 1836 individuals representing 25 species (including exotic and non-resident) were collected during 47.34 minutes of electrofishing in 1366.7 m^2 of stream surface area. This site had the greatest species richness, catch per unit effort (42.62 fish/min.), density (1.34 fish/m^2), and number of individuals collected in the Darby Watershed. Despite high diversity and abundance, four species comprised over 70% of the total fish assemblage and 83% of total biomass. It is important to note, however, that this is the only site in Darby-Cobbs Watershed that contained two intolerant taxa (*Hybognathus regiu*s and *Exoglossum maxillingua*). Also, two benthic insectivorous species, five water column species and 11 cyprinid species were collected at DCD630.

Due to the lack of tidal reference streams, an Index of Biotic Integrity (IBI) could not be determined. However, various metrics were used to estimate biological integrity. Site DCC037 had the lowest proportion of generalist feeders (24%), most insectivores (68%), and lowest percentage of individuals with DELT anomalies in Darby-Cobbs Watershed. Also, this site had the highest Modified Index of Well-Being (11.78) in the watershed, indicating a good quality fish assemblage. DCD630 was only one of two sites that contained more moderately tolerant (62%) than tolerant (37%) fish.

5.3. Habitat Assessment

5.3.1. EPA Habitat Assessment Overview

Habitat impairments in Darby-Cobbs Watershed are numerous, mirroring those of other urban stream systems assessed by PWD. First and foremost, stream habitats within Darby-Cobbs Watershed are impaired due to effects of stormwater. Preponderance of impervious surfaces, particularly within Cobbs Creek Watershed, has diminished baseflow and caused small streams to exhibit increasingly "flashy" hydrographs in response to rain events (Appendix C). According to a baseflow separation analysis based on 27 years of flow data at USGS gauge 01475550, baseflow currently accounts for only 42% of mean total yearly flow from the Cobbs basin. In contrast, Darby Creek Watershed is less affected by impervious surfaces and has a yearly flow regime similar to the reference stream.

Exaggerated storm flows typical of urbanized watersheds result in erosion of banks and deposition of sediment in pools and on point bars. Many stream reaches in the watershed have been excessively overwidened and downcut; channels have been enlarged so severely that baseflow does not completely fill the channel or adequately cover riffle substrates. In many reaches, floodplain disconnection exists during almost all flow conditions. Due to ongoing erosion, nearly all stormwater forces are applied to a bare soil interface. Streambank erosion has also exposed sewer infrastructure (e.g., Manholes, interceptor sewers) increasing susceptibility of infrastructure to damage and leaks.

Fish and benthic macroinvertebrate sampling reinforced the view that stormwater flow is probably the most important factor shaping biological communities in most of the watershed. Stream organisms ill-adapted to extreme flows may be washed downstream and displaced from their optimum habitat. Erosion and sedimentation may decrease reproductive success of invertebrates and fish by washing away eggs, or alternately, covering eggs with sediment. Fish and benthic macroinvertebrate community responses to habitat modification were not consistent throughout the watershed. Serious effects were observed in Cobbs Creek and its tributaries, while upstream reaches of Darby Creek were similar in some aspects to reference conditions. Lower reaches of Darby Creek showed contrasting responses overall.

Common invertebrates of the most degraded portions of Cobbs and Lower Darby Creek have morphological or behavioral adaptations to increased stream velocities. Chironomid midges construct tubes made of silk that are firmly attached to stream substrates. The insect's body may be completely retracted within this protective tube. Similarly, hydropsychid caddisflies construct silk nets, which serve as refugia during exaggerated flow conditions. Free-living shredder taxa (e.g., case building caddisflies and tipulids) were not present at most degraded sites, and very few species with external gills were present.

Dominant fish in degraded reaches also exhibit morphological and behavioral adaptations to increased stream velocities. Blacknose dace and white suckers are generally more rounded in body cross-section (i.e., dorsoventrally flattened) than many other stream fish. This body shape may allow these fish to better hug the stream bottom or slope, thereby avoiding the highest velocities. American eels were dominant (in terms of biomass) at many sites. These fish have the ability to completely bury themselves in sediments, enter small crevices, and easily extract themselves from tight spaces by reversing their undulations and swimming backwards. American eels also have the advantage of reproducing at sea, only entering the watershed once they are able to swim freely. All other fish in the watershed are vulnerable to severe flows or smothering by silt during their embryo or larval stage.

Continuous DO and pH data suggest that periphyton biomass and community structure change fundamentally following severe storm events. Dense periphyton carpets are found in slower water throughout the watershed. While these algae have not been investigated taxonomically, filamentous greens (e.g., *Cladophora* sp.) appear to dominate the biomass of the periphyton climax community. Soil erosion and runoff, particularly during smaller storm events, may be a significant source of the phosphorus that drives these algal blooms.

Instream habitat was evaluated with EPA protocols at seventeen (n=17) sites targeted for benthic macroinvertebrate sampling. A much more detailed reach ranking survey, based in fluvial geomorphological principles, was conducted for Cobbs Creek, and West and East Indian Creeks in 2000. This document, entitled "Cobbs Creek Geomorphologic Survey-Level II: Guiding Principles for Fluvial Geomorphologic Restoration of Cobbs Creek" is available from PWD's Office of Watersheds.

5.3.2. Comparisons to Reference Site

Habitat features at Darby-Cobbs watershed sites were compared to those of the reference sites located in nearby Chester County. Mainstem and third order tributary sites were compared to French Creek reference sites, located in Coventry Township, Chester County, PA (Appendix A). Tributary sites, second order or less, were compared to Rock Run, a tributary to French Creek located in Coventry Township, Chester County, PA (Appendix A). Five Darby Creek sites had greater habitat scores than the reference site, indicating good habitat conditions along mainstem reaches of Darby Creek.

5.3.3. Factor Analysis

Principal components analysis (PCA) in Statistica (Statsoft, 1998) was used to reduce the number of variables needed to explain the variation between scores for 13 different habitat attributes among Darby-Cobbs sites. The first factor extracted accounted for 53% of the variance in the data matrix. Habitat attributes with high loading values for factor one included epifaunal substrate, velocity/depth regime, channel flow status, bank vegetative protection, and all pool attributes (Appendix E). The second factor extracted accounted for 19% of the variance, for a cumulative total of 72% variance explained. No habitat attributes showed high loading scores for factor two (Appendix E). An ordination plot of Darby-Cobbs sites and three reference sites showed the sites distributed widely across PCA axis one, with five highest-rated upstream Darby Creek sites grouped closely between French Creek and Rock Run reference sites.

Overall, the placement of sites along axis 1 correlated closely with total habitat scores and relative comparability to the reference sites (Figure 18). PCA axis 2 was not particularly useful, except for weak negative associations with channel alteration and riparian zone width and positive associations with frequency of riffles, sedimentation, and embeddedness.

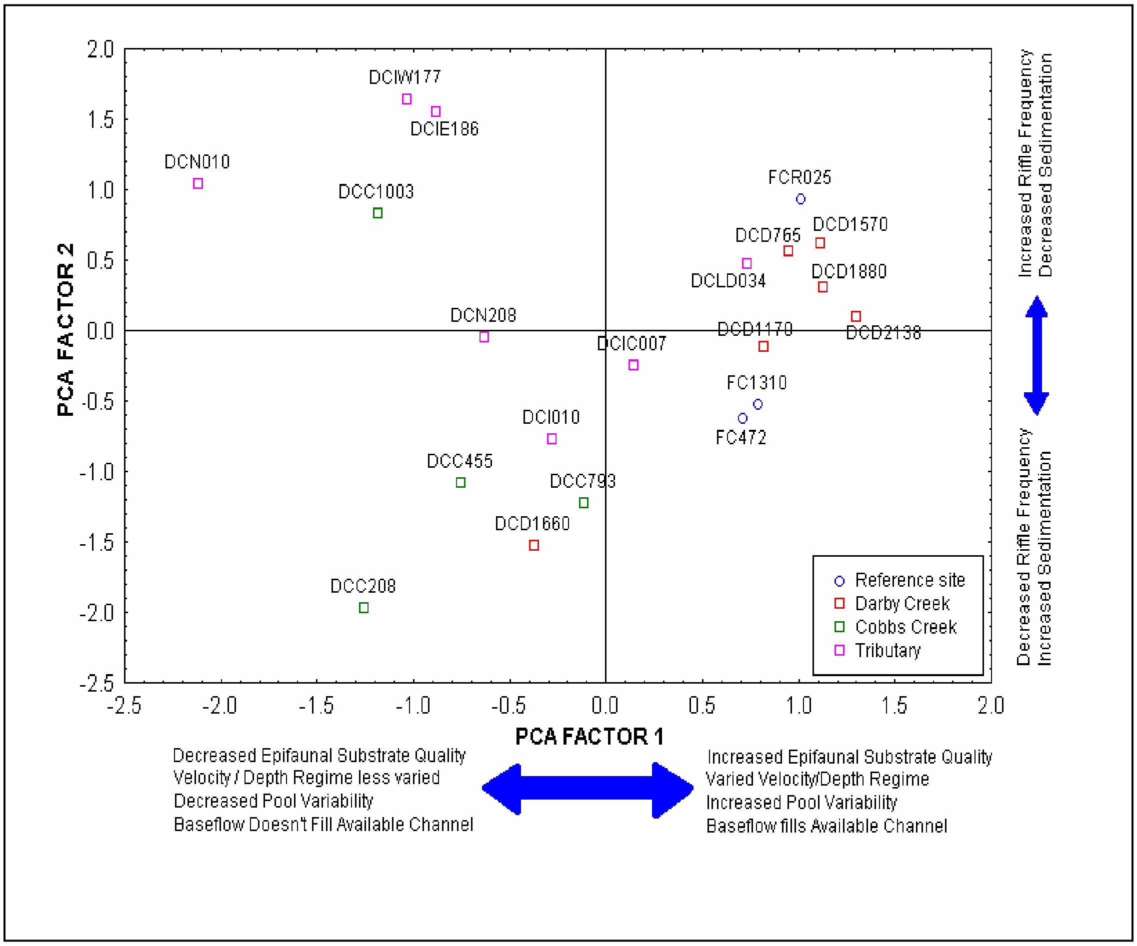


Figure 18. Principal Components Analysis ordination plot of 17 monitoring sites and 3 reference locations.

5.3.4. Individual Site Characterizations

5.3.4.1. Cobbs Creek Mainstem Sites

5.3.4.1.1. DCC208

Site DCC208 received a habitat assessment score of 127.5, and the habitat was deemed "partially supporting" (Figure 19). DCC208 was heavily impacted by sediment deposition (i.e., sand). The inorganic substrate of the site was 40% sand, and 60.0% of the macrohabitat was pools. Sedimentation, embeddedness, channel sinuosity, pool substrate, and epifaunal substrate all received marginal scores. These observations support the conclusion that the site was heavily impacted by stormwater. Poor scores were given for vegetative protection, bank stability and the left bank riparian zone. Overall habitat quality was marginal, with limited potential to support diverse aquatic communities.

5.3.4.1.2. DCC455

The habitat assessment score at site DCC455 was 142.5. This score represents a 75.2% comparison to the reference and classifies it as "supporting". DCC455 is just upstream of DCC208 and exhibited similar habitat impairments. The macrohabitat was a relatively even mix of pools, riffles and runs, but there was heavy sediment deposition throughout the stream reach (40% of substrate was sand). All of the habitat parameters were scored suboptimal or marginal. The stream banks were moderately stable, but were dominated by invasive emergent vegetation (Japanese knotweed). The riparian zone on the right bank was marginal due to areas mowed up to the stream bank. A strong sewage odor was present at the time of the habitat assessment.

5.3.4.1.3. DCC793

Site DCC793 received a habitat assessment score of 163.5, which represents an 86.3% comparison to the reference site ("supporting" designation). Macrohabitat at the site was well distributed among riffles, runs and pools, and the stream substrate was diversified, as well. Epifaunal substrate and available cover in the stream reach was optimal. The width of the riparian zone along the left bank was also favorable. Most other habitat features at DCC793 were suboptimal. Similar to other assessment sites on Cobbs Creek, moderate sand deposition was present throughout the stream reach. Most of the pools within the site were large and deep with a primarily sandy substrate. The riparian vegetative zone was much wider along the left bank of the stream than the right bank. Stability, however, was greatly reduced on the left bank where high flows had previously eroded much of the bank. The increased erosion of the left bank may be due to channel sinuosity at this location, which directs flow in that direction. Habitat at site DCC793 also may have been impacted by an exposed sewer line that crossed the stream at the upstream boundary of the assessment site.

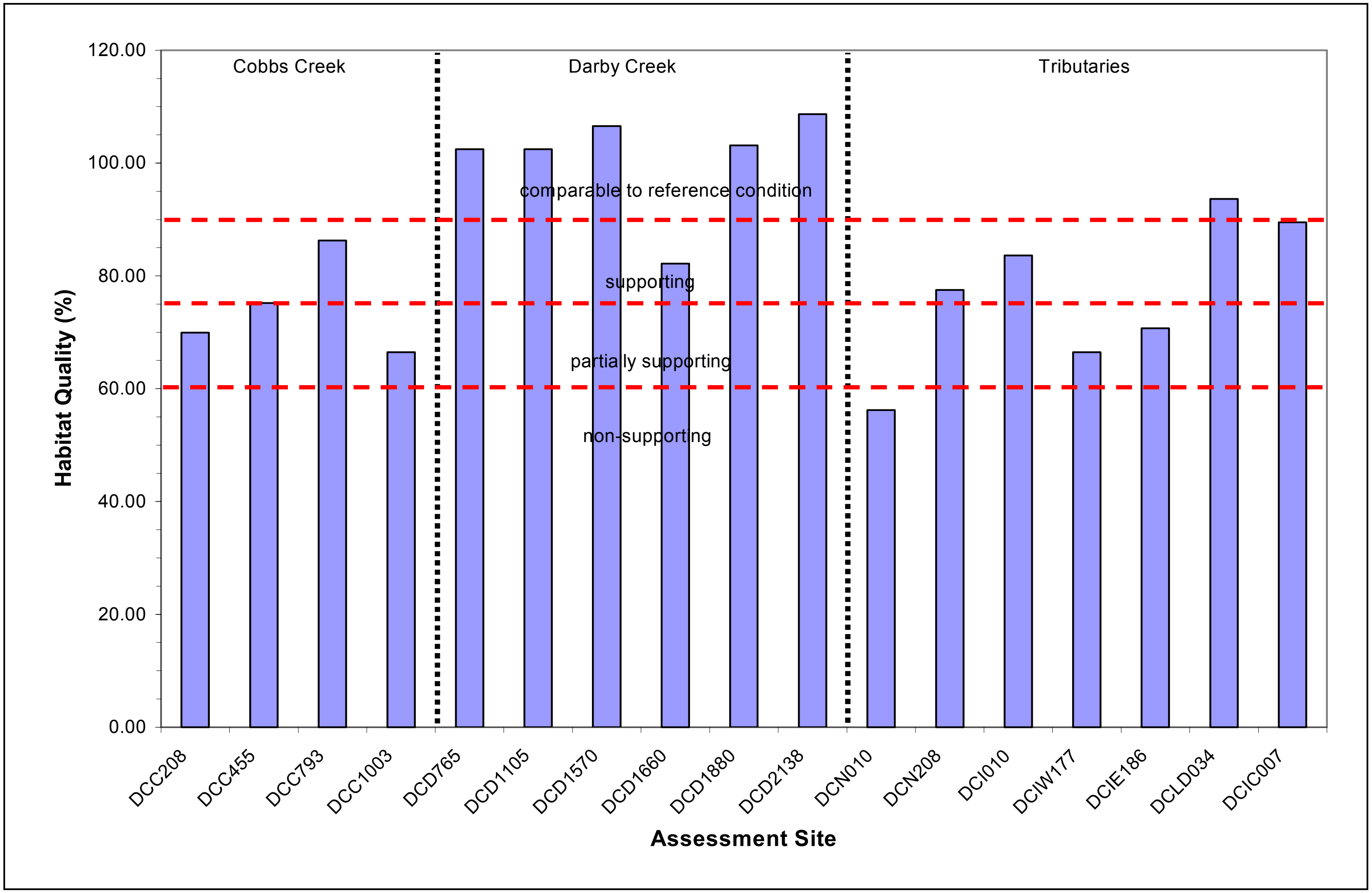


Figure 19. Habitat quality of 17 assessment sites in Darby-Cobbs Watershed. Values are represented as percent comparability to reference conditions.

<u>5.3.4.1.4. DCC1003</u>

Site DCC1003 received a habitat assessment score of 126.0. The site had the lowest score of all mainstem Cobbs Creek sites and was designated "partially supporting". The area surrounding the site was primarily residential with maintained lawns. The epifaunal substrate and available cover, pool substrate, and pool variability all received marginal scores. Evidence of heavy erosion was present throughout the site, and stream banks were moderately unstable. The riparian zone was insufficient, and vegetative protection was marginal. The stream was altered in areas by channelization, and the channel lacked sinuosity. The site appeared highly susceptible to erosion during periods of increased flow.

5.3.4.2 Darby Creek Mainstem Sites

<u>5.3.4.2.1. DCD765</u>

Site DCD765 received a habitat assessment score of 188.5, and the habitat was designated "comparable to reference" (102.4% comparison). Optimal habitat scores for epifaunal substrate and available cover, pool substrate characterization, pool variability, channel flow status, embeddedness, and velocity/depth regime all contributed to the site's excellent habitat score. The site also had an even combination of substrate components. All other condition categories were scored as suboptimal, except for the riparian vegetative zone width along the right bank, which was poor due to the presence of a mowed recreational area adjacent to the creek's right bank. A small area of stream bank was stabilized with rip-rap on the left bank. There was also moderate deposition throughout the stream reach.

<u>5.3.4.2.2. DCD1105</u>

The habitat assessment score of site DCD1105 was 188.5. This represents a 102.4 % comparison to the reference site and deems the habitat "comparable to reference". The habitat features of DCD1105 are very similar to that of DCD765. All of the habitat parameters were rated optimal or suboptimal except for the left bank riparian corridor, which received a marginal score due to an access road and mowed area that parallel the creek. The stream had an even distribution of macrohabitat types (i.e., pool, riffle, run). Both banks were relatively stable with decent vegetative protection.

<u>5.3.4.2.3. DCD1570</u>

Site DCD1570 received a habitat assessment score of 196.0, which represents a 106.5% comparison to the reference ("comparable to reference"). The macrohabitat at the site was primarily riffle (50%). The substrate components were mostly cobble and gravel (40% each), and there was light sand deposition. The predominant land use surrounding DCD1570 was forested area, but I-476 (i.e., the Blue Route) parallels the right bank of the stream. The highway was the main factor for the right bank's low riparian vegetative zone width score. DCD1570 had potential to be impacted by storm water run-off from the interstate highway. The channel sinuosity was marginal, but there were frequent riffles along the stretch.

5.3.4.2.4. DCD1660

The habitat score at DCD1660 was 156.5—an 82.2% comparison to the reference site ("supporting" designation). Most habitat parameters were scored suboptimal or marginal. Inorganic substrate was composed of 40% sand, and the site exhibited evidence of heavy sand deposition. The right bank at DCD1660 was moderately unstable, and the stream reach had low sinuosity. DCD1660 had the lowest habitat score of all mainstem Darby Creek sites.

5.3.4.2.5. DCD1880

Site DCD1880 received a habitat assessment score of 196.5, and the habitat was deemed "comparable to reference" (103.1% comparison). Most habitat attributes were scored optimal or suboptimal. The vegetative zone width on the left bank, however, was poor due to an adjacent pasture that was mowed close to the bank of the creek. An instream habitat restoration project was constructed upstream of the assessment site where submerged logs, snags and other stable habitat/fish cover features were installed along the banks to allow for greater colonization and maintenance of fish populations.

5.3.4.2.6. DCD2138

The habitat at site DCD2138 scored 207.0, and the site was designated "comparable to reference" (108.6% comparison). The site received the highest habitat score of all Darby-Cobbs assessment sites. DCD2138 is the farthest upstream assessment site on Darby Creek, and the site is located within a Brandywine Conservancy property. Habitat parameters were scored optimal or suboptimal. Macrohabitat types and inorganic substrate were both evenly distributed. Banks were stable, and a well-developed riparian corridor was present. Stable banks and not a lot of sedimentation suggest that the site had little impact from stormwater run-off and would have the potential to support a diverse biotic community.

5.3.4.3. Darby-Cobbs Tributary Sites

5.3.4.3.1. DCN010

Habitat assessment at site DCN010 returned a score of 106.5. The site was only 56.2% comparable to the reference site, and habitat was deemed "non-supporting". DCN010 had the lowest habitat score of all assessment sites. Field observations included a sewage odor and slightly turbid water. Inorganic substrate in the forms of boulder, cobble, and gravel was predominantly artificial (i.e. construction debris). The site was devoid of pools and had poor epifaunal substrate and available cover. Due to an overwidening of the stream channel, stream flow no longer reached the stream banks, and sediment bars were left exposed. The banks were moderately stable due to shoring structures (i.e. rip rap) and marginal vegetative protection.

5.3.4.3.2. DCN208

The assessment site at DCN208 scored 146.5 and was a 77.3% comparable to the reference site ("supporting" designation). Most habitat attributes were scored suboptimal or marginal. Field observations included heavy periphyton growth and a sewage odor emanating from the substrate. There was heavy local erosion with moderate sand deposition. Macrohabitat in the stream was predominantly riffle (50%), and substrate was evenly distributed. Suboptimal vegetative protection left the majority of the banks moderately unstable. Trees and Japanese knotweed were the predominant vegetation at DCN208.

5.3.4.3.3. DCI010

Site DCI010 received a habitat assessment score of 158.5, which classified the habitat as "supporting" (83.6% comparison). The site received suboptimal and marginal scores for most habitat condition parameters. Still, channel alteration at the site was optimal as the stream had retained a natural pattern and exhibited fair sinuosity. Cobble and sand dominated the substrate components, and evidence of erosion was moderate throughout the assessment site. The left bank was somewhat unstable, which could be a direct result of stormwater pulses.

5.3.4.3.4. DCIW177

Site DCIW177 received a habitat assessment score of 126.0. The habitat was designated "partially supporting", with a 66.5% comparison to the reference site. Most habitat parameters were scored suboptimal or marginal, with the exception of pool variability and riparian zone width which received "poor" scores. Pools composed only 20.0% of the macrohabitat type, and most of the pools present at DCIW177 were small and shallow. The riparian zone width was very much insufficient along both banks. Various sections of the stream bank within the assessment site were armored with rip-rap to protect against erosion. Excessive erosion rates in the stream segment may have been due to the lack of a satisfactory riparian area.

5.3.4.3.5. DCIE186

The assessment site at DCIE186 received a habitat assessment score of 134.0 which was a 70.71% comparison to the reference site ("partially supporting" designation). Frequency of riffles received an optimal score as riffles composed 50.0% of macrohabitat in the stream. All of the other habitat parameters were scored suboptimal or marginal. Lankenau Hospital is adjacent to the right bank of the assessment site and maintains a mowed field along this bank, decreasing the site's riparian vegetative zone score. Similar to West Branch Indian Run, only 20% of macrohabitat type was pools, and the pools at DCIE186 were all small and shallow.

5.3.4.3.6. DCLD034

The habitat assessment score at site DCLD034 was 177.5 and was 93.7% comparable to the reference site. Habitat conditions at the site were generally scored optimal or suboptimal. The stream segment had numerous riffles, and stream sinuosity was decent. There was moderate erosion along the stream banks and evidence of deposition in the pools. These latter attributes may be due to the lack of a sufficient riparian zone along the stream reach. The vegetative riparian buffers on both sides of the creek were less than desirable due to a maintained field cut short along both banks. The riparian zone width received a marginal score despite the "comparable to reference" designation of the site.

5.3.4.3.7. DCIC007

Site DCIC007 received a habitat assessment score of 170.5, which resulted in a "supporting" designation (89.5% comparison). Vegetative protection on both banks was scored optimal. Vegetation disruption was not evident, and banks were well covered with trees and understory shrubs. Most habitat parameters, however, were scored as suboptimal or marginal. The site was adversely affected by sediment deposition in the form of sand and by moderate erosion.

5.3.5. Habitat Suitability Indices

5.3.5.1. Overview

Habitat Suitability Indices (HSI) developed by The U.S. Fish and Wildlife Service (USFWS) were applied to sites in Darby-Cobbs Watershed targeted for fish sampling. These models integrate the expected effects of a variety of environmental, physicochemical, and hydrological variables on representative native species, as well as species of special environmental or economic concern. As stream restoration activities recommended under Target B of the watershed management plan are implemented, these indices will allow for habitat improvements to be measured quantitatively. Because freshwater fish communities are shaped by myriad inter-related environmental and ecosystem interactions and stressors (e.g., habitat degradation, flow modification, predation, competition, disease, invasive species, toxic substances, prey population dynamics, etc.), beneficial effects of habitat restoration may be obscured by other factors. Numeric HSI allow for habitat to be evaluated independently of these confounding factors.

While it may be possible to model habitat suitability for most (or even all) species found in a waterbody, this level of analysis is probably unnecessary. Habitat requirements of many species are so poorly understood that HSI have not been developed or are only generally applicable. Furthermore, many groups of species (e.g., sunfish) share many habitat requirements, obviating the need to model habitat suitability for each individual species. Best results may be obtained when HSI of a small number of sensitive, recreationally-sought, or economically important species of interest are considered.

5.3.5.2. HSI Model Selection

HSI models for seven species were selected for Darby-Cobbs Watershed. Models were chosen to reflect the range of habitat types and attributes needed to support healthy, naturally-reproducing native fish communities and provide recreational angling opportunities in non-tidal portions of the watershed. Five native minnow species were selected for HSI analysis: Blacknose dace (*Rhinichthys atratulus*), Common shiner (*Luxilis cornutus*), Creek chub (*Semotilus atromaculatus*), Fallfish (*Semotilus corporalis*), and Longnose dace (*Rhinichthys cataractae*). Of these, *R. cataractae* is not known to occur in Darby-Cobbs Watershed. However, this species' known affinity for stable, high quality riffle habitats is reflected in its HSI, prompting inclusion in the analysis as an important indicator of those macrohabitat features. The Longnose dace HSI may be considered a surrogate indicator of habitat suitability for other riffle species (e.g., darters) for which no HSI are available.

Two centrarchid fish, Redbreast sunfish (*Lepomis auritus*), and Smallmouth bass (*Micropterus dolomieu*), were included in the analysis. These species are tolerant of warmer water temperatures and require extensive slow, relatively deep water (i.e., pool) habitats with appropriate cover or structure to achieve maximum biomass. While black basses (*M. dolomieu* and its congener *M. salmoides*) are not native to southeastern Pennsylvania, they occupy the top carnivore niche and are among the most sought-after freshwater game fish in water bodies where they occur. Moreover, the only other large-bodied piscivores known to occur in non-tidal portions of Darby-Cobbs Watershed are American eels, native catadromous fish for which no HSI has been developed, and three salmonids (Rainbow trout, *Oncorhynchus mykiss*; Brown trout, *Salmo trutta*; and Brook trout, *Salvelinus fontalis*), "coldwater" species, maintained in the watershed solely through stocking.

5.3.5.3. Smallmouth Bass HSI Model

The small number of *M. dolomieu* (n=10) collected from non-tidal reaches of Darby-Cobbs watershed hindered data analysis. However, mean HSI score of three Darby Creek sites where these fish were collected was 0.82, while mean HSI score of the 6 sites where fish were not collected was 0.61. Sites where fish were collected had higher HSI scores than sites where fish were not collected in all cases. Correlations between HSI score and Smallmouth bass abundance and biomass were weak, largely due to lack of data. Results of HSI analyses (Table 10) corroborated findings of other research, particularly general habitat and continuous water chemistry analyses.

Table 10. Smallmouth bass HSI individual variable scores, total HSI score and fish data by site.

Habitat Variable	DCC208	SI	DCC455	SI	DCC793	SI	DCD765	SI	DCD1170	SI	DCD1570	SI	DCD1880	SI	DCD2138	SI	FC472	SI
substrate type category	B	0.30	B	0.30	C	1.00	C	1.00	C	1.00	C	1.00	A	0.20	C	1.00	C	1.00
percent pools	36.01	0.69	25.00	0.44	56.98	1.00	34.57	0.66	26.32	0.47	38.74	0.75	26.86	0.49	12.80	0.17	48.08	0.96
Avg. pool Depth	0.71	0.59	0.50	0.42	0.39	0.33	0.83	0.69	0.59	0.49	0.68	0.57	0.51	0.43	0.59	0.49	0.56	0.47
percent cover	12.50	0.50	11.87	0.47	20.63	0.83	21.25	0.85	20.00	0.80	20.00	0.80	21.88	0.88	20.00	0.80	21.25	0.85
average pH	7.45	0.98	7.48	0.99	7.32	0.96	7.86	0.96	7.60	0.99	7.51	0.99	7.20	0.94	7.10	0.92	7.90	0.93
Dissolved Oxygen	2.93	0.16	3.72	0.32	3.96	0.38	4.00	0.38	4.00	0.38	6.00	0.97	6.00	0.97	6.00	0.97	7.00	1.00
Turbidity	25.00	1.00	25.00	1.00	25.00	1.00	25.00	1.00	25.00	1.00	25.00	1.00	25.00	1.00	25.00	1.00	25.00	1.00
Temperature (adult)	19.50	0.83	20.00	0.86	20.20	0.86	19.30	0.82	18.30	0.76	18.10	0.76	18.70	0.79	18.00	0.75	18.00	0.75
Temperature (embryo)	16.95	1.00	19.70	1.00	18.40	1.00	19.10	1.00	18.80	1.00	18.70	1.00	20.30	1.00	17.00	1.00	17.00	1.00
Temperature (fry)	19.50	0.80	20.00	0.83	20.20	0.84	19.30	0.79	18.30	0.73	18.10	0.71	18.70	0.75	18.00	0.71	18.00	0.71
Temperature (juvenile)	19.50	0.84	20.00	0.86	20.20	0.87	19.30	0.83	18.30	0.78	18.10	0.77	18.70	0.80	18.00	0.76	18.00	0.76
Water fluctuations	A	0.30	A	0.30	A	0.30	A	0.30	A	0.30	A	0.30	A	0.30	A	0.30	A	0.30
Stream Gradient	15.10	0.50	4.70	1.00	12.70	0.50	3.50	1.00	3.80	1.00	2.40	1.00	2.40	1.00	12.00	0.50	10.00	0.50
Food (C_F) component		0.47		0.40		0.94		0.82		0.72		0.84		0.44		0.52		0.93
Cover (C_C) Component		0.52		0.41		0.79		0.80		0.69		0.78		0.50		0.62		0.82
Water Quality Component C_{WQ}		0.76		0.80		0.81		0.79		0.78		0.89		0.89		0.87		0.88
Reproduction (C_R) Component		0.49		0.54		0.71		0.72		0.71		0.81		0.65		0.81		0.82
Other (C_{OT}) component		0.50		1.00		0.50		1.00		1.00		1.00		1.00		0.50		0.50
H S I score		**0.49**		**0.54**		**0.73**		**0.82**		**0.77**		**0.86**		**0.66**		**0.65**		**0.77**
abundance		0.00		0.00		0.00		2.00		5.00		3.00		0.00		0.00		0.00
biomass		0.00		0.00		0.00		129.70		340.84		272.30		0.00		0.00		0.00

No smallmouth bass were collected from Cobbs Creek. Sites DCC208 and DCC455 had the lowest HSI scores in the watershed and were limited by dissolved oxygen concentration, cover, and pool substrate composition (Table 10). Site DCC793 was limited by stream gradient and depth of pools, indicating unsuitably high stream velocities in pool habitats. Sites in Cobbs Creek generally exhibited unsuitable characteristics (e.g., lack of cover, decreased substrate size, or increased velocity) in pool habitats; these factors force bass to expend more energy acquiring food. Competition from American eels and the frequency and magnitude of severe storm flow conditions cannot be discounted as factors making Cobbs Creek less suitable for Smallmouth bass.

Ten smallmouth bass individuals were collected from the three downstream-most sites within the non-tidal portion of Darby Creek watershed. The lack of Smallmouth bass at upstream sites is to be expected, as this species requires deeper, calmer water than is typically found in first- or second-order stream sites. It should be noted that Darby Creek watershed is generally less affected by urbanization than Cobbs creek watershed, and has more of its historic tributaries intact. Stream order and river mile-based comparisons between the two watersheds are probably not very meaningful. Within Darby Creek watershed, sites where Smallmouth bass were not collected had, in some cases, pool structure, substrate size and or cover numerically similar to downstream sites, suggesting that distribution may be related stream size.

Like most centrarchids, Smallmouth and Largemouth basses are able to acclimate to brief periods of suboptimal dissolved oxygen concentration. With few exceptions, such as sites in which DO concentrations may frequently drop below 3mg/l for extended periods, or sites in which spawning substrates are chronically anoxic with Hydrogen sulfide (H_2S) present, Smallmouth bass distributions are probably not strongly governed by DO concentrations. Furthermore, many centrarchid species' thermal preferenda are higher than temperatures typical of 2nd to 4th order streams in southeast PA. Most species are known to reach their maximum size in the non-temperate Southern U.S., growing fastest in lentic habitats where conditions are suitable for growth year-round and specific management techniques are employed. HSI model temperature output (Table 10) reflects the fact that optimum temperatures are seldom reached in Southeastern PA.

Stream restoration activities that increase the amount of instream and overhanging cover, or activities that create, expand or improve pool habitats probably will result in increased habitat suitability for Smallmouth bass. Re-meandering of the stream channel, installation of flow diverters such as rock vanes and J-hooks, as well as the creation of undercut banks through log sill cribbing and cantilevered banks should also enhance habitat for Smallmouth bass and forage fish by establishing low velocity refugia during storms.

Infrastructure assessments, inspections, and dry weather pollution source trackdown activities will likely reduce the severity of water quality (i.e., DO and pH related) impacts on HSI scores at some sites, particularly DCC208 and DCD765. It is unlikely that habitat impairment due to frequent water level fluctuations and the effects of erosion and sedimentation will be ameliorated in the near future without significant investments in streambank restoration and basin-wide implementation of stormwater BMPs.

5.3.5.4. Redbreast Sunfish HSI Model

As a generalist species, Redbreast sunfish (*Lepomis auritus*) are adaptable to a range of habitat attributes and may feed opportunistically upon a variety of prey types. Most SI variable expressions in this species' HSI include a large range of highly suitable values (or large area "under the curve"). HSI scores (Table 11) did not generally correlate well with observed *L. auritus* abundance or biomass. Limiting factors included pH, vegetative cover, temperature, and substrate-related variables, but the discriminatory power of the HSI was probably limited by lack of variability among sites.

Site DCC793 received the highest HSI score in the watershed, yet only 1 Redbreast Sunfish was collected at this site. DCC793 was the only site in the watershed that had a sizeable population of Pumpkinseed sunfish (*L. gibbosus*). At most other sites, Redbreast sunfish were more abundant than other sunfish species, though a longitudinal trend in sunfish species diversity increasing from downstream to upstream was observed in Darby Creek. Sunfish species' habitat needs are generally similar; there was no obvious explanation for the change in species relative abundance. Somewhat better correlations resulted from comparison of a modified version of the HSI to grouped *Lepomis* spp. abundance and biomass (Table 12).

pH limitation was indicated at sites DCD765 and DCC208, where pH fluctuations due to algal activity occasionally result in pH >9.0. The Redbreast sunfish HSI model was probably not designed to be used with the least suitable value picked from a continuous database. Because fish can avoid areas of unsuitable pH when they occur infrequently, it would be more suitable for the model to account for how frequently unsuitable pH conditions occur (e.g., take the 90th percentile value, disregard outliers, etc.).

Likewise, summer temperature during spawning may poorly reflect habitat suitability for this species. The HSI was developed for an industrial cooling water investigation in the southern U.S.; temperature parameters should not be expected to be "optimal" in the temperate northeast. Fish collected at upstream sites with less suitable spawning temperatures may spawn at warmer downstream locations or in sunnier, sandy backwaters that are not accounted for in the data.

Observations made during electrofishing surveys suggested that Redbreast sunfish (and congeneric sunfishes) are most frequently found associated with cover, which can be difficult to measure quantitatively. Cover measurements included in the Redbreast Sunfish HSI were normalized to a scale of 0-25 from EPA Habitat assessment variable 1: Epifaunal Substrate and Available cover (Section 5.3.1.). As most sites in Darby-Cobbs Watershed are known to be deficient in vegetative cover, the "% vegetative cover" variable was estimated as half this normalized Epifaunal substrate value (e.g., EPA Epifaunal Substrate and Available Cover score =20, HSI Cover % =25, HSI vegetative cover % = 12.5.)

Table 11. Redbreast sunfish HSI individual variable scores, total HSI score and fish data by site.

Habitat Variable	DCC208	SI	DCC455	SI	DCC793	SI	DCD765	SI	DCD1105	SI	DCD1570	SI	DCD1880	SI	DCD2138	SI	FC472	SI
% cover	12.50	0.70	11.87	0.68	20.63	0.90	21.25	0.91	20.00	0.88	20.00	0.88	21.88	0.93	20.00	0.88	21.25	0.91
vegetated cover	6.25	0.53	5.94	0.52	10.31	0.61	10.63	0.61	10.00	0.60	10.00	0.60	10.94	0.62	10.00	0.60	10.63	0.61
spawning temperature (summer)	19.50	0.40	20.00	1.00	20.20	1.00	19.30	0.40	18.30	0.40	18.10	0.40	18.70	0.40	17.00	0.40	18.00	0.40
% slow pools	36.01	0.96	25.00	0.70	56.98	0.92	34.57	0.93	26.32	0.73	38.74	0.81	26.86	0.74	12.80	0.35	48.08	0.87
% sand/gravel	58.00	1.00	70.00	1.00	43.00	1.00	17.00	0.40	39.00	1.00	47.00	1.00	49.00	1.00	35.00	0.90	16.00	0.39
least suitable pH observed	9.07	0.34	6.89	1.00	6.04	1.00	9.92	0.06	6.50	1.00	6.58	1.00	7.50	1.00	7.50	1.00	7.50	1.00
minimum DO (category)	B	0.70	B	0.70	B	0.70	B	0.70	A	1.00	A	1.00	A	1.00	A	1.00	A	1.00
max temp growing season	23.10	0.80	23.50	0.80	23.20	0.80	24.40	0.80	21.50	0.80	21.30	0.80	22.90	0.80	19.00	0.50	20.00	0.80
stream width	15.23	1.00	10.00	1.00	9.30	1.00	15.07	1.00	14.50	1.00	12.08	1.00	10.77	1.00	5.35	0.84	14.20	1.00
H S I score final		**0.34**		**0.52**		**0.61**		**0.06**		**0.40**		**0.40**		**0.40**		**0.35**		**0.39**
L. auritus abundance		62		227		1		66		39		20		4		25		
L. auritus biomass		638		3365		0		2005		1205		1076		162		1036		

Table 12. Sunfish species HSI individual variable scores, total HSI score and fish data by site.

Habitat Variable	DCC208	SI	DCC455	SI	DCC793	SI	DCD765	SI	DCD1105	SI	DCD1570	SI	DCD1880	SI	DCD2138	SI	FC472	SI
% cover	12.5	0.7	11.87	0.68	20.63	0.9	21.25	0.91	20	0.88	20	0.88	21.88	0.93	20	0.88	21.25	0.91
vegetated cover	6.25	0.53	5.94	0.52	10.31	0.61	10.63	0.61	10	0.6	10	0.6	10.94	0.62	10	0.6	10.63	0.61
spawning temperature (summer)	20	1	20	1	20.2	1	20	1	20	1	20	1	19	0.4	19	0.4	18	0.4
% slow pools	36.01	0.96	25	0.7	56.98	0.92	34.57	0.93	26.32	0.73	38.74	0.81	26.86	0.74	12.8	0.35	48.08	0.87
% sand/gravel	58	1	70	1	43	1	17	0.4	39.00	1	47	1	49	1	35	0.9	16	0.39
least suitable pH observed	8.5	1	6.89	1	6.04	1	8.5	1	6.5	1	6.58	1	7.5	1	7.50	1	7.5	1
minimum DO (category)	B	0.7	B	0.7	B	0.7	B	0.7	A	1	A	1	A	1	A	1	A	1
max temp growing season	23.1	0.8	23.5	0.8	23.2	0.8	24.4	0.8	21.5	0.8	21.30	0.8	22.9	0.8	19	0.5	20	0.8
stream width	15.23	1	10	1	9.3	1	15.07	1	14.5	1	12.08	1	10.77	1	5.35	0.84	14.20	1
H S I score final		**0.53**		**0.52**		**0.61**		**0.4**		**0.6**		**0.6**		**0.4**		**0.35**		**0.39**
Lepomis sp. abundance		67		230		59		68		43		24		24		63		
Lepomis sp. biomass		800		3424		650		2049		1235		1132		1195		1179		

EPA habitat assessment techniques may not be most appropriate to habitat investigations for this species. For example, the EPA habitat technique stipulates that "transitional and new fall" woody debris (e.g., tree limbs and branches) should be disregarded. However, this type of cover is often quite common (and largely beneficial) in urbanized streams that have forested margins and eroding banks, such as Cobbs and Darby Creeks. Though "transitional and new fall" woody debris may not be permanent at a site, it may persist for a year or more, particularly when aggregations form along stream margins. The microhabitat within an aggregation of this woody debris is very complex when compared to most types of permanent hard cover, and qualitative observations during electrofishing surveys suggest that tree limbs and branches are beneficial and a preferred cover type for many fish.

Of course, large aggregations of woody debris may threaten the structural integrity of bridges, culverts and other infrastructure. One of the chief functions of PWD's Waterways Restoration Unit (WRU) is to remove this type of debris. As stream segments are restored, a careful balance should be struck between cleaning the stream of trash and debris and overzealous elimination of beneficial natural habitat features. Another excellent solution to this problem is the selective installation of staked or cabled trees and large tree limbs, Christmas tree bundles, willow stakes, root wads, and, in still water, manufactured fish habitat structures.

5.3.5.5. Blacknose Dace HSI Model

The Blacknose Dace HSI model produced fair results. Site DCC793 had the highest HSI score in the watershed (0.85), as well as the greatest abundance and largest biomass. Sites DCC208 and DCD765 scored 0.15, and (respectively) had the lowest and second lowest abundance and biomass in the watershed. Aside from these extreme values, the HSI model was not a good predictor of Blacknose dace abundance or biomass (Table 13). The Blacknose dace is classified as a tolerant fish. In fact, along with *C. commersoni*, *A. rostrata*, and *Fundulus* spp., Blacknose dace is one of the most common piscine inhabitants of degraded streams in southeast PA. Despite its tolerance of degraded stream conditions, the species' HSI model is quite complex- it includes 16 raw variables, six life requisite components, as well as limiting and compensatory mechanisms.

Limiting variables identified by the model included stream width, stream margin substrate composition, and pool substrate composition. As some of these variables were estimated, results of the HSI model are only as good as the estimates. The model was found to be too sensitive in the range of stream gradient values observed and was adjusted slightly to exclude these effects, which would have been limiting at 5 of 9 sites. While greater stream gradients may be preferred, this species is routinely collected in sites of lower gradient. An overall pattern of increasing abundance from downstream to upstream was evident.

Blacknose dace is a stocky fish, moderate in body form and somewhat rounded (dorsoventrally flattened) in comparison to other, more vertically compressed minnows.

Table 13. Blacknose dace HSI individual variable scores, total HSI score and fish data by site.

Habitat Variable	DCC208	SI	DCC455	SI	DCC793	SI	DCD765	SI	DCD1105	SI	DCD1570	SI	DCD1880	SI	DCD2138	SI	FC472	SI
% Shaded	20.00	0.77	20.00	0.77	60.00	1.00	70.00	1.00	30.00	1.00	45.00	1.00	75.00	1.00	85.00	1.00	70.00	1.00
% Pools	36.01	0.95	25.00	0.81	56.98	1.00	34.57	0.93	26.32	0.83	38.74	0.98	26.86	0.84	12.80	0.66	48.08	1.00
Stream Gradient	15.10	1.00	4.70	0.05	12.70	1.00	3.50	0.05	3.80	0.05	2.40	0.05	2.40	0.05	12.00	1.00	10.00	1.00
Stream Width	15.23	0.15	10.00	0.68	9.30	0.76	15.07	0.15	14.50	0.21	12.08	0.46	10.77	0.60	5.35	1.00	14.20	0.24
Temperature (growing seas.)	19.50	1.00	20.00	1.00	20.20	1.00	19.30	1.00	18.30	1.00	18.10	1.00	18.70	1.00	18.00	1.00	18.00	1.00
Turbidity	25.00	1.00	25.00	1.00	25.00	1.00	25.00	1.00	25.00	1.00	25.00	1.00	25.00	1.00	25.00	1.00	25.00	1.00
Riffle Substrate Category	D	0.60	C	1.00	D	0.60	E	0.40	D	0.60	D	0.60	D	0.60	D	0.60	E	0.40
Riffle Depth	12.00	1.00	20.00	1.00	10.00	1.00	35.00	0.82	29.00	1.00	26.00	1.00	18.00	1.00	16.00	1.00	18.00	1.00
Velocity in Riffles	30.20	1.00	19.40	0.96	25.40	1.00	17.00	0.80	17.60	0.84	14.80	0.66	14.80	0.66	24.00	1.00	20.00	1.00
Temperature (spawning seas.)	16.95	1.00	19.70	1.00	18.40	1.00	19.10	1.00	18.80	1.00	18.70	1.00	20.30	1.00	17.00	1.00	17.00	1.00
Pool Substrate Category	C	1.00	C	1.00	D	1.00	E	0.20	A	0.80	E	0.20	A	0.80	E	0.20	E	0.20
Velocity in Pools	9.00	1.00	4.00	1.00	10.00	1.00	6.00	1.00	6.00	1.00	4.00	1.00	4.00	1.00	9.00	1.00	7.00	1.00
Riffle Substrate Category	D	0.50	C	1.00	D	0.50	E	0.30	D	0.50	D	0.50	D	0.50	D	0.50	E	0.30
Velocity in Riffles	30.20	1.00	19.40	1.00	25.40	1.00	17.00	1.00	17.60	1.00	14.80	0.99	14.80	0.99	24.00	1.00	20.00	1.00
Substrate in Stream Margins	A	1.00	B	0.70	A	1.00	A	1.00	C	0.40	D	0.30	D	0.30	E	0.20	E	0.20
Velocity in Stream Margins	4.00	1.00	4.70	1.00	6.00	1.00	3.50	1.00	3.80	1.00	2.40	1.00	2.40	1.00	12.00	0.85	10.00	1.00
Food/Cover Component C_{FC}		0.15		0.68		0.94		0.15		0.21		0.46		0.60		0.92		0.24
Water Quality Component C_{WQ}		1.00		1.00		1.00		1.00		1.00		1.00		1.00		1.00		1.00
Reproduction Component C_R		0.94		0.99		0.94		0.40		0.90		0.86		0.86		0.94		0.40
Adult Component C_A		1.00		1.00		1.00		0.20		0.89		0.20		0.89		0.20		0.20
Juvenile Component C_J		0.71		1.00		0.71		0.30		0.71		0.70		0.70		0.71		0.30
Fry Component C_F		1.00		0.84		1.00		1.00		0.40		0.30		0.30		0.20		0.20
H S I Score		**0.15**		**0.68**		**0.85**		**0.15**		**0.21**		**0.20**		**0.30**		**0.20**		**0.20**
Abundance		1		97		1126		5		50		213		353		103		
Biomass		1		204		1979		10		112		490		683		231		

Hydrodynamics may play a part in its adaptability to a variety of flow conditions and, in part, explain its abundance at degraded sites that are periodically exposed to intense scouring flows. Other minnow species may not be as well adapted at surviving these types of flows. As stormwater BMPs and streambank restoration proceed under Target B of the watershed management plan, perhaps these hydrologically-impaired sites will begin to support more diverse fish communities rather than being dominated by three or four tolerant species.

5.3.5.6. Creek Chub HSI Model

The Creek Chub HSI model produced satisfactory results overall. Sites where no fish were collected had the lowest HSI scores in the watershed (Table 14). The site with the highest HSI score had the greatest abundance and biomass in the watershed. While biomass increased at all sites as HSI scores increased, and abundance showed the same pattern in 8 of 9 cases, the HSI model's scale of resolution was greatly compacted. Five sites had HSI scores between 0.80 and 0.88, while the two lowest scores were 0.4 and 0.69. When the lowest score corresponding to zero fish collected was taken as the origin rather than (0,0), the strongest correlations between (log-transformed) HSI scores and fish biomass and abundance were observed (R^2 values 0.94 and 0.93, respectively).

With 20 habitat and water quality variables and 5 life requisite components, the Creek Chub HSI model was most complex of the models used. As many water quality variables returned optimum suitability values (i.e., SI= 1.0), and most had limited discriminatory power, the model could be made simpler without sacrificing predictability. It is likely that if a smaller number of critical habitat variables were focused on, the model could have better resolution over a larger scale of final HSI scores.

5.3.5.7. Common Shiner HSI Model

Common shiner HSI model output was not very useful. Much like the Redbreast sunfish model, the SI variables used are general in nature, and contain a large range of suitable values (Redbreast sunfish and Common shiners are both considered generalist species). With the exception of two sites that were severely limited by a single SI variable (pH at site DCD765 and % pools at site DCD2138), SI variable attributes of most sites were very similar and the resulting HSI scores were also similar, ranging from 0.80 to 0.93 (Table 15). If the influence of a single low pH value and the smaller proportion of pools at these sites were disregarded, all sites would have HSI scores within this narrow range.

Common shiner abundance and biomass were fairly similar at all sites with the exception of DCC793, where a much greater number were collected. Perhaps the most interesting finding with regard to Common shiners was the greatly reduced average size of individual fish collected at site DCC455 compared to other sites.

Table 14. Creek chub HSI individual variable scores, total HSI score and fish data by site.

Habitat Variable	DC208	SI	DCC455	SI	DCC793	SI	DCD765	SI	DCD1105	SI	DCD1570	SI	DCD1880	SI	DCD2138	SI	FC472	SI
% pools	36.01	0.98	25.00	0.74	56.98	1.00	34.57	0.97	26.32	0.79	38.74	1.00	26.86	0.81	12.80	0.39	48.08	1.00
Pool class (category)	A	1.00	B	0.60	B	0.60	A	1.00	B	0.60	A	1.00	B	0.60	B	0.60	B	0.60
% cover	12.50	0.37	11.87	0.35	20.63	0.61	21.25	0.63	20.00	0.59	20.00	0.59	21.88	0.64	20.00	0.59	21.25	0.63
Winter thermal cover	YES	0.91	YES	0.74	YES	0.92	YES	1.00	NO	0.45	NO	0.64	NO	0.48	NO	0.32	NO	0.52
Stream gradient	15.10	0.80	4.70	0.79	12.70	1.00	3.50	0.57	3.80	0.63	2.40	0.37	2.40	0.37	12.00	1.00	10.00	1.00
Stream width	15.23	0.30	10.00	0.56	9.30	0.63	15.07	0.30	14.50	0.32	12.08	0.42	10.77	0.50	5.35	1.00	14.20	0.33
Turbidity	25.00	1.00	25.00	1.00	25.00	1.00	25.00	1.00	25.00	1.00	25.00	1.00	25.00	1.00	25.00	1.00	25.00	1.00
pH (category)	B	0.80	A	1.00	B	0.80	C	0.40	A	1.00	A	1.00	A	1.00	A	1.00	A	1.00
Vegetation index	37.50	0.54	65.00	0.95	72.50	1.00	67.50	0.97	67.50	0.97	90.00	1.00	75.00	1.00	80.00	1.00	62.50	0.92
Substrate food index	C	0.50	B	0.70	B	0.70	C	0.50	B	0.70	C	0.50	B	0.70	B	0.70	B	0.70
Average summer water temp.	21.80	1.00	21.20	1.00	20.60	1.00	20.80	1.00	21.00	1.00	20.90	1.00	20.00	1.00	19.00	1.00	19.00	1.00
Minimum summer DO conc.	2.93	0.47	3.72	0.76	3.96	0.83	4.00	0.85	4.00	0.85	6.00	1.00	6.00	1.00	6.00	1.00	7.00	1.00
Average velocity (0.6 depth)	18.00	1.00	8.00	0.94	20.00	1.00	12.00	1.00	12.00	1.00	8.00	0.94	8.00	0.94	18.00	1.00	14.00	1.00
Average spring water temp	17.10	1.00	19.20	1.00	19.90	1.00	19.10	1.00	17.60	1.00	17.30	1.00	18.50	1.00	16.00	1.00	16.00	1.00
Minimum spring DO conc.	4.00	0.50	5.00	0.76	5.50	0.86	5.00	0.76	5.00	0.76	7.00	1.00	7.00	1.00	8.00	1.00	8.00	1.00
Average spring riffle velocity	45.30	1.00	29.10	1.00	38.10	1.00	25.50	1.00	26.40	1.00	22.20	1.00	22.20	1.00	36.00	1.00	30.00	1.00
Riffle substrate index	89.75	1.00	100.00	1.00	100.00	1.00	97.10	1.00	89.95	1.00	100.00	1.00	90.91	1.00	100.00	1.00	100.00	1.00
Average stream margin velocity	4.00	1.00	4.70	1.00	6.00	1.00	3.50	1.00	3.80	1.00	2.40	1.00	2.40	1.00	12.00	0.69	10.00	1.00
% summer shade	20.00	0.33	20.00	0.33	60.00	0.92	70.00	1.00	30.00	0.47	45.00	0.72	75.00	1.00	85.00	1.00	70.00	1.00
Average maximum depth	0.71	1.00	0.50	1.00	0.39	0.94	0.83	1.00	0.59	1.00	0.68	1.00	0.51	1.00	0.59	1.00	0.56	1.00
Food component		0.52		0.83		0.85		0.74		0.84		0.75		0.85		0.85		0.81
Cover component		0.83		0.69		0.83		0.92		0.71		0.84		0.72		0.56		0.76
Water Quality component		0.59		0.71		0.89		0.40		0.80		0.92		1.00		1.00		1.00
Reproduction component		0.87		0.95		0.97		0.95		0.95		1.00		1.00		1.00		1.00
Other component		0.70		0.78		0.86		0.62		0.65		0.59		0.62		1.00		0.78
H S I score		**0.69**		**0.79**		**0.88**		**0.40**		**0.78**		**0.81**		**0.82**		**0.86**		**0.86**
biomass		0		52.47		998		0		12.27		33.09		107.68		193.59		

Table 15. Common shiner HSI individual variable scores, total HSI score and fish data by site.

Habitat Variable	DCC208	SI	DCC455	SI	DCC793	SI	DCD765	SI	DCD1105	SI	DCD1570	SI	DCD1880	SI	DCD2138	SI	FC472	SI
Temperature	22.90	0.79	23.50	0.67	23.20	0.72	24.40	0.50	21.20	1.00	21.30	1.00	21.90	1.00	20.00	1.00	20.00	1.00
pH	9.07	0.88	6.89	1.00	6.04	0.58	9.92	0.14	6.50	0.99	6.58	1.00	7.50	1.00	7.50	1.00	7.50	1.00
turbidity	25.00	1.00	25.00	1.00	25.00	1.00	25.00	1.00	25.00	1.00	25.00	1.00	25.00	1.00	25.00	1.00	25.00	1.00
Riffle Substrate Category	D	0.80	C	1.00	D	0.80	E	0.20	D	0.80	D	0.80	D	0.80	D	0.80	E	0.20
% pools	36.01	0.85	25.00	0.56	56.98	0.99	34.57	0.80	26.32	0.59	38.74	0.89	26.86	0.59	12.80	0.07	48.08	0.99
Velocity in Pools	9.00	1.00	4.00	0.87	10.00	1.00	6.00	0.94	6.00	0.94	4.00	0.87	4.00	0.87	9.00	1.00	7.00	0.96
Pool Class	B	1.00	B	1.00	C	0.60	B	1.00	B	1.00	B	1.00	B	1.00	B	1.00	B	1.00
Temperature (Spawning seas.)	15.63	0.95	17.35	1.00	16.20	1.00	17.45	1.00	16.55	1.00	16.30	1.00	17.70	1.00	15.00	0.76	15.00	0.76
riffle Velocity	30.20	0.53	19.40	1.00	25.40	0.75	17.00	1.00	17.60	1.00	14.80	1.00	14.80	1.00	24.00	0.82	20.00	1.00
Food/Cover Component C_{FC}		0.91		0.86		0.85		0.20		0.83		0.89		0.82		0.07		0.20
Water Quality Component C_{WQ}		0.88		0.87		0.75		0.14		1.00		1.00		1.00		1.00		1.00
Reproduction Component C_R		0.75		1.00		0.83		0.20		0.89		0.89		0.89		0.80		0.20
H S I Score		**0.85**		**0.91**		**0.81**		**0.14**		**0.91**		**0.93**		**0.90**		**0.07**		**0.20**
Abundance		13		86		398		34		42		74		60		41		
Biomass		121.2		250		4324		288.5		316.3		389.2		530.1		437.8		

5.3.5.8. Fallfish HSI Model

Interpretation of Fallfish HSI model output was hindered by a lack of data; only 19 individuals were collected in total. Only one individual was collected in the Cobbs Creek sub-basin (site DCC793). The Fallfish HSI model is one of the simplest HSI models available, considering only six variables. Furthermore, as applied to the Darby-Cobbs Watershed, only five variables were considered because it was not possible to convert modern NTU turbidity data to JTU data. Differences between sites were not very large for most of the remaining five variables (Table 16).

Substrate type, however, is an important factor because Fallfish construct and spawn over gravel nest structures. Fallfish males push and carry gravel and smalls stones to create a nest pile which may be quite large. Following a spawning episode, eggs are buried, after which additional material may be added to the nest structure and the process repeated. Similar egg burying behavior is practiced by other minnow species (e.g., Cutlips minnow, Creek chub). Since developing eggs rely on oxygen exchange through interstitial spaces, clean, oxygenated gravel is necessary. Several phenomena arising from urbanization may reduce spawning success of these species.

Increased stream velocities resulting from increased impervious cover may be severe enough to damage or completely scour away nest structures. Alternately, nests built in depositional areas may become silted over, smothering eggs. Substrates may contain significant amounts of dead and decaying organic matter or be inhabited by other aerobic and chemosynthetic microbial communities. If oxygen-depleting biochemical processes within the sediments outpace re-oxygenation, or if the overlying water itself is low in dissolved oxygen, eggs may die. Decreased reproductive success may partially explain the very low abundance of Fallfish and complete absence of Cutlips minnow in the Cobbs Creek basin.

While Fallfish HSI model applicability was very limited, the biogeography of Fallfish and other egg-burying cyprinids may be helpful in identifying macro-scale impairments to run and pool stability, as well as the oxygen state and suitability of stream substrates for not only their eggs, but sediment dwelling benthic invertebrates as well. Site-specific conclusions should be avoided, however, because fish are mobile and may be collected far away from their spawning sites.

5.3.5.9. Longnose dace HSI Model

Longnose dace HSI model output predicted that water temperatures in all Cobbs Creek sites and site DCD765 would preclude survivorship of naturally reproducing population of Longnose dace (Table 17). Other sites were severely limited by stream velocity. Though the model requires average stream velocity data, it might be more appropriate to consider only riffle velocity, as sites chosen for fish surveys in Darby-Cobbs were selected based on a relatively even mix of macrohabitat features. If surveys were

Table 16. Fallfish HSI individual variable scores, total HSI score and fish data by site.

Habitat Variable	DCC208	SI	DCC455	SI	DCC793	SI	DCD765	SI	DCD1170	SI	DCD1570	SI	DCD1880	SI	DCD2138	SI	FCR024	SI
Temperature	21.80	0.78	21.20	0.86	20.60	0.93	20.80	0.90	21.00	0.88	20.90	0.89	20.00	1.00	19.00	1.00	19.00	1.00
Turbidity	25.00	1.00	25.00	1.00	25.00	1.00	25.00	1.00	25.00	1.00	25.00	1.00	25.00	1.00	25.00	1.00	25.00	1.00
Mode of Stream Depth	0.17	0.84	0.16	0.83	0.11	0.79	0.44	1.00	0.51	1.00	0.29	0.93	0.13	0.80	0.46	1.00	0.47	1.00
Spawning Temperature	15.63	0.53	17.35	1.00	16.20	0.84	17.45	1.00	16.55	1.00	16.30	0.89	17.70	0.56	15.00	0.20	15.00	0.20
Substrate Category	E	0.10	C	1.00	D	0.40	E	0.10	D	0.40	C	1.00	D	0.40	D	0.40	E	0.10
Cover category	C	0.40	C	0.40	B	0.70	B	0.70	B	0.70	B	0.70	A	1.00	B	0.70	B	0.70
Water Quality Component C_{WQ}		0.89		0.93		0.96		0.95		0.94		0.94		1.00		1.00		1.00
Reproduction Component C_R		0.18		0.69		0.57		0.41		0.65		0.84		0.56		0.20		0.20
H S I score		**0.53**		**0.81**		**0.77**		**0.68**		**0.80**		**0.89**		**0.78**		**0.60**		**0.60**
abundance		0		0		1		6		11		0		1		0		0
Total Biomass (g)		0		0		16.03		760		372.47		0		3.42		0		0

Table 17. Longnose dace HSI individual variable scores, total HSI score and fish data by site.

Habitat Variable	DCC208	SI	DCC455	SI	DCC793	SI	DCD765	SI	DCD1105	SI	DCD1570	SI	DCD1880	SI	DCD2138	SI	FC472	SI
Average Stream Velocity	18.00	0.33	8.00	0.07	20.00	0.39	12.00	0.15	12.00	0.15	8.00	0.07	8.00	0.07	18.00	0.33	14.00	0.21
Maximum Depth in Riffles	0.17	0.74	0.15	0.69	0.16	0.72	0.51	1.00	0.51	1.00	0.35	1.00	0.31	1.00	0.30	1.00	0.29	1.00
% Riffles	28.57	1.00	23.81	0.95	19.05	0.76	23.81	0.95	19.05	0.76	19.05	0.76	28.57	1.00	19.00	0.76	14.29	0.57
% of Substrate >5cm	42.00	0.84	30.00	0.60	57.00	1.00	83.00	1.00	61.00	1.00	53.00	1.00	51.00	1.00	65.00	1.00	84.00	1.00
Spring/Summer Maximum Temp.	22.90	0.00	23.50	0.00	23.20	0.00	24.40	0.00	21.20	0.64	21.30	0.56	21.90	0.08	20.00	0.90	20.00	0.90
% Cover	12.50	0.50	11.87	0.47	20.63	0.83	21.25	0.85	20.00	0.80	20.00	0.80	21.88	0.88	20.00	0.80	21.25	0.85
H S I Score		**0.00**		**0.00**		**0.00**		**0.00**		**0.15**		**0.07**		**0.07**		**0.33**		**0.21**

conducted strictly for riffle dwelling species such as Longnose dace, the average depth would be much smaller and average velocity would be much higher for a given "site".

The Longnose dace HSI model was applied to Darby-Cobbs Watershed despite the fact that this species was not collected from the watershed in the 2003 fish survey. A review of historical fish distribution records conducted for the Fairmount Park Commission by researchers at the Academy of Natural Sciences indicates that this species has never been recorded from the watershed. Longnose dace are, however, present in other streams in the Delaware and Schuylkill drainages. This species is considered a riffle specialist, feeding and spawning in fast water in higher gradient, clear and cool streams. High Longnose dace HSI scores may thus indicate favorable riffle conditions, not only for this species, but for a variety of other riffle dwellers, including sensitive macroinvertebrate bioindicator taxa.

5.4. Chemical Assessment

5.4.1. Overview

Discrete (fixed interval) chemical sampling was conducted weekly under a variety of conditions (e.g., wet weather, ice) that may have influenced results of many chemical and water quality analyses. For example, instream measurements of dissolved oxygen and grab samples taken for fecal coliform analyses may exhibit great variability in response to environmental conditions. The former is dependent on time of day and sunlight intensity, while the latter may vary with rainfall. For this reason, results of discrete chemical sampling are most useful for characterizing dry weather water quality under Target A of the Watershed Management Plan. Target C and indicator 9 of the Watershed Management Plan were specifically targeted by PWD's Wet Weather Monitoring Program and Continuous Water Monitoring Program, respectively.

Much of Darby-Cobbs Watershed is served by a combined sewer system. Wet weather overflows at CSO structures periodically cause releases of combined sewage to streams. Effects of these releases may extend beyond the times when rain is falling or overflows are occurring. CSO discharges, even when infrequent, may thusly be a significant factor in shaping a stream's water quality. Philadelphia's streams can not be expected to meet water quality criteria during wet weather (Target C) unless CSO discharges are addressed and stormwater is treated. Conversely, combined sewer systems may be more efficient than separate sewer systems at capturing (diverting) pollutants from small, diffuse, and/or periodic sources (e.g., very small storms, gradual snowmelt, car and equipment washing, intentional dumping in storm drains).

Many watersheds in developed and developing areas are poorly protected from surface runoff from landscapes, golf courses, industrial areas, etc., which may introduce nutrients to the stream. A wide buffer of riparian vegetation around the stream can intercept and filter this runoff, reducing nutrient concentrations before they reach the stream. Another important benefit of streamside vegetated buffer zones, especially those with mature trees, is shading. Beyond direct influences of shading on algal biomass, primary productivity and amplitude of diel fluctuations in dissolved oxygen, shading reduces temperature effects, thereby affecting dissolved oxygen levels indirectly. Though only 9% of the Cobbs Creek watershed is forested, nearly all this forest land lies within stream corridors.

Additionally, suburban and urban landscapes, such as the Darby Cobbs Watershed, abound in potential point and non-point sources of organic, thermal, microbial, and heavy metal pollution. Acute and chronic effects of these pollutants on stream habitats and organisms are difficult to quantify.

5.4.2. Indicator 7: Bacteria

Fecal coliform bacteria concentration is positively correlated with point and non-point contamination of water resources by human and animal waste and is used as an indicator of poor water quality (Indicator 7 of the Watershed Management Plan). PADEP has established a maximum limit of 200 colony forming units, or “CFUs,” per 100ml sample during the period 05/01-9/30, the “swimming season” and a less stringent limit of 2000CFUs/100ml for all other times. It should be noted that the state criterion is based on the geometric mean of five consecutive samples collected over a 30-day period. As bacterial concentrations can be significantly affected by rain events and otherwise may exhibit high variability, individual samples are not as reliable as replicate or multiple samples taken over a short period.

Based on data from numerous sources (PADEP, EPA, USDA-NRCS, volunteer and non-profit organizations, etc.), it appears likely that many, if not most, southeastern PA streams would be found in violation of water quality criteria given sufficient sampling effort. PWD has expended considerable resources toward documenting concentrations of fecal coliform bacteria and *E. coli* in Philadelphia's watersheds. The sheer amount of data collected allows for more comprehensive analysis and a more complete picture of the impairment than does the minimum sampling effort needed to verify compliance with water quality criteria. In keeping with the organizational structure of the watershed management plan, fecal coliform bacteria analysis has been broken into dry (Target A) and wet weather (Target C) components, defined by a period with at least 48 hours without rain as measured at the nearest gauge in PWD's rain gauge network.

5.4.2.1. Target A: Dry Weather Fecal Coliform Bacteria

All individual dry weather samples collected from Darby-Cobbs Watershed during the non-swimming season (n=18) showed fecal coliform bacteria concentration well below the water quality criterion of 2000CFU/100ml. But geometric means of fecal coliform concentration at all sites exceeded water quality criteria during the swimming season (Table 18 and Figure 20). Samples from sites DCI010, DCC208, and DCC455 on 6/12/03 were likely affected by a leaking sewer. The sewer leak was subsequently detected by PWD biologists conducting a fish assessment downstream. Geometric means of fecal coliform from these sites would be 366, 324 and 696, respectively, with these samples omitted.

With the exception of intense sampling upstream and downstream of a point source, surface water grab samples do not usually allow one to determine the source(s) of fecal contamination. Recent research has shown that fecal coliform bacteria may adsorb to sediment particles and persist for extended periods in sediments (VanDonsel, et al. 1967, Gerba 1976). Presence of bacterial indicators in dry weather may thus more strongly reflect past wet weather loadings than dry weather inputs (Dutka and Kwan, 1980). Clearly, there exist several possible sources of fecal coliform bacteria within the watershed, all or combinations of which may be acting within different spatial and

Table 18. Fecal coliform concentrations at the nine water quality monitoring sites.

Site	n	Max	Min	Median	Mean	Std. Dev.	Geometric Mean
DCC208	7	2600	140	410	674.29	859.03	437.06
DCC455	7	2900	390	540	1097.14	991.66	815.75
DCC770	7	1060	220	300	407.14	293.58	351.92
DCD765	7	530	160	310	311.43	118.80	292.60
DCD1170	4	700	120	400	412.50	32.02	411.61
DCD1570	4	320	210	240	252.50	49.92	249.00
DCD1660	7	380	160	240	257.14	68.97	249.36
DCI010	4	20000	150	600	5337.50	9778.40	995.67
DCN010	4	3000	770	1020	1227.50	598.02	1136.70

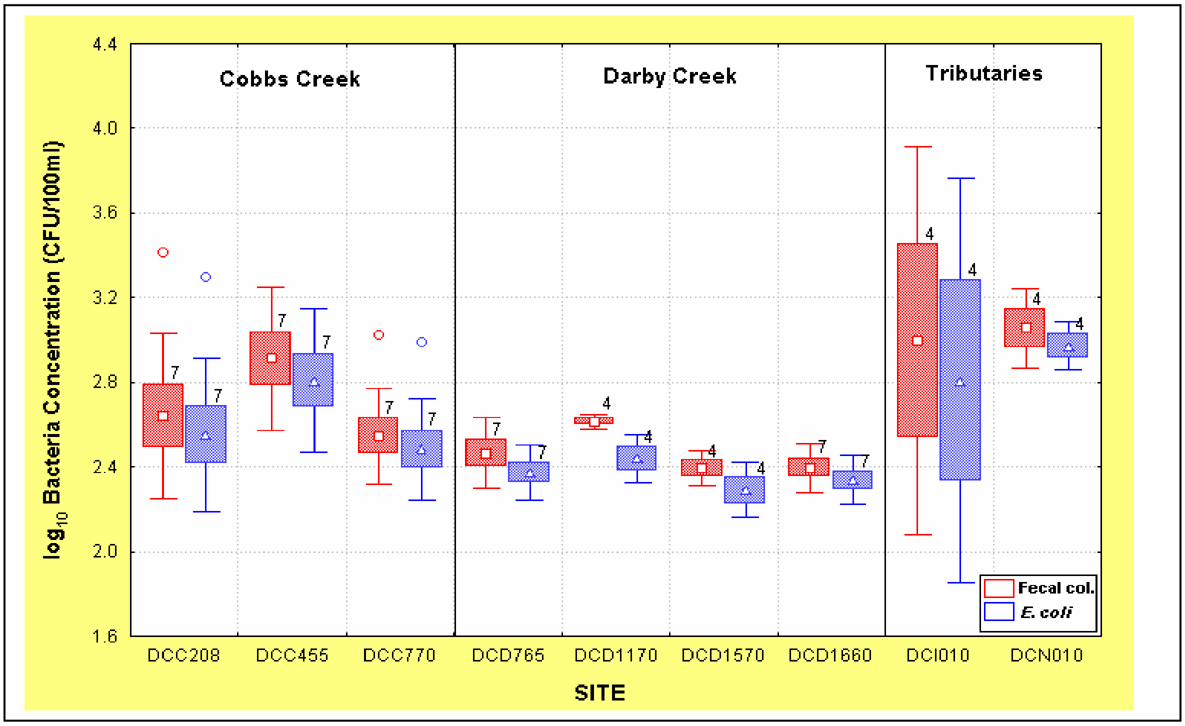


Figure 20. Dry weather fecal coliform and *E. coli* concentrations at the 9 monitoring sites.

temporal dimensions. PWD is piloting a Bacterial Source Tracking (BST) program that may eventually be useful in identifying the sources of fecal coliform bacteria collected in dry weather. Of particular interest is the relative proportion of the total bacterial load from human sources vs. domestic and wildlife animal sources.

5.4.2.2. Target C: Wet Weather Fecal Coliform Bacteria

Surface water grab samples (n=54) were collected at nine sites throughout Darby- Cobbs Watershed during or within 48 hours of wet weather as part of PWD's 2003 fixed interval (weekly) discrete chemical sampling program. Results of weekly discrete fecal coliform bacteria concentration analysis appear in Table 19. An additional 130 automatic sampler composite samples were collected from 5 sites during two individual wet weather events as part of PWD's intensive wet weather monitoring program. Hydrograph-matched scatterplots of fecal coliform bacteria concentration at each site for each event appear in (Appendix F). The data from these events is summarized in Tables 20 and 21.

Not surprisingly, wet weather fecal coliform bacteria concentration is elevated significantly at each site compared to dry weather concentrations. Both Cobbs and Darby Creeks exhibited a typical pattern of fecal coliform bacteria concentration increasing at downstream locations. Though all sites sampled probably could be in violation of state fecal coliform bacteria standards (e.g., many samples in excess of 1000 CFU/100ml, more than 10% of samples in excess of 400CFU/ml), Cobbs Creek and its tributaries within Philadelphia (i.e., Naylors Run and the Indian Creeks) appear more severely affected than suburban Delaware County sites.

Table 19. Fixed interval fecal coliform samples collected in wet weather.

Site	n	Max	Min	Median	Arithmetic Mean	Std. Dev.	Geometric Mean
DCC208	6	43,000	350	6,700	15,192	17,184	6,648
DCC455	6	36,000	310	2,550	8,162	13,838	2,629
DCC770	6	2,900	140	495	1,115	1,174	657
DCD765	6	4,000	440	710	1,452	1,402	1,040
DCD1170	6	3,000	320	675	1,288	1,274	802
DCD1570	6	4,000	160	325	1,133	1,537	532
DCD1660	6	5,300	30	275	1,772	2,474	449
DCI010	6	110,000	450	3,000	21,017	43,706	3,614
DCN010	6	4900	590	3,300	2,902	1,888	2,187

Table 20. Fecal coliform concentrations recorded at the 5 wet weather monitoring locations during storm event 1.

Site	n	Max	Min	Median	Arithmetic Mean	Std. Dev.	Geometric Mean
DCC208	18	182,000	350	78,500	71,275	54,242	28,423
DCC455	19	200,000	1,400	43,000	63,168	63,202	28,615
DCC770	18	20,000	420	2,300	6,004	7,424	2,378
DCD765	11	41,000	1,000	9,400	12,100	11,731	7,199
DCD1660	19	161,000	1,800	6,600	26,763	39,534	11,101

Table 21. Fecal coliform concentrations recorded at the 5 wet weather monitoring locations during storm event 2.

Site	n	Max	Min	Median	Arithmetic Mean	Std. Dev.	Geometric Mean
DCC208	9	82,000	25,000	29,000	41,000	21,529	36,891
DCC455	9	103,000	8,800	30,000	32,744	28,561	24,975
DCC770	9	46,000	2,200	6,600	14,167	16,827	8,387
DCD765	9	20,000	3,600	8,500	8,300	4,220	7,466
DCD1660	9	18,000	3,100	5,500	6,733	5,140	5,721

5.4.3. Indicator 8: Metals

Metals occur in all natural waters in varying concentrations due to runoff, erosion, atmospheric deposition, and interactions with streambed geological features. However, because certain metals may be toxic even in very small concentrations, toxic metals concentrations are included in the CCIWMP (indicator 8). Darby Creek Watershed (32.3 river miles including Darby Creek, Hermesprota Creek, Muckinipattis Creek, Stony Creek, Langford Run, and Whetstone Run) was listed by PADEP in 1996 as impaired due to metals in urban runoff/storm sewers, though individual segments were not identified. Cobbs Creek watershed (24.8 river miles, including Indian creek) was listed by PADEP in 2002 as impaired due to urban runoff/storm sewers and municipal point sources, but cause(s) of the impairment were not identified.

Metals of concern (e.g., lead, chromium, cadmium, copper, and zinc) were most often undetectable or present in minimal concentrations in water samples taken in 2003 from Darby-Cobbs watershed. However, increases in concentration during rainfall were observed for copper, iron, and lead. Though water column toxic metal concentrations may be generally small, many metals readily adsorb to sediment particles, interact with organic molecules, or otherwise precipitate or become deposited or incorporated into stream sediments. Since most aquatic organisms either inhabit sediments or feed upon benthic invertebrates, possible toxic effects may not be reflected by water column concentrations alone.

Calcium and magnesium concentrations of Darby-Cobbs watershed were not unusual, keeping with the predominant rock types in the watershed (schists and gneiss). As the major divalent cations in surface water, Calcium and Magnesium are used to compute hardness (expressed as mg/l $CaCO_3$). This is an important parameter, because toxicity of other metals generally has an inverse relationship with hardness. Most EPA and PADEP toxic metal water quality criteria are currently defined as linear regression equations that account for observed decreases in toxicity as hardness increases. Each sample metal concentration is evaluated against the criterion as calculated with sample hardness. Furthermore, two water quality criteria exist for each toxic metal, criteria continuous concentration (CCC) and criteria maximum concentration (CMC); these criteria address chronic and acute toxicity, respectively. Dry weather water samples were compared to CCC and wet weather samples were compared to CMC.

PADEP dissolved metal criteria are based on EPA toxic metals standards originally developed for total recoverable metals. Though these criteria have been modified to include a conversion factor for use with dissolved metals data, actual dissolved metal concentrations cannot be predictably determined as a proportion of total recoverable metals concentrations. Solubility of metals in natural waters varies with other environmental variables. Because of the degree to which metals may adsorb to sediment and form complexes with organic particles, it is likely that actual water column dissolved metal concentrations in Darby-Cobbs Watershed are smaller than those predicted using these conversion factors. To assess the effects of using these conversion factors, total recoverable metal concentrations were compared to both dissolved and total recoverable criteria.

5.4.3.1. Target A: Dry Weather Metals Concentrations

With the exception of copper, metals concentrations were relatively small in dry weather (Table 22). Cadmium and Chromium were not detected in any of 69 dry weather samples from Darby-Cobbs Watershed. Lead was detected in only 3 samples, 2 from site DCC208 and one from site DCC455; only one of these three detections was a possible violation of the dry weather (continuous) criterion (CCC) for lead. Aluminum and zinc were detected in approximately two thirds of dry weather samples. Aluminum concentrations were consistently small, the maximum value was less than 50% of the CMC and the mean concentration was less than 10% of the CMC (no CCC has been established for aluminum). Zinc concentrations were typically 10% or less of the CCC. Copper was detected in all dry weather samples; three samples may have exceeded the CCC. While standards for each sample vary with hardness, many samples had copper concentration at 50% or more of the CCC. Based on ICP-MS performance on individual check standards, reporting limits for some metals were higher than 1µg/l on some occasions.

Table 22. Metal concentrations collected during dry weather in Darby-Cobbs Watershed.

Metal	non-detects	Max	Min	Arithmetic Mean	Std. Dev.	Geometric Mean	WQ Violations
Aluminum	16	0.363	0.015	0.067	0.053	0.055	N/A
Cadmium	69	N/A	N/A	N/A	N/A	N/A	0
Calcium	0	52.0	24.0	34.89	6.573	34.311	N/A
Chromium	69	N/A	N/A	N/A	N/A	N/A	0
Copper	0	0.020	0.002	0.006	0.004	0.006	3
Iron	4	0.785	0.052	0.196	0.113	0.171	0
Lead	66	0.007	0.002	0.004	0.003	0.003	1
Magnesium	0	19.320	11.700	14.945	1.510	14.781	N/A
Manganese	3	0.142	0.010	0.033	0.024	0.027	0
Zinc	19	0.084	0.002	0.017	0.017	0.012	0

Water column total recoverable metals concentrations often do not accurately reflect bioavailability of toxic constituents and cannot be expected to reliably predict effects along and among stream sediments. Much recent research has been focused on metals toxicity and studies have focused on determination of toxic constituents of sediments themselves; toxic constituents of interstitial waters; re-suspension of toxicants by storm flows, recreational use, or bioturbation by benthic biota; controlled laboratory testing with experimental organisms; *in-situ* toxicity investigations; and development and refinement of sediment toxicity models.

EPA has begun the process of revising water quality criteria for toxic metals to incorporate the considerable body of research that has been conducted since the original criteria were published. These new criteria more appropriately reflect the chemical behavior of toxicants in surface waters and account for their bioavailability. For example, cupric ions (Cu^{2+}) have been recognized as the major cause of copper toxicity (Sunda and Guillard 1976; Sunda and Hansen 1979). However, complexes formed through ligand bonding with inorganic and organic molecules may reduce free copper concentrations by three or more orders of magnitude (Morel & Hering 1993) through competition for ligand bonding sites. EPA's draft copper water quality standard (2003) incorporates the Biotic Ligand Model (DiToro et al., 2001) and more reliably predicts the toxic effects of copper concentrations than linear regression equations that consider only hardness as a covariable.

5.4.3.2. Target B: Wet Weather Metals Concentrations

Wet weather metals concentrations were generally greater than concentrations in dry weather; the incidence of possible water quality violations was much higher overall in wet weather than in dry weather. For example, metals that may have violated water quality criteria only in wet weather included aluminum, cadmium, manganese, and zinc. Possible violations of copper and lead criteria were more frequent in wet weather as well. Hydrograph-matched scatterplots of toxic metal concentrations appear in (Appendix G).

While surface runoff undoubtedly contributes to increases in wet weather metals concentrations, it is likely that re-suspension of metals associated with sediments contributes to excursions from water quality criteria.

5.4.4. Indicator 9: Dissolved Oxygen Concentration

Continuous monitoring Sondes at sites within Darby-Cobbs Watershed measured, among other parameters, water column dissolved oxygen (DO) concentration. DO concentrations often strongly reflect autotrophic community metabolism and in turn, affect the heterotrophic community structure as a limiting factor for numerous organisms. Because sufficient DO concentration is critical for fish, amphibians, crustacea, insects, and other aquatic invertebrates, DO concentration is used as a general indicator of a stream's ability to support a balanced ecosystem. The Pennsylvania Department of Environmental Protection (PADEP) has established criteria for both instantaneous minimum and minimum daily average DO concentration. Criteria are intended to be protective of the types of aquatic biota inhabiting a particular lake, stream, river, or segment thereof.

All water chemistry monitoring sites within Darby-Cobbs Watershed, with the exception of DCD1660, are designated as Warm Water Fisheries (WWF). Site DCD1660, and all segments of Darby Creek north of PA Rte. 3 (West Chester Pike) are designated a Trout Stocking Fishery (TSF). PADEP water quality criteria require that minimum DO levels in WWF not fall below 4.0 mg O_2/L and that daily averages remain at or above 5.0 mg O_2/L. A Trout Stocking Fishery such as DCD1660 has more stringent DO standards to support more sensitive stocked salmonid fish species from February 15 to July 31 each year. During this period, a minimum daily DO average of 6.0 mg O_2/L is required, and allowable DO instantaneous minimum is 5.0 mg O_2/L. For the remainder of the year, TSF criteria align with WWF standards. These regulations, along with corresponding temperature criteria, form the foundation of stream protection in general and allow for propagation and maintenance of healthy fish communities.

Combinations of natural and anthropogenic environmental factors may affect DO concentration. Autotrophic and heterotrophic organisms are influenced by nutrient concentrations, solar radiation, temperature, and other environmental factors. Daily fluctuations of oxygen in surface waters are due primarily to the metabolic activity of these organisms. If temperature alone influenced DO concentration, saturation would increase at night, when water temperature drops, and decrease during the day as the water warms. Because the watershed is generally dominated by biological activity, the reverse occurs: DO concentrations in Darby-Cobbs Watershed rise during the day when autotrophic organisms are photosynthesizing and decrease at night when community respiration is the dominant influence. Another factor in the amount of oxygen dissolved in the water is re-aeration (diffusion of atmospheric oxygen). Barometric pressure, surface area, turbulence and oxygen saturation deficit influence the amount of oxygen transferred to the stream from the atmosphere. Effects of re-aeration tend to augment or diminish (rather than shift or change) effects of stream metabolism.

Stream sites that support abundant algal growth often exhibit dramatic diel fluctuations in dissolved oxygen concentration. Algal photosynthesis infuses oxygen during the day (often to the point of supersaturation), while algae and heterotrophic organisms remove oxygen throughout the night. These sites are more susceptible to oxygen deficits on cloudy days when the amount of photosynthesis is limited by sunlight and community respiration dominates system activity.

DO fluctuations were more pronounced at some sites than at others, due in part to specific placement of the continuous monitoring instrument (Sonde) at each site. When interpreting this continuous DO data, one must keep in mind that the instrument can only measure dissolved oxygen concentration of water in direct contact with the DO probe membrane. Furthermore, to obtain the most accurate readings of DO, probes should be exposed to flowing water or probes themselves must be in motion. Local microclimate conditions surrounding the probe and biological growth on the probe itself may also contribute to errors in measurement. It is possible for Sondes situated in subtly different areas of the same stream site to exhibit marked differences in DO concentration due to flow, shading, and local microclimate differences. Sonde measurements of DO concentrations during the summer period (8/14/03-9/14/03) are depicted in figures 21 thru 25.

The Sonde located at DCC208, for example, is located in a pool upstream of a dam. Additionally, the Sonde at DCC208 is not shaded. Deep pools, slower stream velocity, and ample sunlight provide excellent conditions for algal growth which are reflected in diel DO fluctuations (Figure 21). DCD765 is another site in which the Sonde is only

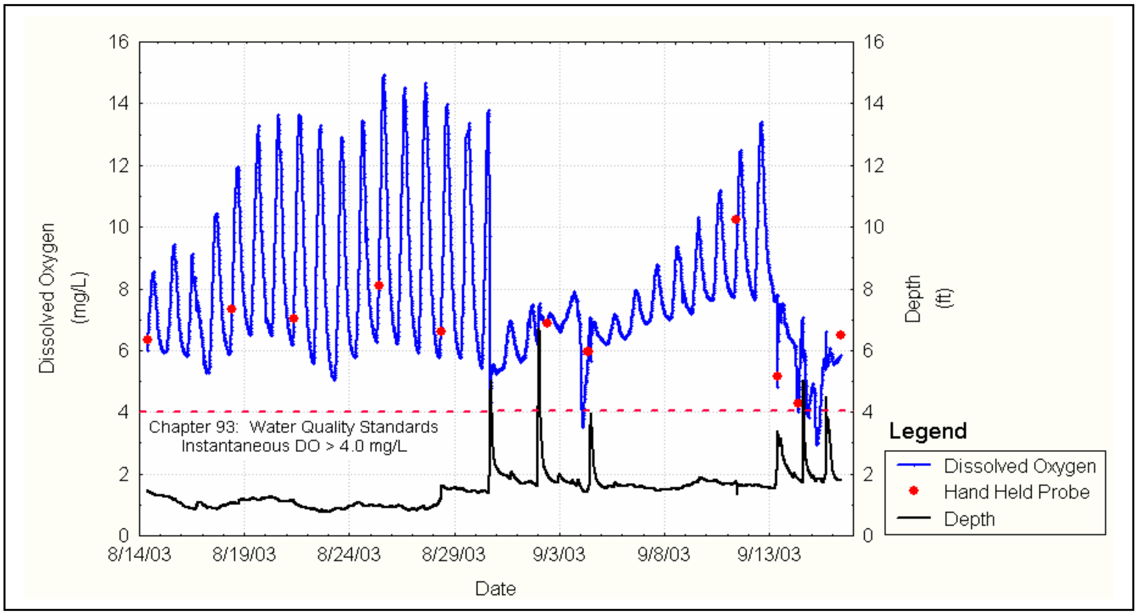


Figure 21. Continuous measurements of dissolved oxygen at DCC 208.

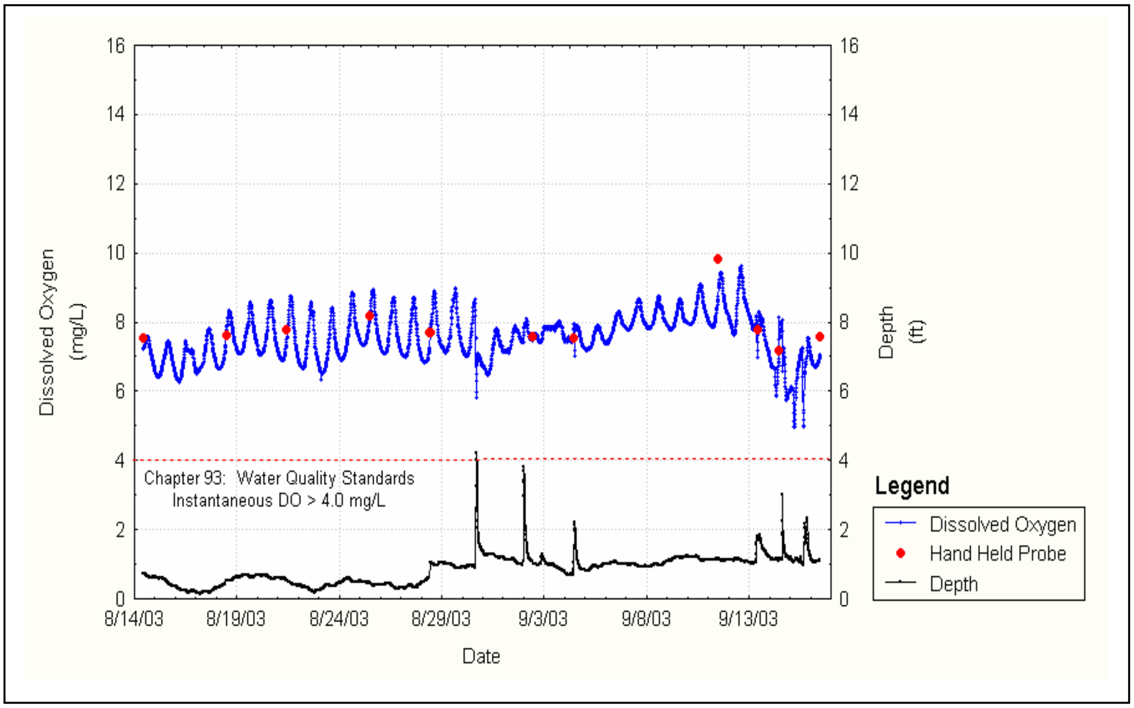


Figure 22. Continuous measurements of dissolved oxygen at DCC 455.

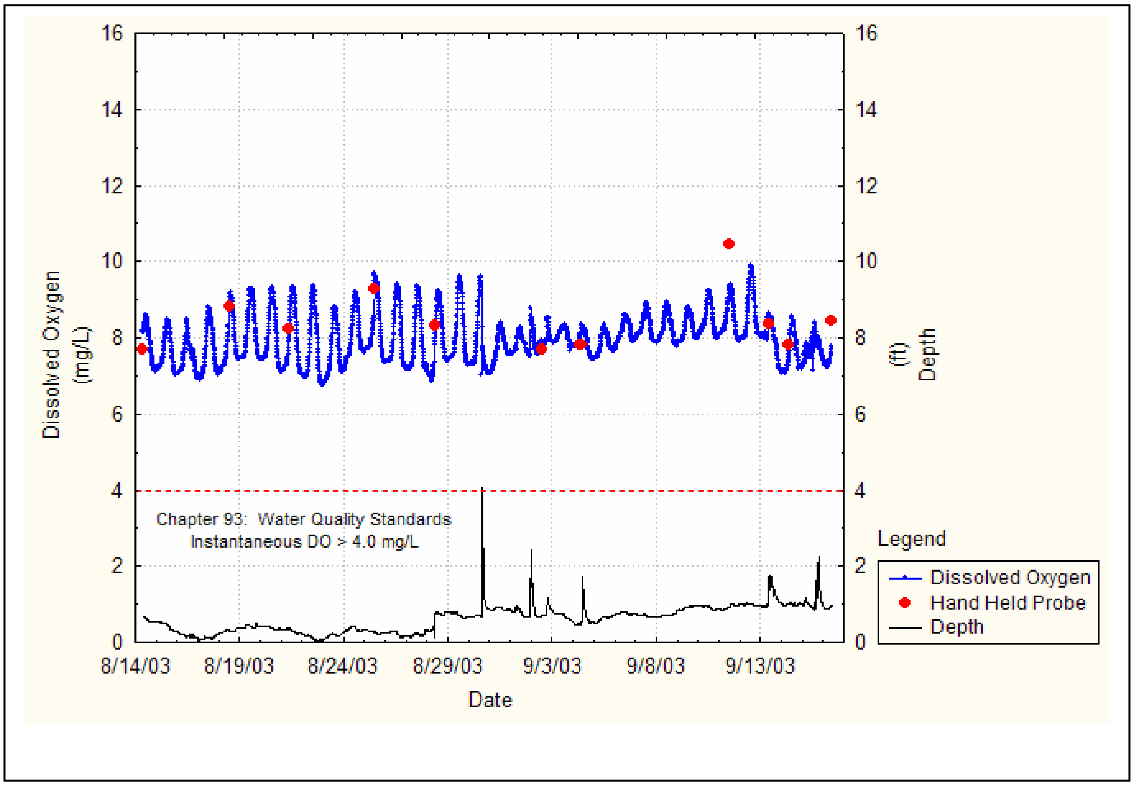


Figure 23. Continuous measurements of dissolved oxygen at DCC 770.

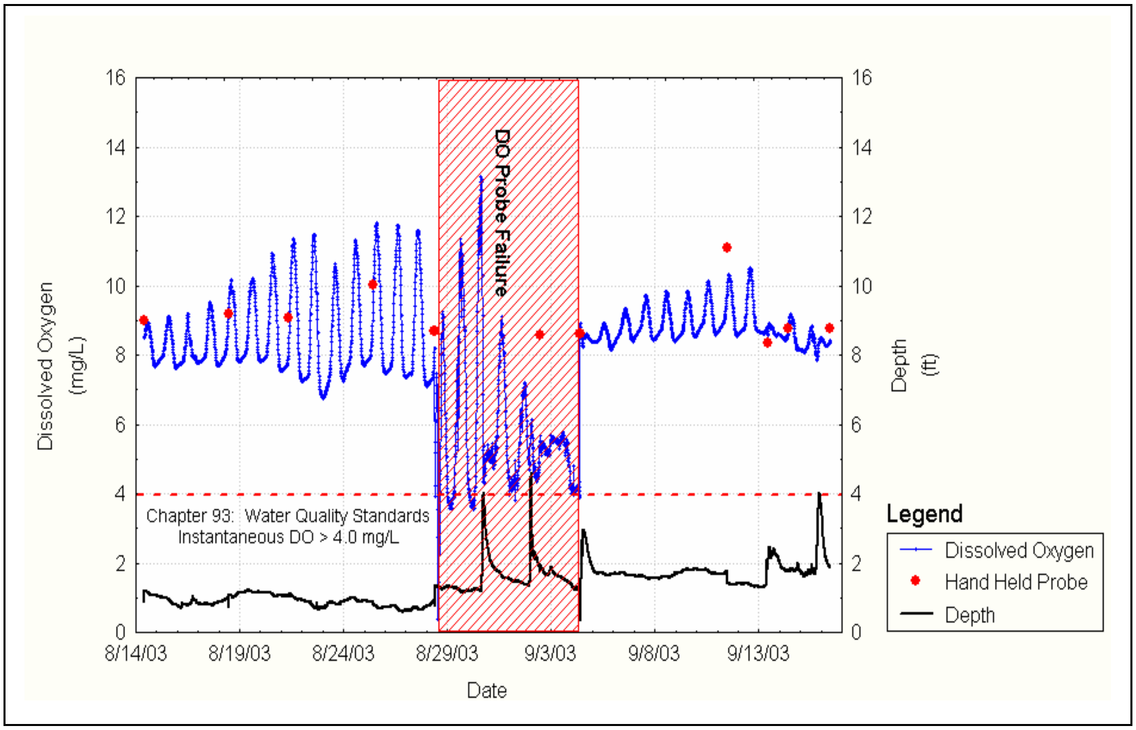


Figure 24. Continuous measurements of dissolved oxygen at DCD 765.

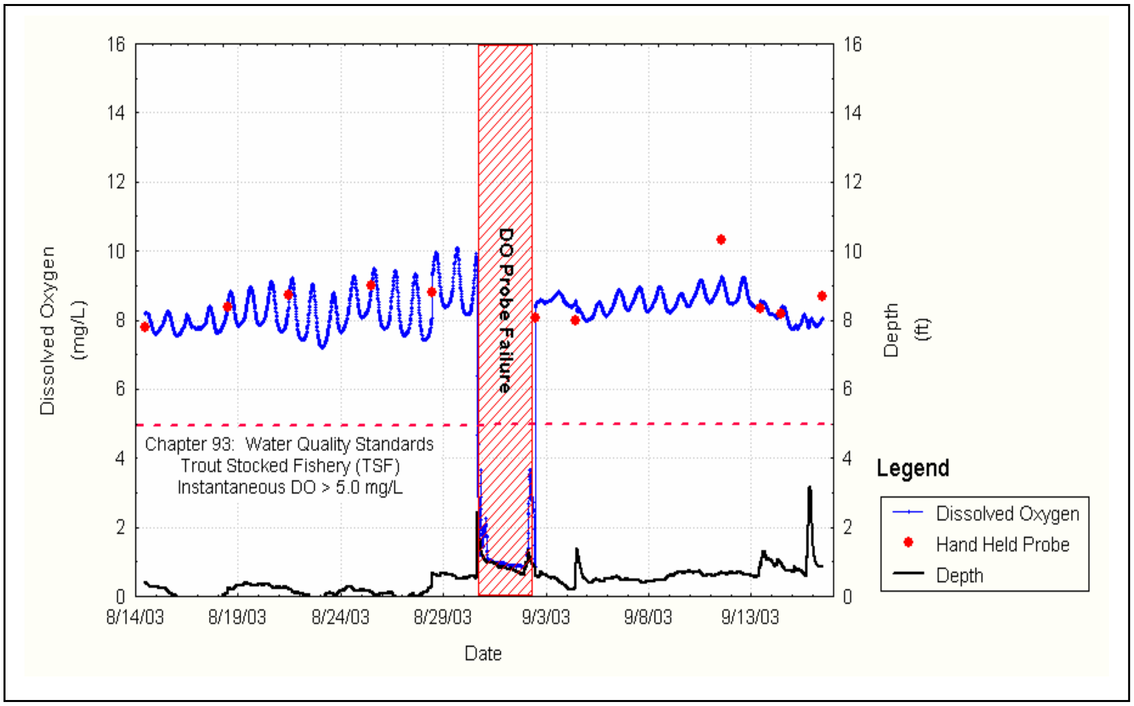


Figure 25. Continuous measurements of dissolved oxygen at DCD 1660.

partially shaded. While not as large as DCC208, the amplitude of DO fluctuations exceeded 3 mg/L at this site. In contrast, the Sonde at DCD1660 is located under a bridge in shallow water. While not measured quantitatively, it is likely that algal periphyton density was smaller at this site; resulting diel fluctuations are damped in comparison to sites exposed to more sunlight (Figure 25). Sondes at sites DCC455 and DCC770 are in areas that are mostly shaded (Figures 22 and 23, respectively).

Two separate rain events occurred during the period of Sonde deployments in Darby-Cobbs Watershed. During and following the rain events, DO concentrations decreased considerably. Following sloughing of algal periphyton (benthic algae, biofilm, *aufwuchs*), the stream exhibits effects of diminished productivity. An August 30, 2003 rain event demonstrated this phenomenon at all five continuously monitored sites. DCC208 is the only site in which DO suppression violated the state water quality standards for instantaneous dissolved oxygen. Site DCC208, as discussed earlier, has many site-specific attributes that result in dense algal periphyton communities. These same factors also make it more difficult to measure DO concentrations with veracity. (DO probe failure occurred at two sites during this rain event. Cleaning of debris from DO probes, in both cases, corrected the problem in time to record a period of diminished productivity due to sloughing at these sites). Following the disturbance, autotrophic communities became reestablished, as evidenced by the return of normal, exaggerated diel fluctuations in DO concentration.

5.4.5. pH

Continuous monitoring through the use of Sondes on the Darby and Cobbs Creeks recorded pH values at each of five sites. pH is a measure of acidity, or the concentration of hydrogen ions in a solution. In natural waters, the balance between acidity and alkalinity is determined by concentrations of various dissolved compounds, salts and gases and typically remains near neutral, or pH 7. Fluctuations in pH can occur in freshwater systems as a result of natural and anthropogenic influences. Interplay between inorganic carbon species, known as the bicarbonate buffer system, generally maintains pH within a range suitable for aquatic life.

The bicarbonate buffer system is a function of the equilibrium relationship between carbon dioxide (CO_2) and carbonic acid (H_2CO_3), as well as bicarbonate (HCO_3^-) and carbonate (CO_3^{2-}) ions. In natural waters, the predominant source of hydrogen ions is carbonic acid. Biochemical metabolism of carbon throughout the day continually shifts the equilibrium equation, causing fluctuations in pH. As plants and algae consume carbon dioxide during photosynthesis, carbonic acid dissociates to replenish the CO_2 and maintain equilibrium. Decreasing carbonic acid concentrations cause elevated pH. As photosynthetic rates decline after peak sunlight hours, respiratory activities of aquatic biota replenish carbon dioxide to the system, decreasing pH. Acidity in Darby-Cobbs watershed is chiefly determined by this metabolic activity; the watershed is not heavily influenced by bedrock composition, groundwater sources or anthropogenic inputs, such as acid mine drainage.

Water quality criteria established by PADEP regulate pH to a range of 6.0 to 9.0 in Pennsylvania's freshwater streams. pH values between 6 and 9 units do not negatively affect stream biota. Organisms can be indirectly affected by pH due to its influences on the dissociation of many compounds, such as ammonia. As pH increases, a greater fraction of ammonia N is present as unionized NH_3 (gas). For example, ammonia is ten times as toxic at pH 8 as at pH 7. Extreme pH values may increase dissociation of or general toxicity of other constituents. For example, pH levels affect the bioavailability of metals (e.g., copper), which have individually regulated criteria established by PADEP.

Continuous pH data was discretized to 15 min intervals and plotted against time and stream depth. Figures 26 through 30 depict pH trends at each of five continuously-monitored sites on the Darby-Cobbs watershed, including the large diel pH fluctuations that accompany highly productive sites with abundant periphytic algae. Community metabolism regulates the extent of pH fluctuations. Environmental conditions, including ample sunlight, led to a dense autotrophic community at sites DCC208 and DCD765, which exhibited greater diel pH fluctuations than the other monitored sites; these sites also generally came closest to and occasionally violated water quality criteria by exceeding pH 9.0 (Figures 26 and 29, respectively). pH at shadier sites (i.e., DCC770, DCC455 and DCD1660) is probably less influenced by metabolic activity, and oscillations in pH appear noticeably damped as a result.

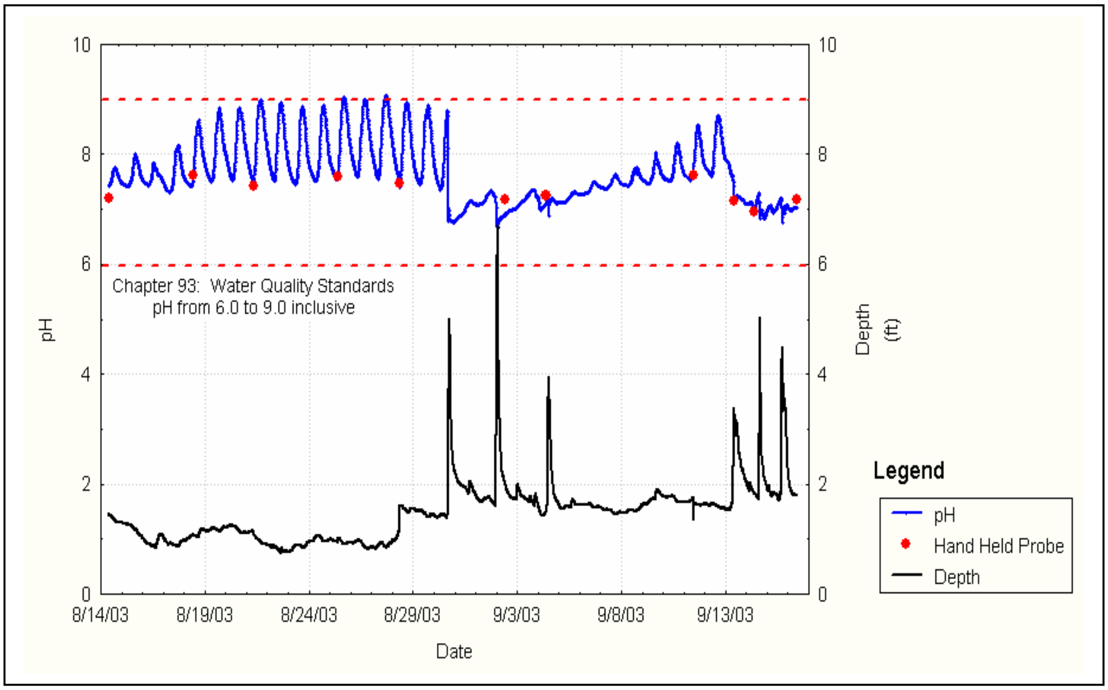


Figure 26. Continuous measurements of pH at DCC 208.

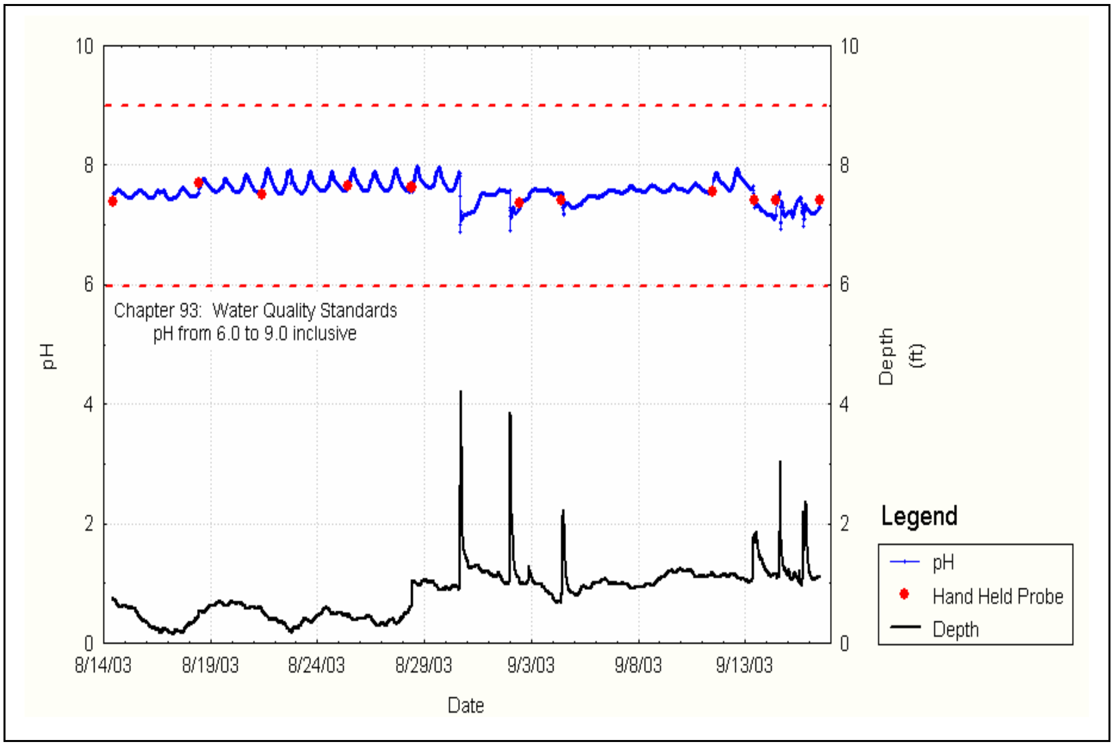


Figure 27. Continuous measurements of pH at DCC 455.

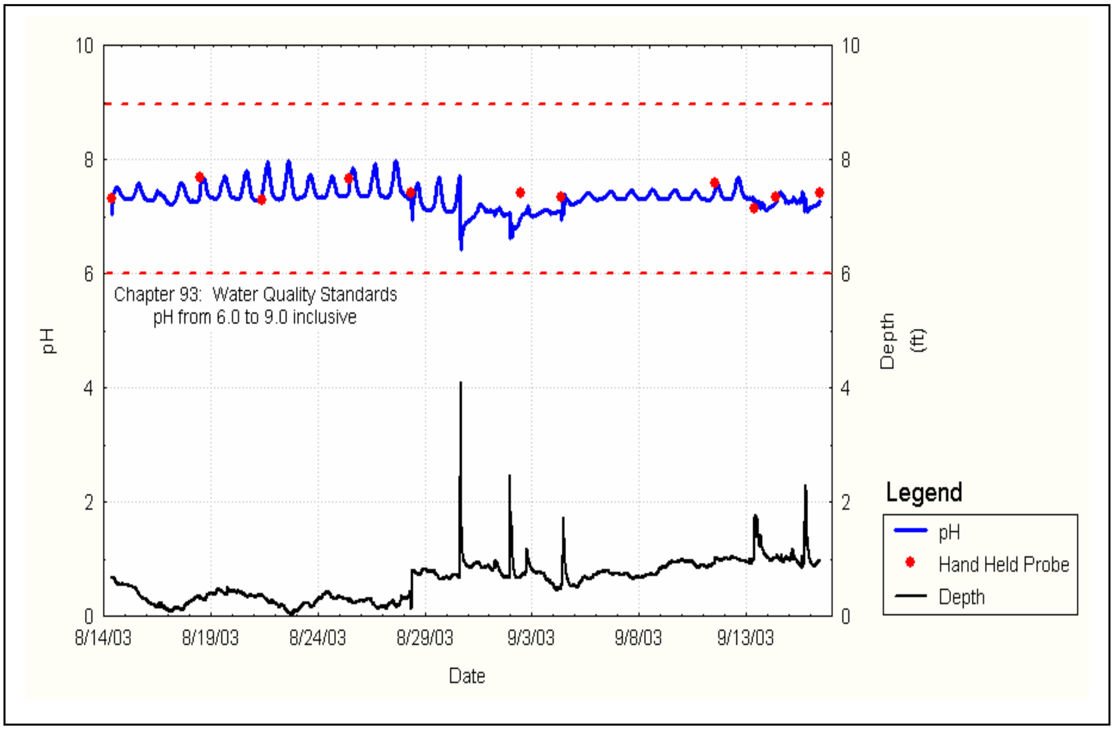


Figure 28. Continuous measurements of pH at DCC 770.

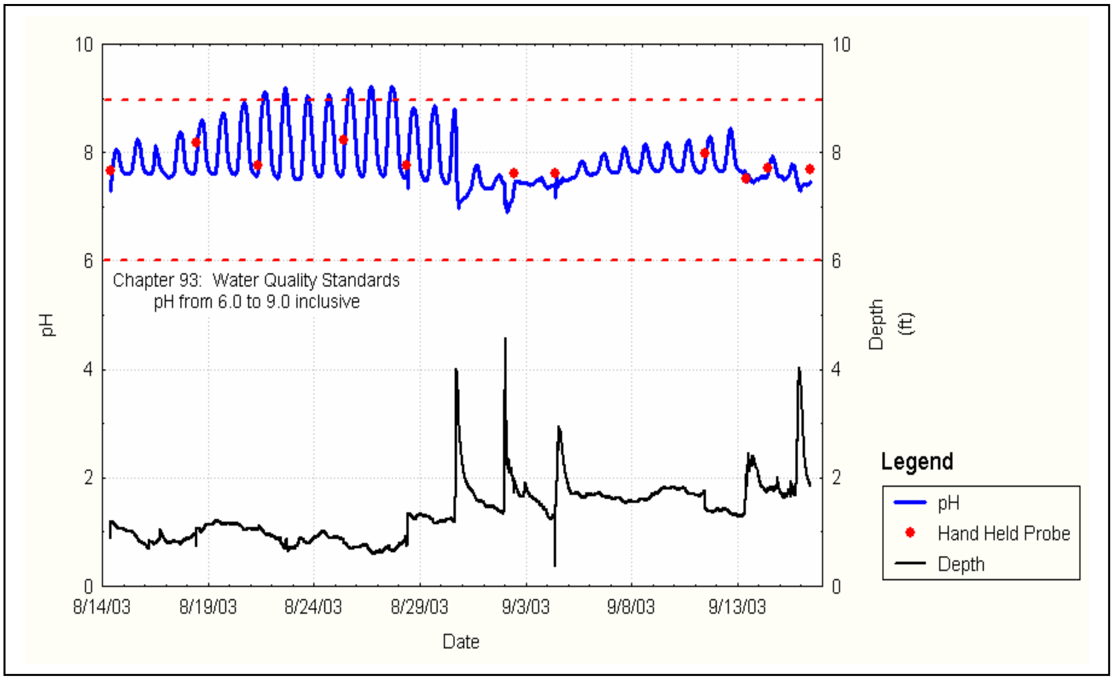


Figure 29. Continuous measurements of pH at DCD 765.

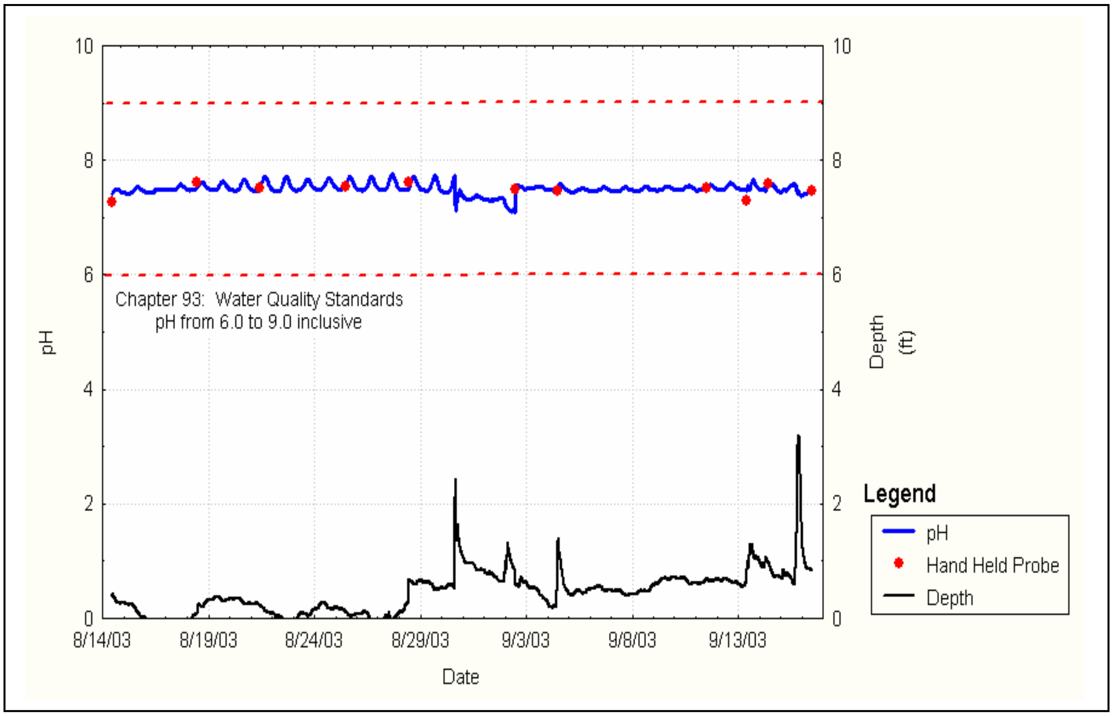


Figure 30. Continuous measurements of pH at DCD 1660.

Two separate rain events occurred during the period of Sonde deployments in Darby-Cobbs Watershed. Increased velocities and larger flows during wet weather swept away attached algae, macrophytes and suspended periphyton. Figures 26 through 30 demonstrate that without autotrophs to reduce carbon dioxide through photosynthesis, pH levels remain steady. The autotrophic community recovers from this disturbance over subsequent weeks and pH gradually returns to normal fluctuations at each site. Decreased pH levels during and following wet weather events did not violate minimum pH standards.

5.4.6. Specific Conductance

Specific conductance is a measure of waters' ability to pass electrical current and is an approximate predictor of total dissolved ions in solution. This measure is often used to monitor changes in water chemistry. Daily fluctuations in specific conductance result from biological activity changes that occur throughout the day. Sites DCC208 and DCD765 experienced more pronounced daily changes in specific conductance due to the presence of a denser biological community (Figures 31 and 34, respectively). Other factors affecting specific conductance include rain events, which decrease conductivity due to dilution of stream water by storm water and increases in total ionic strength due to application of de-icing compounds and road salts during cold weather. Following a large rain event, dissolved ion concentrations may remain below normal baseflow concentrations for more than a week as the stream's natural chemistry gradually reestablishes itself.

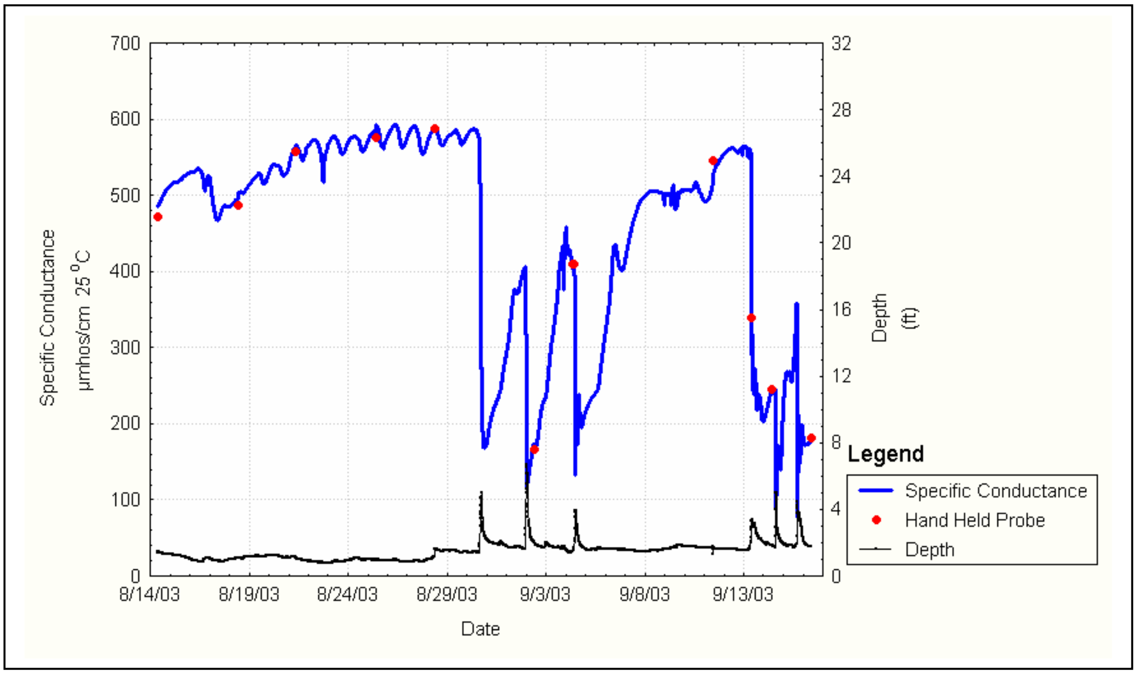


Figure 31. Continuous measurements of Specific Conductance at DCC 208.

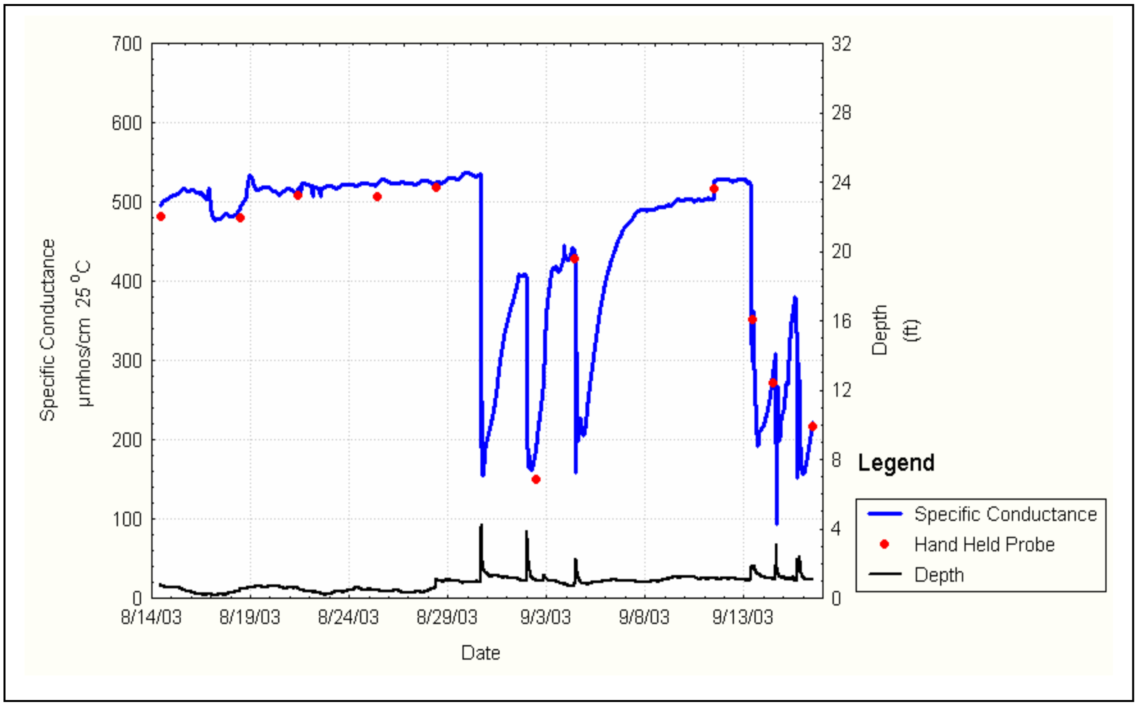


Figure 32. Continuous measurements of Specific Conductance at DCC 455.

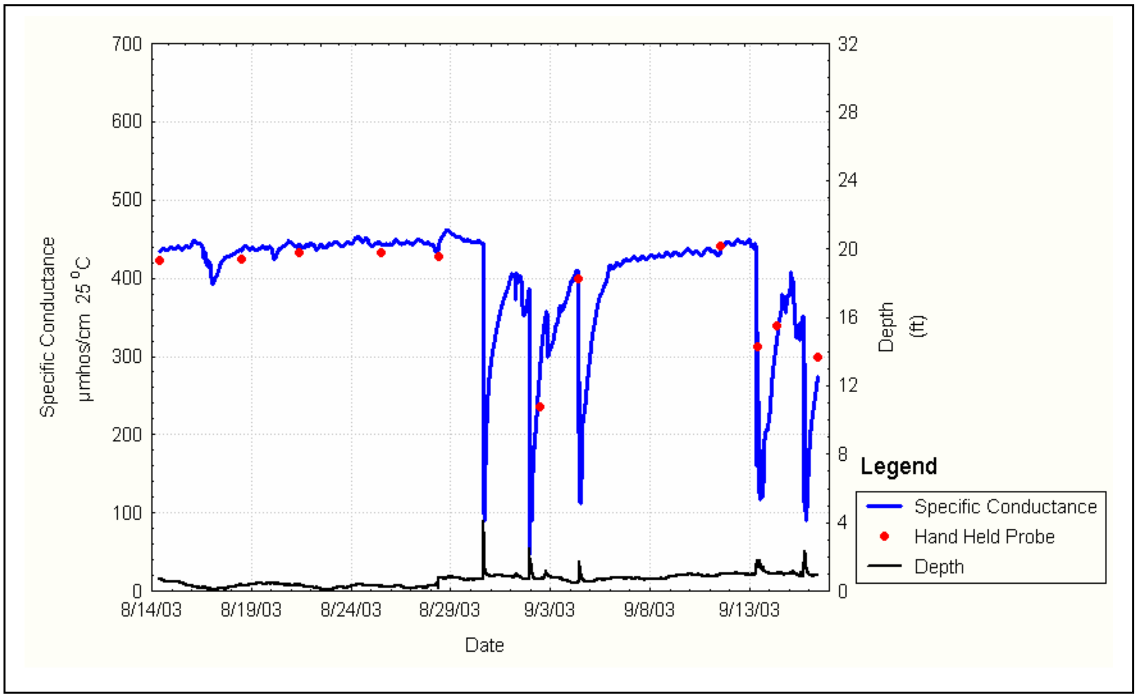


Figure 33. Continuous measurements of Specific Conductance at DCC 770.

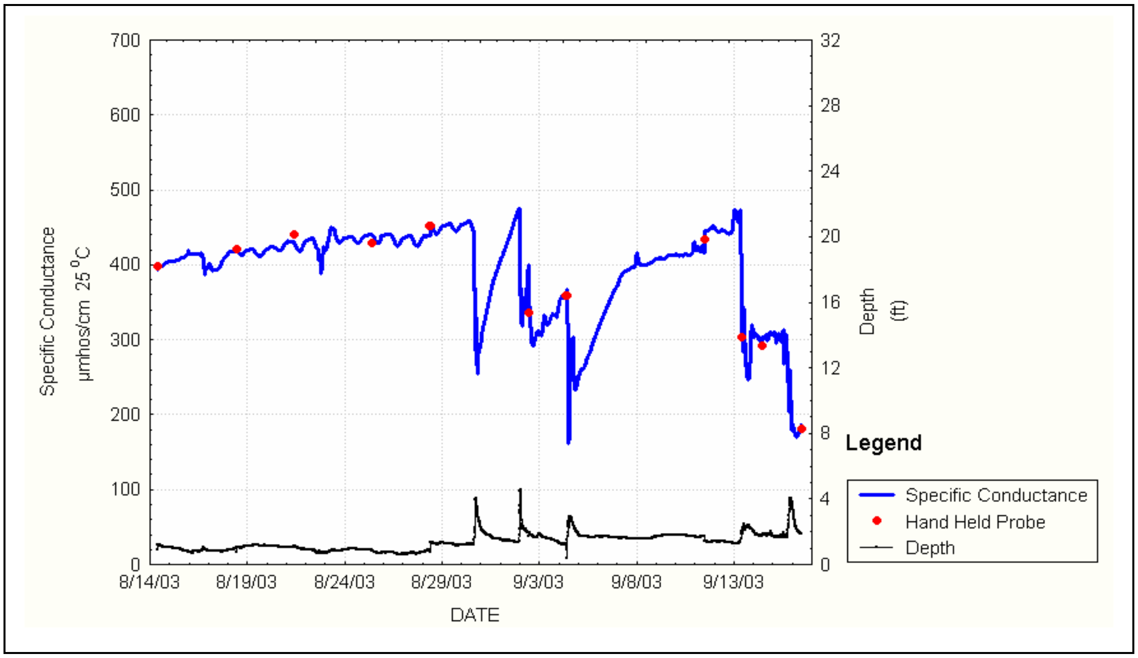


Figure 34. Continuous measurements of Specific Conductance at DCD 765.

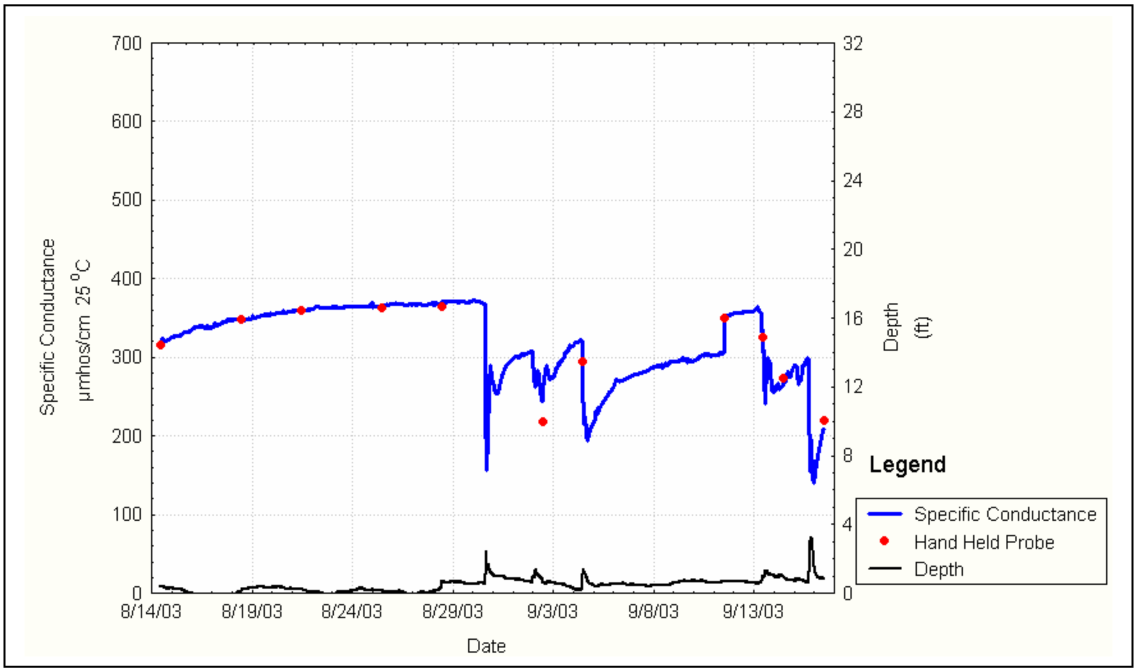


Figure 35. Continuous measurements of Specific Conductance at DCD 1660.

5.4.7. Temperature

The role of temperature in shaping aquatic communities cannot be understated. With the exception of birds and mammals, all freshwater aquatic organisms are poikilotherms ("cold-blooded"). Unable to regulate body temperature through metabolism, these organisms must select suitable temperature conditions within their habitats. PADEP has established temperature criteria for the waters of the commonwealth, largely to delineate areas requiring more stringent thermal protection for naturally-reproducing populations of sensitive ("cold water") fish species, recreationally-sought salmonids, in particular. Temperature criteria also serve to protect aquatic life from increases in temperature from industrial activity (e.g., cooling water). Darby-Cobbs Watershed does not support natural populations of coldwater fish, and is not known to be significantly affected by discharges of cooling waters.

Many water bodies that cannot support natural populations of cold water fish do have adequate thermal protection to maintain hatchery-raised adult trout. Segments of Darby Creek watershed north of PA Rte 3 (West Chester Pike) are so protected and are designated a trout stocking fishery (TSF); the remainder of Darby-Cobbs watershed is designated a warmwater fishery (WWF). Thermal maxima for sites in Darby Cobbs Watershed, as measured with continuous water quality monitoring equipment, never exceeded State water quality standards (Figures 36 through 40). Changes in temperature of 2°C or more were observed at most sites on a number of occasions; however, changes of this magnitude occurred in dry and in wet weather.

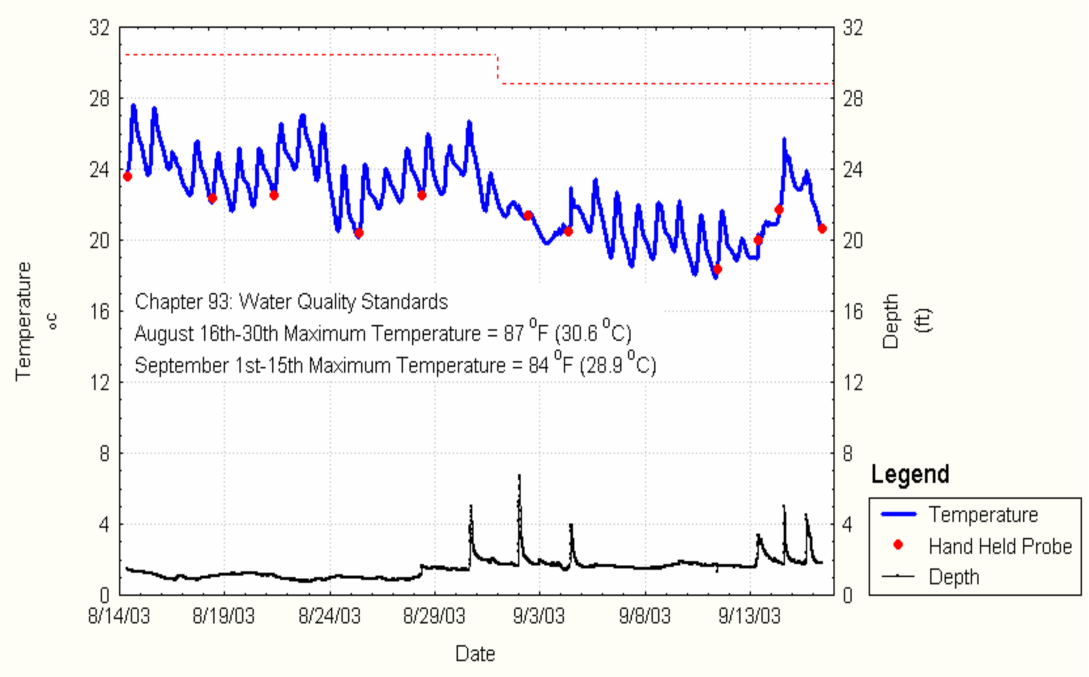


Figure 36. Continuous measurements of temperature at DCC 208.

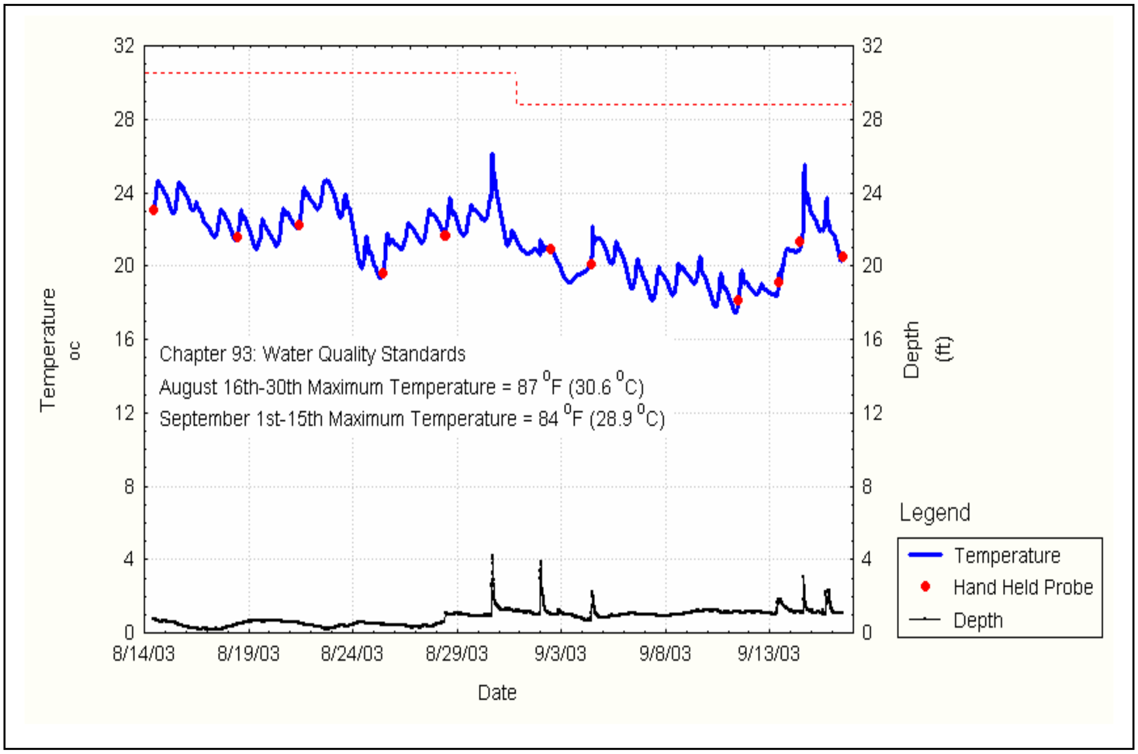


Figure 37. Continuous measurements of temperature at DCC 455.

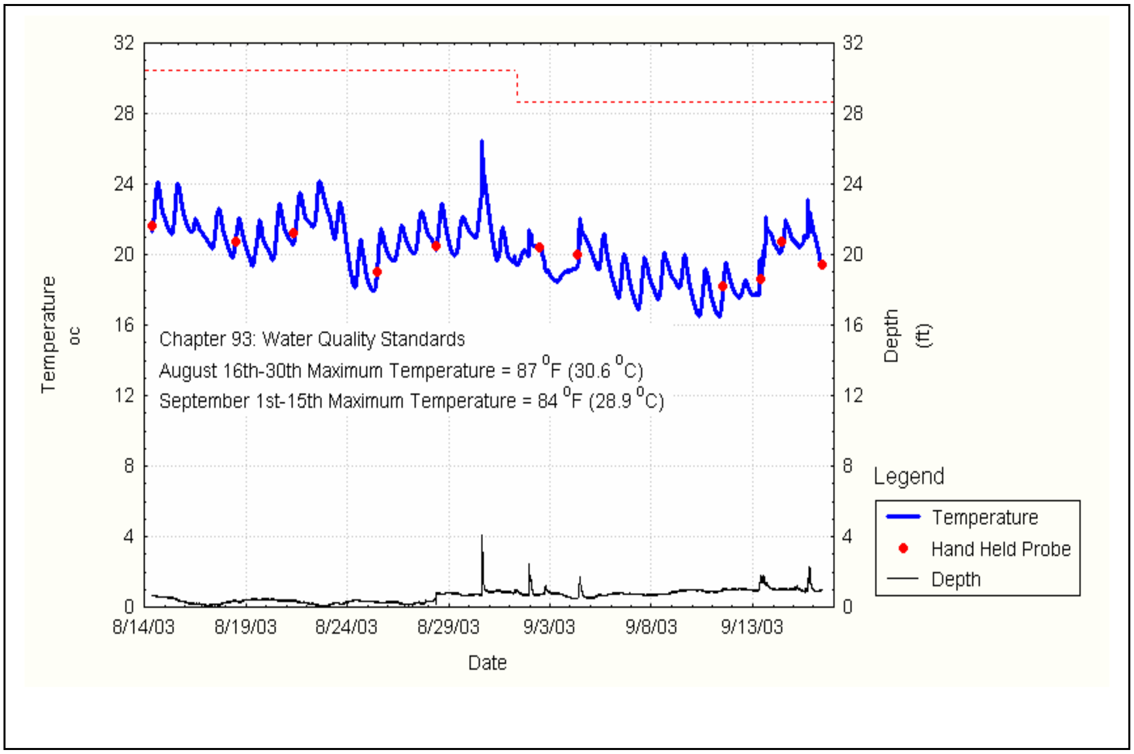


Figure 38. Continuous measurements of temperature at DCC 770.

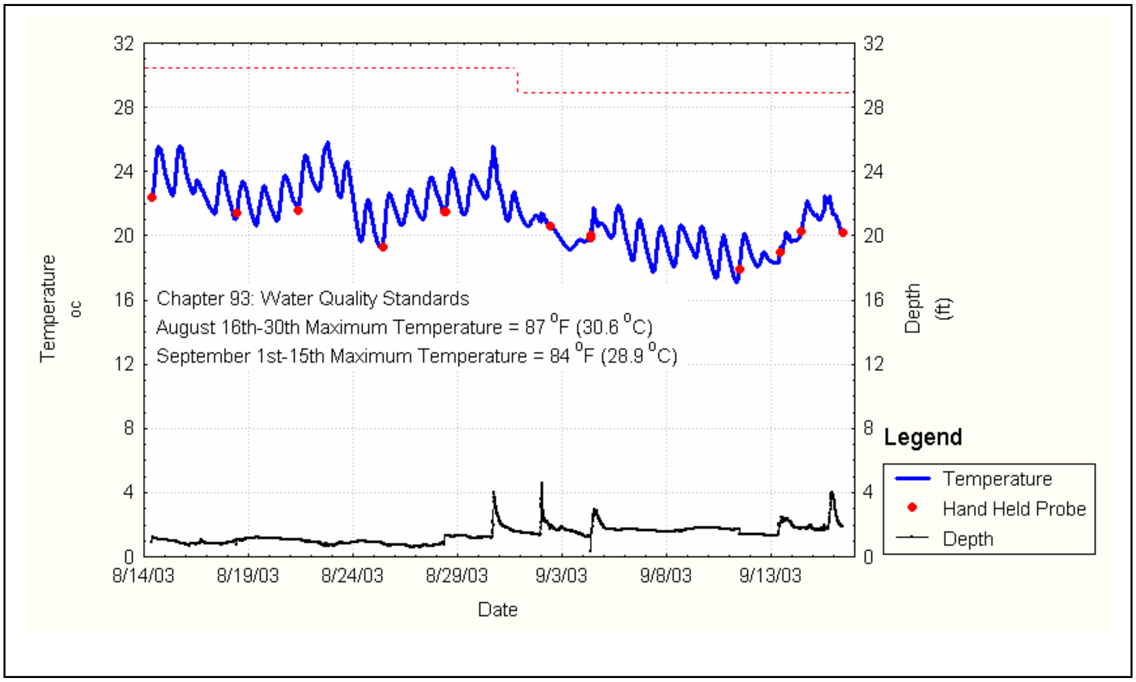


Figure 39. Continuous measurements of temperature at DCD 765.

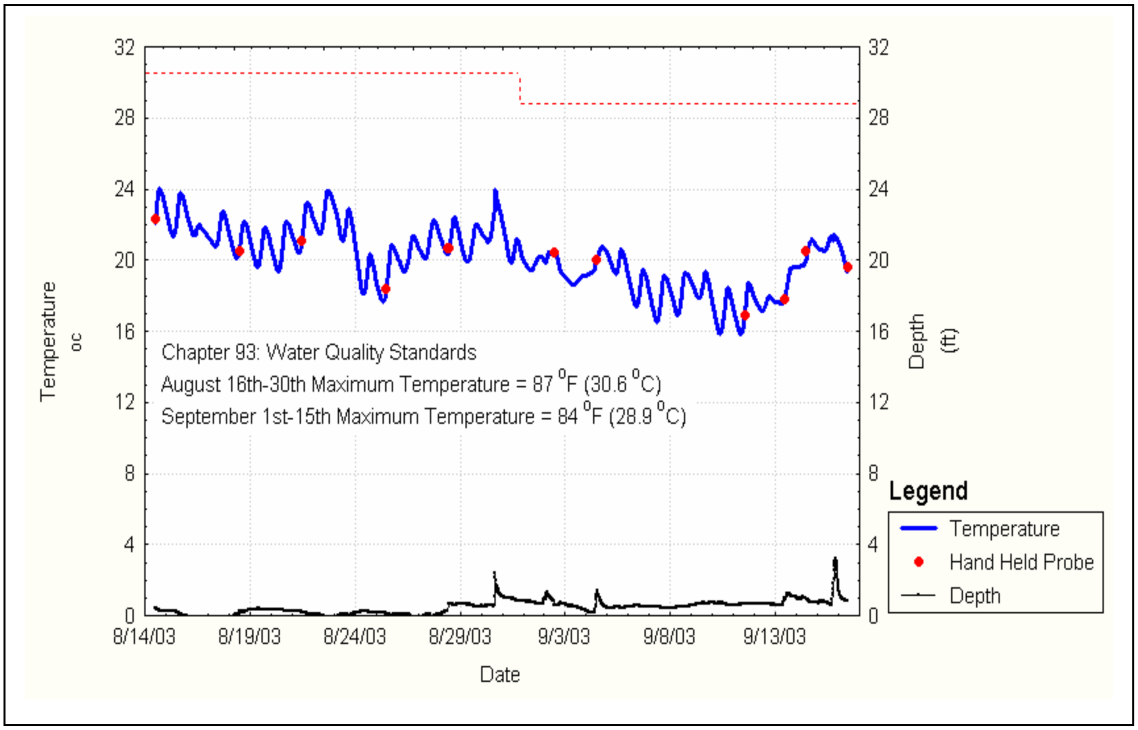


Figure 40. Continuous measurements of temperature at DCD 1660.

In addition to limiting effects of lethal and sublethal temperatures on fish survival, temperature regime has myriad implications for aquatic communities. These effects are discussed in greater detail in Section 5.3.5. (Habitat Suitability Indices).

5.4.8. Nutrients

Universally applicable minimum nutrient criteria for protecting water resources are difficult to establish. Furthermore, determining unimpaired, or “natural” nutrient conditions for streams in the Piedmont and Eastern Coastal Plain regions of Pennsylvania is made difficult by extensive land development and preponderance of agricultural land use. EPA has proposed nutrient criteria for protection of aquatic life in rivers and streams; though nutrient management strategies formulated to prevent (or reverse) eutrophication of one water body may not be appropriate for other water bodies. When a water body has been identified as nutrient impaired, thorough nutrient investigations may be conducted to determine Total Maximum Daily Loads (TMDLs) of pollutants that a water body can assimilate.

With the exception of ammonia, PADEP does not currently have aquatic life-based nutrient criteria, only a limit on oxidized inorganic nitrogen (i.e., nitrate and nitrite) that is intended to protect public water supplies. Elevated nutrient concentrations have been identified as the principal cause of nuisance algal blooms that may cause taste and odor problems in treated drinking water. A small number of algal taxa are known to produce toxins that represent a human, livestock, or wildlife health risk. While such effects are serious where and when they occur, increased biomass of naturally occurring attached periphyton algae communities is a far more widespread phenomenon that may negatively affect water quality. Data from minimally impaired sites in PADEP & EPA water quality databases have been included with Darby-Cobbs Watershed nutrient data for comparison where appropriate and/or applicable.

5.4.8.1. Nutrients: Nitrogen species

Surface water samples were analyzed for nitrate (NO_3), nitrite (NO_2) and ammonia nitrogen (NH_3-N) concentration. The Kjeldahl method of determining total organic N was also applied. All N species may be naturally present in aquatic systems; however, elevated levels of N are indicative of both point and non-point sources of pollution. Nitrate and ammonia (specifically ammonium ions, $NH4^+$) are the forms of N most useful to stream producers such as green plants, algae and cyanobacteria. Naturally occurring chemical reactions and metabolic activities of common bacteria (e.g., *Nitrosomonas*, *Nitrobacter*) are responsible for altering the ratio of inorganic N species in freshwater systems. In the presence of oxygen, ammonia is converted first to nitrite, then to nitrate (nitrification). Efficiency of the reactions in which ammonia N is converted to oxidized forms is dependent on environmental conditions (i.e., temperature, pH and dissolved oxygen concentration).

Though deep stagnant water is present in a few locations, particularly in pools behind dams and in "plunge pools", most of Darby-Cobbs Watershed consists of shallow, well mixed and (at a minimum, partially) oxygenated stream segments. Inputs of organic matter and inorganic N, particularly concentrated inputs from SSOs and CSOs, may tax dissolved oxygen levels and result in violations of water quality standards. These effects are most severe in summer, when the rate of N-oxidizing reactions is fastest, dissolved oxygen capacity of stream water is reduced, instream biomass is high, and baseflow may be at or near yearly minimum.

5.4.8.2. Nitrite

As an intermediate product in the oxidation of organic matter and ammonia to nitrate, nitrite is seldom found in unimpaired natural waters in great concentrations provided that oxygen and denitrifying bacteria are present. Nitrite was never detected in any 2003 samples from Darby Creek or Naylors Run regardless of weather conditions, but was detected in 21 of 100 wet weather samples and 3 of 69 dry weather samples from Cobbs Creek. Observed wet-weather nitrite concentrations are likely due to CSO/SSO discharge and runoff. On 6/12/03, nitrite was detected during dry weather at sites DCI010, DCC455 and DCC208. The inability to detect nitrite at site DCC770 and observed pattern of longitudinally diminishing concentrations (from upstream to downstream) suggested a point source, later determined to be a leaking sewer. PADEP has established a maximum limit of 10mg/l for total nitrate and nitrite N. Nitrite concentrations in Darby-Cobbs watershed never exceeded nitrate concentrations, and were never responsible for water samples exceeding this criterion.

5.4.8.3. Nitrate

Concentrations of nitrate are often greatest in watersheds impacted by (secondary) treated sewage and agricultural runoff, but elevated nitrate concentrations in surface waters may also be attributed to runoff from residential and industrial land uses, as well as atmospheric deposition and precipitation (e.g., HNO_3 in acid rain). Nitrate is a less toxic inorganic form of N than ammonia and serves as an essential nutrient for photosynthetic autotrophs. Availability of inorganic N can be a growth-limiting factor for producers, though usually only in oligotrophic (nutrient-poor) lakes and streams or acidic bogs.

According to US EPA's nutrient criteria database, samples collected from unimpaired surface waters in the eastern coastal plain region of Pennsylvania had mean nitrate concentration of 1.9mg/l (n = 786). The 75th percentile seasonal median nitrate + nitrite concentration in EPA ecoregion IV, sub region 64 watersheds was 2.9mg/l. Close examination of nitrate data collected from southeastern PA streams by PWD and PADEP showed at least some nutrient impaired streams could be assigned to one of two broadly defined categories- streams in which nitrate concentrations increase due to runoff, and streams in which nitrate concentrations are elevated during baseflow conditions and diluted by stormwater. The former stream type is characteristic of agricultural regions, while the latter is characteristic of streams affected by wastewater effluent.

PADEP has established a maximum limit of 10mg/l for total nitrate and nitrite N, but this limit is based on protection of drinking water and cannot reasonably be expected to prevent eutrophication of natural water bodies. No sites in Darby-Cobbs Watershed violated water quality criteria- the watershed is not affected by treated wastewater effluent, does not contain extensive areas of agricultural land use, and has not been listed as nutrient impaired by PADEP under section 303d of the Clean Water Act. However, all sites in Darby-Cobbs have mean nitrate concentration >1.5mg/l and would be considered "eutrophic" under the stream trophic classification system of Dobbs (1998).

During wet weather, nitrate concentrations were generally diluted; nitrate concentration was significantly higher (t-test, $p<0.05$) in dry weather at five of nine sites in Darby Cobbs Watershed (Figure 41). While nitrate concentrations were similar among Darby Creek sites, Cobbs Creek sites showed nitrate concentration decreasing in a downstream direction, suggesting uptake by producers, dilution as link magnitude increases, or denitrification by bacteria under anoxic conditions, where they exist. Indian Creek Watershed had the highest mean nitrate concentration of all sites. Land use in the Indian Creeks' basins includes golf courses as well as areas where resident Canada geese congregate; topography is steep upstream of the sampling site.

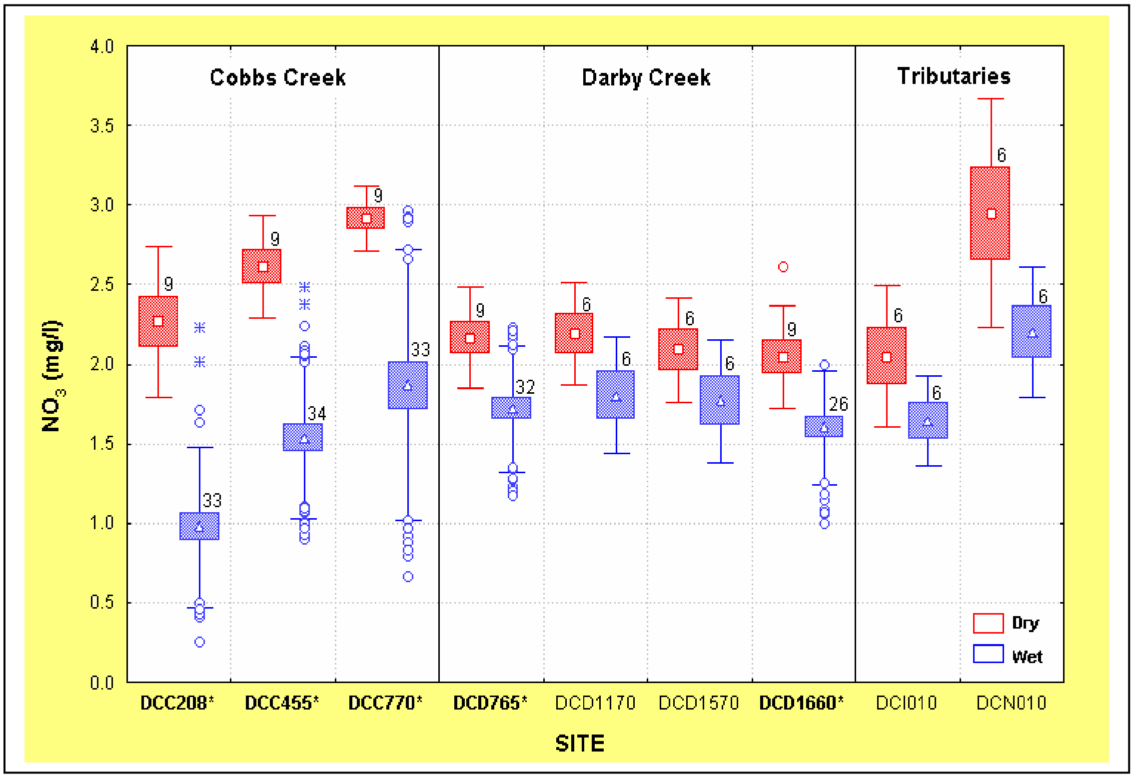


Figure 41. Dry and wet weather nitrate concentrations at the 9 monitoring sites

5.4.8.4. Ammonia

Ammonia, present in surface waters as un-ionized ammonia gas (NH_3), or as ammonium ion (NH_4^+), is produced by deamination of organic nitrogen-containing compounds, such as proteins, and also by hydrolysis of urea. Secondary treatment, as practiced in most modern sewage treatment facilities, removes dissolved organic compounds, effectively reducing ammonia concentrations in both the effluent and the receiving stream. In the presence of oxygen, ammonia is converted to nitrate by a pair of bacteria-mediated reactions, together known as the process of nitrification.

Overall, Darby Cobbs Watershed sites had relatively low ammonia concentration; 95 of 208 discrete grab samples (45%) taken in 2003 had ammonia concentration below detection limits. Mean ammonia concentration was highest at site DCI010, but this value was artificially high due to a sewage leak during dry weather on 6/12/03 (0.907mg/l). Wet weather impacts on ammonia concentration were most noticeable at Cobbs Creek sites DCC208 and DCC455 (Figure 42), which are likely affected by CSO discharge. Ammonia impacts from wet weather event 1 appeared more severe than from event 2.

PADEP has established maximum total ammonia nitrogen standards for the waters of the Commonwealth, but each sample must be compared individually to a standard that integrates sample temperature and pH to account for dissociation of ammonia in water. Higher temperatures and more alkaline pH allow more ammonia to be present in the toxic, unionized form. Total ammonia nitrogen concentration was above 1.0mg/l in only 1 of 208 samples, a wet weather sample from site DCC208. Despite pH values that occasionally exceeded 8.0, no violations of ammonia water quality standards were observed. However, continuous water quality monitoring instruments recorded pronounced fluctuations in pH at sites DCD765 and DCC110 due to algal blooms. It is likely that if ammonia nitrogen were present during periods of upper-range pH violations (i.e., measurements greater than 9.0), its toxicity would be high.

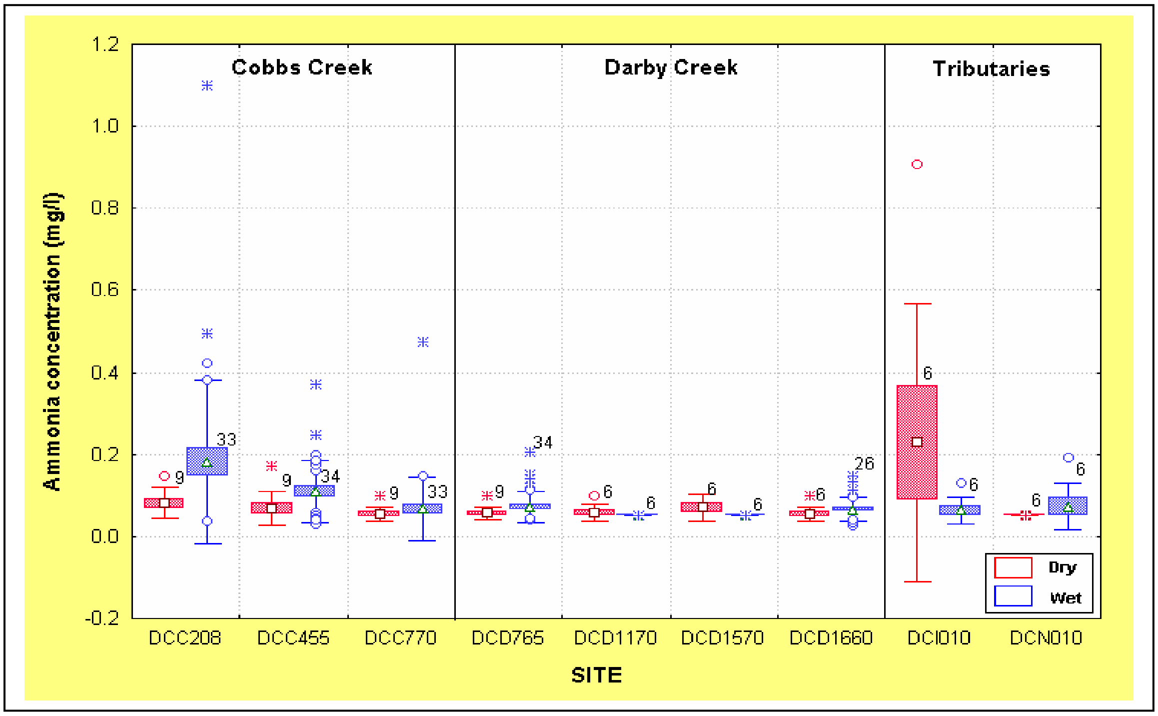


Figure 42. Dry and wet weather ammonia concentrations at the 9 monitoring sites.

5.4.8.5. Total Kjeldahl Nitrogen (TKN)

TKN provides an estimate of the concentration of organically-bound N, but the test actually measures all N present in the trinegative oxidation state. Ammonia must be subtracted from TKN values to give the organically bound fraction. TKN analysis also does not account for several other N compounds (e.g., azides, nitriles, hydrazone); these compounds are rarely present in significant concentrations in surface waters. Two outliers were excluded from the data analysis and graphics- these samples were collected from sites DCI010 and DCC455 during a sewer leak 6/12/03. TKN concentrations from these two sites were much greater than other dry weather samples and correspond with abnormally large concentrations of other parameters that serve as indicators of sewage contamination, (i.e., fecal coliform and *E.coli* bacteria, nitrate, ammonia, etc.) observed at these sites on this date.

Every site but DCC208 had TKN concentration less than the reporting limit of 0.3mg/l on at least one occasion. All sites experienced increases in TKN concentration during wet weather, but this phenomenon was more pronounced at Darby Creek sites. Increases during wet weather can probably be attributed to organic compounds in stormwater runoff, breakdown products of accumulated streamside (allochthonous) plant material, re-suspended organic sediment particles, and displaced (sloughed) algae. Much of the TKN present during larger flows in Darby-Cobbs Watershed may reach the Delaware estuary still in an organically-bound state.

5.4.8.6. Phosphorus

Phosphorus, like nitrogen, is a macronutrient (element required by plants in relatively large amounts); P concentrations are often correlated with algal density and are used as a primary indicator of cultural eutrophication of water bodies. Phosphorus readily adsorbs to soil particles and is generally less mobile in soils than nitrogen compounds. Potential non-point sources of P are decomposing organic matter in or near the stream, runoff from industrial parks, agriculture and residential areas, and inorganic P adsorbed to soil particles that are washed into the stream by erosive forces. In fact, soil erosion may be the greatest source of P in some portions of Darby-Cobbs watershed. Point sources of P include CSO and SSO discharges; though infrequent, they contribute large amounts of phosphorus where and when they occur.

Total P includes some smaller fraction of P that is considered to be bioavailable, or readily usable by stream producers. Bioavailable P (BAP) includes soluble reactive P (SRP) and, depending on other factors, some portion of particulate inorganic P. Furthermore, some producer taxa can obtain P through production of endogenous alkaline phosphatases. Nutrient dynamics and the effects of P limitation have been studied extensively in limnetic systems, but care should be taken when applying conclusions from phytoplankton dominated systems (i.e., lakes) to small streams. For example, in periphyton dominated streams, nutrients may be re-mineralized and recycled many times within the biofilm.

Stream producers in Darby-Cobbs Watershed are exposed to flow and a somewhat constant rate of nutrient delivery, albeit one that is punctuated with episodic inputs of greater P concentration due to runoff and erosion. These inputs, however, are coupled with physical disturbances (e.g., hydraulic shear stress, other abrasive forces, reduced light availability). These stressors respond to changes in flow in a non-linear fashion. Many taxa have the ability to store intercellular reserves of inorganic nutrients ("luxury consumption") when concentrations exceed immediate demands. It is thus very difficult to estimate the concentration of P available to stream producers and draw conclusions about stream trophic status from the (usually limited) data available.

Nevertheless, stream nutrient criteria have been proposed. For example, New Jersey's Department of Environmental Protection (NJDEP) has established a criterion of 0.10mg/l total P for streams and rivers and 0.05mg/l total P for lakes and their tributaries. USEPA has suggested the use of ecoregion-specific criteria based on the 75th percentile of total P concentration in unimpacted reference streams, or, in the case of insufficient reference stream data, the 25th percentile of TP for all streams in the ecoregion. For the ecoregion that includes Darby-Cobbs Watershed, this criterion is (0.14) mg/l. Dobbs (1998) suggested that the mesotrophic/eutrophic boundary for TP is 0.07mg/l.

Total P concentration was used in analysis of Darby-Cobbs Watershed because orthophosphate (PO_4) concentrations were nearly always below reporting limits. Two data points from 6/12/03 at sites DCI010 and DCC455 were excluded from the analysis, because TP concentrations at these sites (0.22 and 0.130 mg/l, respectively) were likely influenced by a sewer leak in the immediate area. This sample from DCI010 was also the only dry weather sample in which PO_4 was detected (0.149mg/l).

5.4.8.7. Phosphorus Concentration: Dry Weather

Darby Creek sites generally had less TP in dry weather than Cobbs Creek sites (Figure 43). Overall, 77% of Darby Creek dry weather samples had total P concentration below the reporting limit of 0.05mg/l, while only 21% of Cobbs Creek sites had dry weather TP concentration below reporting limits. Though only two samples were above reporting limits, greatest mean total P concentration in dry weather (0.106 mg/l) was observed at site DCI010, which is located downstream of golf courses and areas where resident Canada geese congregate. Excluding samples below reporting limits, the watershed overall had mean dry weather TP concentration of 0.073mg/l, which is below NJDEP's criterion, approximately half the proposed EPA criterion, and slightly greater than the mesotrophic-eutrophic boundary concentration proposed by Dobbs (1998).

5.4.8.8. Phosphorus Concentration: Wet Weather

Total P concentrations were significantly higher in wet weather than in dry weather at sites DCC208, DCC455, DCC770, and DCD767 (student's t-tests, $p<0.05$) (Figure 43). Total P concentrations were also higher at all other sites, but statistical power was limited

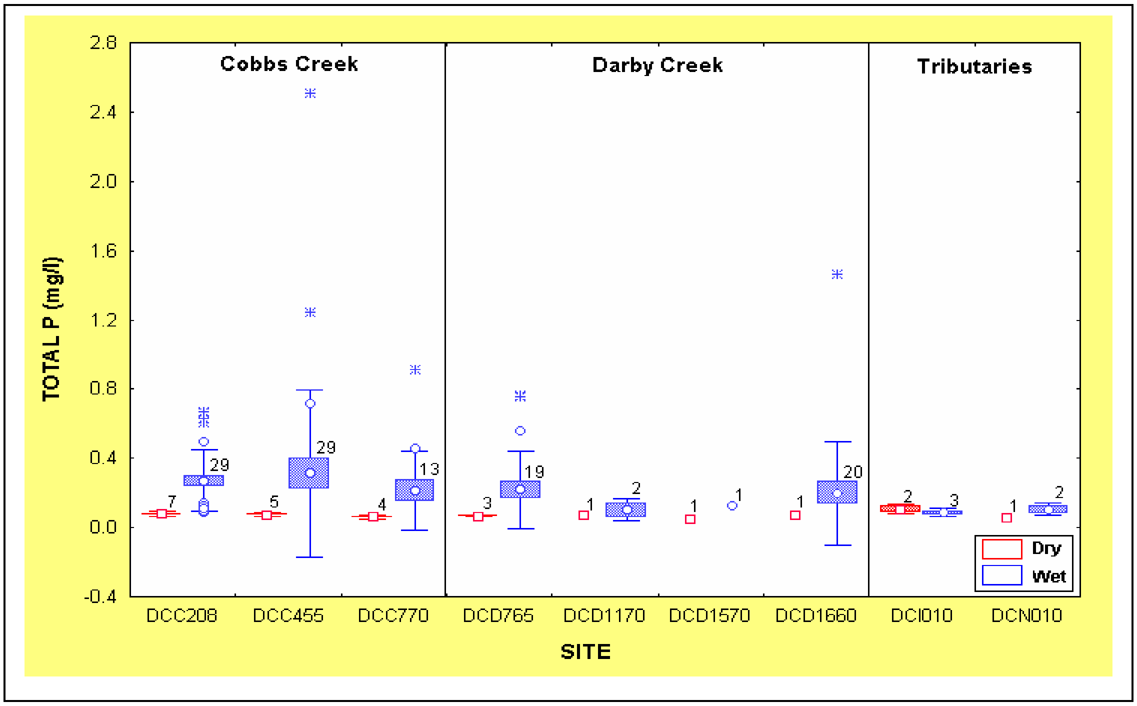


Figure 43. Dry and wet weather total phosphorus concentrations at the 9 monitoring sites.

with too few samples exceeding reporting limits. Despite greater total P concentrations in wet weather, PO_4 concentrations never exceeded reporting limits in wet weather, indicating that the majority of P within the watershed is adsorbed to sediment particles or organically-bound and is not immediately usable by stream producers. The degree to which wet weather P becomes bioavailable to stream producers depends on a variety of factors. Organically-bound macronutrients probably become transported out of the system (loading to the Delaware Estuary) during larger flows; P appears to be no exception.

5.4.8.9. Dry Weather N:P Ratios

Estimates of dry weather total N:P nutrient ratios were hindered by the number of samples with nitrite, total phosphorus, ammonia and/or TKN values below reporting limits. Only 3 of 69 samples could have nutrient ratios estimated directly. To generate a greater number of N:P ratio estimates, a value equal to half the reporting limit was substituted for all parameters with sample concentration less than the reporting limit (Figure 44). However, because of the lower reporting limit for total P, these values probably greatly overestimated N:P ratio. A more unorthodox comparison of NO_3 vs. actual TP observations was also used in an attempt to better estimate the relative proportions of these two nutrients (Figure 44). In any case, all sites within the watershed appear strongly P-limited.

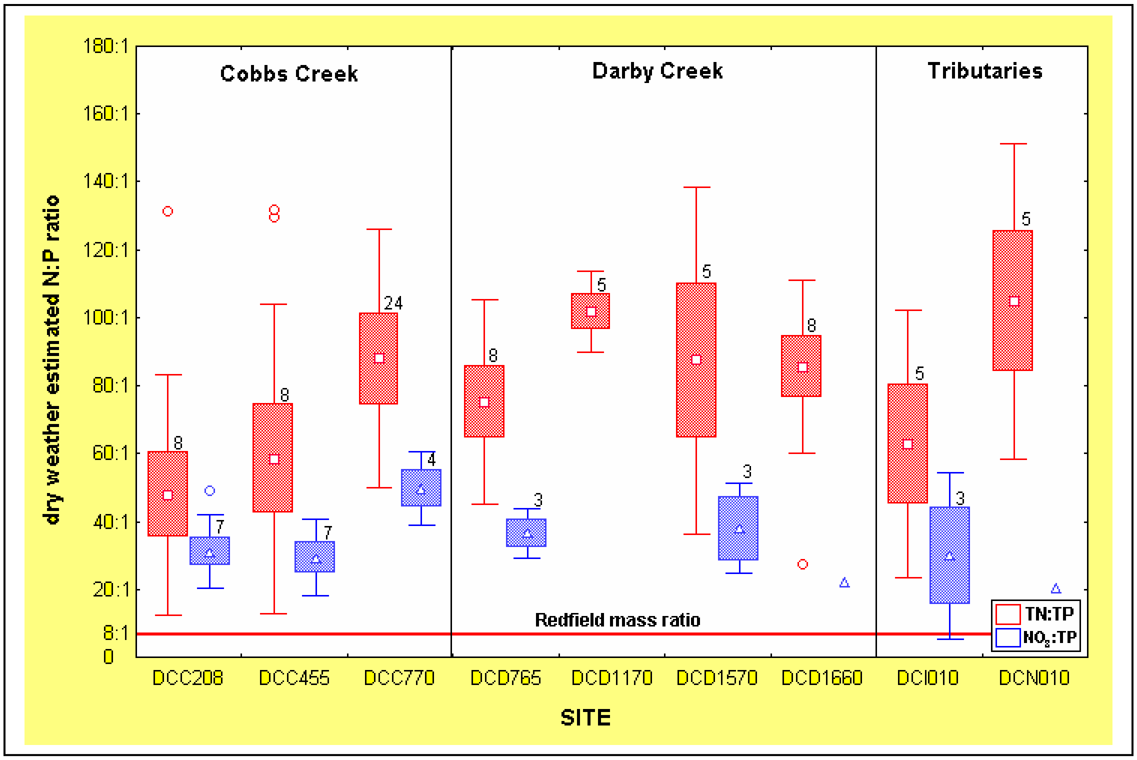


Figure 44. Estimated dry weather N:P ratios at the 9 monitoring sites.

5.4.8.10. Stream Nutrient Concentrations: Flow Implications

Stream nutrient concentrations in Darby-Cobbs Watershed are dynamic, often increasing in wet weather due to CSO discharge, runoff, and erosion. But concomitant increases in physical stressors probably impose limits on the degree to which stream producers can take advantage of these increased concentrations. Particle size selection, traditionally related to flow by entrainment velocity curves, may determine the effective P loading for a given sediment load. Smaller particles, due to their greater relative surface area, can adsorb relatively more P than larger particles. Smaller particles are also generally more readily eroded and entrained in stormwater flow than larger particles.

Smaller storm events in Darby-Cobbs Watershed probably contribute more to eutrophication than larger events. For example, if smaller sediment particles adsorb more P than larger particles as has been suggested, P loading becomes less efficient as larger particles are entrained in runoff. As shear stresses increase, streambank materials comprise a greater proportion of the sediment load. These particles are likely more similar to the soil parent material (i.e., lower in P concentration than more superficial soils layers that tend to incorporate more organic material). As flows increase, a greater proportion of the total load is transported out of the system, a greater proportion of the total nutrient load is inaccessible to producers, and much of the photosynthetic biomass (filamentous green algae and their associated epiphytes in particular) may be sloughed away and transported out of the system.

In areas served by combined sewers, the relative impact of small, intense storms is magnified. CSO discharge is minimally diluted by stormwater in the initial overflow phase, or "first flush". If nutrients present in these overflows can become deposited along with sediment or rapidly taken up by stream producers, discharges of short duration, particularly in which shear stresses do not result in major sloughing of algal communities, may have far-reaching consequences for stream nutrient dynamics and aquatic biota. A greater benefit may result from reducing frequency, number, and volume of small CSO discharges rather than attempting to capture releases from larger events.

SECTION 6: INDICATOR STATUS UPDATE

6.1. Overview

An important component of the Comprehensive Characterization Report is to provide concise updates on the biological, chemical and physical conditions within the Darby-Cobbs Watershed. Indicator status updates derived from this report will be used as a tool for identifying spatial and temporal trends of a particular stream reach or for the entire watershed. Moreover, indicators defined in the Cobbs Creek Integrated Watershed Management Plan will serve as benchmarks for future restoration projects. The indicators addressed in this report are as follows:

- Indicator 3: Stream Channels and Aquatic Habitat
- Indicator 5: Fish
- Indicator 6: Benthos
- Indicator 7: Effects on Public Health (Bacteria)
- Indicator 8: Effects on Public Health (Metals and Fish Consumption)
- Indicator 9: Effects on Aquatic Life (Dissolved Oxygen)

6.2. Indicator 3: Stream Channels and Aquatic Habitat

Indicator 3 of the Cobb Creek Integrated Watershed Management Plan stresses the importance of physical habitat features that will support healthy fish and benthic communities. As described in Section 5.3.1. EPA Habitat Assessment, thirteen habitat variables, ranging from instream parameters to riparian health, were compared against reference conditions to obtain an overall habitat integrity score.

In 2003, habitat at 17 sites throughout the Darby-Cobbs Watershed was surveyed by PWD staff biologists. Monitoring locations along Darby Creek mainstem received consistent scores, ranging from the highest value, “Comparable to Reference Conditions”, to the next incremental level, “Supporting” (Figure 45). Similarly, two tributary sites, Little Darby Creek and Ithan Creek, received ratings of “Comparable to Reference Conditions”.

In contrast to Darby Creek, habitat values along Cobbs Creek and its tributaries were less desirable. Of the four main stem locations, two sites received “Supporting” while the remaining two locations were designated as “Partially Supporting” (i.e., marginal). Naylor’s Run, a 2nd order tributary to lower Cobbs Creek, received rankings of “Supporting” in the upper portion and “Non-Supporting” near the confluence with Cobbs Creek. Similarly, sites on the east and west branches of Indian Creek were determined to be only “Partially Supporting” of aquatic communities.

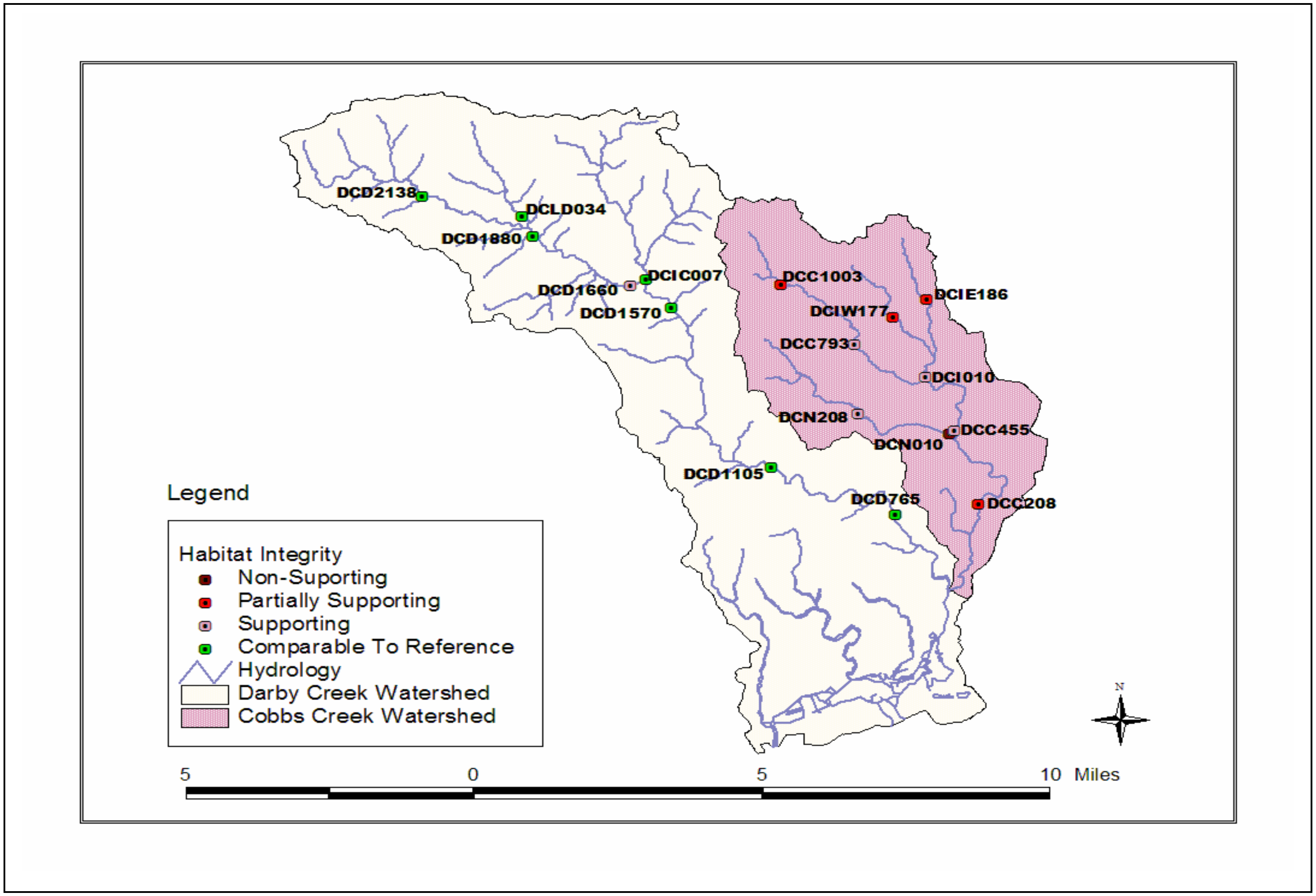


Figure 45. Stream channels and aquatic habitat indicator status update.

6.3. Indicator 5: Fish

During 1999, three surrogate indicators were used to define the integrity of fish communities in the Cobbs Creek Basin. Relative abundance (i.e., density), pollution tolerance and number of native species provided a semi-quantitative measurement of fish assemblage health. With the development of ecoregion-specific metrics, PWD has substituted the past indicators with the Index of Biological Integrity (IBI), a multi-metric approach that characterizes fish community health at a particular stream reach or at the watershed scale (Section 4.2.4. Fish IBI Metrics).

Fisheries data collected in 2003 revealed IBI scores varying among watersheds and spatially along the river continuum. More specifically, downstream sites on Darby Creek received scores of "good", while upstream locations were designated as "fair" or "poor" (Figure 46). Greater diversity, the presence of pollution-intolerant fish species and variation in trophic levels were among the major reasons for higher IBI scores in downstream portions of Darby Creek. Conversely, sites in Cobbs Creek received IBI scores in the "fair" to "poor" categories. Although fish density was generally greater in Cobbs Creek, community structure consisted of pollution-tolerant taxa with generalist feeding strategies.

After a thorough review of historical and recent data compiled on Cobbs Creek (i.e., 1999 and 2003), it is evident that active restoration strategies must be implemented and monitored over time to measure the efficacy of planned habitat restoration projects, as defined in the Darby-Cobbs Integrated Watershed Management Plan.

6.4. Indicator 6: Benthos

Benthic macroinvertebrate monitoring occurred at 17 sites in Darby-Cobbs Watershed during 2003. Similar to the 1999 sampling effort, Rapid Bioassessment Protocol III (RBP III) was chosen as the approved method for assessing the condition of the macroinvertebrate community in Darby-Cobbs Watershed.

The assessment conducted in 2003 reconfirmed findings of the Pennsylvania Department of Environmental Protection (PADEP) and Philadelphia Water Department (PWD). Benthic impairment in Cobbs Creek was omnipresent; stream designations ranged from "moderately impaired" to "severely impaired" (Figure 47). Darby Creek monitoring sites received the same designations, with the exception of one upstream site which scored as "slightly impaired".

The severity of impairment throughout Darby-Cobbs Watershed suggests that attaining healthy benthic communities in mainstem localities and associated tributaries is not a feasible option at this time. Habitat restoration, flow attenuation and active re-introduction (i.e., "invertebrate seeding") may be the only solutions to ensure a viable benthic community within this watershed.

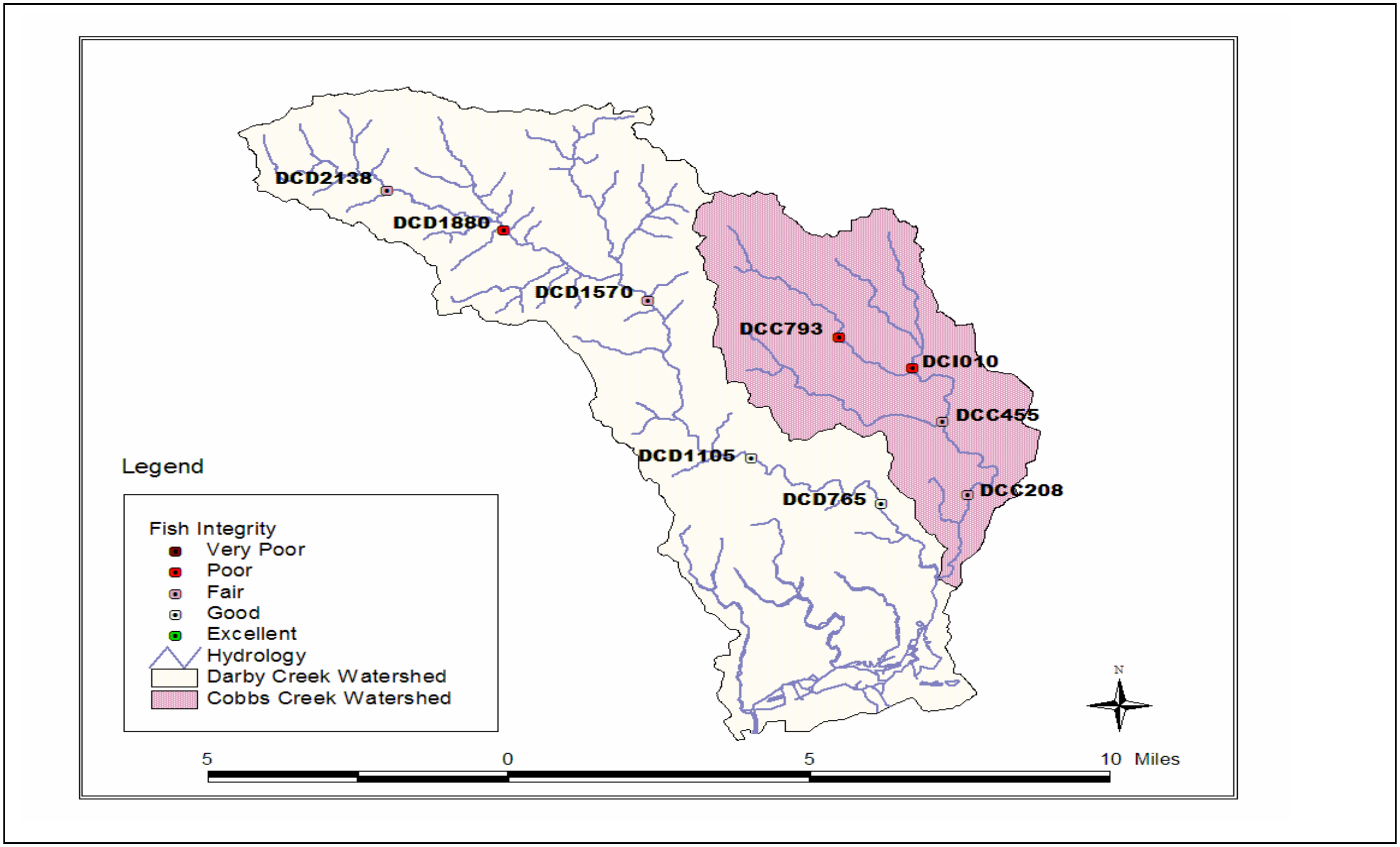


Figure 46. Fish indicator status update.

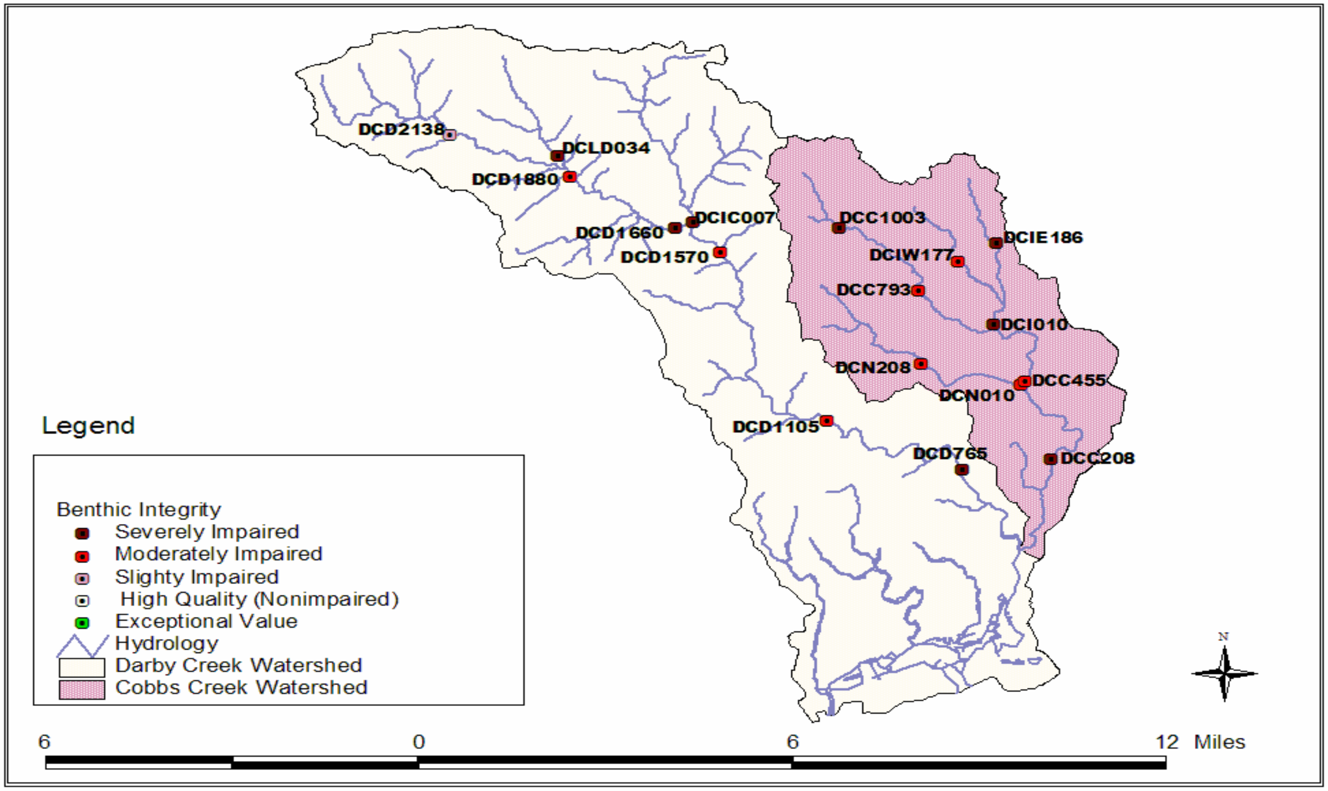


Figure 47. Benthic indicator status update.

6.5. Indicator 7: Public Health Effects (Bacteria)

Based on Pennsylvania's water quality criteria, the maximum fecal coliform concentration during the swimming season (i.e., May 1 through September 30) shall not exceed a geometric mean of 200 CFU per 100 ml for five nonconsecutive samples. During the remainder of the year, the maximum fecal coliform level should be equal to or less than a geometric mean of 2000 CFU per 100 ml based on five consecutive samples collected on different days.

During 2003, discrete chemical samples were taken at nine sites in Darby-Cobbs Watershed. Sampling events occurred at each site at weekly intervals for one month during three separate seasons (n= 12 sampling events per site). In addition, wet weather samples were collected during two runoff-producing storm events. Geometric means of fecal coliform concentrations were calculated during wet and dry periods for each site and compared to the appropriate standard.

Similar to 1999 and 2000 water quality sampling, mean concentration of fecal coliform during dry weather exceeded standards at all sites in Darby-Cobbs Watershed. In general, 33.3 % of all sites along Darby Creek mainstem met water quality standards during dry weather in 2003 (Figure 48). Geometric means calculated for Darby Creek sites revealed that values were generally between 2 to 4 times the season standards (i.e., 200 CFU/100 ml or 2000 CFU/100 ml) (Figure 49). In Cobbs Creek, sites DCI 010 and DCC 208 met water quality standards in 50.0 % and 33.3 % of the samples, respectively. Upstream and midstream sites (DCC 770 and DCC 455) had less desirable results, with standards being met only 22% of the time. No samples taken on Naylor's Run (DCN 010) met water quality standards during the swimming and non-swimming seasons.

Wet weather sampling results showed concentrations of fecal coliform exceeding water quality standards at all sites in Darby-Cobbs Watershed (Figure 50). Thirty-three percent of samples at Darby Creek sites met standards while only 16.7% of samples in Cobbs Creek were below water quality standards. Moreover, fecal coliform concentrations were between 2 to 10 times greater than standard values in Darby Creek (i.e., 400-2000 CFU/100 ml during the swimming season). Similarly, mean concentrations of fecal coliform were greater than the water quality standard but varied spatially along the river continuum (Figure 51). For example, concentrations at the upstream location (DCC 770) were between 2 to 10 times the standard limit and increased steadily until values reached between 50 to 200 times (i.e., 10,000-40,000 CFU/100 ml) the water quality standards at Site DCC 208. Similarly, concentrations of fecal coliform at tributary locations (i.e., DCN 010 and DCI 010 ranged between 2,000 to 10,000 CFU/100 ml during wet conditions.

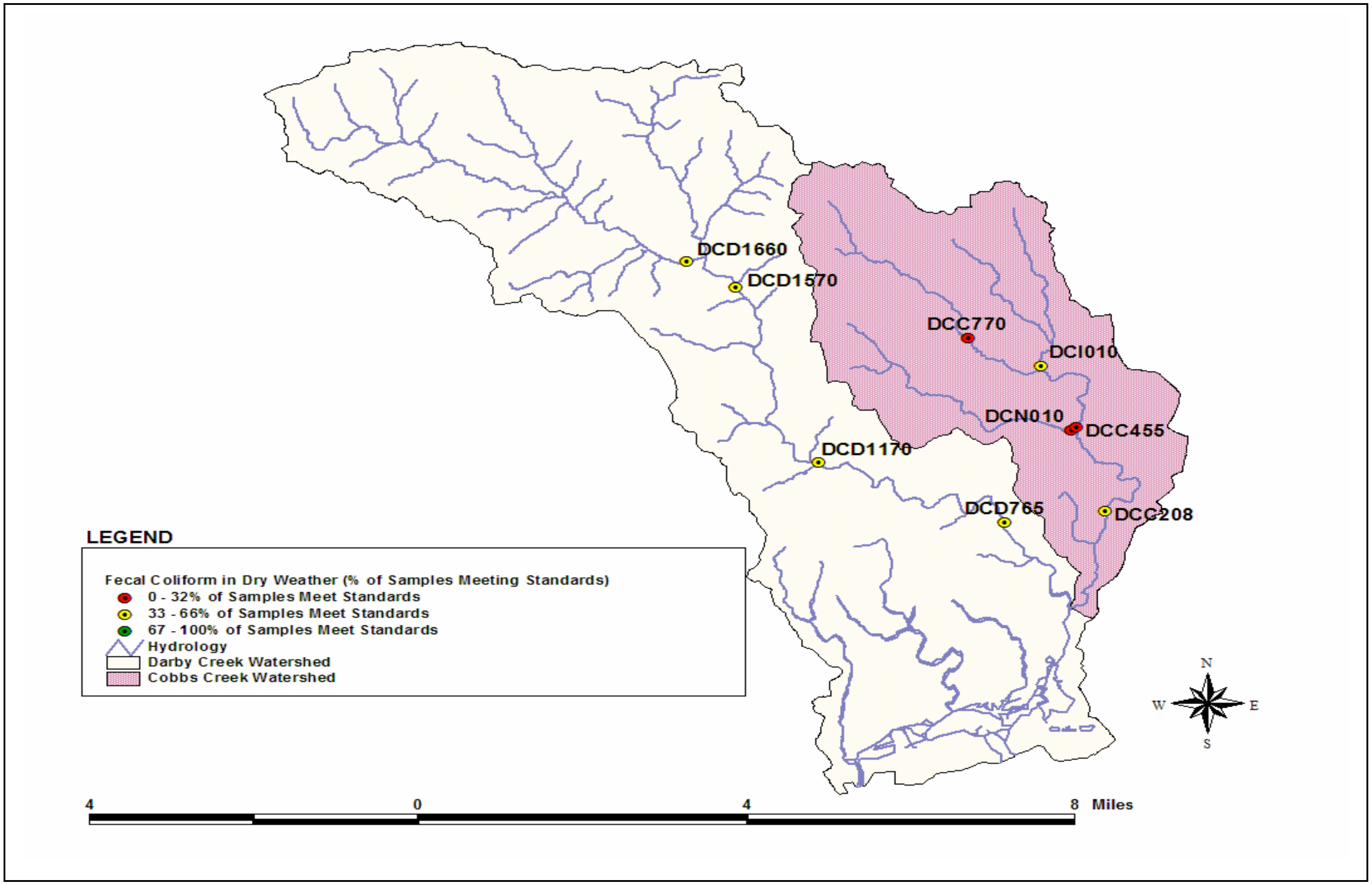


Figure 48. Dry weather fecal coliform indicator status update.

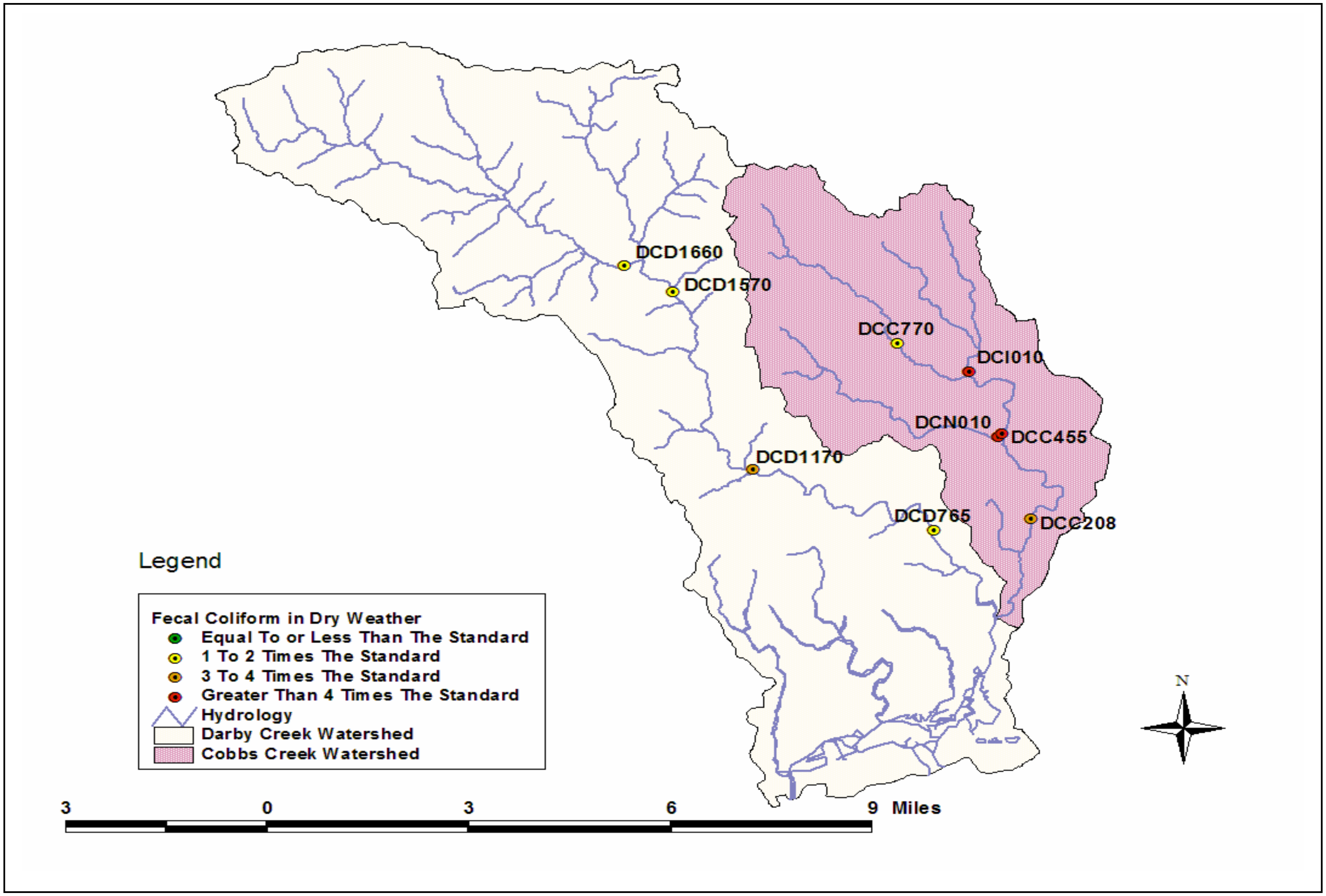


Figure 49. Geometric means of fecal coliform concentrations in dry weather

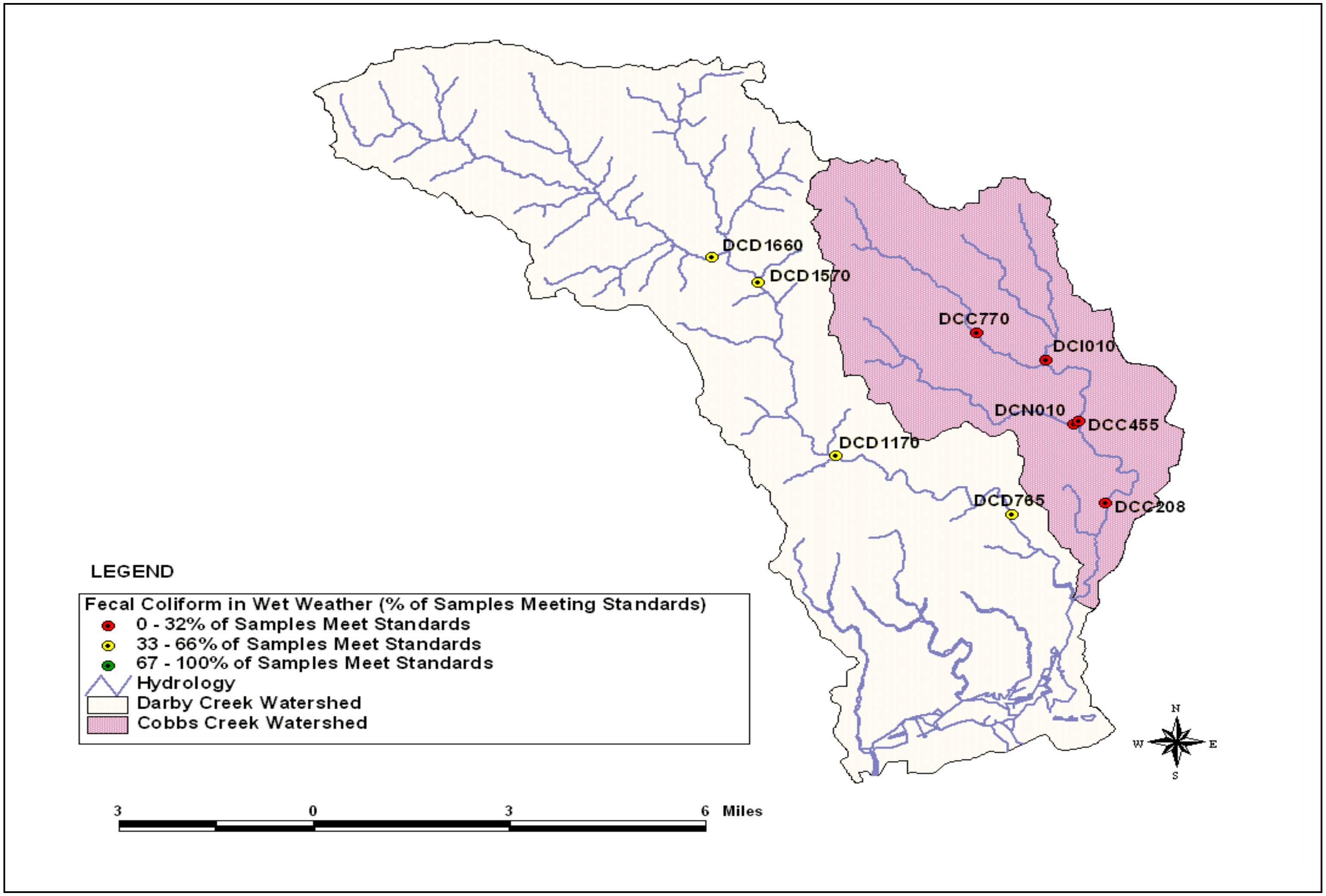


Figure 50. Wet weather fecal coliform indicator status update.

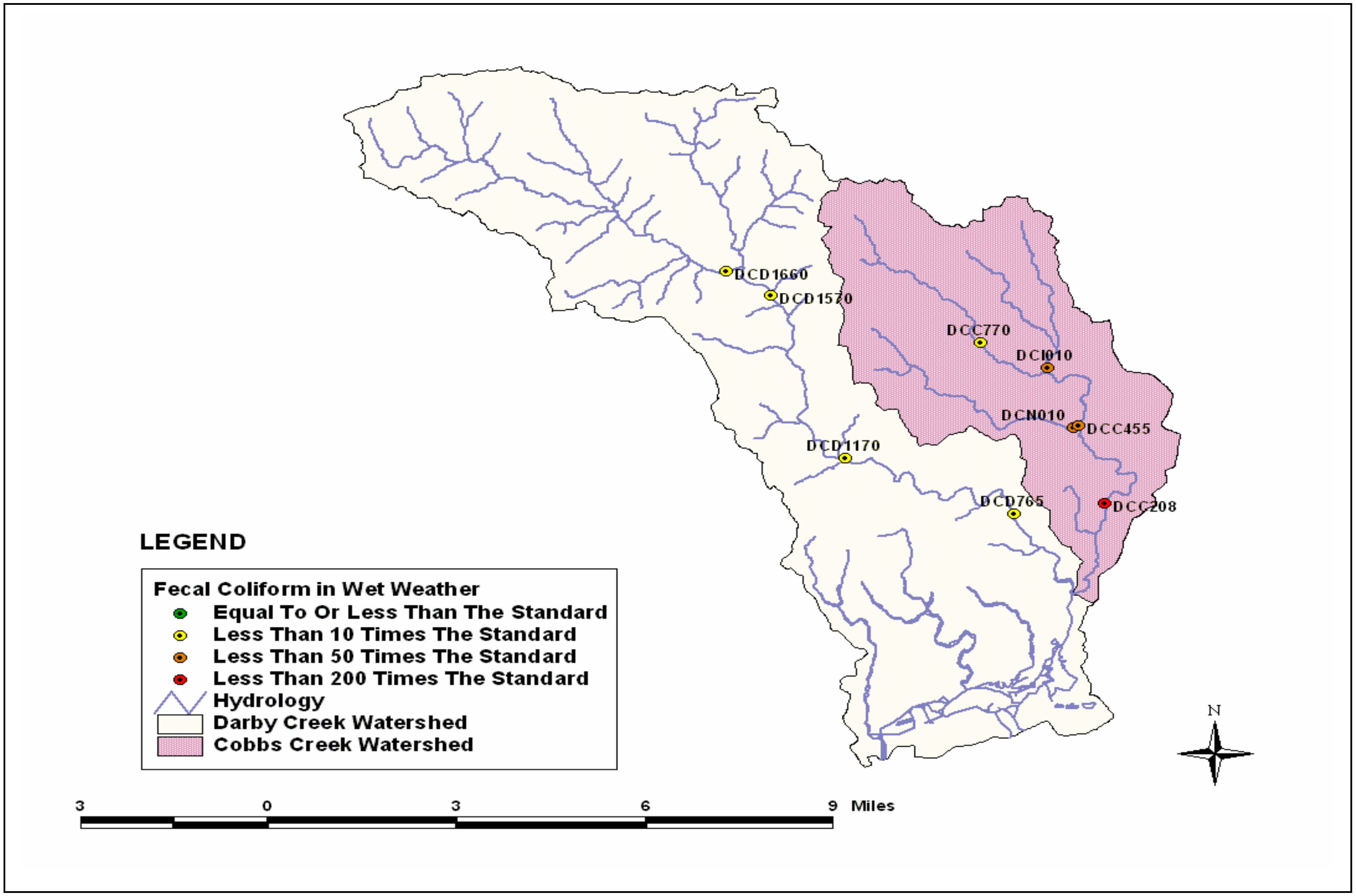


Figure 51. Geometric means of fecal coliform concentrations in wet weather.

6.6. Indicator 8: Public Health Effects (Metals and Fish Consumption)

Relatively small amounts of certain toxic compounds can kill aquatic life through acute poisoning, while chronic levels may be harmful to developmental stages of fish and macroinvertebrates. For example, bioaccumulation of toxins in fish may have a profound effect on fecundity and may also pose a threat to humans who regularly consume fish.

The established indicator measures the percent of cadmium, chromium, copper and zinc samples meeting state standards at various sites in Darby-Cobbs Watershed. In 2003, PWD scientists collected 48 samples at each site for Cd, Cr, Cu and Zn during dry and wet weather. An additional 48 to 56 samples were collected at each site during two wet-weather targeted events.

Results suggest standards intended to protect aquatic life were met at all locations during dry-weather in 2003 with the exception of copper in the upper reach of Darby Creek (Figure 52). Conversely, wet-weather exceedances were omnipresent on both the Darby Creek and Cobbs Creek (Figure 53). Of the metals, aluminum and copper generally exceeded standards more than 10 % of the time, while chromium and lead samples were greater than Pennsylvania's water quality criteria between 2% - 10% of the time.

6.7. Indicator 9: Aquatic Life Effects (Dissolved Oxygen)

During 2003, automated water quality monitors (i.e., Sondes) were deployed in Darby-Cobbs Watershed at three locations in Cobbs Creek and two locations in Darby Creek. Sondes were deployed for approximately one month, recording dissolved oxygen concentrations (mg/L) every 15 minutes. In total, approximately 792 hours of data were recorded at each site between 8/14/03-9/16/03.

Continuous data in from two Darby Creek sites indicated that DO concentrations did not fall below the instantaneous concentration standards (i.e., 5 mg/l in the upstream location and 4 mg/l in lower Darby Creek) (Figure 54). Similar results were observed in the upper reaches of Cobbs Creek (DCC 770). At site DCC 455, dissolved oxygen concentrations fell below the 4 mg/l limit less than one percent of the total recorded data. At site DCC 455, however, dissolved oxygen levels violated water quality criteria approximately 2.9 % of the time.

A probable explanation for this occurrence is the high level of algal activity as a result of stagnant flow, nutrient inputs and lack of forest canopy in this vicinity. As indicated in the Darby-Cobbs Integrated Watershed Management Plan, plans to increase stream velocity, such as dam removal and physical restoration, and increased vegetative protection will potentially eliminate the large diurnal DO swings associated with an overabundance of primary producers in downstream of Cobbs Creek sites.

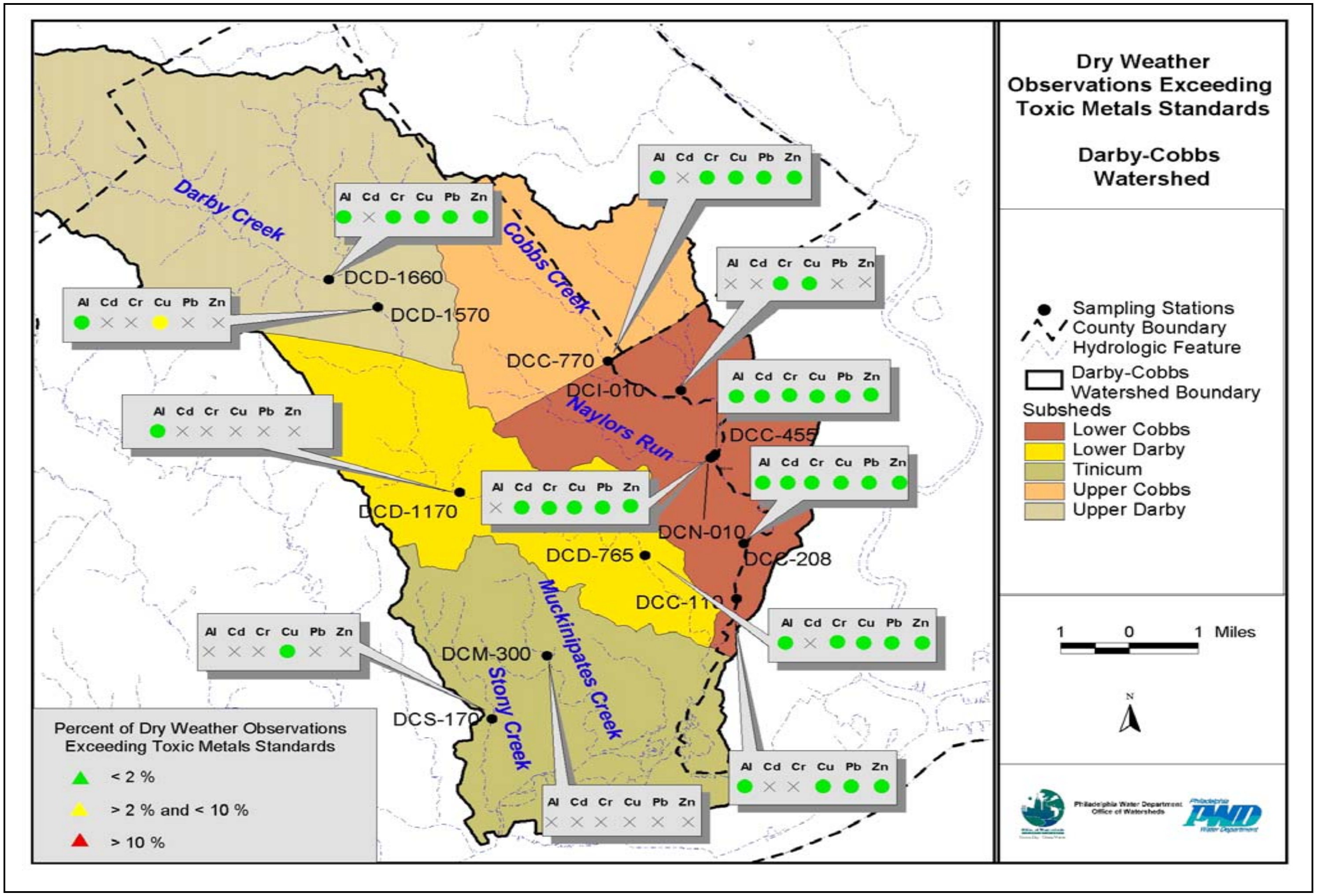


Figure 52. Dry weather metals indicator status update.

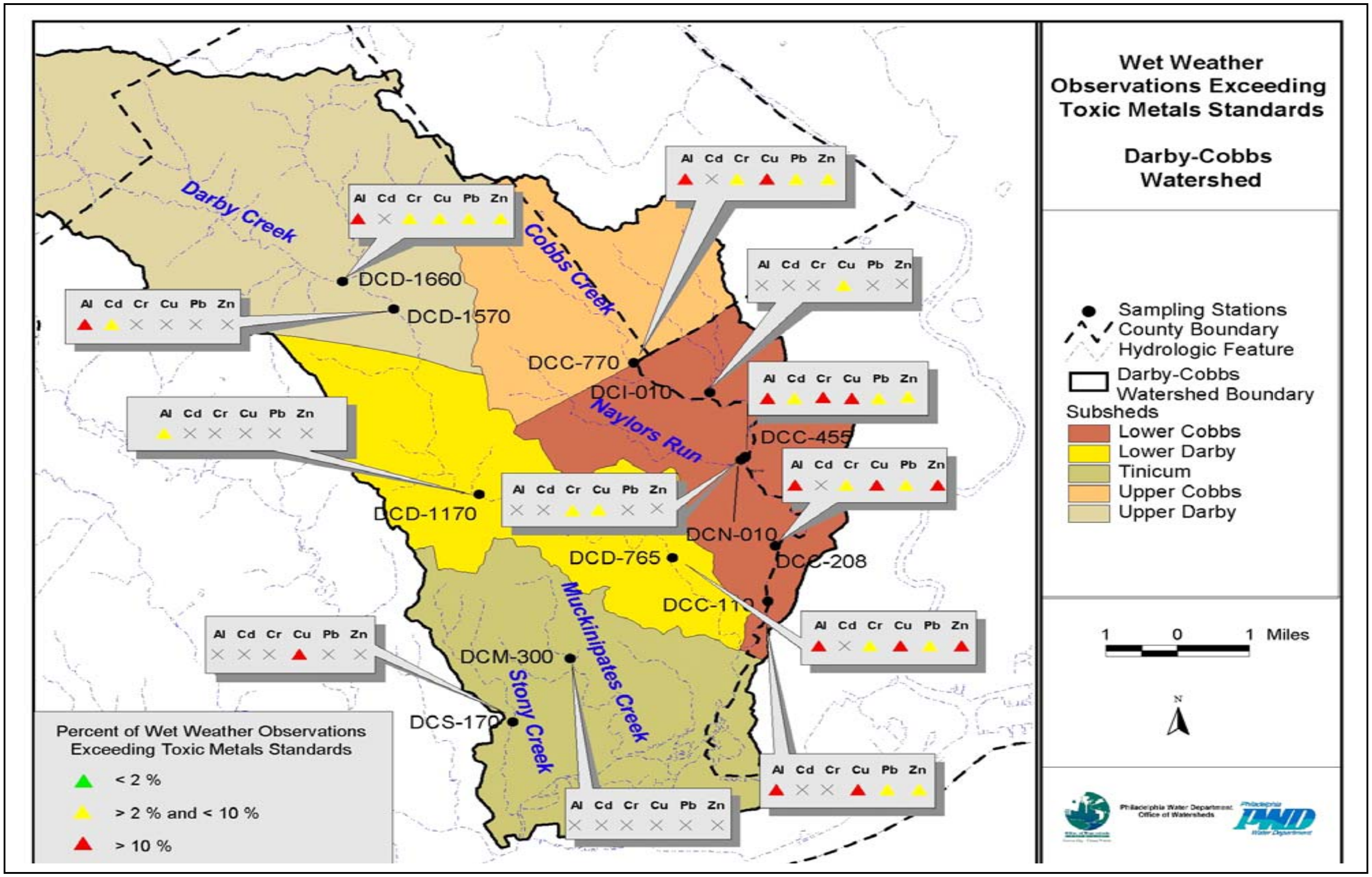


Figure 53. Wet weather metals indicator status update.

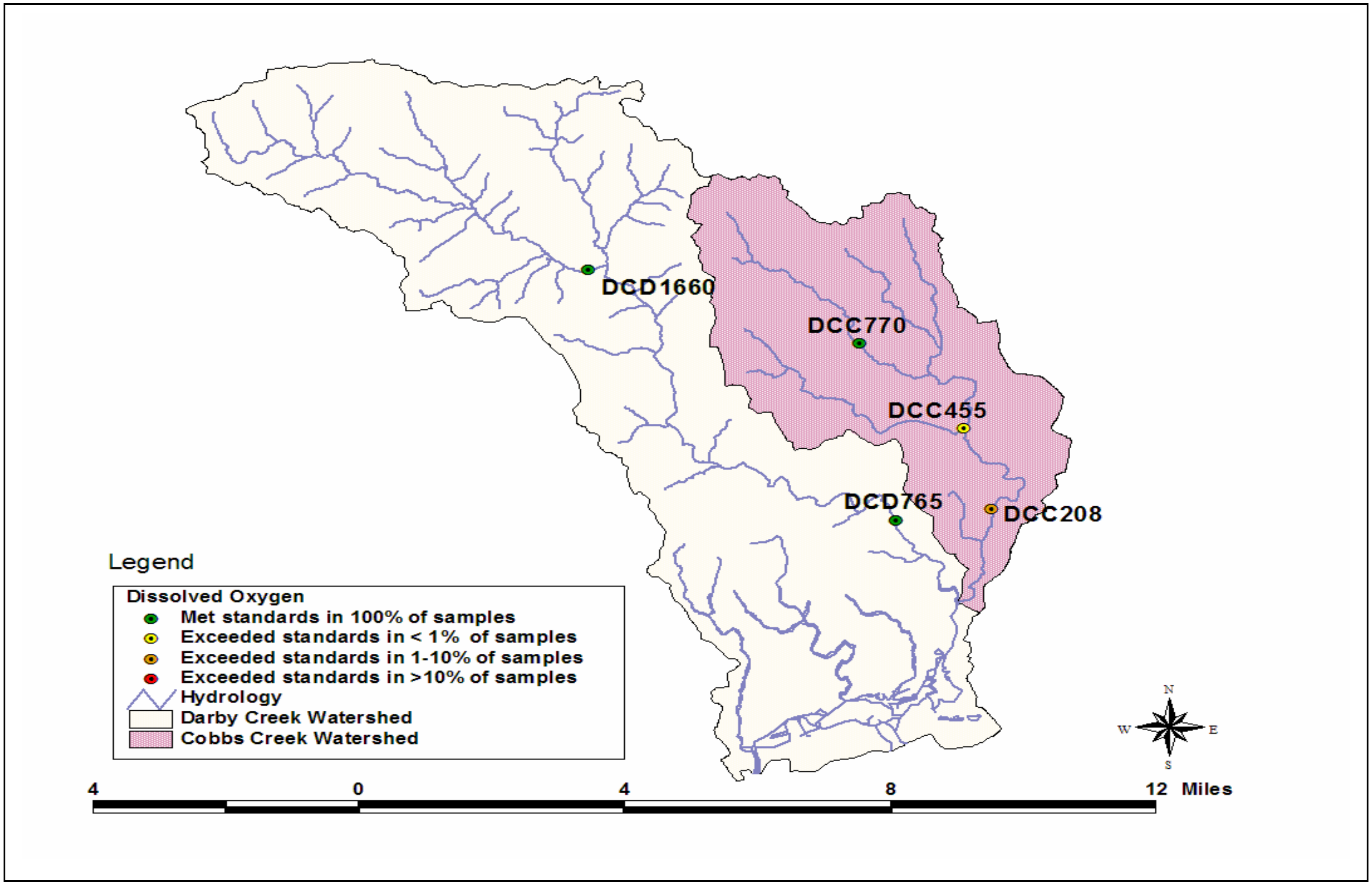


Figure 54. Dissolved oxygen indicator status update.

SECTION 7: EXECUTIVE SUMMARY

Problems faced by the Darby-Cobbs Watershed stem from many sources, but succinctly, the watershed suffers from excess land development and urbanization. These effects are evident in the physical habitat, and reflected by biological communities and water quality samples collected from the watershed. Though numerous impairments exist, habitat modification and physical disturbances stand out as the most important factors, underlying all other biological impairments. Healthy ecosystems cannot exist without healthy habitats.

With impervious cover contributing in excess of 30% of the land area in many subsheds, stormwater flows have de-stabilized much of the stream channels of the watershed. Many first order tributaries have been lost. Urbanization promotes a cumulative, self-reinforcing pattern of streambank erosion. As stream channels become physically larger and further disconnected from their historic floodplains, more stormwater forces are restricted to the stream channel, where compromised, heavily eroded banks are least suited to dissipate them.

Widespread urbanization, as present in the Cobbs Creek Watershed, magnifies flow modification by decreasing infiltration and groundwater recharge- establishing a hydrologic pattern of "feast or famine". Presently, baseflow accounts for only 42% of total mean annual flow in the Cobbs basin. Effects of urbanization and physical habitat degradation were evident in biomonitoring data, but these effects were more severe in Cobbs Creek Watershed. The Cobbs Creek Integrated Watershed Management Plan (CCIWMP) outlines several options for detaining, infiltrating, and treating stormwater to reduce its impact on the stream channel and aquatic habitats. The watershed cannot be restored without addressing these stormwater impacts.

Sunlight provides most energy to the Darby-Cobbs Watershed. Attached algae and aquatic mosses are the primary producers, and constitute the base of the aquatic ecosystem. Algae were not generally observed to grow to nuisance levels, with the possible exception of slow water areas behind dams and other obstructions. Continuous water quality monitoring and field observations at some sites suggest that periphytic algae are responsible for pronounced diurnal fluctuations in dissolved oxygen (DO) concentration and pH that may stress natural fish and invertebrate communities. Algal community structure and biomass also change drastically at some sites due to scouring storm events.

It is expected that activities recommended under Target B of the CCIWMP (i.e., streambank restoration, dam removal and modification, and re-engineering of slow water areas and scour pools) will greatly reduce the amount of stream area subject to severe DO and pH fluctuations. Identification and correction of dry weather sewage inputs, as required by existing regulations, should also help reduce nutrient inputs that drive algal production. Riparian shading reduces both algal biomass potential and the magnitude of DO fluctuations, but riparian zone management must balance stream shading needs with allowing enough light penetration to support a multi-tiered native plant community. If stream habitat is restored and dissolved oxygen conditions are favorable, invertebrate and fish communities can be restored as well.

Invertebrate communities in Darby-Cobbs Watershed sampled in 2003 generally indicated impairment when compared to reference conditions, but this impairment was more severe in Cobbs Creek than in Darby Creek. Most sites showed a simplified invertebrate community dominated by chironomid midges and net spinning caddisflies- moderately tolerant invertebrates with generalized food requirements. These invertebrates can resist scouring and frequent disturbance of their habitat by firmly attaching themselves to stream substrates with silk. Free-living active invertebrates, predators, sensitive species, and invertebrates with feathery external gills were rare at some Darby Creek sites and completely absent from most Cobbs Creek sites and tributaries. The role of sediment toxicity or anoxia on invertebrate communities remains unknown, but water chemistry samples from some sites showed that concentrations of metals of concern (e.g., copper, lead, aluminum, iron, and zinc) may exceed state water quality criteria.

Fish assessments generally mirrored results of the macroinvertebrate study, with most sites exhibiting less diversity and specialization than fish communities found at reference sites. As a whole, the watershed was dominated by a small number of moderately tolerant species with generalized feeding habits and life history strategies. Fish species that have been shown to be tolerant of habitat degradation and food source limitation were dominant, while species that have specialized habitat, food or reproductive needs were largely missing from the Cobbs Creek basin. The most important species (in terms of biomass) was American eel, a species that spawns in the ocean, can tolerate extreme flows, and epitomizes the term "generalist feeder". Though upper reaches of Darby Creek watershed support a put-and-take trout fishery, fishery restoration plans for the watershed as a whole must be realistic in view of the watershed's "warmwater" designation and the immutable constraints of climate, geology and geography. Temperature and DO regime are ultimately and absolutely bound by these constraints.

Water quality investigations documented many violations (or in the case of toxic metals, possible violations) of state water quality criteria, particularly in wet weather. Combined sewers periodically release a mixture of raw sewage and stormwater to many areas of Darby-Cobbs Watershed. Damaged, improperly sized, or choked sanitary sewers and illicit connections may also release raw sewage to the watershed. Because much of Darby-Cobbs Watershed is not meeting state water quality standards for fecal coliform bacteria during dry weather, investigation and abatement of dry weather sewage sources is one of the most important components of Target A of the CCIWMP. Streams must be safe during the times when people are most likely to come in contact with them. Dry weather source trackdown is the most cost effective step toward meeting water quality standards during dry weather.

However, research shows that fecal coliform bacteria may persist for extended periods of time in stream sediments. It is possible that the effects of periodic wet weather CSO discharge may be long-lasting and cause some streams to have "background" fecal coliform concentrations in excess of water quality standards even once dry weather sources are eliminated. Wildlife and domestic animals are also sources of fecal coliform bacteria that cannot be overlooked. Reducing wet weather sewage sources is the goal of The City of Philadelphia's CSO Long Term Control Plan (LTCP). Over the next two years PWD is committed to a 20% reduction in CSO volume citywide.

These CSO reductions may be realized through a number of technologies, but it is imperative that the chosen solution (or solutions) address the actual cause of impairment. For example, small storm events likely contribute maximally to nutrient enrichment and algal blooms, as the relative proportion of sanitary sewage is largest and physical stresses due to sloughing and turbidity are smallest. While large storm events cause a greater amount of nutrients to be passed through the system, sloughing and turbidity reduce the ability of the algal community to take advantage of these nutrients. The greatest improvements may arise from prioritizing, controlling, and eliminating sources of nutrients when and where conditions are favorable for algae.

Recognition of the need to protect people from water and sewage-borne diseases and parasites has extricated us from the "dark ages" of public health, spawning regulations and the technical innovations needed to meet them. As our knowledge of threats to people and the natural environment grows, water quality regulations are under continuous revision. Unfortunately, scientific research and environmental regulations often outpace practical implementation of corrective measures.

The current state of the Darby-Cobbs Watershed is the product of more than a century of neglect and abuse, and correcting these problems will require an enormous commitment. Furthermore, this effort will take many years and cost millions of dollars. As a group of engineers and scientists in the service of the public, the Philadelphia Water Department is working to ensure that Philadelphia's watershed improvements are cost-effective and based on sound science. We believe that the ideas and options presented in the Cobbs Creek Integrated Watershed Management Plan represent reachable goals and provide a road map for attaining those goals.

SECTION 8: REFERENCES

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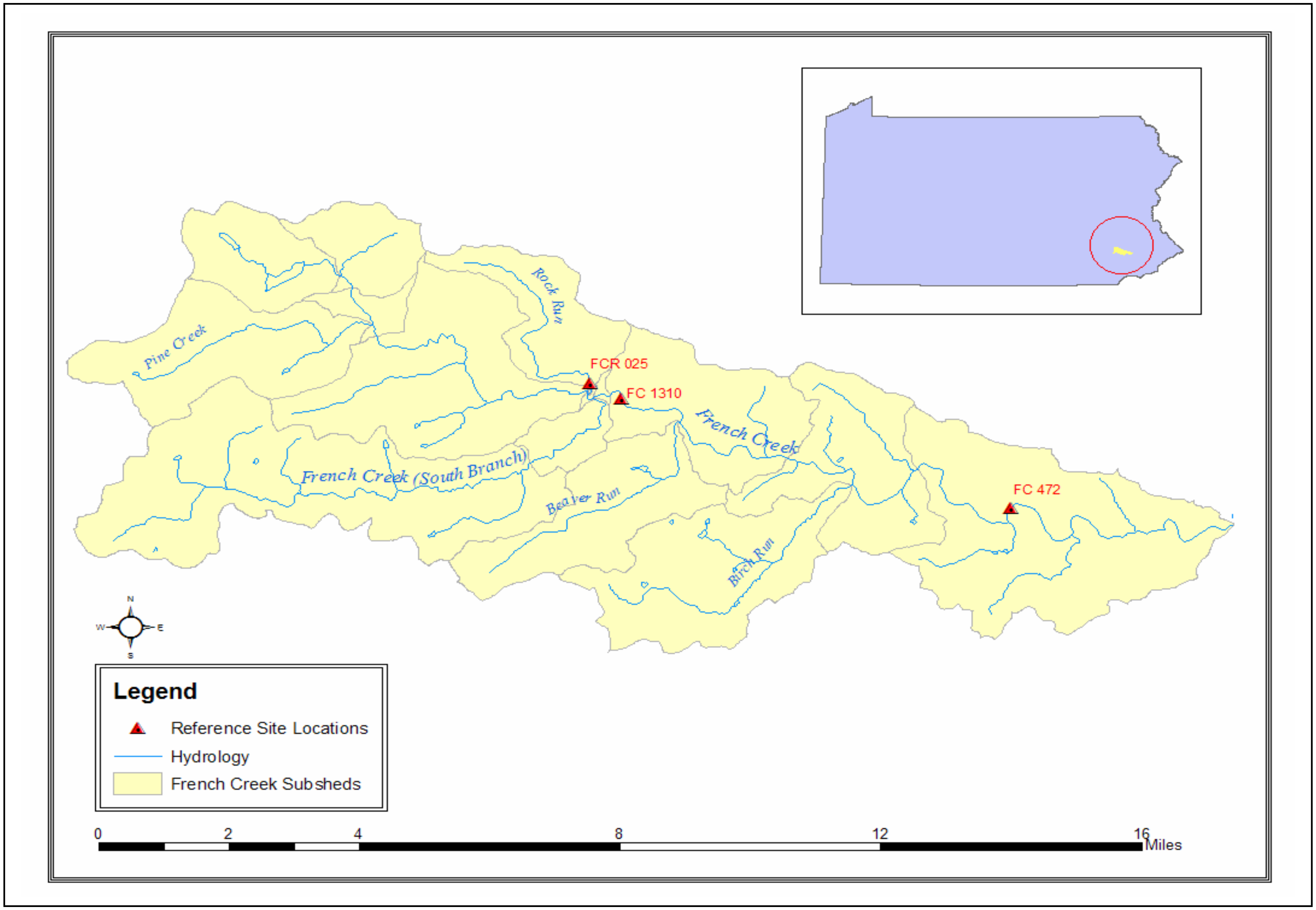
APPENDIX A: REFERENCE MONITORING LOCATIONS

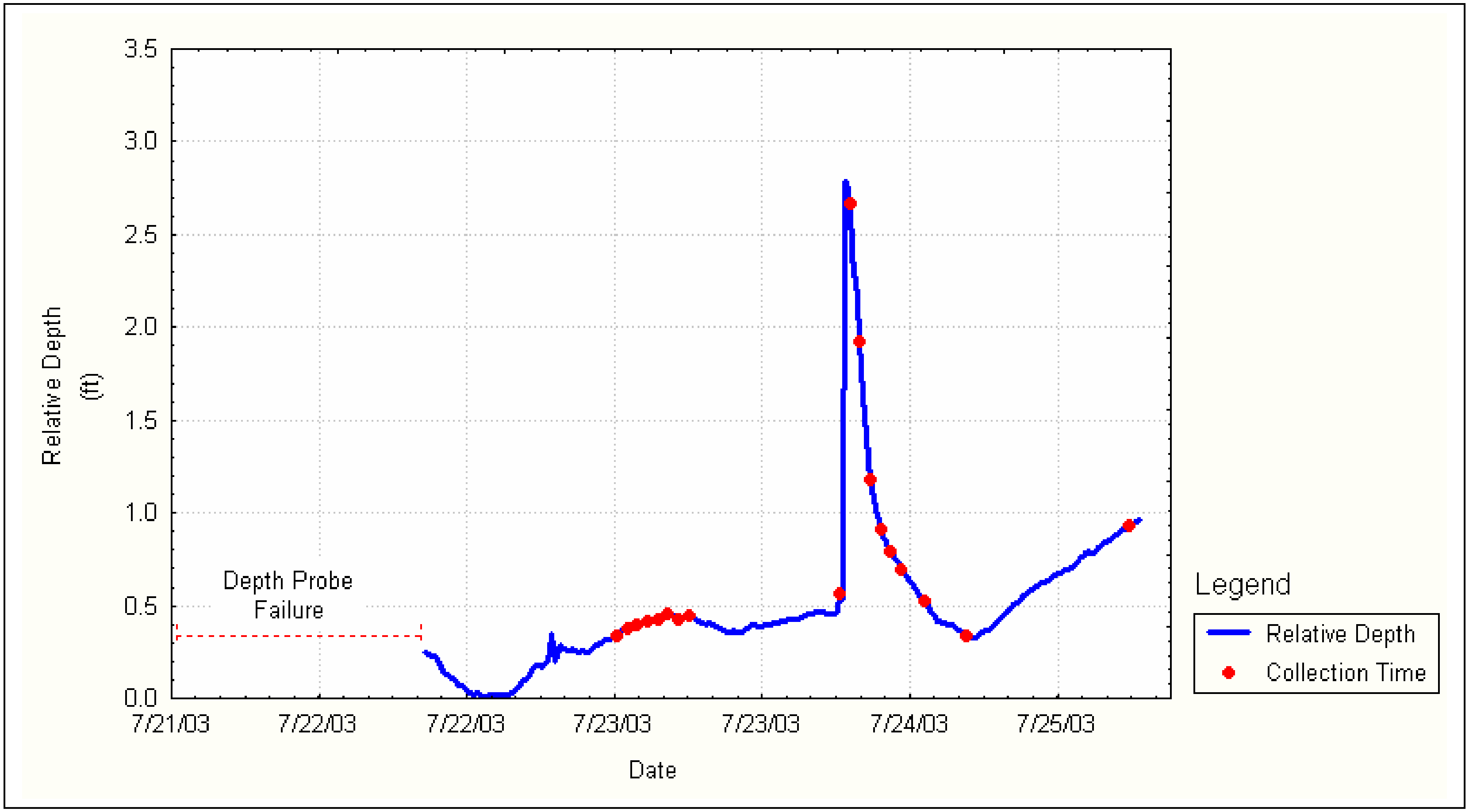

Pine Creek
Rock Run
FCR 025
FC 1310
French Creek
French Creek (South Branch)
Beaver Run
Birch Run
FC 472
N
W
E
S
Legend
Reference Site Locations
Hydrology
French Creek Subsheds
0
2
4
8
12
16
Miles

APPENDIX B: SIMPLE LINEAR REGRESSION (SLR) EQUATIONS OF FISH SPECIES IN DARBY-COBBS WATERSHED

SCIENTIFIC NAME	**COMMON NAME**	**SPECIES CODE**	**SLR EQUATION**	**R^2 VALUE**
Ameiurus nebulosus	Brown Bullhead Catfish	AMNEB	y = 3.1186x - 1.9473	R2 = 0.9938
Ambloplites rupestris	Rock Bass	AMRUP	y = 2.8935x - 1.5764	R2 = 0.9916
Anguilla rostrata	American Eel	ANROS	y = 3.3829x - 3.2737	R2 = 0.9958
Catostomus commersoni	White Sucker	CACOM	y = 3.0851x - 2.0466	R2 = 0.9956
Cyprinella analostana	Satinfin Shiner	CYANA	y = 2.7327x - 1.7254	R2 = 0.9081
Etheostoma olmstedi	Tessellated Darter	ETOLM	y = 2.6587x - 1.6963	R2 = 0.8395
Exoglossum maxillingua	Cutlips Minnow	EXMAX	y = 3.1629x - 2.032	R2 = 0.9915
Fundulus diaphanus	Banded Killifish	FUDIA	y = 3.1926x - 2.1244	R2 = 0.9741
Fundulus heteroclitus	Mummichog	FUHET	y = 3.2904x - 2.0907	R2 = 0.9859
Lepomis auritus	Redbreast Sunfish	LEAUR	y = 3.2349x - 1.9202	R2 = 0.9959
Lepomis gibbosus	Pumpkinseed Sunfish	LEGIB	y = 3.337x - 1.9906	R2 = 0.992
Lepomis macrochirus	Bluegill Sunfish	LEMAC	y = 3.2184x - 1.9574	R2 = 0.9976
Luxilus cornutus	Common Shiner	LUCOR	y = 3.4176x - 2.2849	R2 = 0.9895
Micropterus dolomieu	Smallmouth Bass	MIDOL	y = 2.6582x - 1.456	R2 = 0.9805
Micropterus salmoides	Largemouth Bass	MISAL	y = 3.0914x - 2.0213	R2 = 0.9938
Notropis hudsonius	Spottail Shiner	NOHUD	y = 2.9066x - 1.9642	R2 = 0.9743
Notropis procne	Swallowtail Shiner	NOPRO	y = 3.0687x - 2.0479	R2 = 0.9443
Oncorhynchus mykiss	Rainbow Trout	ONMYK	y = 2.9476x - 1.9371	R2 = 0.8555
Pimephales promelas	Fathead Minnow	PIPRO	y = 3.2744x - 2.1155	R2 = 0.9664
Rhinichthys atratulus	Blacknose Dace	RHATR	y = 3.1448x - 2.1292	R2 = 0.9874
Salmo trutta	Brown Trout	SATRU	y = 1.9894x - 0.6302	R2 = 0.326
Semotilus atromaculatus	Creek Chub	SEATR	y = 3.0031x - 1.9344	R2 = 0.9847
Semotilus corporalis	Fallfish	SECOR	y = 2.9238x - 1.8627	R2 = 0.994

APPENDIX C: WET-WEATHER SAMPLING FREQUENCIES

C.1.1. Sampling Times At DCC 770 (7/21/03-7/25/03)



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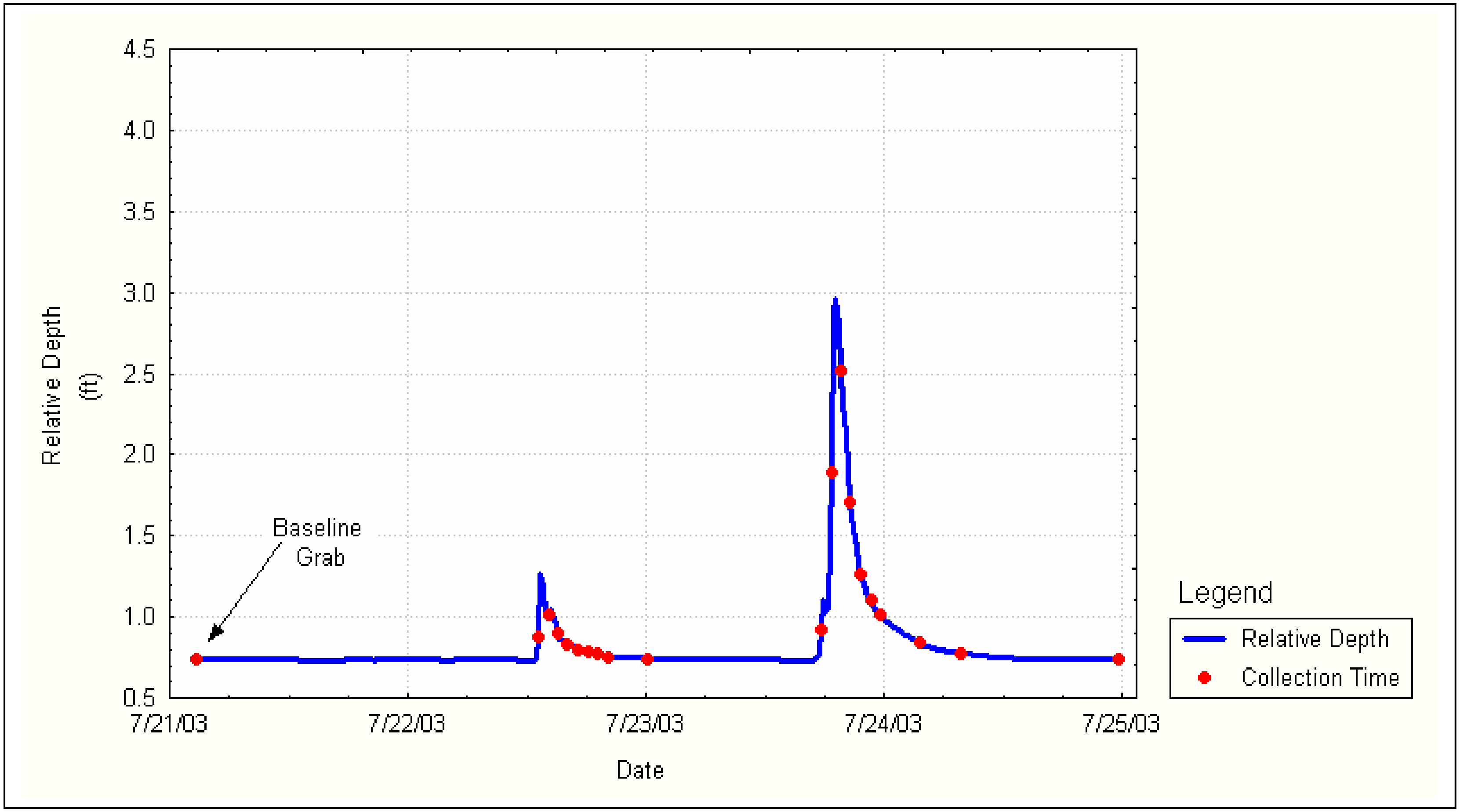

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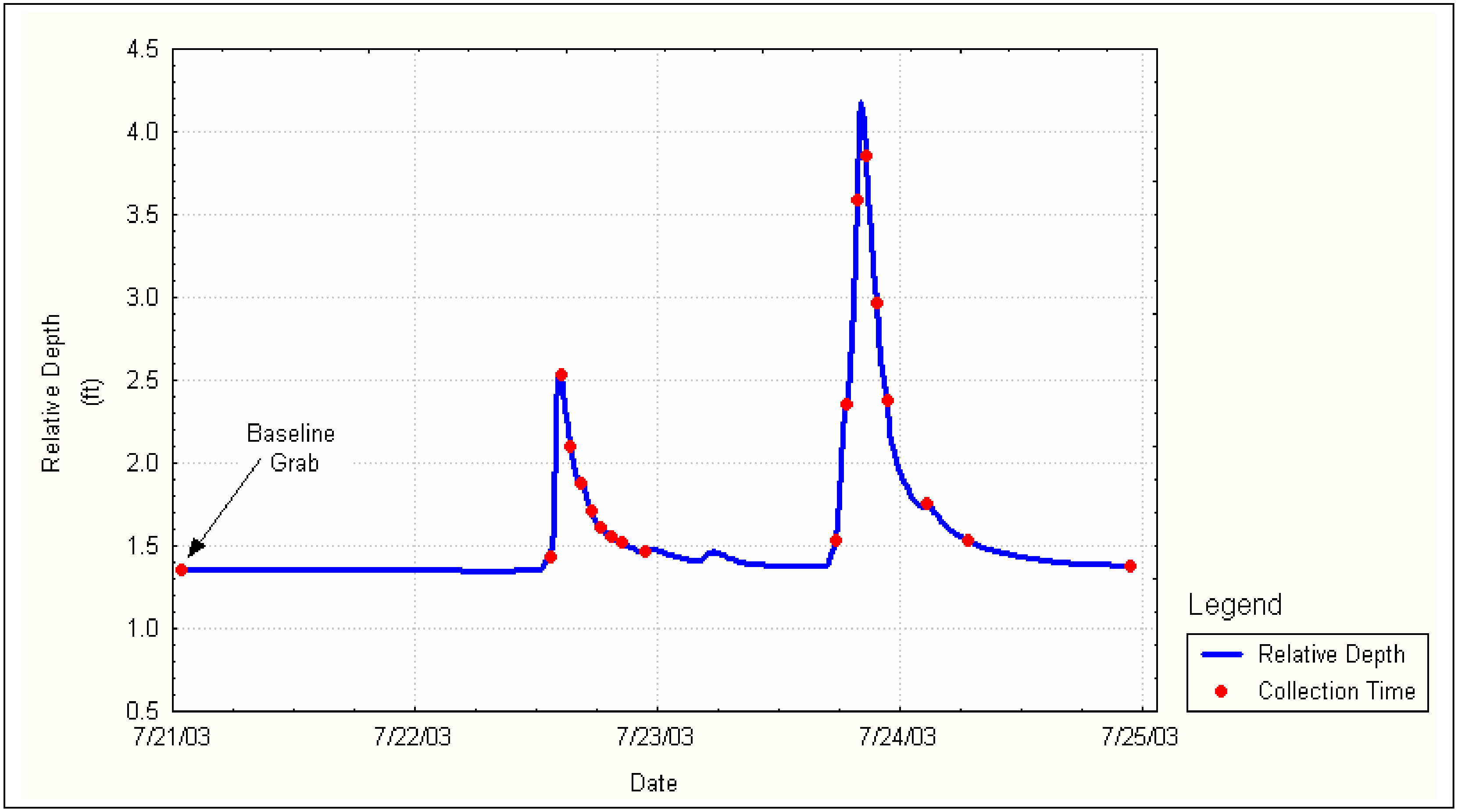

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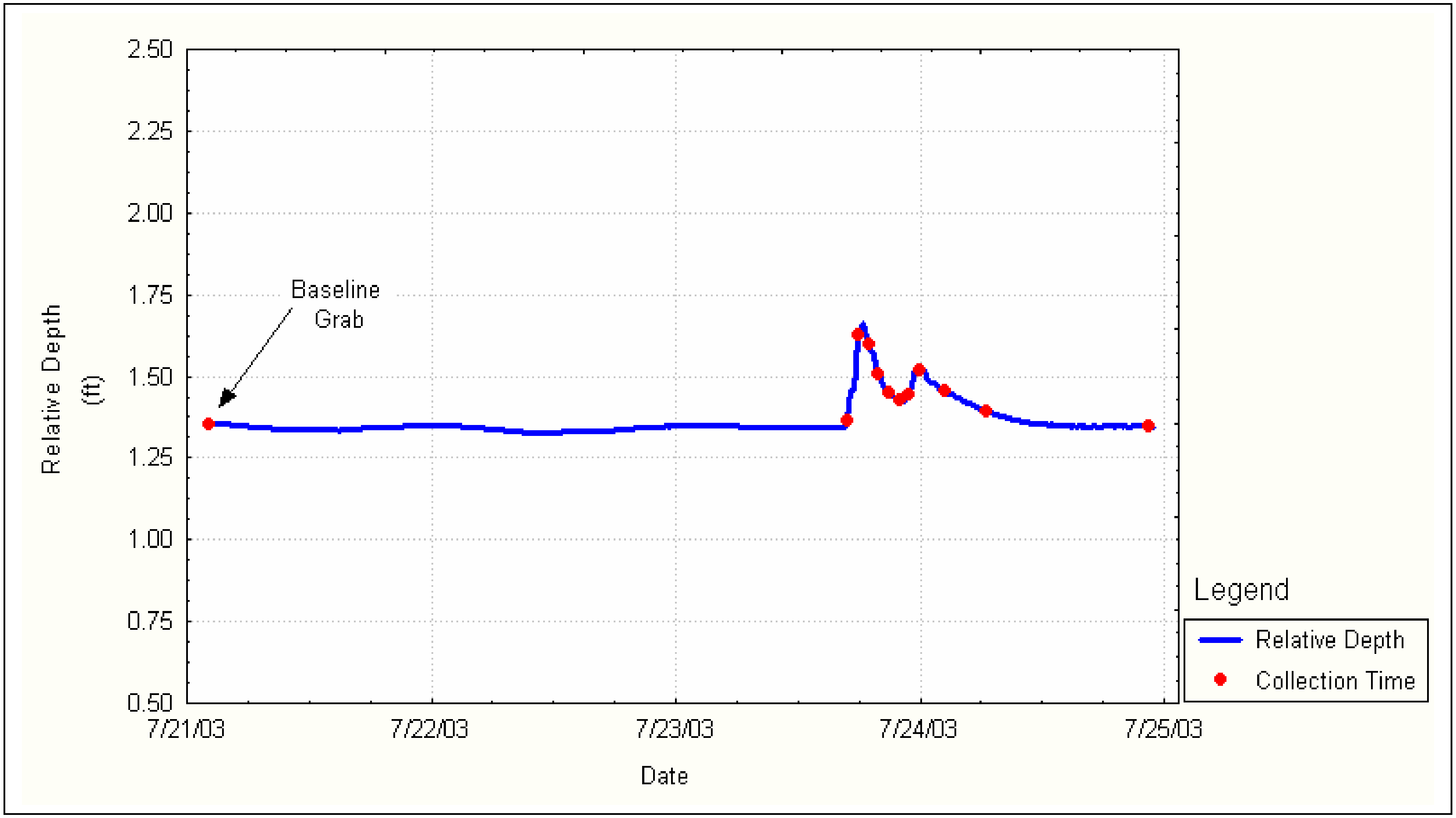

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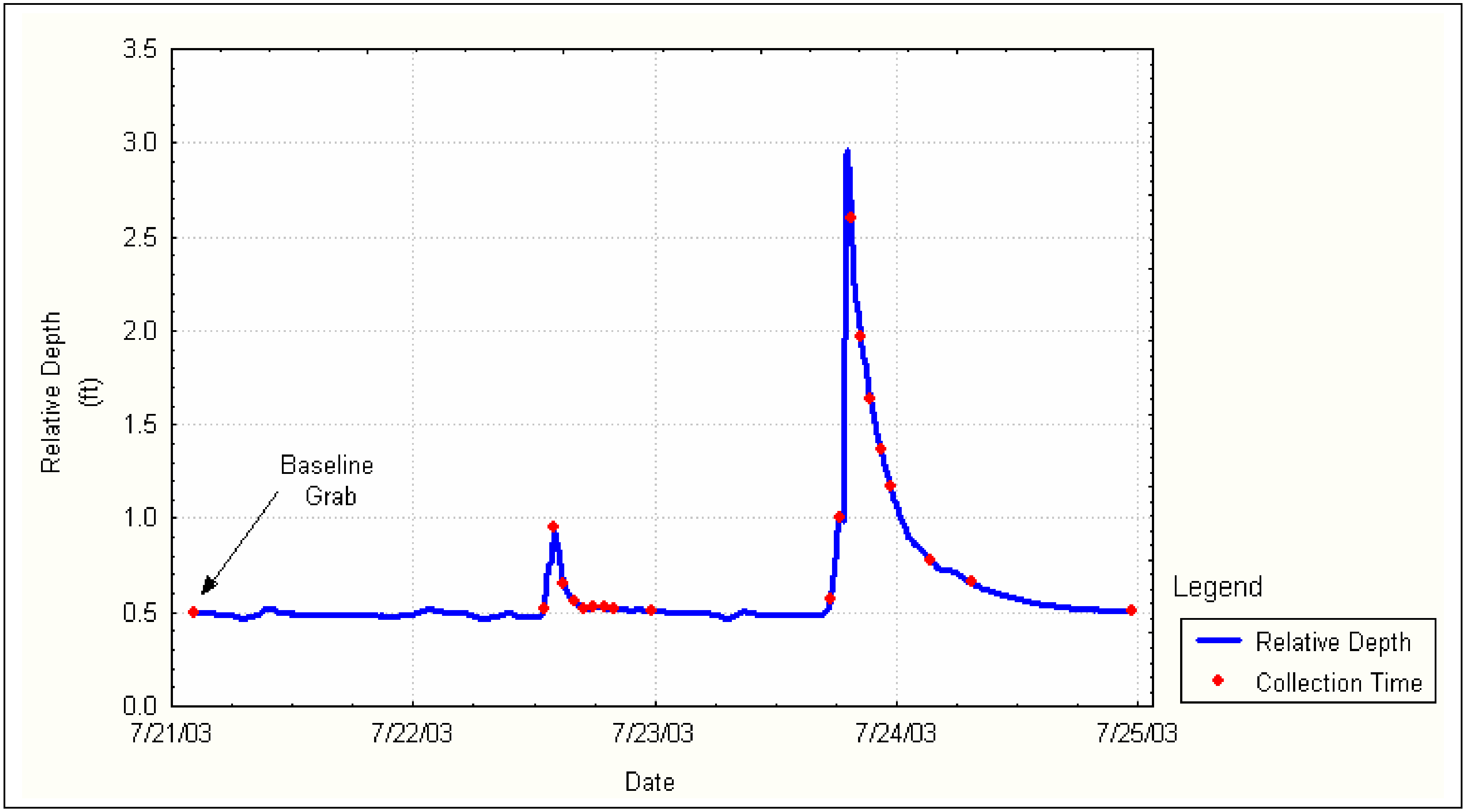
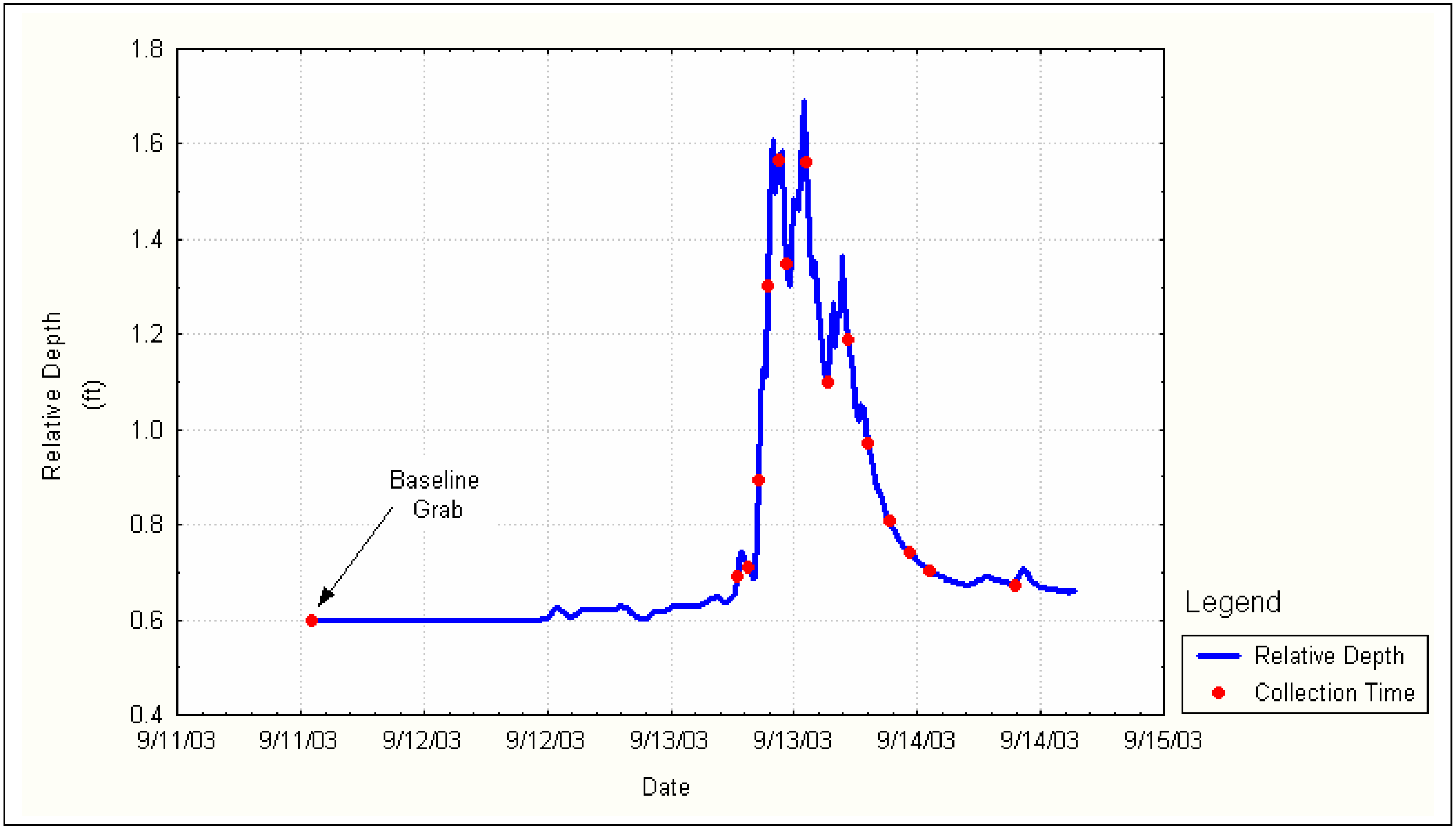


C.2.1. Sampling Times At DCC 770 (9/11/03-9/14/03)



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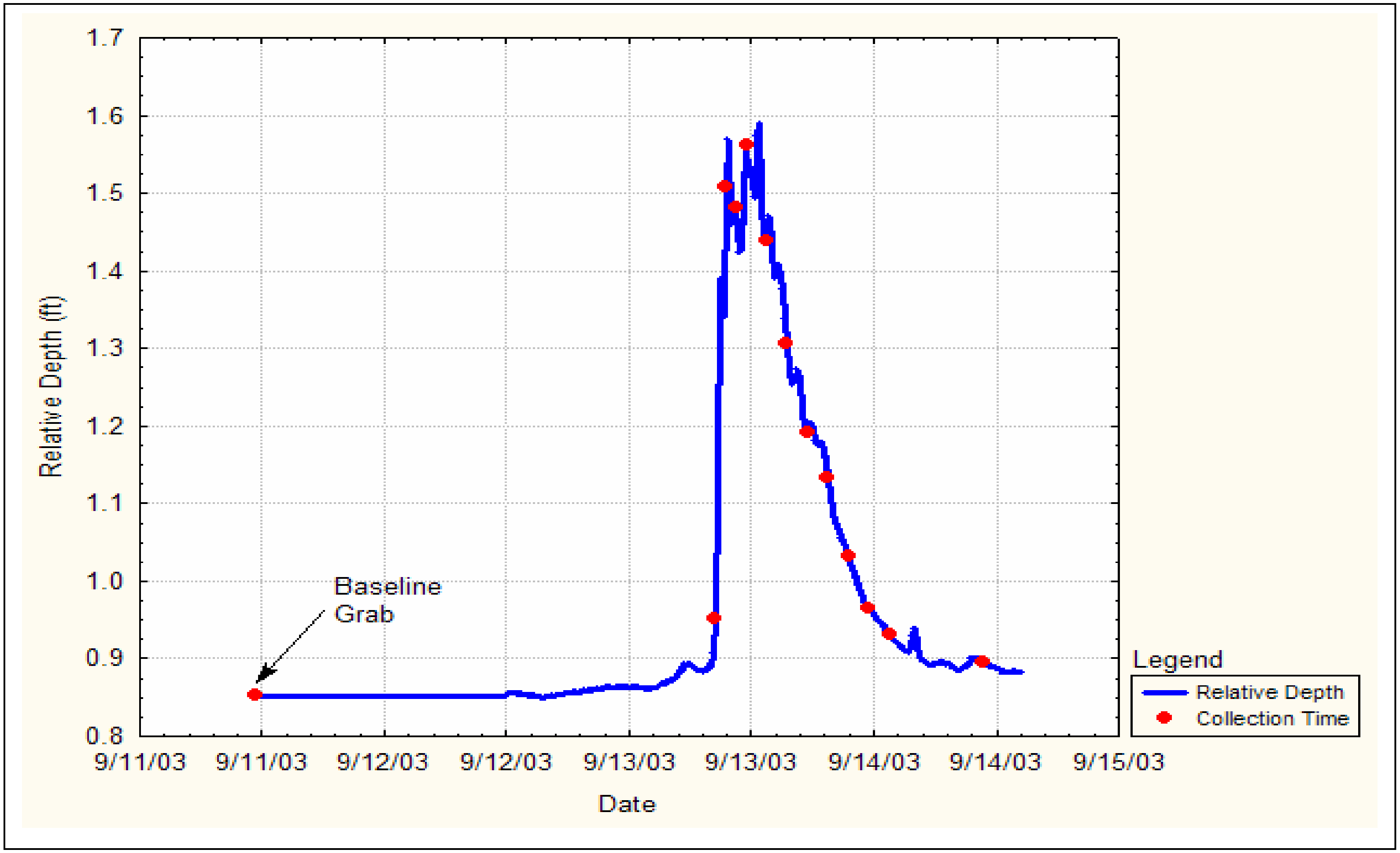

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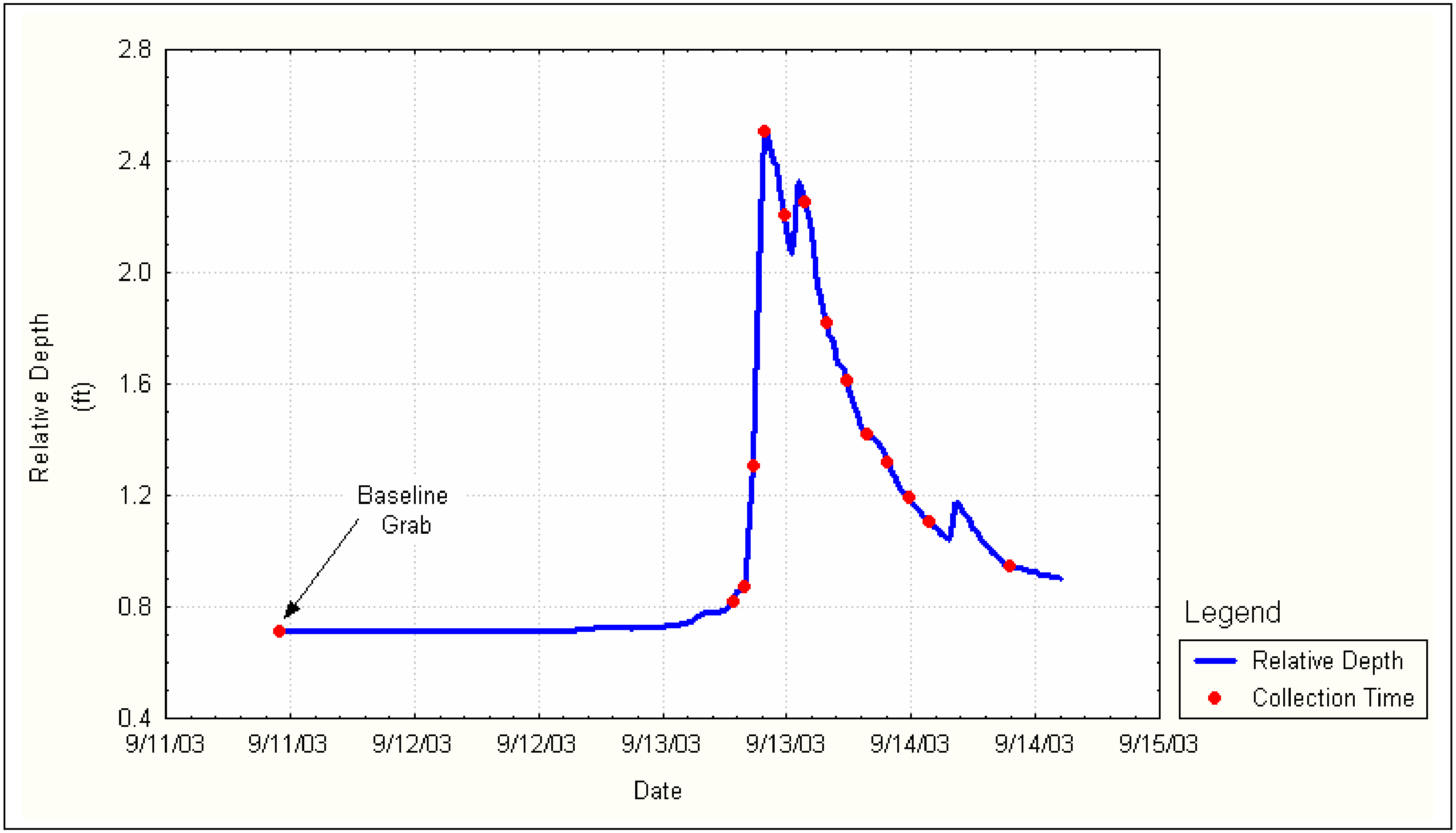

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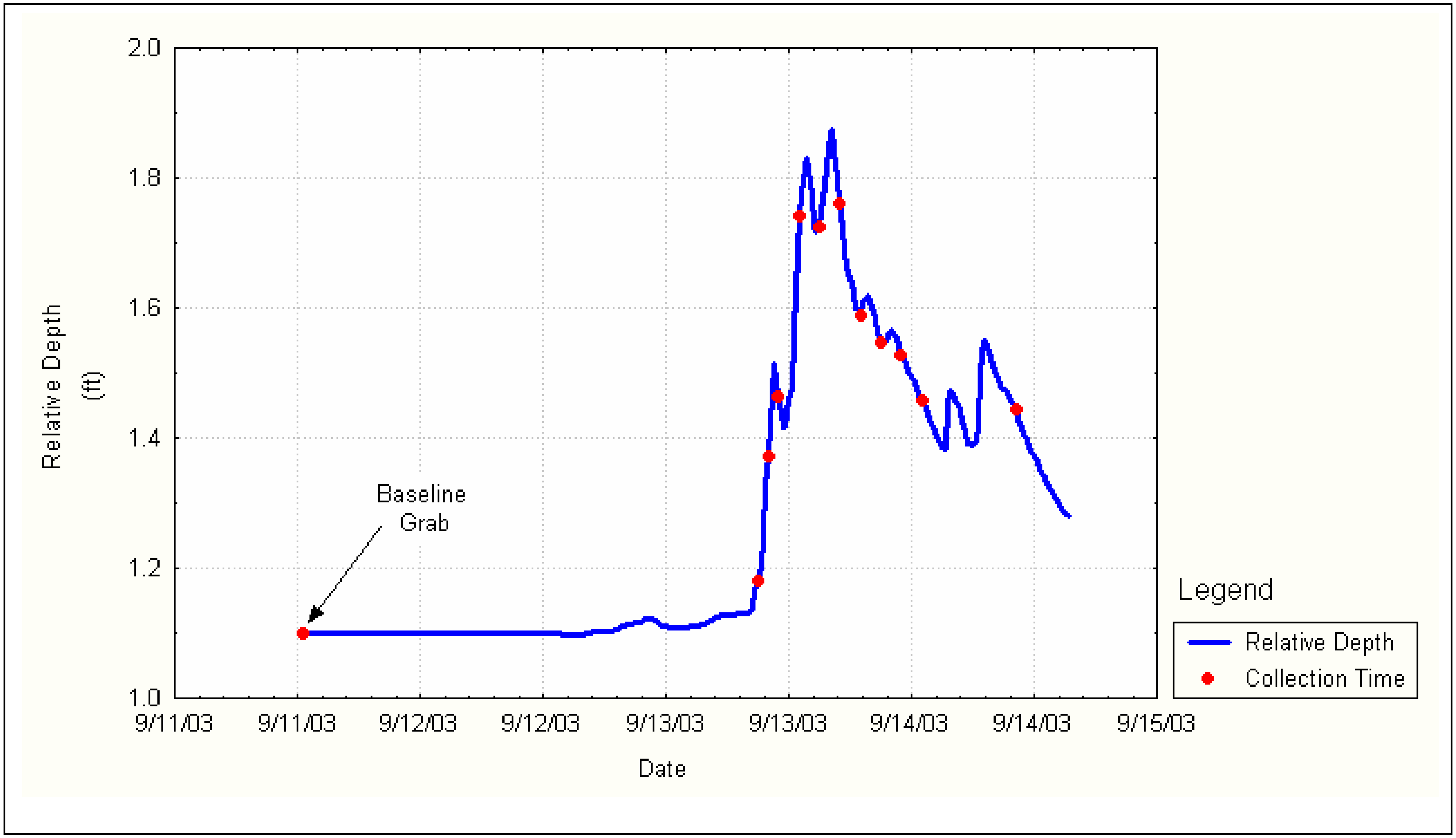
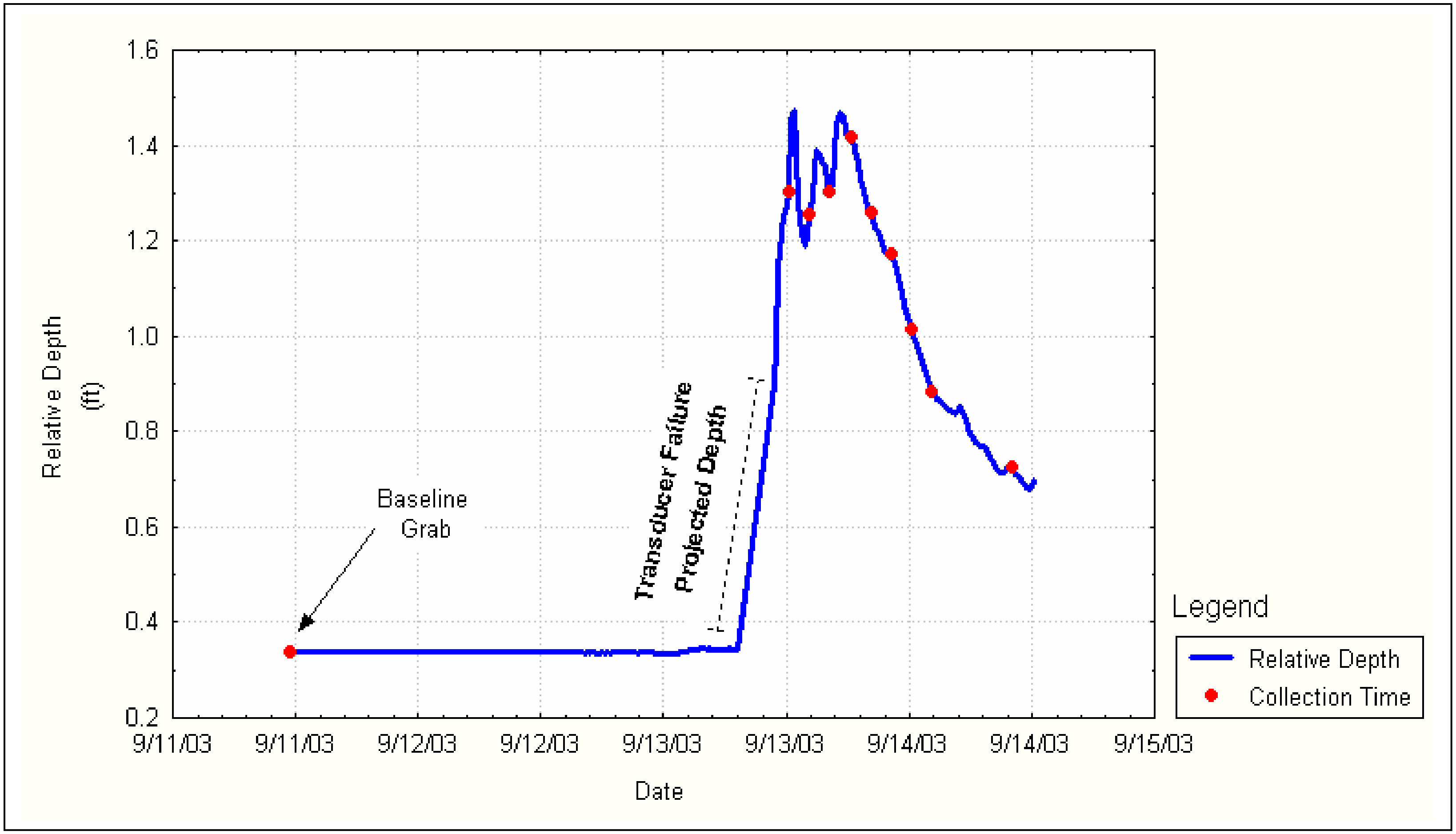


C.2.5. *Sampling Times At DCD 765 (9/11/03-9/14/03)*



APPENDIX D: MASTER LIST OF MACROINVERTEBRATE TAXA COLLECTED IN DARBY-COBBS WATERSHED

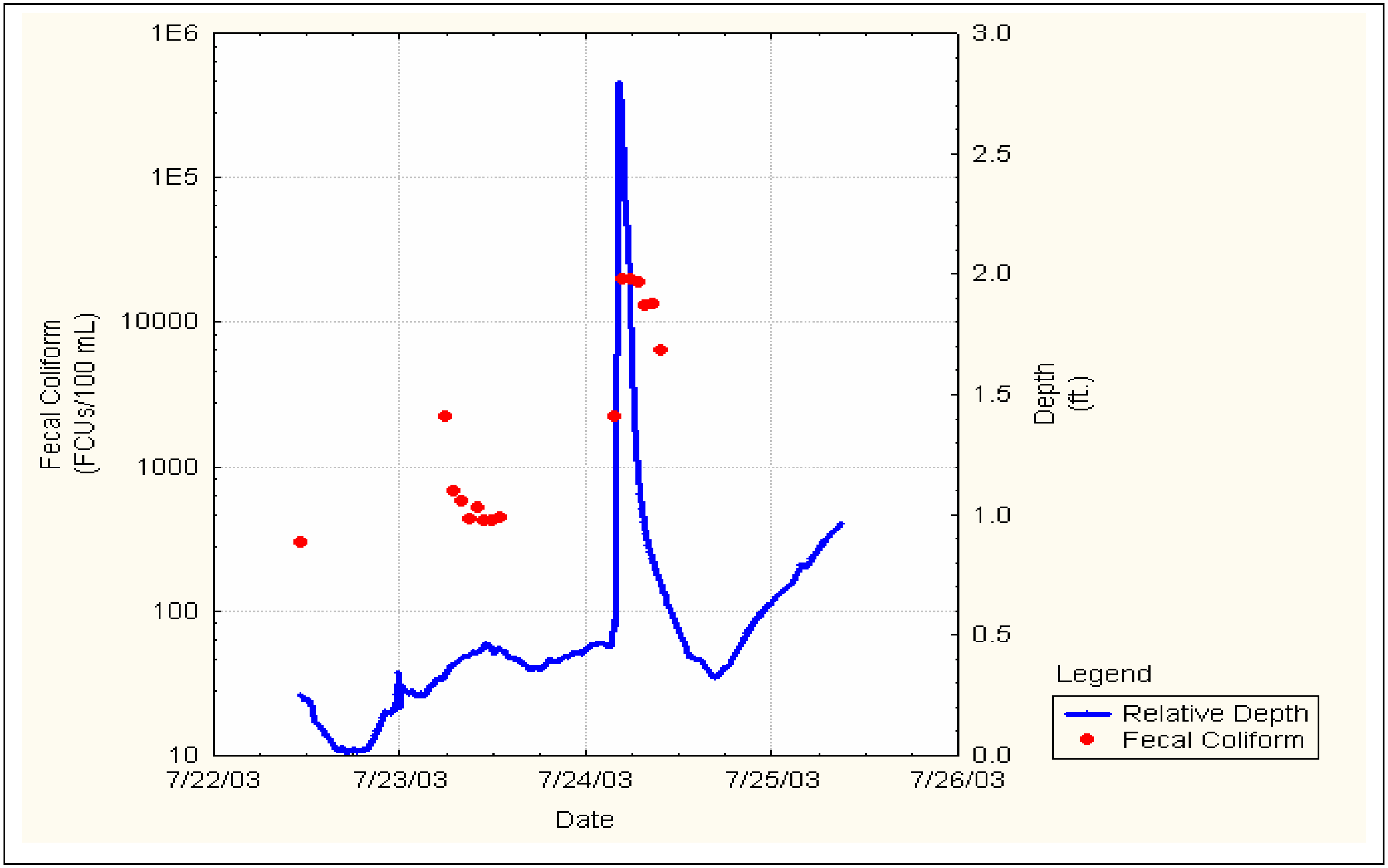
Family	**Genus**
Aeshnidae	*Boyeria*
Ancylidae	*sp.*
Asellidae	*Caecidotea*
Baetidae	*Baetis*
Cambaridae	*sp.*
Chironomidae	*sp.*
Coenagrionidae	*Argia*
Corbiculidae	*Corbicula*
Crangonyctidae	*Crangonyx*
Elmidae	*Macronychus*
Elmidae	*Optioservus*
Elmidae	*Stenelmis*
Epididae	*Hemerodromia*
Erpobdellidae	*sp.*
Gammaridae	*Gammarus*
Glossosomatidae	*Glossosoma*
Gomphidae	*Progomphus*
Helicopsychidae	*Helicopsyche*
Heptageniidae	*Stenacron*
Hydropsychidae	*Hydropsyche*
Hydropsychidae	*Cheumatopsyche*
Hydroptilidae	*Ochrotrichia*
Hydroptilidae	*Agraylea*
Lumbriculidae	*sp.*
Lymnaeidae	*sp.*
Muscidae	*sp.*
Nemouridae	*Prostoia*
Oxidae	*Oxus*
Perlidae	*Acroneuria*
Philopotamidae	*Chimarra*
Physidae	*sp.*
Planariidae	*Cura*
Planorbidae	*sp.*
Polycentropodidae	*Nyctiophylax*
Psephenidae	*Psephenus*
Simuliidae	*Simulium*
Simuliidae	*Prosimulium*
Tipulidae	*Antocha*
Tipulidae	*Tipula*
Tubificidae	*sp.*

APPENDIX E. PRINCIPAL COMPONENTS ANALYSIS (PCA) FACTOR LOADING SCORES

Habitat Variable	Factor 1	Factor 2
Bank Stability	0.624644334	0.534454383
Channel Alteration	0.68519826	-0.613778676
Channel Flow Status	0.887283517	-0.154711094
Channel Sinuosity	0.646498442	-0.162836359
Embeddedness	0.676814129	0.59480918
Epifaunal Substrate /Cover	0.928540686	-0.163641469
Riffle Frequency	0.478714469	0.628922847
Pool Substrate	0.884876311	0.098273276
Pool Variability	0.828192386	-0.473655723
Riparian Zone Width	0.108106765	-0.607800328
Sedimentation	0.664596427	0.606005429
Vegetative Protection	0.765062404	-0.022199009
Velocity/Depth Regime	0.914921054	-0.259234876
Variance Explained	**6.959027402**	**2.527304108**
Proportional Total Variance	**0.5353098**	**0.194408008**

APPENDIX F: WET-WEATHER FECAL COLIFORM CONCENTRATIONS

F.1.1. Fecal Coliform Concentrations At DCC 770 (7/21/03-7/25/03)



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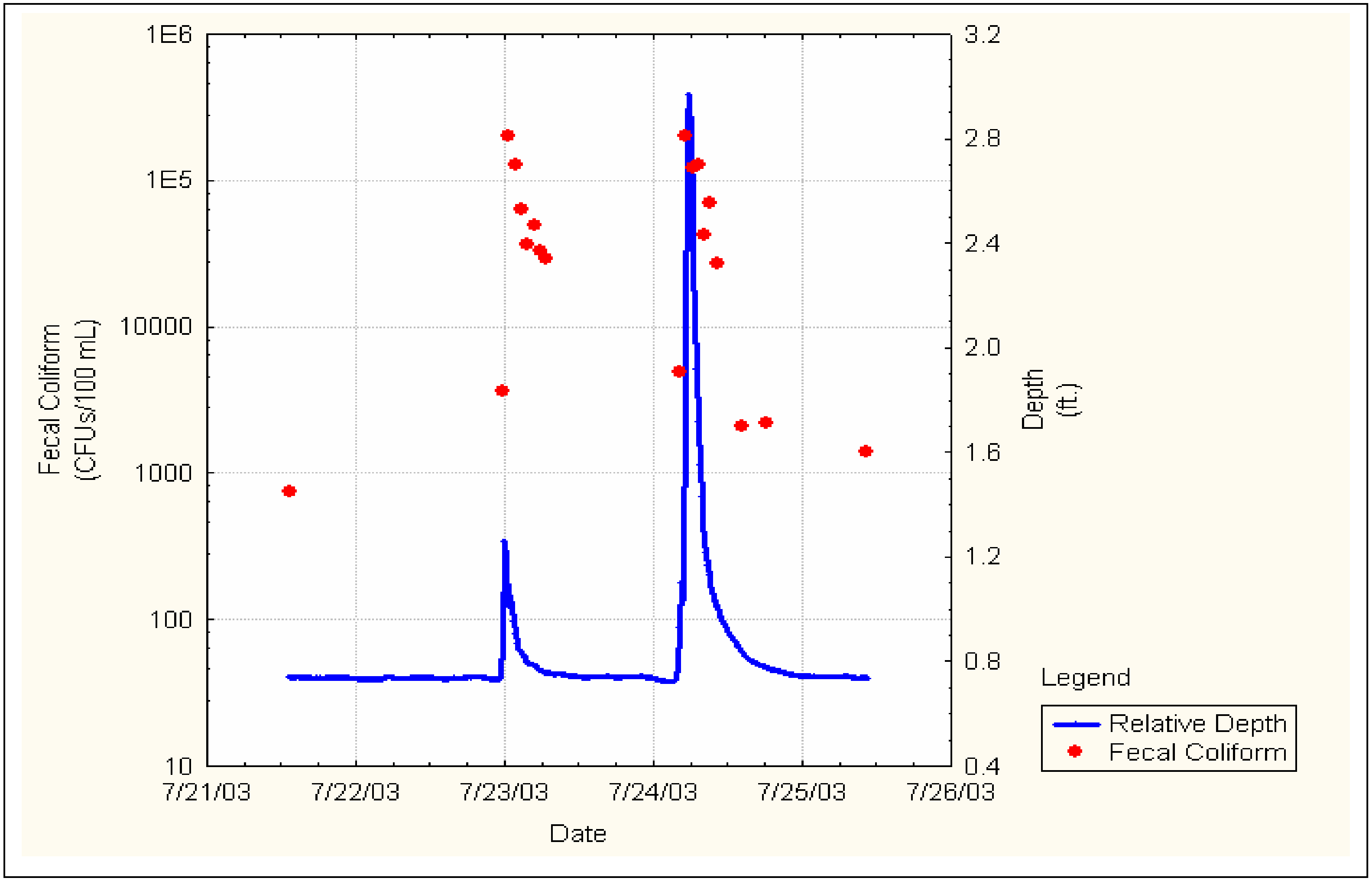

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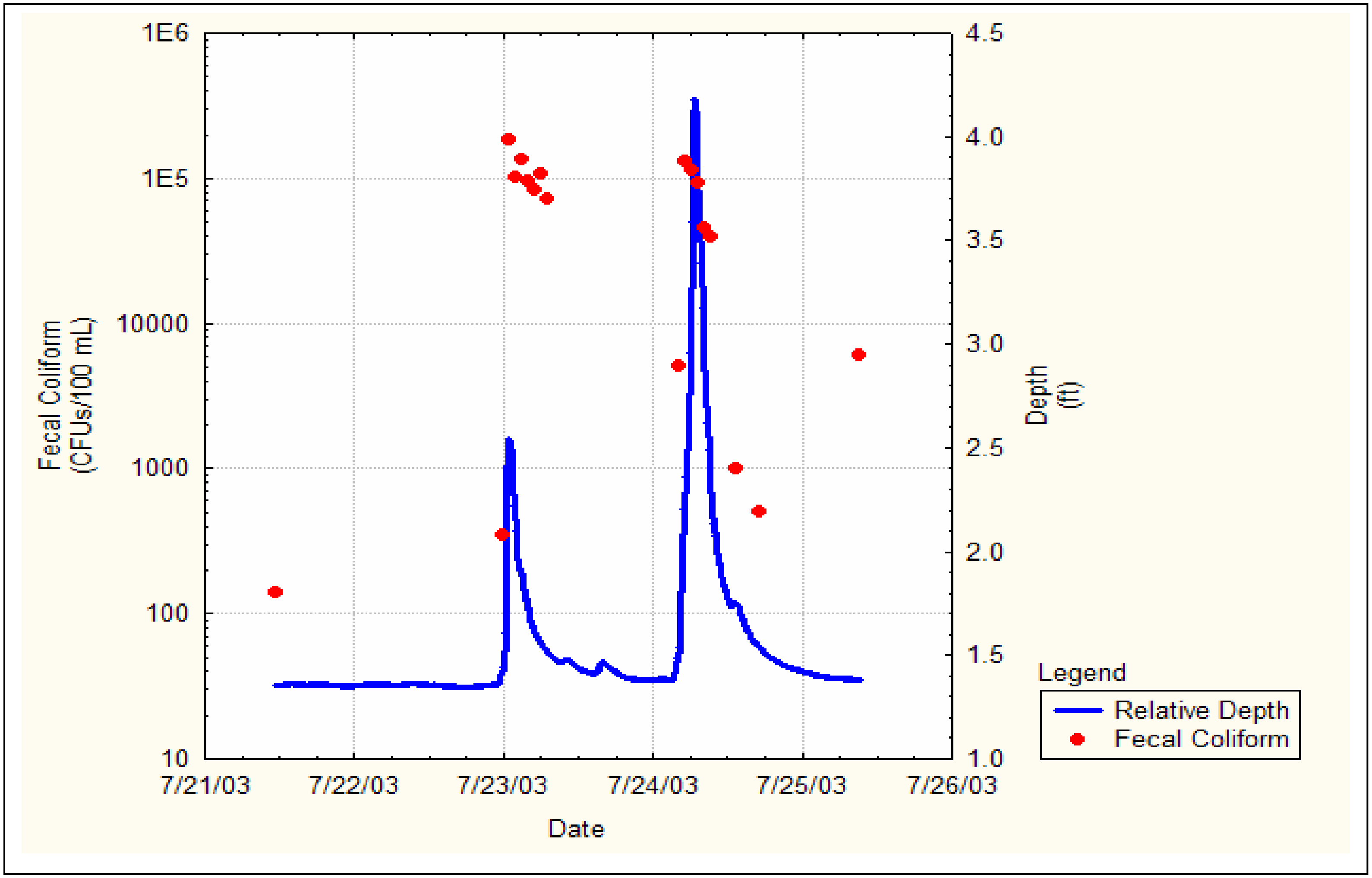

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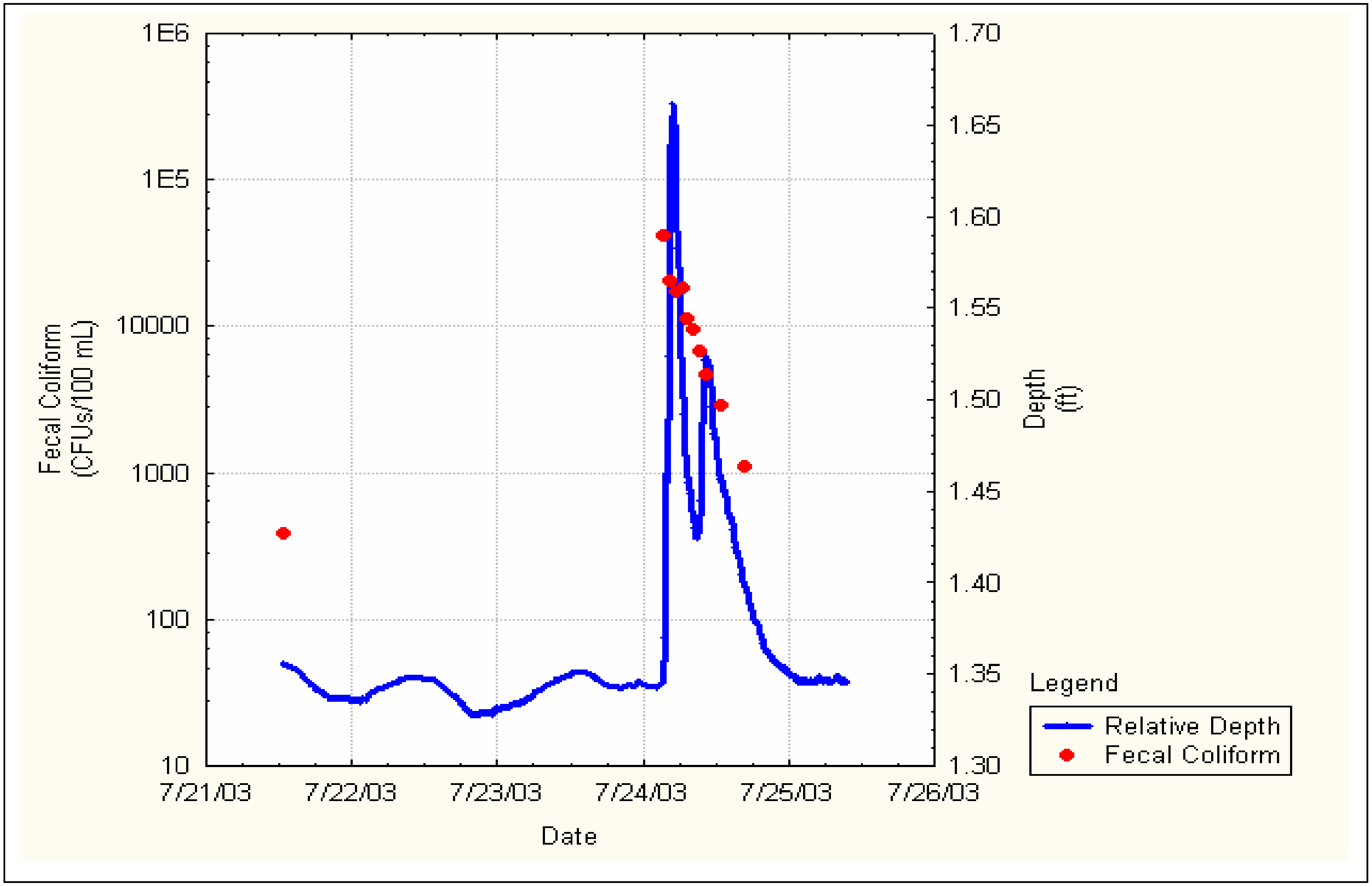
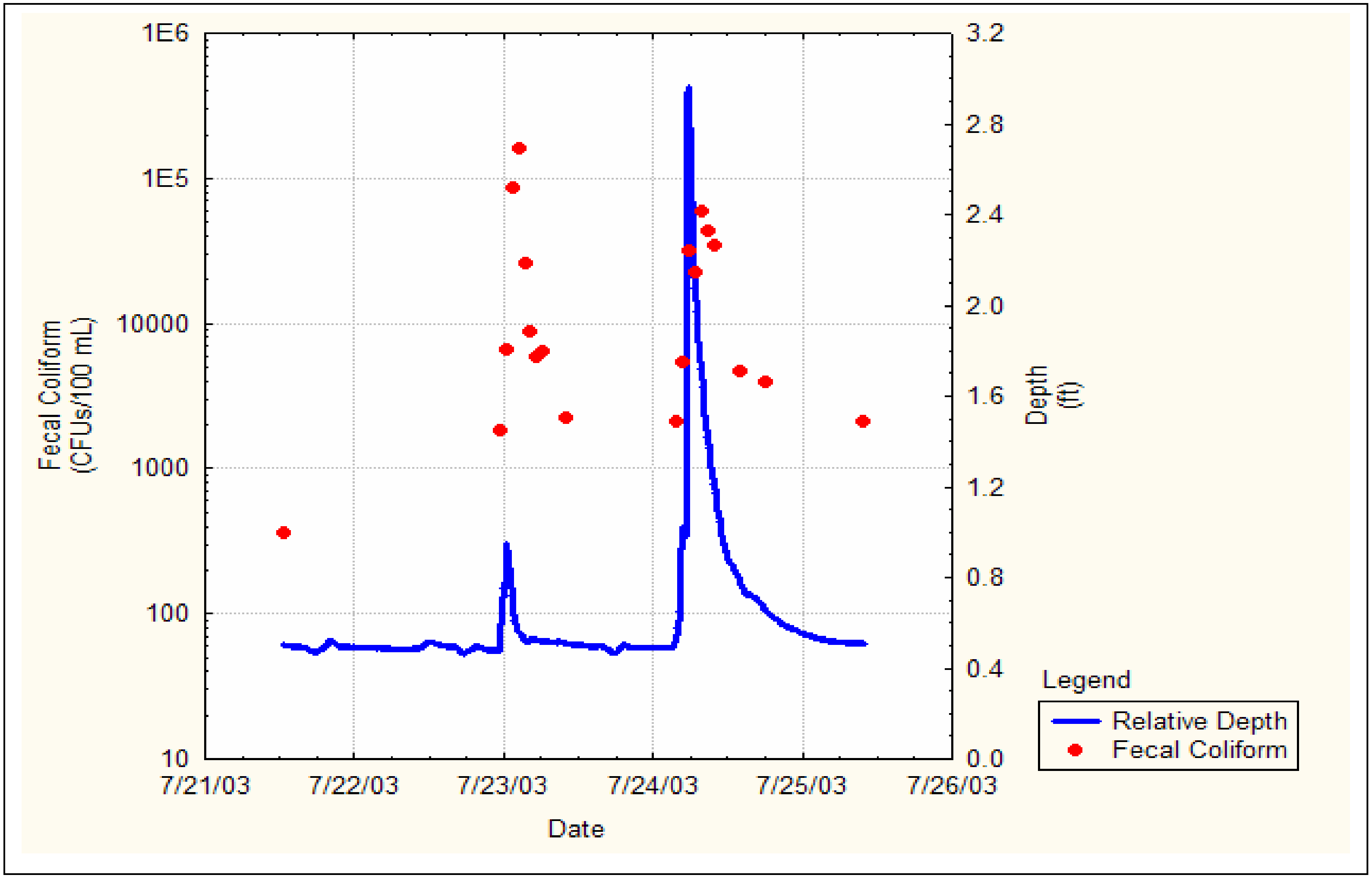


F.1.5. Fecal Coliform Concentrations At DCC 765 (7/21/03-7/25/03)



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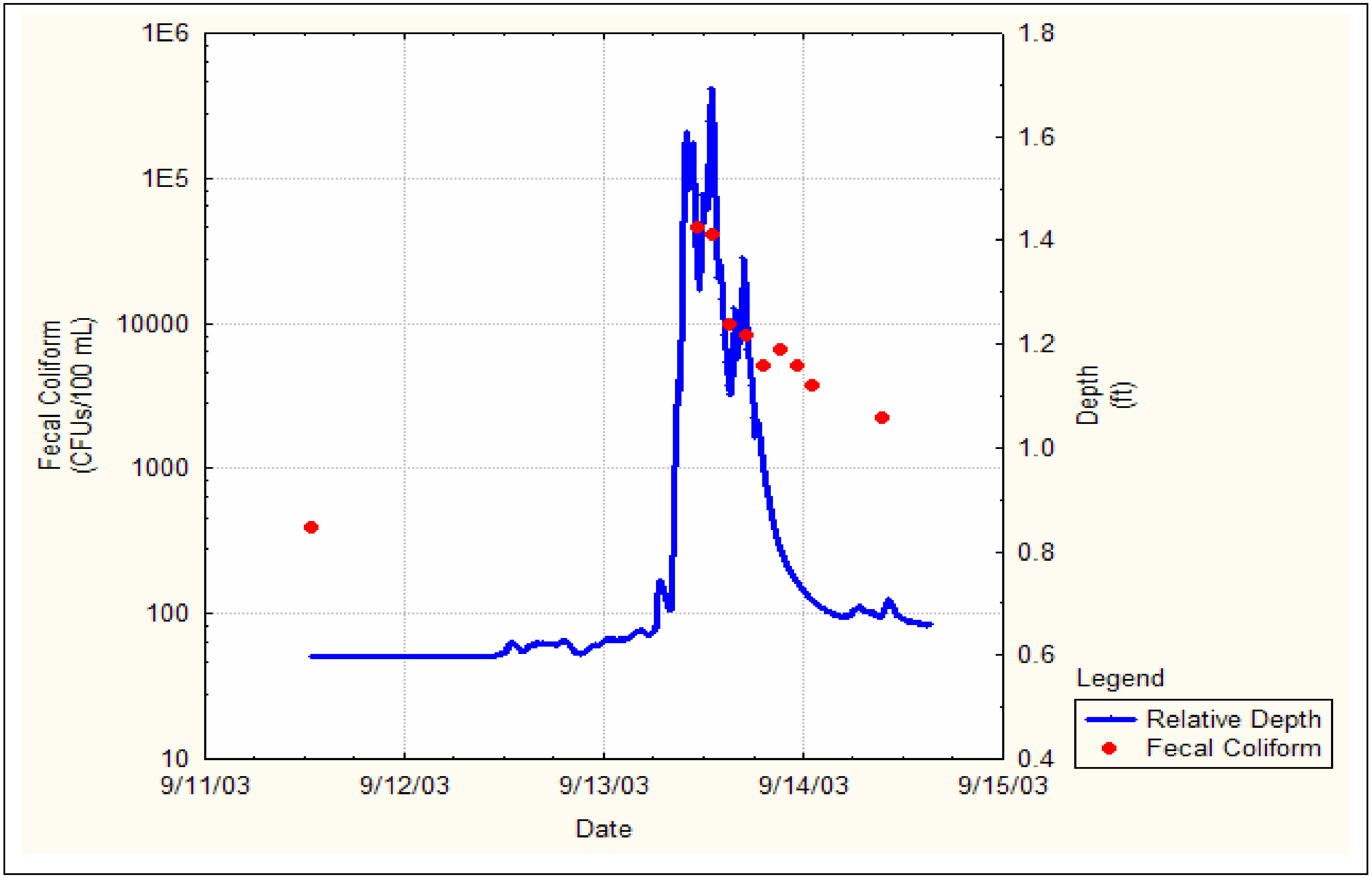

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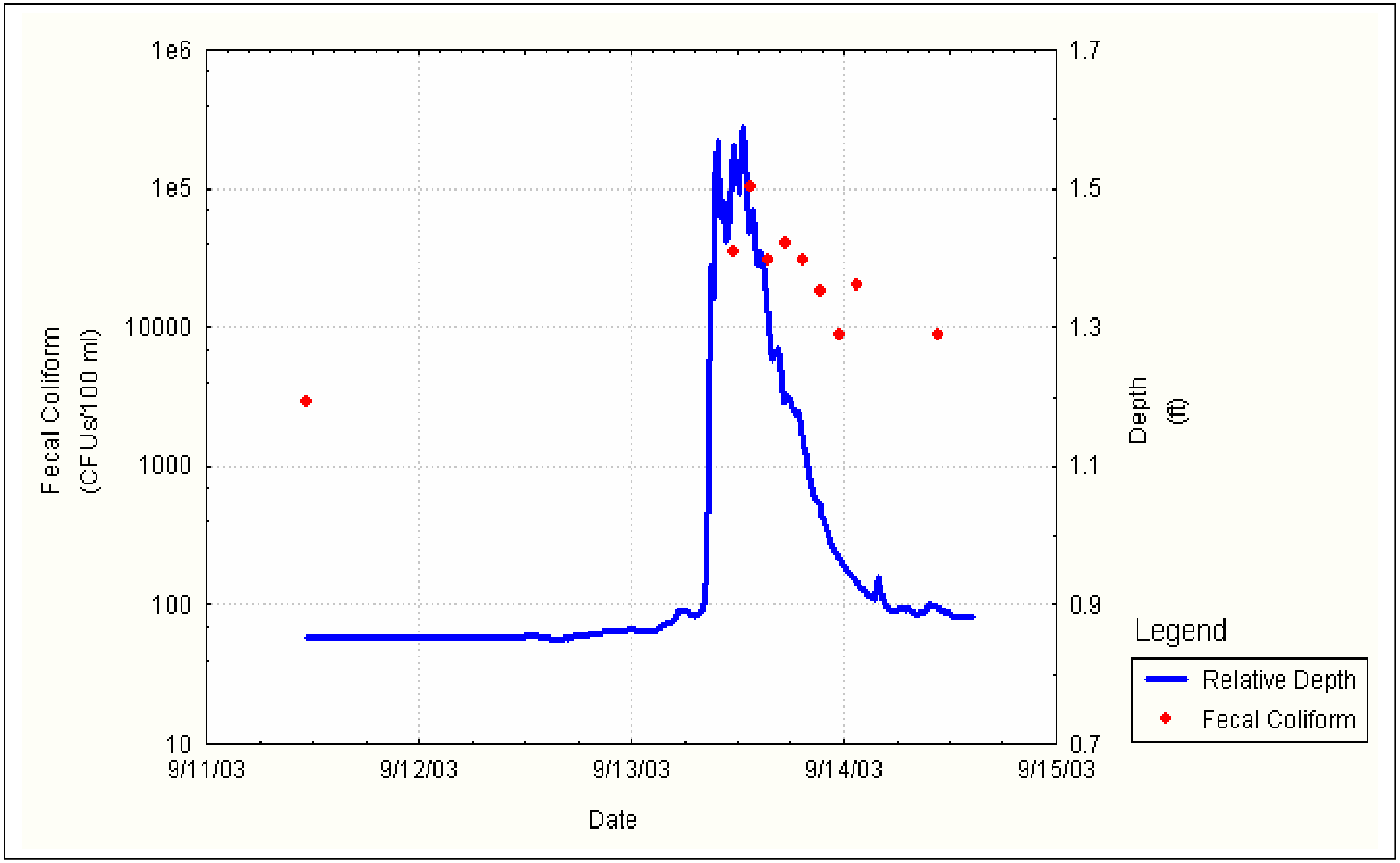

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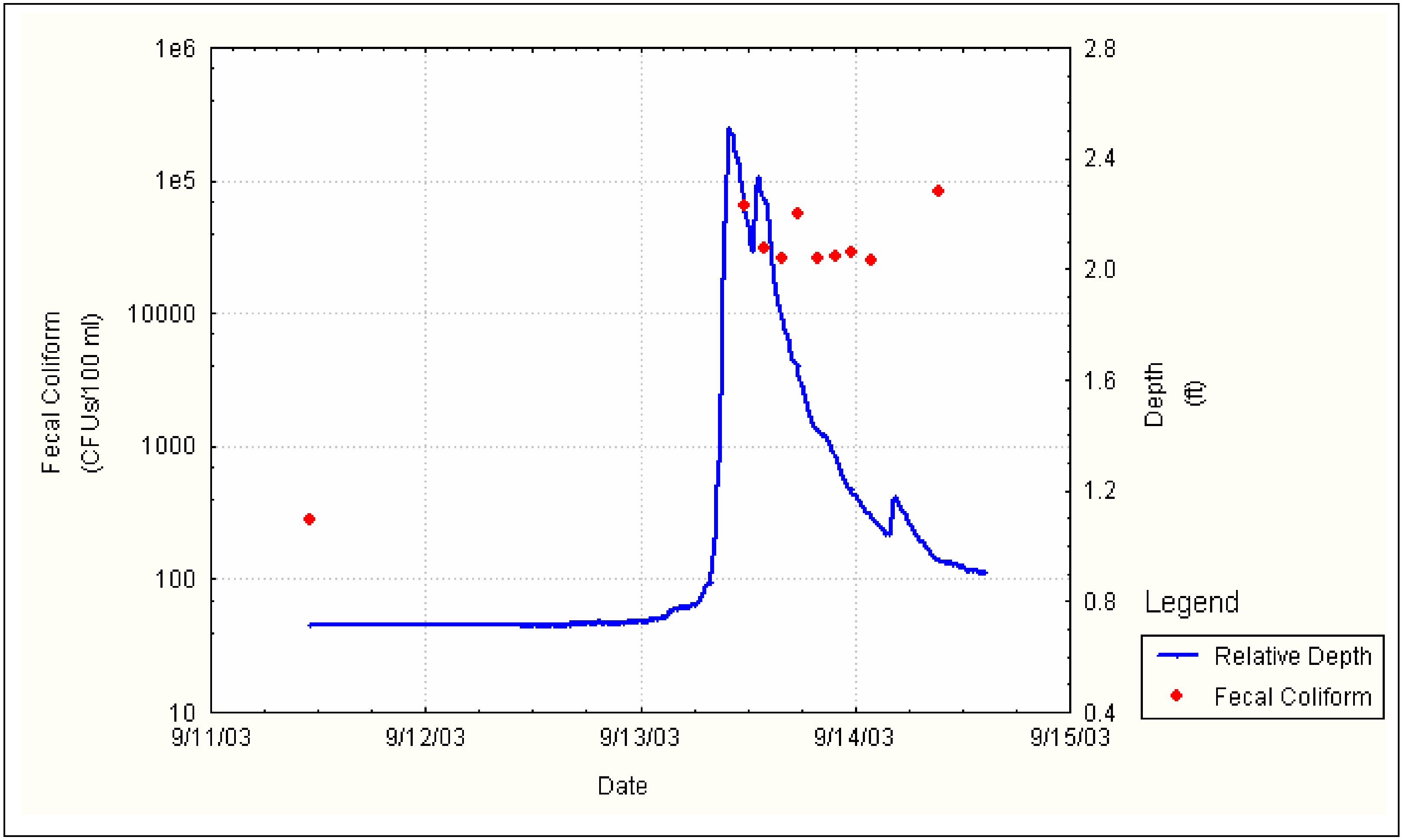

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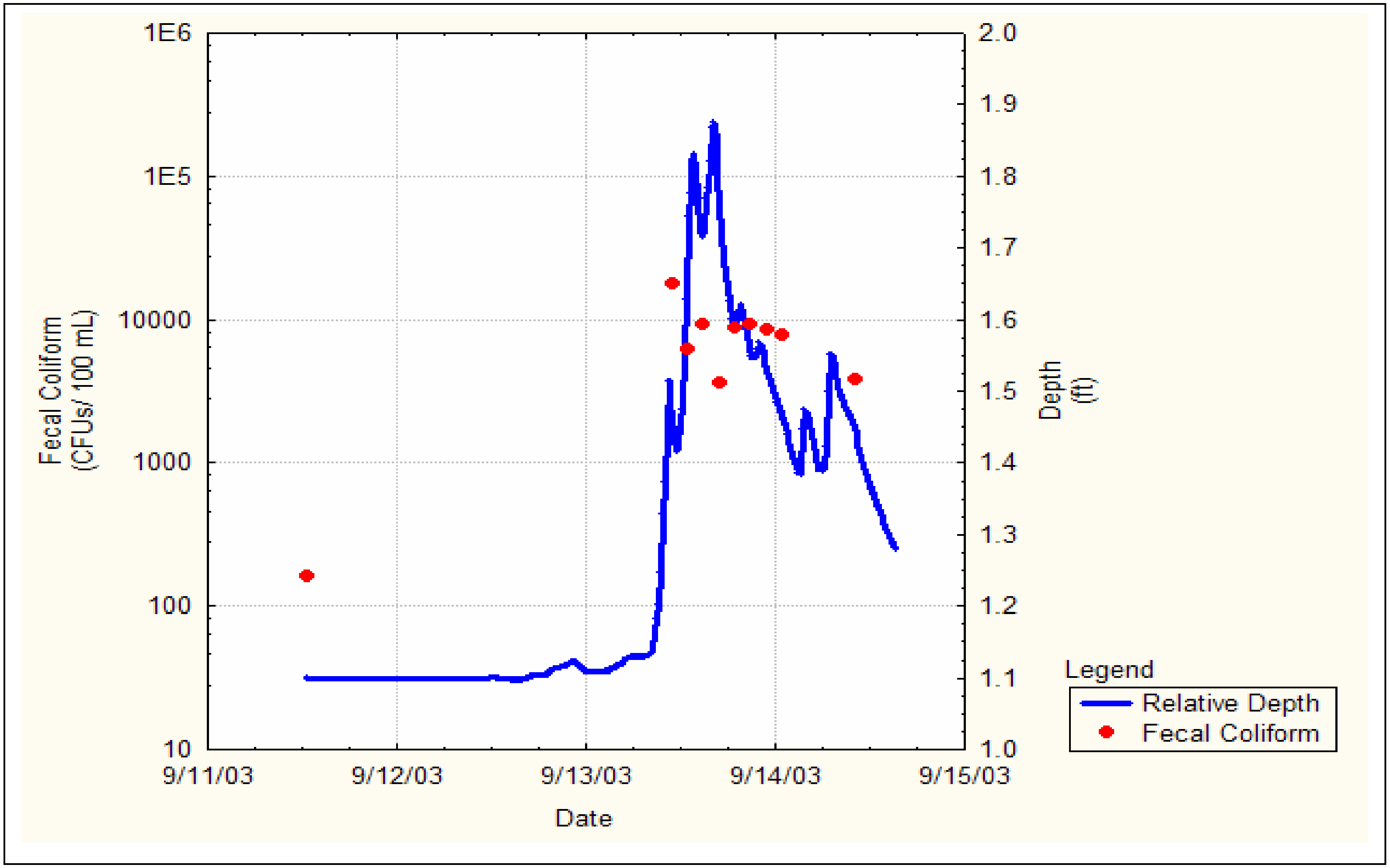

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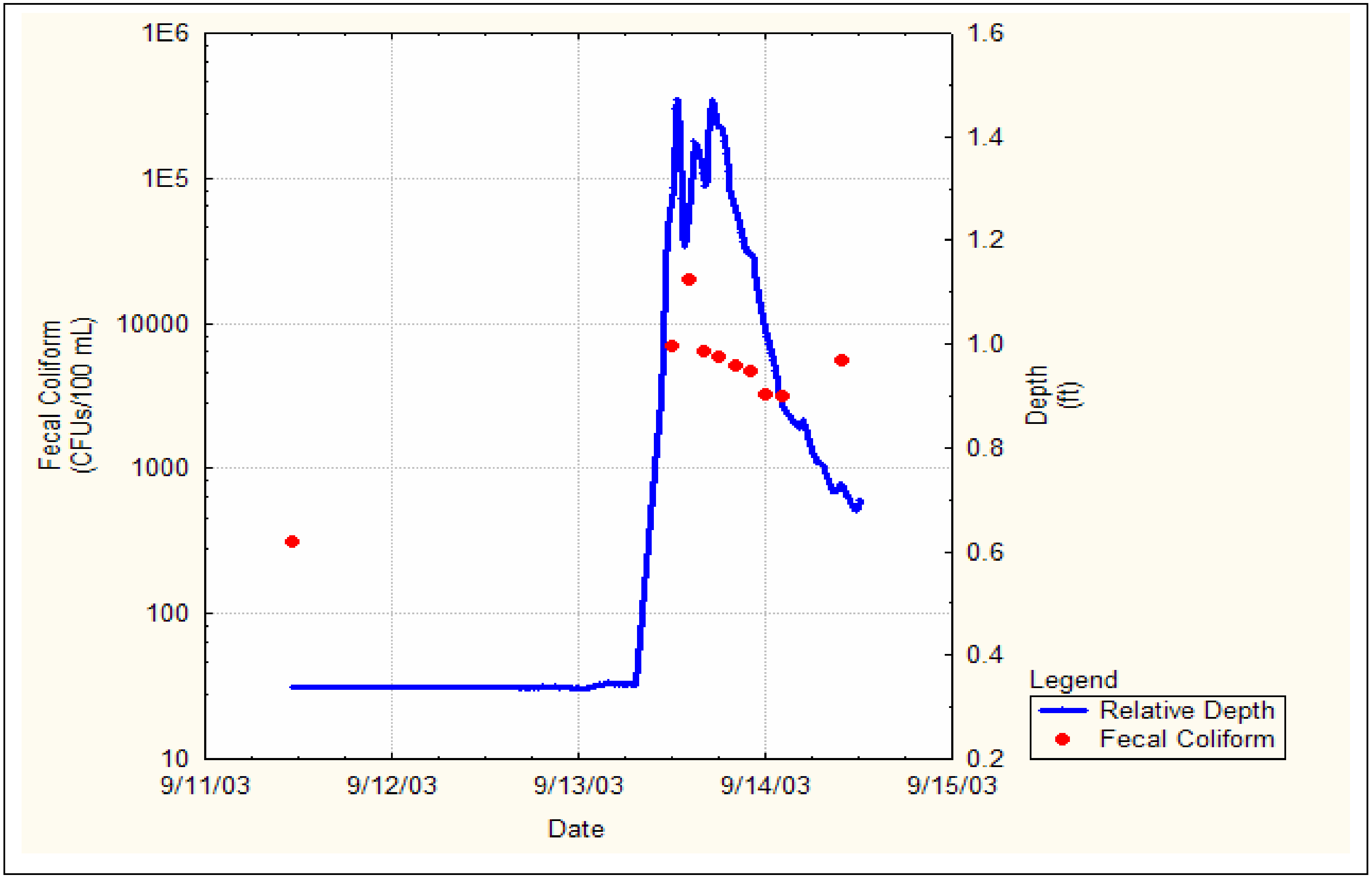
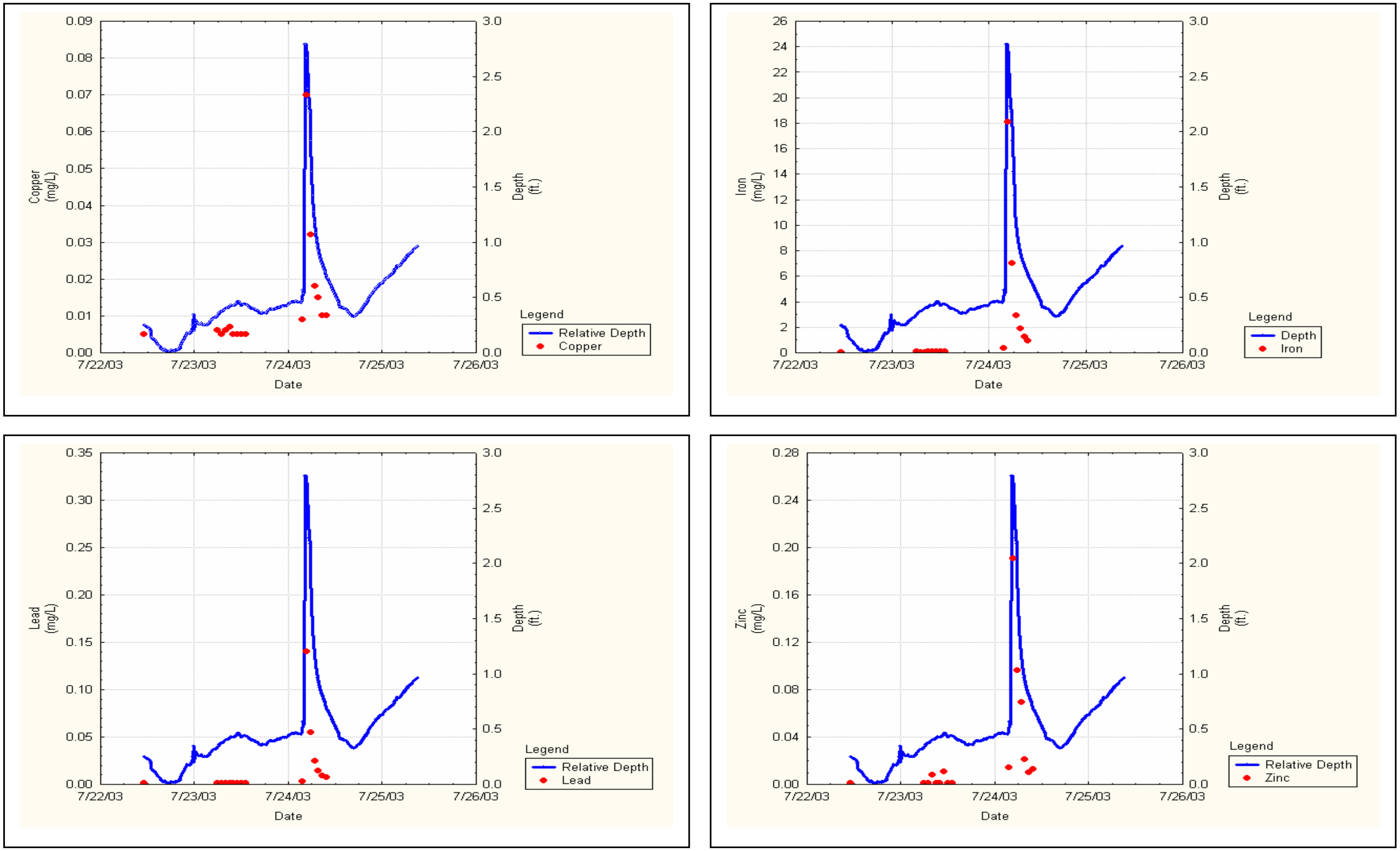
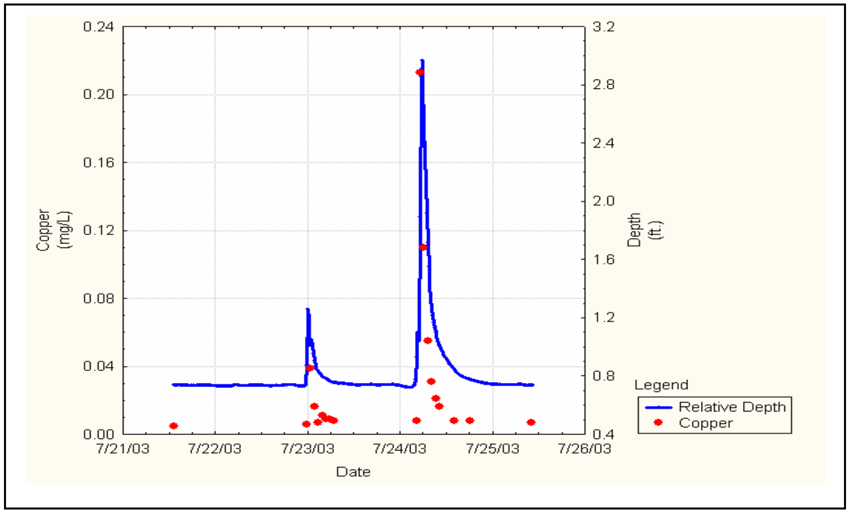


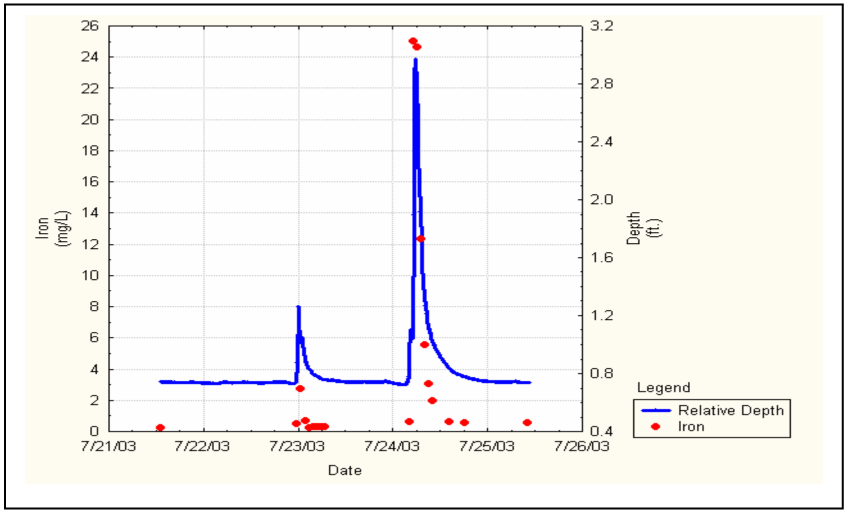
APPENDIX G. WET WEATHER METAL CONCENTRATIONS OF SAMPLES COLLECTED DURING STORM EVENTS

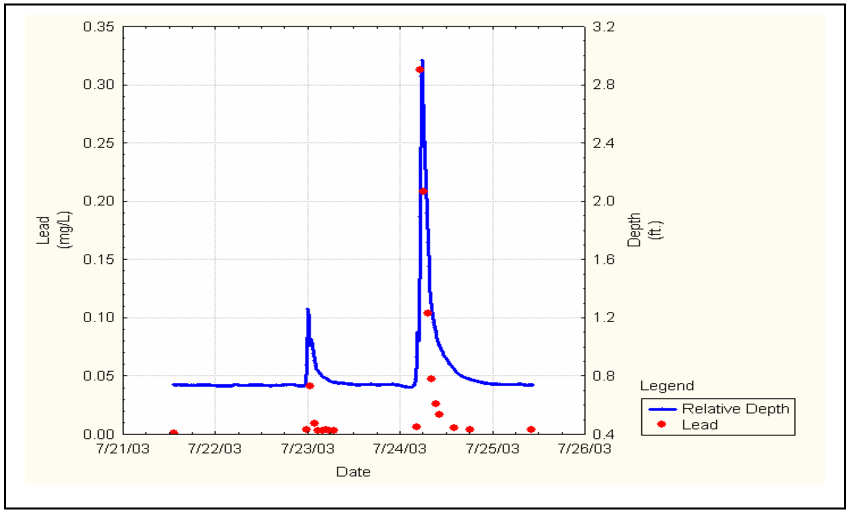
G.1.1. Metal Concentrations At DCC 770 (7/21/03-7/25/03)

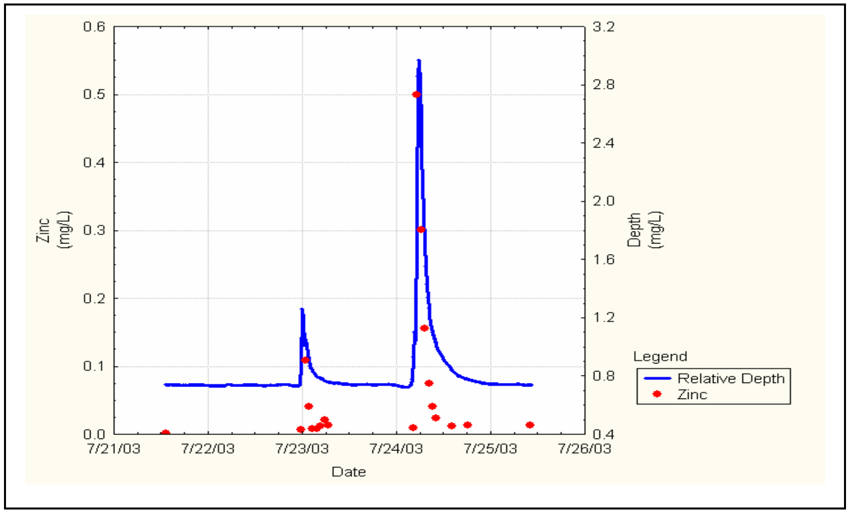


G.1.2. *Metal Concentrations At DCC 455 (7/21/03-7/25/03)*

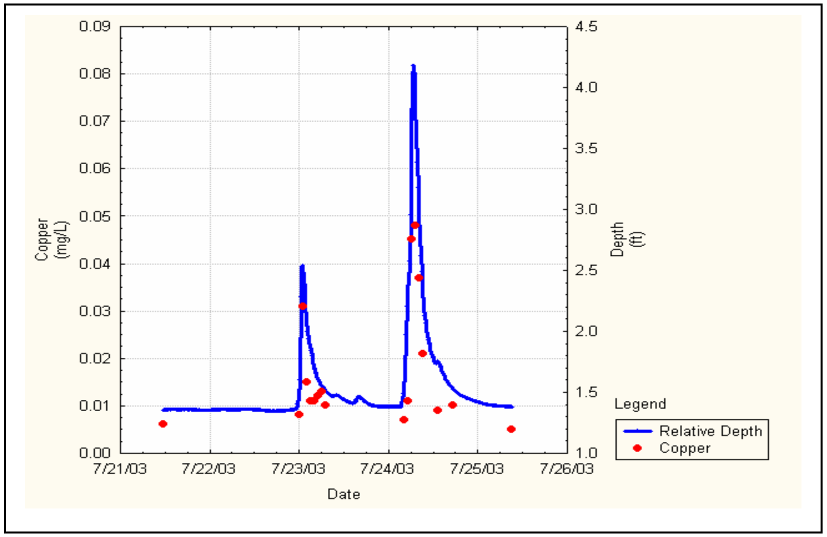


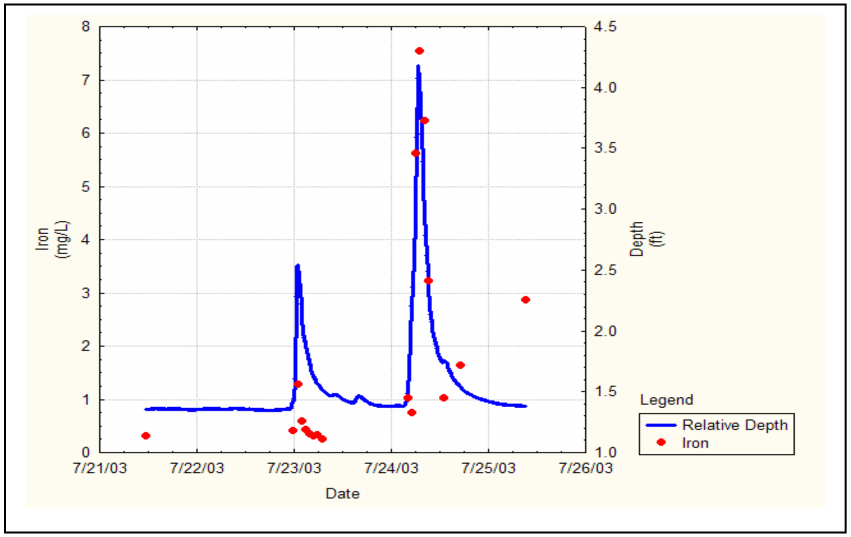


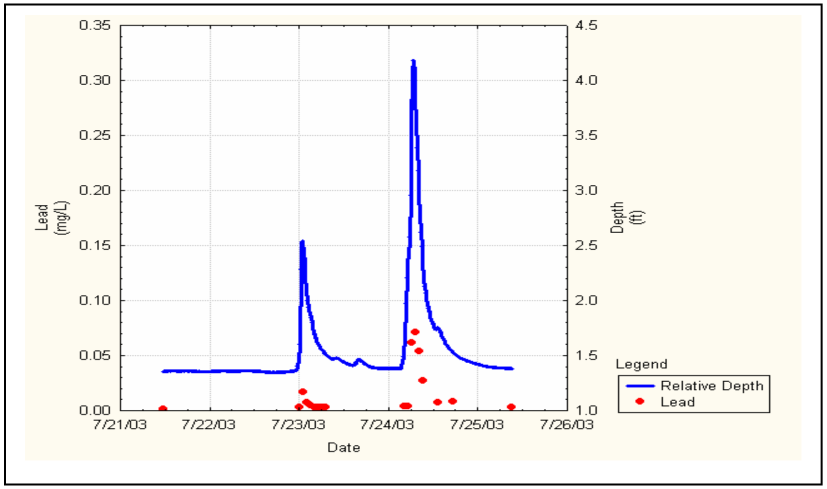


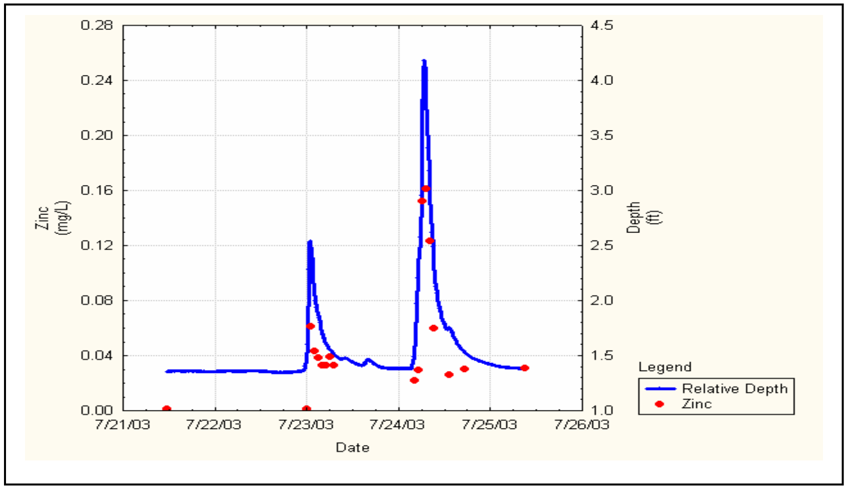


G.1.3. Metal Concentrations At DCC 208 (7/21/03-7/25/03)

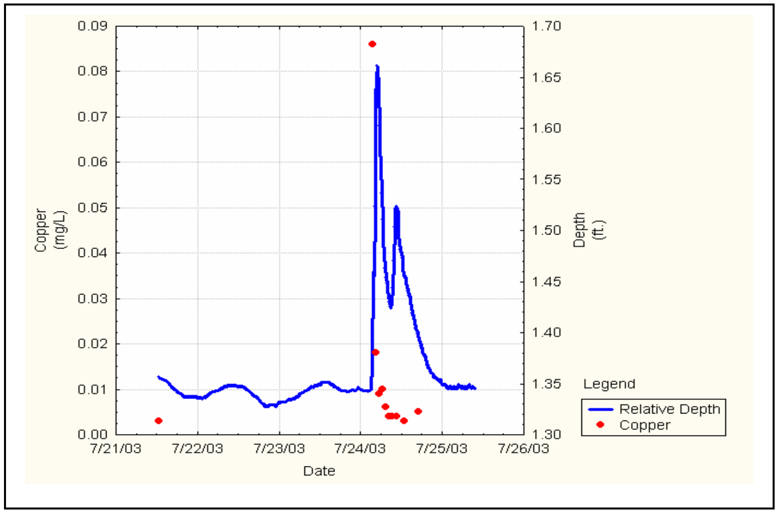


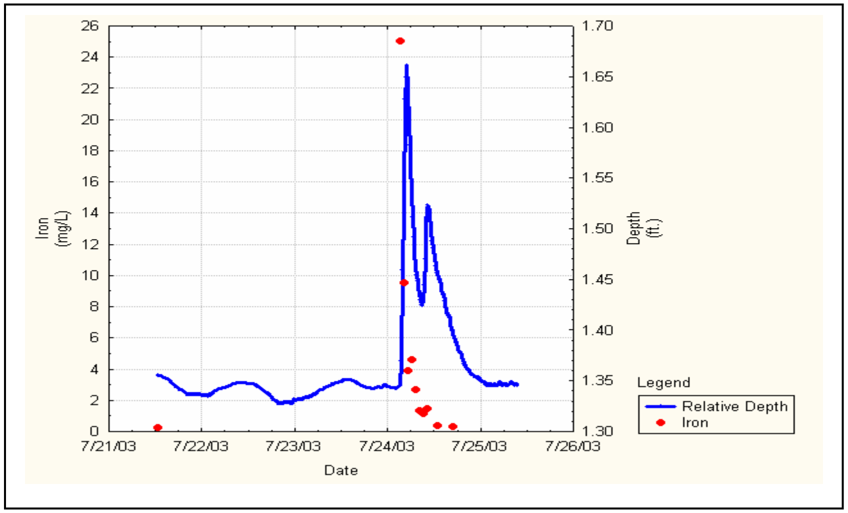


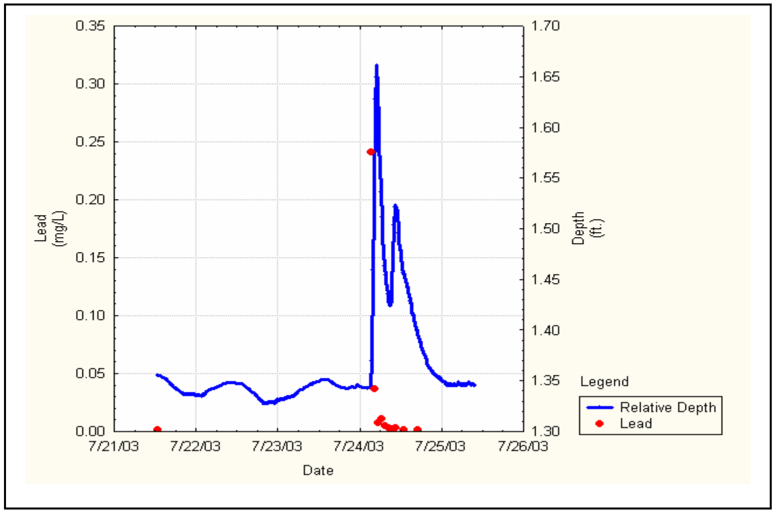


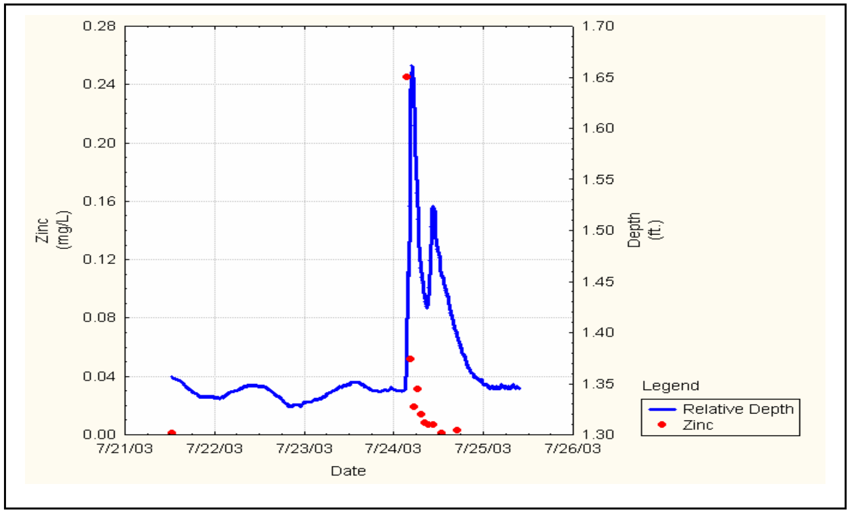


G.1.4. Metal Concentrations At DCD 1660 (7/21/03-7/25/03)

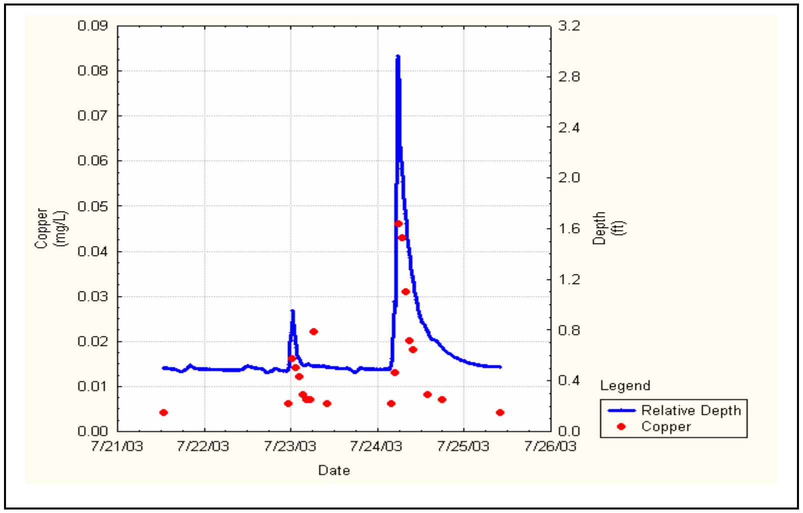


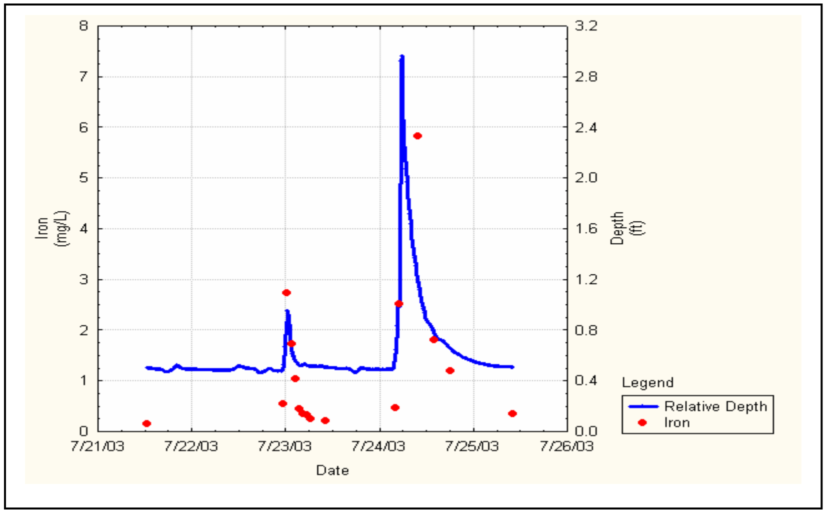


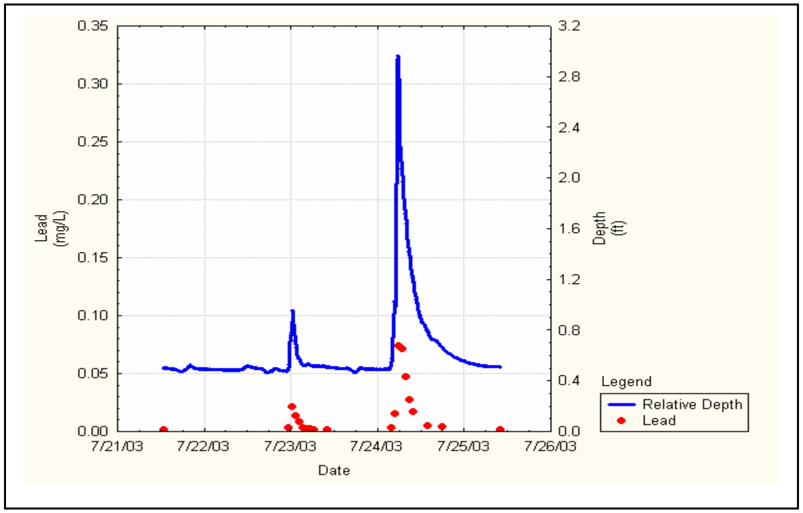


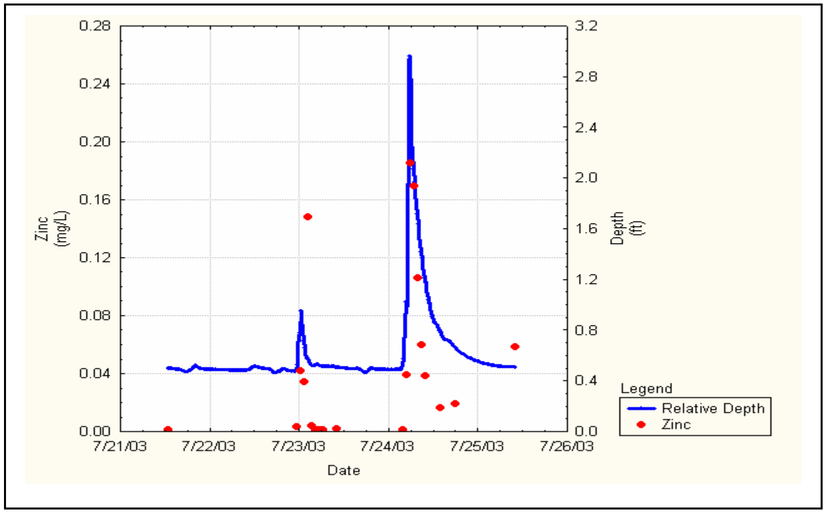


G.1.5. Metal Concentrations At DCD 765 (7/21/03-7/25/03)

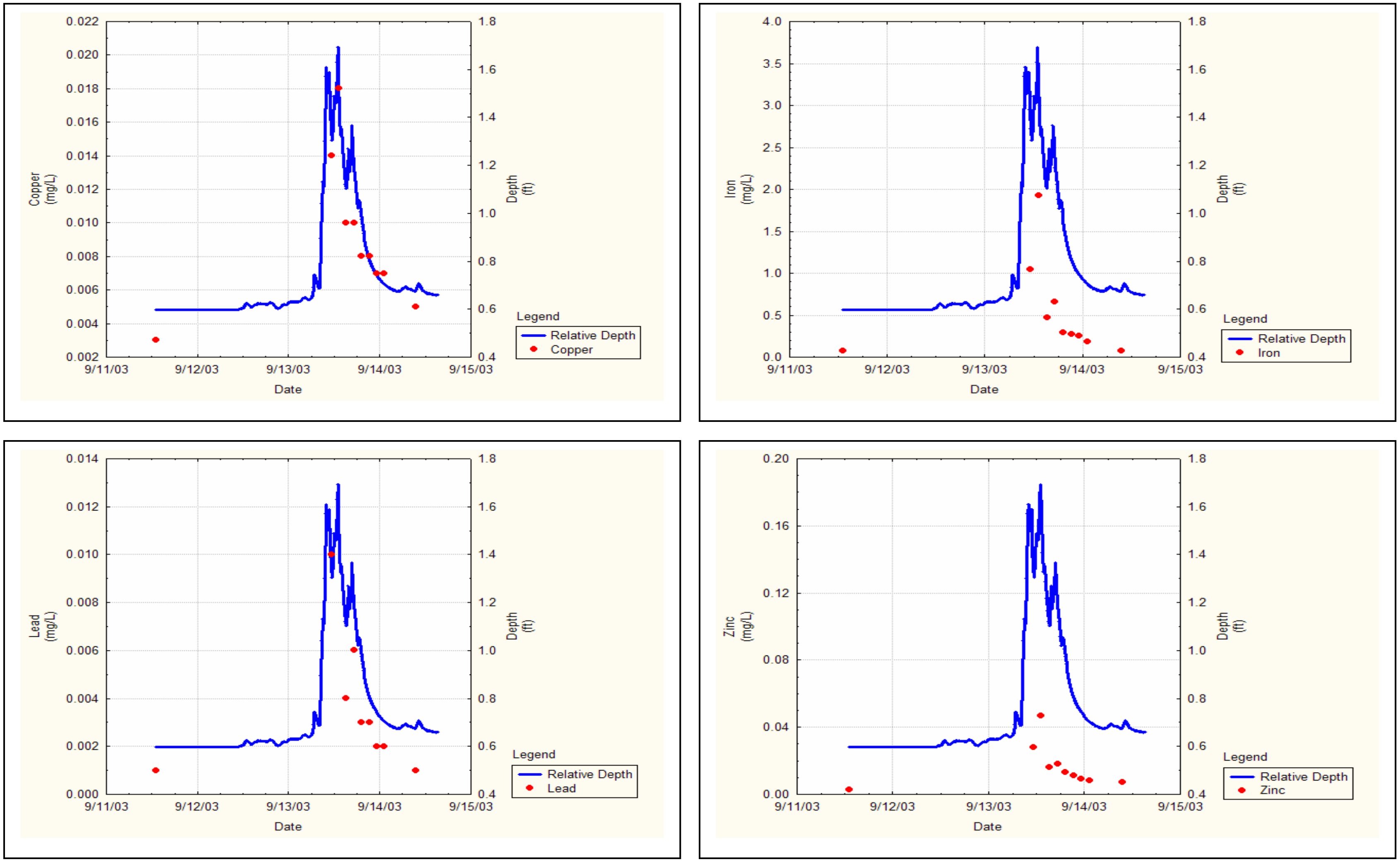




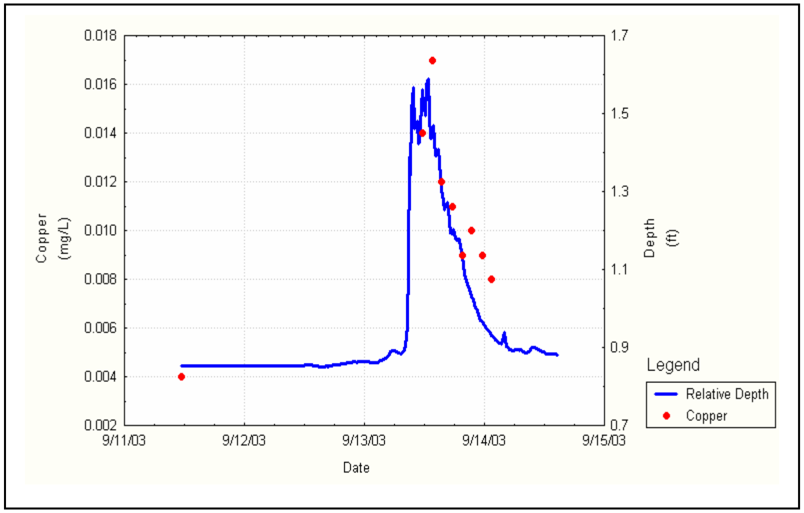


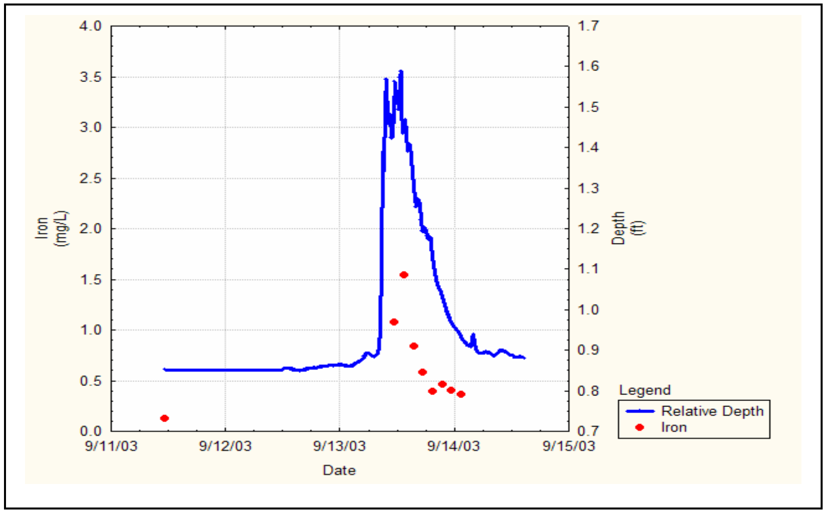


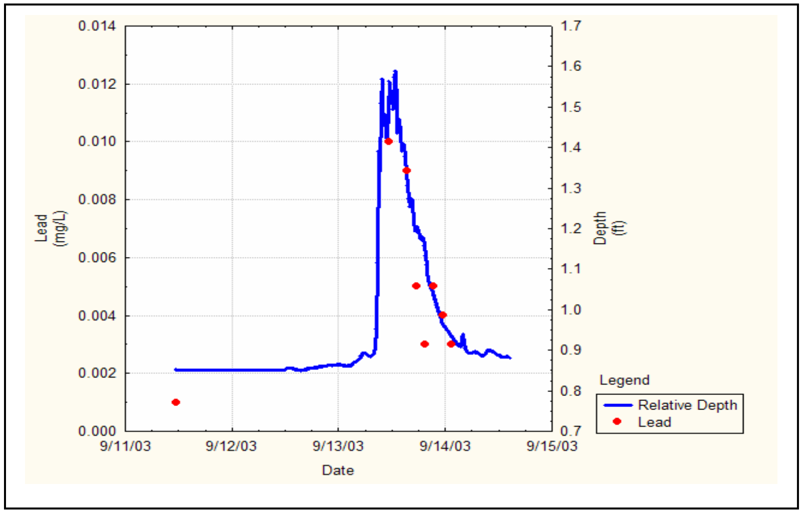
G.2.1. Metal Concentrations At DCC 770 (9/11/03-9/14/03)

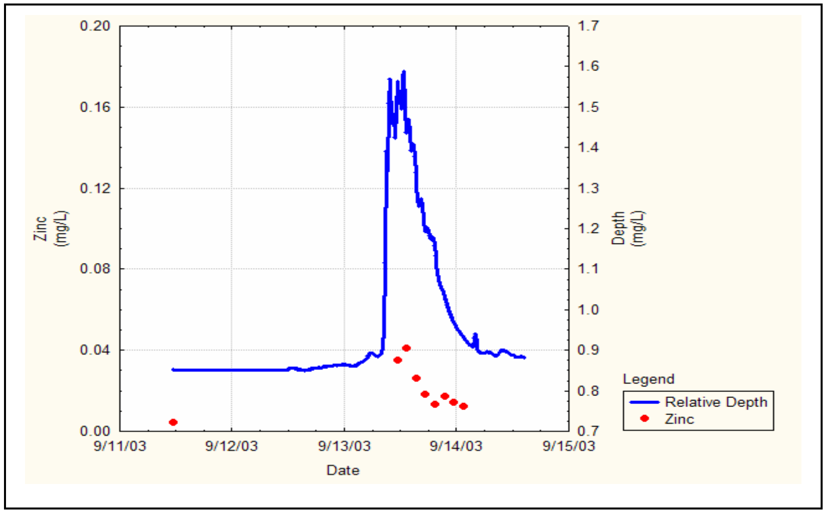


G.2.2. *Metal Concentrations At DCC 455 (9/11/03-9/14/03)*

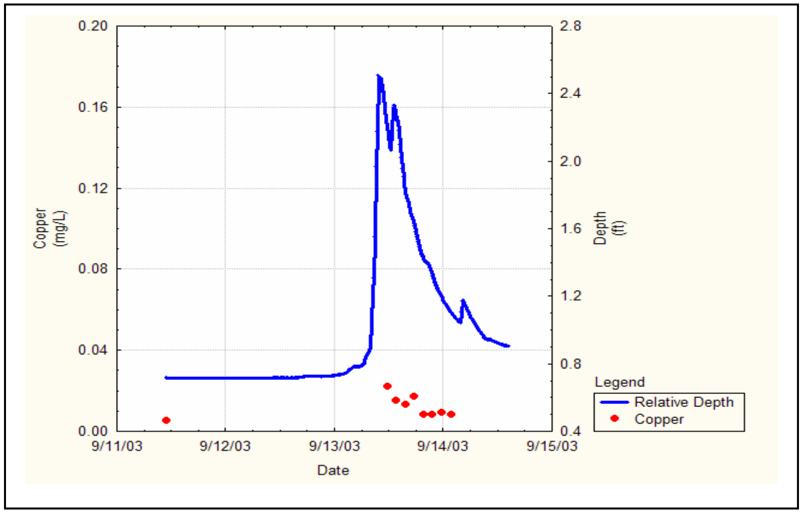


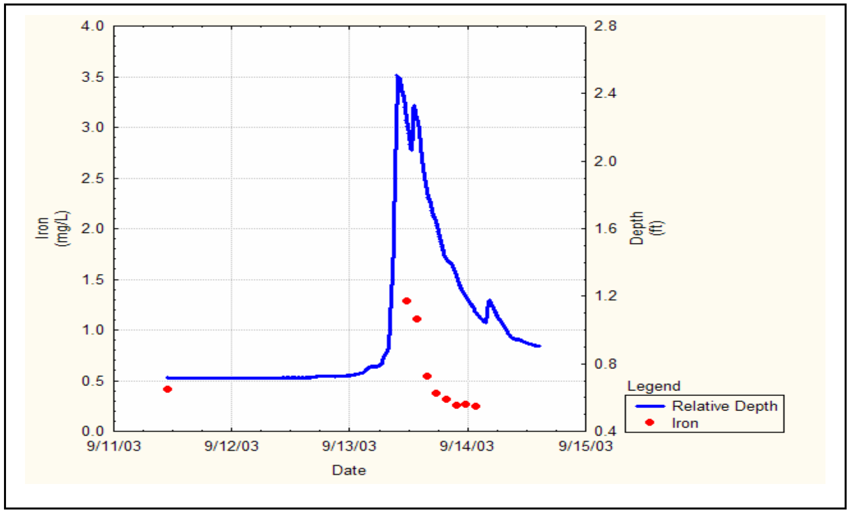


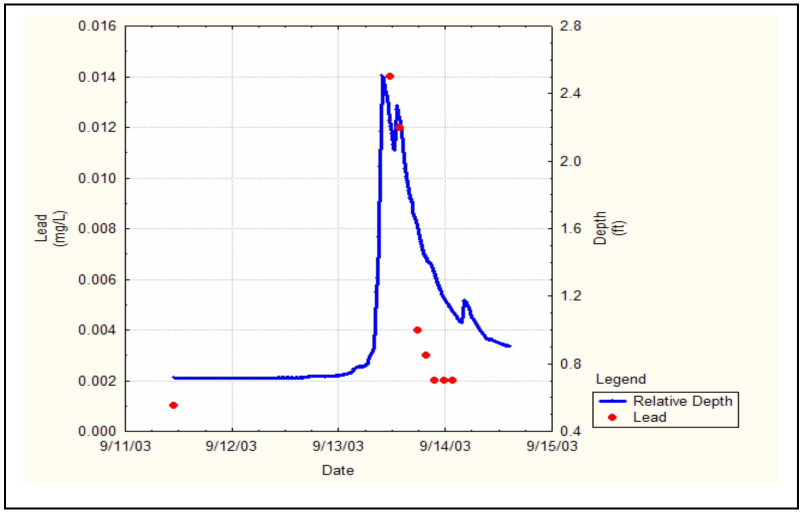


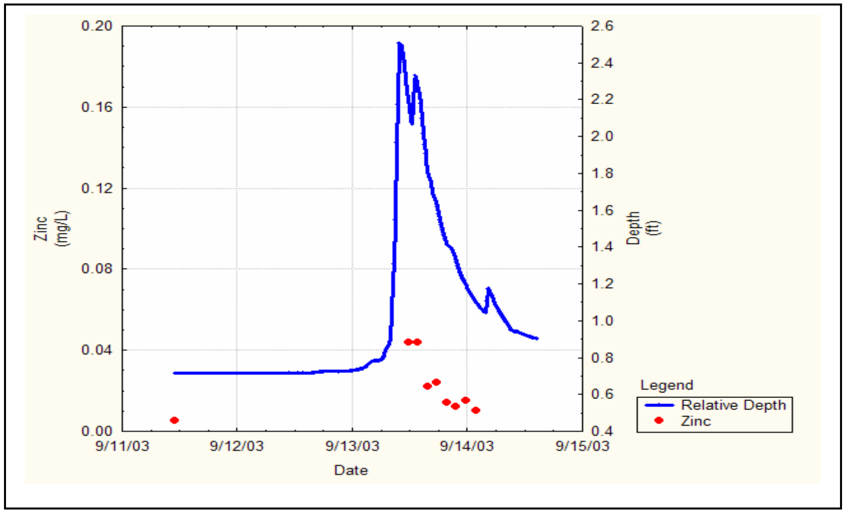


G.2.3. Metal Concentrations At DCC 208 (9/11/03-9/14/03)

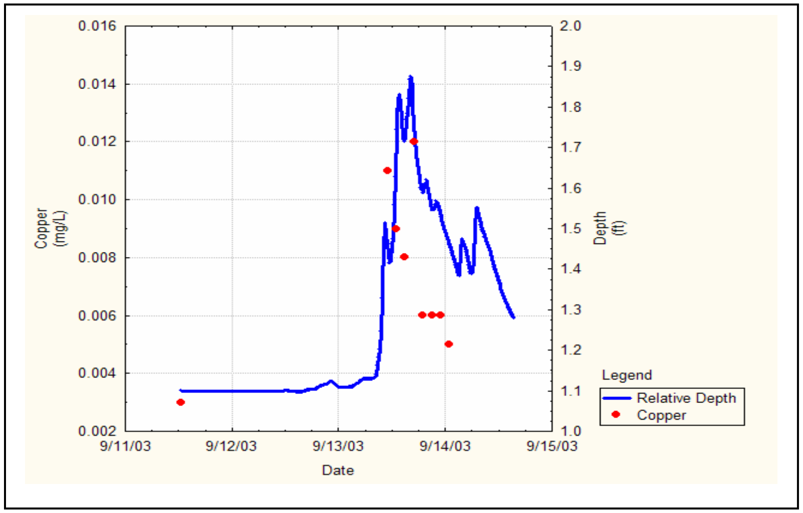


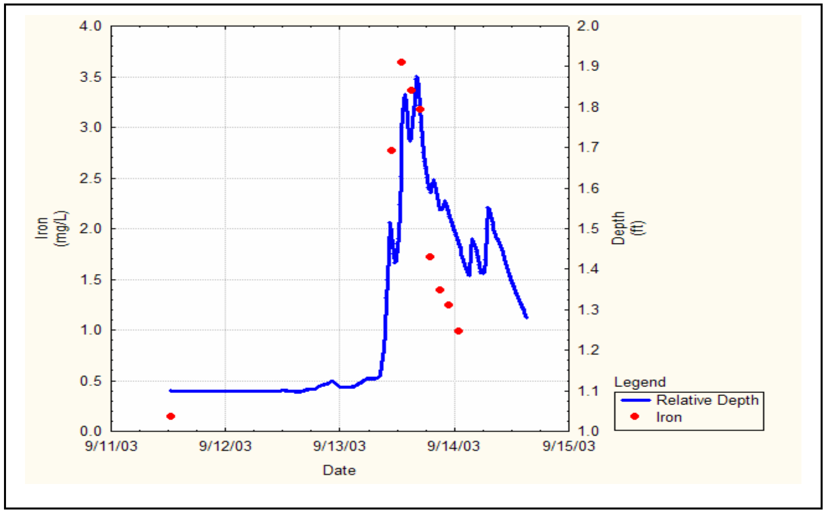


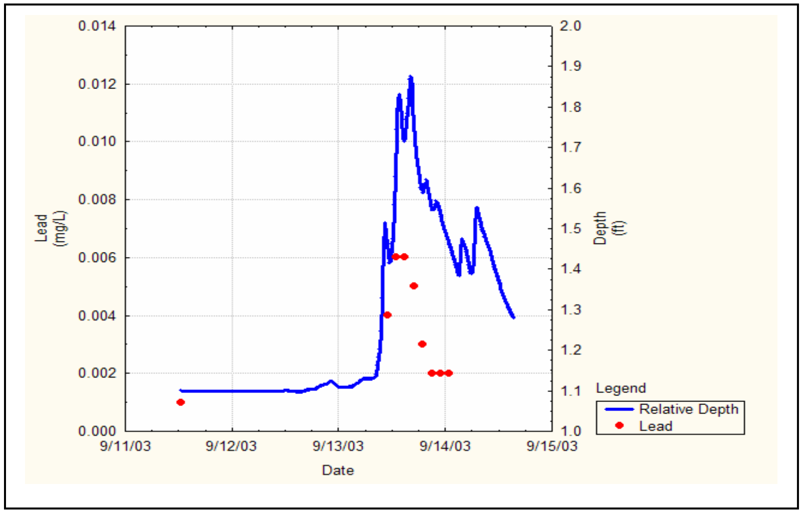


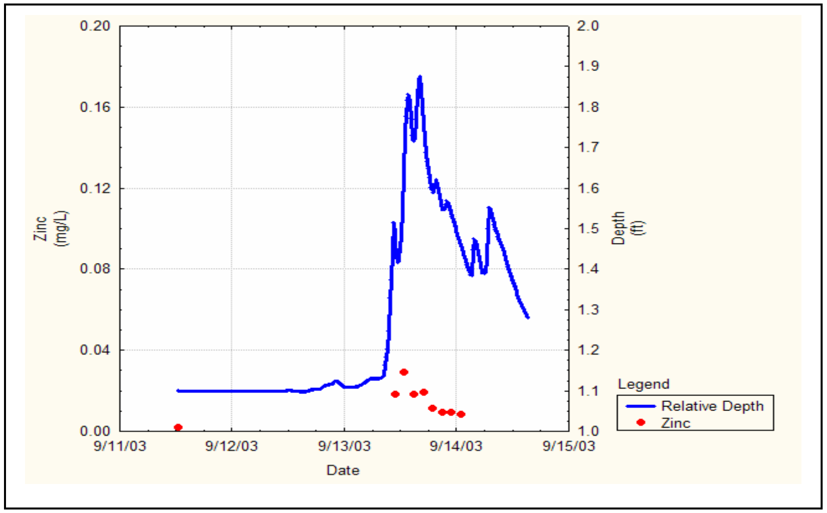


G.2.4. *Metal Concentrations At DCD 1660 (9/11/03-9/14/03)*









G.2.5. Metal Concentrations At DCD 765 (9/11/03-9/14/03)