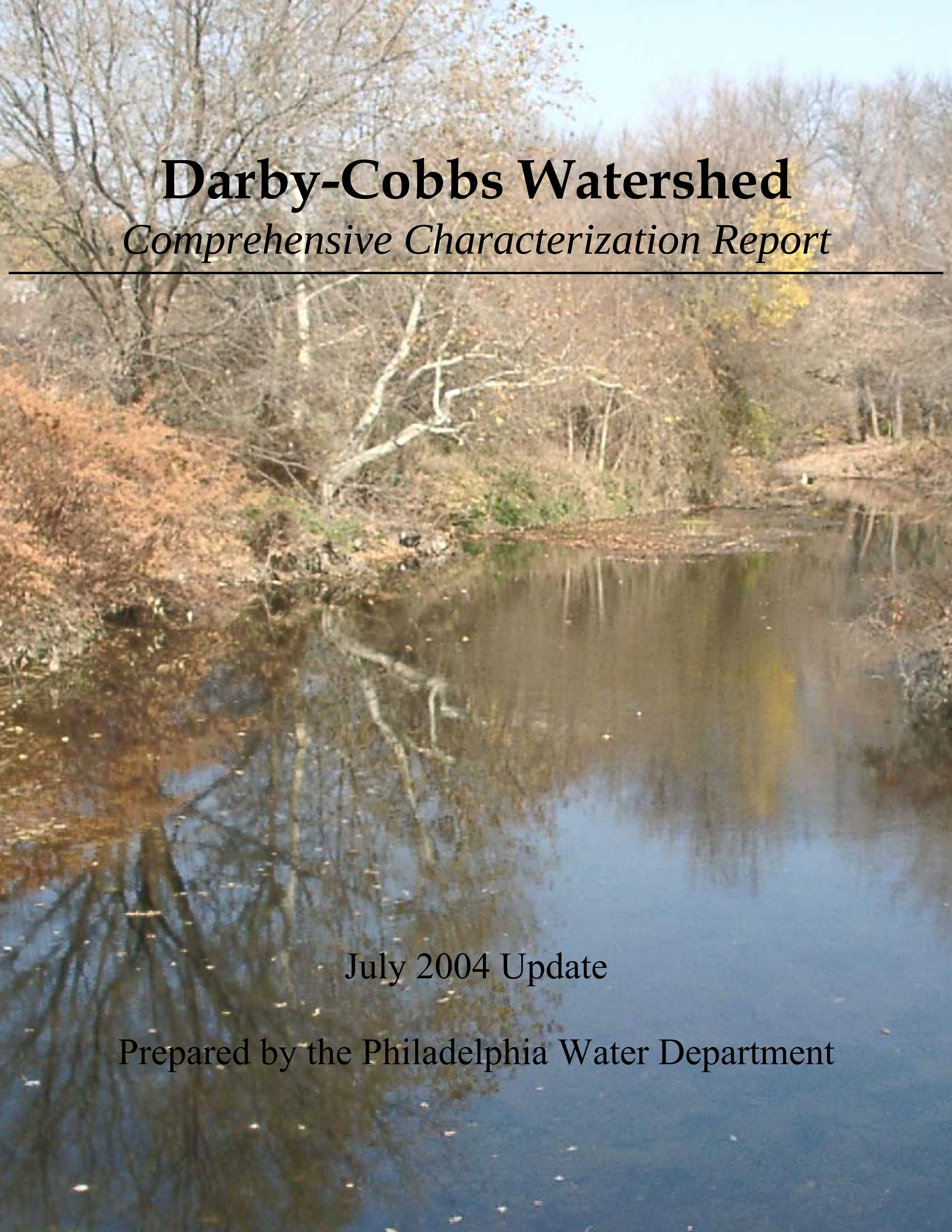

Darby-Cobbs Watershed

Comprehensive Characterization Report

July 2004 Update

Prepared by the Philadelphia Water Department

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CONTACT INFORMATION

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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.

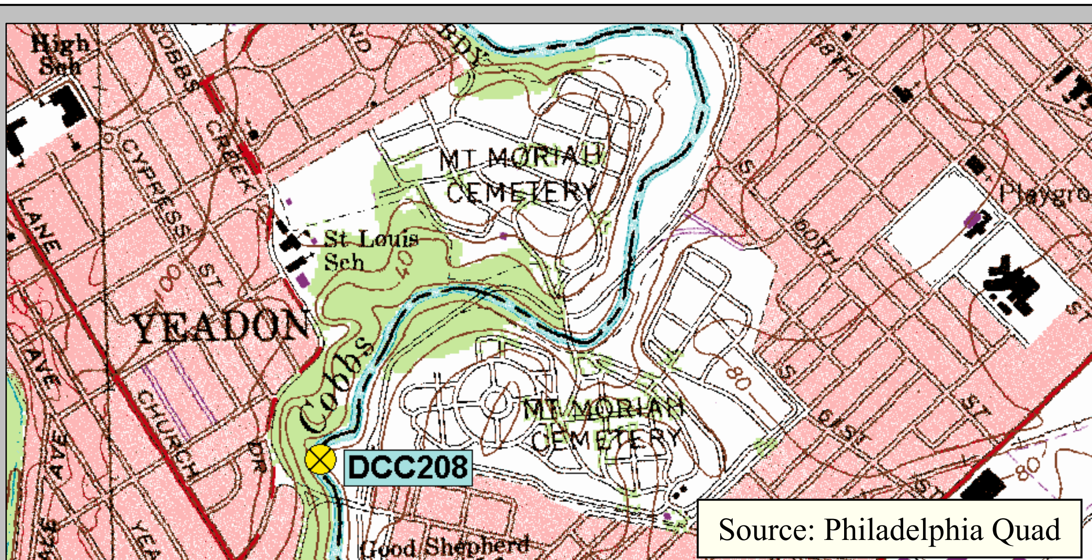
As impairments are identified and corrected, the Watershed Sciences Group is responsible for measuring improvements quantitatively. If improvements are unsatisfactory or absent, PWD and its CCIWMP partners must identify remaining causes of impairment. Many tools available to aquatic biologists were developed 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

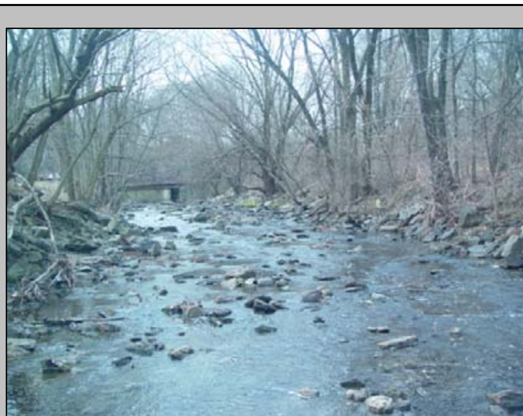
Location:

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

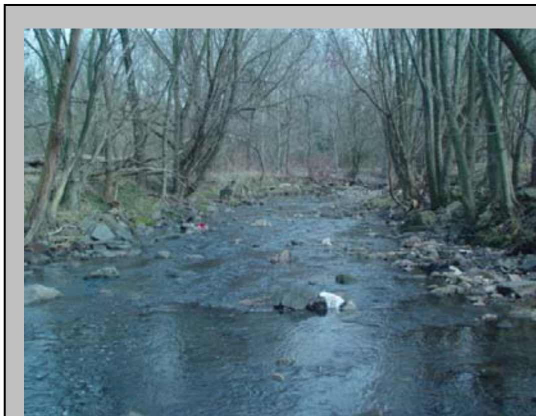
Description:

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.

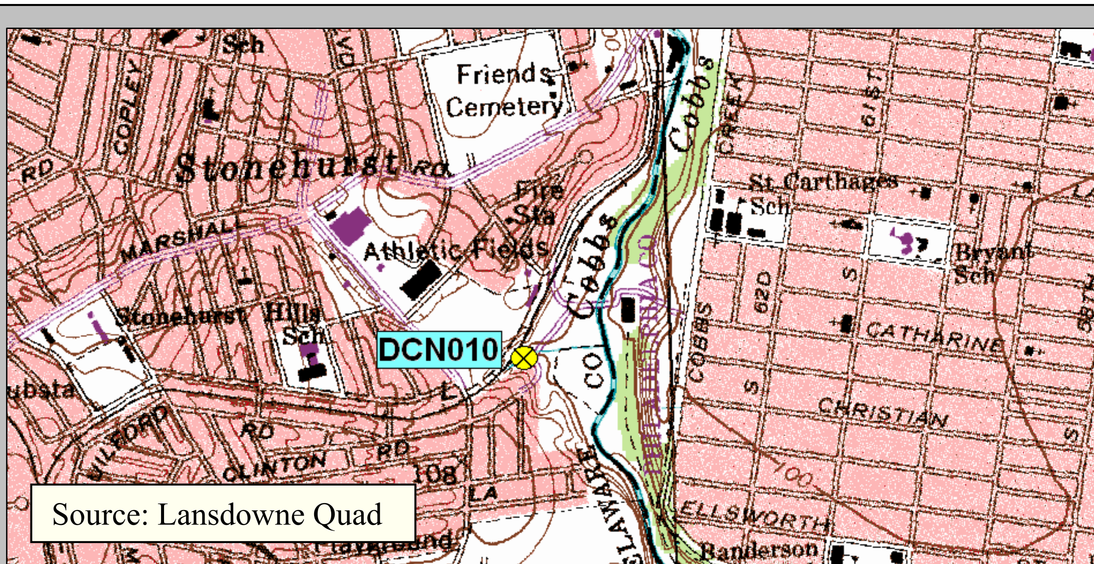
2.2. *DCN 010: Darby-Cobbs Study Area* *Delaware County*



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)

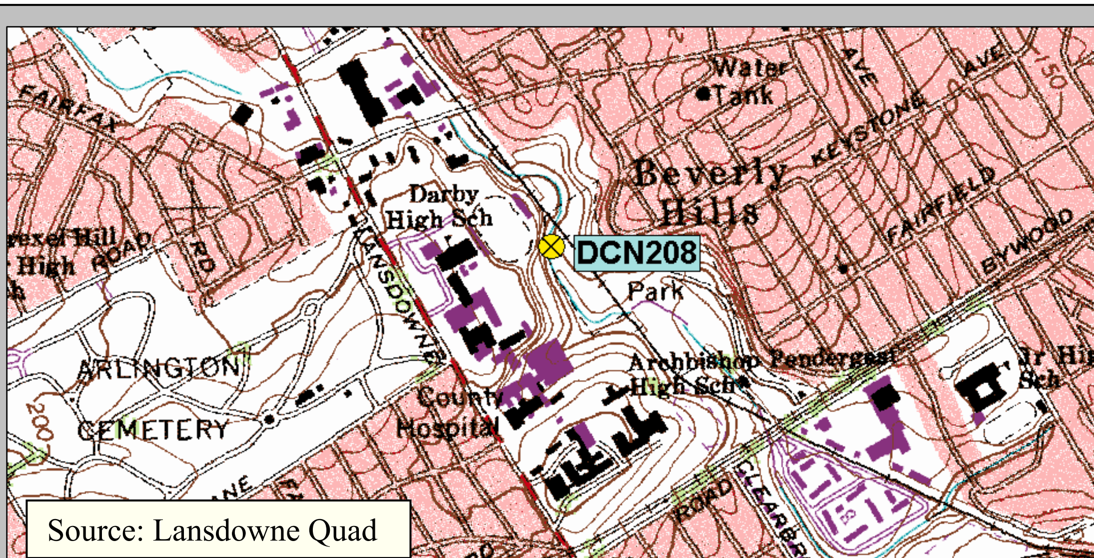
Description:

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:

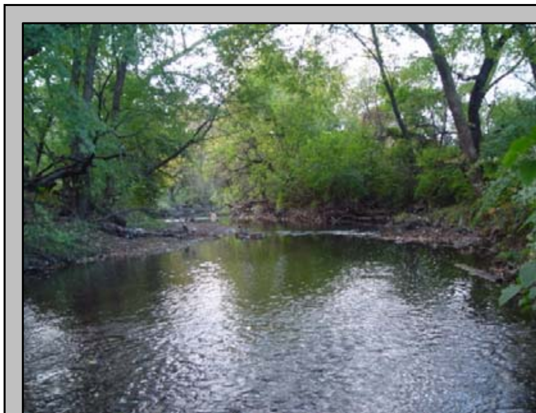
Access gained off of Garrett Road across from Barclay Square. (Latitude: -75.28287, Longitude: 39.95743)

Description:

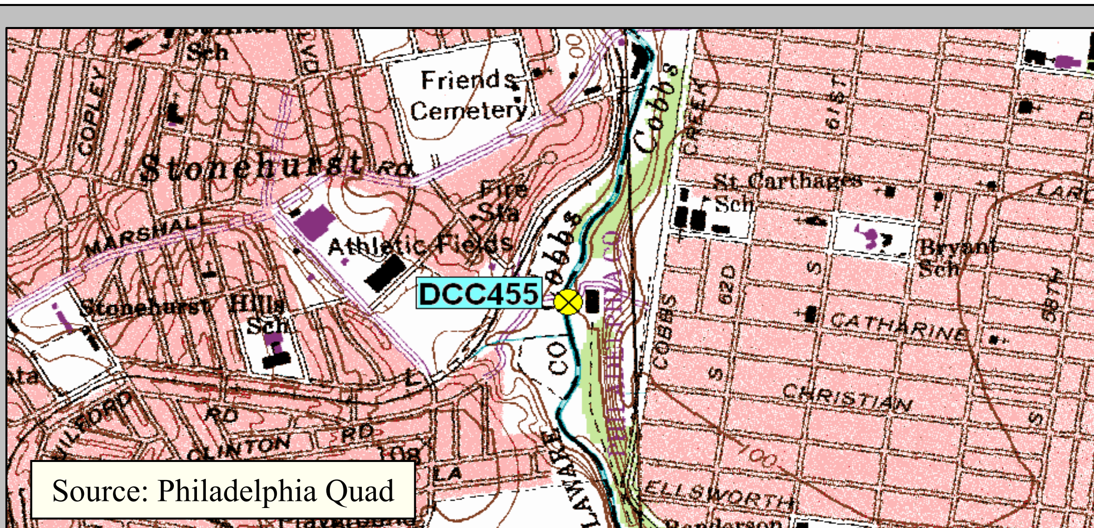
DCN208 is located on Naylors Run near Upper Darby High School. The surrounding land use is residential, and obvious sources of nonpoint source pollution exist near the site. A dam is present 250 meters downstream from the site, at which point the stream is also channelized.

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

Upstream view of DCC455



Downstream view of DCC455



Source: Philadelphia Quad

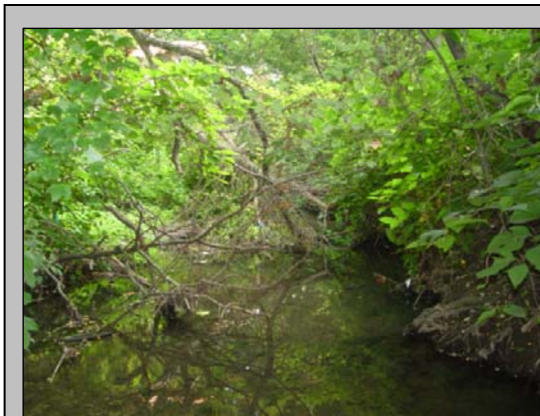
Location:

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

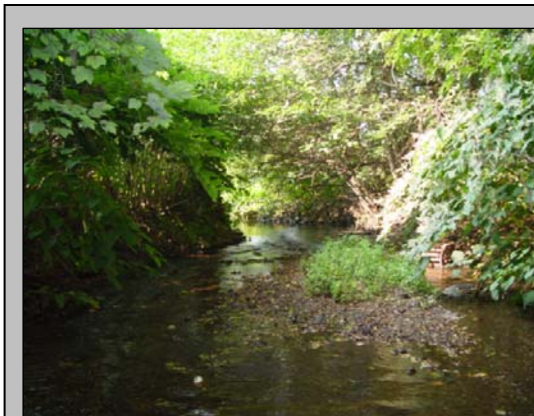
Description:

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.

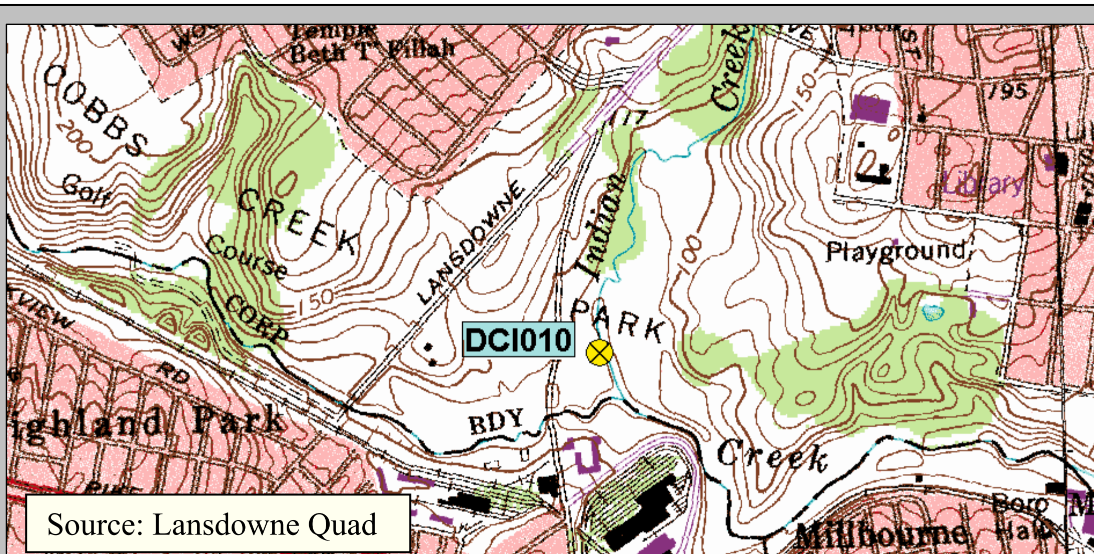
2.5. *DCI 010: Darby-Cobbs Study Area* **Montgomery County**



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)

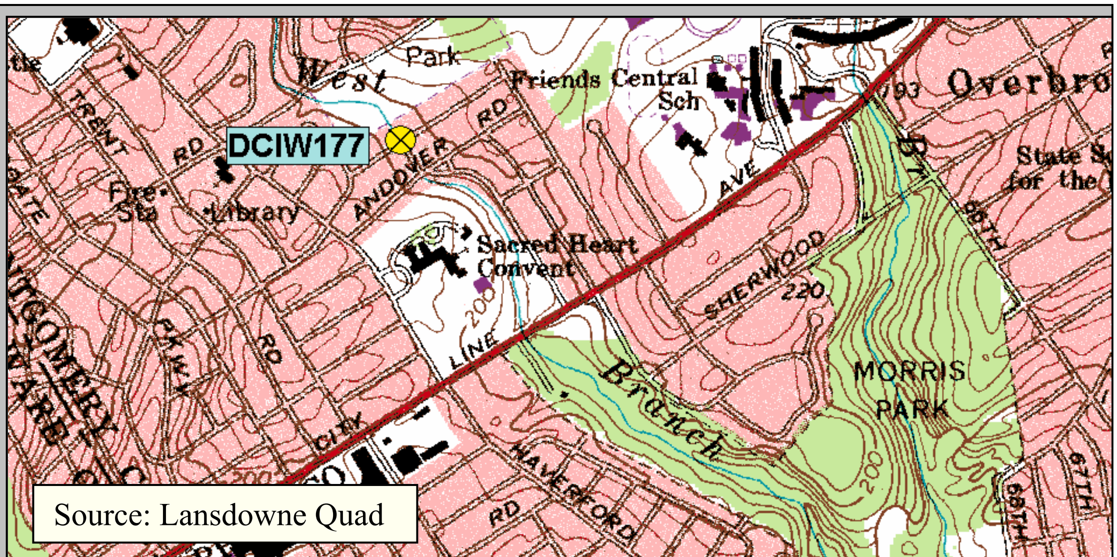
Description:

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)

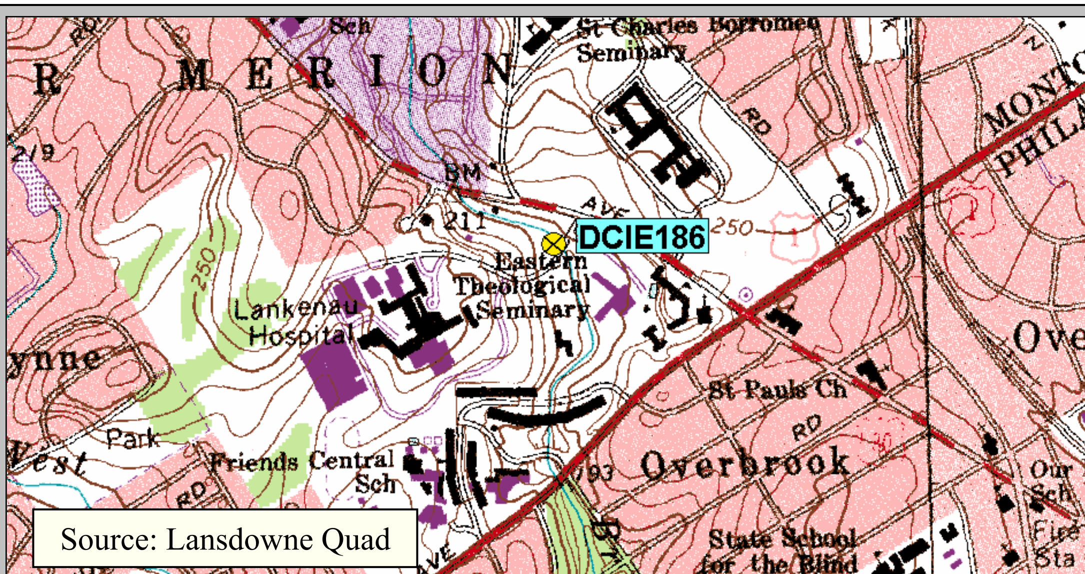
Description:

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

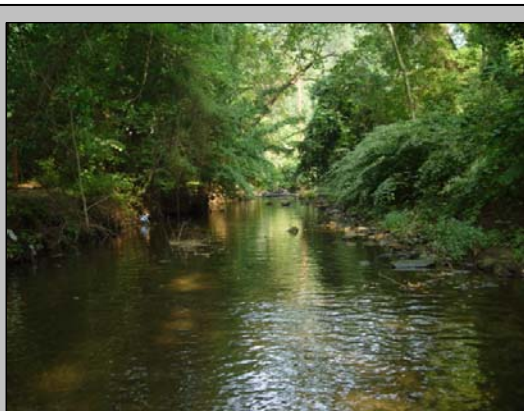
Location:

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

Description:

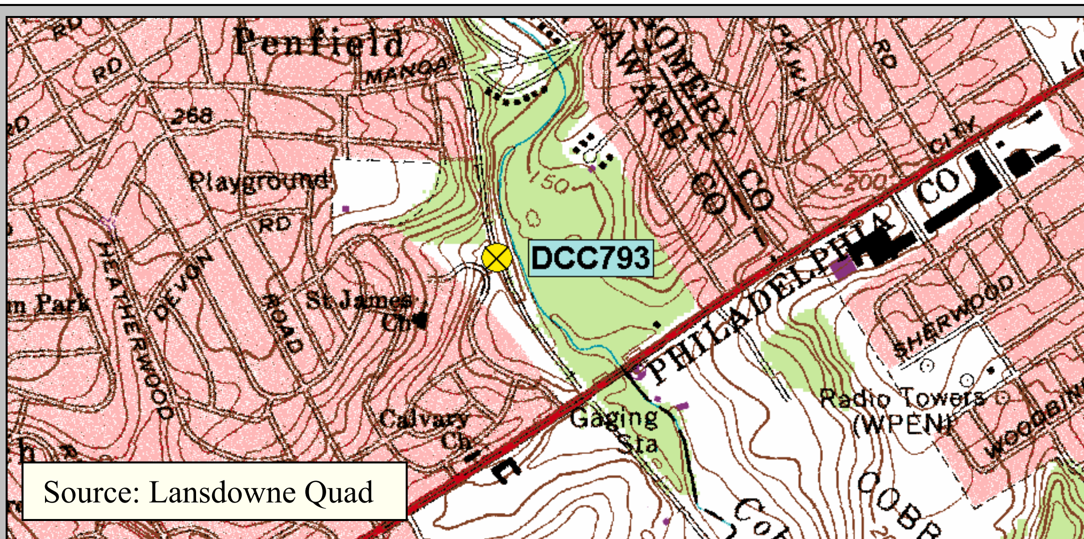
DCIE186 is located on the East Branch of Indian Creek near the Lankenau Hospital. The surrounding land use consists of the hospital as well as other commercial facilities and residential areas.

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



Upstream view of DCC793

Downstream view of DCC793



Source: Lansdowne Quad

Location:

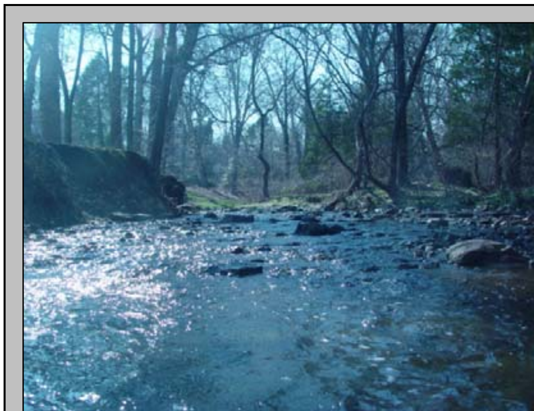
Access gained by a private road on the Grange Estate Property near City Line Avenue (official entrance off of Myrtle Street). (Latitude: -75.28322, Longitude: 39.97710)

Description:

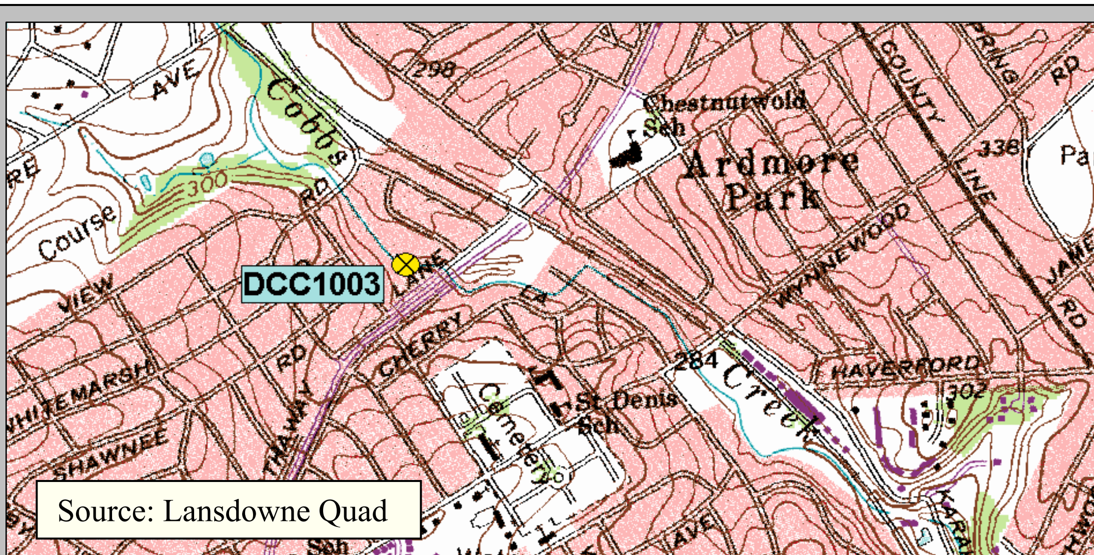
DCC793 is located on the edge of a private estate. The surrounding land use is residential and field/pasture land. The Creek passes underneath a railroad track close to the site.

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

Upstream view of DCC1003



Downstream view of DCC1003



Source: Lansdowne Quad

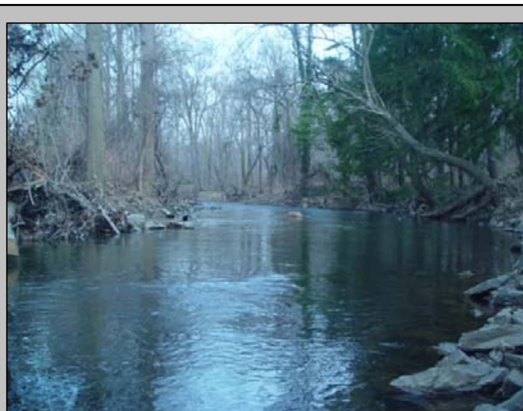
Location:

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

Description:

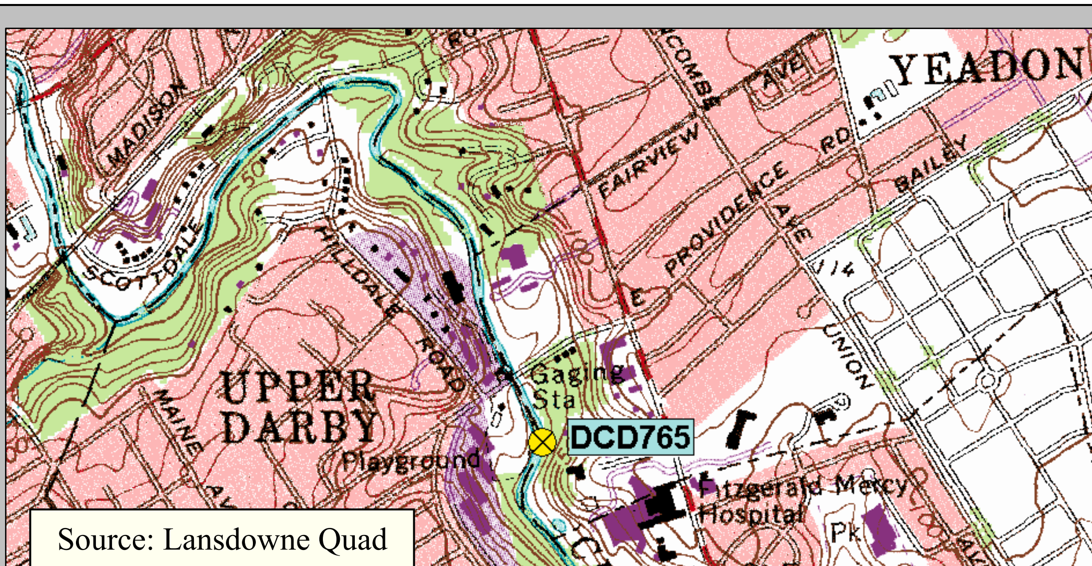
DCC1003 is the most upstream site on Cobbs Creek. It is located just upstream of the bridge on Hathaway Lane. The surrounding land use is single-family residential housing.

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



Upstream view of DCD765

Downstream view of DCD765



Source: Lansdowne Quad

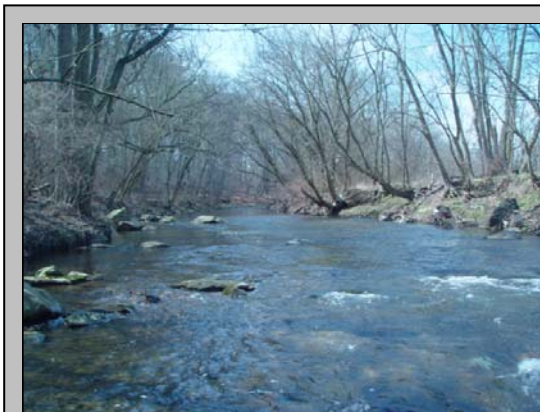
Location:

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:

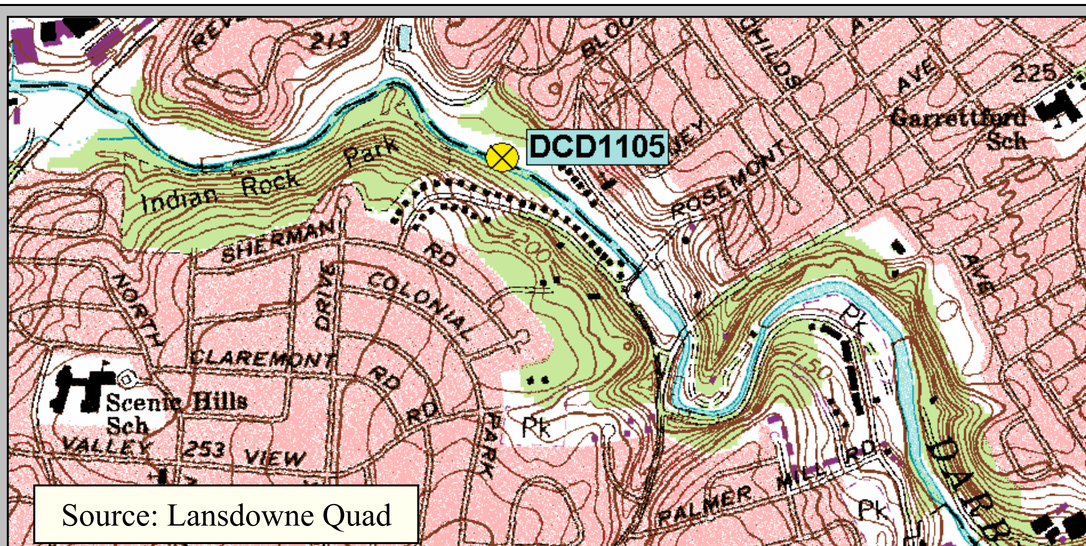
The general land use surrounding DCD765 is residential and commercial. The area immediately surrounding the site includes a baseball field and playground. The left bank of the stream reach has been modified with riprap.

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)

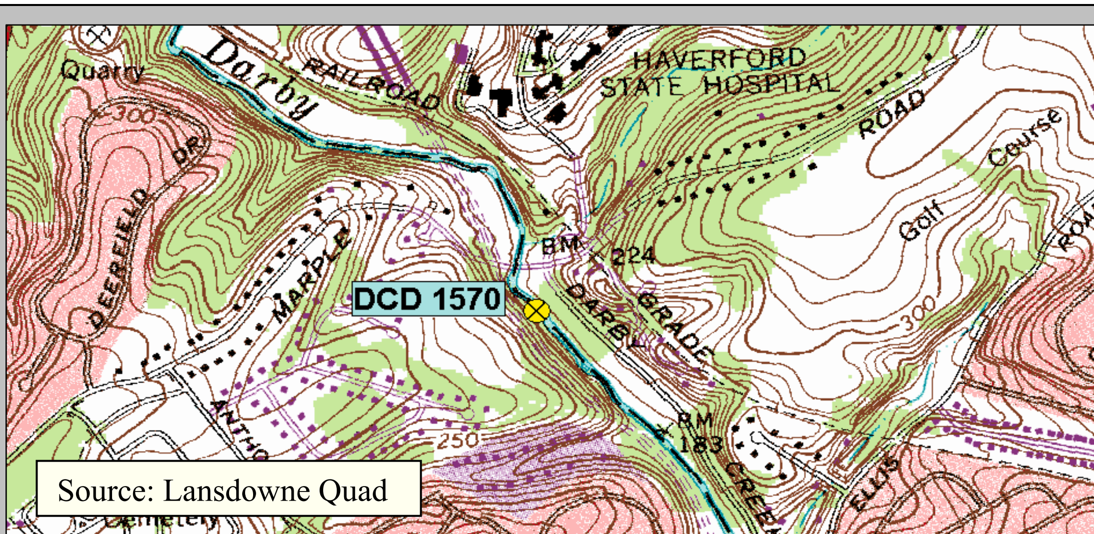
Description:

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

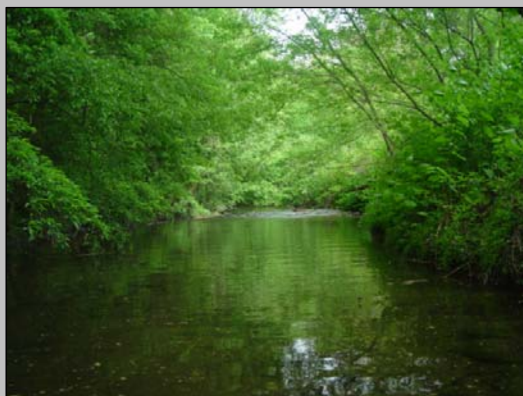
Location:

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:

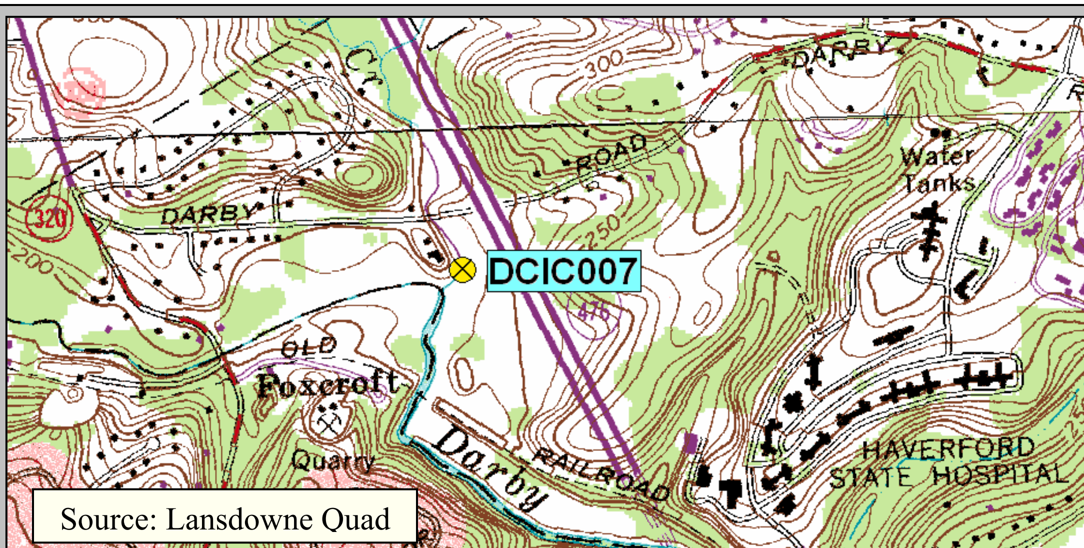
Site DCD1570 is located off of Darby Creek Road near the Marple Road overpass of Interstate 476. The site is situated alongside Interstate 476. The predominant land use surrounding the site is forest and the interstate highway.

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



Upstream view of DCIC007

Downstream view of DCIC007



Source: Lansdowne Quad

Location:

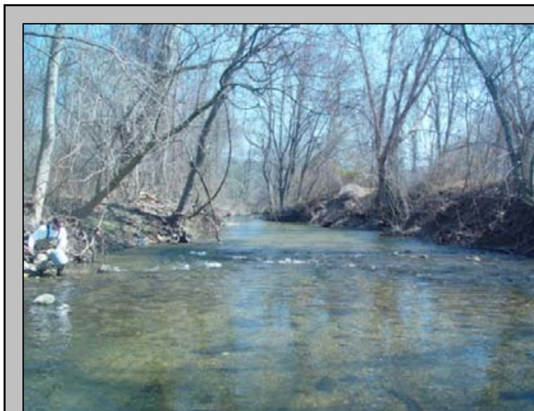
Access gained from Darby Road in Radnor Township. Site is located 75 meters downstream of Darby Road. (Latitude: -75.35076, Longitude: 39.99756)

Description:

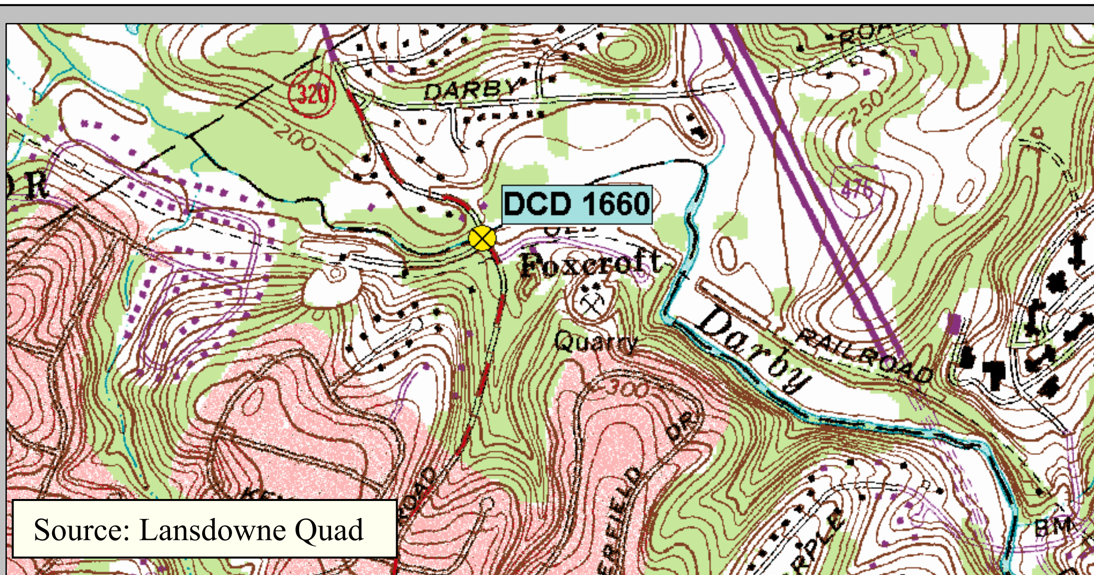
Site DCIC007 is located on Ithan Creek just downstream of Darby Road near the confluence of Ithan and Darby Creeks. The site is close to Interstate 476 and the Darby Creek Valley Park. The land use surrounding the site is field/pasture and residential.

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)

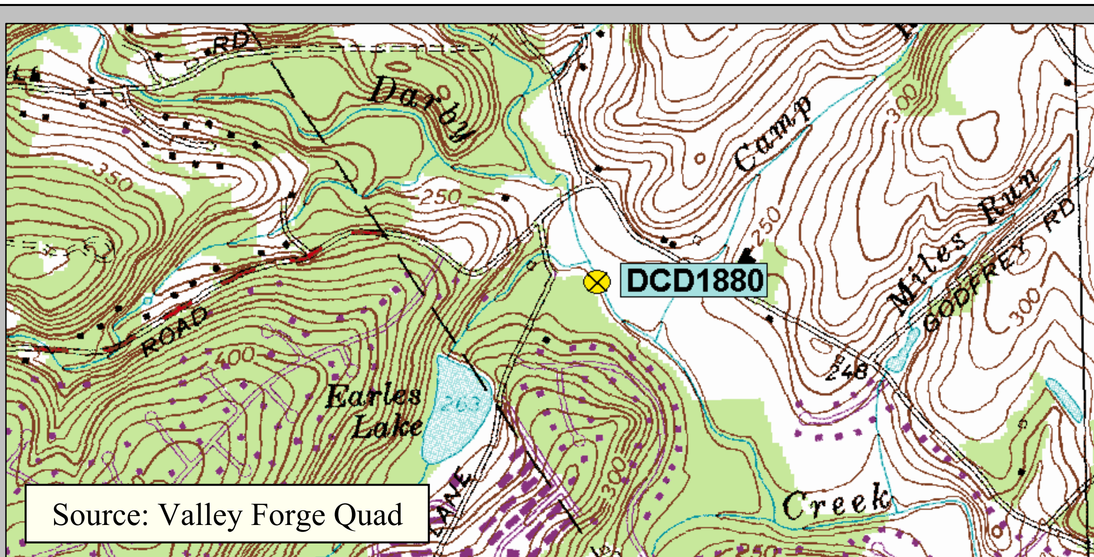
Description:

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)

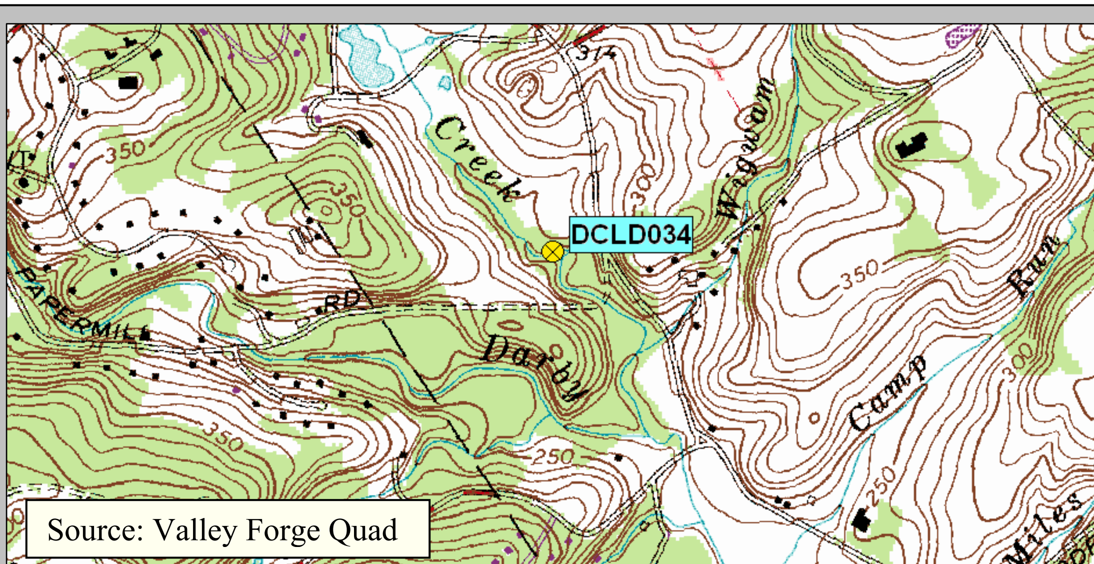
Description:

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

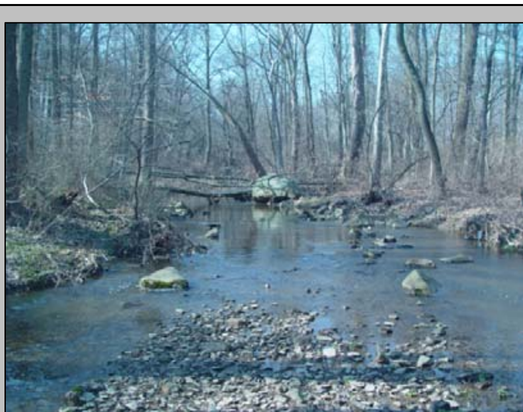
Location:

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).

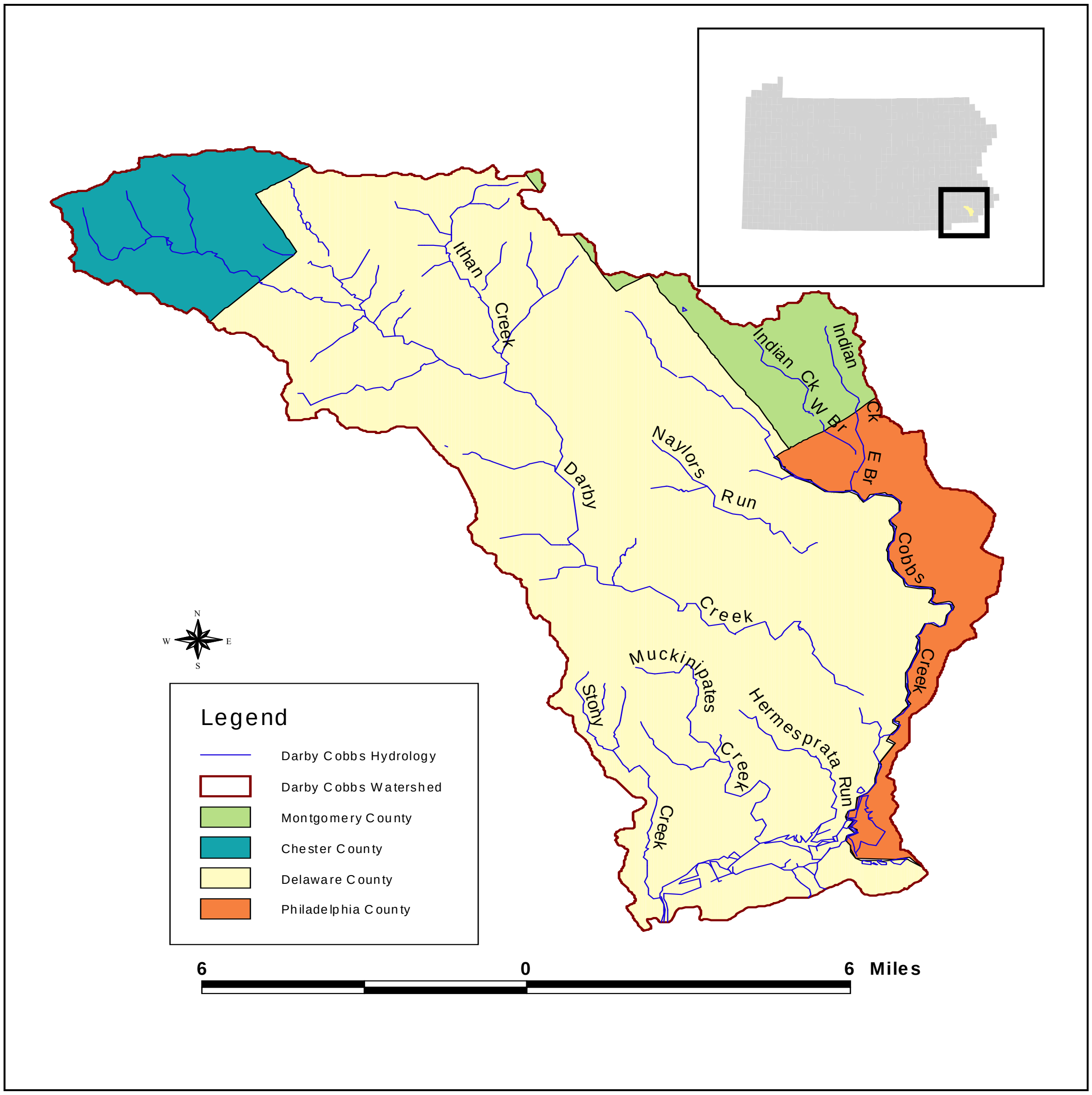


Figure 1. Darby-Cobbs Watershed and associated tributaries.

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.

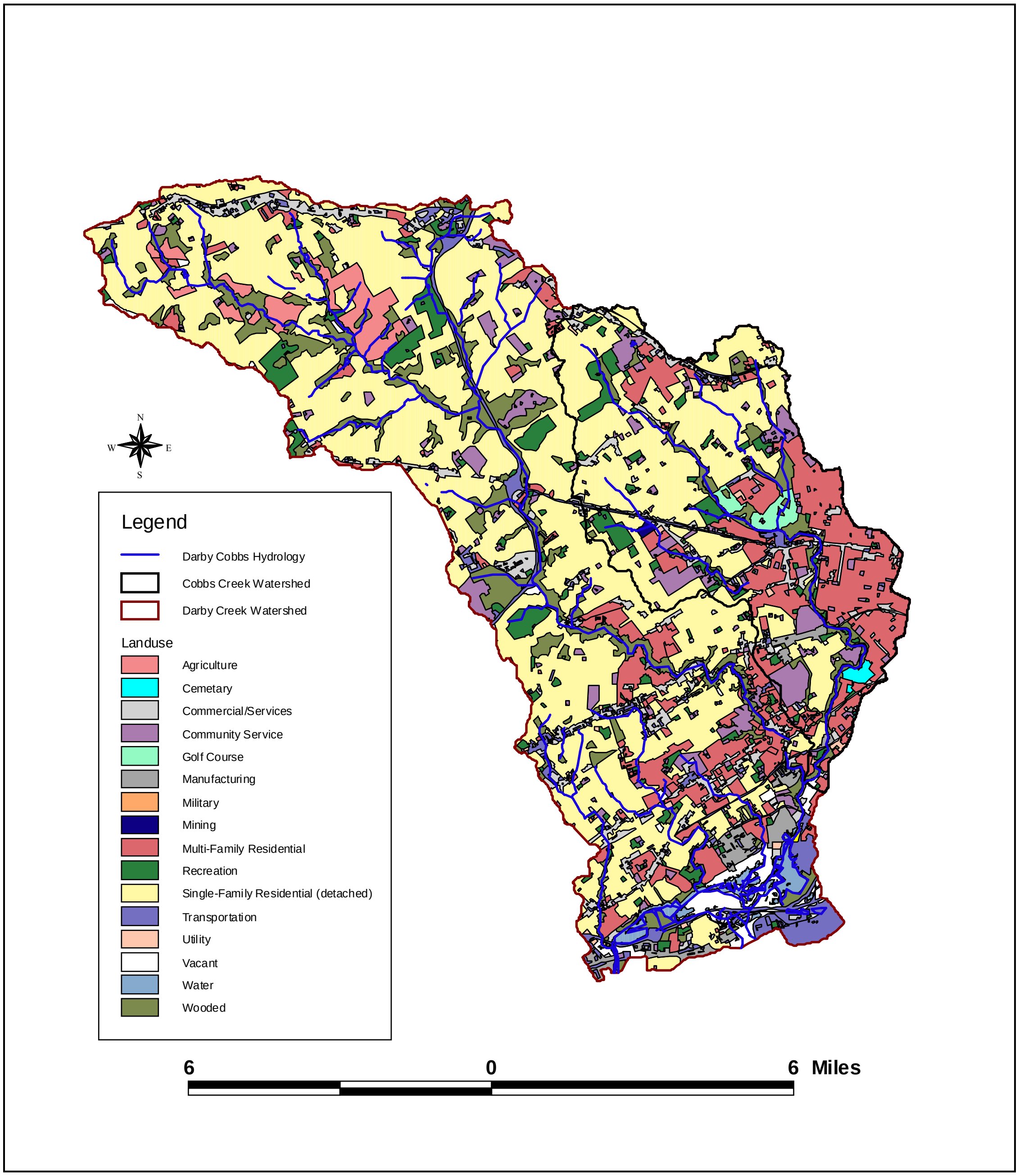


Figure 2. Darby-Cobbs Watershed land use patterns.

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).

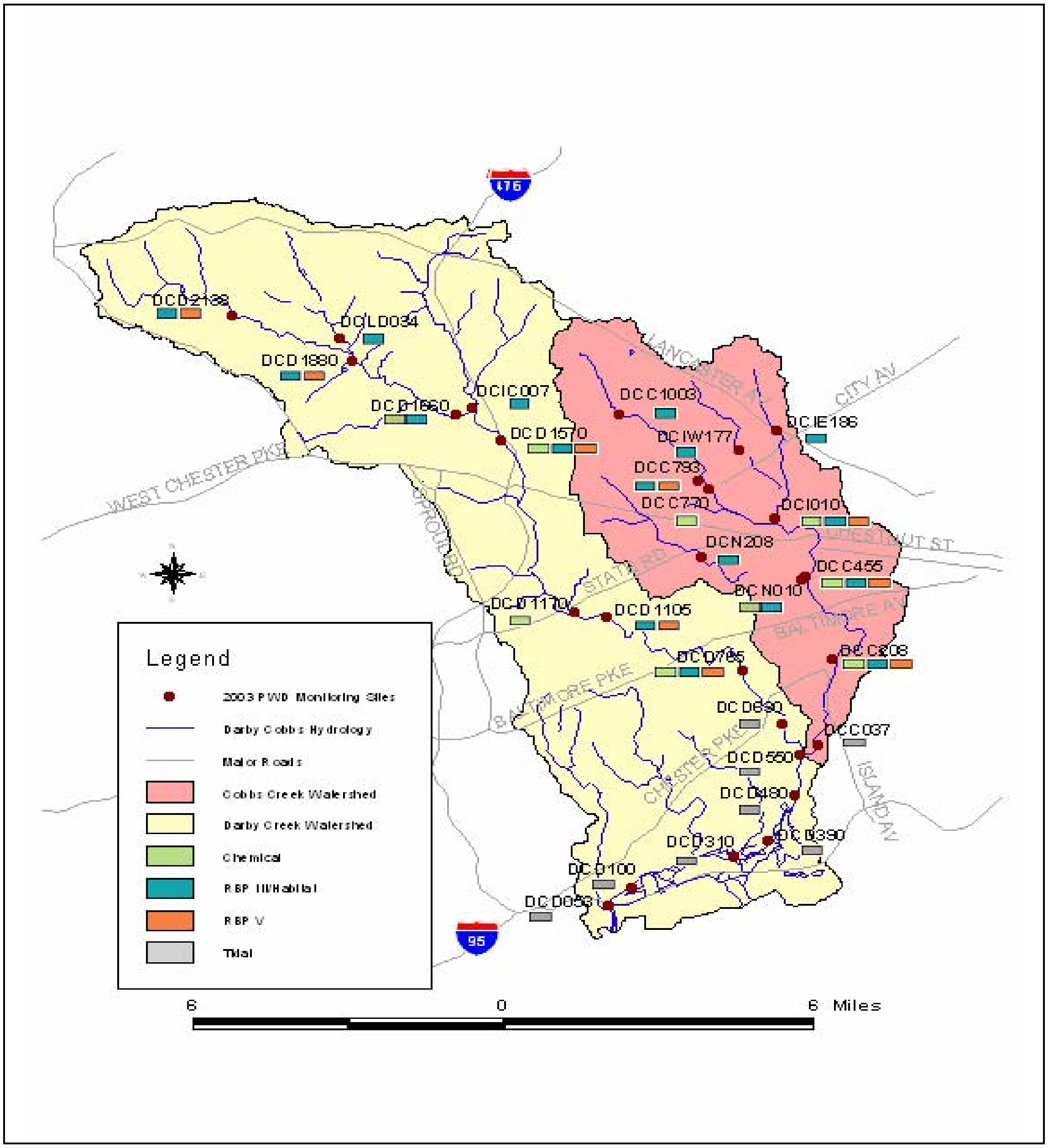


Figure 3. PWD monitoring locations in the Darby-Cobbs Watershed.

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.

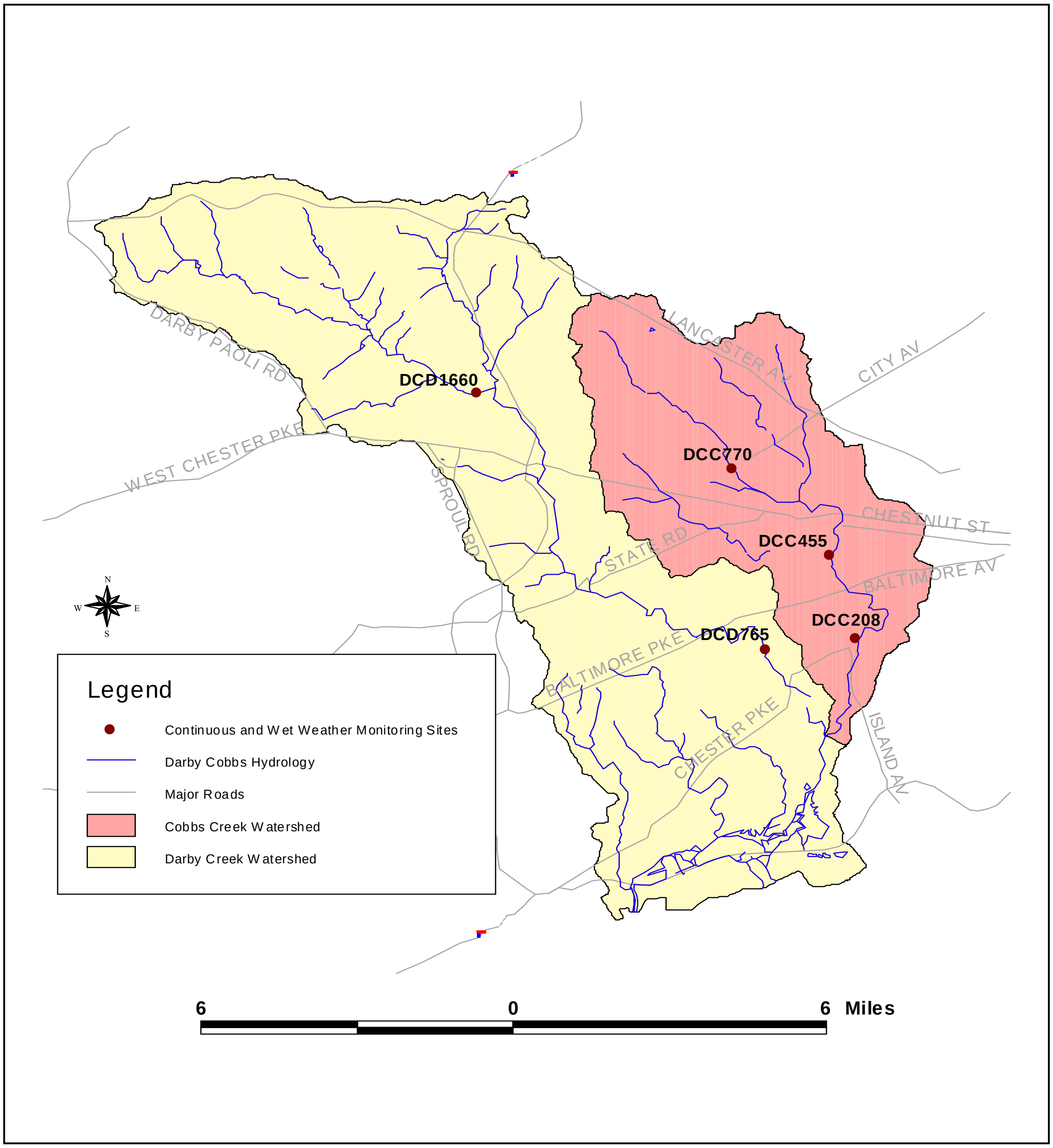


Figure 4. PWD continuous and wet-weather monitoring locations in Darby-Cobbs Watershed

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.

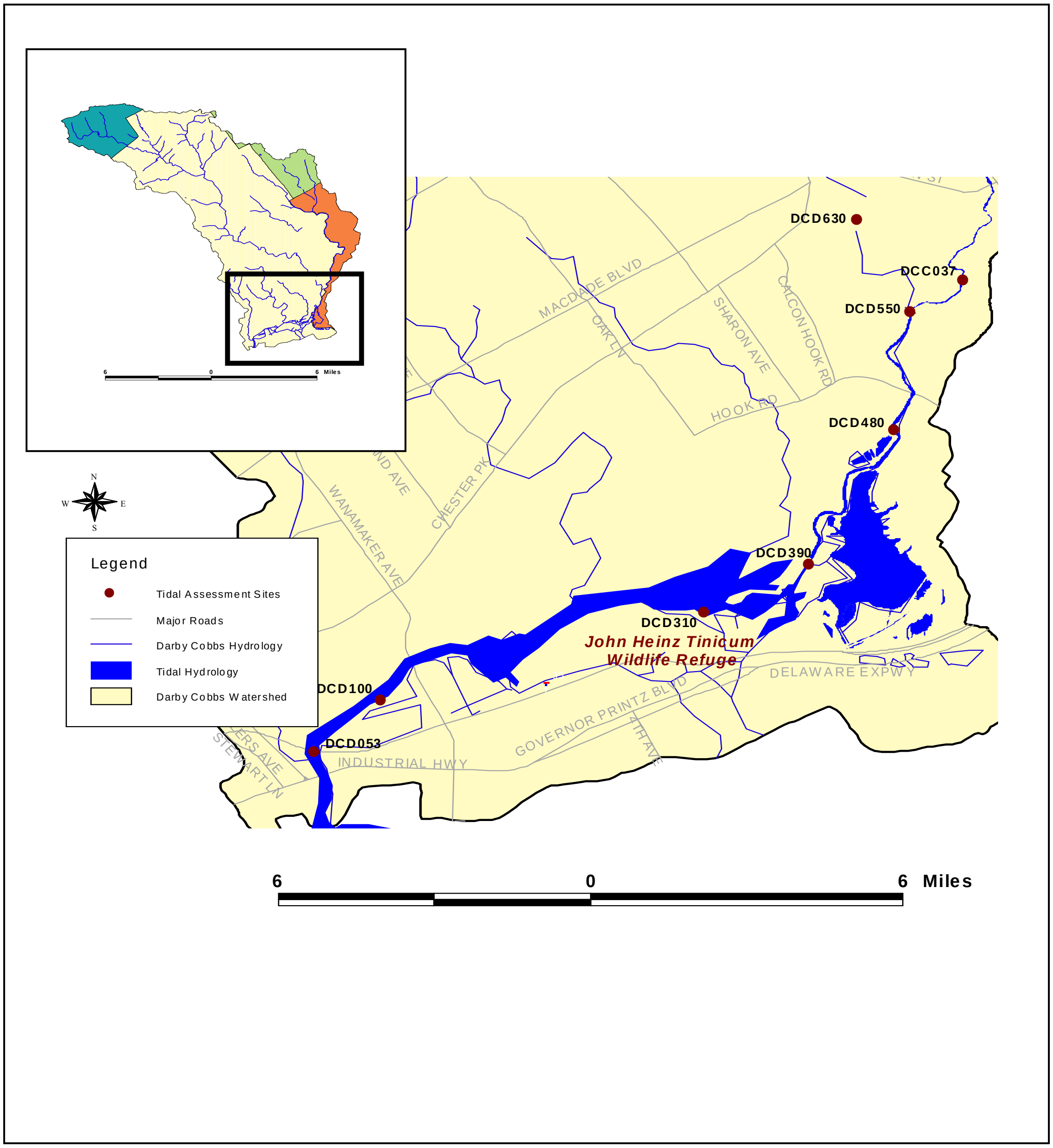


Figure 5. Tidal assessment locations in lower Darby Creek.

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.

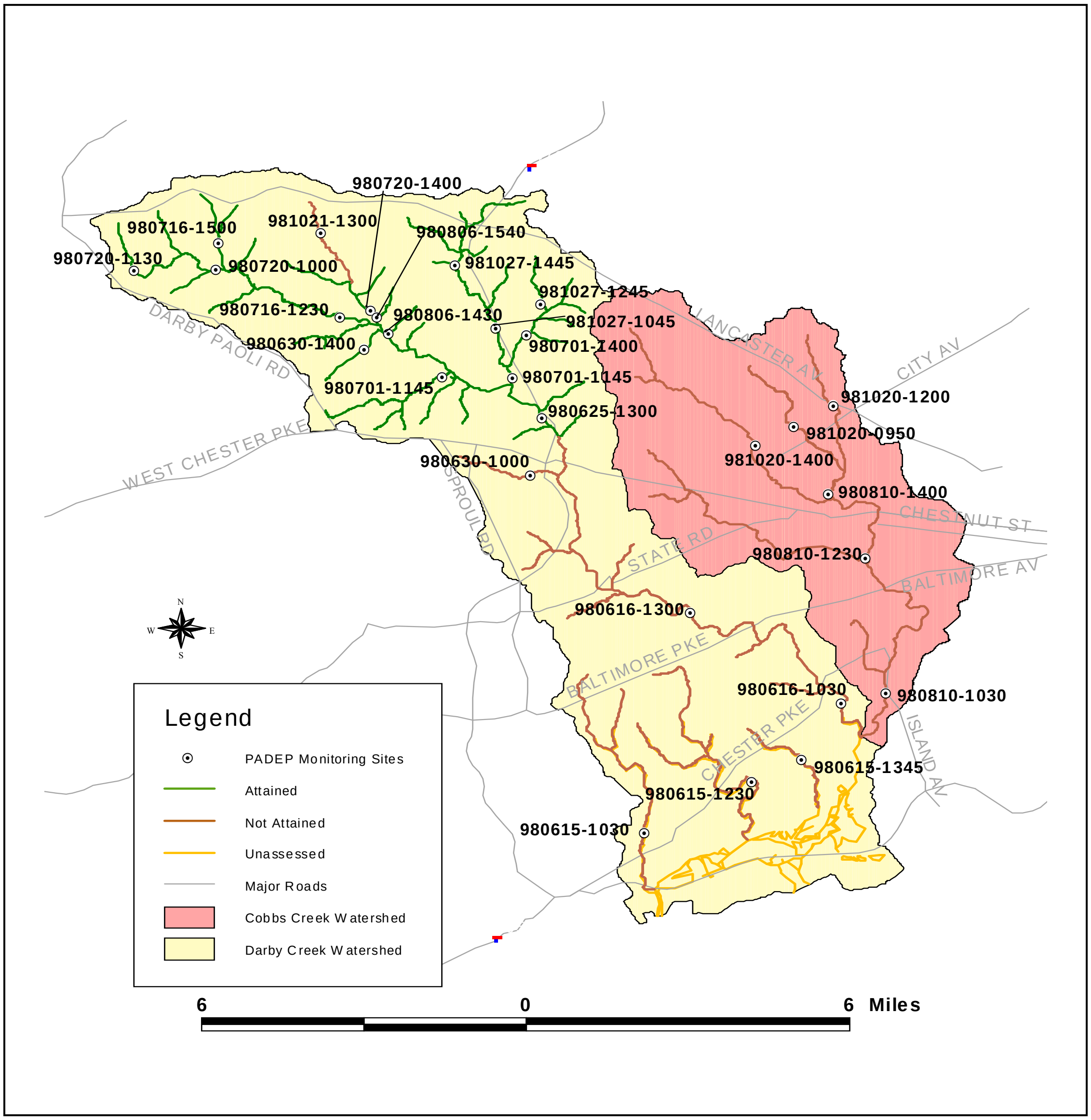


Figure 6. PADEP surface water assessment locations (1998-1999)

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.

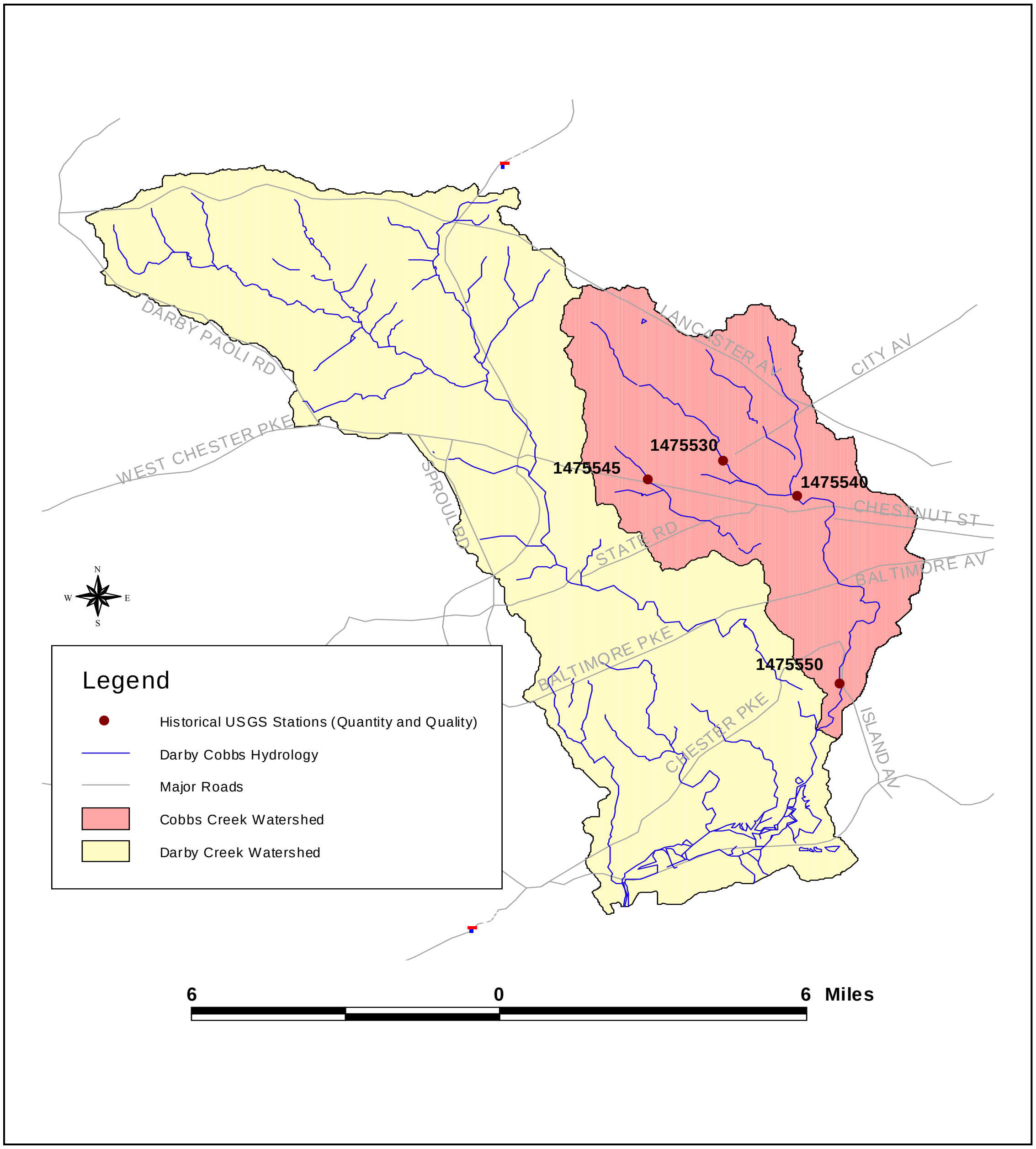


Figure 7. Historical USGS monitoring locations in Darby-Cobbs Watershed.

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):

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

where;

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

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.

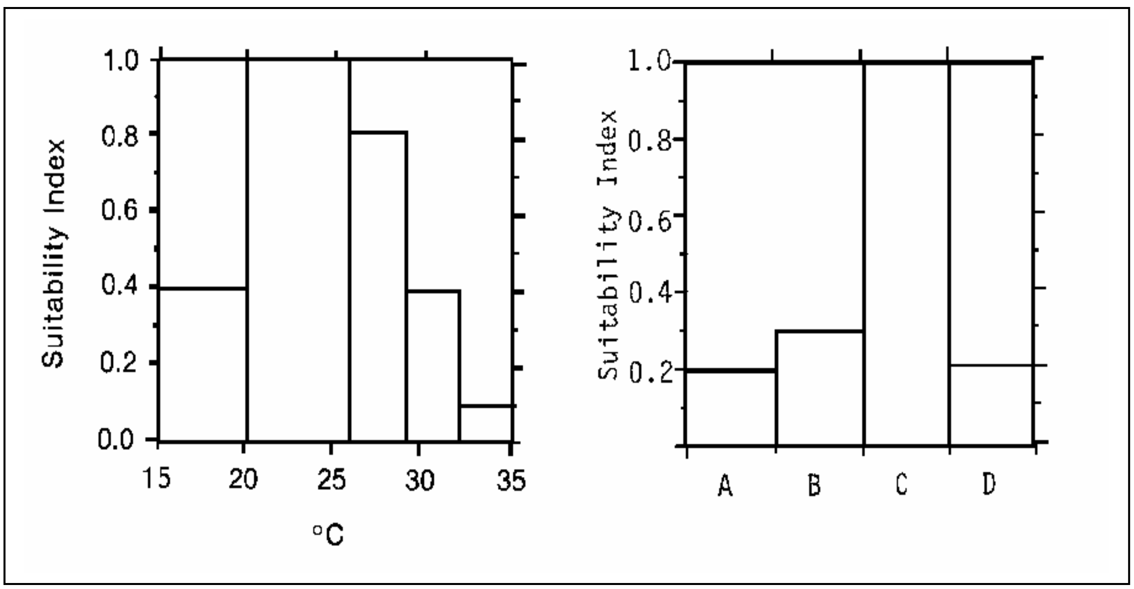


Figure 8. Categorized expressions in HSI models.

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.

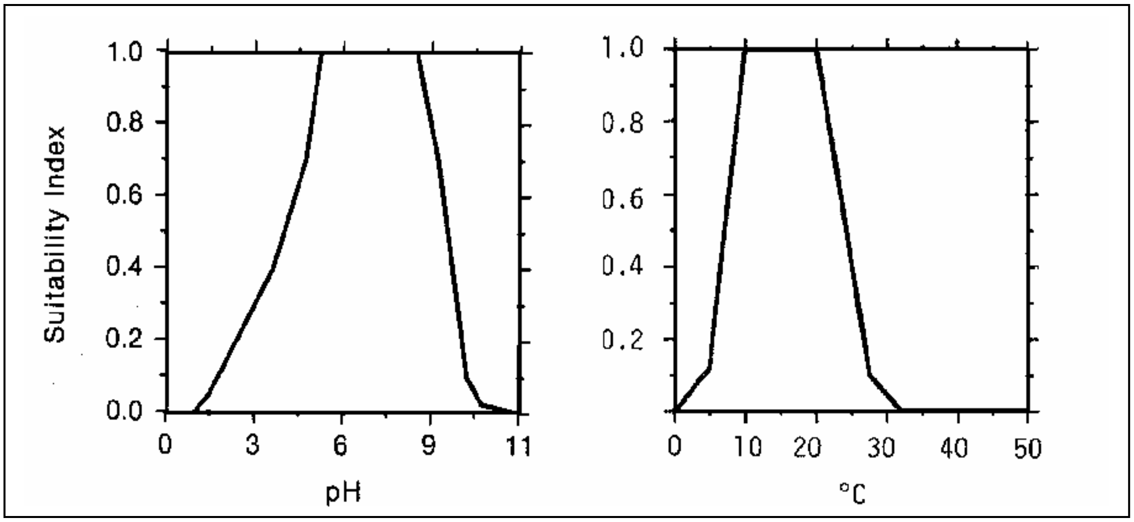


Figure 9. Linear expressions in HSI models.

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.

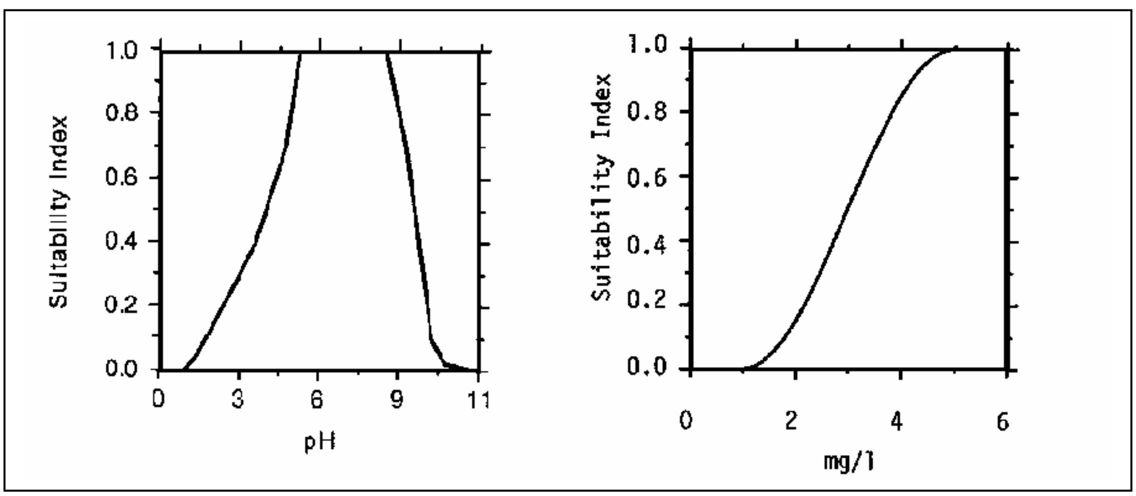


Figure 10. Curve relationships in HSI models.

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 sub-sheds may have contributed more runoff than others.

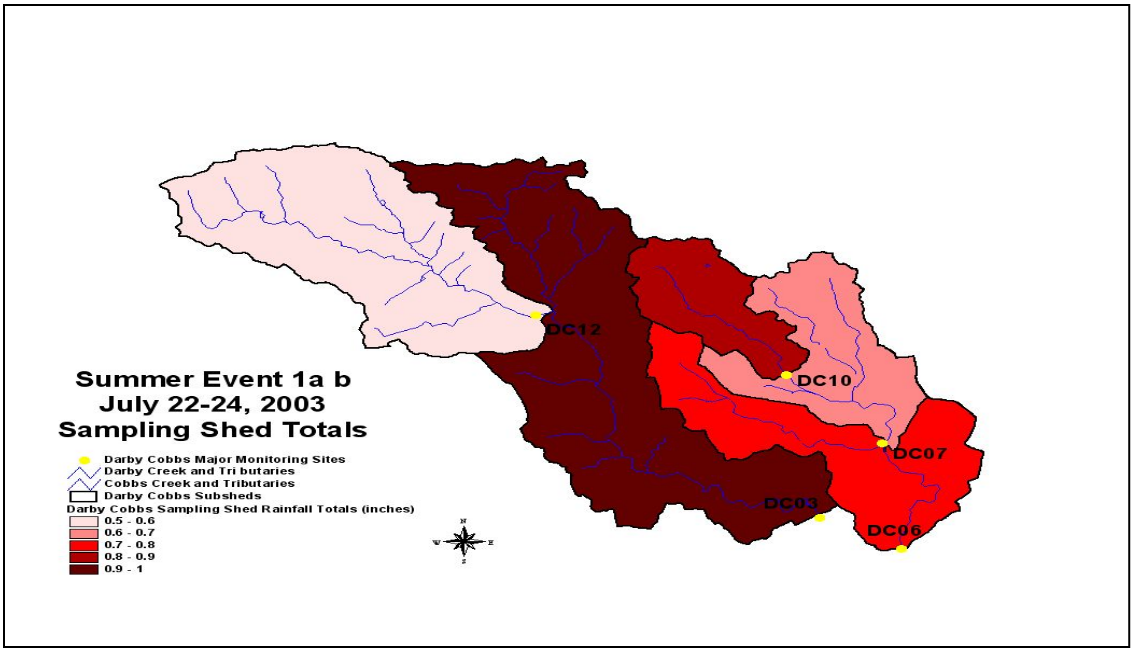


Figure 11. RADAR Rainfall totals by subshed (7/22/03-7/24/03).

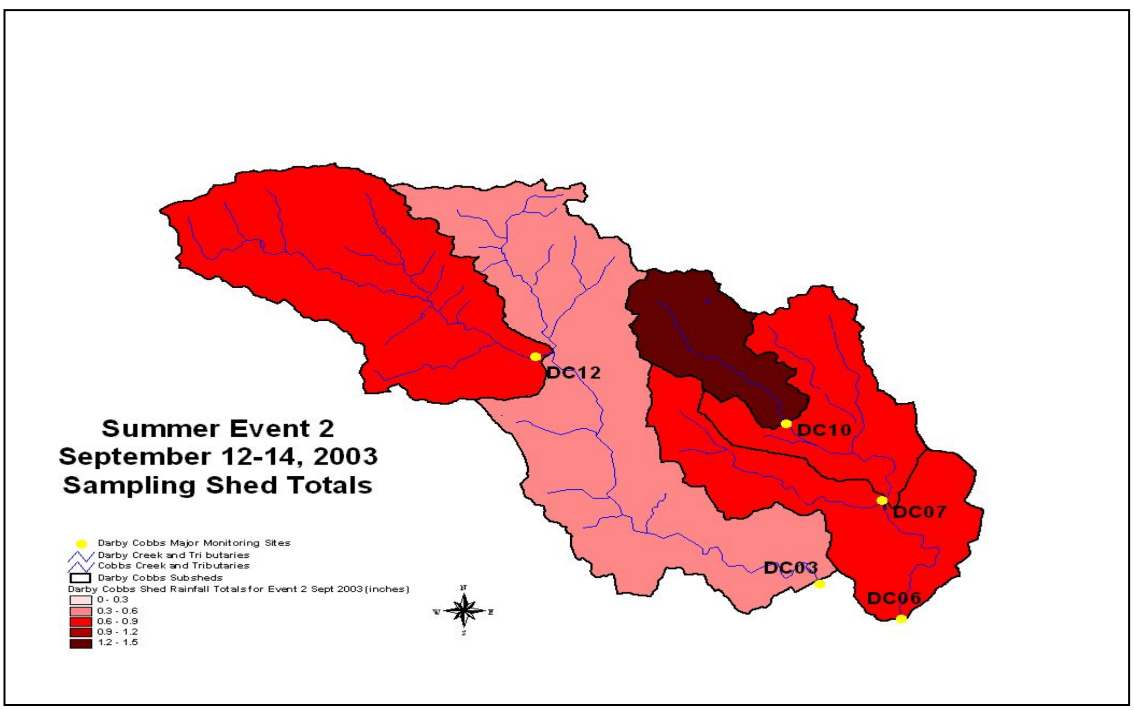


Figure 12. RADAR Rainfall totals by subshed (9/12/03-9/14/03).

SECTION 5: RESULTS AND DISCUSSION

5.1. Benthic Macroinvertebrate Assessment

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

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

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

5.1.1. Watershed Overview

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

Table 8. Biological condition results for RBP III.

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

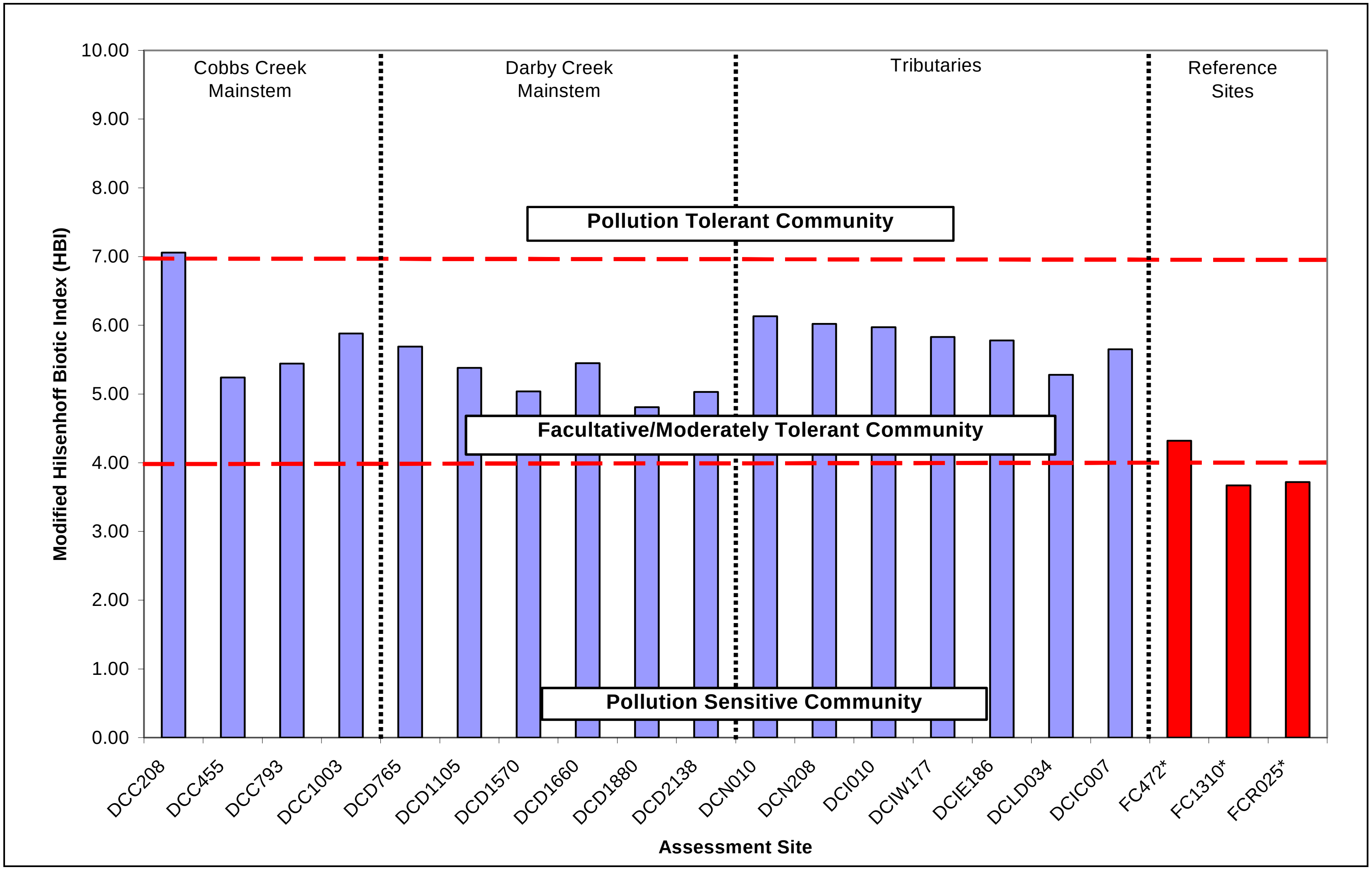


Figure 13. Modified Hilsenhoff Biotic Index (HBI) scores of assessment sites in Darby-Cobbs Watershed.

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

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

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

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

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

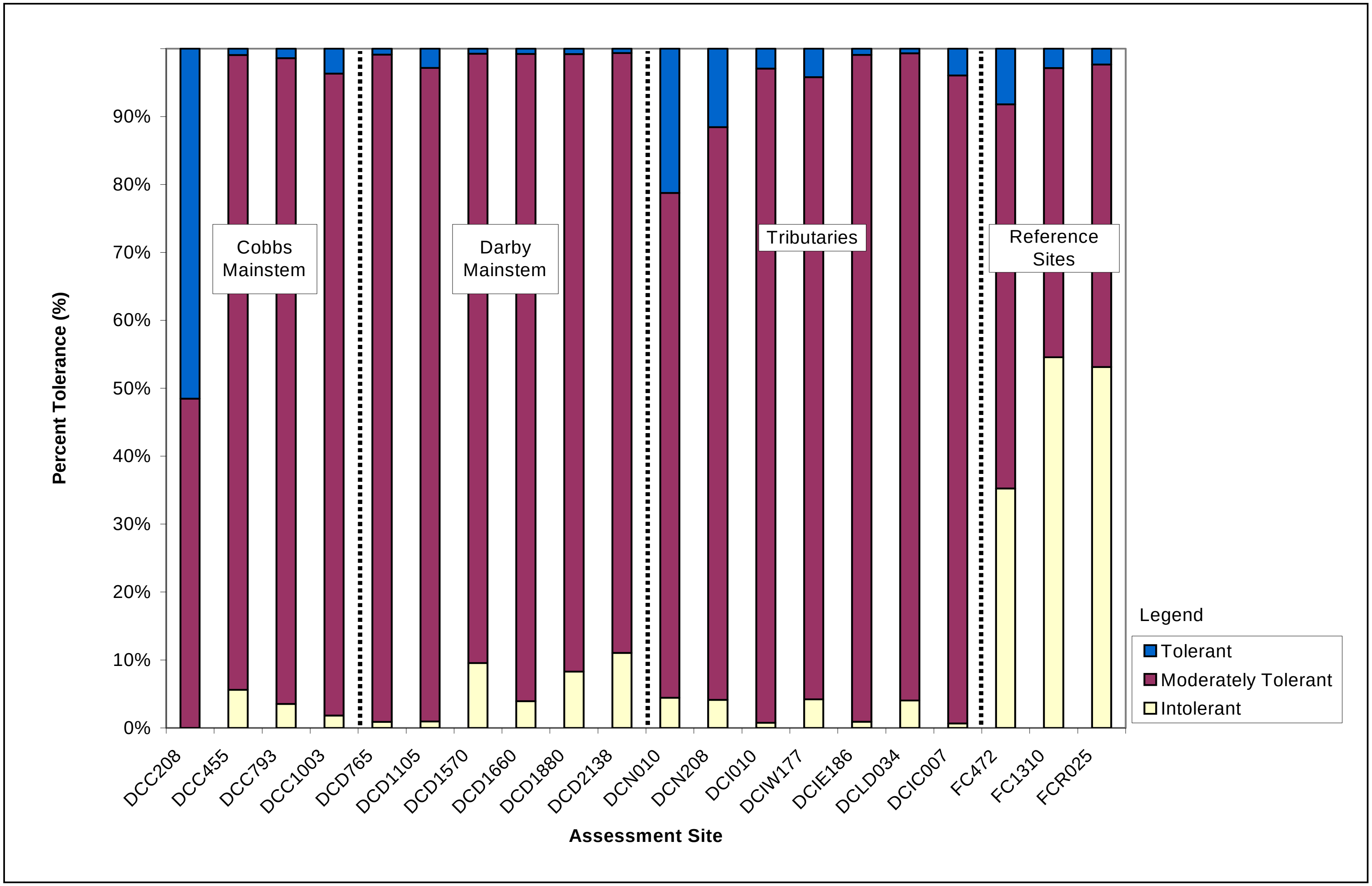


Figure 14. Pollution tolerance values (%) of macroinvertebrate assemblages at each assessment site in Darby-Cobbs Watershed.

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

5.1.2. Cobbs Creek Mainstem Sites

5.1.2.1. DCC208

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

5.1.2.2. DCC455

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

5.1.2.3. DCC793

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

5.1.2.4. DCC1003

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

5.1.3. Darby Creek Mainstem Sites

5.1.3.1. DCD765

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

5.1.3.2. DCD1105

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

5.1.3.3. DCD1570

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

5.1.3.4. DCD1660

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

5.1.3.5. DCD1880

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

5.1.3.6. DCD2138

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

5.1.4. Darby-Cobbs Tributary Sites

5.1.4.1. DCN010

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

5.1.4.2. DCN208

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

5.1.4.3. DCI010

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

5.1.4.4. DCIW177

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

5.1.4.5. DCIE186

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

5.1.4.6. DCLD034

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

5.1.4.7. DCIC007

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

5.2. Fish Assessment

5.2.1. Overview

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

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

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

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

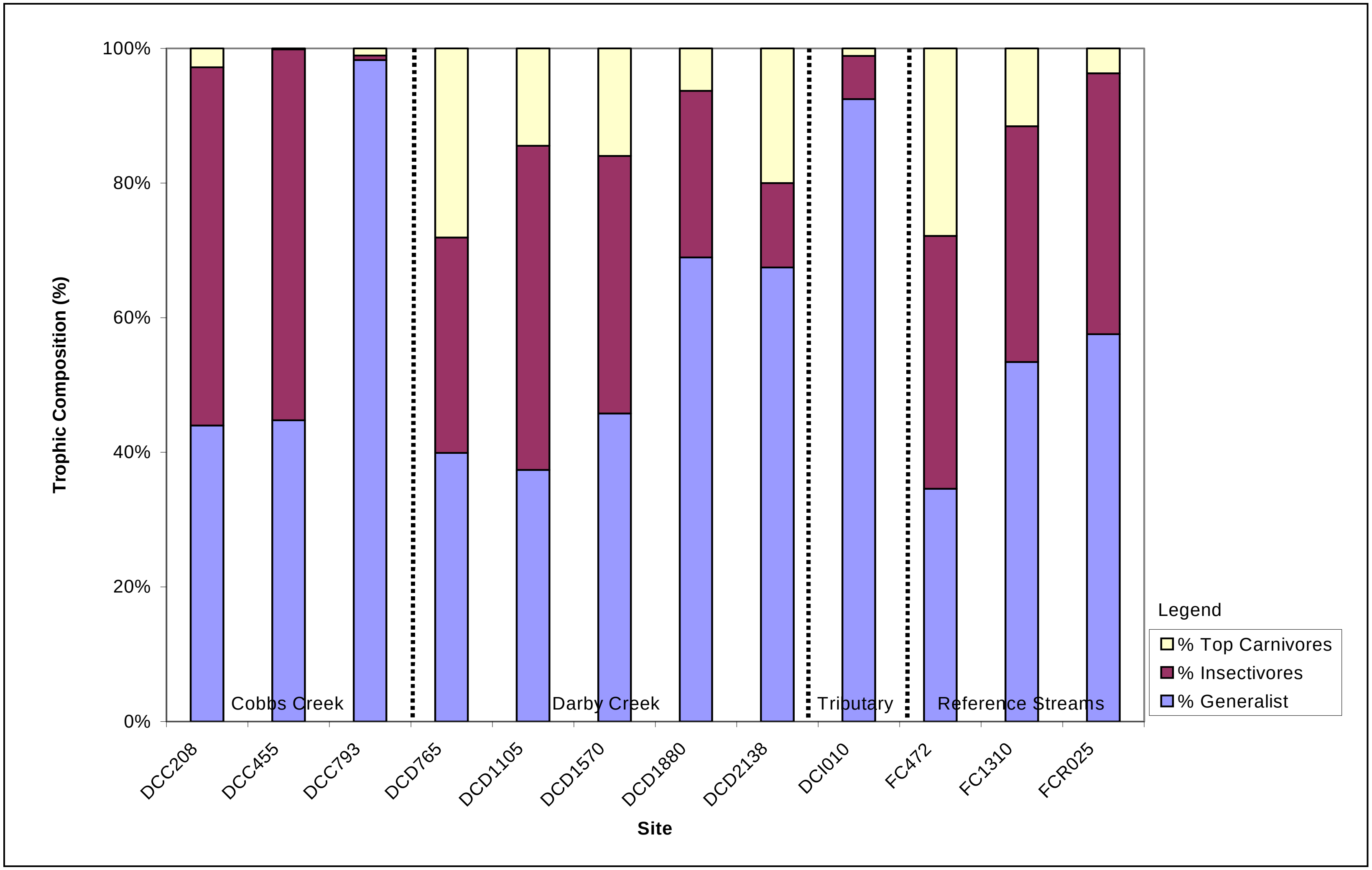


Figure 15. Trophic structure of fish assemblages in the Darby-Cobbs Watershed.

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

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

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

5.2.2. Cobbs Creek Mainstem Sites

5.2.2.1. DCC208

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

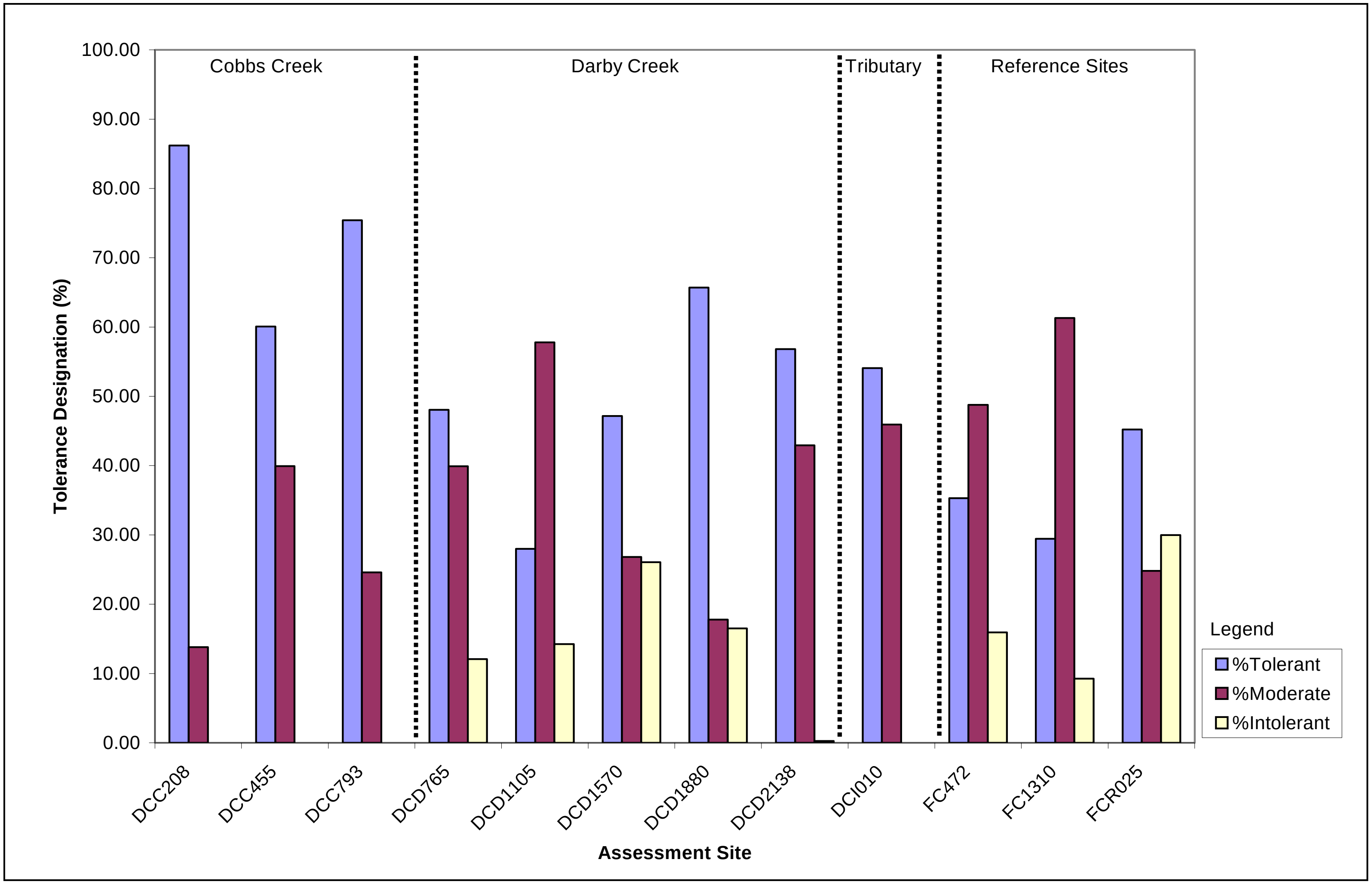


Figure 16. Pollution tolerance values at the monitoring sites in Darby-Cobbs Watershed.

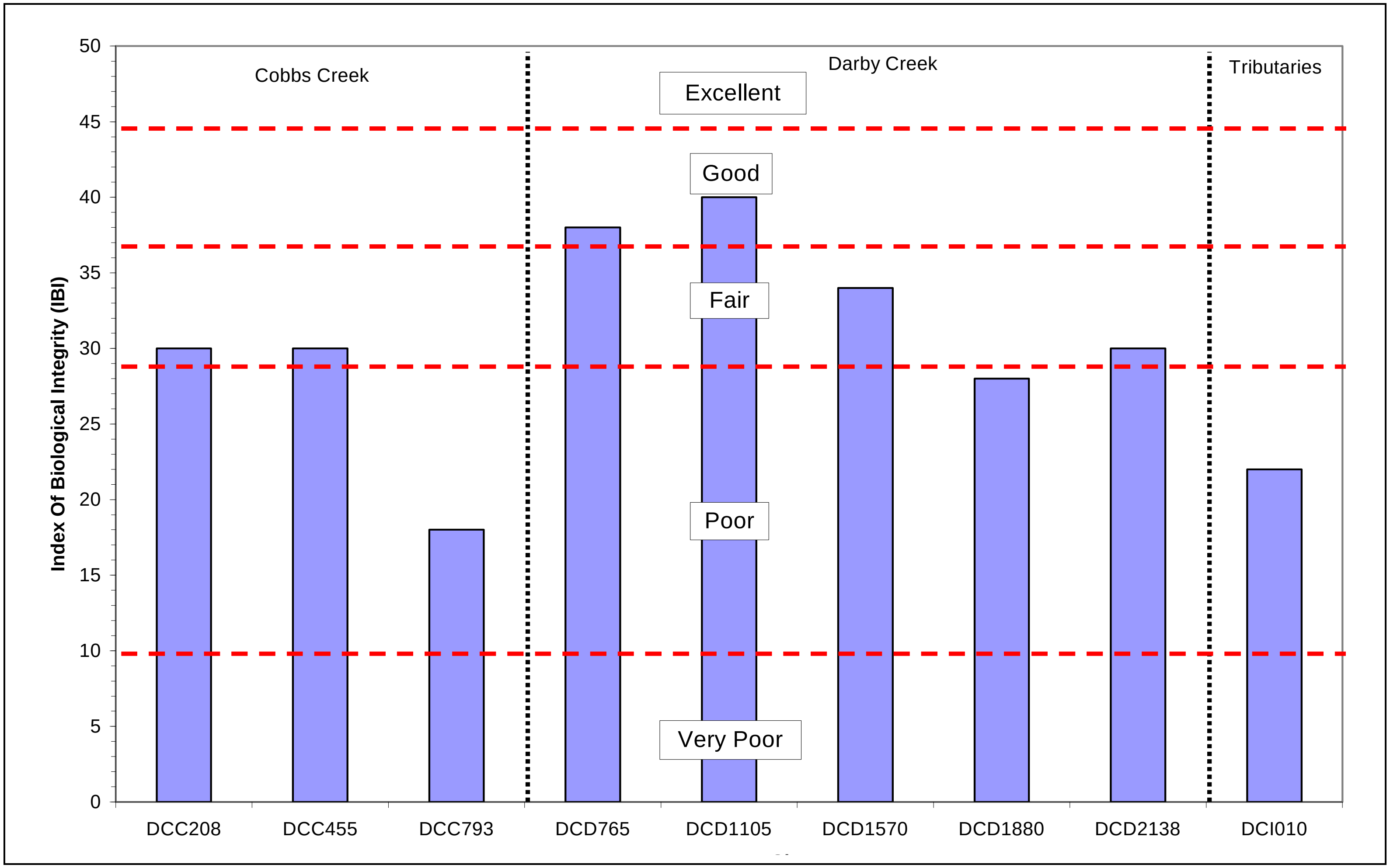


Figure 17. Index of Biological Integrity (IBI) scores at the nine assessment sites in Darby-Cobbs Watershed.

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

5.2.2.2. DCC455

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

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

5.2.2.3. DCC793

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

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

5.2.3. Darby Creek Mainstem Sites

5.2.3.1. DCD765

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

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

5.2.3.2. DCD1105

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

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

5.2.3.3. DCD1570

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

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

5.2.3.4. DCD1880

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

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

5.2.3.5. DCD2138

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

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

5.2.4. Darby-Cobbs Tributary Sites

5.2.4.1. DCI010

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

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

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

5.2.5. Darby-Cobbs Tidal Sites

5.2.5.1. DCC037

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

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

5.2.5.2. DCD630

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

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

5.3. Habitat Assessment

5.3.1. EPA Habitat Assessment Overview

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

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

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

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

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

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

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

5.3.2. Comparisons to Reference Site

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

5.3.3. Factor Analysis

Principal components analysis (PCA) in Statistica (Statsoft, 1998) was used to reduce the number of variables needed to explain the variation between scores for 13 different habitat attributes among Darby-Cobbs sites. The first factor extracted accounted for 53% of the variance in the data matrix. Habitat attributes with high loading values for factor one included epifaunal substrate, velocity/depth regime, channel flow status, bank vegetative protection, and all pool attributes (Appendix E). The second factor extracted accounted for 19% of the variance, for a cumulative total of 72% variance explained. No habitat attributes showed high loading scores for factor two (Appendix E). An ordination plot of Darby-Cobbs sites and three reference sites showed the sites distributed widely across PCA axis one, with five highest-rated upstream Darby Creek sites grouped closely between French Creek and Rock Run reference sites.

Overall, the placement of sites along axis 1 correlated closely with total habitat scores and relative comparability to the reference sites (Figure 18). PCA axis 2 was not particularly useful, except for weak negative associations with channel alteration and riparian zone width and positive associations with frequency of riffles, sedimentation, and embeddedness.

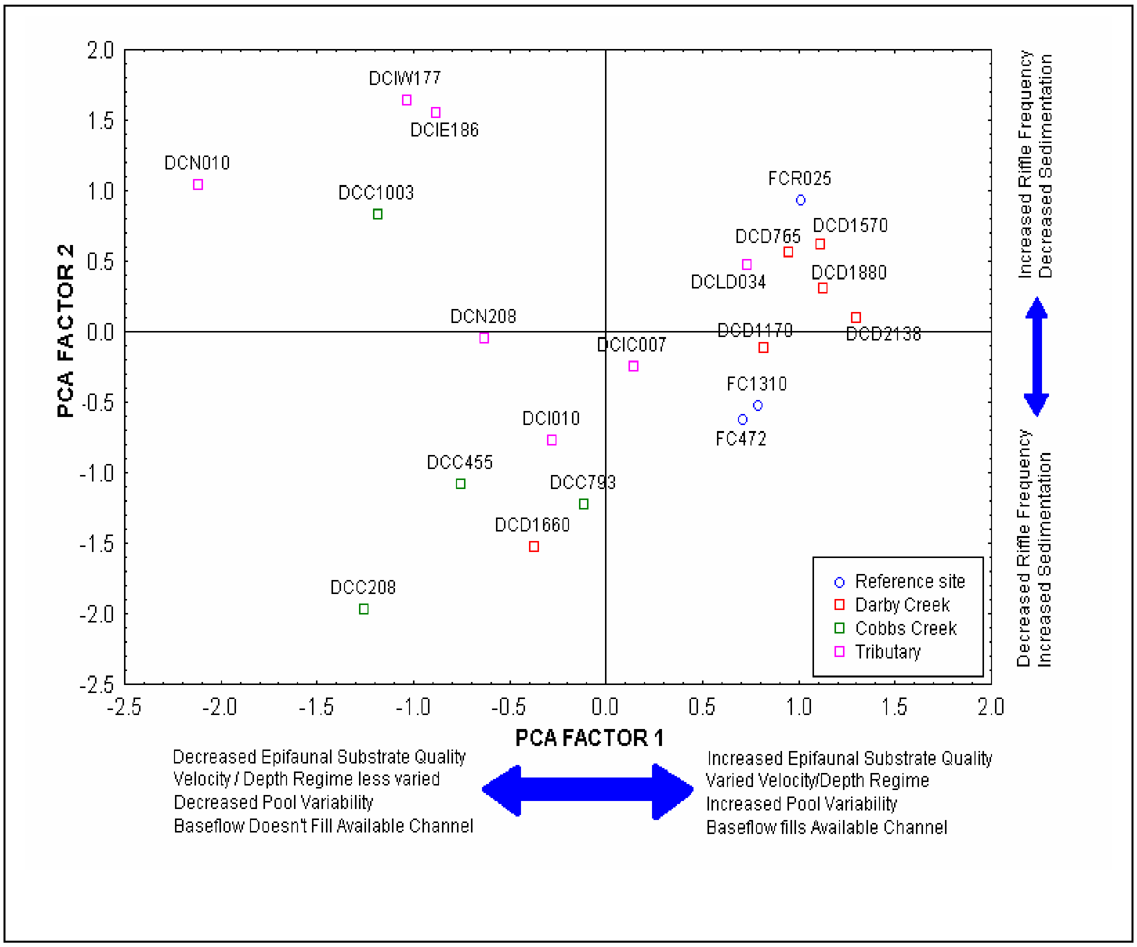


Figure 18. Principal Components Analysis ordination plot of 17 monitoring sites and 3 reference locations.

5.3.4. Individual Site Characterizations

5.3.4.1. Cobbs Creek Mainstem Sites

5.3.4.1.1. DCC208

Site DCC208 received a habitat assessment score of 127.5, and the habitat was deemed "partially supporting" (Figure 19). DCC208 was heavily impacted by sediment deposition (i.e., sand). The inorganic substrate of the site was 40% sand, and 60.0% of the macrohabitat was pools. Sedimentation, embeddedness, channel sinuosity, pool substrate, and epifaunal substrate all received marginal scores. These observations support the conclusion that the site was heavily impacted by stormwater. Poor scores were given for vegetative protection, bank stability and the left bank riparian zone. Overall habitat quality was marginal, with limited potential to support diverse aquatic communities.

5.3.4.1.2. DCC455

The habitat assessment score at site DCC455 was 142.5. This score represents a 75.2% comparison to the reference and classifies it as "supporting". DCC455 is just upstream of DCC208 and exhibited similar habitat impairments. The macrohabitat was a relatively even mix of pools, riffles and runs, but there was heavy sediment deposition throughout the stream reach (40% of substrate was sand). All of the habitat parameters were scored suboptimal or marginal. The stream banks were moderately stable, but were dominated by invasive emergent vegetation (Japanese knotweed). The riparian zone on the right bank was marginal due to areas mowed up to the stream bank. A strong sewage odor was present at the time of the habitat assessment.

5.3.4.1.3. DCC793

Site DCC793 received a habitat assessment score of 163.5, which represents an 86.3% comparison to the reference site ("supporting" designation). Macrohabitat at the site was well distributed among riffles, runs and pools, and the stream substrate was diversified, as well. Epifaunal substrate and available cover in the stream reach was optimal. The width of the riparian zone along the left bank was also favorable. Most other habitat features at DCC793 were suboptimal. Similar to other assessment sites on Cobbs Creek, moderate sand deposition was present throughout the stream reach. Most of the pools within the site were large and deep with a primarily sandy substrate. The riparian vegetative zone was much wider along the left bank of the stream than the right bank. Stability, however, was greatly reduced on the left bank where high flows had previously eroded much of the bank. The increased erosion of the left bank may be due to channel sinuosity at this location, which directs flow in that direction. Habitat at site DCC793 also may have been impacted by an exposed sewer line that crossed the stream at the upstream boundary of the assessment site.

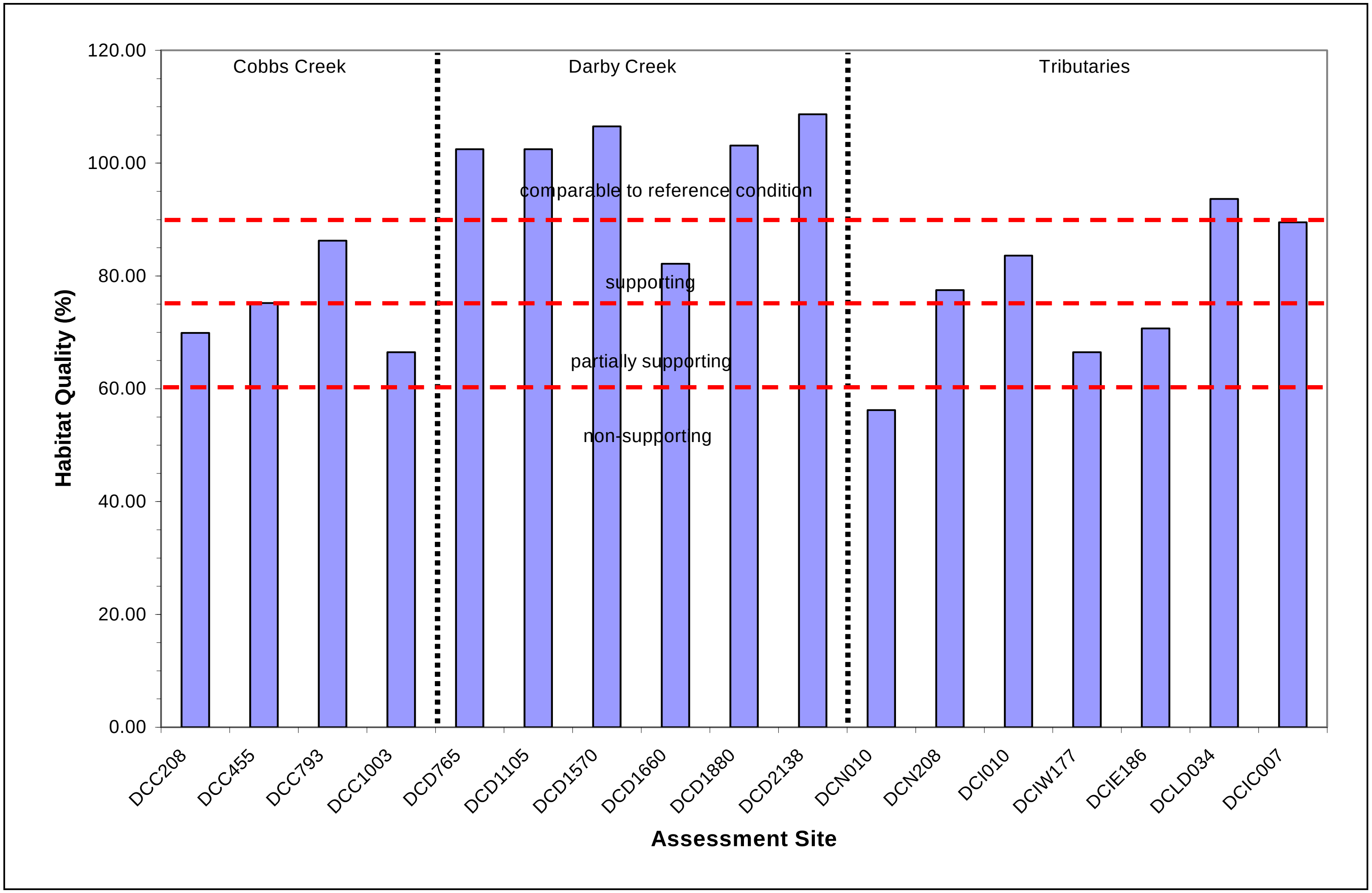


Figure 19. Habitat quality of 17 assessment sites in Darby-Cobbs Watershed. Values are represented as percent comparability to reference conditions.

5.3.4.1.4. DCC1003

Site DCC1003 received a habitat assessment score of 126.0. The site had the lowest score of all mainstem Cobbs Creek sites and was designated "partially supporting". The area surrounding the site was primarily residential with maintained lawns. The epifaunal substrate and available cover, pool substrate, and pool variability all received marginal scores. Evidence of heavy erosion was present throughout the site, and stream banks were moderately unstable. The riparian zone was insufficient, and vegetative protection was marginal. The stream was altered in areas by channelization, and the channel lacked sinuosity. The site appeared highly susceptible to erosion during periods of increased flow.

5.3.4.2 Darby Creek Mainstem Sites

5.3.4.2.1. DCD765

Site DCD765 received a habitat assessment score of 188.5, and the habitat was designated "comparable to reference" (102.4% comparison). Optimal habitat scores for epifaunal substrate and available cover, pool substrate characterization, pool variability, channel flow status, embeddedness, and velocity/depth regime all contributed to the site's excellent habitat score. The site also had an even combination of substrate components. All other condition categories were scored as suboptimal, except for the riparian vegetative zone width along the right bank, which was poor due to the presence of a mowed recreational area adjacent to the creek's right bank. A small area of stream bank was stabilized with rip-rap on the left bank. There was also moderate deposition throughout the stream reach.

5.3.4.2.2. DCD1105

The habitat assessment score of site DCD1105 was 188.5. This represents a 102.4 % comparison to the reference site and deems the habitat "comparable to reference". The habitat features of DCD1105 are very similar to that of DCD765. All of the habitat parameters were rated optimal or suboptimal except for the left bank riparian corridor, which received a marginal score due to an access road and mowed area that parallel the creek. The stream had an even distribution of macrohabitat types (i.e., pool, riffle, run). Both banks were relatively stable with decent vegetative protection.

5.3.4.2.3. DCD1570

Site DCD1570 received a habitat assessment score of 196.0, which represents a 106.5% comparison to the reference ("comparable to reference"). The macrohabitat at the site was primarily riffle (50%). The substrate components were mostly cobble and gravel (40% each), and there was light sand deposition. The predominant land use surrounding DCD1570 was forested area, but I-476 (i.e., the Blue Route) parallels the right bank of the stream. The highway was the main factor for the right bank's low riparian vegetative zone width score. DCD1570 had potential to be impacted by storm water run-off from the interstate highway. The channel sinuosity was marginal, but there were frequent riffles along the stretch.

5.3.4.2.4. DCD1660

The habitat score at DCD1660 was 156.5—an 82.2% comparison to the reference site (“supporting” designation). Most habitat parameters were scored suboptimal or marginal. Inorganic substrate was composed of 40% sand, and the site exhibited evidence of heavy sand deposition. The right bank at DCD1660 was moderately unstable, and the stream reach had low sinuosity. DCD1660 had the lowest habitat score of all mainstem Darby Creek sites.

5.3.4.2.5. DCD1880

Site DCD1880 received a habitat assessment score of 196.5, and the habitat was deemed “comparable to reference” (103.1% comparison). Most habitat attributes were scored optimal or suboptimal. The vegetative zone width on the left bank, however, was poor due to an adjacent pasture that was mowed close to the bank of the creek. An instream habitat restoration project was constructed upstream of the assessment site where submerged logs, snags and other stable habitat/fish cover features were installed along the banks to allow for greater colonization and maintenance of fish populations.

5.3.4.2.6. DCD2138

The habitat at site DCD2138 scored 207.0, and the site was designated “comparable to reference” (108.6% comparison). The site received the highest habitat score of all Darby-Cobbs assessment sites. DCD2138 is the farthest upstream assessment site on Darby Creek, and the site is located within a Brandywine Conservancy property. Habitat parameters were scored optimal or suboptimal. Macrohabitat types and inorganic substrate were both evenly distributed. Banks were stable, and a well-developed riparian corridor was present. Stable banks and not a lot of sedimentation suggest that the site had little impact from stormwater run-off and would have the potential to support a diverse biotic community.

5.3.4.3. Darby-Cobbs Tributary Sites

5.3.4.3.1. DCN010

Habitat assessment at site DCN010 returned a score of 106.5. The site was only 56.2% comparable to the reference site, and habitat was deemed “non-supporting”. DCN010 had the lowest habitat score of all assessment sites. Field observations included a sewage odor and slightly turbid water. Inorganic substrate in the forms of boulder, cobble, and gravel was predominantly artificial (i.e. construction debris). The site was devoid of pools and had poor epifaunal substrate and available cover. Due to an overwidening of the stream channel, stream flow no longer reached the stream banks, and sediment bars were left exposed. The banks were moderately stable due to shoring structures (i.e. rip rap) and marginal vegetative protection.

5.3.4.3.2. DCN208

The assessment site at DCN208 scored 146.5 and was a 77.3% comparable to the reference site ("supporting" designation). Most habitat attributes were scored suboptimal or marginal. Field observations included heavy periphyton growth and a sewage odor emanating from the substrate. There was heavy local erosion with moderate sand deposition. Macrohabitat in the stream was predominantly riffle (50%), and substrate was evenly distributed. Suboptimal vegetative protection left the majority of the banks moderately unstable. Trees and Japanese knotweed were the predominant vegetation at DCN208.

5.3.4.3.3. DCI010

Site DCI010 received a habitat assessment score of 158.5, which classified the habitat as "supporting" (83.6% comparison). The site received suboptimal and marginal scores for most habitat condition parameters. Still, channel alteration at the site was optimal as the stream had retained a natural pattern and exhibited fair sinuosity. Cobble and sand dominated the substrate components, and evidence of erosion was moderate throughout the assessment site. The left bank was somewhat unstable, which could be a direct result of stormwater pulses.

5.3.4.3.4. DCIW177

Site DCIW177 received a habitat assessment score of 126.0. The habitat was designated "partially supporting", with a 66.5% comparison to the reference site. Most habitat parameters were scored suboptimal or marginal, with the exception of pool variability and riparian zone width which received "poor" scores. Pools composed only 20.0% of the macrohabitat type, and most of the pools present at DCIW177 were small and shallow. The riparian zone width was very much insufficient along both banks. Various sections of the stream bank within the assessment site were armored with rip-rap to protect against erosion. Excessive erosion rates in the stream segment may have been due to the lack of a satisfactory riparian area.

5.3.4.3.5. DCIE186

The assessment site at DCIE186 received a habitat assessment score of 134.0 which was a 70.71% comparison to the reference site ("partially supporting" designation). Frequency of riffles received an optimal score as riffles composed 50.0% of macrohabitat in the stream. All of the other habitat parameters were scored suboptimal or marginal. Lankenau Hospital is adjacent to the right bank of the assessment site and maintains a mowed field along this bank, decreasing the site's riparian vegetative zone score. Similar to West Branch Indian Run, only 20% of macrohabitat type was pools, and the pools at DCIE186 were all small and shallow.

5.3.4.3.6. DCLD034

The habitat assessment score at site DCLD034 was 177.5 and was 93.7% comparable to the reference site. Habitat conditions at the site were generally scored optimal or suboptimal. The stream segment had numerous riffles, and stream sinuosity was decent. There was moderate erosion along the stream banks and evidence of deposition in the pools. These latter attributes may be due to the lack of a sufficient riparian zone along the stream reach. The vegetative riparian buffers on both sides of the creek were less than desirable due to a maintained field cut short along both banks. The riparian zone width received a marginal score despite the "comparable to reference" designation of the site.

5.3.4.3.7. DCIC007

Site DCIC007 received a habitat assessment score of 170.5, which resulted in a "supporting" designation (89.5% comparison). Vegetative protection on both banks was scored optimal. Vegetation disruption was not evident, and banks were well covered with trees and understory shrubs. Most habitat parameters, however, were scored as suboptimal or marginal. The site was adversely affected by sediment deposition in the form of sand and by moderate erosion.

5.3.5. Habitat Suitability Indices

5.3.5.1. Overview

Habitat Suitability Indices (HSI) developed by The U.S. Fish and Wildlife Service (USFWS) were applied to sites in Darby-Cobbs Watershed targeted for fish sampling. These models integrate the expected effects of a variety of environmental, physicochemical, and hydrological variables on representative native species, as well as species of special environmental or economic concern. As stream restoration activities recommended under Target B of the watershed management plan are implemented, these indices will allow for habitat improvements to be measured quantitatively. Because freshwater fish communities are shaped by myriad inter-related environmental and ecosystem interactions and stressors (e.g., habitat degradation, flow modification, predation, competition, disease, invasive species, toxic substances, prey population dynamics, etc.), beneficial effects of habitat restoration may be obscured by other factors. Numeric HSI allow for habitat to be evaluated independently of these confounding factors.

While it may be possible to model habitat suitability for most (or even all) species found in a waterbody, this level of analysis is probably unnecessary. Habitat requirements of many species are so poorly understood that HSI have not been developed or are only generally applicable. Furthermore, many groups of species (e.g., sunfish) share many habitat requirements, obviating the need to model habitat suitability for each individual species. Best results may be obtained when HSI of a small number of sensitive, recreationally-sought, or economically important species of interest are considered.

5.3.5.2. HSI Model Selection

HSI models for seven species were selected for Darby-Cobbs Watershed. Models were chosen to reflect the range of habitat types and attributes needed to support healthy, naturally-reproducing native fish communities and provide recreational angling opportunities in non-tidal portions of the watershed. Five native minnow species were selected for HSI analysis: Blacknose dace (*Rhinichthys atratulus*), Common shiner (*Luxilis cornutus*), Creek chub (*Semotilus atromaculatus*), Fallfish (*Semotilus corporalis*), and Longnose dace (*Rhinichthys cataractae*). Of these, *R. cataractae* is not known to occur in Darby-Cobbs Watershed. However, this species' known affinity for stable, high quality riffle habitats is reflected in its HSI, prompting inclusion in the analysis as an important indicator of those macrohabitat features. The Longnose dace HSI may be considered a surrogate indicator of habitat suitability for other riffle species (e.g., darters) for which no HSI are available.

Two centrarchid fish, Redbreast sunfish (*Lepomis auritus*), and Smallmouth bass (*Micropterus dolomieu*), were included in the analysis. These species are tolerant of warmer water temperatures and require extensive slow, relatively deep water (i.e., pool) habitats with appropriate cover or structure to achieve maximum biomass. While black basses (*M. dolomieu* and its congener *M. salmoides*) are not native to southeastern Pennsylvania, they occupy the top carnivore niche and are among the most sought-after freshwater game fish in water bodies where they occur. Moreover, the only other large-bodied piscivores known to occur in non-tidal portions of Darby-Cobbs Watershed are American eels, native catadromous fish for which no HSI has been developed, and three salmonids (Rainbow trout, *Oncorhynchus mykiss*; Brown trout, *Salmo trutta*; and Brook trout, *Salvelinus fontalis*), "coldwater" species, maintained in the watershed solely through stocking.

5.3.5.3. Smallmouth Bass HSI Model

The small number of *M. dolomieu* (n=10) collected from non-tidal reaches of Darby-Cobbs watershed hindered data analysis. However, mean HSI score of three Darby Creek sites where these fish were collected was 0.82, while mean HSI score of the 6 sites where fish were not collected was 0.61. Sites where fish were collected had higher HSI scores than sites where fish were not collected in all cases. Correlations between HSI score and Smallmouth bass abundance and biomass were weak, largely due to lack of data. Results of HSI analyses (Table 10) corroborated findings of other research, particularly general habitat and continuous water chemistry analyses.

Table 10. Smallmouth bass HSI individual variable scores, total HSI score and fish data by site.

Habitat Variable	DCC208	SI	DCC455	SI	DCC793	SI	DCD765	SI	DCD1170	SI	DCD1570	SI	DCD1880	SI	DCD2138	SI	FC472	SI
substrate type category	B	0.30	B	0.30	C	1.00	C	1.00	C	1.00	C	1.00	A	0.20	C	1.00	C	1.00
percent pools	36.01	0.69	25.00	0.44	56.98	1.00	34.57	0.66	26.32	0.47	38.74	0.75	26.86	0.49	12.80	0.17	48.08	0.96
Avg. pool Depth	0.71	0.59	0.50	0.42	0.39	0.33	0.83	0.69	0.59	0.49	0.68	0.57	0.51	0.43	0.59	0.49	0.56	0.47
percent cover	12.50	0.50	11.87	0.47	20.63	0.83	21.25	0.85	20.00	0.80	20.00	0.80	21.88	0.88	20.00	0.80	21.25	0.85
average pH	7.45	0.98	7.48	0.99	7.32	0.96	7.86	0.96	7.60	0.99	7.51	0.99	7.20	0.94	7.10	0.92	7.90	0.93
Dissolved Oxygen	2.93	0.16	3.72	0.32	3.96	0.38	4.00	0.38	4.00	0.38	6.00	0.97	6.00	0.97	6.00	0.97	7.00	1.00
Turbidity	25.00	1.00	25.00	1.00	25.00	1.00	25.00	1.00	25.00	1.00	25.00	1.00	25.00	1.00	25.00	1.00	25.00	1.00
Temperature (adult)	19.50	0.83	20.00	0.86	20.20	0.86	19.30	0.82	18.30	0.76	18.10	0.76	18.70	0.79	18.00	0.75	18.00	0.75
Temperature (embryo)	16.95	1.00	19.70	1.00	18.40	1.00	19.10	1.00	18.80	1.00	18.70	1.00	20.30	1.00	17.00	1.00	17.00	1.00
Temperature (fry)	19.50	0.80	20.00	0.83	20.20	0.84	19.30	0.79	18.30	0.73	18.10	0.71	18.70	0.75	18.00	0.71	18.00	0.71
Temperature (juvenile)	19.50	0.84	20.00	0.86	20.20	0.87	19.30	0.83	18.30	0.78	18.10	0.77	18.70	0.80	18.00	0.76	18.00	0.76
Water fluctuations	A	0.30	A	0.30	A	0.30	A	0.30	A	0.30	A	0.30	A	0.30	A	0.30	A	0.30
Stream Gradient	15.10	0.50	4.70	1.00	12.70	0.50	3.50	1.00	3.80	1.00	2.40	1.00	2.40	1.00	12.00	0.50	10.00	0.50
Food (C_F) component		0.47		0.40		0.94		0.82		0.72		0.84		0.44		0.52		0.93
Cover (C_C) Component		0.52		0.41		0.79		0.80		0.69		0.78		0.50		0.62		0.82
Water Quality Component C_{WQ}		0.76		0.80		0.81		0.79		0.78		0.89		0.89		0.87		0.88
Reproduction (C_R) Component		0.49		0.54		0.71		0.72		0.71		0.81		0.65		0.81		0.82
Other (C_{OT}) component		0.50		1.00		0.50		1.00		1.00		1.00		1.00		0.50		0.50
H S I score		**0.49**		**0.54**		**0.73**		**0.82**		**0.77**		**0.86**		**0.66**		**0.65**		**0.77**
abundance		0.00		0.00		0.00		2.00		5.00		3.00		0.00		0.00		0.00
biomass		0.00		0.00		0.00		129.70		340.84		272.30		0.00		0.00		0.00

No smallmouth bass were collected from Cobbs Creek. Sites DCC208 and DCC455 had the lowest HSI scores in the watershed and were limited by dissolved oxygen concentration, cover, and pool substrate composition (Table 10). Site DCC793 was limited by stream gradient and depth of pools, indicating unsuitably high stream velocities in pool habitats. Sites in Cobbs Creek generally exhibited unsuitable characteristics (e.g., lack of cover, decreased substrate size, or increased velocity) in pool habitats; these factors force bass to expend more energy acquiring food. Competition from American eels and the frequency and magnitude of severe storm flow conditions cannot be discounted as factors making Cobbs Creek less suitable for Smallmouth bass.

Ten smallmouth bass individuals were collected from the three downstream-most sites within the non-tidal portion of Darby Creek watershed. The lack of Smallmouth bass at upstream sites is to be expected, as this species requires deeper, calmer water than is typically found in first- or second-order stream sites. It should be noted that Darby Creek watershed is generally less affected by urbanization than Cobbs creek watershed, and has more of its historic tributaries intact. Stream order and river mile-based comparisons between the two watersheds are probably not very meaningful. Within Darby Creek watershed, sites where Smallmouth bass were not collected had, in some cases, pool structure, substrate size and or cover numerically similar to downstream sites, suggesting that distribution may be related stream size.

Like most centrarchids, Smallmouth and Largemouth basses are able to acclimate to brief periods of suboptimal dissolved oxygen concentration. With few exceptions, such as sites in which DO concentrations may frequently drop below 3mg/l for extended periods, or sites in which spawning substrates are chronically anoxic with Hydrogen sulfide (H_2S) present, Smallmouth bass distributions are probably not strongly governed by DO concentrations. Furthermore, many centrarchid species' thermal preferenda are higher than temperatures typical of 2nd to 4th order streams in southeast PA. Most species are known to reach their maximum size in the non-temperate Southern U.S., growing fastest in lentic habitats where conditions are suitable for growth year-round and specific management techniques are employed. HSI model temperature output (Table 10) reflects the fact that optimum temperatures are seldom reached in Southeastern PA.

Stream restoration activities that increase the amount of instream and overhanging cover, or activities that create, expand or improve pool habitats probably will result in increased habitat suitability for Smallmouth bass. Re-meandering of the stream channel, installation of flow diverters such as rock vanes and J-hooks, as well as the creation of undercut banks through log sill cribbing and cantilevered banks should also enhance habitat for Smallmouth bass and forage fish by establishing low velocity refugia during storms.

Infrastructure assessments, inspections, and dry weather pollution source trackdown activities will likely reduce the severity of water quality (i.e., DO and pH related) impacts on HSI scores at some sites, particularly DCC208 and DCD765. It is unlikely that habitat impairment due to frequent water level fluctuations and the effects of erosion and sedimentation will be ameliorated in the near future without significant investments in streambank restoration and basin-wide implementation of stormwater BMPs.

5.3.5.4. Redbreast Sunfish HSI Model

As a generalist species, Redbreast sunfish (*Lepomis auritus*) are adaptable to a range of habitat attributes and may feed opportunistically upon a variety of prey types. Most SI variable expressions in this species' HSI include a large range of highly suitable values (or large area "under the curve"). HSI scores (Table 11) did not generally correlate well with observed *L. auritus* abundance or biomass. Limiting factors included pH, vegetative cover, temperature, and substrate-related variables, but the discriminatory power of the HSI was probably limited by lack of variability among sites.

Site DCC793 received the highest HSI score in the watershed, yet only 1 Redbreast Sunfish was collected at this site. DCC793 was the only site in the watershed that had a sizeable population of Pumpkinseed sunfish (*L. gibbosus*). At most other sites, Redbreast sunfish were more abundant than other sunfish species, though a longitudinal trend in sunfish species diversity increasing from downstream to upstream was observed in Darby Creek. Sunfish species' habitat needs are generally similar; there was no obvious explanation for the change in species relative abundance. Somewhat better correlations resulted from comparison of a modified version of the HSI to grouped *Lepomis* spp. abundance and biomass (Table 12).

pH limitation was indicated at sites DCD765 and DCC208, where pH fluctuations due to algal activity occasionally result in pH >9.0. The Redbreast sunfish HSI model was probably not designed to be used with the least suitable value picked from a continuous database. Because fish can avoid areas of unsuitable pH when they occur infrequently, it would be more suitable for the model to account for how frequently unsuitable pH conditions occur (e.g., take the 90th percentile value, disregard outliers, etc.).

Likewise, summer temperature during spawning may poorly reflect habitat suitability for this species. The HSI was developed for an industrial cooling water investigation in the southern U.S.; temperature parameters should not be expected to be "optimal" in the temperate northeast. Fish collected at upstream sites with less suitable spawning temperatures may spawn at warmer downstream locations or in sunnier, sandy backwaters that are not accounted for in the data.

Observations made during electrofishing surveys suggested that Redbreast sunfish (and congeneric sunfishes) are most frequently found associated with cover, which can be difficult to measure quantitatively. Cover measurements included in the Redbreast Sunfish HSI were normalized to a scale of 0-25 from EPA Habitat assessment variable 1: Epifaunal Substrate and Available cover (Section 5.3.1.). As most sites in Darby-Cobbs Watershed are known to be deficient in vegetative cover, the "% vegetative cover" variable was estimated as half this normalized Epifaunal substrate value (e.g., EPA Epifaunal Substrate and Available Cover score =20, HSI Cover % =25, HSI vegetative cover % = 12.5.)

Table 11. Redbreast sunfish HSI individual variable scores, total HSI score and fish data by site.

Habitat Variable	DCC208	SI	DCC455	SI	DCC793	SI	DCD765	SI	DCD1105	SI	DCD1570	SI	DCD1880	SI	DCD2138	SI	FC472	SI
% cover	12.50	0.70	11.87	0.68	20.63	0.90	21.25	0.91	20.00	0.88	20.00	0.88	21.88	0.93	20.00	0.88	21.25	0.91
vegetated cover	6.25	0.53	5.94	0.52	10.31	0.61	10.63	0.61	10.00	0.60	10.00	0.60	10.94	0.62	10.00	0.60	10.63	0.61
spawning temperature (summer)	19.50	0.40	20.00	1.00	20.20	1.00	19.30	0.40	18.30	0.40	18.10	0.40	18.70	0.40	17.00	0.40	18.00	0.40
% slow pools	36.01	0.96	25.00	0.70	56.98	0.92	34.57	0.93	26.32	0.73	38.74	0.81	26.86	0.74	12.80	0.35	48.08	0.87
% sand/gravel	58.00	1.00	70.00	1.00	43.00	1.00	17.00	0.40	39.00	1.00	47.00	1.00	49.00	1.00	35.00	0.90	16.00	0.39
least suitable pH observed	9.07	0.34	6.89	1.00	6.04	1.00	9.92	0.06	6.50	1.00	6.58	1.00	7.50	1.00	7.50	1.00	7.50	1.00
minimum DO (category)	B	0.70	B	0.70	B	0.70	B	0.70	A	1.00	A	1.00	A	1.00	A	1.00	A	1.00
max temp growing season	23.10	0.80	23.50	0.80	23.20	0.80	24.40	0.80	21.50	0.80	21.30	0.80	22.90	0.80	19.00	0.50	20.00	0.80
stream width	15.23	1.00	10.00	1.00	9.30	1.00	15.07	1.00	14.50	1.00	12.08	1.00	10.77	1.00	5.35	0.84	14.20	1.00
H S I score final		**0.34**		**0.52**		**0.61**		**0.06**		**0.40**		**0.40**		**0.40**		**0.35**		**0.39**
***L. auritus* abundance**		62		227		1		66		39		20		4		25		
***L. auritus* biomass**		638		3365		0		2005		1205		1076		162		1036		

Table 12. Sunfish species HSI individual variable scores, total HSI score and fish data by site.

Habitat Variable	DCC208	SI	DCC455	SI	DCC793	SI	DCD765	SI	DCD1105	SI	DCD1570	SI	DCD1880	SI	DCD2138	SI	FC472	SI
% cover	12.5	0.7	11.87	0.68	20.63	0.9	21.25	0.91	20	0.88	20	0.88	21.88	0.93	20	0.88	21.25	0.91
vegetated cover	6.25	0.53	5.94	0.52	10.31	0.61	10.63	0.61	10	0.6	10	0.6	10.94	0.62	10	0.6	10.63	0.61
spawning temperature (summer)	20	1	20	1	20.2	1	20	1	20	1	20	1	19	0.4	19	0.4	18	0.4
% slow pools	36.01	0.96	25	0.7	56.98	0.92	34.57	0.93	26.32	0.73	38.74	0.81	26.86	0.74	12.8	0.35	48.08	0.87
% sand/gravel	58	1	70	1	43	1	17	0.4	39.00	1	47	1	49	1	35	0.9	16	0.39
least suitable pH observed	8.5	1	6.89	1	6.04	1	8.5	1	6.5	1	6.58	1	7.5	1	7.50	1	7.5	1
minimum DO (category)	B	0.7	B	0.7	B	0.7	B	0.7	A	1	A	1	A	1	A	1	A	1
max temp growing season	23.1	0.8	23.5	0.8	23.2	0.8	24.4	0.8	21.5	0.8	21.30	0.8	22.9	0.8	19	0.5	20	0.8
stream width	15.23	1	10	1	9.3	1	15.07	1	14.5	1	12.08	1	10.77	1	5.35	0.84	14.20	1
H S I score final		**0.53**		**0.52**		**0.61**		**0.4**		**0.6**		**0.6**		**0.4**		**0.35**		**0.39**
***Lepomis* sp. abundance**		67		230		59		68		43		24		24		63		
***Lepomis* sp. biomass**		800		3424		650		2049		1235		1132		1195		1179		

EPA habitat assessment techniques may not be most appropriate to habitat investigations for this species. For example, the EPA habitat technique stipulates that "transitional and new fall" woody debris (e.g., tree limbs and branches) should be disregarded. However, this type of cover is often quite common (and largely beneficial) in urbanized streams that have forested margins and eroding banks, such as Cobbs and Darby Creeks. Though "transitional and new fall" woody debris may not be permanent at a site, it may persist for a year or more, particularly when aggregations form along stream margins. The microhabitat within an aggregation of this woody debris is very complex when compared to most types of permanent hard cover, and qualitative observations during electrofishing surveys suggest that tree limbs and branches are beneficial and a preferred cover type for many fish.

Of course, large aggregations of woody debris may threaten the structural integrity of bridges, culverts and other infrastructure. One of the chief functions of PWD's Waterways Restoration Unit (WRU) is to remove this type of debris. As stream segments are restored, a careful balance should be struck between cleaning the stream of trash and debris and overzealous elimination of beneficial natural habitat features. Another excellent solution to this problem is the selective installation of staked or cabled trees and large tree limbs, Christmas tree bundles, willow stakes, root wads, and, in still water, manufactured fish habitat structures.

5.3.5.5. Blacknose Dace HSI Model

The Blacknose Dace HSI model produced fair results. Site DCC793 had the highest HSI score in the watershed (0.85), as well as the greatest abundance and largest biomass. Sites DCC208 and DCD765 scored 0.15, and (respectively) had the lowest and second lowest abundance and biomass in the watershed. Aside from these extreme values, the HSI model was not a good predictor of Blacknose dace abundance or biomass (Table 13). The Blacknose dace is classified as a tolerant fish. In fact, along with *C. commersoni*, *A. rostrata*, and *Fundulus* spp., Blacknose dace is one of the most common piscine inhabitants of degraded streams in southeast PA. Despite its tolerance of degraded stream conditions, the species' HSI model is quite complex- it includes 16 raw variables, six life requisite components, as well as limiting and compensatory mechanisms.

Limiting variables identified by the model included stream width, stream margin substrate composition, and pool substrate composition. As some of these variables were estimated, results of the HSI model are only as good as the estimates. The model was found to be too sensitive in the range of stream gradient values observed and was adjusted slightly to exclude these effects, which would have been limiting at 5 of 9 sites. While greater stream gradients may be preferred, this species is routinely collected in sites of lower gradient. An overall pattern of increasing abundance from downstream to upstream was evident.

Blacknose dace is a stocky fish, moderate in body form and somewhat rounded (dorsoventrally flattened) in comparison to other, more vertically compressed minnows.

Table 13. Blacknose dace HSI individual variable scores, total HSI score and fish data by site.

Habitat Variable	DCC208	SI	DCC455	SI	DCC793	SI	DCD765	SI	DCD1105	SI	DCD1570	SI	DCD1880	SI	DCD2138	SI	FC472	SI
% Shaded	20.00	0.77	20.00	0.77	60.00	1.00	70.00	1.00	30.00	1.00	45.00	1.00	75.00	1.00	85.00	1.00	70.00	1.00
% Pools	36.01	0.95	25.00	0.81	56.98	1.00	34.57	0.93	26.32	0.83	38.74	0.98	26.86	0.84	12.80	0.66	48.08	1.00
Stream Gradient	15.10	1.00	4.70	0.05	12.70	1.00	3.50	0.05	3.80	0.05	2.40	0.05	2.40	0.05	12.00	1.00	10.00	1.00
Stream Width	15.23	0.15	10.00	0.68	9.30	0.76	15.07	0.15	14.50	0.21	12.08	0.46	10.77	0.60	5.35	1.00	14.20	0.24
Temperature (growing seas.)	19.50	1.00	20.00	1.00	20.20	1.00	19.30	1.00	18.30	1.00	18.10	1.00	18.70	1.00	18.00	1.00	18.00	1.00
Turbidity	25.00	1.00	25.00	1.00	25.00	1.00	25.00	1.00	25.00	1.00	25.00	1.00	25.00	1.00	25.00	1.00	25.00	1.00
Riffle Substrate Category	D	0.60	C	1.00	D	0.60	E	0.40	D	0.60	D	0.60	D	0.60	D	0.60	E	0.40
Riffle Depth	12.00	1.00	20.00	1.00	10.00	1.00	35.00	0.82	29.00	1.00	26.00	1.00	18.00	1.00	16.00	1.00	18.00	1.00
Velocity in Riffles	30.20	1.00	19.40	0.96	25.40	1.00	17.00	0.80	17.60	0.84	14.80	0.66	14.80	0.66	24.00	1.00	20.00	1.00
Temperature (spawning seas.)	16.95	1.00	19.70	1.00	18.40	1.00	19.10	1.00	18.80	1.00	18.70	1.00	20.30	1.00	17.00	1.00	17.00	1.00
Pool Substrate Category	C	1.00	C	1.00	D	1.00	E	0.20	A	0.80	E	0.20	A	0.80	E	0.20	E	0.20
Velocity in Pools	9.00	1.00	4.00	1.00	10.00	1.00	6.00	1.00	6.00	1.00	4.00	1.00	4.00	1.00	9.00	1.00	7.00	1.00
Riffle Substrate Category	D	0.50	C	1.00	D	0.50	E	0.30	D	0.50	D	0.50	D	0.50	D	0.50	E	0.30
Velocity in Riffles	30.20	1.00	19.40	1.00	25.40	1.00	17.00	1.00	17.60	1.00	14.80	0.99	14.80	0.99	24.00	1.00	20.00	1.00
Substrate in Stream Margins	A	1.00	B	0.70	A	1.00	A	1.00	C	0.40	D	0.30	D	0.30	E	0.20	E	0.20
Velocity in Stream Margins	4.00	1.00	4.70	1.00	6.00	1.00	3.50	1.00	3.80	1.00	2.40	1.00	2.40	1.00	12.00	0.85	10.00	1.00
Food/Cover Component C_{FC}		0.15		0.68		0.94		0.15		0.21		0.46		0.60		0.92		0.24
Water Quality Component C_{WQ}		1.00		1.00		1.00		1.00		1.00		1.00		1.00		1.00		1.00
Reproduction Component C_R		0.94		0.99		0.94		0.40		0.90		0.86		0.86		0.94		0.40
Adult Component C_A		1.00		1.00		1.00		0.20		0.89		0.20		0.89		0.20		0.20
Juvenile Component C_J		0.71		1.00		0.71		0.30		0.71		0.70		0.70		0.71		0.30
Fry Component C_F		1.00		0.84		1.00		1.00		0.40		0.30		0.30		0.20		0.20
H S I Score		**0.15**		**0.68**		**0.85**		**0.15**		**0.21**		**0.20**		**0.30**		**0.20**		**0.20**
Abundance		1		97		1126		5		50		213		353		103		
Biomass		1		204		1979		10		112		490		683		231		

Hydrodynamics may play a part in its adaptability to a variety of flow conditions and, in part, explain its abundance at degraded sites that are periodically exposed to intense scouring flows. Other minnow species may not be as well adapted at surviving these types of flows. As stormwater BMPs and streambank restoration proceed under Target B of the watershed management plan, perhaps these hydrologically-impaired sites will begin to support more diverse fish communities rather than being dominated by three or four tolerant species.

5.3.5.6. Creek Chub HSI Model

The Creek Chub HSI model produced satisfactory results overall. Sites where no fish were collected had the lowest HSI scores in the watershed (Table 14). The site with the highest HSI score had the greatest abundance and biomass in the watershed. While biomass increased at all sites as HSI scores increased, and abundance showed the same pattern in 8 of 9 cases, the HSI model's scale of resolution was greatly compacted. Five sites had HSI scores between 0.80 and 0.88, while the two lowest scores were 0.4 and 0.69. When the lowest score corresponding to zero fish collected was taken as the origin rather than (0,0), the strongest correlations between (log-transformed) HSI scores and fish biomass and abundance were observed (R^2 values 0.94 and 0.93, respectively).

With 20 habitat and water quality variables and 5 life requisite components, the Creek Chub HSI model was most complex of the models used. As many water quality variables returned optimum suitability values (i.e., SI= 1.0), and most had limited discriminatory power, the model could be made simpler without sacrificing predictability. It is likely that if a smaller number of critical habitat variables were focused on, the model could have better resolution over a larger scale of final HSI scores.

5.3.5.7. Common Shiner HSI Model

Common shiner HSI model output was not very useful. Much like the Redbreast sunfish model, the SI variables used are general in nature, and contain a large range of suitable values (Redbreast sunfish and Common shiners are both considered generalist species). With the exception of two sites that were severely limited by a single SI variable (pH at site DCD765 and % pools at site DCD2138), SI variable attributes of most sites were very similar and the resulting HSI scores were also similar, ranging from 0.80 to 0.93 (Table 15). If the influence of a single low pH value and the smaller proportion of pools at these sites were disregarded, all sites would have HSI scores within this narrow range.

Common shiner abundance and biomass were fairly similar at all sites with the exception of DCC793, where a much greater number were collected. Perhaps the most interesting finding with regard to Common shiners was the greatly reduced average size of individual fish collected at site DCC455 compared to other sites.

Table 14. Creek chub HSI individual variable scores, total HSI score and fish data by site.

Habitat Variable	DC208	SI	DCC455	SI	DCC793	SI	DCD765	SI	DCD1105	SI	DCD1570	SI	DCD1880	SI	DCD2138	SI	FC472	SI
% pools	36.01	0.98	25.00	0.74	56.98	1.00	34.57	0.97	26.32	0.79	38.74	1.00	26.86	0.81	12.80	0.39	48.08	1.00
Pool class (category)	A	1.00	B	0.60	B	0.60	A	1.00	B	0.60	A	1.00	B	0.60	B	0.60	B	0.60
% cover	12.50	0.37	11.87	0.35	20.63	0.61	21.25	0.63	20.00	0.59	20.00	0.59	21.88	0.64	20.00	0.59	21.25	0.63
Winter thermal cover	YES	0.91	YES	0.74	YES	0.92	YES	1.00	NO	0.45	NO	0.64	NO	0.48	NO	0.32	NO	0.52
Stream gradient	15.10	0.80	4.70	0.79	12.70	1.00	3.50	0.57	3.80	0.63	2.40	0.37	2.40	0.37	12.00	1.00	10.00	1.00
Stream width	15.23	0.30	10.00	0.56	9.30	0.63	15.07	0.30	14.50	0.32	12.08	0.42	10.77	0.50	5.35	1.00	14.20	0.33
Turbidity	25.00	1.00	25.00	1.00	25.00	1.00	25.00	1.00	25.00	1.00	25.00	1.00	25.00	1.00	25.00	1.00	25.00	1.00
pH (category)	B	0.80	A	1.00	B	0.80	C	0.40	A	1.00	A	1.00	A	1.00	A	1.00	A	1.00
Vegetation index	37.50	0.54	65.00	0.95	72.50	1.00	67.50	0.97	67.50	0.97	90.00	1.00	75.00	1.00	80.00	1.00	62.50	0.92
Substrate food index	C	0.50	B	0.70	B	0.70	C	0.50	B	0.70	C	0.50	B	0.70	B	0.70	B	0.70
Average summer water temp.	21.80	1.00	21.20	1.00	20.60	1.00	20.80	1.00	21.00	1.00	20.90	1.00	20.00	1.00	19.00	1.00	19.00	1.00
Minimum summer DO conc.	2.93	0.47	3.72	0.76	3.96	0.83	4.00	0.85	4.00	0.85	6.00	1.00	6.00	1.00	6.00	1.00	7.00	1.00
Average velocity (0.6 depth)	18.00	1.00	8.00	0.94	20.00	1.00	12.00	1.00	12.00	1.00	8.00	0.94	8.00	0.94	18.00	1.00	14.00	1.00
Average spring water temp	17.10	1.00	19.20	1.00	19.90	1.00	19.10	1.00	17.60	1.00	17.30	1.00	18.50	1.00	16.00	1.00	16.00	1.00
Minimum spring DO conc.	4.00	0.50	5.00	0.76	5.50	0.86	5.00	0.76	5.00	0.76	7.00	1.00	7.00	1.00	8.00	1.00	8.00	1.00
Average spring riffle velocity	45.30	1.00	29.10	1.00	38.10	1.00	25.50	1.00	26.40	1.00	22.20	1.00	22.20	1.00	36.00	1.00	30.00	1.00
Riffle substrate index	89.75	1.00	100.00	1.00	100.00	1.00	97.10	1.00	89.95	1.00	100.00	1.00	90.91	1.00	100.00	1.00	100.00	1.00
Average stream margin velocity	4.00	1.00	4.70	1.00	6.00	1.00	3.50	1.00	3.80	1.00	2.40	1.00	2.40	1.00	12.00	0.69	10.00	1.00
% summer shade	20.00	0.33	20.00	0.33	60.00	0.92	70.00	1.00	30.00	0.47	45.00	0.72	75.00	1.00	85.00	1.00	70.00	1.00
Average maximum depth	0.71	1.00	0.50	1.00	0.39	0.94	0.83	1.00	0.59	1.00	0.68	1.00	0.51	1.00	0.59	1.00	0.56	1.00
Food component		0.52		0.83		0.85		0.74		0.84		0.75		0.85		0.85		0.81
Cover component		0.83		0.69		0.83		0.92		0.71		0.84		0.72		0.56		0.76
Water Quality component		0.59		0.71		0.89		0.40		0.80		0.92		1.00		1.00		1.00
Reproduction component		0.87		0.95		0.97		0.95		0.95		1.00		1.00		1.00		1.00
Other component		0.70		0.78		0.86		0.62		0.65		0.59		0.62		1.00		0.78
H S I score		**0.69**		**0.79**		**0.88**		**0.40**		**0.78**		**0.81**		**0.82**		**0.86**		**0.86**
biomass		0		52.47		998		0		12.27		33.09		107.68		193.59		

Table 15. Common shiner HSI individual variable scores, total HSI score and fish data by site.

Habitat Variable	DCC208	SI	DCC455	SI	DCC793	SI	DCD765	SI	DCD1105	SI	DCD1570	SI	DCD1880	SI	DCD2138	SI	FC472	SI
Temperature	22.90	0.79	23.50	0.67	23.20	0.72	24.40	0.50	21.20	1.00	21.30	1.00	21.90	1.00	20.00	1.00	20.00	1.00
pH	9.07	0.88	6.89	1.00	6.04	0.58	9.92	0.14	6.50	0.99	6.58	1.00	7.50	1.00	7.50	1.00	7.50	1.00
turbidity	25.00	1.00	25.00	1.00	25.00	1.00	25.00	1.00	25.00	1.00	25.00	1.00	25.00	1.00	25.00	1.00	25.00	1.00
Riffle Substrate Category	D	0.80	C	1.00	D	0.80	E	0.20	D	0.80	D	0.80	D	0.80	D	0.80	E	0.20
% pools	36.01	0.85	25.00	0.56	56.98	0.99	34.57	0.80	26.32	0.59	38.74	0.89	26.86	0.59	12.80	0.07	48.08	0.99
Velocity in Pools	9.00	1.00	4.00	0.87	10.00	1.00	6.00	0.94	6.00	0.94	4.00	0.87	4.00	0.87	9.00	1.00	7.00	0.96
Pool Class	B	1.00	B	1.00	C	0.60	B	1.00	B	1.00	B	1.00	B	1.00	B	1.00	B	1.00
Temperature (Spawning seas.)	15.63	0.95	17.35	1.00	16.20	1.00	17.45	1.00	16.55	1.00	16.30	1.00	17.70	1.00	15.00	0.76	15.00	0.76
riffle Velocity	30.20	0.53	19.40	1.00	25.40	0.75	17.00	1.00	17.60	1.00	14.80	1.00	14.80	1.00	24.00	0.82	20.00	1.00
Food/Cover Component C_{FC}		0.91		0.86		0.85		0.20		0.83		0.89		0.82		0.07		0.20
Water Quality Component C_{WQ}		0.88		0.87		0.75		0.14		1.00		1.00		1.00		1.00		1.00
Reproduction Component C_R		0.75		1.00		0.83		0.20		0.89		0.89		0.89		0.80		0.20
H S I Score		**0.85**		**0.91**		**0.81**		**0.14**		**0.91**		**0.93**		**0.90**		**0.07**		**0.20**
Abundance		13		86		398		34		42		74		60		41		
Biomass		121.2		250		4324		288.5		316.3		389.2		530.1		437.8		

5.3.5.8. Fallfish HSI Model

Interpretation of Fallfish HSI model output was hindered by a lack of data; only 19 individuals were collected in total. Only one individual was collected in the Cobbs Creek sub-basin (site DCC793). The Fallfish HSI model is one of the simplest HSI models available, considering only six variables. Furthermore, as applied to the Darby-Cobbs Watershed, only five variables were considered because it was not possible to convert modern NTU turbidity data to JTU data. Differences between sites were not very large for most of the remaining five variables (Table 16).

Substrate type, however, is an important factor because Fallfish construct and spawn over gravel nest structures. Fallfish males push and carry gravel and smalls stones to create a nest pile which may be quite large. Following a spawning episode, eggs are buried, after which additional material may be added to the nest structure and the process repeated. Similar egg burying behavior is practiced by other minnow species (e.g., Cutlips minnow, Creek chub). Since developing eggs rely on oxygen exchange through interstitial spaces, clean, oxygenated gravel is necessary. Several phenomena arising from urbanization may reduce spawning success of these species.

Increased stream velocities resulting from increased impervious cover may be severe enough to damage or completely scour away nest structures. Alternately, nests built in depositional areas may become silted over, smothering eggs. Substrates may contain significant amounts of dead and decaying organic matter or be inhabited by other aerobic and chemosynthetic microbial communities. If oxygen-depleting biochemical processes within the sediments outpace re-oxygenation, or if the overlying water itself is low in dissolved oxygen, eggs may die. Decreased reproductive success may partially explain the very low abundance of Fallfish and complete absence of Cutlips minnow in the Cobbs Creek basin.

While Fallfish HSI model applicability was very limited, the biogeography of Fallfish and other egg-burying cyprinids may be helpful in identifying macro-scale impairments to run and pool stability, as well as the oxygen state and suitability of stream substrates for not only their eggs, but sediment dwelling benthic invertebrates as well. Site-specific conclusions should be avoided, however, because fish are mobile and may be collected far away from their spawning sites.

5.3.5.9. Longnose dace HSI Model

Longnose dace HSI model output predicted that water temperatures in all Cobbs Creek sites and site DCD765 would preclude survivorship of naturally reproducing population of Longnose dace (Table 17). Other sites were severely limited by stream velocity. Though the model requires average stream velocity data, it might be more appropriate to consider only riffle velocity, as sites chosen for fish surveys in Darby-Cobbs were selected based on a relatively even mix of macrohabitat features. If surveys were

Table 16. Fallfish HSI individual variable scores, total HSI score and fish data by site.

Habitat Variable	DCC208	SI	DCC455	SI	DCC793	SI	DCD765	SI	DCD1170	SI	DCD1570	SI	DCD1880	SI	DCD2138	SI	FCR024	SI
Temperature	21.80	0.78	21.20	0.86	20.60	0.93	20.80	0.90	21.00	0.88	20.90	0.89	20.00	1.00	19.00	1.00	19.00	1.00
Turbidity	25.00	1.00	25.00	1.00	25.00	1.00	25.00	1.00	25.00	1.00	25.00	1.00	25.00	1.00	25.00	1.00	25.00	1.00
Mode of Stream Depth	0.17	0.84	0.16	0.83	0.11	0.79	0.44	1.00	0.51	1.00	0.29	0.93	0.13	0.80	0.46	1.00	0.47	1.00
Spawning Temperature	15.63	0.53	17.35	1.00	16.20	0.84	17.45	1.00	16.55	1.00	16.30	0.89	17.70	0.56	15.00	0.20	15.00	0.20
Substrate Category	E	0.10	C	1.00	D	0.40	E	0.10	D	0.40	C	1.00	D	0.40	D	0.40	E	0.10
Cover category	C	0.40	C	0.40	B	0.70	B	0.70	B	0.70	B	0.70	A	1.00	B	0.70	B	0.70
Water Quality Component C_{WQ}		0.89		0.93		0.96		0.95		0.94		0.94		1.00		1.00		1.00
Reproduction Component C_R		0.18		0.69		0.57		0.41		0.65		0.84		0.56		0.20		0.20
H S I score		**0.53**		**0.81**		**0.77**		**0.68**		**0.80**		**0.89**		**0.78**		**0.60**		**0.60**
abundance		0		0		1		6		11		0		1		0		0
Total Biomass (g)		0		0		16.03		760		372.47		0		3.42		0		0

Table 17. Longnose dace HSI individual variable scores, total HSI score and fish data by site.

Habitat Variable	DCC208	SI	DCC455	SI	DCC793	SI	DCD765	SI	DCD1105	SI	DCD1570	SI	DCD1880	SI	DCD2138	SI	FC472	SI
Average Stream Velocity	18.00	0.33	8.00	0.07	20.00	0.39	12.00	0.15	12.00	0.15	8.00	0.07	8.00	0.07	18.00	0.33	14.00	0.21
Maximum Depth in Riffles	0.17	0.74	0.15	0.69	0.16	0.72	0.51	1.00	0.51	1.00	0.35	1.00	0.31	1.00	0.30	1.00	0.29	1.00
% Riffles	28.57	1.00	23.81	0.95	19.05	0.76	23.81	0.95	19.05	0.76	19.05	0.76	28.57	1.00	19.00	0.76	14.29	0.57
% of Substrate >5cm	42.00	0.84	30.00	0.60	57.00	1.00	83.00	1.00	61.00	1.00	53.00	1.00	51.00	1.00	65.00	1.00	84.00	1.00
Spring/Summer Maximum Temp.	22.90	0.00	23.50	0.00	23.20	0.00	24.40	0.00	21.20	0.64	21.30	0.56	21.90	0.08	20.00	0.90	20.00	0.90
% Cover	12.50	0.50	11.87	0.47	20.63	0.83	21.25	0.85	20.00	0.80	20.00	0.80	21.88	0.88	20.00	0.80	21.25	0.85
H S I Score		**0.00**		**0.00**		**0.00**		**0.00**		**0.15**		**0.07**		**0.07**		**0.33**		**0.21**

conducted strictly for riffle dwelling species such as Longnose dace, the average depth would be much smaller and average velocity would be much higher for a given "site".

The Longnose dace HSI model was applied to Darby-Cobbs Watershed despite the fact that this species was not collected from the watershed in the 2003 fish survey. A review of historical fish distribution records conducted for the Fairmount Park Commission by researchers at the Academy of Natural Sciences indicates that this species has never been recorded from the watershed. Longnose dace are, however, present in other streams in the Delaware and Schuylkill drainages. This species is considered a riffle specialist, feeding and spawning in fast water in higher gradient, clear and cool streams. High Longnose dace HSI scores may thus indicate favorable riffle conditions, not only for this species, but for a variety of other riffle dwellers, including sensitive macroinvertebrate bioindicator taxa.

5.4. Chemical Assessment

5.4.1. Overview

Discrete (fixed interval) chemical sampling was conducted weekly under a variety of conditions (e.g., wet weather, ice) that may have influenced results of many chemical and water quality analyses. For example, instream measurements of dissolved oxygen and grab samples taken for fecal coliform analyses may exhibit great variability in response to environmental conditions. The former is dependent on time of day and sunlight intensity, while the latter may vary with rainfall. For this reason, results of discrete chemical sampling are most useful for characterizing dry weather water quality under Target A of the Watershed Management Plan. Target C and indicator 9 of the Watershed Management Plan were specifically targeted by PWD's Wet Weather Monitoring Program and Continuous Water Monitoring Program, respectively.

Much of Darby-Cobbs Watershed is served by a combined sewer system. Wet weather overflows at CSO structures periodically cause releases of combined sewage to streams. Effects of these releases may extend beyond the times when rain is falling or overflows are occurring. CSO discharges, even when infrequent, may thusly be a significant factor in shaping a stream's water quality. Philadelphia's streams can not be expected to meet water quality criteria during wet weather (Target C) unless CSO discharges are addressed and stormwater is treated. Conversely, combined sewer systems may be more efficient than separate sewer systems at capturing (diverting) pollutants from small, diffuse, and/or periodic sources (e.g., very small storms, gradual snowmelt, car and equipment washing, intentional dumping in storm drains).

Many watersheds in developed and developing areas are poorly protected from surface runoff from landscapes, golf courses, industrial areas, etc., which may introduce nutrients to the stream. A wide buffer of riparian vegetation around the stream can intercept and filter this runoff, reducing nutrient concentrations before they reach the stream. Another important benefit of streamside vegetated buffer zones, especially those with mature trees, is shading. Beyond direct influences of shading on algal biomass, primary productivity and amplitude of diel fluctuations in dissolved oxygen, shading reduces temperature effects, thereby affecting dissolved oxygen levels indirectly. Though only 9% of the Cobbs Creek watershed is forested, nearly all this forest land lies within stream corridors.

Additionally, suburban and urban landscapes, such as the Darby Cobbs Watershed, abound in potential point and non-point sources of organic, thermal, microbial, and heavy metal pollution. Acute and chronic effects of these pollutants on stream habitats and organisms are difficult to quantify.

5.4.2. Indicator 7: Bacteria

Fecal coliform bacteria concentration is positively correlated with point and non-point contamination of water resources by human and animal waste and is used as an indicator of poor water quality (Indicator 7 of the Watershed Management Plan). PADEP has established a maximum limit of 200 colony forming units, or "CFUs," per 100ml sample during the period 05/01-9/30, the "swimming season" and a less stringent limit of 2000CFUs/100ml for all other times. It should be noted that the state criterion is based on the geometric mean of five consecutive samples collected over a 30-day period. As bacterial concentrations can be significantly affected by rain events and otherwise may exhibit high variability, individual samples are not as reliable as replicate or multiple samples taken over a short period.

Based on data from numerous sources (PADEP, EPA, USDA-NRCS, volunteer and non-profit organizations, etc.), it appears likely that many, if not most, southeastern PA streams would be found in violation of water quality criteria given sufficient sampling effort. PWD has expended considerable resources toward documenting concentrations of fecal coliform bacteria and *E. coli* in Philadelphia's watersheds. The sheer amount of data collected allows for more comprehensive analysis and a more complete picture of the impairment than does the minimum sampling effort needed to verify compliance with water quality criteria. In keeping with the organizational structure of the watershed management plan, fecal coliform bacteria analysis has been broken into dry (Target A) and wet weather (Target C) components, defined by a period with at least 48 hours without rain as measured at the nearest gauge in PWD's rain gauge network.

5.4.2.1. Target A: Dry Weather Fecal Coliform Bacteria

All individual dry weather samples collected from Darby-Cobbs Watershed during the non-swimming season (n=18) showed fecal coliform bacteria concentration well below the water quality criterion of 2000CFU/100ml. But geometric means of fecal coliform concentration at all sites exceeded water quality criteria during the swimming season (Table 18 and Figure 20). Samples from sites DCI010, DCC208, and DCC455 on 6/12/03 were likely affected by a leaking sewer. The sewer leak was subsequently detected by PWD biologists conducting a fish assessment downstream. Geometric means of fecal coliform from these sites would be 366, 324 and 696, respectively, with these samples omitted.

With the exception of intense sampling upstream and downstream of a point source, surface water grab samples do not usually allow one to determine the source(s) of fecal contamination. Recent research has shown that fecal coliform bacteria may adsorb to sediment particles and persist for extended periods in sediments (VanDonsel, et al. 1967, Gerba 1976). Presence of bacterial indicators in dry weather may thus more strongly reflect past wet weather loadings than dry weather inputs (Dutka and Kwan, 1980). Clearly, there exist several possible sources of fecal coliform bacteria within the watershed, all or combinations of which may be acting within different spatial and

Table 18. Fecal coliform concentrations at the nine water quality monitoring sites.

Site	n	Max	Min	Median	Mean	Std. Dev.	Geometric Mean
DCC208	7	2600	140	410	674.29	859.03	437.06
DCC455	7	2900	390	540	1097.14	991.66	815.75
DCC770	7	1060	220	300	407.14	293.58	351.92
DCD765	7	530	160	310	311.43	118.80	292.60
DCD1170	4	700	120	400	412.50	32.02	411.61
DCD1570	4	320	210	240	252.50	49.92	249.00
DCD1660	7	380	160	240	257.14	68.97	249.36
DCI010	4	20000	150	600	5337.50	9778.40	995.67
DCN010	4	3000	770	1020	1227.50	598.02	1136.70

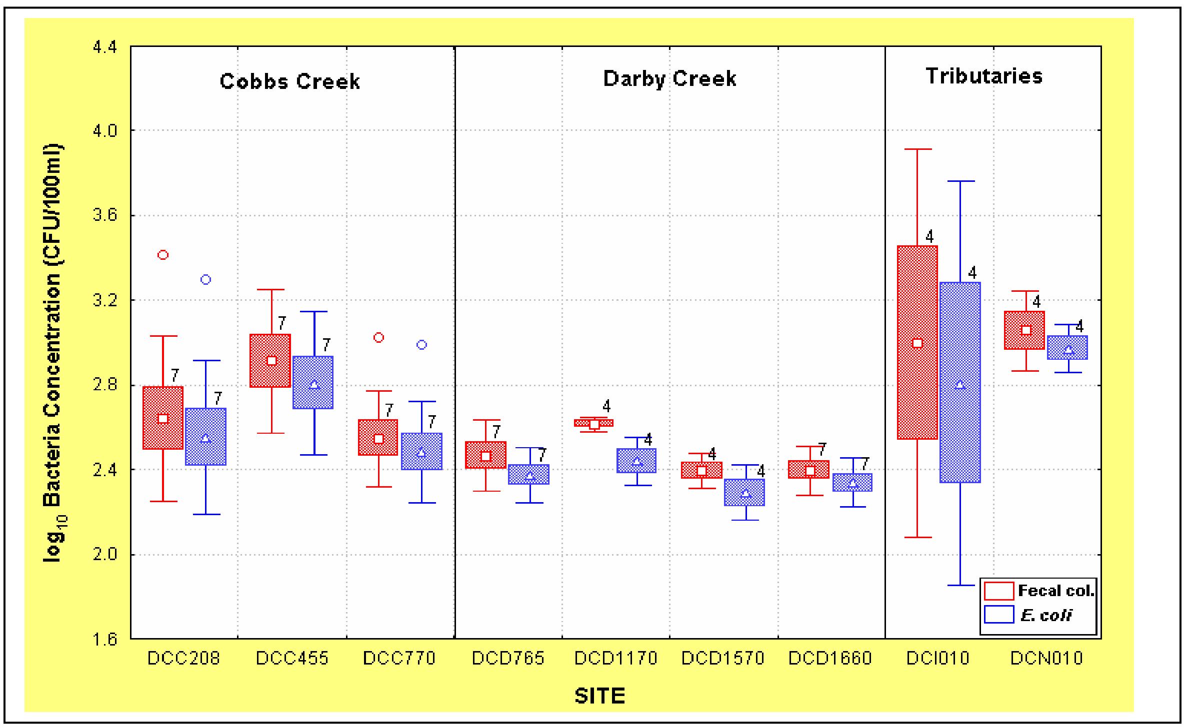


Figure 20. Dry weather fecal coliform and *E. coli* concentrations at the 9 monitoring sites.

temporal dimensions. PWD is piloting a Bacterial Source Tracking (BST) program that may eventually be useful in identifying the sources of fecal coliform bacteria collected in dry weather. Of particular interest is the relative proportion of the total bacterial load from human sources vs. domestic and wildlife animal sources.

5.4.2.2. Target C: Wet Weather Fecal Coliform Bacteria

Surface water grab samples (n=54) were collected at nine sites throughout Darby- Cobbs Watershed during or within 48 hours of wet weather as part of PWD's 2003 fixed interval (weekly) discrete chemical sampling program. Results of weekly discrete fecal coliform bacteria concentration analysis appear in Table 19. An additional 130 automatic sampler composite samples were collected from 5 sites during two individual wet weather events as part of PWD's intensive wet weather monitoring program. Hydrograph-matched scatterplots of fecal coliform bacteria concentration at each site for each event appear in (Appendix F). The data from these events is summarized in Tables 20 and 21.

Not surprisingly, wet weather fecal coliform bacteria concentration is elevated significantly at each site compared to dry weather concentrations. Both Cobbs and Darby Creeks exhibited a typical pattern of fecal coliform bacteria concentration increasing at downstream locations. Though all sites sampled probably could be in violation of state fecal coliform bacteria standards (e.g., many samples in excess of 1000 CFU/100ml, more than 10% of samples in excess of 400CFU/ml), Cobbs Creek and its tributaries within Philadelphia (i.e., Naylors Run and the Indian Creeks) appear more severely affected than suburban Delaware County sites.

Table 19. Fixed interval fecal coliform samples collected in wet weather.

Site	n	Max	Min	Median	Arithmetic Mean	Std. Dev.	Geometric Mean
DCC208	6	43,000	350	6,700	15,192	17,184	6,648
DCC455	6	36,000	310	2,550	8,162	13,838	2,629
DCC770	6	2,900	140	495	1,115	1,174	657
DCD765	6	4,000	440	710	1,452	1,402	1,040
DCD1170	6	3,000	320	675	1,288	1,274	802
DCD1570	6	4,000	160	325	1,133	1,537	532
DCD1660	6	5,300	30	275	1,772	2,474	449
DCI010	6	110,000	450	3,000	21,017	43,706	3,614
DCN010	6	4900	590	3,300	2,902	1,888	2,187

Table 20. Fecal coliform concentrations recorded at the 5 wet weather monitoring locations during storm event 1.

Site	n	Max	Min	Median	Arithmetic Mean	Std. Dev.	Geometric Mean
DCC208	18	182,000	350	78,500	71,275	54,242	28,423
DCC455	19	200,000	1,400	43,000	63,168	63,202	28,615
DCC770	18	20,000	420	2,300	6,004	7,424	2,378
DCD765	11	41,000	1,000	9,400	12,100	11,731	7,199
DCD1660	19	161,000	1,800	6,600	26,763	39,534	11,101

Table 21. Fecal coliform concentrations recorded at the 5 wet weather monitoring locations during storm event 2.

Site	n	Max	Min	Median	Arithmetic Mean	Std. Dev.	Geometric Mean
DCC208	9	82,000	25,000	29,000	41,000	21,529	36,891
DCC455	9	103,000	8,800	30,000	32,744	28,561	24,975
DCC770	9	46,000	2,200	6,600	14,167	16,827	8,387
DCD765	9	20,000	3,600	8,500	8,300	4,220	7,466
DCD1660	9	18,000	3,100	5,500	6,733	5,140	5,721

5.4.3. Indicator 8: Metals

Metals occur in all natural waters in varying concentrations due to runoff, erosion, atmospheric deposition, and interactions with streambed geological features. However, because certain metals may be toxic even in very small concentrations, toxic metals concentrations are included in the CCIWMP (indicator 8). Darby Creek Watershed (32.3 river miles including Darby Creek, Hermesprota Creek, Muckinipattis Creek, Stony Creek, Langford Run, and Whetstone Run) was listed by PADEP in 1996 as impaired due to metals in urban runoff/storm sewers, though individual segments were not identified. Cobbs Creek watershed (24.8 river miles, including Indian creek) was listed by PADEP in 2002 as impaired due to urban runoff/storm sewers and municipal point sources, but cause(s) of the impairment were not identified.

Metals of concern (e.g., lead, chromium, cadmium, copper, and zinc) were most often undetectable or present in minimal concentrations in water samples taken in 2003 from Darby-Cobbs watershed. However, increases in concentration during rainfall were observed for copper, iron, and lead. Though water column toxic metal concentrations may be generally small, many metals readily adsorb to sediment particles, interact with organic molecules, or otherwise precipitate or become deposited or incorporated into stream sediments. Since most aquatic organisms either inhabit sediments or feed upon benthic invertebrates, possible toxic effects may not be reflected by water column concentrations alone.

Calcium and magnesium concentrations of Darby-Cobbs watershed were not unusual, keeping with the predominant rock types in the watershed (schists and gneiss). As the major divalent cations in surface water, Calcium and Magnesium are used to compute hardness (expressed as mg/l $CaCO_3$). This is an important parameter, because toxicity of other metals generally has an inverse relationship with hardness. Most EPA and PADEP toxic metal water quality criteria are currently defined as linear regression equations that account for observed decreases in toxicity as hardness increases. Each sample metal concentration is evaluated against the criterion as calculated with sample hardness. Furthermore, two water quality criteria exist for each toxic metal, criteria continuous concentration (CCC) and criteria maximum concentration (CMC); these criteria address chronic and acute toxicity, respectively. Dry weather water samples were compared to CCC and wet weather samples were compared to CMC.

PADEP dissolved metal criteria are based on EPA toxic metals standards originally developed for total recoverable metals. Though these criteria have been modified to include a conversion factor for use with dissolved metals data, actual dissolved metal concentrations cannot be predictably determined as a proportion of total recoverable metals concentrations. Solubility of metals in natural waters varies with other environmental variables. Because of the degree to which metals may adsorb to sediment and form complexes with organic particles, it is likely that actual water column dissolved metal concentrations in Darby-Cobbs Watershed are smaller than those predicted using these conversion factors. To assess the effects of using these conversion factors, total recoverable metal concentrations were compared to both dissolved and total recoverable criteria.

5.4.3.1. Target A: Dry Weather Metals Concentrations

With the exception of copper, metals concentrations were relatively small in dry weather (Table 22). Cadmium and Chromium were not detected in any of 69 dry weather samples from Darby-Cobbs Watershed. Lead was detected in only 3 samples, 2 from site DCC208 and one from site DCC455; only one of these three detections was a possible violation of the dry weather (continuous) criterion (CCC) for lead. Aluminum and zinc were detected in approximately two thirds of dry weather samples. Aluminum concentrations were consistently small, the maximum value was less than 50% of the CMC and the mean concentration was less than 10% of the CMC (no CCC has been established for aluminum). Zinc concentrations were typically 10% or less of the CCC. Copper was detected in all dry weather samples; three samples may have exceeded the CCC. While standards for each sample vary with hardness, many samples had copper concentration at 50% or more of the CCC. Based on ICP-MS performance on individual check standards, reporting limits for some metals were higher than 1µg/l on some occasions.

Table 22. Metal concentrations collected during dry weather in Darby-Cobbs Watershed.

Metal	non-detects	Max	Min	Arithmetic Mean	Std. Dev.	Geometric Mean	WQ Violations
Aluminum	**16**	**0.363**	**0.015**	**0.067**	**0.053**	**0.055**	**N/A**
Cadmium	**69**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**0**
Calcium	**0**	**52.0**	**24.0**	**34.89**	**6.573**	**34.311**	**N/A**
Chromium	**69**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**0**
Copper	**0**	**0.020**	**0.002**	**0.006**	**0.004**	**0.006**	**3**
Iron	**4**	**0.785**	**0.052**	**0.196**	**0.113**	**0.171**	**0**
Lead	**66**	**0.007**	**0.002**	**0.004**	**0.003**	**0.003**	**1**
Magnesium	**0**	**19.320**	**11.700**	**14.945**	**1.510**	**14.781**	**N/A**
Manganese	**3**	**0.142**	**0.010**	**0.033**	**0.024**	**0.027**	**0**
Zinc	**19**	**0.084**	**0.002**	**0.017**	**0.017**	**0.012**	**0**

Water column total recoverable metals concentrations often do not accurately reflect bioavailability of toxic constituents and cannot be expected to reliably predict effects along and among stream sediments. Much recent research has been focused on metals toxicity and studies have focused on determination of toxic constituents of sediments themselves; toxic constituents of interstitial waters; re-suspension of toxicants by storm flows, recreational use, or bioturbation by benthic biota; controlled laboratory testing with experimental organisms; *in-situ* toxicity investigations; and development and refinement of sediment toxicity models.

EPA has begun the process of revising water quality criteria for toxic metals to incorporate the considerable body of research that has been conducted since the original criteria were published. These new criteria more appropriately reflect the chemical behavior of toxicants in surface waters and account for their bioavailability. For example, cupric ions (Cu^{2+}) have been recognized as the major cause of copper toxicity (Sunda and Guillard 1976; Sunda and Hansen 1979). However, complexes formed through ligand bonding with inorganic and organic molecules may reduce free copper concentrations by three or more orders of magnitude (Morel & Hering 1993) through competition for ligand bonding sites. EPA's draft copper water quality standard (2003) incorporates the Biotic Ligand Model (DiToro et al., 2001) and more reliably predicts the toxic effects of copper concentrations than linear regression equations that consider only hardness as a covariable.

5.4.3.2. Target B: Wet Weather Metals Concentrations

Wet weather metals concentrations were generally greater than concentrations in dry weather; the incidence of possible water quality violations was much higher overall in wet weather than in dry weather. For example, metals that may have violated water quality criteria only in wet weather included aluminum, cadmium, manganese, and zinc. Possible violations of copper and lead criteria were more frequent in wet weather as well. Hydrograph-matched scatterplots of toxic metal concentrations appear in (Appendix G).

While surface runoff undoubtedly contributes to increases in wet weather metals concentrations, it is likely that re-suspension of metals associated with sediments contributes to excursions from water quality criteria.

5.4.4. Indicator 9: Dissolved Oxygen Concentration

Continuous monitoring Sondes at sites within Darby-Cobbs Watershed measured, among other parameters, water column dissolved oxygen (DO) concentration. DO concentrations often strongly reflect autotrophic community metabolism and in turn, affect the heterotrophic community structure as a limiting factor for numerous organisms. Because sufficient DO concentration is critical for fish, amphibians, crustacea, insects, and other aquatic invertebrates, DO concentration is used as a general indicator of a stream's ability to support a balanced ecosystem. The Pennsylvania Department of Environmental Protection (PADEP) has established criteria for both instantaneous minimum and minimum daily average DO concentration. Criteria are intended to be protective of the types of aquatic biota inhabiting a particular lake, stream, river, or segment thereof.

All water chemistry monitoring sites within Darby-Cobbs Watershed, with the exception of DCD1660, are designated as Warm Water Fisheries (WWF). Site DCD1660, and all segments of Darby Creek north of PA Rte. 3 (West Chester Pike) are designated a Trout Stocking Fishery (TSF). PADEP water quality criteria require that minimum DO levels in WWF not fall below 4.0 mg O_2/L and that daily averages remain at or above 5.0 mg O_2/L. A Trout Stocking Fishery such as DCD1660 has more stringent DO standards to support more sensitive stocked salmonid fish species from February 15 to July 31 each year. During this period, a minimum daily DO average of 6.0 mg O_2/L is required, and allowable DO instantaneous minimum is 5.0 mg O_2/L. For the remainder of the year, TSF criteria align with WWF standards. These regulations, along with corresponding temperature criteria, form the foundation of stream protection in general and allow for propagation and maintenance of healthy fish communities.

Combinations of natural and anthropogenic environmental factors may affect DO concentration. Autotrophic and heterotrophic organisms are influenced by nutrient concentrations, solar radiation, temperature, and other environmental factors. Daily fluctuations of oxygen in surface waters are due primarily to the metabolic activity of these organisms. If temperature alone influenced DO concentration, saturation would increase at night, when water temperature drops, and decrease during the day as the water warms. Because the watershed is generally dominated by biological activity, the reverse occurs: DO concentrations in Darby-Cobbs Watershed rise during the day when autotrophic organisms are photosynthesizing and decrease at night when community respiration is the dominant influence. Another factor in the amount of oxygen dissolved in the water is re-aeration (diffusion of atmospheric oxygen). Barometric pressure, surface area, turbulence and oxygen saturation deficit influence the amount of oxygen transferred to the stream from the atmosphere. Effects of re-aeration tend to augment or diminish (rather than shift or change) effects of stream metabolism.

Stream sites that support abundant algal growth often exhibit dramatic diel fluctuations in dissolved oxygen concentration. Algal photosynthesis infuses oxygen during the day (often to the point of supersaturation), while algae and heterotrophic organisms remove oxygen throughout the night. These sites are more susceptible to oxygen deficits on cloudy days when the amount of photosynthesis is limited by sunlight and community respiration dominates system activity.

DO fluctuations were more pronounced at some sites than at others, due in part to specific placement of the continuous monitoring instrument (Sonde) at each site. When interpreting this continuous DO data, one must keep in mind that the instrument can only measure dissolved oxygen concentration of water in direct contact with the DO probe membrane. Furthermore, to obtain the most accurate readings of DO, probes should be exposed to flowing water or probes themselves must be in motion. Local microclimate conditions surrounding the probe and biological growth on the probe itself may also contribute to errors in measurement. It is possible for Sondes situated in subtly different areas of the same stream site to exhibit marked differences in DO concentration due to flow, shading, and local microclimate differences. Sonde measurements of DO concentrations during the summer period (8/14/03-9/14/03) are depicted in figures 21 thru 25.

The Sonde located at DCC208, for example, is located in a pool upstream of a dam. Additionally, the Sonde at DCC208 is not shaded. Deep pools, slower stream velocity, and ample sunlight provide excellent conditions for algal growth which are reflected in diel DO fluctuations (Figure 21). DCD765 is another site in which the Sonde is only

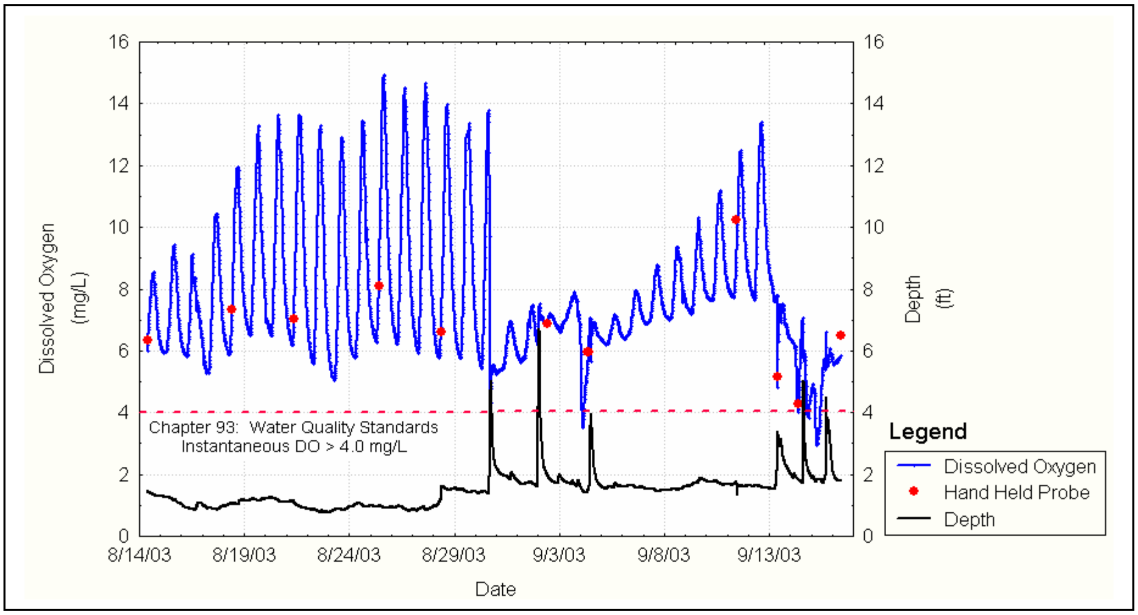


Figure 21. Continuous measurements of dissolved oxygen at DCC 208.

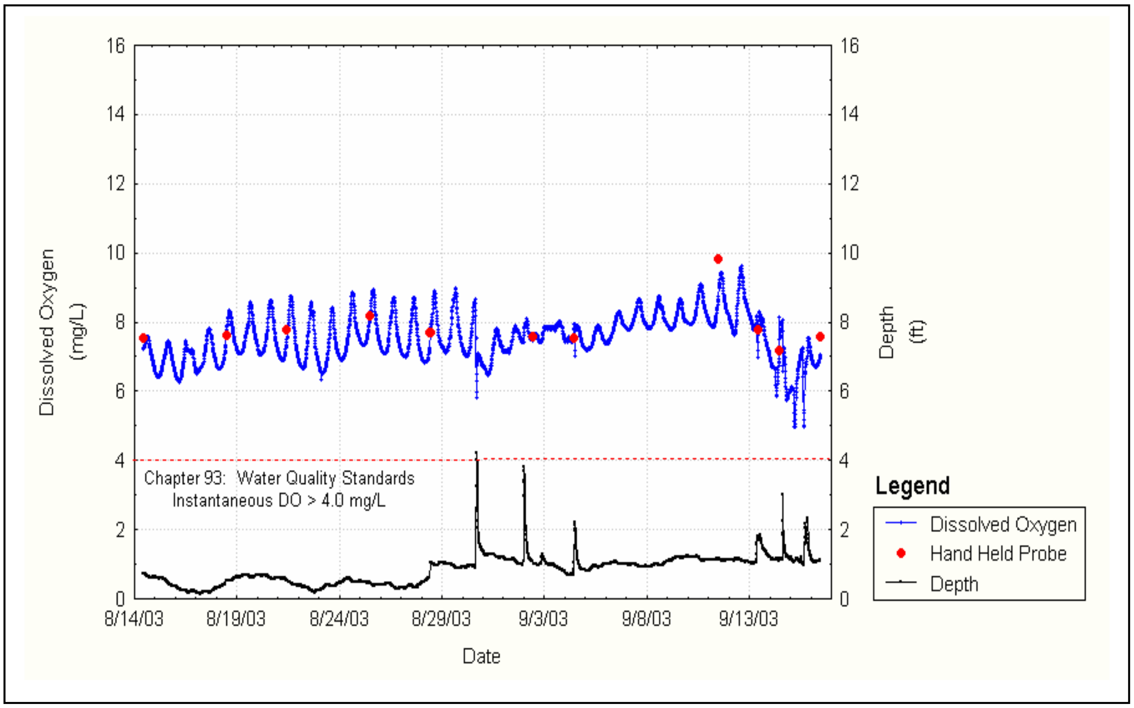


Figure 22. Continuous measurements of dissolved oxygen at DCC 455.

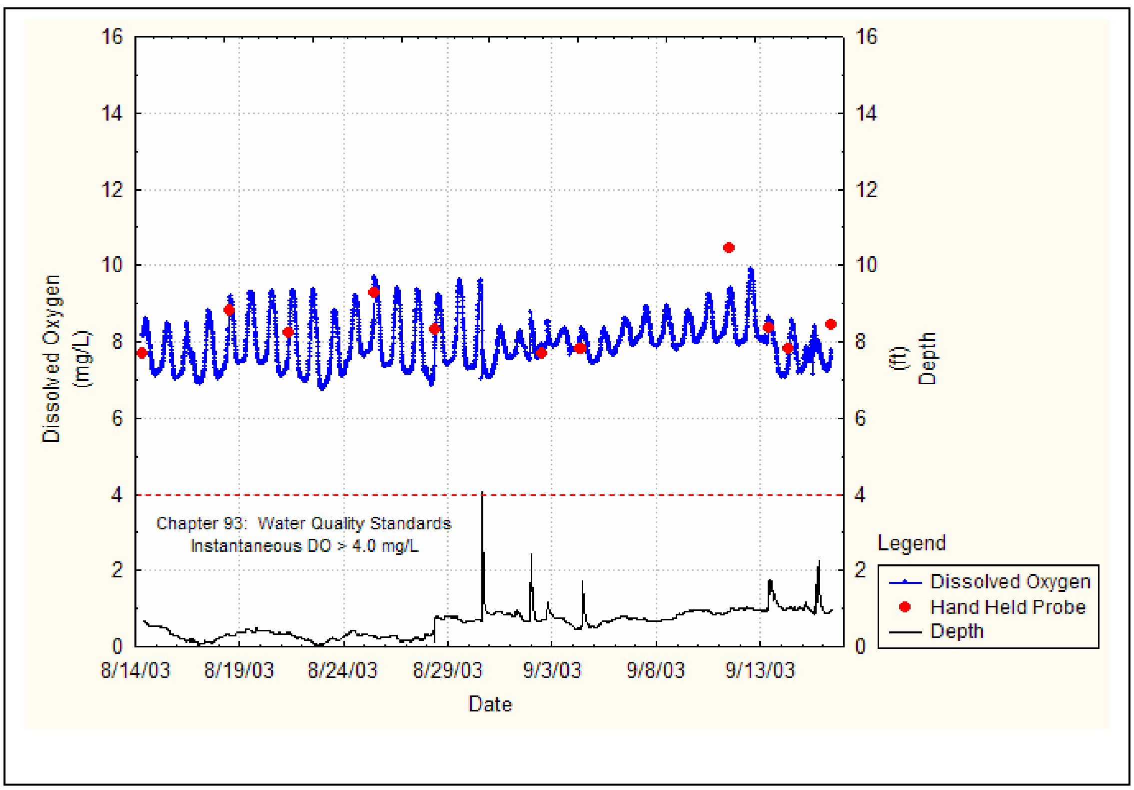


Figure 23. Continuous measurements of dissolved oxygen at DCC 770.

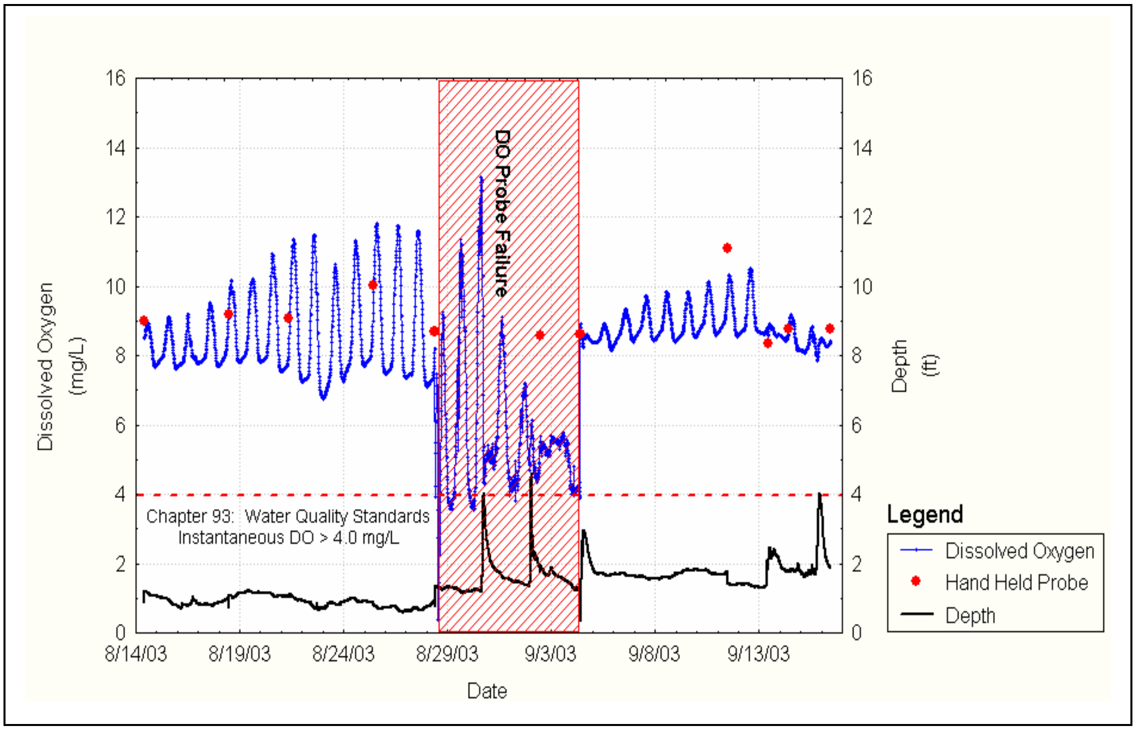


Figure 24. Continuous measurements of dissolved oxygen at DCD 765.

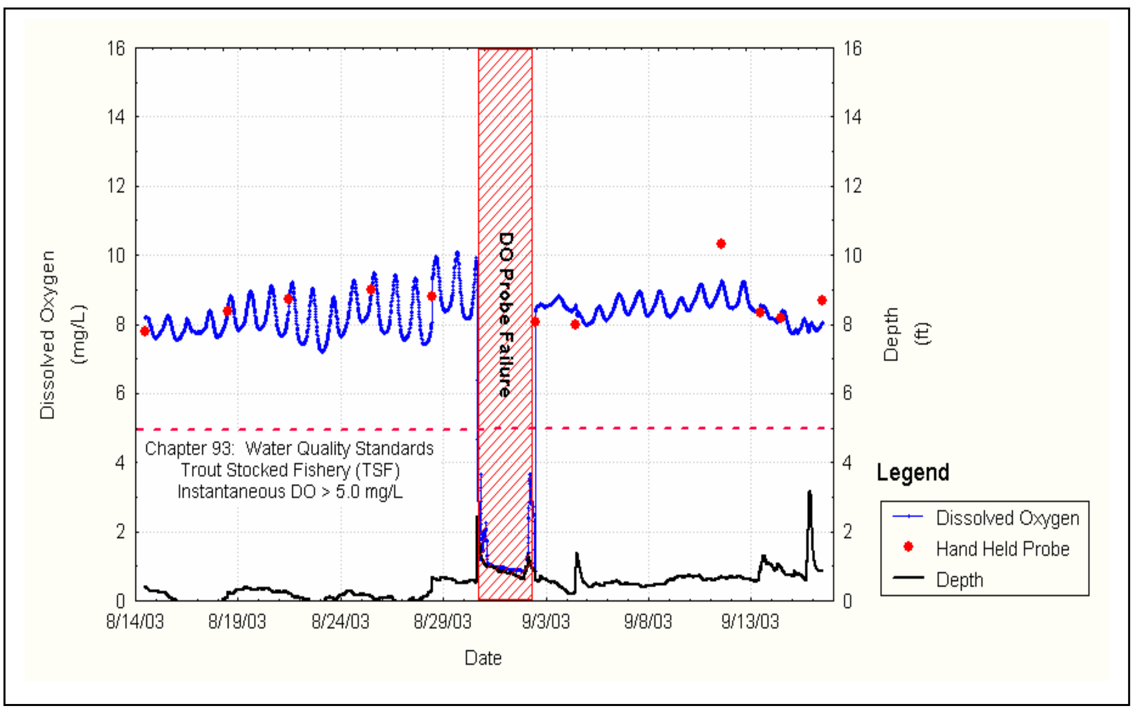


Figure 25. Continuous measurements of dissolved oxygen at DCD 1660.

partially shaded. While not as large as DCC208, the amplitude of DO fluctuations exceeded 3 mg/L at this site. In contrast, the Sonde at DCD1660 is located under a bridge in shallow water. While not measured quantitatively, it is likely that algal periphyton density was smaller at this site; resulting diel fluctuations are damped in comparison to sites exposed to more sunlight (Figure 25). Sondes at sites DCC455 and DCC770 are in areas that are mostly shaded (Figures 22 and 23, respectively).

Two separate rain events occurred during the period of Sonde deployments in Darby-Cobbs Watershed. During and following the rain events, DO concentrations decreased considerably. Following sloughing of algal periphyton (benthic algae, biofilm, *aufwuchs*), the stream exhibits effects of diminished productivity. An August 30, 2003 rain event demonstrated this phenomenon at all five continuously monitored sites. DCC208 is the only site in which DO suppression violated the state water quality standards for instantaneous dissolved oxygen. Site DCC208, as discussed earlier, has many site-specific attributes that result in dense algal periphyton communities. These same factors also make it more difficult to measure DO concentrations with veracity. (DO probe failure occurred at two sites during this rain event. Cleaning of debris from DO probes, in both cases, corrected the problem in time to record a period of diminished productivity due to sloughing at these sites). Following the disturbance, autotrophic communities became reestablished, as evidenced by the return of normal, exaggerated diel fluctuations in DO concentration.

5.4.5. pH

Continuous monitoring through the use of Sondes on the Darby and Cobbs Creeks recorded pH values at each of five sites. pH is a measure of acidity, or the concentration of hydrogen ions in a solution. In natural waters, the balance between acidity and alkalinity is determined by concentrations of various dissolved compounds, salts and gases and typically remains near neutral, or pH 7. Fluctuations in pH can occur in freshwater systems as a result of natural and anthropogenic influences. Interplay between inorganic carbon species, known as the bicarbonate buffer system, generally maintains pH within a range suitable for aquatic life.

The bicarbonate buffer system is a function of the equilibrium relationship between carbon dioxide (CO_2) and carbonic acid (H_2CO_3), as well as bicarbonate (HCO_3^-) and carbonate (CO_3^{2-}) ions. In natural waters, the predominant source of hydrogen ions is carbonic acid. Biochemical metabolism of carbon throughout the day continually shifts the equilibrium equation, causing fluctuations in pH. As plants and algae consume carbon dioxide during photosynthesis, carbonic acid dissociates to replenish the CO_2 and maintain equilibrium. Decreasing carbonic acid concentrations cause elevated pH. As photosynthetic rates decline after peak sunlight hours, respiratory activities of aquatic biota replenish carbon dioxide to the system, decreasing pH. Acidity in Darby-Cobbs watershed is chiefly determined by this metabolic activity; the watershed is not heavily influenced by bedrock composition, groundwater sources or anthropogenic inputs, such as acid mine drainage.

Water quality criteria established by PADEP regulate pH to a range of 6.0 to 9.0 in Pennsylvania's freshwater streams. pH values between 6 and 9 units do not negatively affect stream biota. Organisms can be indirectly affected by pH due to its influences on the dissociation of many compounds, such as ammonia. As pH increases, a greater fraction of ammonia N is present as unionized NH_3 (gas). For example, ammonia is ten times as toxic at pH 8 as at pH 7. Extreme pH values may increase dissociation of or general toxicity of other constituents. For example, pH levels affect the bioavailability of metals (e.g., copper), which have individually regulated criteria established by PADEP.

Continuous pH data was discretized to 15 min intervals and plotted against time and stream depth. Figures 26 through 30 depict pH trends at each of five continuously-monitored sites on the Darby-Cobbs watershed, including the large diel pH fluctuations that accompany highly productive sites with abundant periphytic algae. Community metabolism regulates the extent of pH fluctuations. Environmental conditions, including ample sunlight, led to a dense autotrophic community at sites DCC208 and DCD765, which exhibited greater diel pH fluctuations than the other monitored sites; these sites also generally came closest to and occasionally violated water quality criteria by exceeding pH 9.0 (Figures 26 and 29, respectively). pH at shadier sites (i.e., DCC770, DCC455 and DCD1660) is probably less influenced by metabolic activity, and oscillations in pH appear noticeably damped as a result.

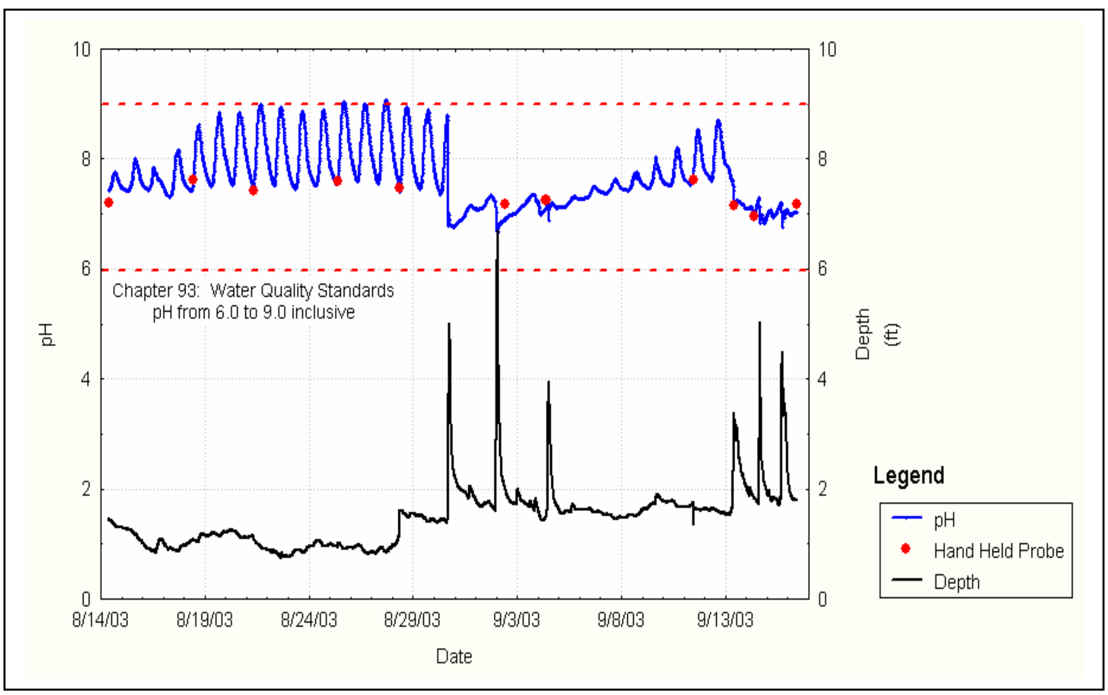


Figure 26. Continuous measurements of pH at DCC 208.

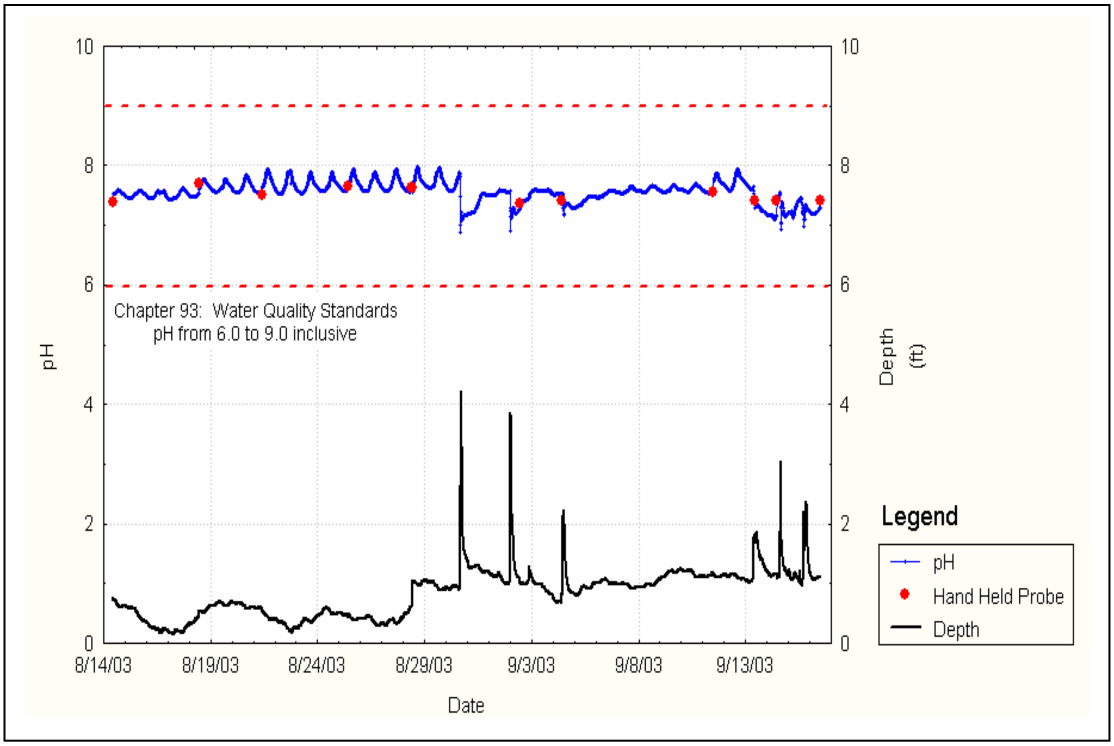


Figure 27. Continuous measurements of pH at DCC 455.

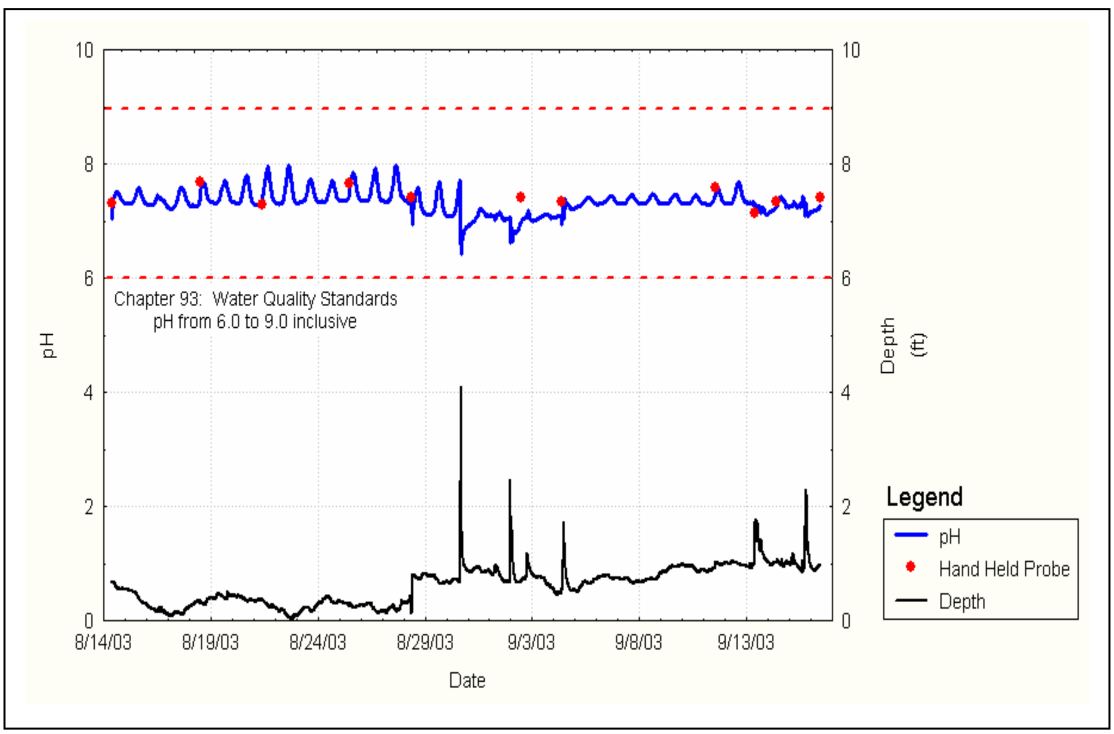


Figure 28. Continuous measurements of pH at DCC 770.

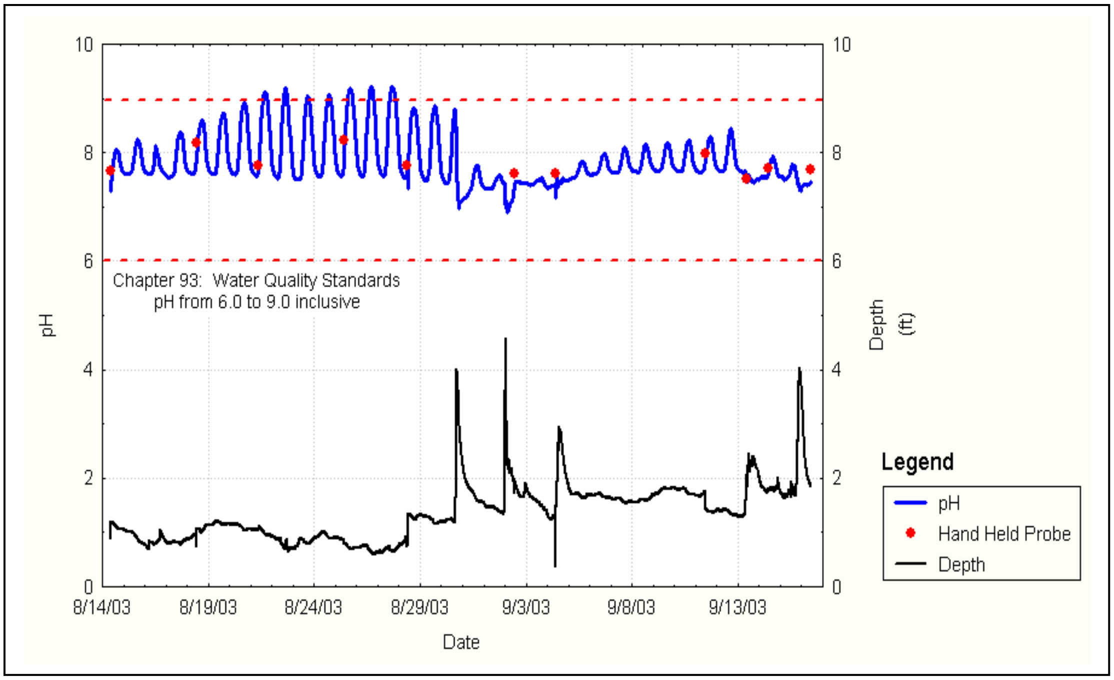


Figure 29. Continuous measurements of pH at DCD 765.

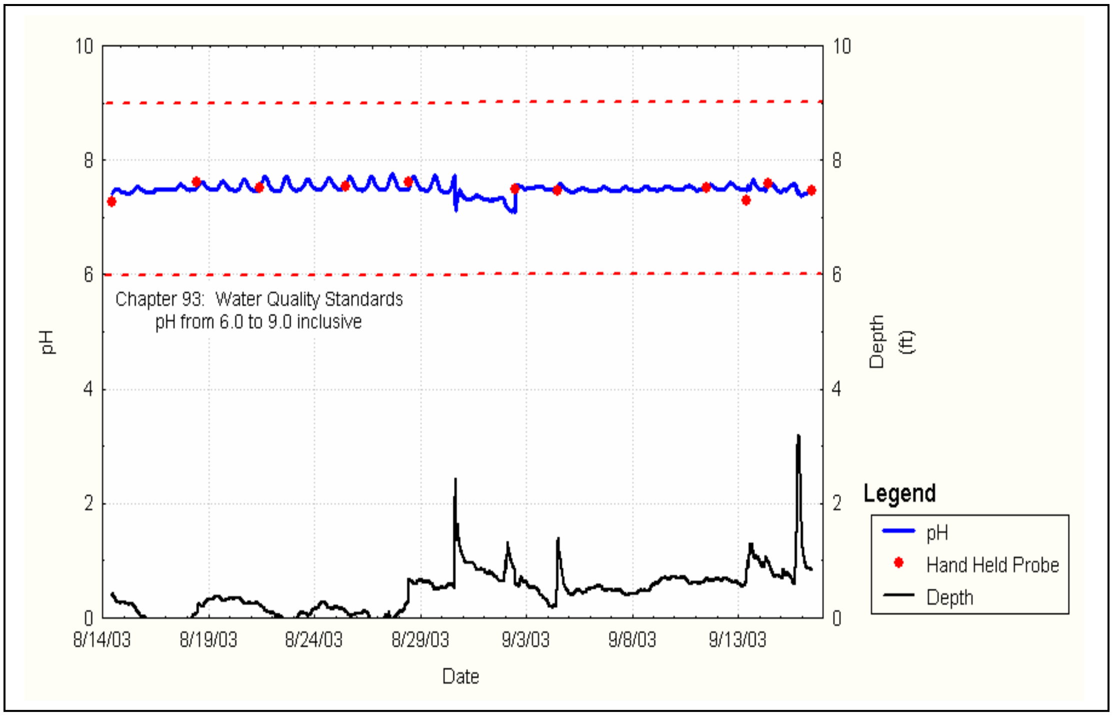


Figure 30. Continuous measurements of pH at DCD 1660.

Two separate rain events occurred during the period of Sonde deployments in Darby-Cobbs Watershed. Increased velocities and larger flows during wet weather swept away attached algae, macrophytes and suspended periphyton. Figures 26 through 30 demonstrate that without autotrophs to reduce carbon dioxide through photosynthesis, pH levels remain steady. The autotrophic community recovers from this disturbance over subsequent weeks and pH gradually returns to normal fluctuations at each site. Decreased pH levels during and following wet weather events did not violate minimum pH standards.

5.4.6. Specific Conductance

Specific conductance is a measure of waters' ability to pass electrical current and is an approximate predictor of total dissolved ions in solution. This measure is often used to monitor changes in water chemistry. Daily fluctuations in specific conductance result from biological activity changes that occur throughout the day. Sites DCC208 and DCD765 experienced more pronounced daily changes in specific conductance due to the presence of a denser biological community (Figures 31 and 34, respectively). Other factors affecting specific conductance include rain events, which decrease conductivity due to dilution of stream water by storm water and increases in total ionic strength due to application of de-icing compounds and road salts during cold weather. Following a large rain event, dissolved ion concentrations may remain below normal baseflow concentrations for more than a week as the stream's natural chemistry gradually reestablishes itself.

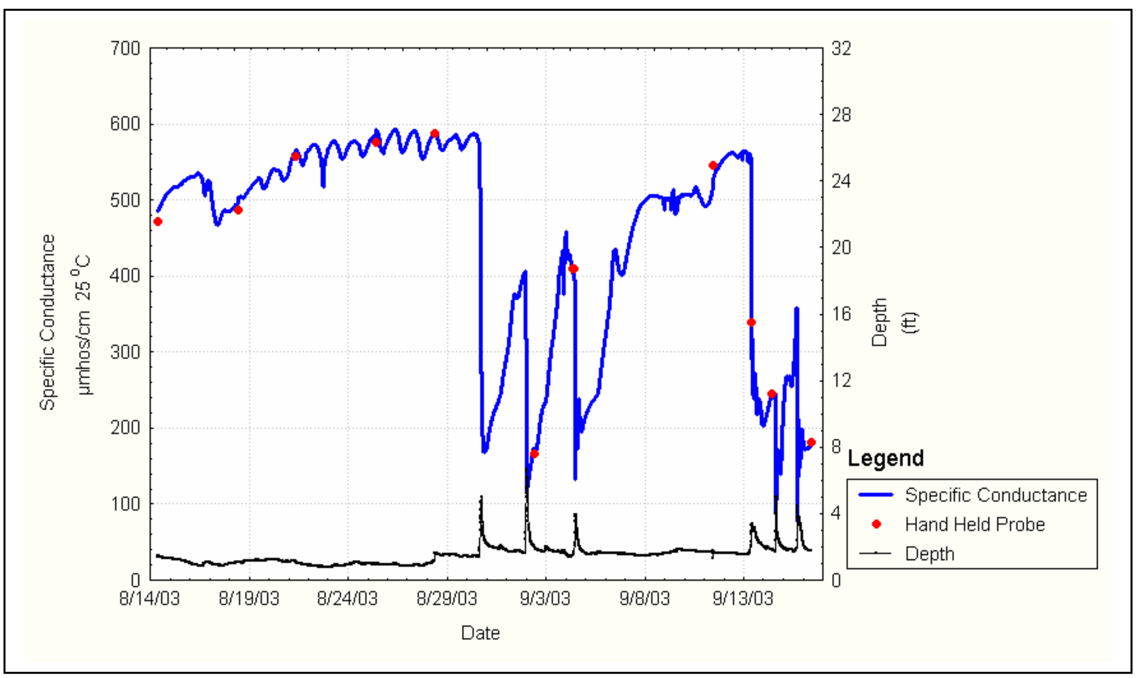


Figure 31. Continuous measurements of Specific Conductance at DCC 208.

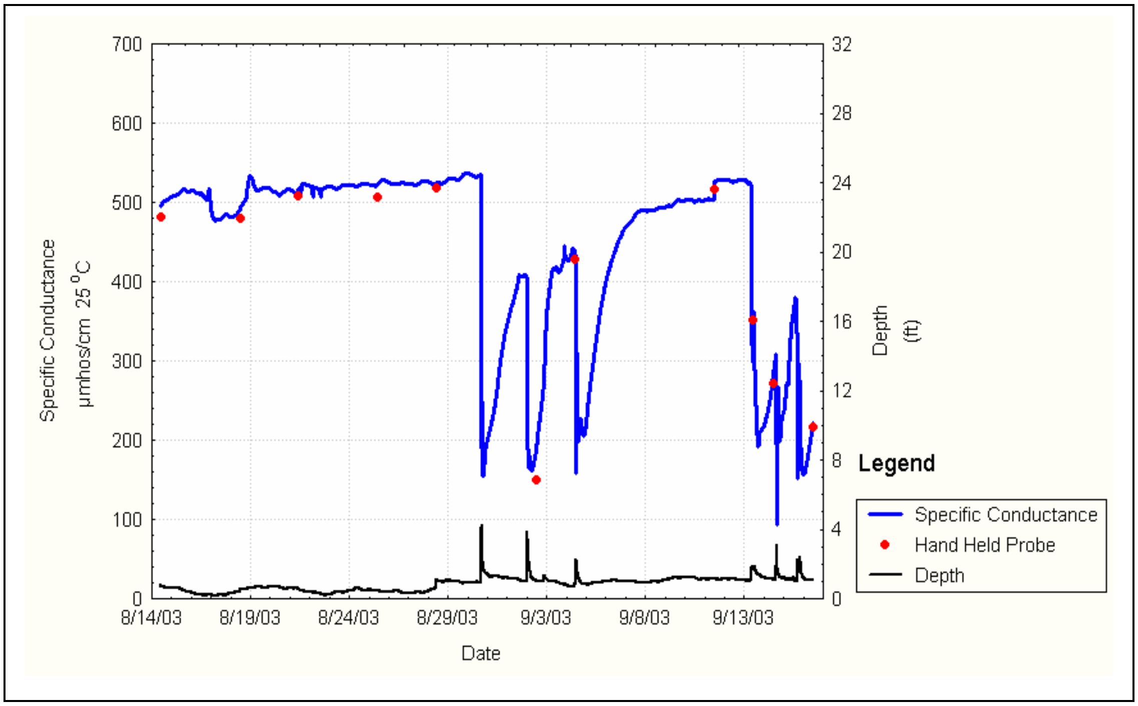


Figure 32. Continuous measurements of Specific Conductance at DCC 455.

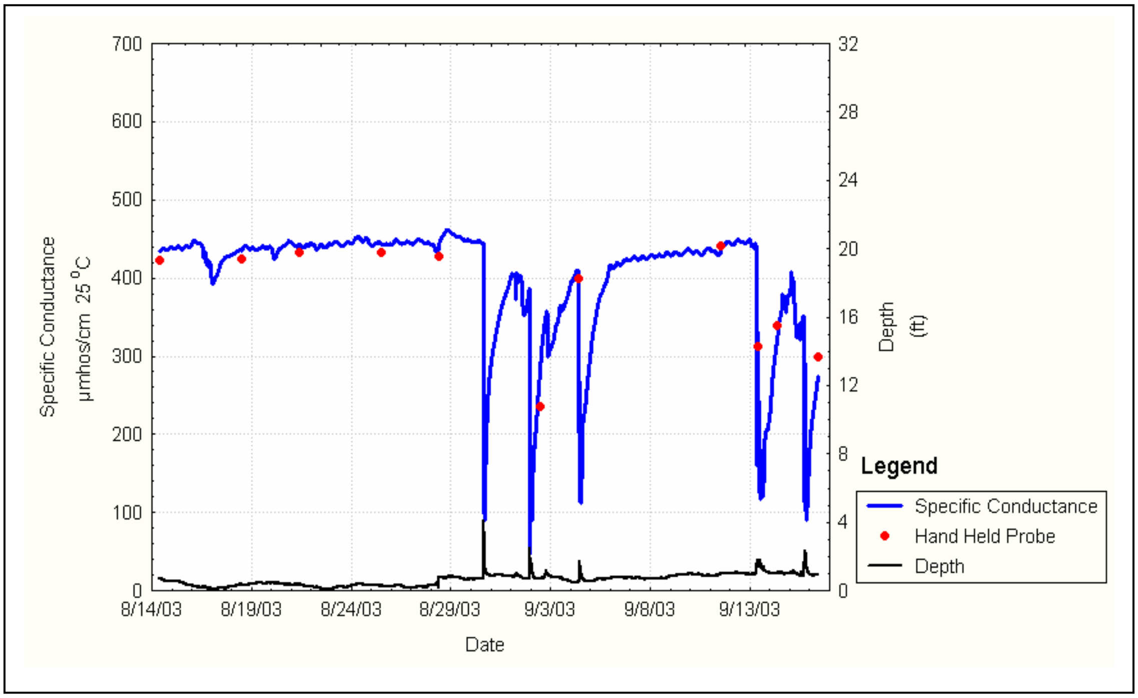


Figure 33. Continuous measurements of Specific Conductance at DCC 770.

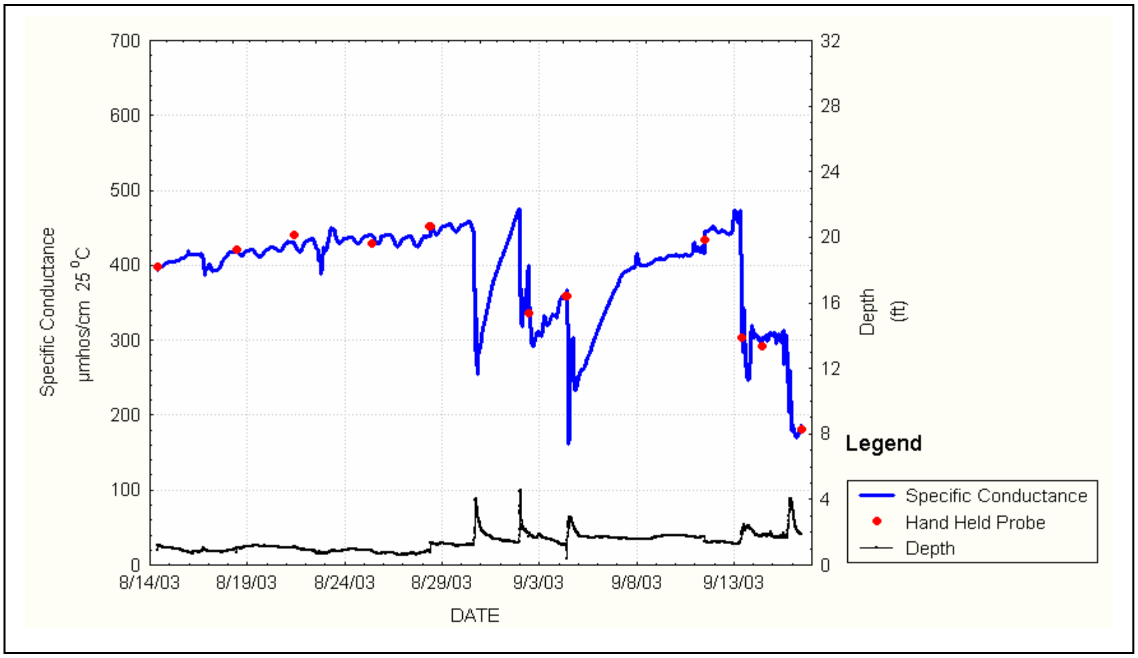


Figure 34. Continuous measurements of Specific Conductance at DCD 765.

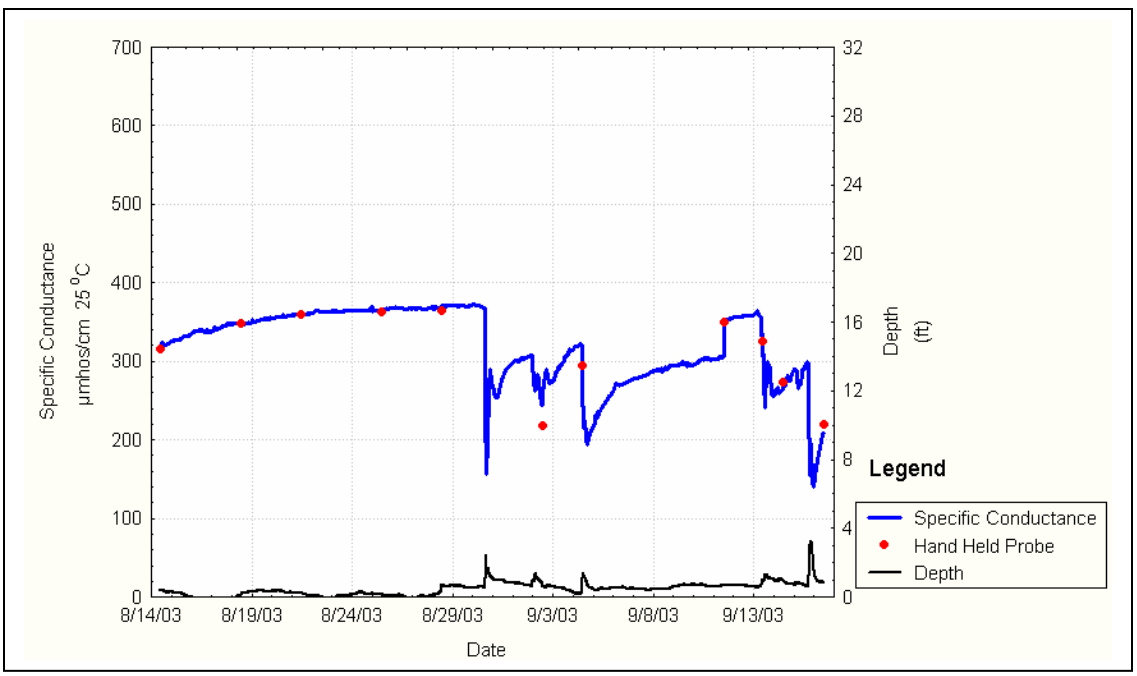


Figure 35. Continuous measurements of Specific Conductance at DCD 1660.

5.4.7. Temperature

The role of temperature in shaping aquatic communities cannot be understated. With the exception of birds and mammals, all freshwater aquatic organisms are poikilotherms ("cold-blooded"). Unable to regulate body temperature through metabolism, these organisms must select suitable temperature conditions within their habitats. PADEP has established temperature criteria for the waters of the commonwealth, largely to delineate areas requiring more stringent thermal protection for naturally-reproducing populations of sensitive ("cold water") fish species, recreationally-sought salmonids, in particular. Temperature criteria also serve to protect aquatic life from increases in temperature from industrial activity (e.g., cooling water). Darby-Cobbs Watershed does not support natural populations of coldwater fish, and is not known to be significantly affected by discharges of cooling waters.

Many water bodies that cannot support natural populations of cold water fish do have adequate thermal protection to maintain hatchery-raised adult trout. Segments of Darby Creek watershed north of PA Rte 3 (West Chester Pike) are so protected and are designated a trout stocking fishery (TSF); the remainder of Darby-Cobbs watershed is designated a warmwater fishery (WWF). Thermal maxima for sites in Darby Cobbs Watershed, as measured with continuous water quality monitoring equipment, never exceeded State water quality standards (Figures 36 through 40). Changes in temperature of 2ºC or more were observed at most sites on a number of occasions; however, changes of this magnitude occurred in dry and in wet weather.

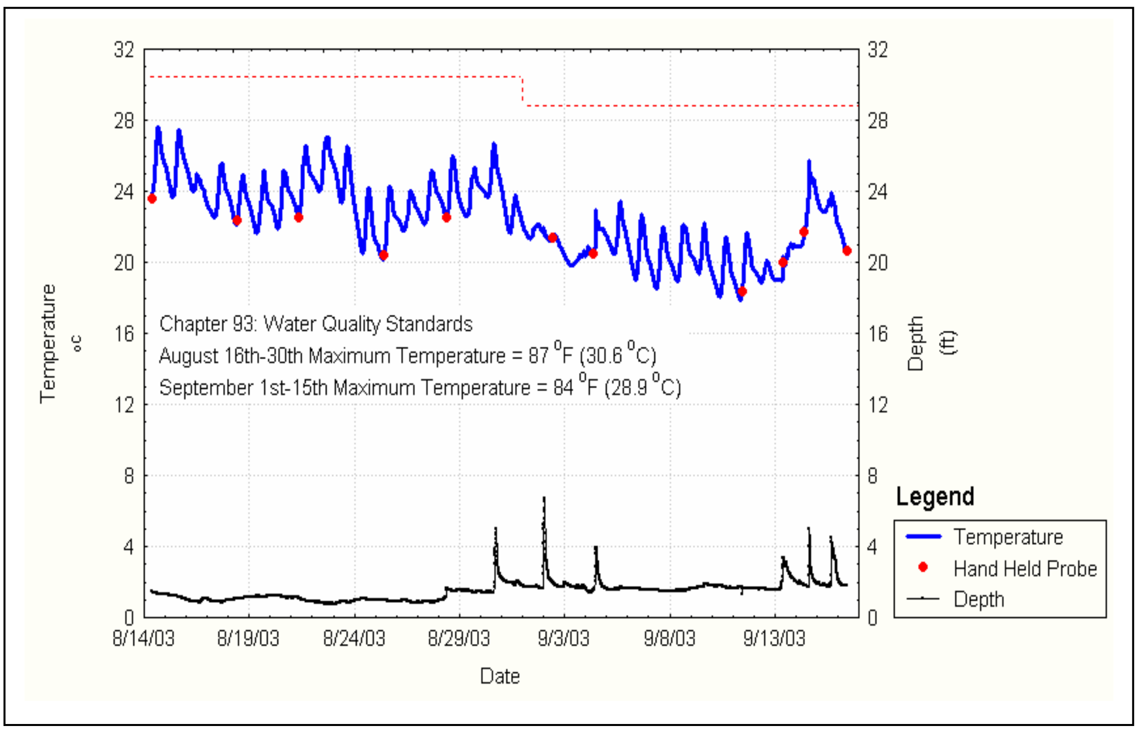


Figure 36. Continuous measurements of temperature at DCC 208.

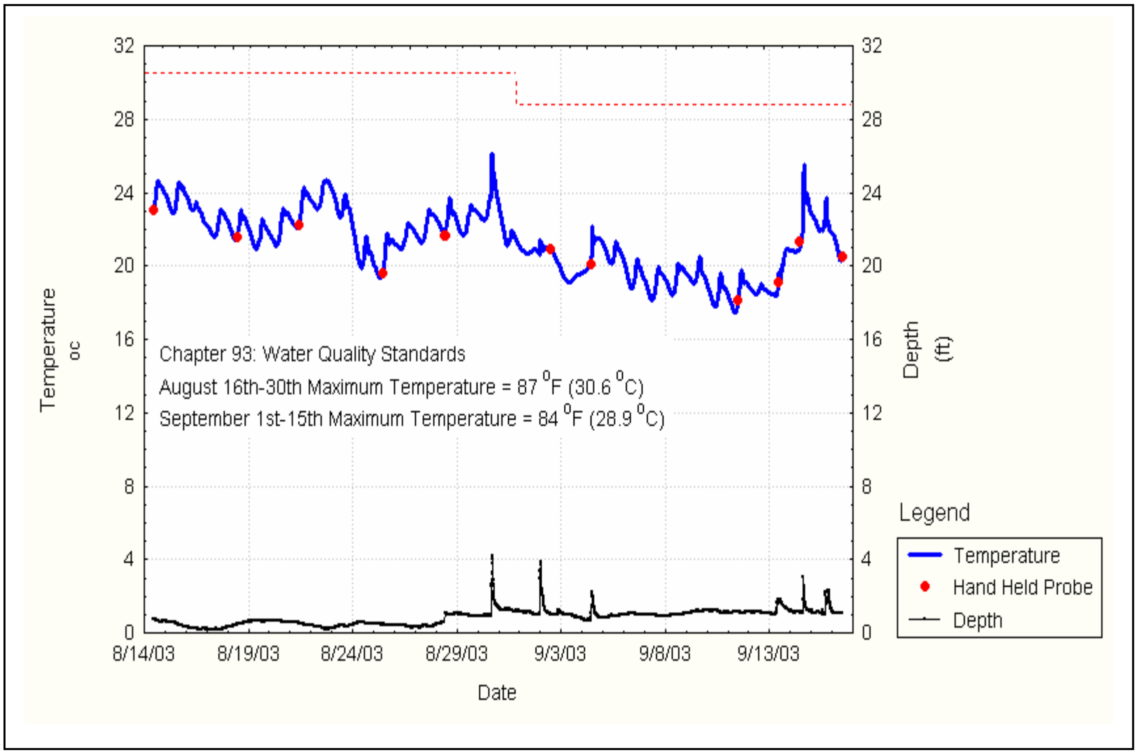


Figure 37. Continuous measurements of temperature at DCC 455.

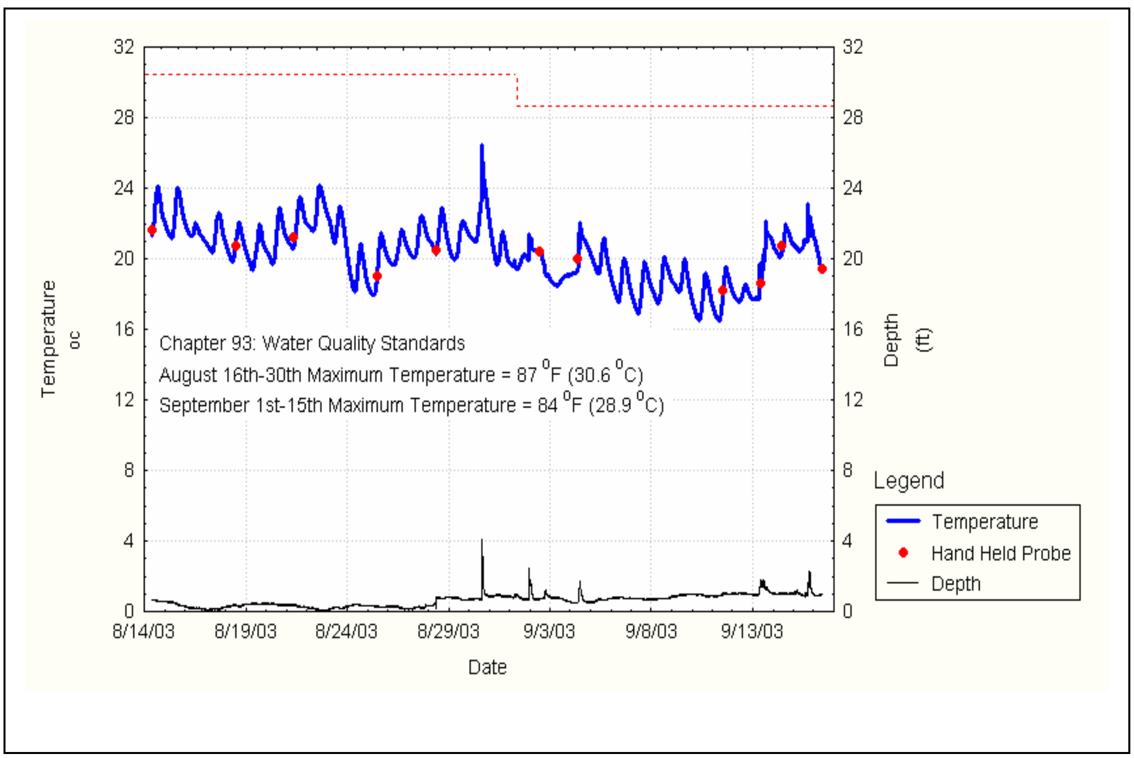


Figure 38. Continuous measurements of temperature at DCC 770.

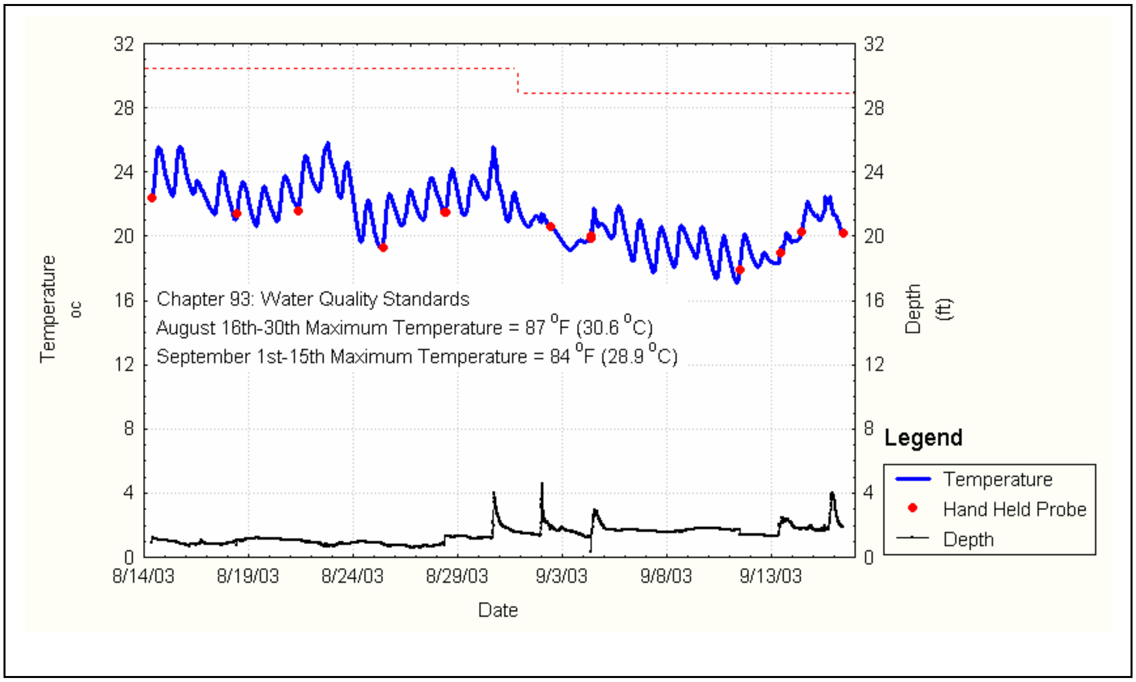


Figure 39. Continuous measurements of temperature at DCD 765.

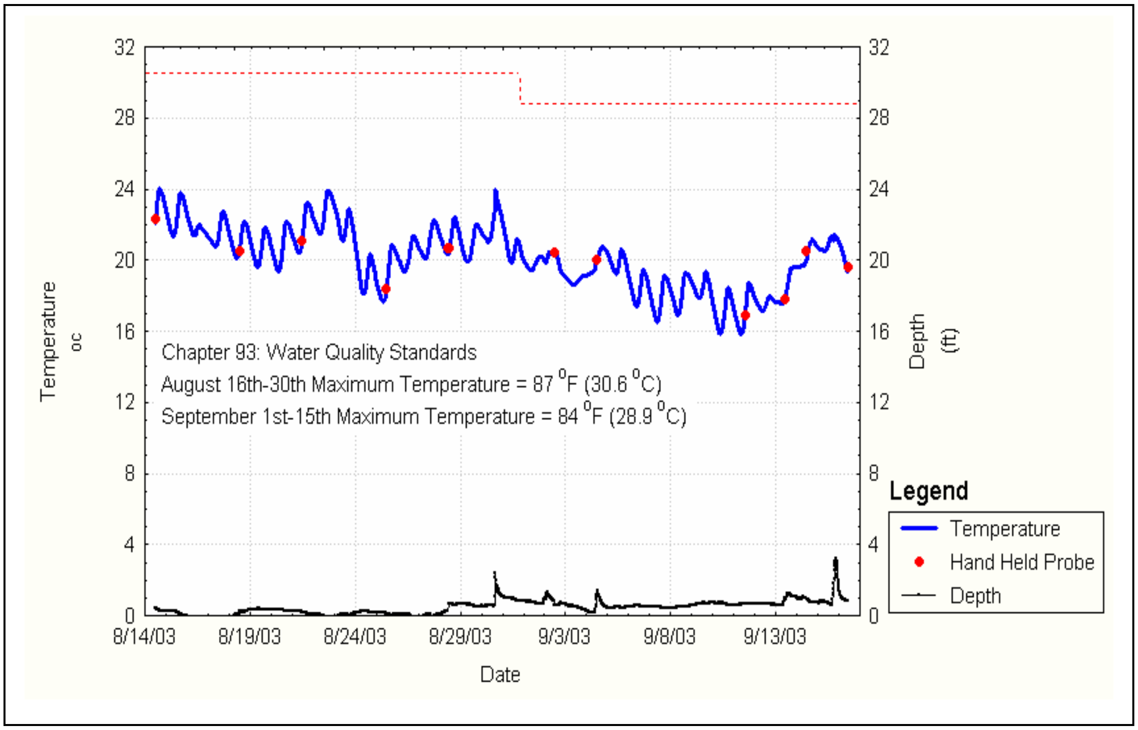


Figure 40. Continuous measurements of temperature at DCD 1660.

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.

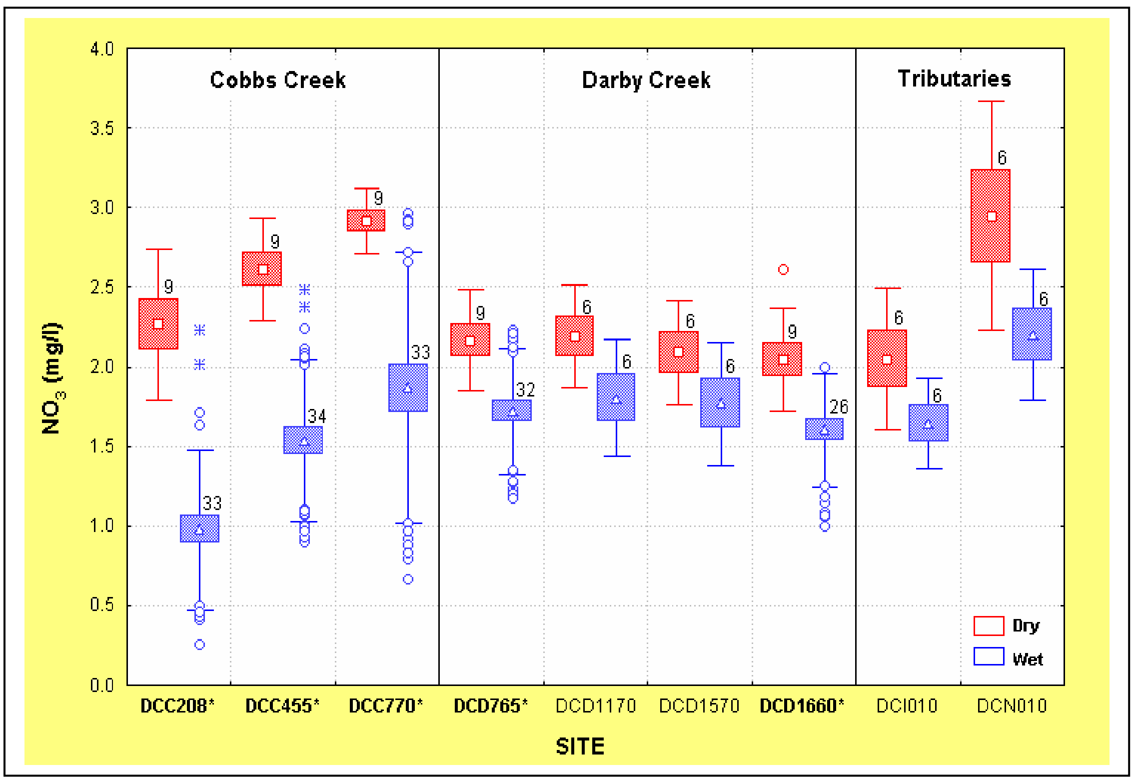


Figure 41. Dry and wet weather nitrate concentrations at the 9 monitoring sites

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

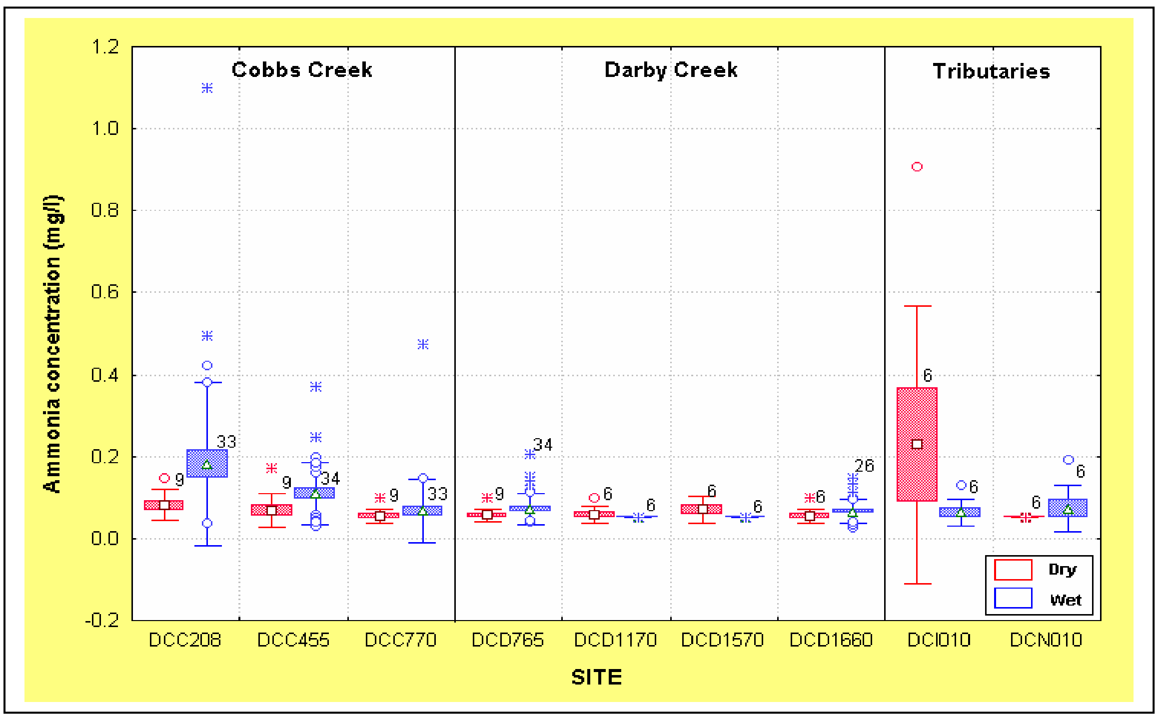


Figure 42. Dry and wet weather ammonia concentrations at the 9 monitoring sites.

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.

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

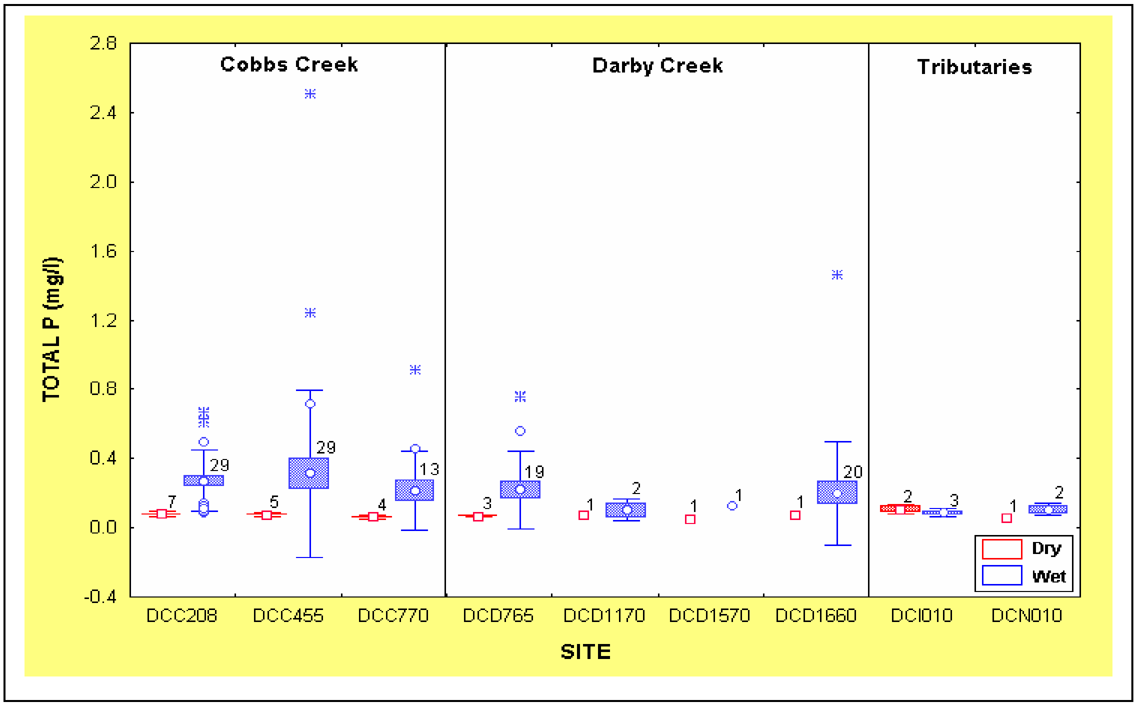


Figure 43. Dry and wet weather total phosphorus concentrations at the 9 monitoring sites.

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.

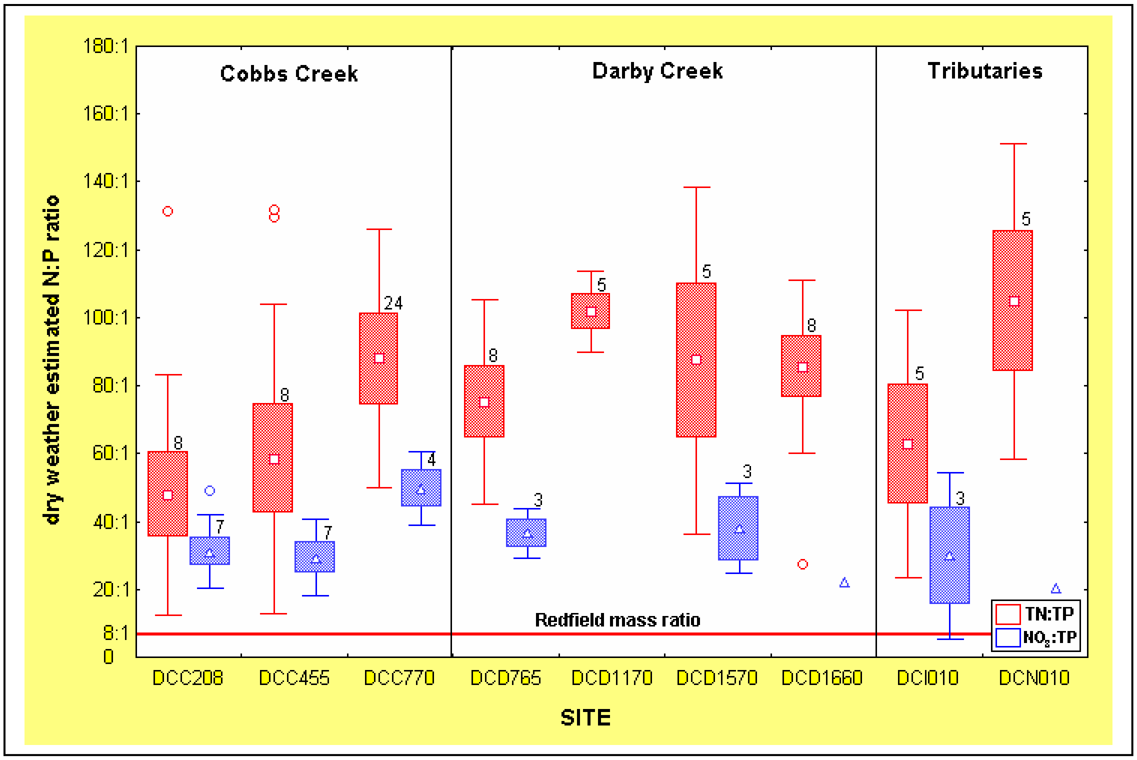


Figure 44. Estimated dry weather N:P ratios at the 9 monitoring sites.

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.

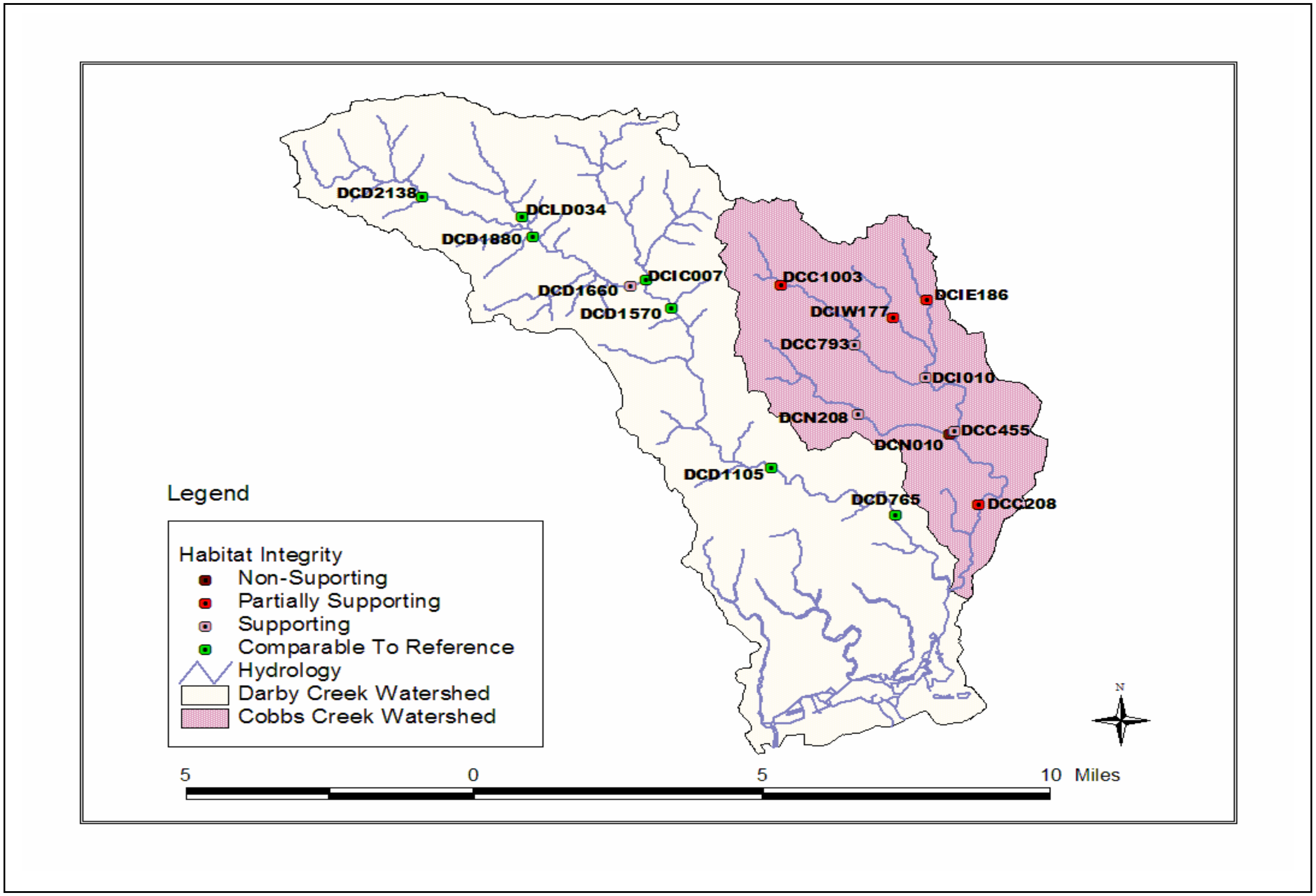


Figure 45. Stream channels and aquatic habitat indicator status update.

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.

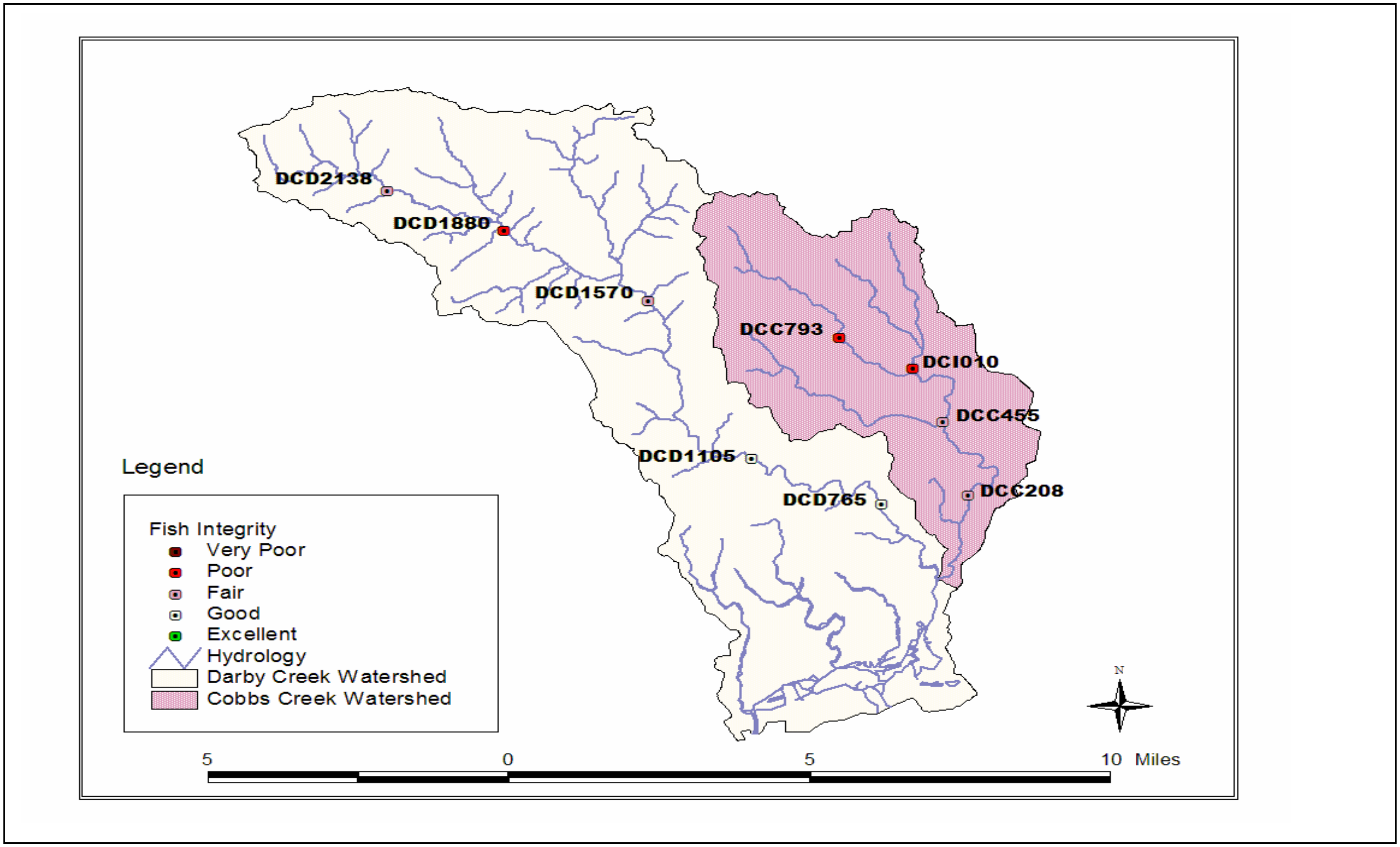


Figure 46. Fish indicator status update.

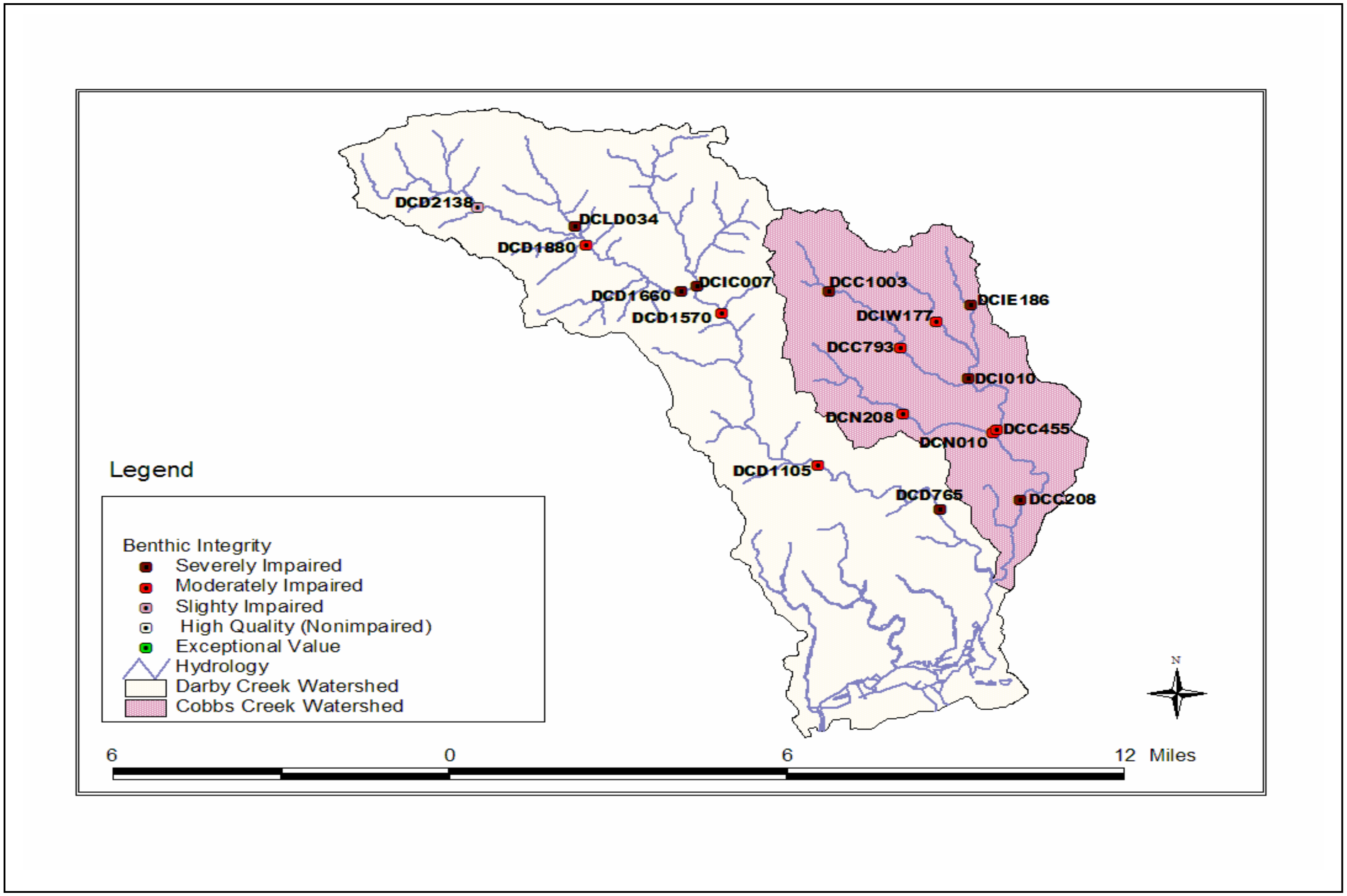


Figure 47. Benthic indicator status update.

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.

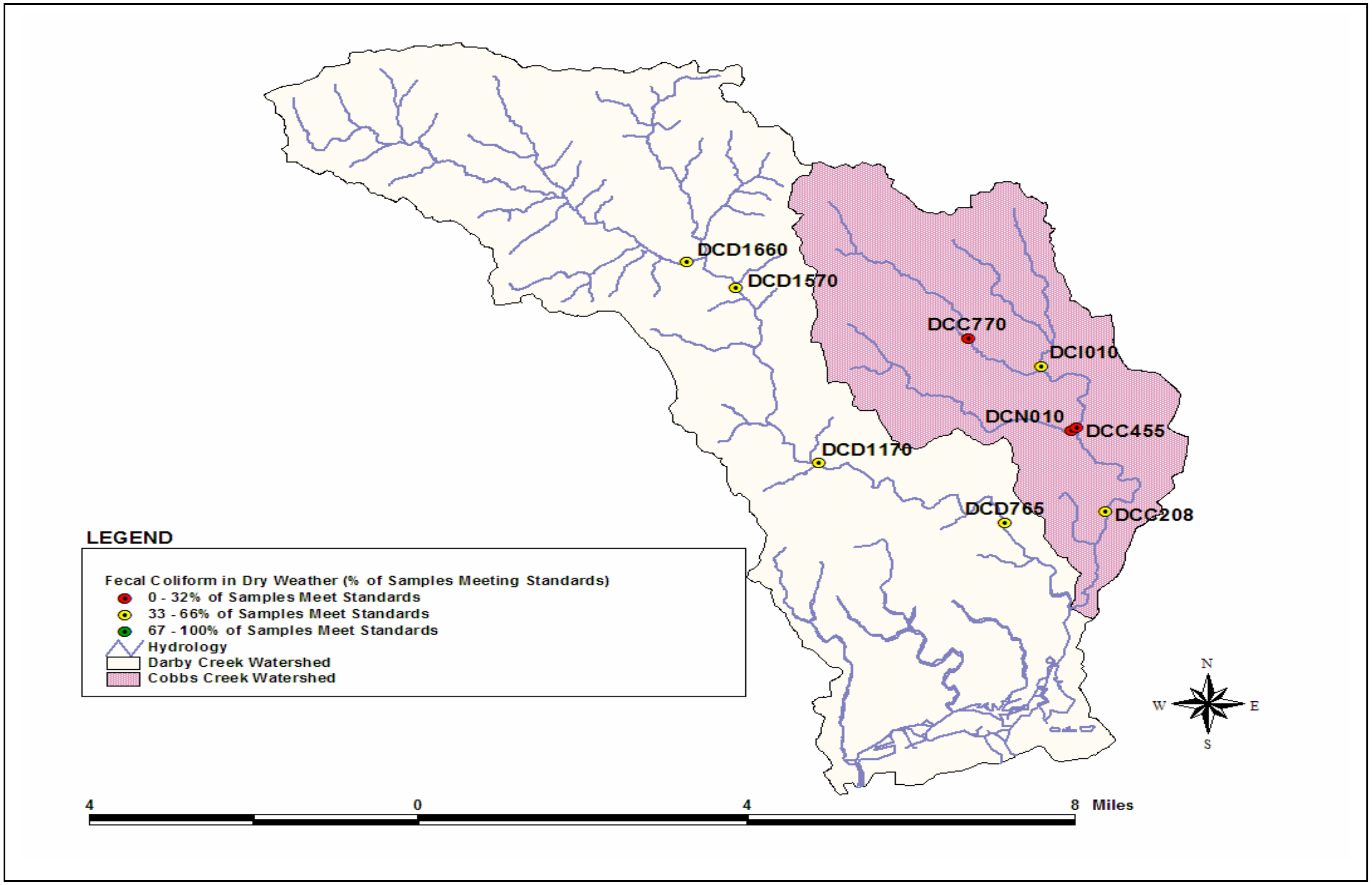


Figure 48. Dry weather fecal coliform indicator status update.

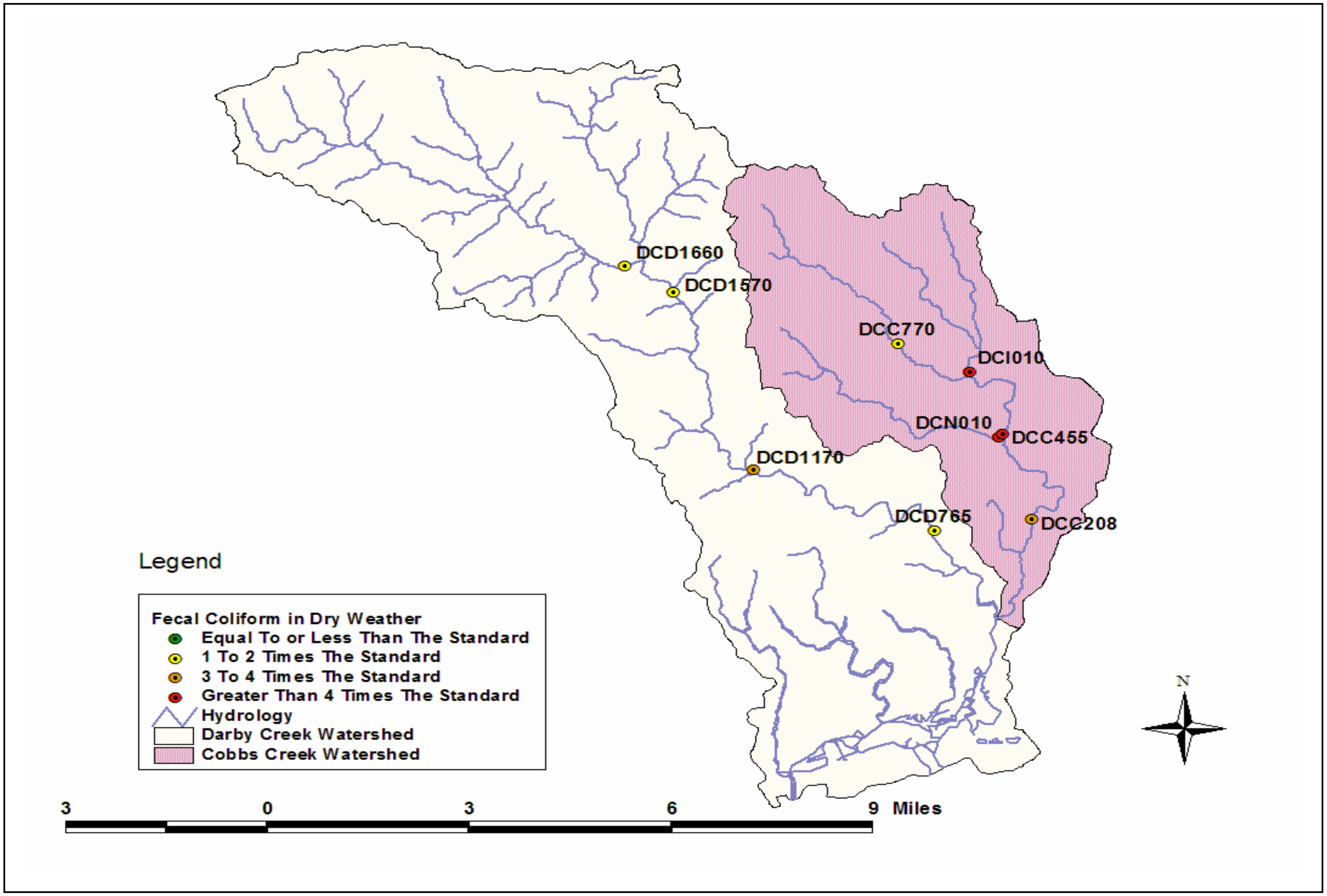


Figure 49. Geometric means of fecal coliform concentrations in dry weather

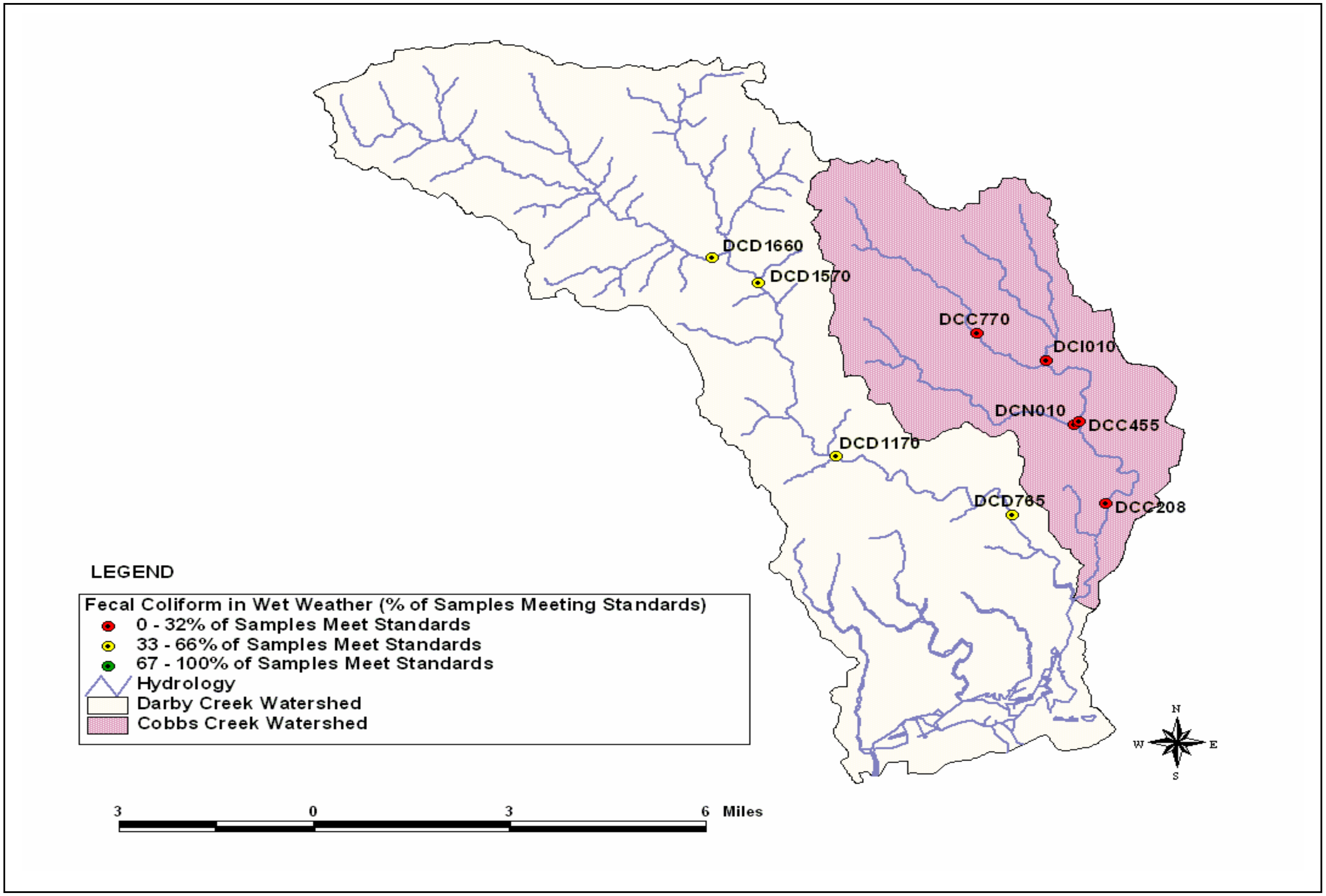


Figure 50. Wet weather fecal coliform indicator status update.

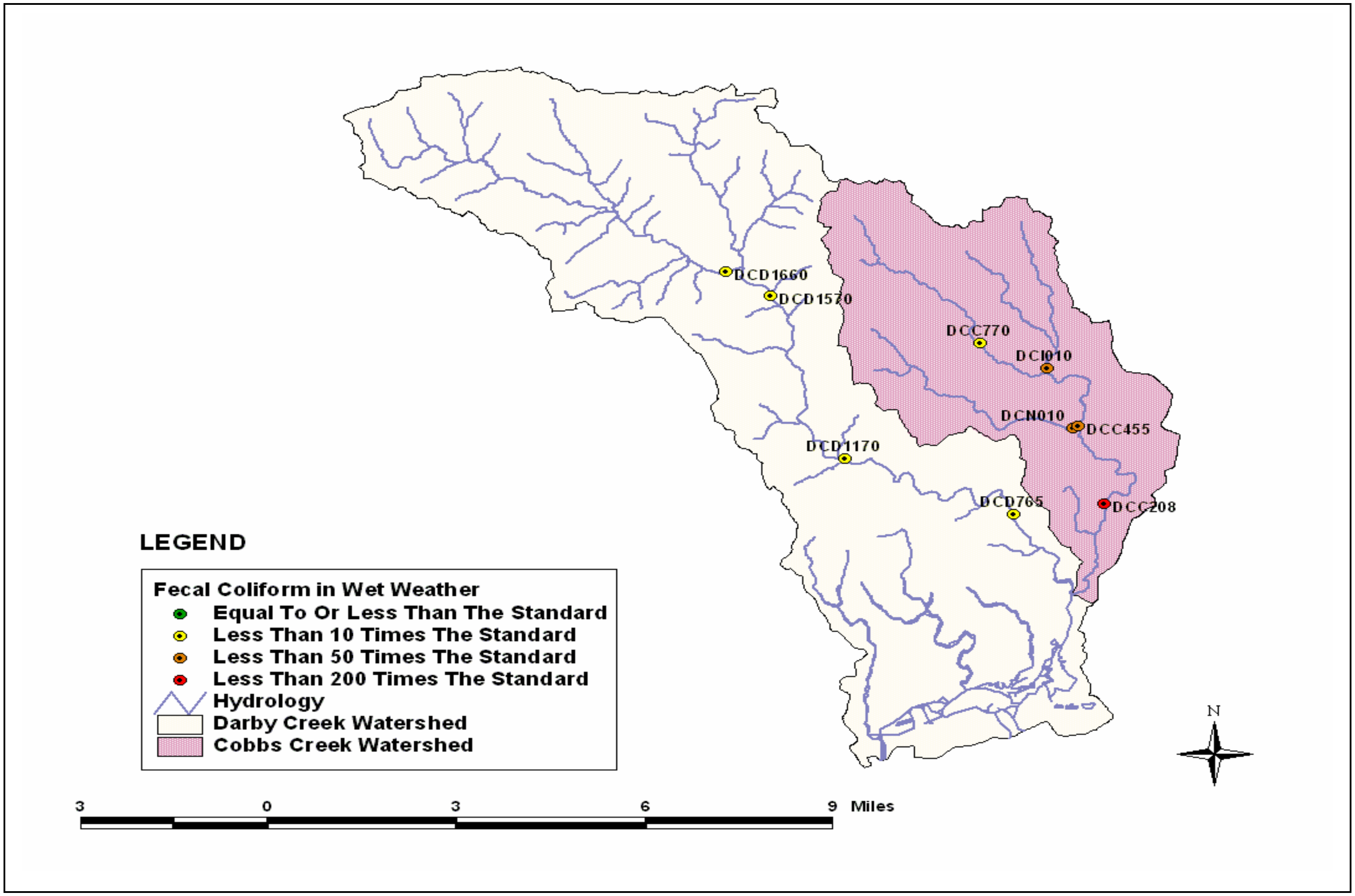


Figure 51. Geometric means of fecal coliform concentrations in wet weather.

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.

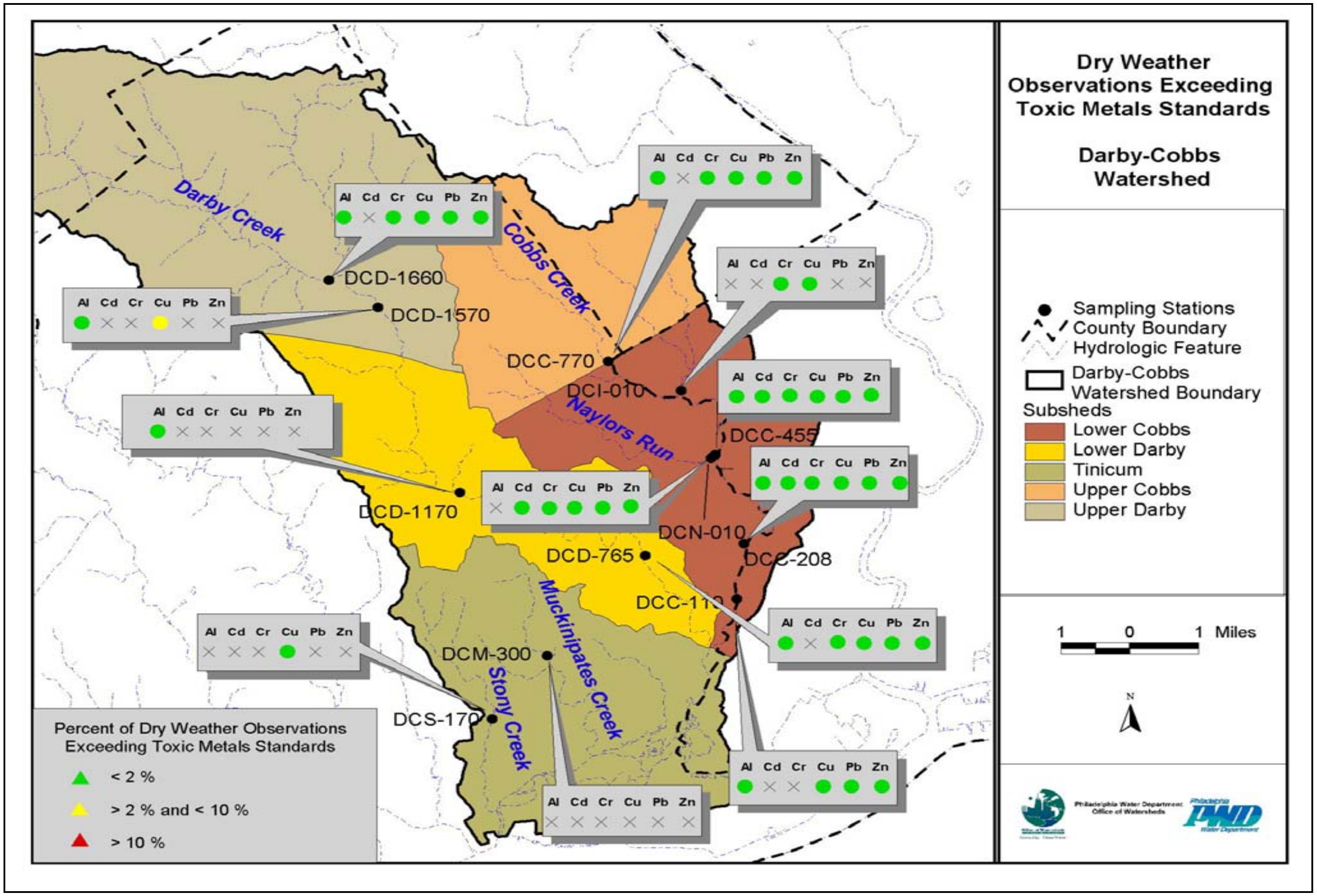


Figure 52. Dry weather metals indicator status update.

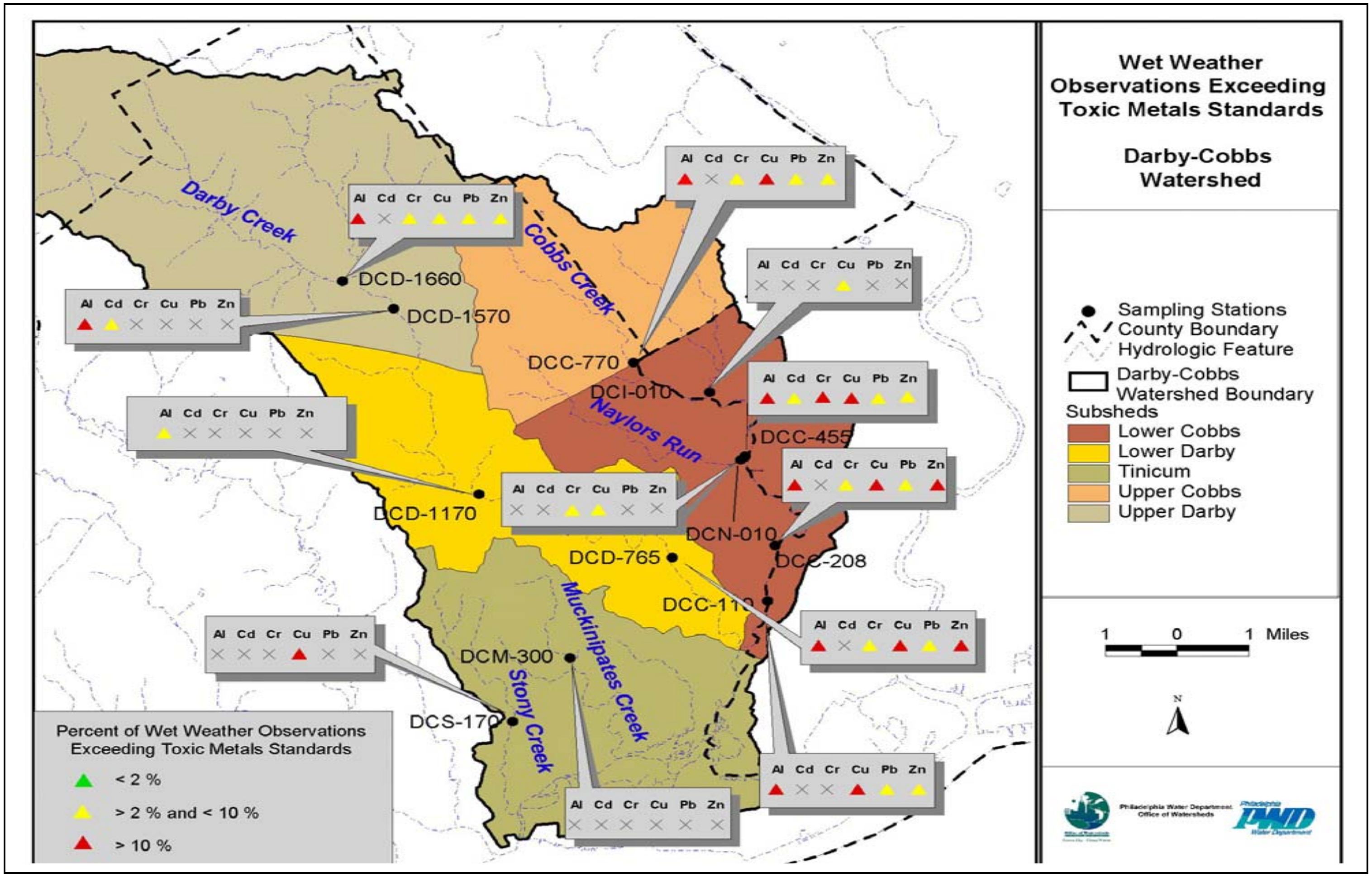


Figure 53. Wet weather metals indicator status update.

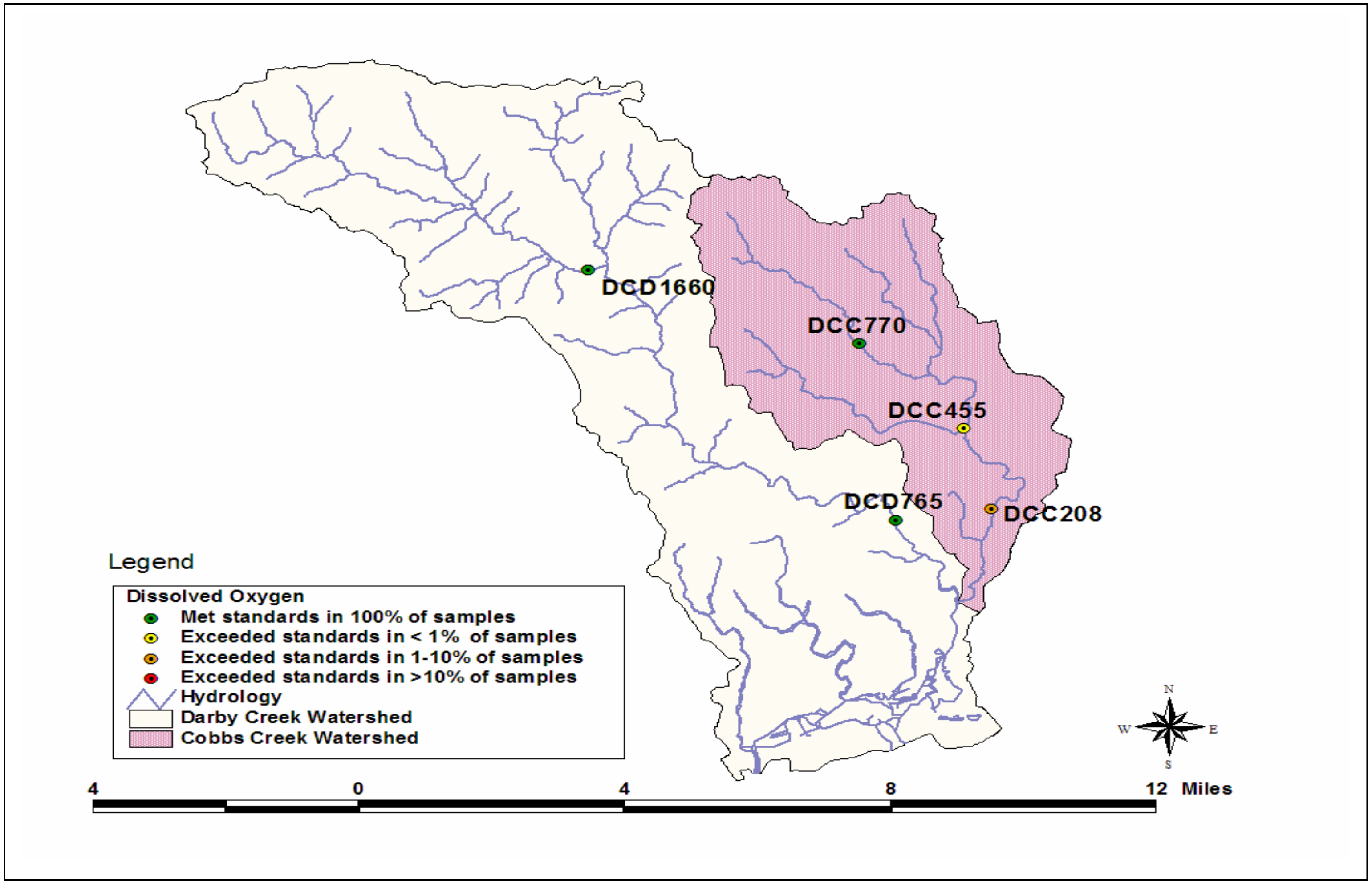


Figure 54. Dissolved oxygen indicator status update.

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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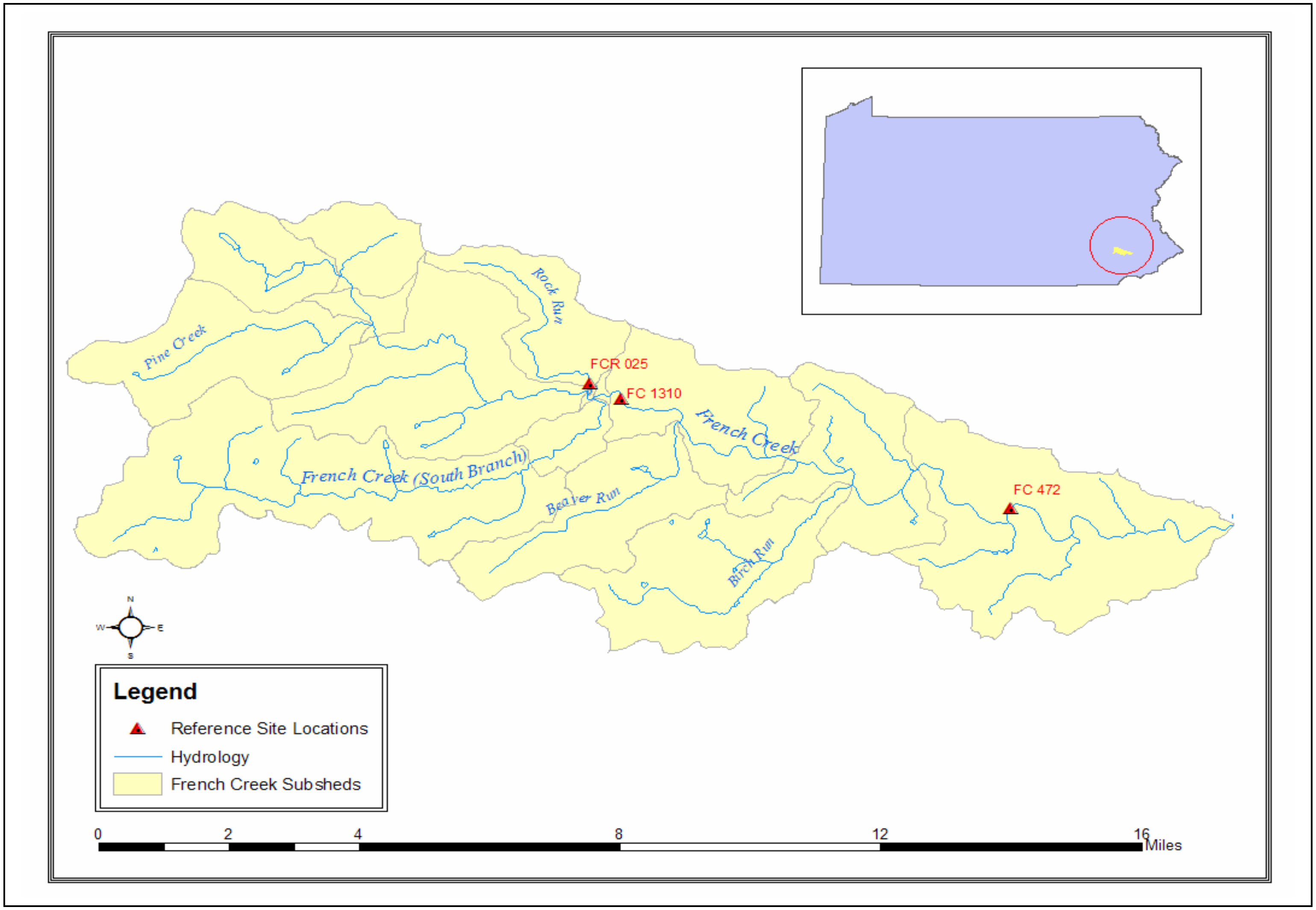
APPENDIX A: REFERENCE MONITORING LOCATIONS



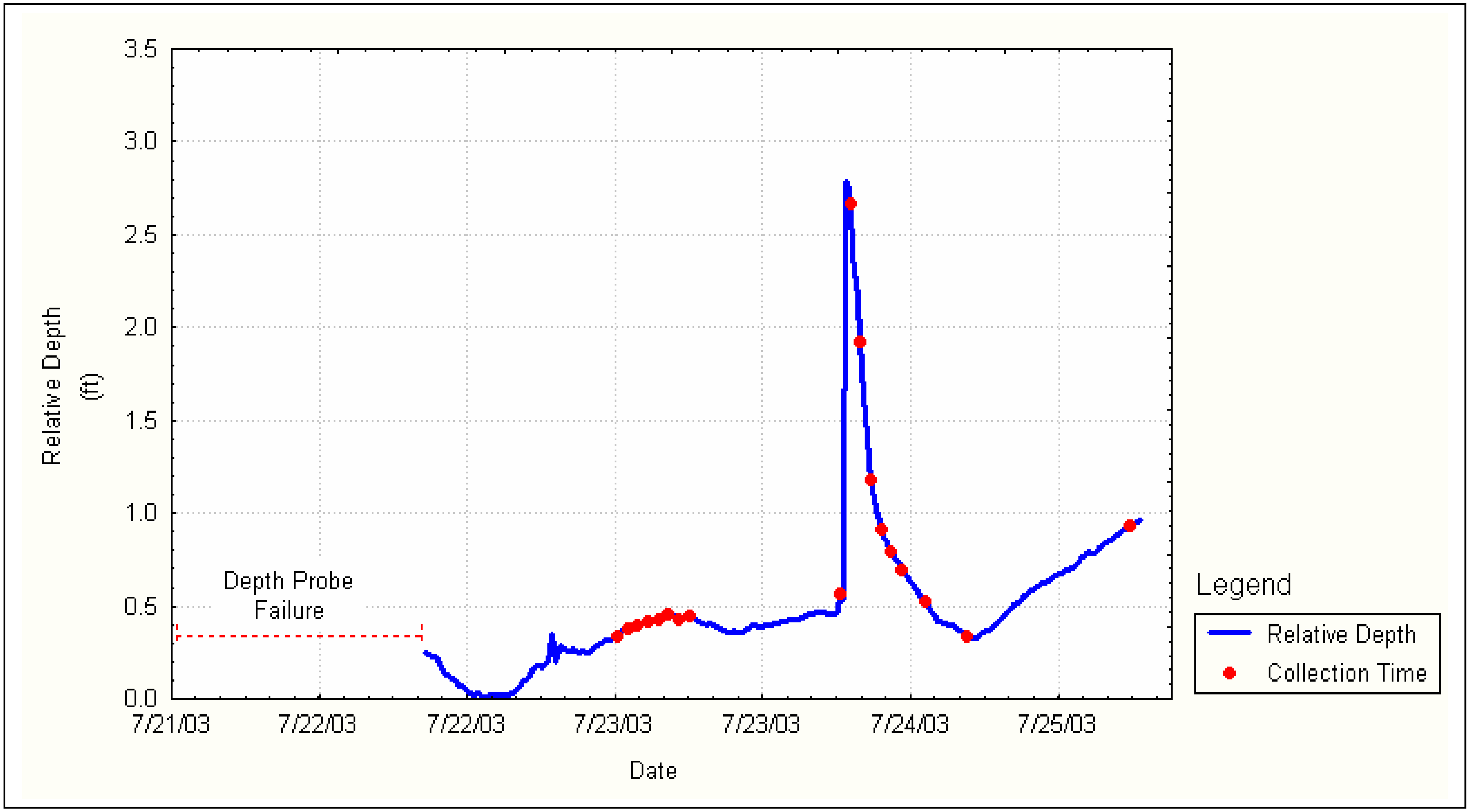
Pine Creek
Rock Run
FCR 025
FC 1310
French Creek
French Creek (South Branch)
Beaver Run
Birch Run
FC 472
Legend
Reference Site Locations
Hydrology
French Creek Subsheds
0
2
4
8
12
16
Miles

APPENDIX B: SIMPLE LINEAR REGRESSION (SLR) EQUATIONS OF FISH SPECIES IN DARBY-COBBS WATERSHED

SCIENTIFIC NAME	COMMON NAME	SPECIES CODE	SLR EQUATION	R^2 VALUE
Ameiurus nebulosus	Brown Bullhead Catfish	AMNEB	y = 3.1186x - 1.9473	R2 = 0.9938
Ambloplites rupestris	Rock Bass	AMRUP	y = 2.8935x - 1.5764	R2 = 0.9916
Anguilla rostrata	American Eel	ANROS	y = 3.3829x - 3.2737	R2 = 0.9958
Catostomus commersoni	White Sucker	CACOM	y = 3.0851x - 2.0466	R2 = 0.9956
Cyprinella analostana	Satinfin Shiner	CYANA	y = 2.7327x - 1.7254	R2 = 0.9081
Etheostoma olmstedi	Tessellated Darter	ETOLM	y = 2.6587x - 1.6963	R2 = 0.8395
Exoglossum maxillingua	Cutlips Minnow	EXMAX	y = 3.1629x - 2.032	R2 = 0.9915
Fundulus diaphanus	Banded Killifish	FUDIA	y = 3.1926x - 2.1244	R2 = 0.9741
Fundulus heteroclitus	Mummichog	FUHET	y = 3.2904x - 2.0907	R2 = 0.9859
Lepomis auritus	Redbreast Sunfish	LEAUR	y = 3.2349x - 1.9202	R2 = 0.9959
Lepomis gibbosus	Pumpkinseed Sunfish	LEGIB	y = 3.337x - 1.9906	R2 = 0.992
Lepomis macrochirus	Bluegill Sunfish	LEMAC	y = 3.2184x - 1.9574	R2 = 0.9976
Luxilus cornutus	Common Shiner	LUCOR	y = 3.4176x - 2.2849	R2 = 0.9895
Micropterus dolomieu	Smallmouth Bass	MIDOL	y = 2.6582x - 1.456	R2 = 0.9805
Micropterus salmoides	Largemouth Bass	MISAL	y = 3.0914x - 2.0213	R2 = 0.9938
Notropis hudsonius	Spottail Shiner	NOHUD	y = 2.9066x - 1.9642	R2 = 0.9743
Notropis procne	Swallowtail Shiner	NOPRO	y = 3.0687x - 2.0479	R2 = 0.9443
Oncorhynchus mykiss	Rainbow Trout	ONMYK	y = 2.9476x - 1.9371	R2 = 0.8555
Pimephales promelas	Fathead Minnow	PIPRO	y = 3.2744x - 2.1155	R2 = 0.9664
Rhinichthys atratulus	Blacknose Dace	RHATR	y = 3.1448x - 2.1292	R2 = 0.9874
Salmo trutta	Brown Trout	SATRU	y = 1.9894x - 0.6302	R2 = 0.326
Semotilus atromaculatus	Creek Chub	SEATR	y = 3.0031x - 1.9344	R2 = 0.9847
Semotilus corporalis	Fallfish	SECOR	y = 2.9238x - 1.8627	R2 = 0.994

APPENDIX C: WET-WEATHER SAMPLING FREQUENCIES

C.1.1. Sampling Times At DCC 770 (7/21/03-7/25/03)



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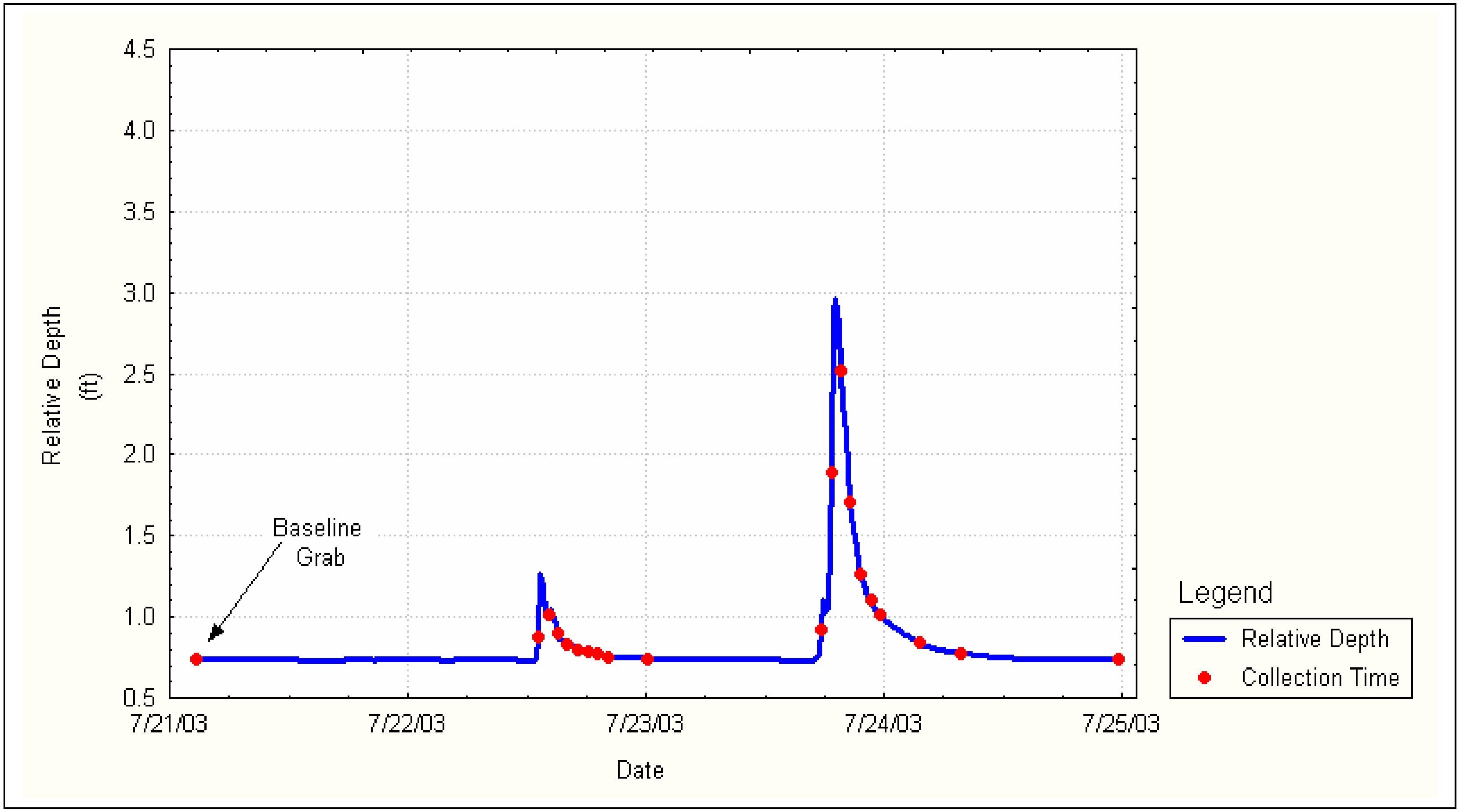

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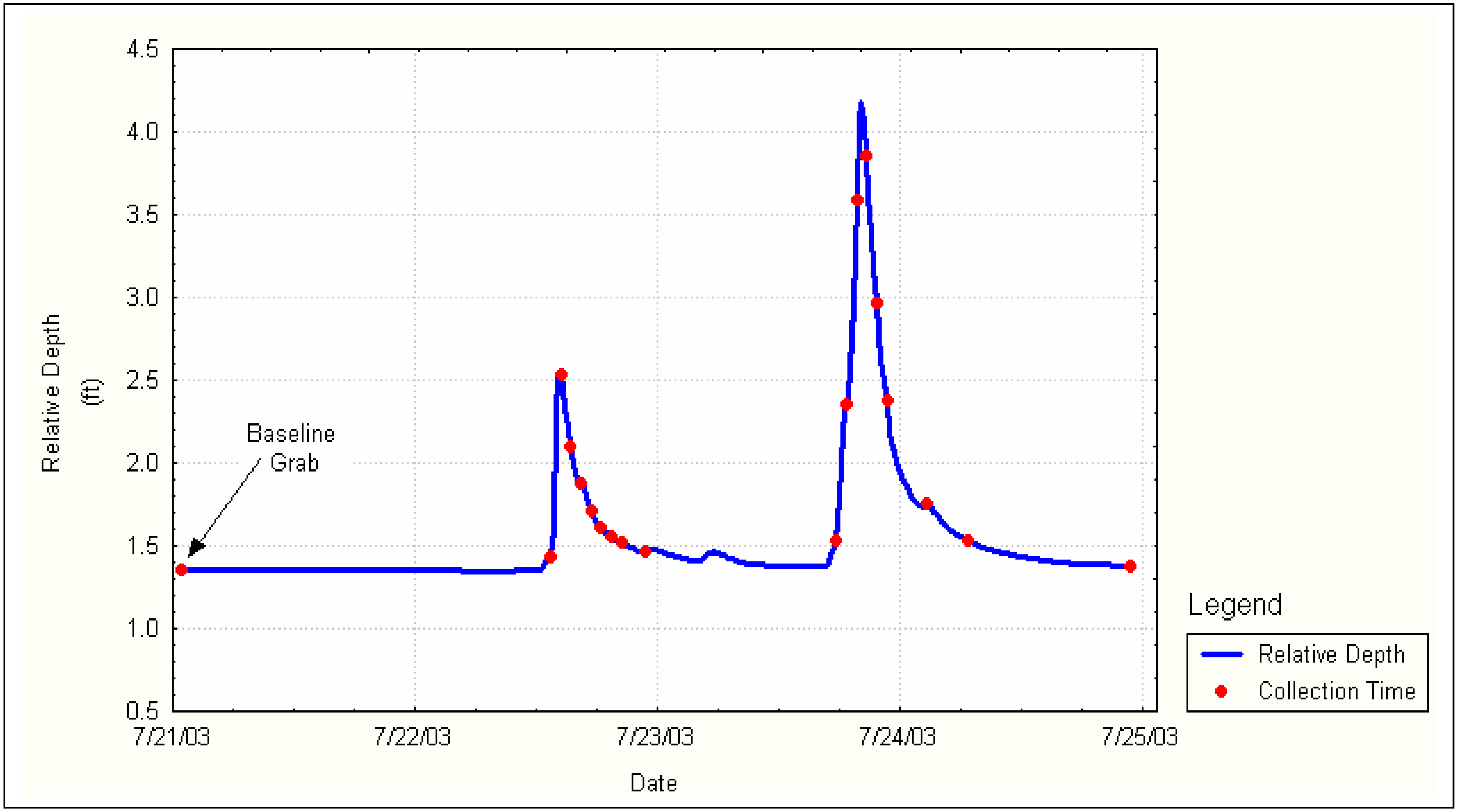
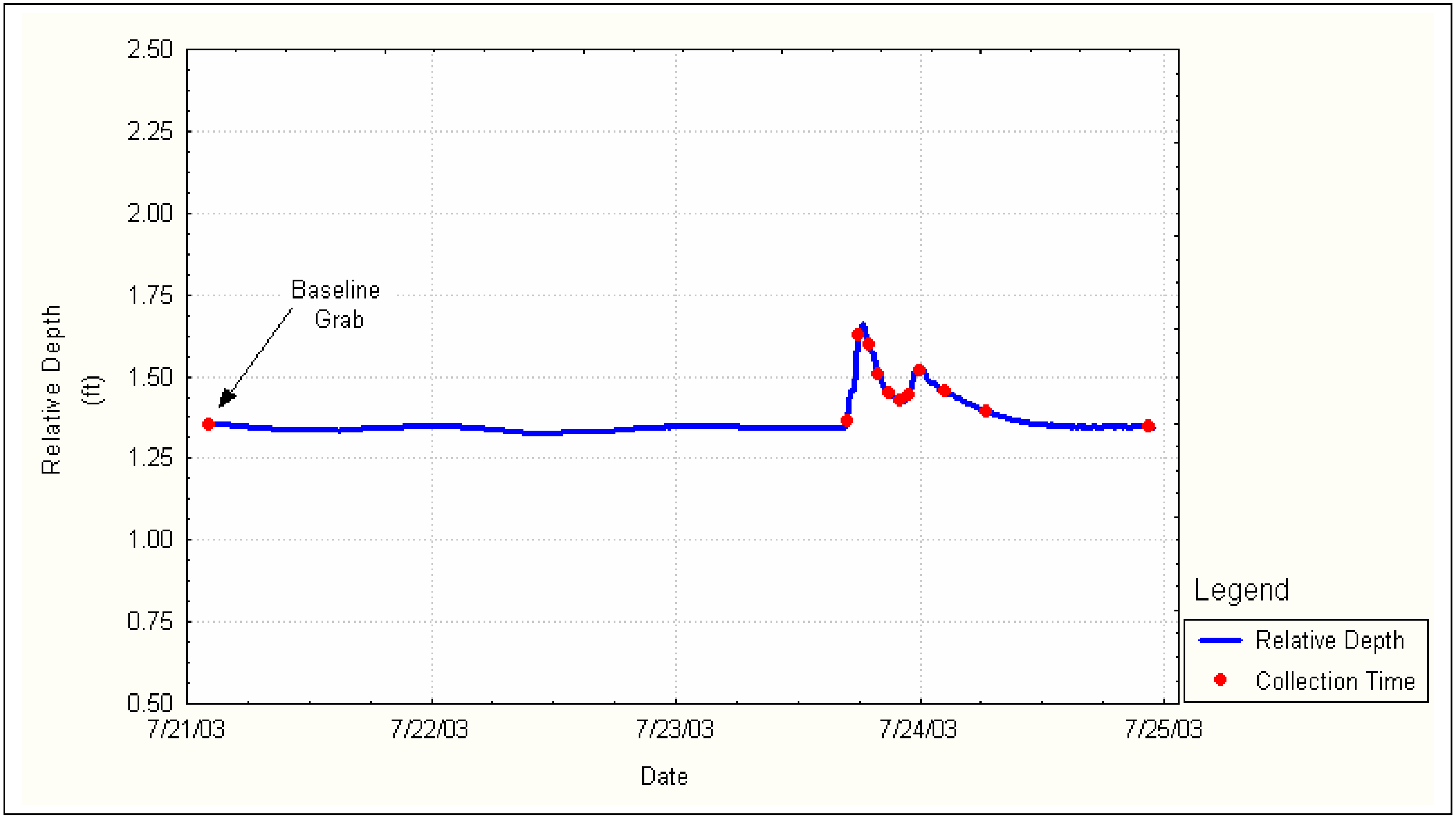
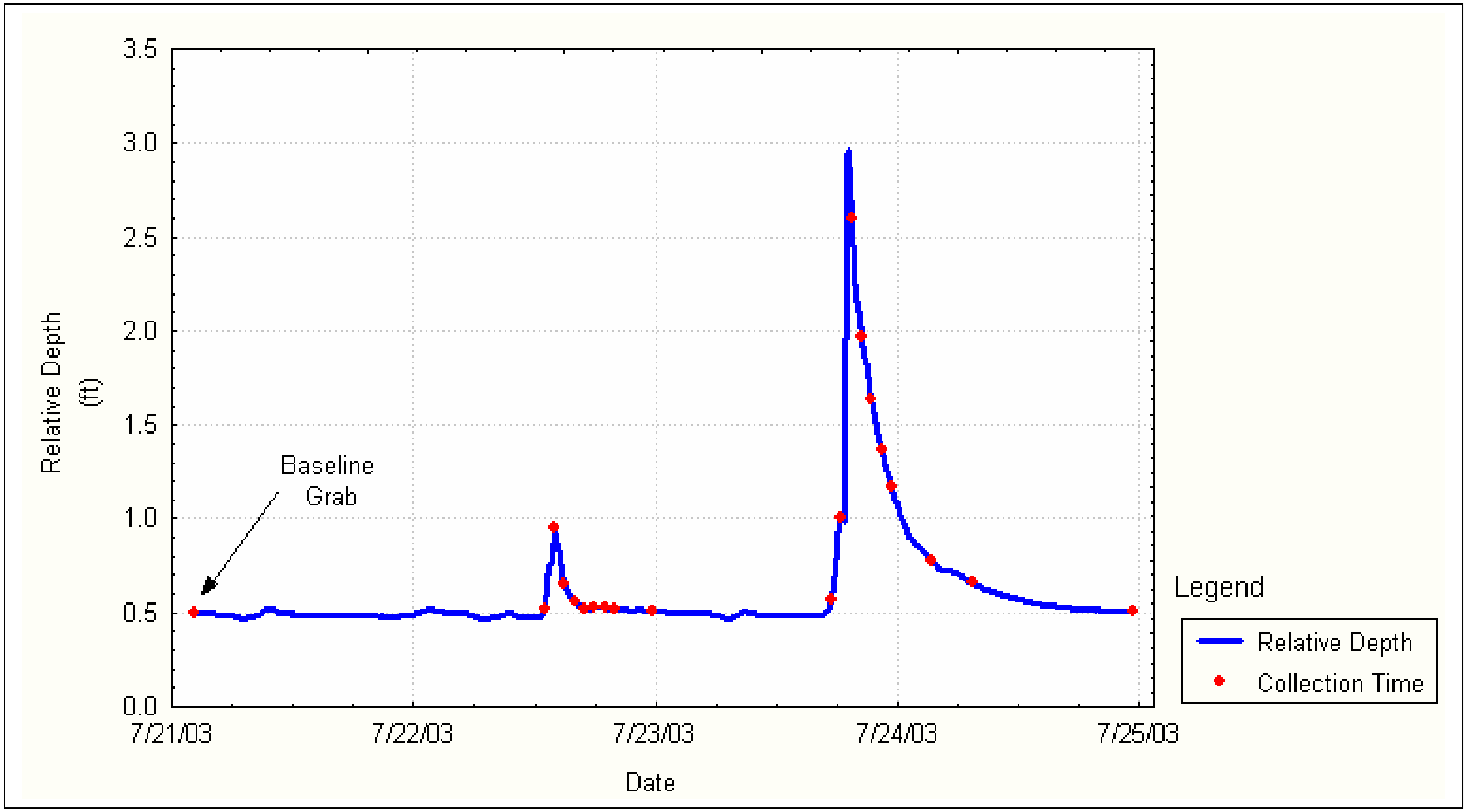


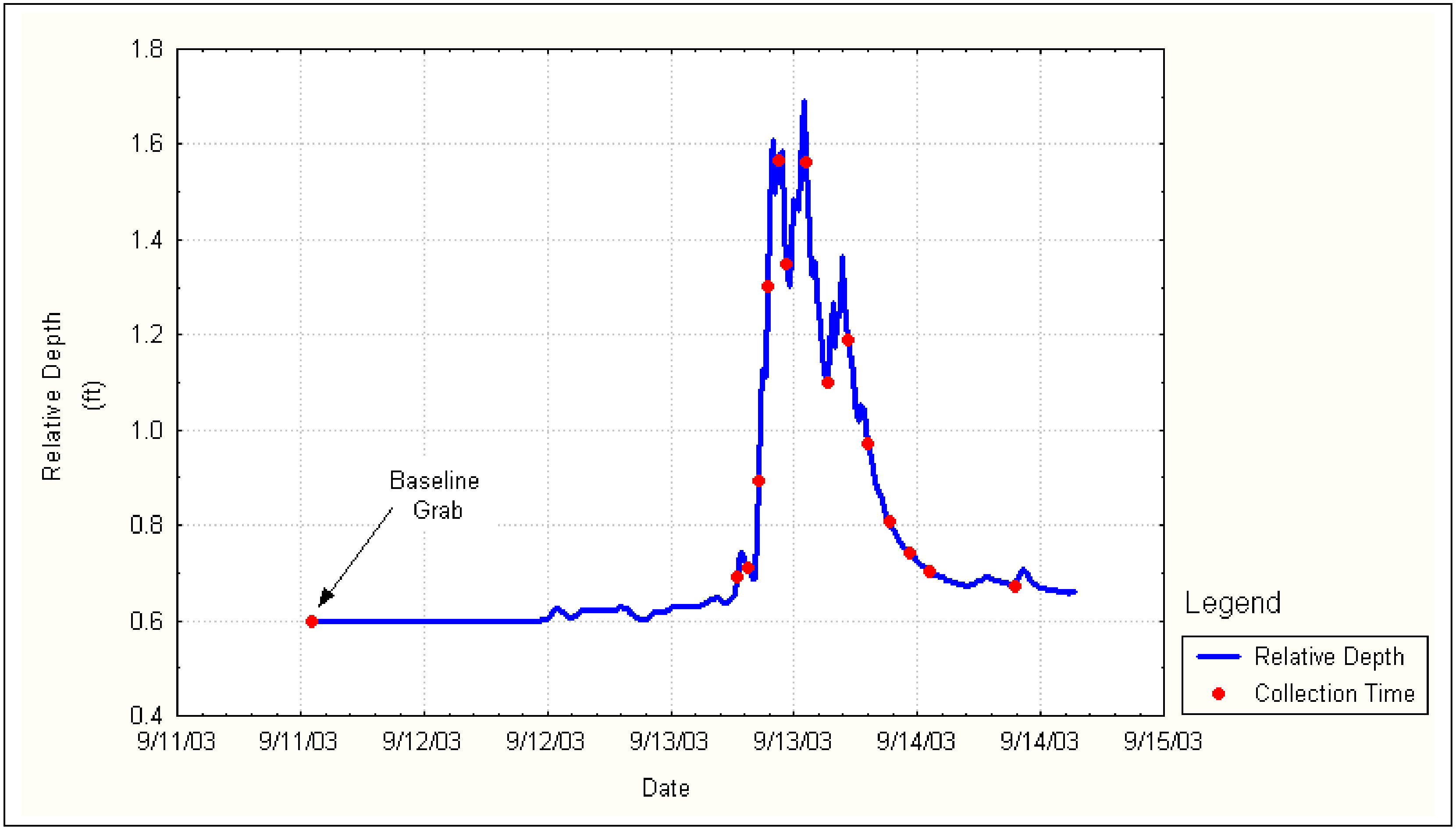
C.1.4. Sampling Times At DCD 1660 (7/21/03-7/25/03)



C.1.5. Sampling Times At DCD 765 (7/21/03-7/25/03)



C.2.1. Sampling Times At DCC 770 (9/11/03-9/14/03)



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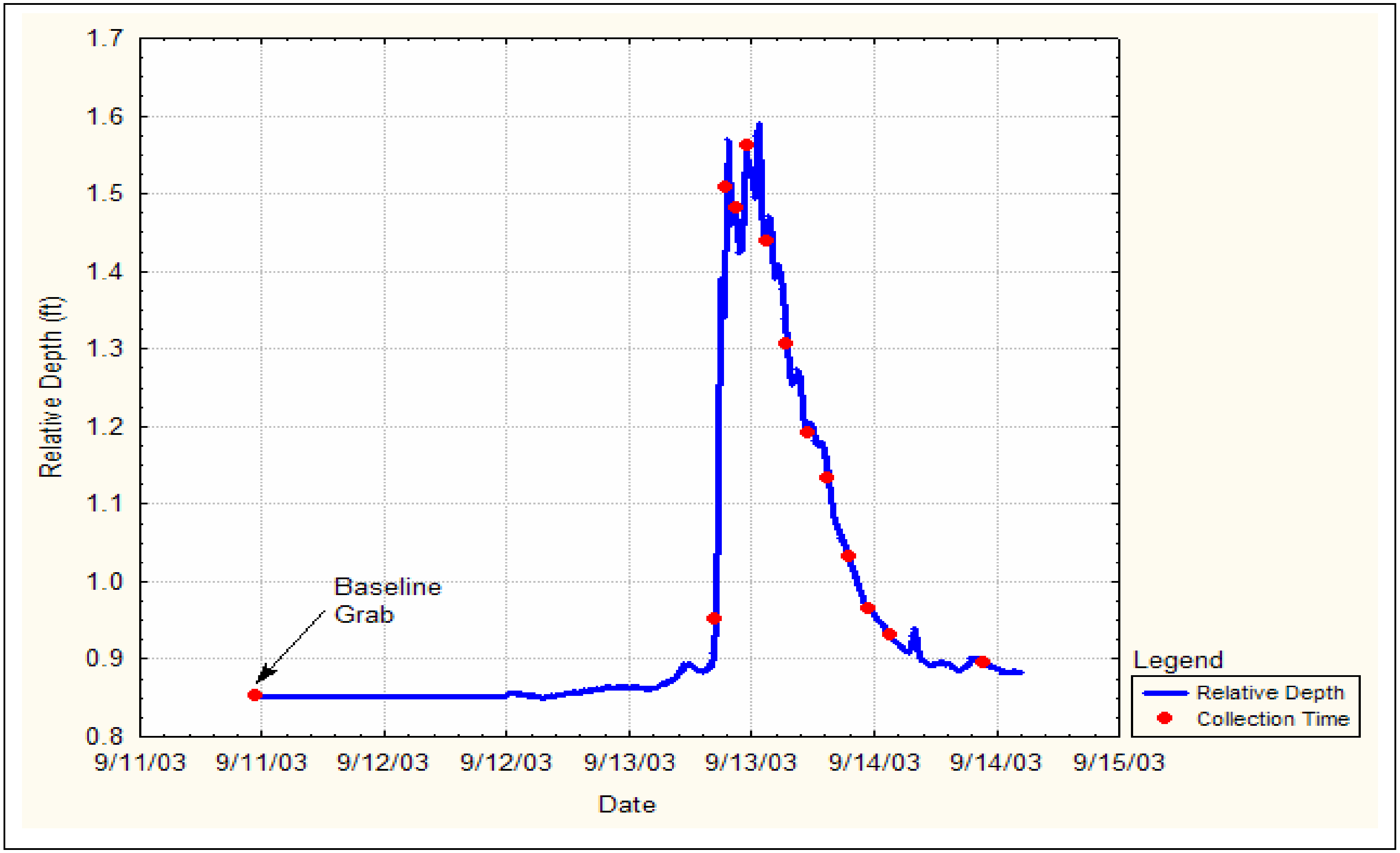

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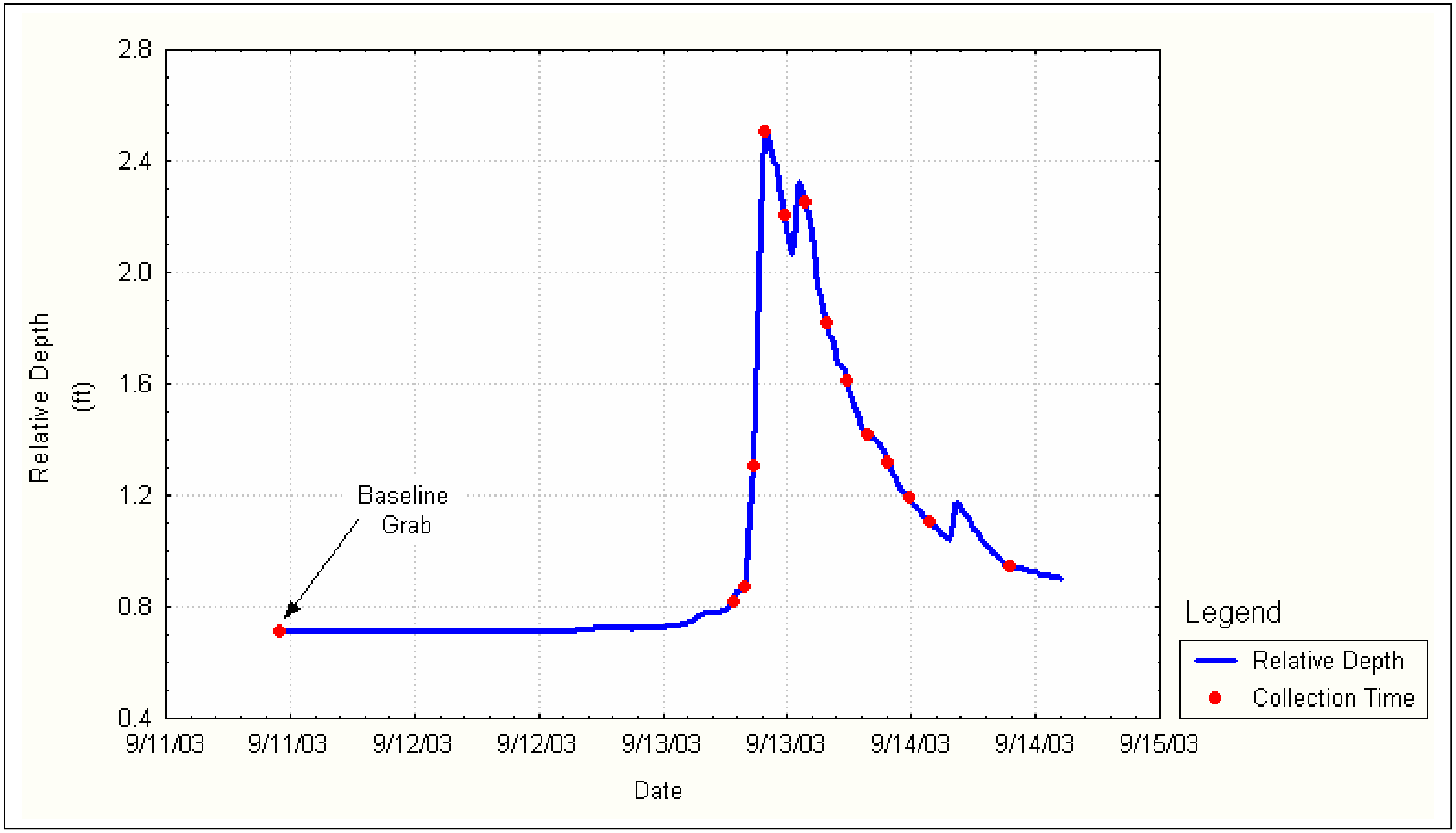

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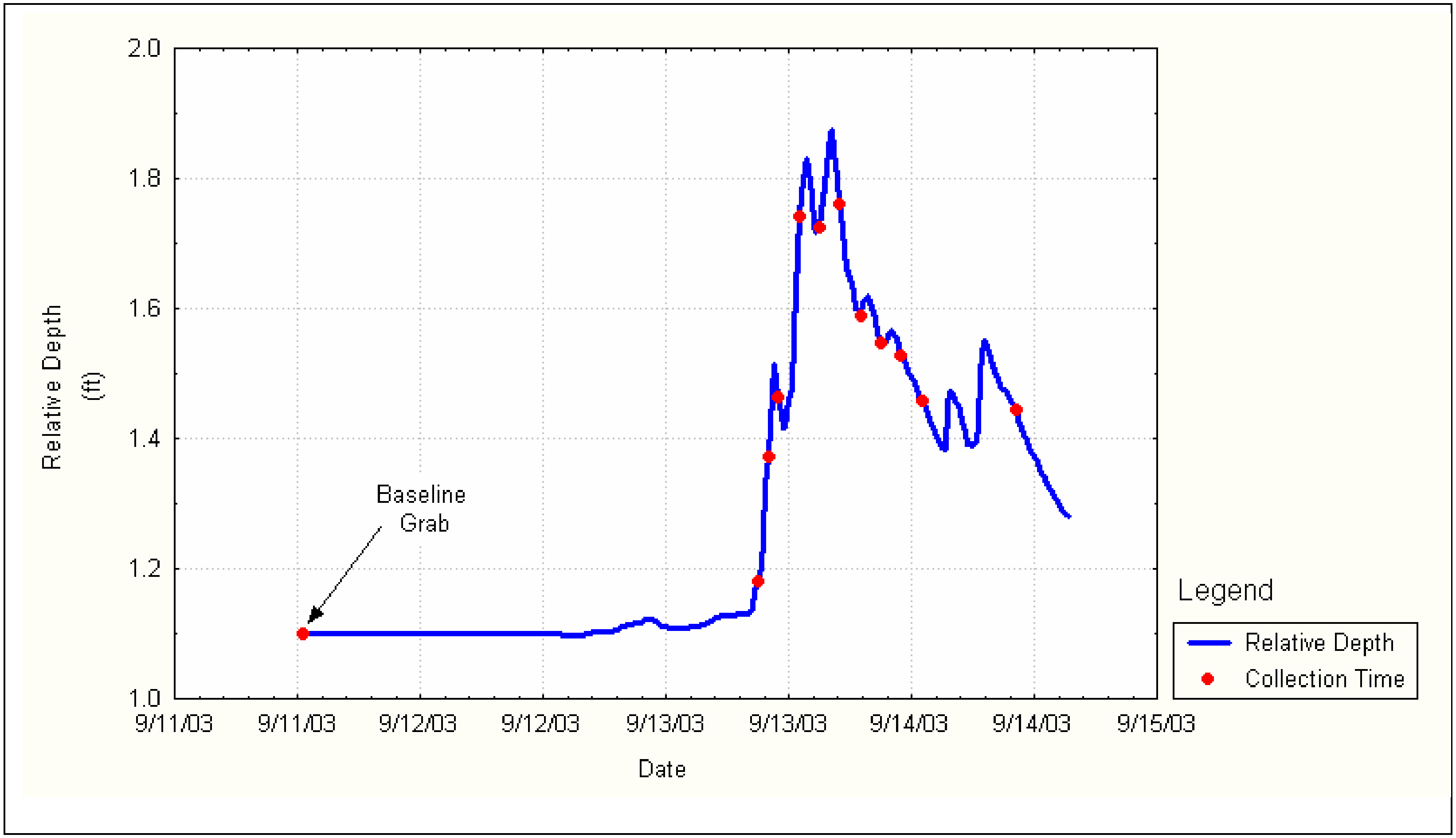

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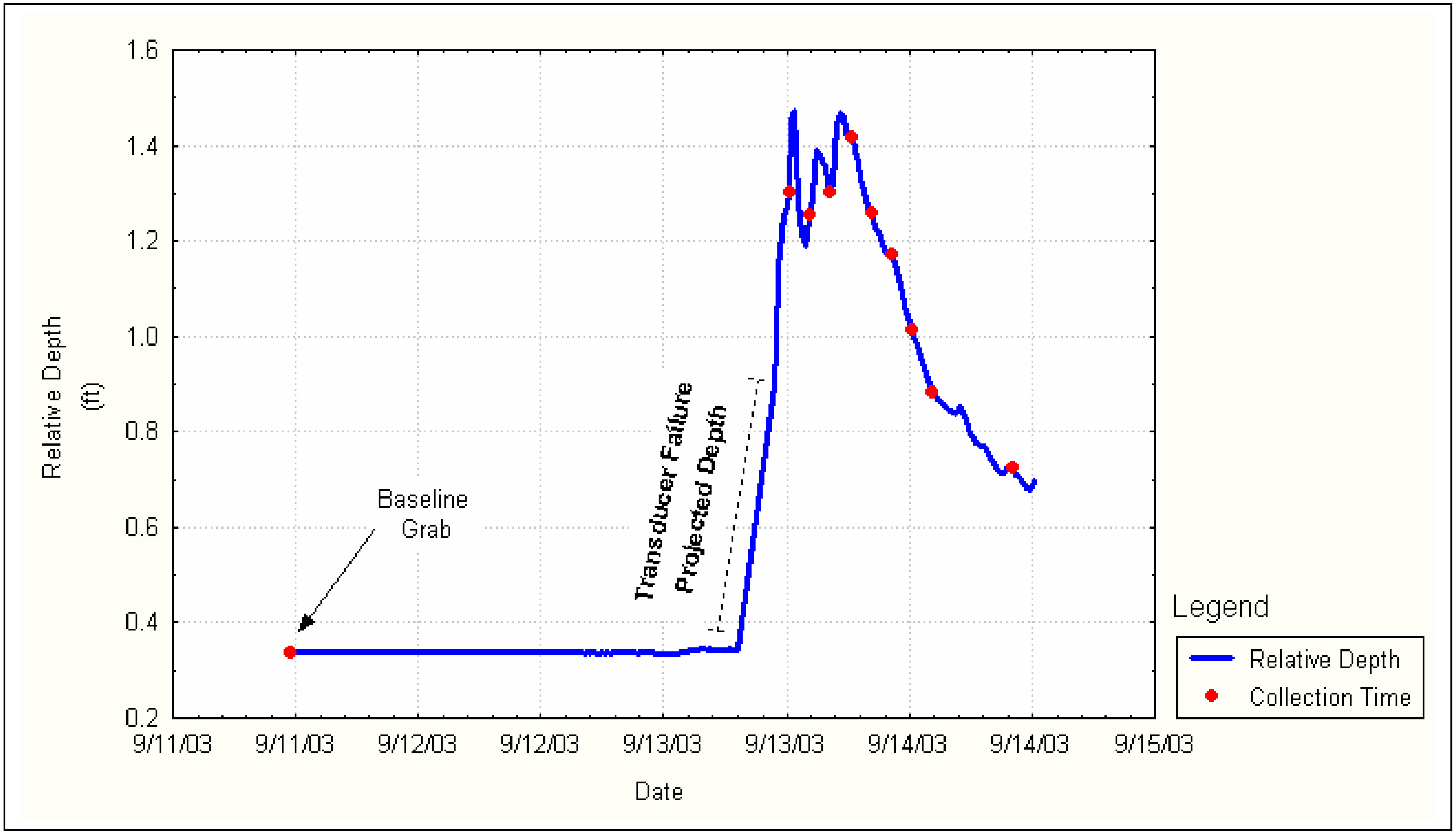


APPENDIX D: MASTER LIST OF MACROINVERTEBRATE TAXA COLLECTED IN DARBY-COBBS WATERSHED

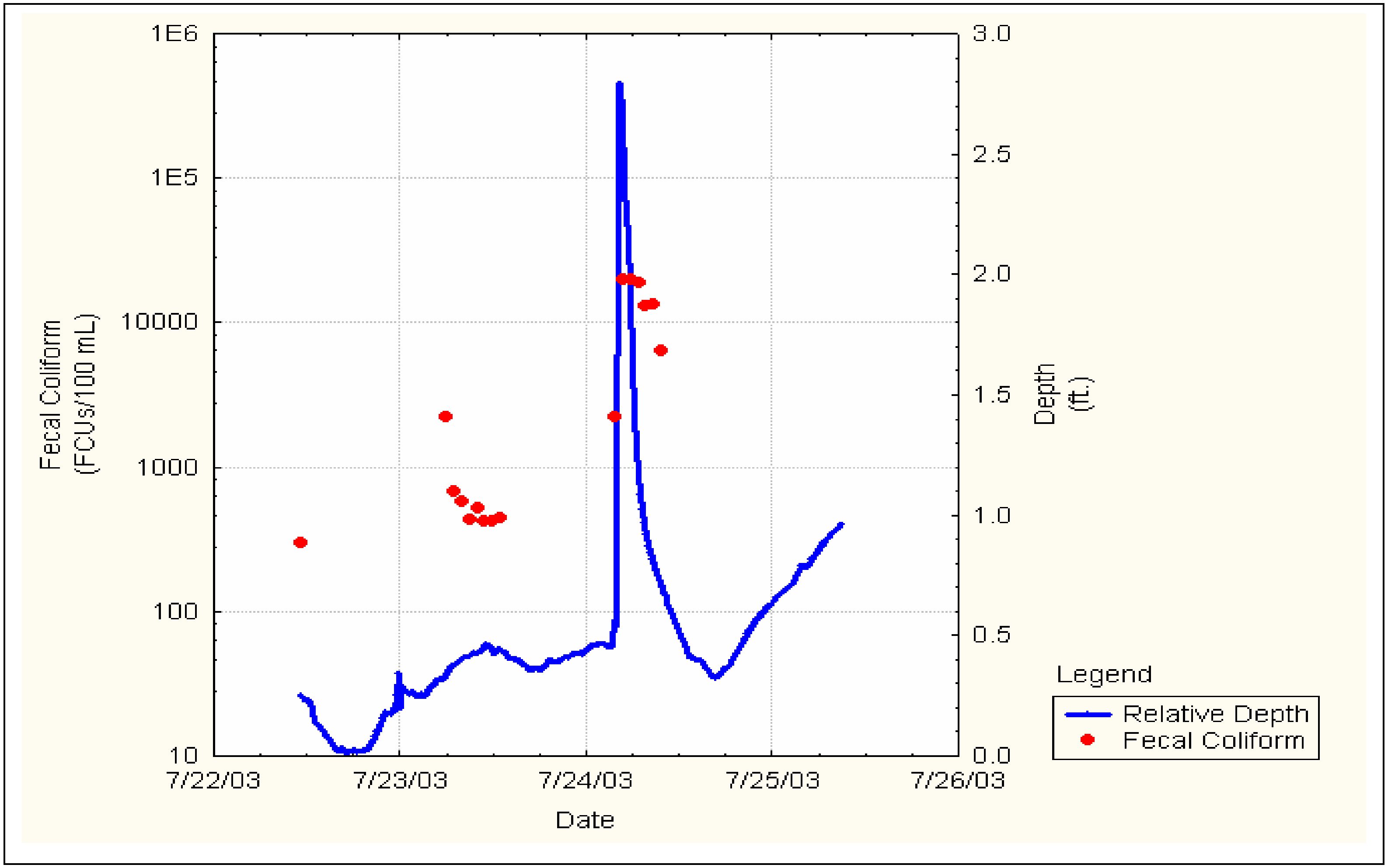
Family	Genus
Aeshnidae	*Boyeria*
Ancylidae	*sp.*
Asellidae	*Caecidotea*
Baetidae	*Baetis*
Cambaridae	*sp.*
Chironomidae	*sp.*
Coenagrionidae	*Argia*
Corbiculidae	*Corbicula*
Crangonyctidae	*Crangonyx*
Elmidae	*Macronychus*
Elmidae	*Optioservus*
Elmidae	*Stenelmis*
Epididae	*Hemerodromia*
Erpobdellidae	*sp.*
Gammaridae	*Gammarus*
Glossosomatidae	*Glossosoma*
Gomphidae	*Progomphus*
Helicopsychidae	*Helicopsyche*
Heptageniidae	*Stenacron*
Hydropsychidae	*Hydropsyche*
Hydropsychidae	*Cheumatopsyche*
Hydroptilidae	*Ochrotrichia*
Hydroptilidae	*Agraylea*
Lumbriculidae	*sp.*
Lymnaeidae	*sp.*
Muscidae	*sp.*
Nemouridae	*Prostoia*
Oxidae	*Oxus*
Perlidae	*Acroneuria*
Philopotamidae	*Chimarra*
Physidae	*sp.*
Planariidae	*Cura*
Planorbidae	*sp.*
Polycentropodidae	*Nyctiophylax*
Psephenidae	*Psephenus*
Simuliidae	*Simulium*
Simuliidae	*Prosimulium*
Tipulidae	*Antocha*
Tipulidae	*Tipula*
Tubificidae	*sp.*

APPENDIX E. PRINCIPAL COMPONENTS ANALYSIS (PCA) FACTOR LOADING SCORES

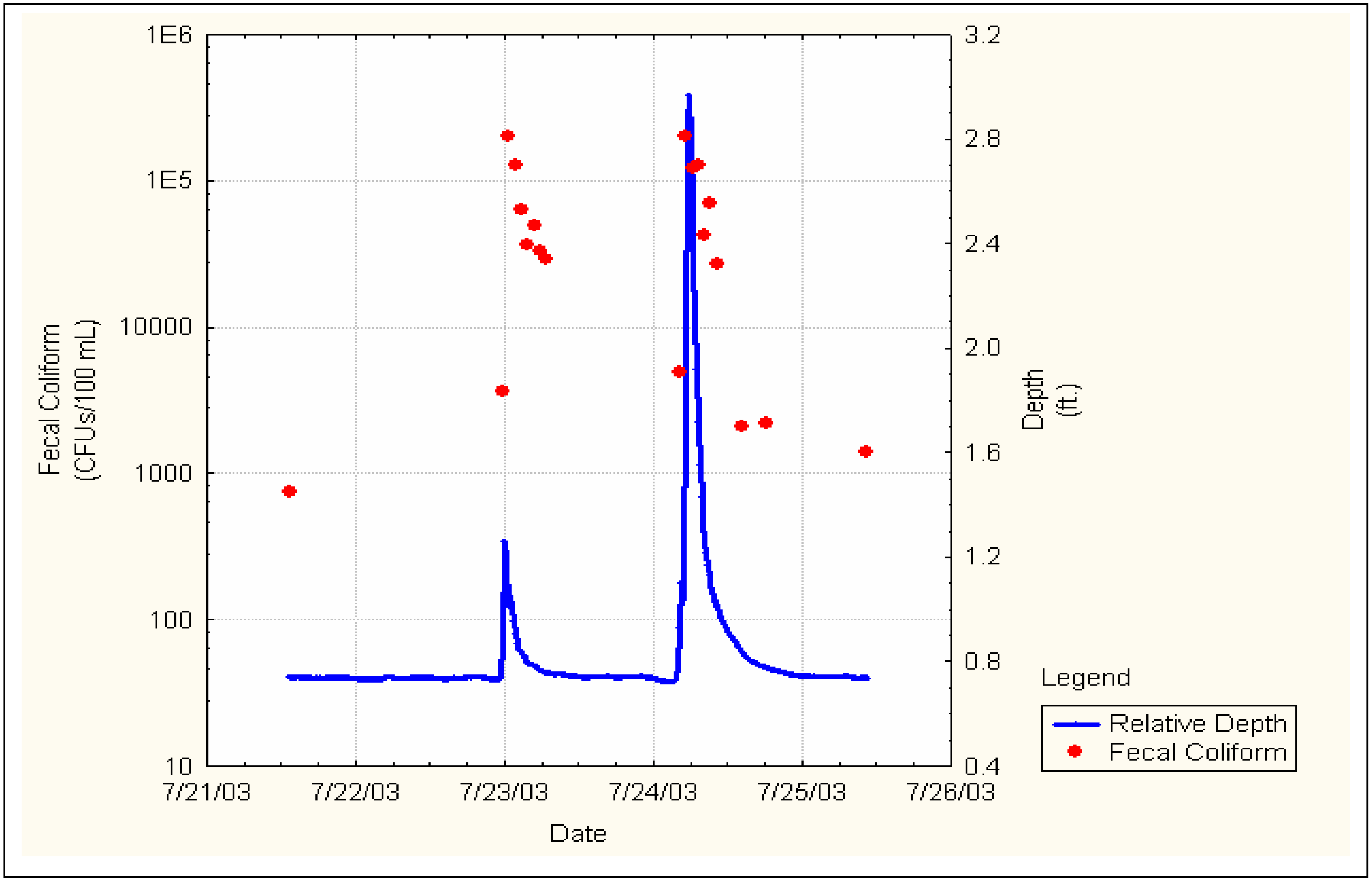
Habitat Variable	Factor 1	Factor 2
Bank Stability	0.624644334	0.534454383
Channel Alteration	0.68519826	-0.613778676
Channel Flow Status	0.887283517	-0.154711094
Channel Sinuosity	0.646498442	-0.162836359
Embeddedness	0.676814129	0.59480918
Epifaunal Substrate /Cover	0.928540686	-0.163641469
Riffle Frequency	0.478714469	0.628922847
Pool Substrate	0.884876311	0.098273276
Pool Variability	0.828192386	-0.473655723
Riparian Zone Width	0.108106765	-0.607800328
Sedimentation	0.664596427	0.606005429
Vegetative Protection	0.765062404	-0.022199009
Velocity/Depth Regime	0.914921054	-0.259234876
Variance Explained	**6.959027402**	**2.527304108**
Proportional Total Variance	**0.5353098**	**0.194408008**

APPENDIX F: WET-WEATHER FECAL COLIFORM CONCENTRATIONS

F.1.1. Fecal Coliform Concentrations At DCC 770 (7/21/03-7/25/03)



F.1.2. Fecal Coliform Concentrations At DCC 455 (7/21/03-7/25/03)



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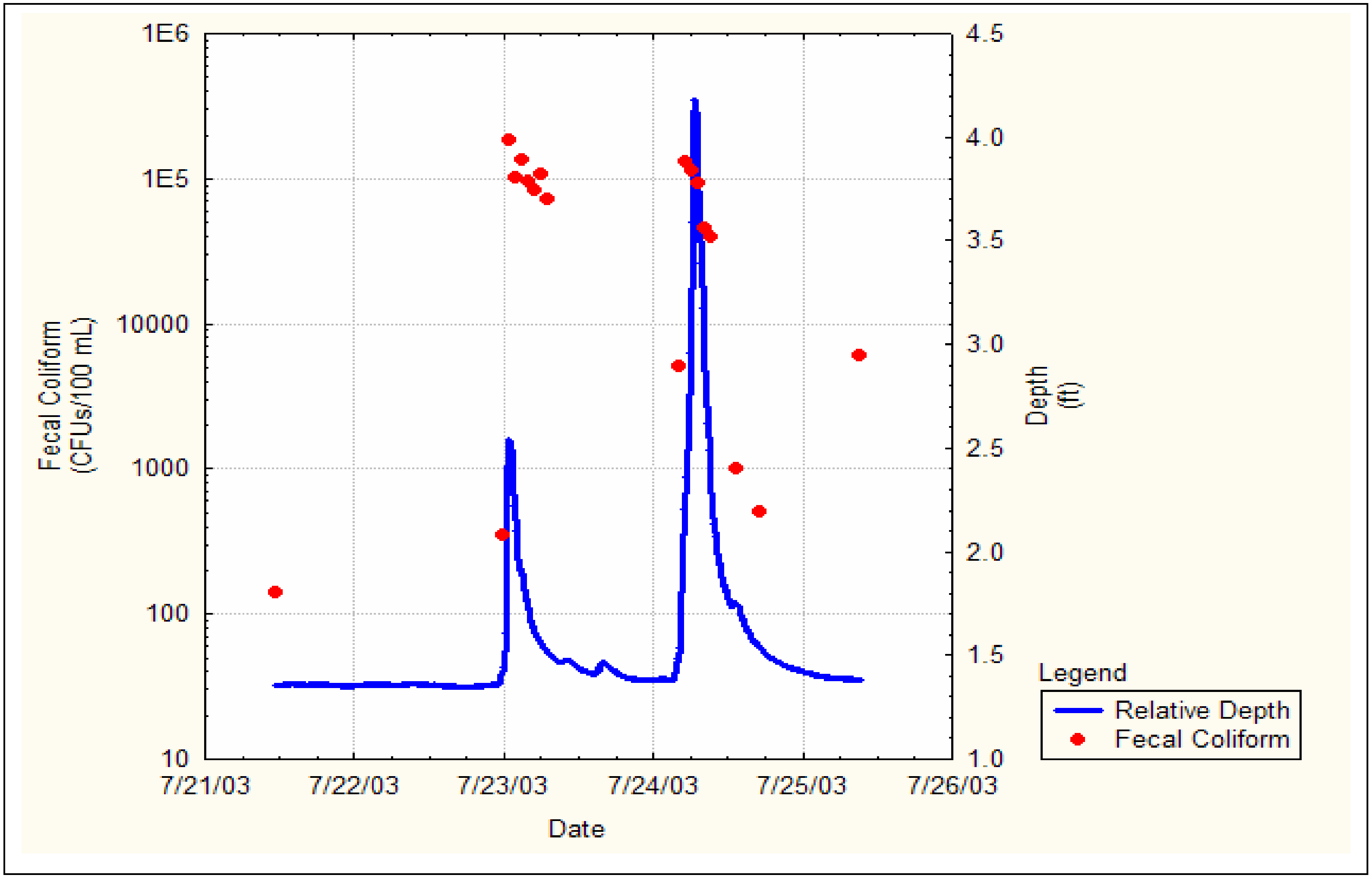

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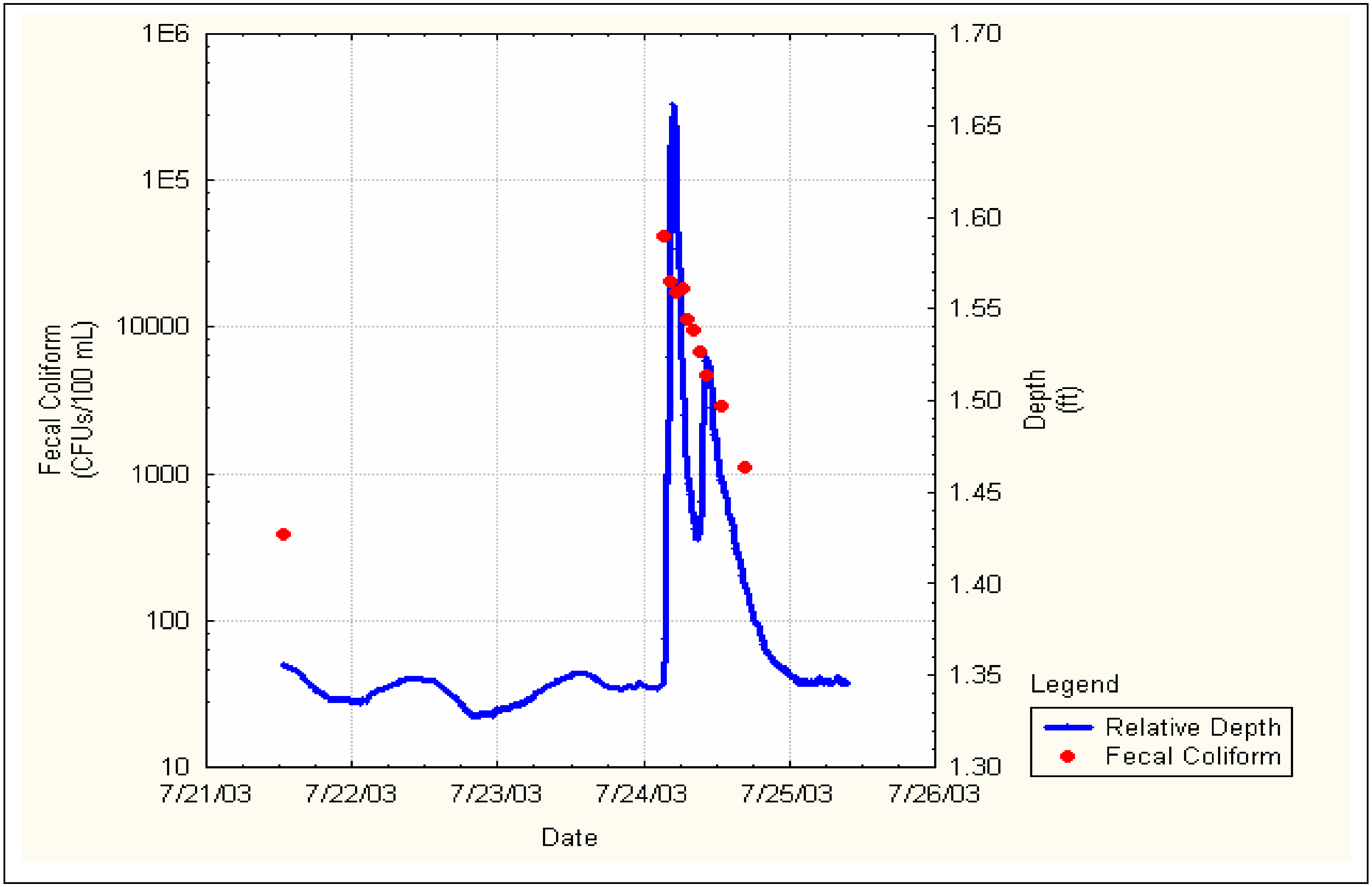
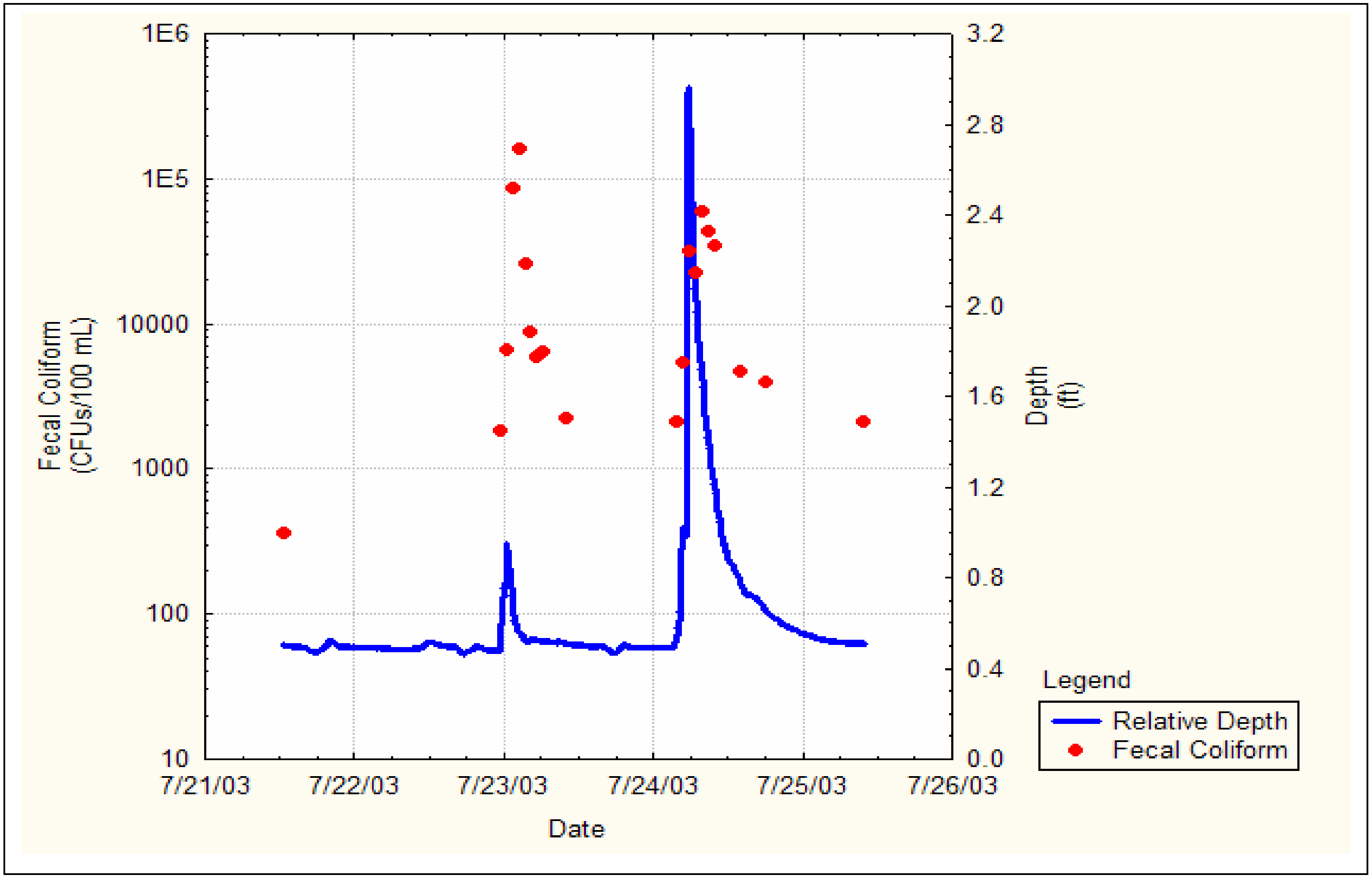
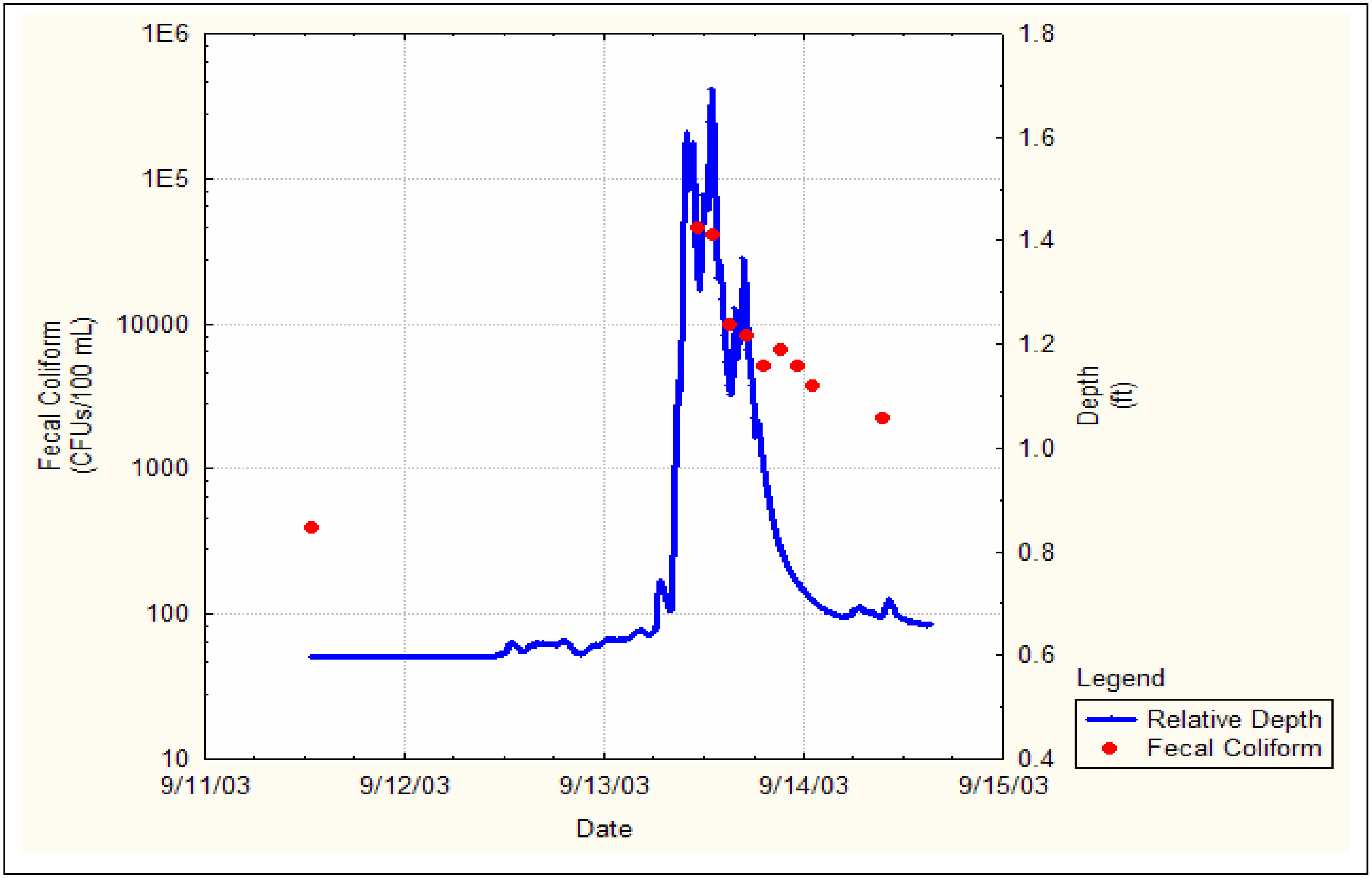


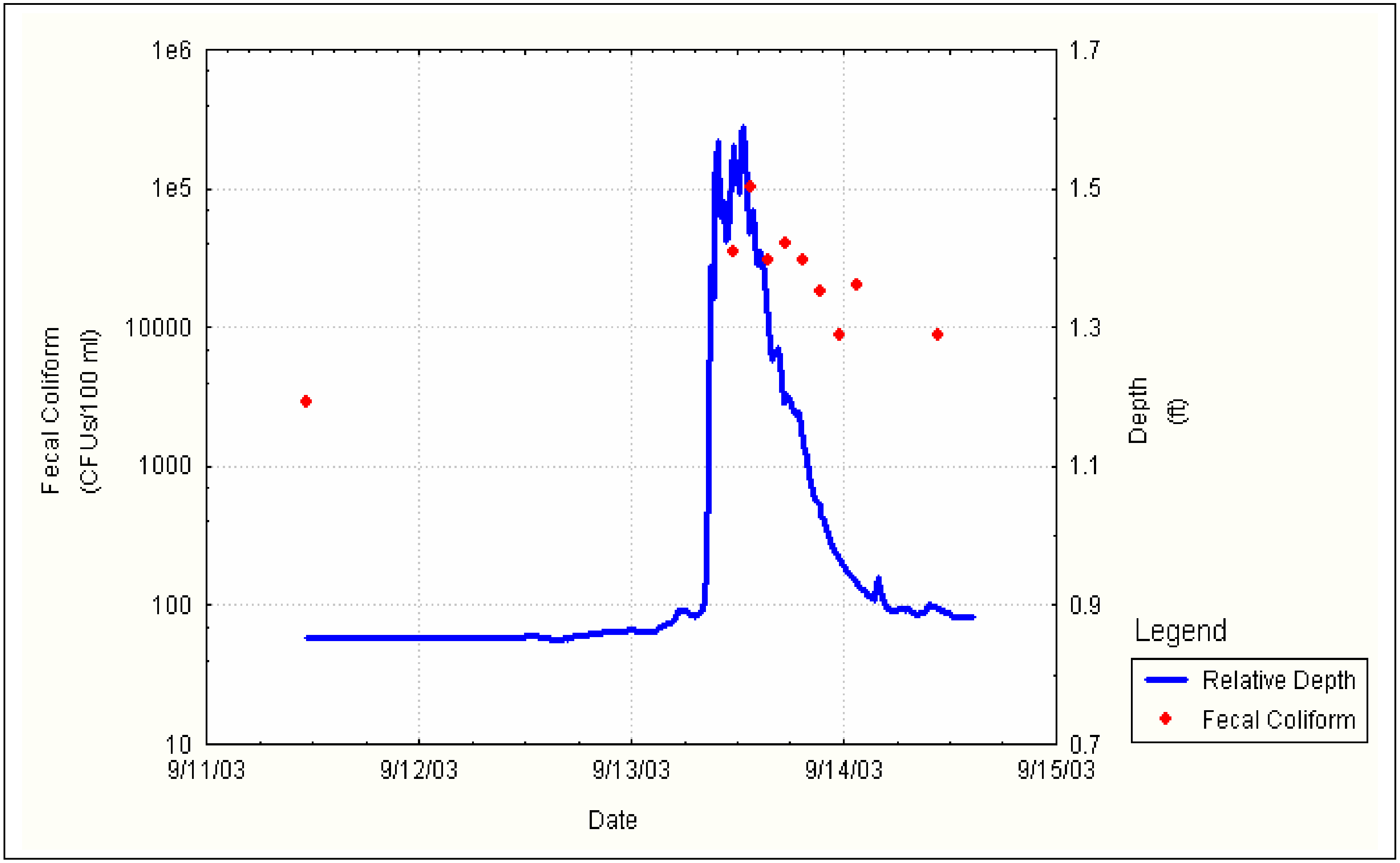
F.1.5. Fecal Coliform Concentrations At DCC 765 (7/21/03-7/25/03)



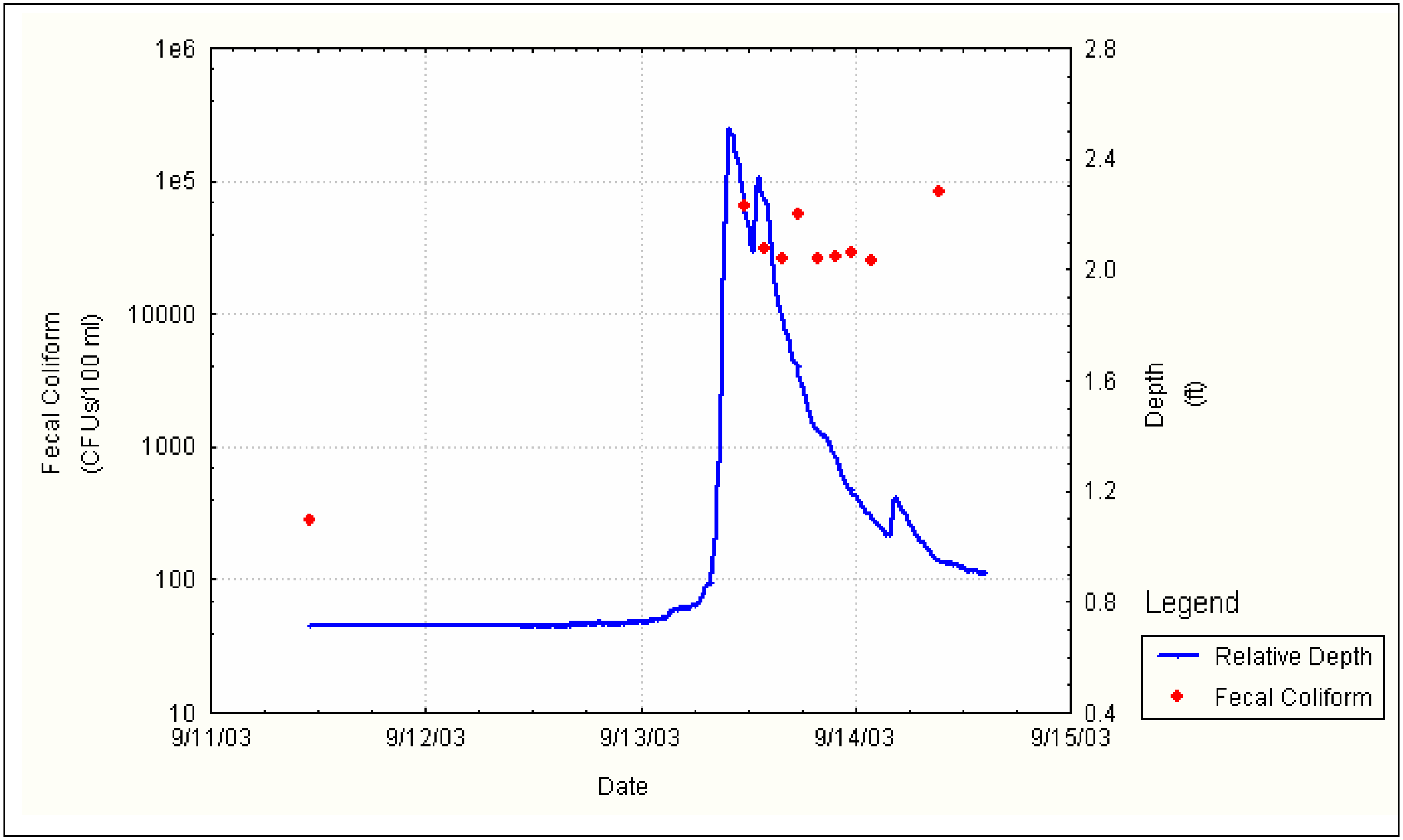
F.2.1. Fecal Coliform Concentrations At DCC 770 (9/11/03-9/14/03)



F.2.2. Fecal Coliform Concentrations At DCC 455 (9/11/03-9/14/03)



F.2.3. Fecal Coliform Concentrations At DCC 208 (9/11/03-9/14/03)



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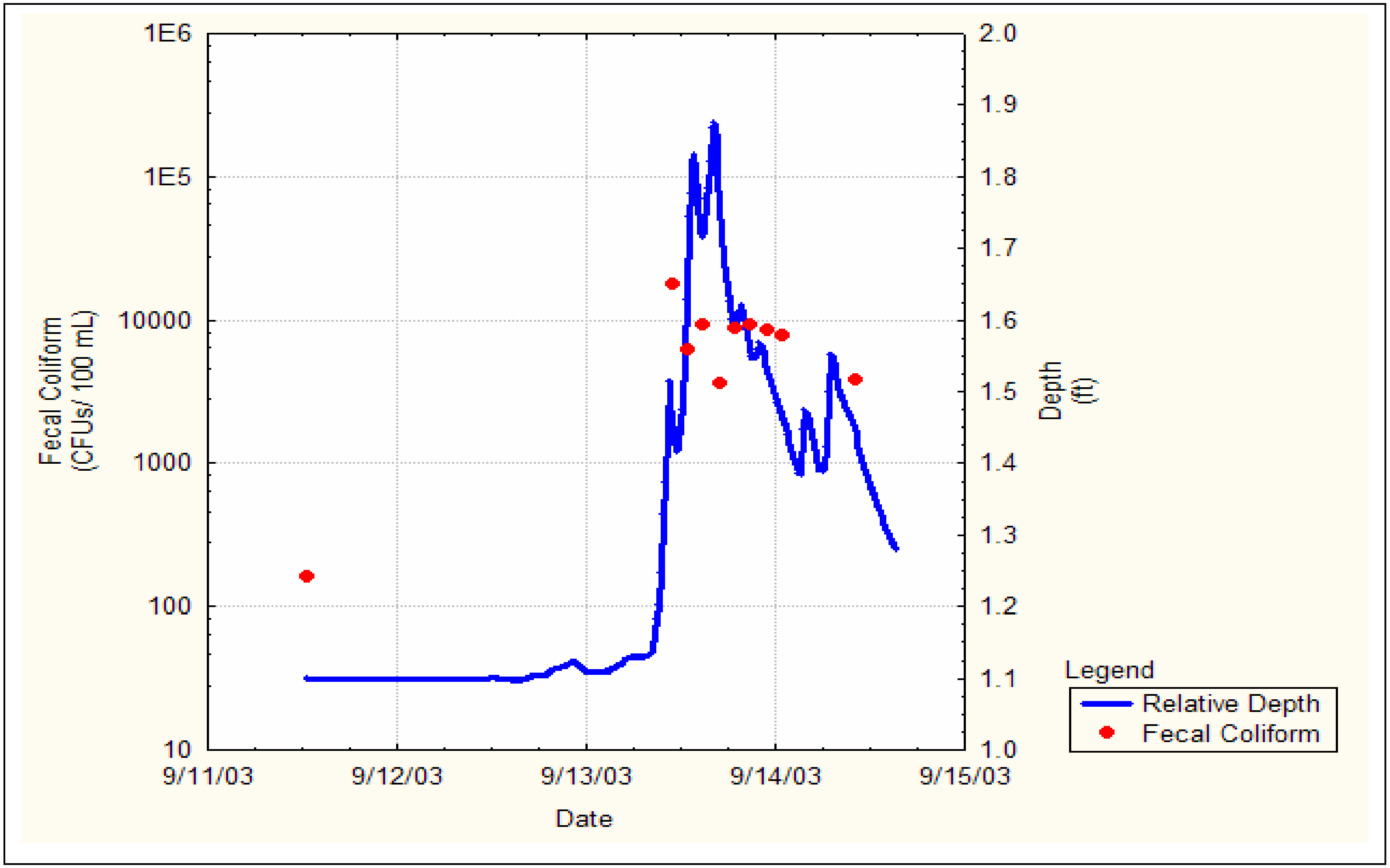

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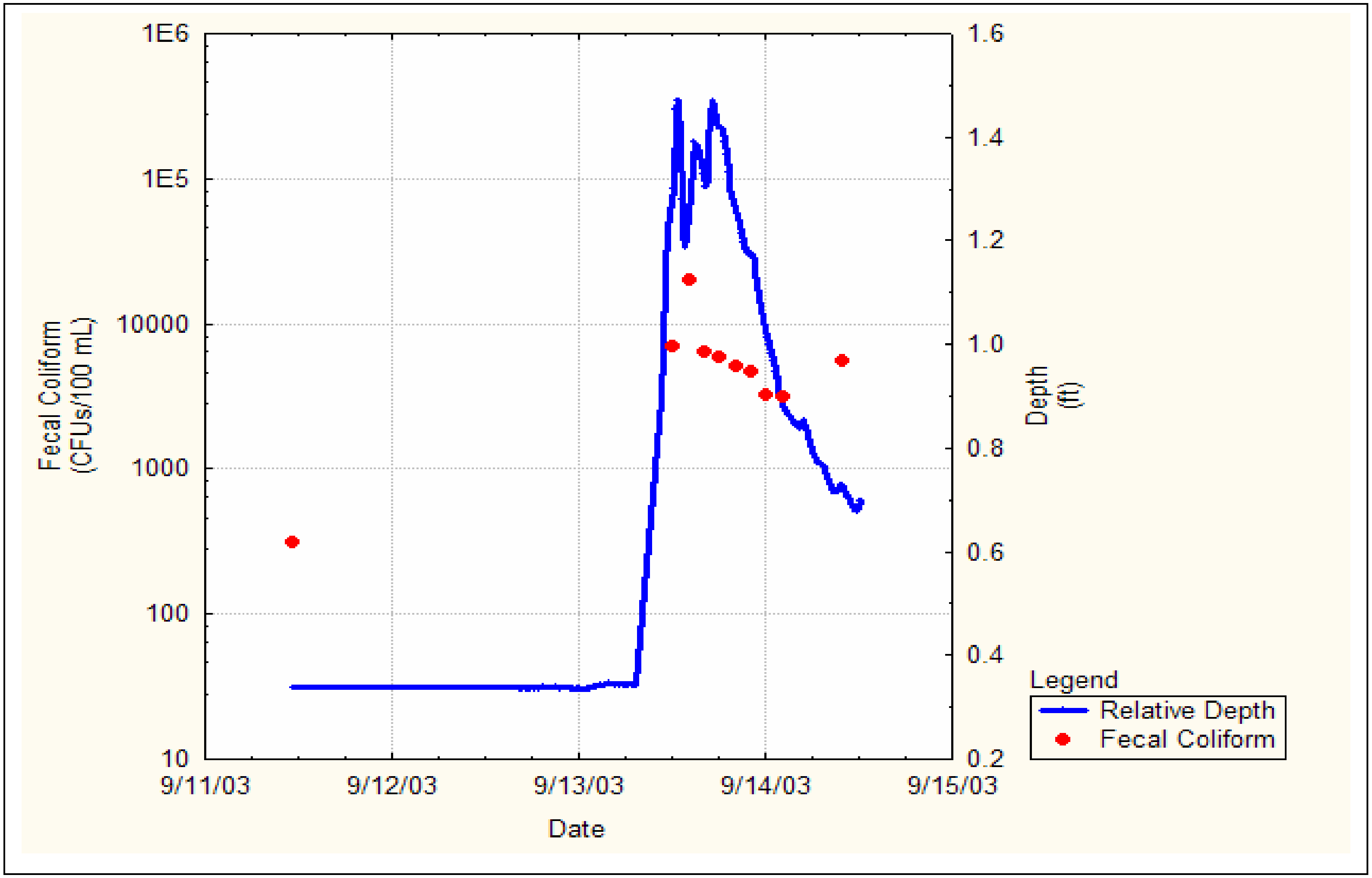

APPENDIX G. WET WEATHER METAL CONCENTRATIONS OF SAMPLES COLLECTED DURING STORM EVENTS

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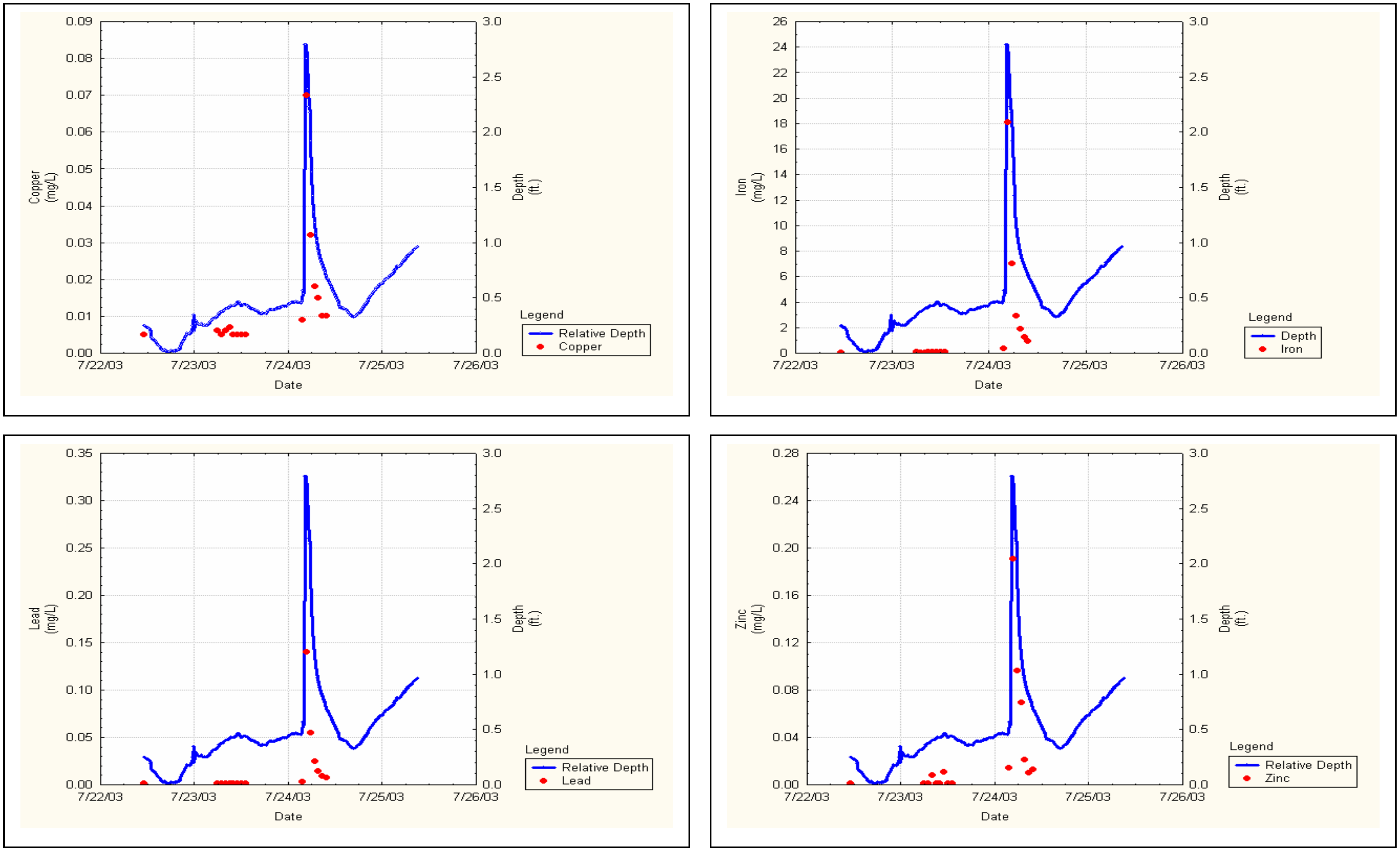

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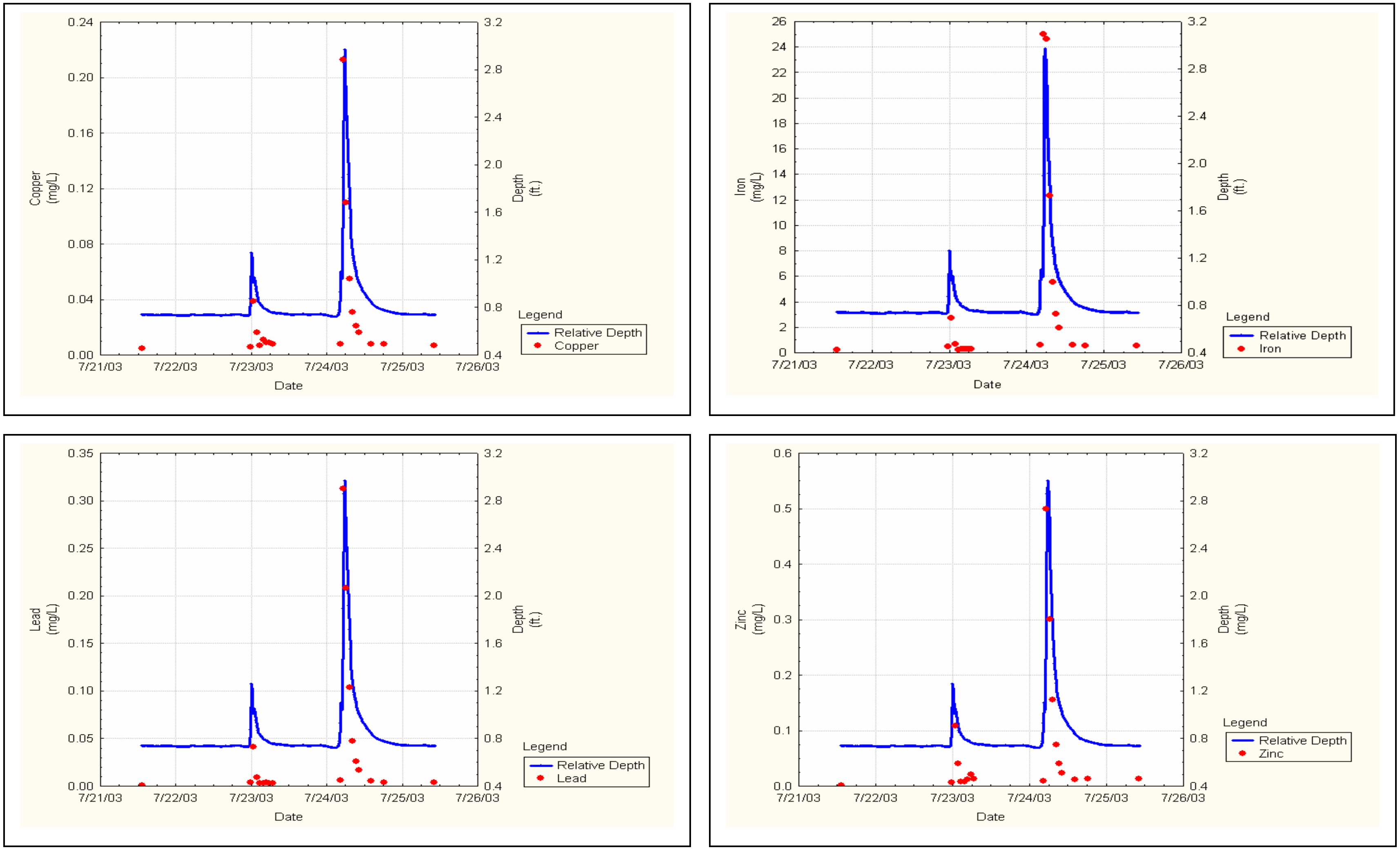

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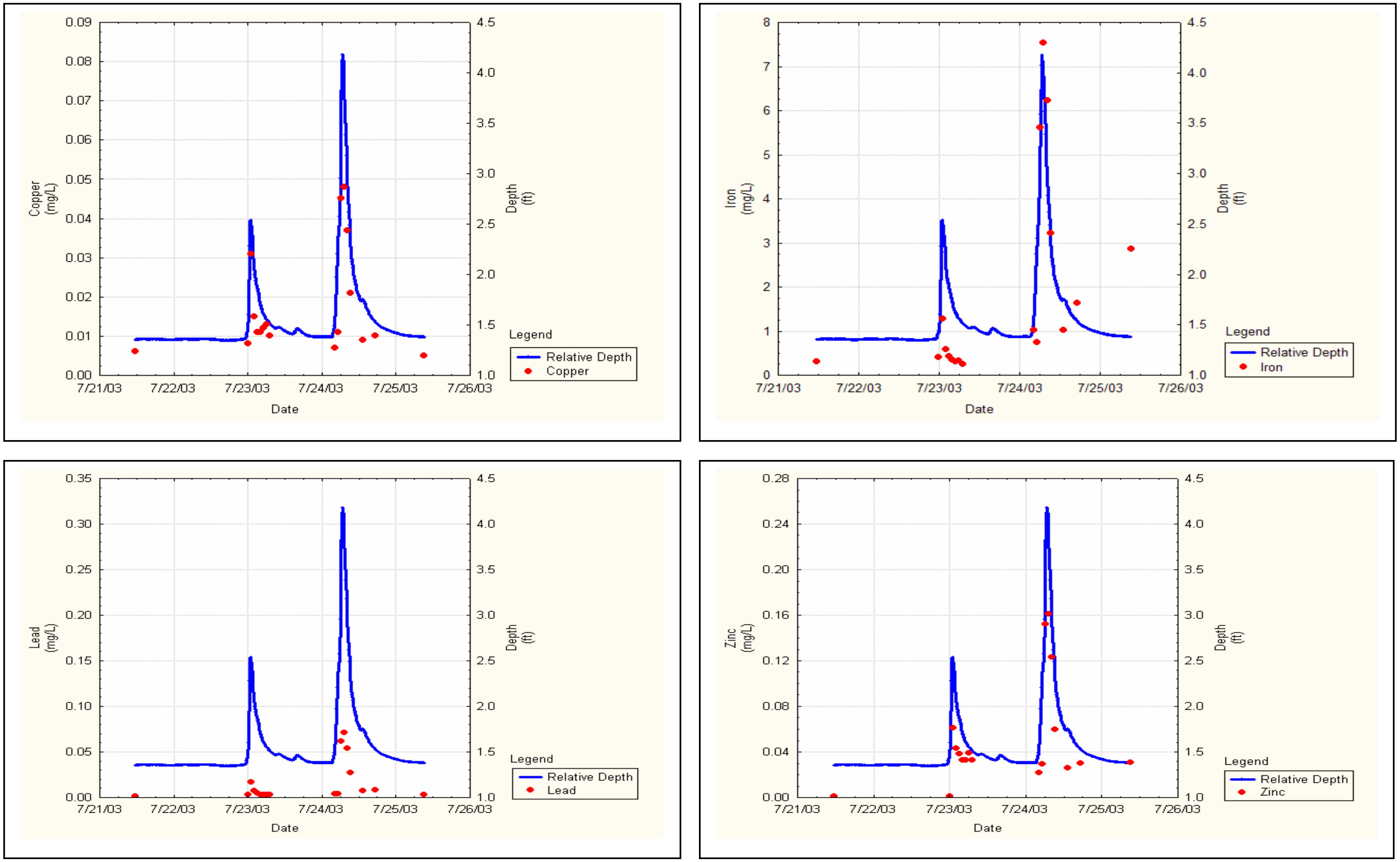
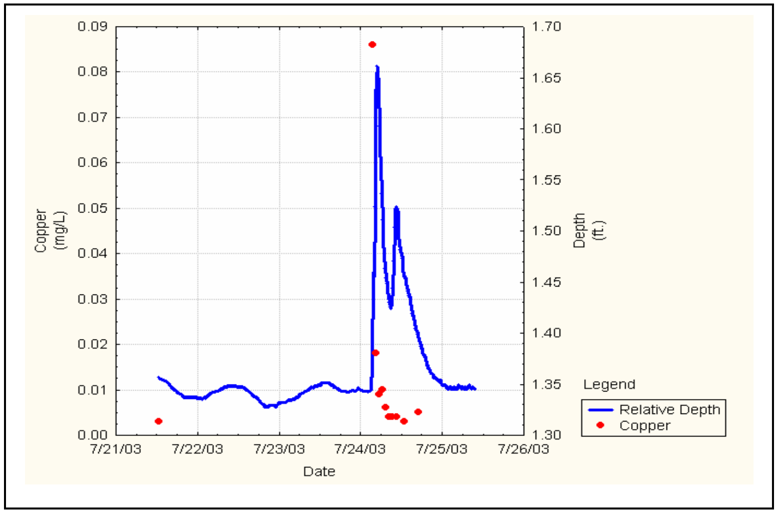
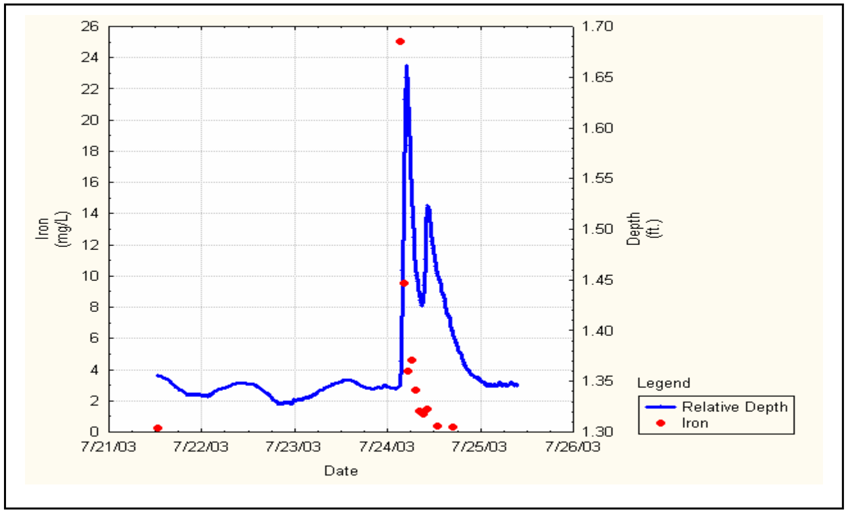
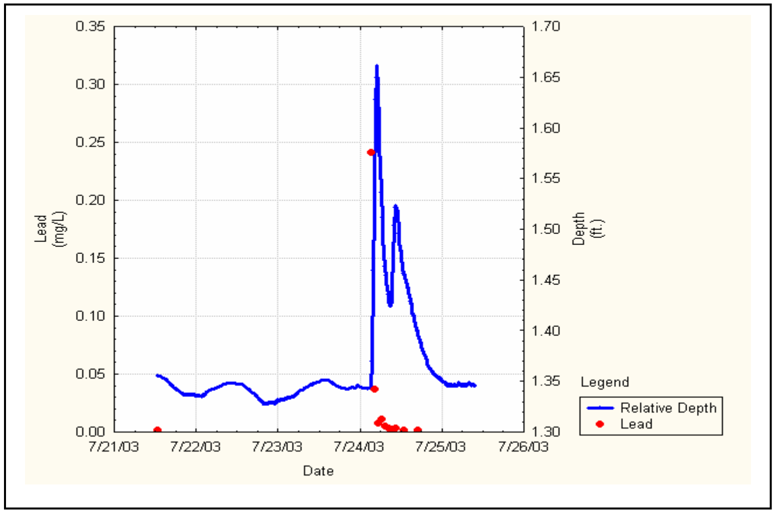
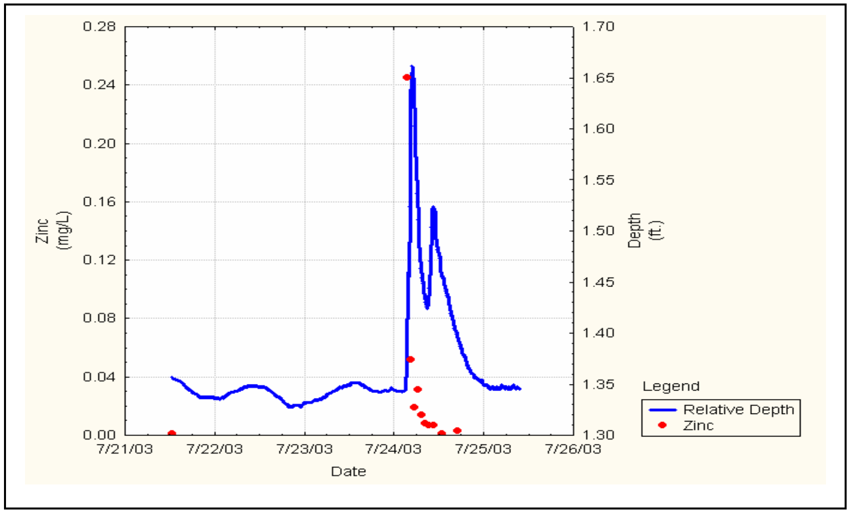


G.1.4. Metal Concentrations At DCD 1660 (7/21/03-7/25/03)

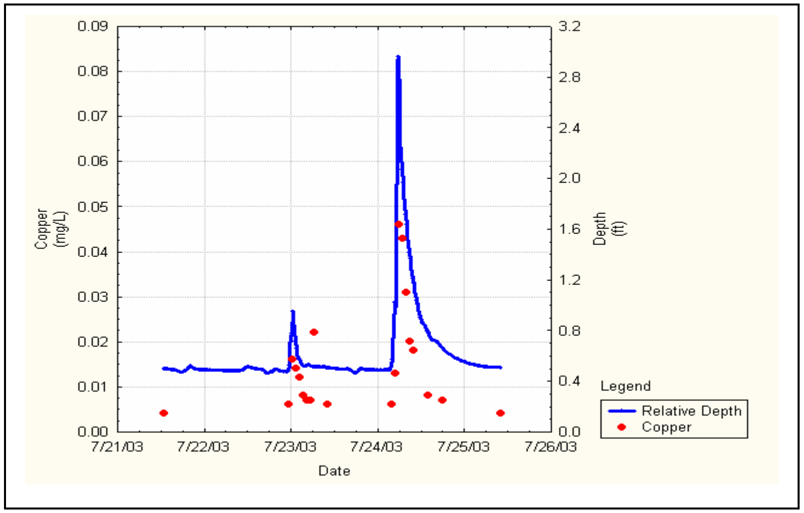


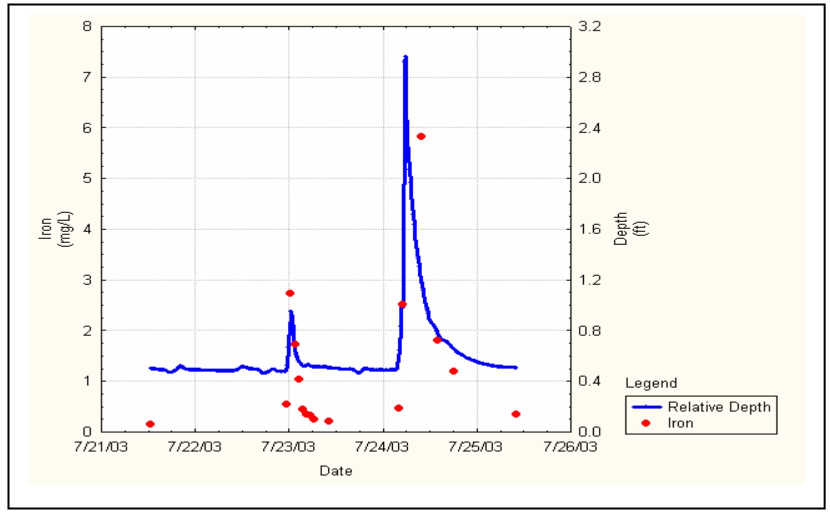


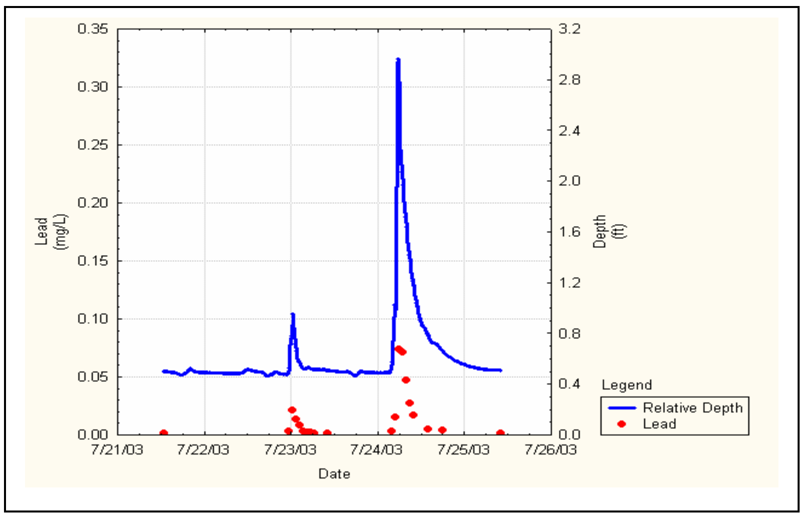


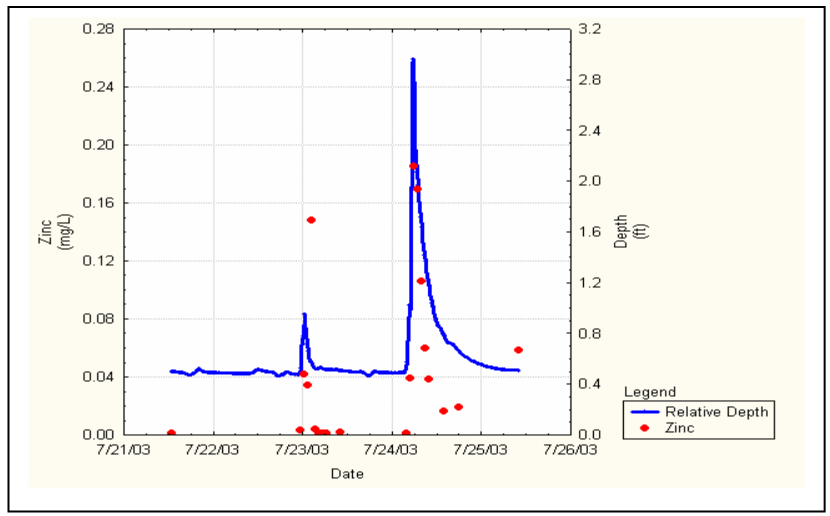


G.1.5. Metal Concentrations At DCD 765 (7/21/03-7/25/03)

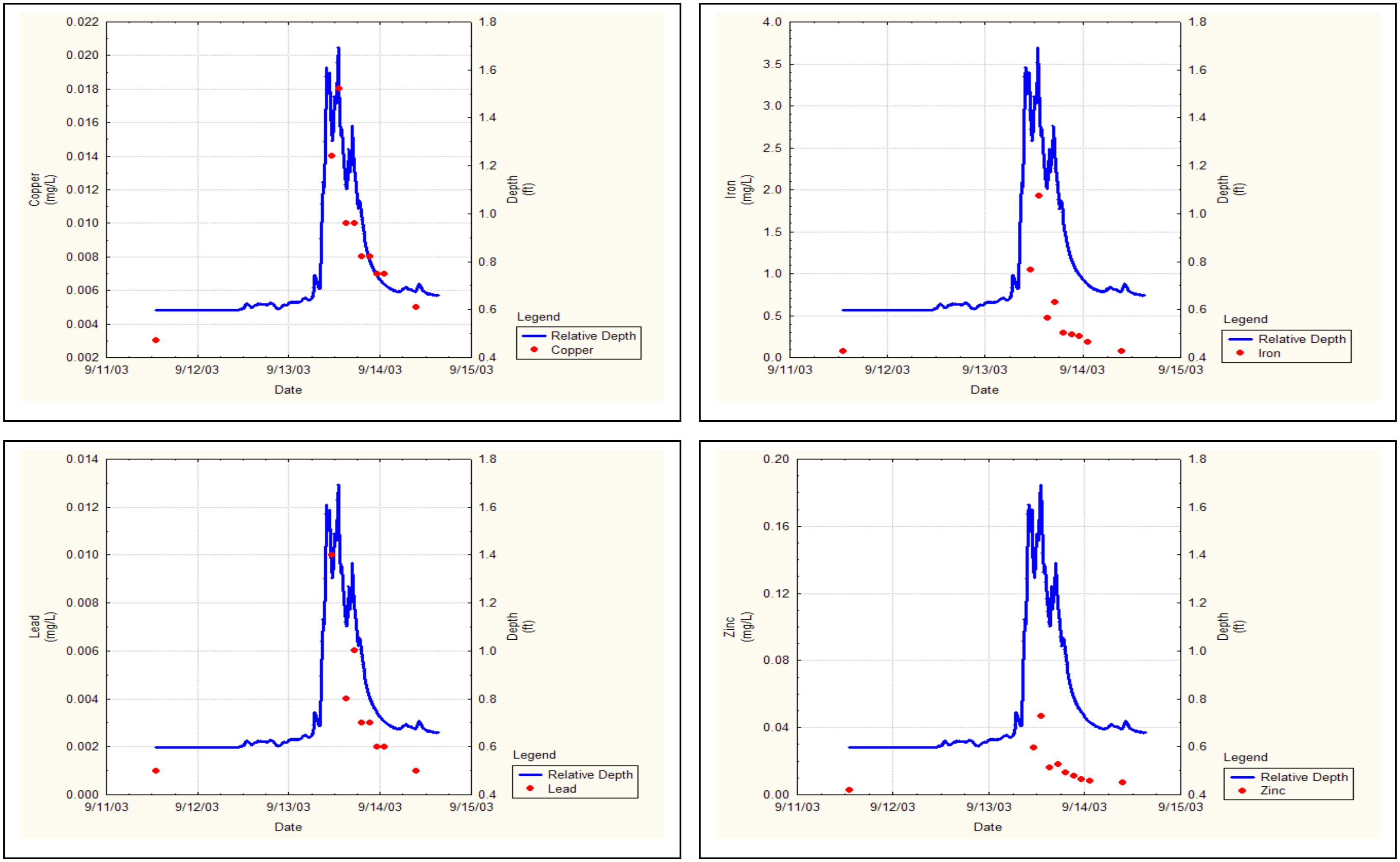




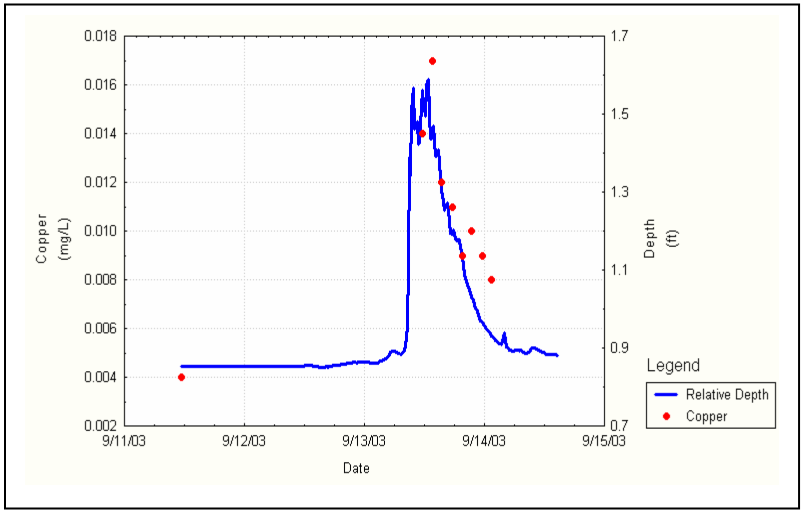


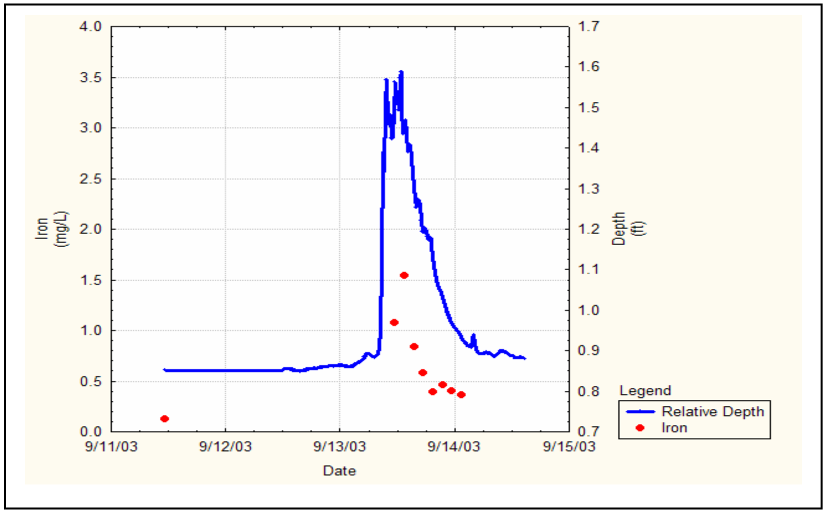


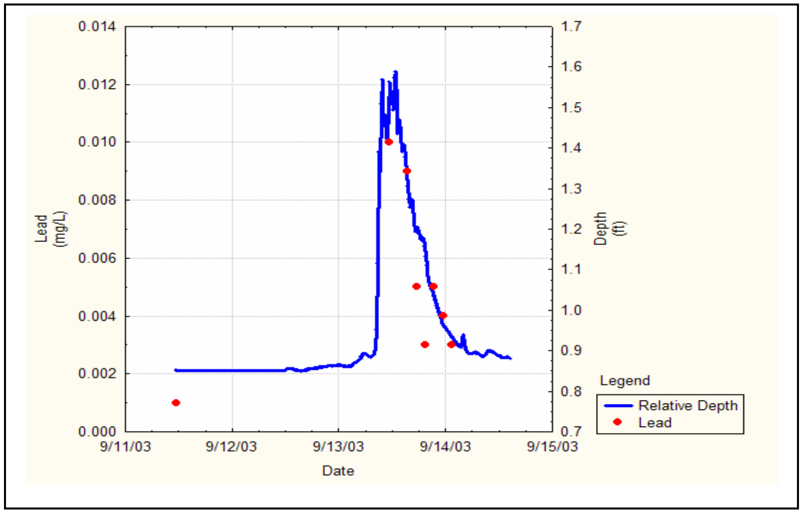
G.2.1. Metal Concentrations At DCC 770 (9/11/03-9/14/03)

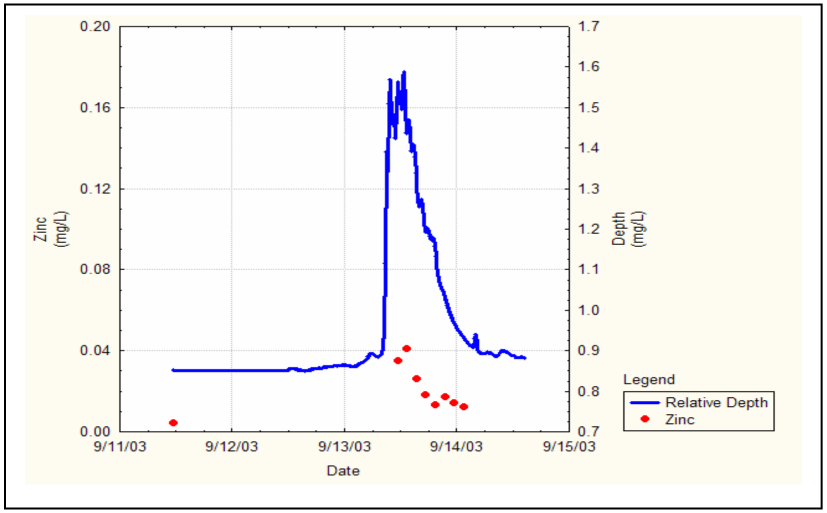


G.2.2. Metal Concentrations At DCC 455 (9/11/03-9/14/03)

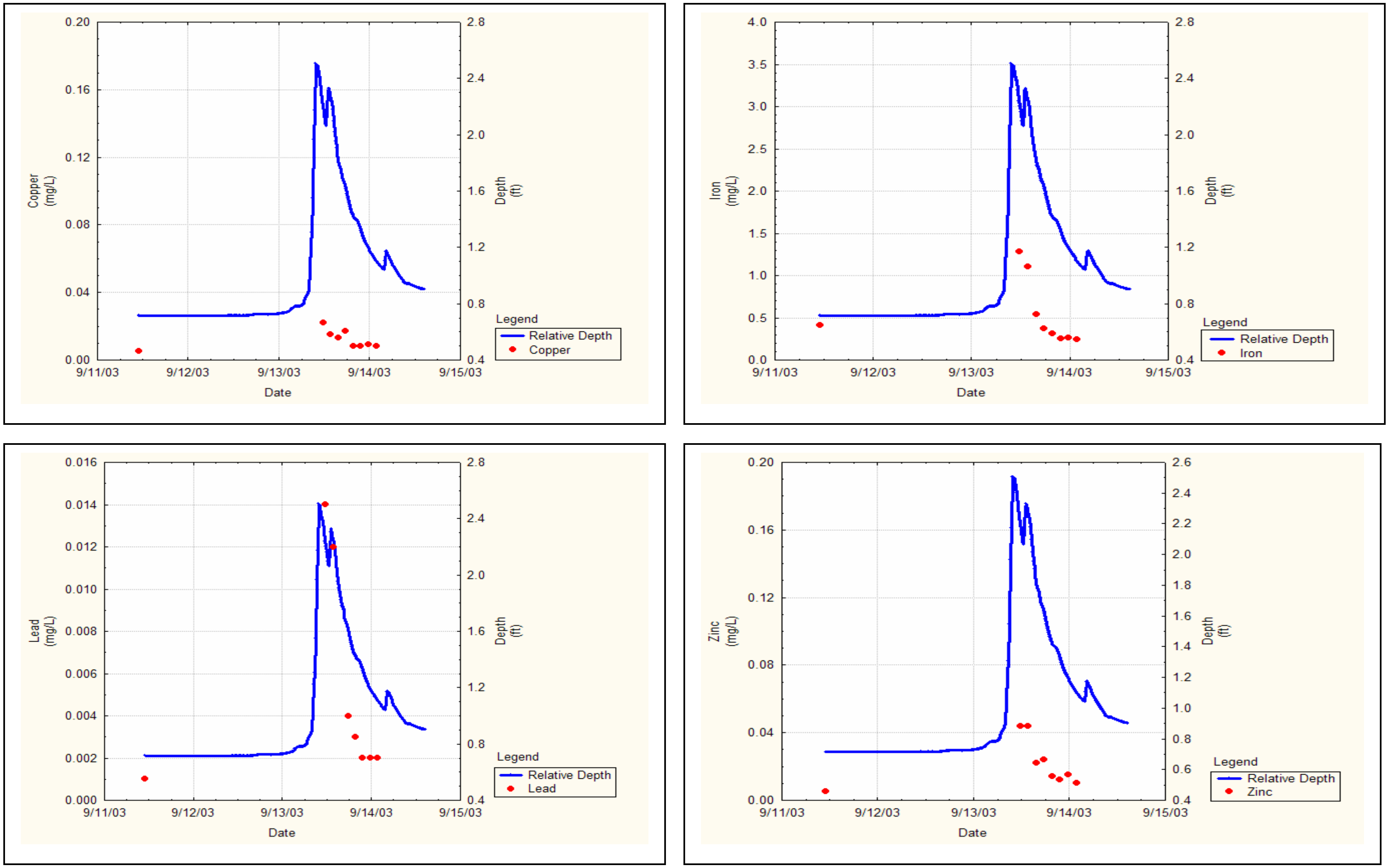




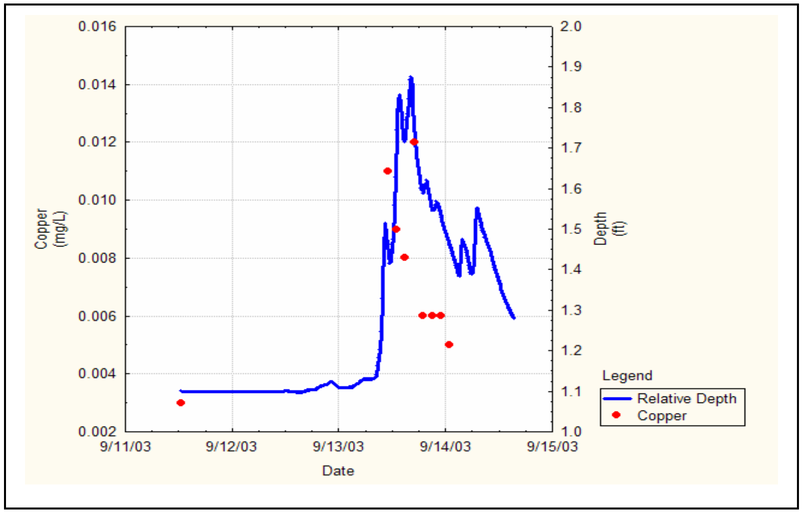


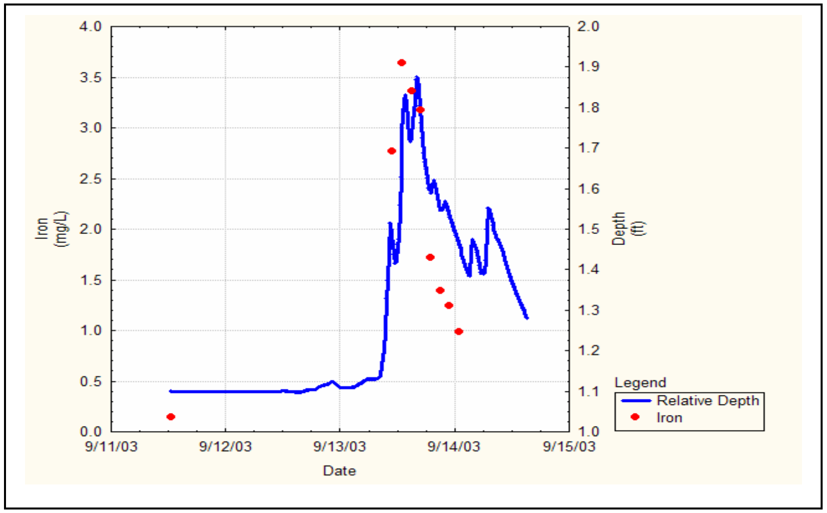


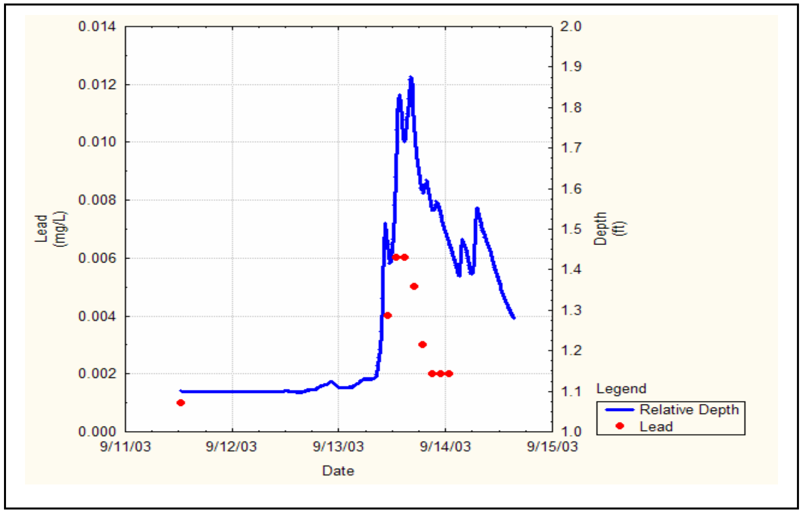
G.2.3. Metal Concentrations At DCC 208 (9/11/03-9/14/03)

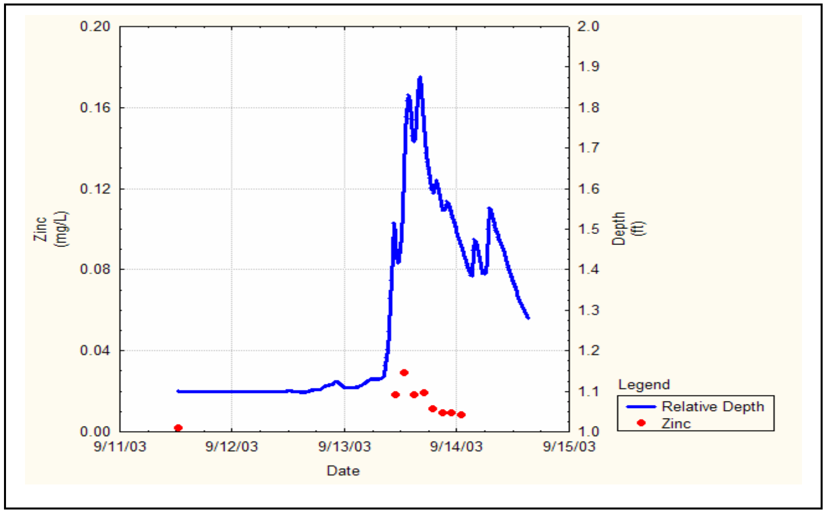


G.2.4. Metal Concentrations At DCD 1660 (9/11/03-9/14/03)









G.2.5. Metal Concentrations At DCD 765 (9/11/03-9/14/03)