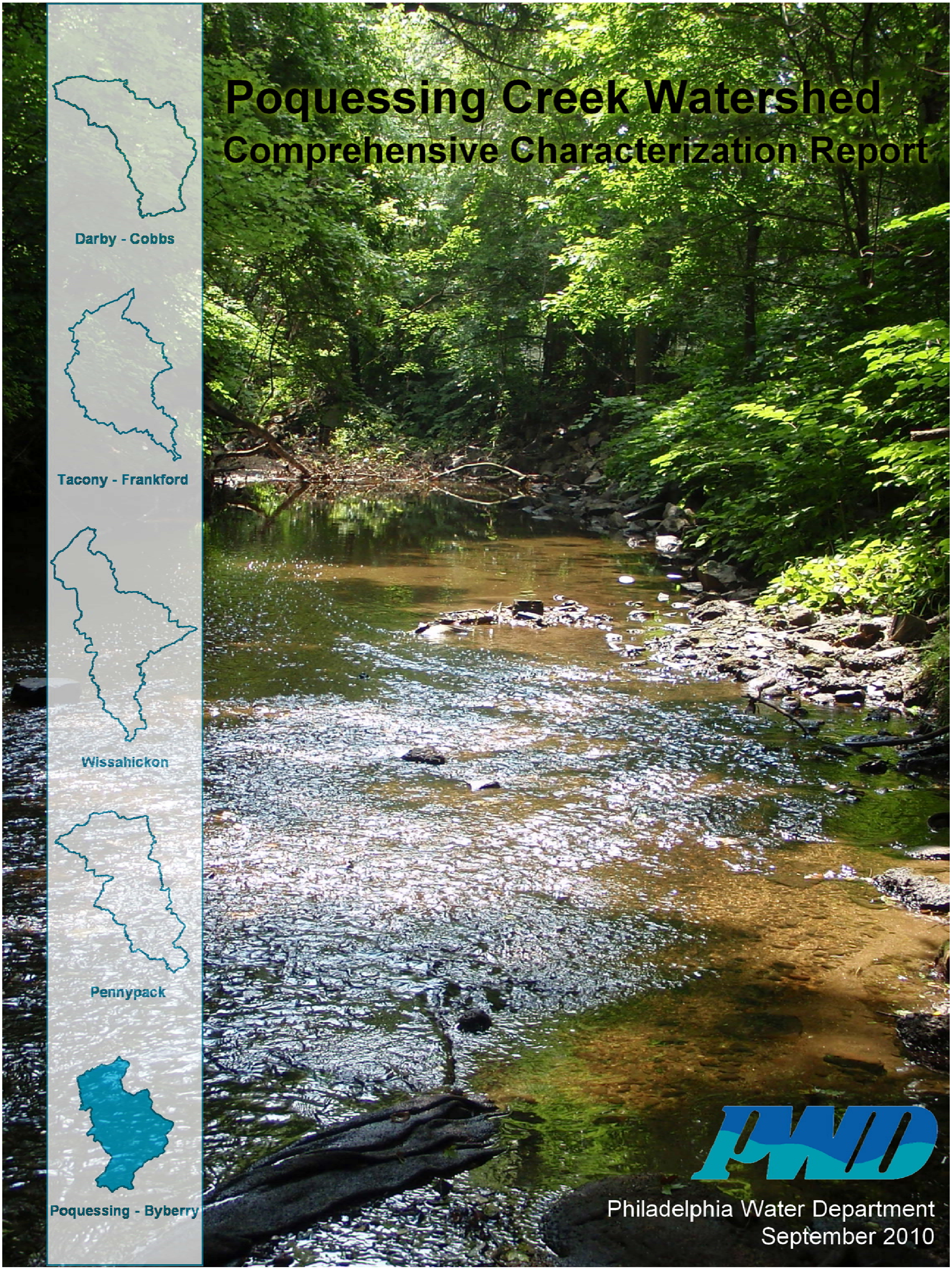
Poquessing Creek Watershed

Comprehensive Characterization Report



Philadelphia Water Department
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EXECUTIVE SUMMARY

Problems faced by the Poquessing Creek Watershed stem from many sources. The watershed suffers from physical disturbance due to urbanization and excess stormwater runoff. These effects are evident in the comprehensive assessment of aquatic habitat, water quality, and biological communities documented in this report. Healthy aquatic ecosystems cannot thrive in physically unstable habitats or when streamflow is dominated by urban runoff that does not maintain healthy stream chemistry. This report forms a technical basis for the forthcoming Poquessing Creek Integrated Watershed Management Plan (PCIWMP), a plan for restoration and enhancement of the creek and its watershed.

As with all urban watersheds, modern-day problems are directly related to the way that land within the watershed was developed. Smallest and last to be developed, Poquessing Creek Watershed is unique among Philadelphia’s watersheds in many ways. Unlike Philadelphia’s other watersheds, Poquessing Creek does not enjoy the protection, access, and stewardship opportunities of a large and well-connected park system. Much of the development within Poquessing Creek Watershed occurred after 1978, and was thus subject to stormwater management regulations. Furthermore, Poquessing Creek is not affected by Combined Sewer Overflows or inputs of treated wastewater, making it relatively simple to identify stormwater runoff as the primary stressor affecting aquatic life.

With impervious cover making up over 30% of the land area in many subsheds, stormwater flows have de-stabilized most stream channels of Poquessing Creek Watershed. Erosion and sedimentation effects are very severe in small tributary streams. Though some stream channels are protected within parkland, most either originate as stormwater outfalls or otherwise accept large volumes of urban stormwater. Traditional stormwater management practices aimed at managing flooding are insufficient to protect stream channels from storm events that occur more frequently. Throughout the watershed, many small ephemeral streams and first-order tributaries have been lost to development. Moreover, destabilizing infrastructure features, such as culverts, bridges, channelization, and small dams are omnipresent. 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 Poquessing Creek Watershed, also magnifies flow modification by decreasing infiltration and groundwater recharge – establishing a hydrologic pattern of "feast or famine." Presently, baseflow accounts for only 37% of total mean annual flow at the Grant Ave. Poquessing Creek USGS gage. Effects of urbanization and physical habitat degradation are evident in biomonitoring data collected throughout the basin. The Poquessing Creek Integrated Watershed Management Plan (PCIWMP, in preparation) will contain several options for detaining, infiltrating, and treating stormwater to reduce its impact on the stream channel and aquatic habitats. The watershed simply cannot be restored without addressing stormwater impacts.

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

Though stormwater runoff undoubtedly has the greatest influence on physical habitat and erosion-related problems in Poquessing Creek Watershed, dry weather (baseflow) conditions should not be overlooked as sources of impairment. PWD found evidence of dry weather discharge of untreated sewage to Poquessing Creek, in one case possibly explaining violation of dissolved oxygen water quality criteria. In addition to direct dissolved oxygen impairment effects, nutrient concentrations greatly exceed EPA recommended guidelines for healthy stream ecosystems. Algae were observed to grow to nuisance levels throughout the watershed, and continuous water quality monitoring suggests algae are primarily responsible for dissolved oxygen (DO) and pH fluctuations that may stress natural fish and invertebrate communities. Though fluctuations may be severe, dissolved oxygen water quality criteria do not appear to have been violated as a result of algal activity. Reductions of instream nutrient concentrations are needed to reduce algal density and severity of DO fluctuations, and to support a more diverse and healthy aquatic ecosystem overall.

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

Fish abundance (number of fish collected per site) decreased dramatically between assessments conducted in 2001 and 2008. The cause of this decline in fish abundance is unknown, but the widespread nature of this trend perhaps suggests a response to coarse-scale disturbance. Fish communities of Poquessing Creek Watershed generally exhibit less diversity and specialization than fish communities found at reference sites and nearly all fish found in the watershed are moderately tolerant of pollution. Poquessing Creek is dominated by moderately tolerant fish with generalized feeding habits and life history strategies, while species that have specialized habitat, food or reproductive needs are largely missing. Fish that require firm, stable, well-oxygenated substrates for spawning are also generally not found in the basin.

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

1 INTRODUCTION

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

Coordination of these different programs has been greatly facilitated by PWD's creation of the Office of Watersheds (OOW), which is aligned to work closely with PWD's Planning and Research, Combined Sewer Overflow (CSO), Collector Systems, Bureau of Laboratory Services, and other key functional groups. One of OOW's responsibilities is to characterize existing conditions in local watersheds to provide a basis for long-term watershed planning and management.

The OOW is developing integrated watershed management plans for five of the City's watersheds including the Cobbs, Tookany/Tacony-Frankford, Wissahickon, Pennypack, and Poquessing. In the summer of 2004, the Cobbs Creek became the first watershed for which an integrated watershed management plan was completed. The Tookany/Tacony-Frankford Watershed plan was completed in the summer of 2005. PWD and the respective Watershed Partnerships are presently working to complete Integrated Watershed Management Plans for the Pennypack, Wissahickon and Poquessing Creek Watersheds.

This Comprehensive Characterization Report (CCR) for the Poquessing Creek forms the scientific basis for the Poquessing Creek Integrated Watershed Management Plan, characterizing land use, geology, soils, hydrology, water quality, ecology, and pollutant loads found in the watershed. This report presents data collected through fall 2009, and is intended as a compilation of background and technical documents that can be periodically updated as additional field work or data analyses are completed.

2 CHARACTERIZATION OF THE STUDY AREA

Note: The Poquessing Creek Watershed Rivers Conservation Plan (RCP), published in 2007, was invaluable in compiling information for the Poquessing Creek Watershed Comprehensive Characterization Report. An excellent resource to complement the watershed description in this section, the Poquessing Creek Watershed RCP is available from http://www.phillywatersheds.org.

2.1 WATERSHED DESCRIPTION

The Poquessing Creek Watershed (PCW) is the smallest of Philadelphia's major watersheds, encompassing roughly 22 square miles. The headwaters of mainstem Poquessing Creek originate in Lower Southampton and Lower Moreland Townships, within Bucks and Montgomery counties, respectively. Poquessing Creek flows roughly 8 miles south to its confluence with the Byberry Creek, which is a major tributary, draining portions of northeast Philadelphia. Downstream of the confluence with Byberry Creek, Poquessing Creek flows approximately one mile to its confluence with the Delaware River. For most of its length, Poquessing Creek serves as the approximate dividing line between the City of Philadelphia and Bucks County.

2.1.1 DRAINAGE AREA

The Poquessing Creek Watershed drains portions of four municipalities and northeast Philadelphia before reaching the Delaware River (Table 2.1, Figure 2.1). With a total drainage area of 21.87 square miles, the watershed spans highly developed suburban communities and multiple neighborhoods within the City of Philadelphia (Table 2.1). Approximately 60% of the Poquessing Creek Watershed lies within the City of Philadelphia, and 35% is within Bucks County. Less than 5% of the total watershed area is in Montgomery County (Lower Moreland Township)

Table 2.1 Municipalities within Poquessing Creek Watershed

County, Municipality, Neighborhood	**Area within Watershed (sq. mi.)**	**Percentage of Watershed**
Bucks County	**7.82**	**35.75%**
Upper Southampton Twp.	0.003	0.01%
Lower Southampton Twp.	3.02	13.83%
Bensalem Twp.	4.79	21.90%
Montgomery County	**0.86**	**3.91%**
Lower Moreland Twp.	0.86	3.91%
Philadelphia County	**13.19**	**60.34%**
Total Poquessing Creek Watershed	**21.87**	**100%**

Figure 2.1 Poquessing Creek Watershed

In addition to Byberry Creek, numerous other tributaries flow into Poquessing Creek (Figures 2.1 and 2.2); the total number of stream miles within Poquessing Creek Watershed is estimated to be 46 miles. Many tributaries to Poquessing Creek are unnamed, or PWD was unable to find local names by consulting historical maps of the area. Unnamed tributaries were assigned letters, beginning with "A" and proceeding upstream. Unnamed tributaries to unnamed tributaries were assigned two letters, such as "AA," and so on.

Utilizing orthophotography and topography data from 2004, hydrology of Poquessing Creek Watershed was traced in order to give a detailed account of stream mileage (Table 2.2). Sub-watersheds of Poquessing Creek (Figure 2.2) were delineated using topographical data, PWD storm sewer data, ArcHydro GIS software, and manual digitization by PWD staff as needed. Note that in earlier documents, such as the Baseline Assessment of Poquessing-Byberry Watershed (PWD 2001), PWD misidentified the mainstem of Poquessing Creek just upstream of the county border. Mainstem Poquessing Creek is now correctly identified as the easternmost branch which flows from north to south within Lower Southampton Township as depicted in USGS topographic maps (Figure 2.2).

Table 2.2 Poquessing Creek and Tributary Stream Lengths

Reach Name	Length Miles	Reach Name, Continued	Length Miles
Black Lake Run	0.77	Poquessing Creek, unnamed trib (CAA)	0.10
Bloody Run	0.50	Poquessing Creek, unnamed trib (CB)	0.40
Byberry Creek	5.32	Poquessing Creek, unnamed trib (CC)	0.71
Byberry Creek, unnamed trib	0.06	Poquessing Creek, unnamed trib (D)	3.45
Byberry Creek, unnamed trib (A)	0.33	Poquessing Creek, unnamed trib (E)	0.21
Byberry Creek, unnamed trib (B)	0.49	Poquessing Creek, unnamed trib (F)	0.65
Byberry Creek, unnamed trib (C)	0.54	Poquessing Creek, unnamed trib (G)	0.55
Colbert's Run	1.73	Poquessing Creek, unnamed trib (H)	1.00
Elwood's Run	1.21	Poquessing Creek, unnamed trib (I)	0.39
Elwood's Run, unnamed trib	0.11	Poquessing Creek, unnamed trib (J)	0.89
Gilbert's Run	0.90	Poquessing Creek, unnamed trib (K)	1.03
Gilbert's Run, unnamed trib (A)	0.10	Walton's Run	3.40
Poquessing Creek	11.57	Walton's Run, unnamed trib	0.77
Poquessing Creek, unnamed trib	2.48	Walton's Run, unnamed trib (A)	0.21
Poquessing Creek, unnamed trib (A)	0.13	Walton's Run, unnamed trib (B)	0.32
Poquessing Creek, unnamed trib (B)	0.55	Wilson's Run	1.20
Poquessing Creek, unnamed trib (C)	2.49	Wilson's Run, unnamed trib (A)	0.81
Poquessing Creek, unnamed trib (CA)	0.57		

*Total river mile distance of 31 unnamed tributary segments of Poquessing Creek

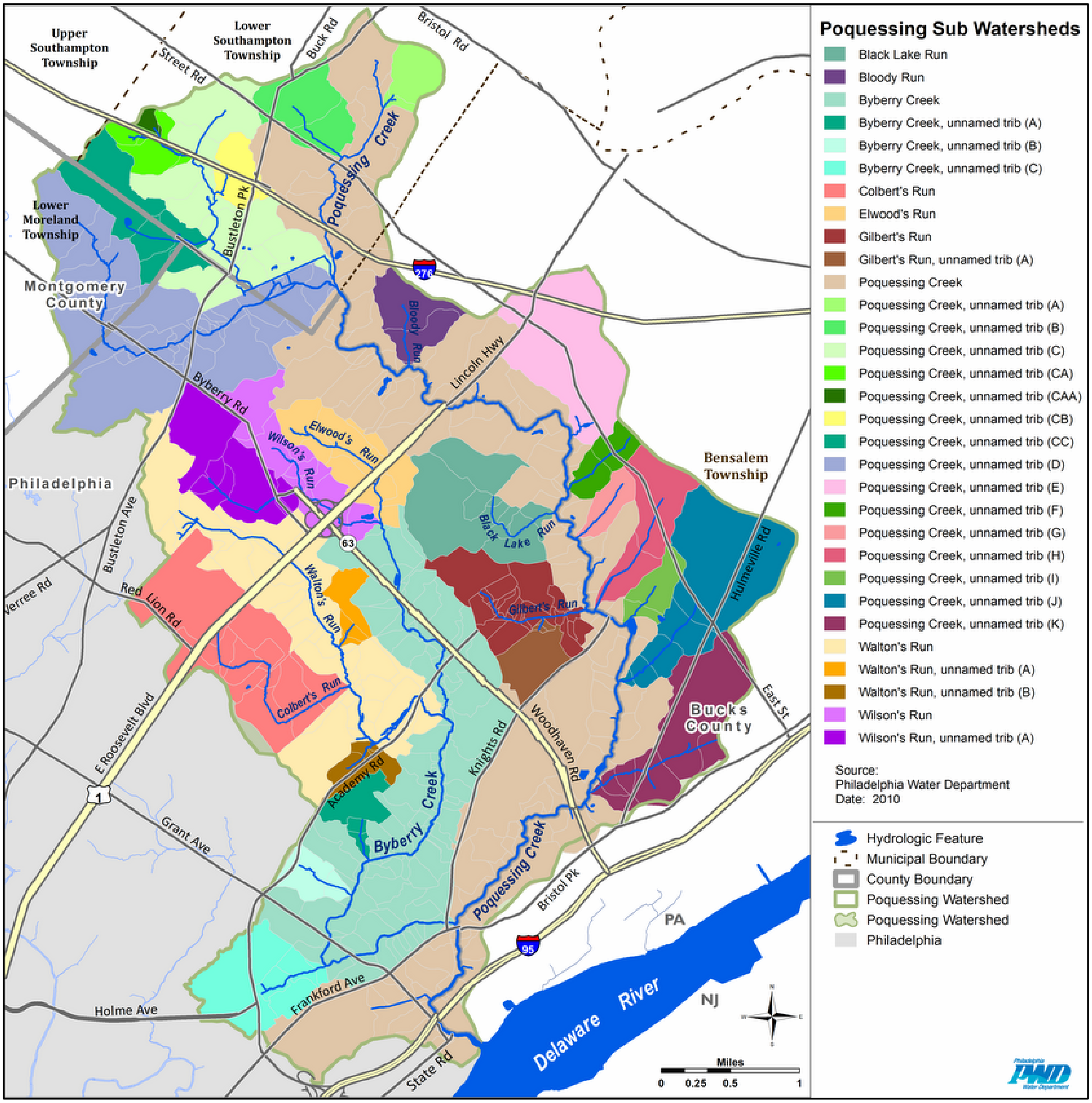


Figure 2.2 Poquessing Creek Sub-Watersheds

2.2 LAND USE IN THE POQUESSING CREEK WATERSHED

Land use information for the Poquessing Creek Watershed was obtained from the Delaware Valley Regional Planning Commission (DVRPC). Over time, the Poquessing Creek Watershed has experienced continual and extensive urban and suburban land development. Presently, nearly half of the Poquessing Creek Watershed is covered by residential development with single-family detached residential (26.67%) making up the majority of that development (Table 2.3, Figure 2.3).

Several major arterial roads transect this watershed area, including the Pennsylvania Turnpike Rt. 276, Roosevelt Boulevard/Lincoln Highway (Rt. 1), Woodhaven Rd. (Rt 63), and Bustleton Ave/Bustleton Pike. Residential, commercial, and industrial development closely follows these major transportation corridors. SEPTA regional railroad lines R3 to West Trenton and Trenton (formerly R3 and R7 lines, respectively) have stops within the Poquessing Creek Watershed.

A modest riparian corridor along Poquessing Creek and its tributaries has remained wooded land, mostly protected through long-term preservation efforts of the Fairmount Park Commission and Benjamin Rush State Park, but the Poquessing Creek Watershed generally has the smallest and narrowest riparian zone as preserved land among Philadelphia area watersheds. While there are a few large tracts of privately owned open space, such as recreational land and golf courses, most of the watershed has been developed.

Table 2.3 Land Use in the Poquessing Creek Watershed by County

Land Use	Philadelphia County	Montgomery County	Bucks County	Total Poquessing Watershed
Agriculture	1.33%	0.00%	0.38%	1.71%
Commercial	2.24%	0.01%	3.48%	5.73%
Community Services	2.42%	0.84%	1.98%	5.24%
Manufacturing: Light Industrial	7.26%	0.00%	1.11%	8.37%
Military	0.03%	0.00%	0.00%	0.03%
Parking	4.31%	0.01%	3.89%	8.21%
Recreation	4.20%	0.04%	1.87%	6.11%
Residential: Mobile Home	0.00%	0.00%	0.00%	0.00%
Residential: Multi-Family	5.80%	0.08%	0.01%	5.89%
Residential: Row Home	7.21%	0.00%	1.51%	8.72%
Residential: Single-Family Detached	9.74%	2.56%	14.37%	26.67%
Transportation	3.34%	0.00%	1.22%	4.56%
Utility	0.33%	0.00%	0.09%	0.42%
Vacant	3.17%	0.06%	1.56%	4.79%
Water	0.20%	0.01%	0.39%	0.60%
Wooded	7.92%	0.30%	4.72%	12.94%
Total	**100.00%**	**100.00%**	**100.00%**	**100.00%**

Source: Delaware Valley Regional Planning Commission, 2000.

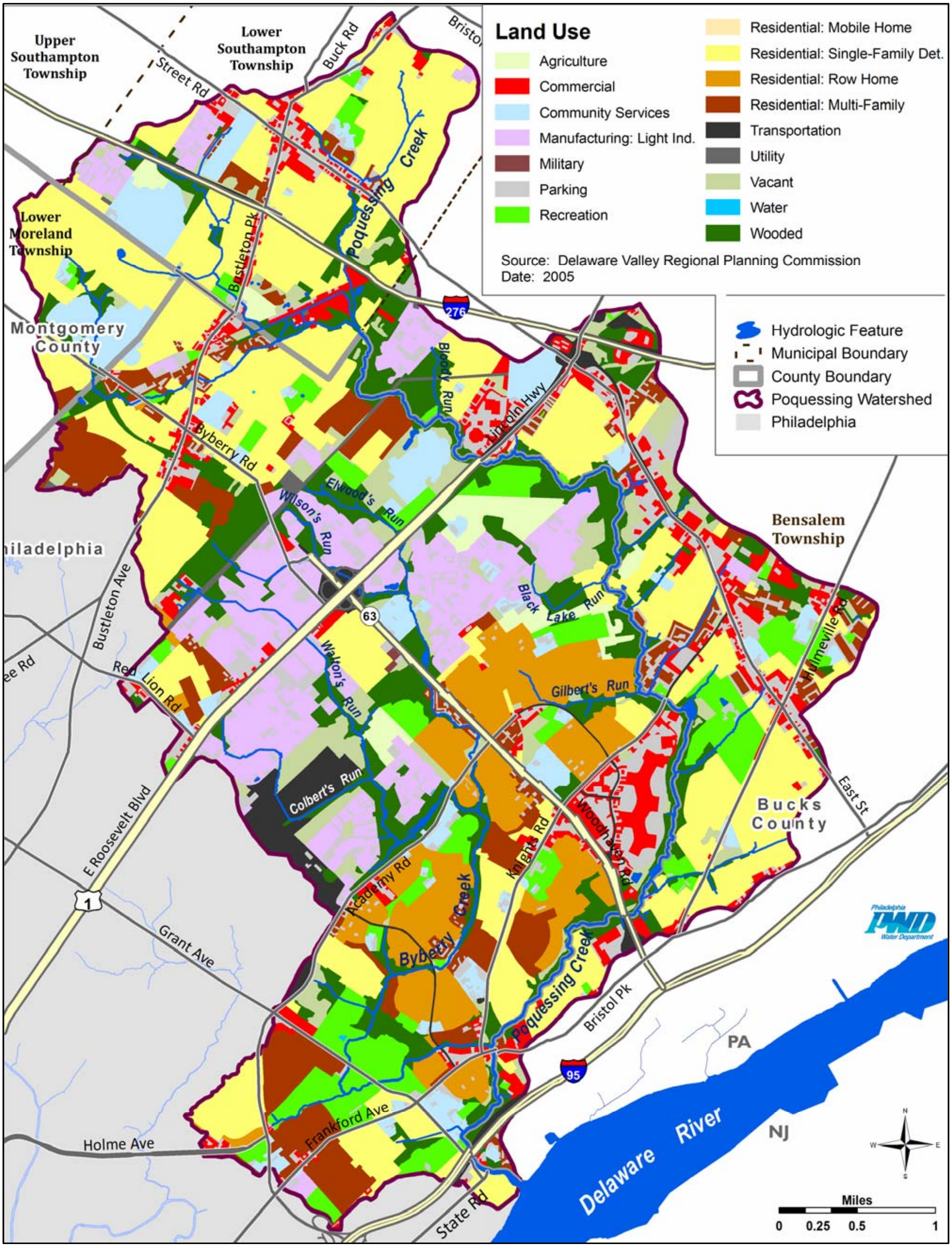


Figure 2.3 Land Use in the Poquessing Creek Watershed

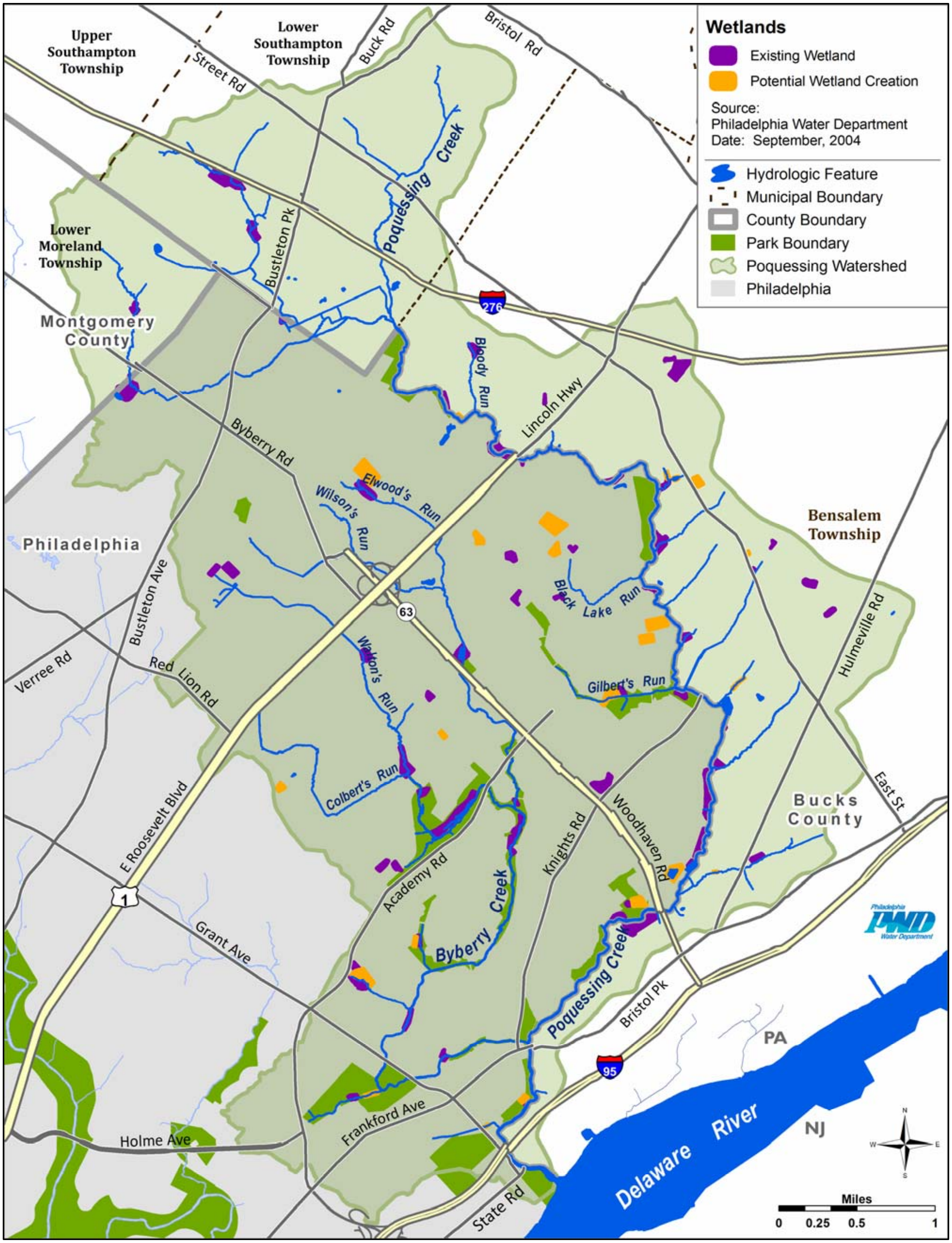
2.3 WETLANDS

Due to the well-documented benefits that wetlands have on water quality and stormwater management, PWD initiated a wetlands assessment to inventory and maximize the function and protection of such critical areas. PWD performed assessments of existing wetland restoration opportunities and potential wetland creation sites in the Poquessing Creek Watershed from 2001-2002 and continued the program in 2004. Initially, the assessments took place within the Philadelphia portion of the Poquessing Creek watershed during 2001 and 2002 as part of a city-wide effort. In 2004, assessments were extended into the Montgomery and Bucks County portions of the Poquessing Creek Watershed.

The 2001-2002 and 2004 assessments were performed with slightly different methods due to individual objectives for the urban and suburban locations. Within Philadelphia, the objective of the wetlands assessment was to identify potential wetland creation sites that could be used to provide stormwater treatment as well as improve overall water quality of the Poquessing Creek. The Philadelphia assessments examined outfalls and existing wetlands in order to identify potential creation sites in close proximity to these features. The Montgomery and Bucks County assessments were intended to be a complete inventory of existing wetlands outside of Philadelphia in the Poquessing Creek Watershed, and to identify potential creation sites that would enhance the wetland resources within the watershed.

Although the objectives of the two wetland surveys were slightly different, similar geographic data sets and classification methods were used to locate existing and potential sites. Any existing wetlands were identified according to the criteria set by the U.S. Army Corps of Engineers Wetlands Delineation Manual (Environmental Laboratory, 1987). The function and levels of disturbance for all existing and potential wetland sites were evaluated using modified versions of the Oregon Freshwater Wetland Assessment Methodology (Roth *et al.*, 1996) and the Human Disturbance Gradient (Gernes and Helgen, 2002).

The PWD Poquessing Creek Watershed wetlands assessment found 13 potential wetland creation sites; nine sites within Philadelphia County, and 10 sites within Bucks County. The estimated size of combined potential wetland creation sites is 32 acres in Philadelphia County and 12 acres in Bucks County. In addition to potential creation sites, the PWD assessments identified wetland enhancement locations where restoration methods can improve the function and stormwater treatment capabilities of existing wetland areas. PWD recommends enhancement of 15 of 37 wetland sites within Philadelphia and 9 of 13 existing wetlands in Bucks County (Figure 2.4). The "Southeast Regional Wetland Inventory and Water Quality Improvement Initiative" for the Poquessing Creek Watershed is available for review at www.phillywatersheds.org.



Source:
Philadelphia Water Department
Date: September, 2004

Figure 2.4 Existing and Potential Wetland Creation Sites in Poquessing Creek Watershed

2.4 GEOLOGY AND SOILS

Geology and soils play a role in the hydrology, water quality, and ecology of a watershed. The watershed features can be described through the physiographic provinces that characterize the area, surface geological formations, soil texture, and the hydrologic grouping of soil types. The physiographic provinces of the Poquessing Creek Watershed are presented in Table 2.4 and Figure 2.5. The location and descriptions of the geology and soils within the Poquessing Creek Watershed are detailed in Figures 2.6 and 2.7, and Table 2.5.

Table 2.4 Generalized descriptions of Physiographic Provinces and Sections within the Poquessing Creek Watershed

Province and Section	Description
Province: Atlantic Coastal Plain **Section:** Lowland and Intermediate Upland	Flat upper terrace surface but by numerous short streams; short straight streams; narrow and steep sided stream valleys and some wide bottomed valleys; upper terrace composed of unconsolidated to poorly consolidated sand and gravel resting on metamorphic rock; valleys composed of upper sands and gravels resting on metamorphic rocks.
Province: Piedmont **Section:** Piedmont Upland	Broad rolling hills and valleys; metamorphic schist; bedrock; dendritic and rectangular drainage.

Source: Pennsylvania Department of Conservation and Natural Resources, 2008.

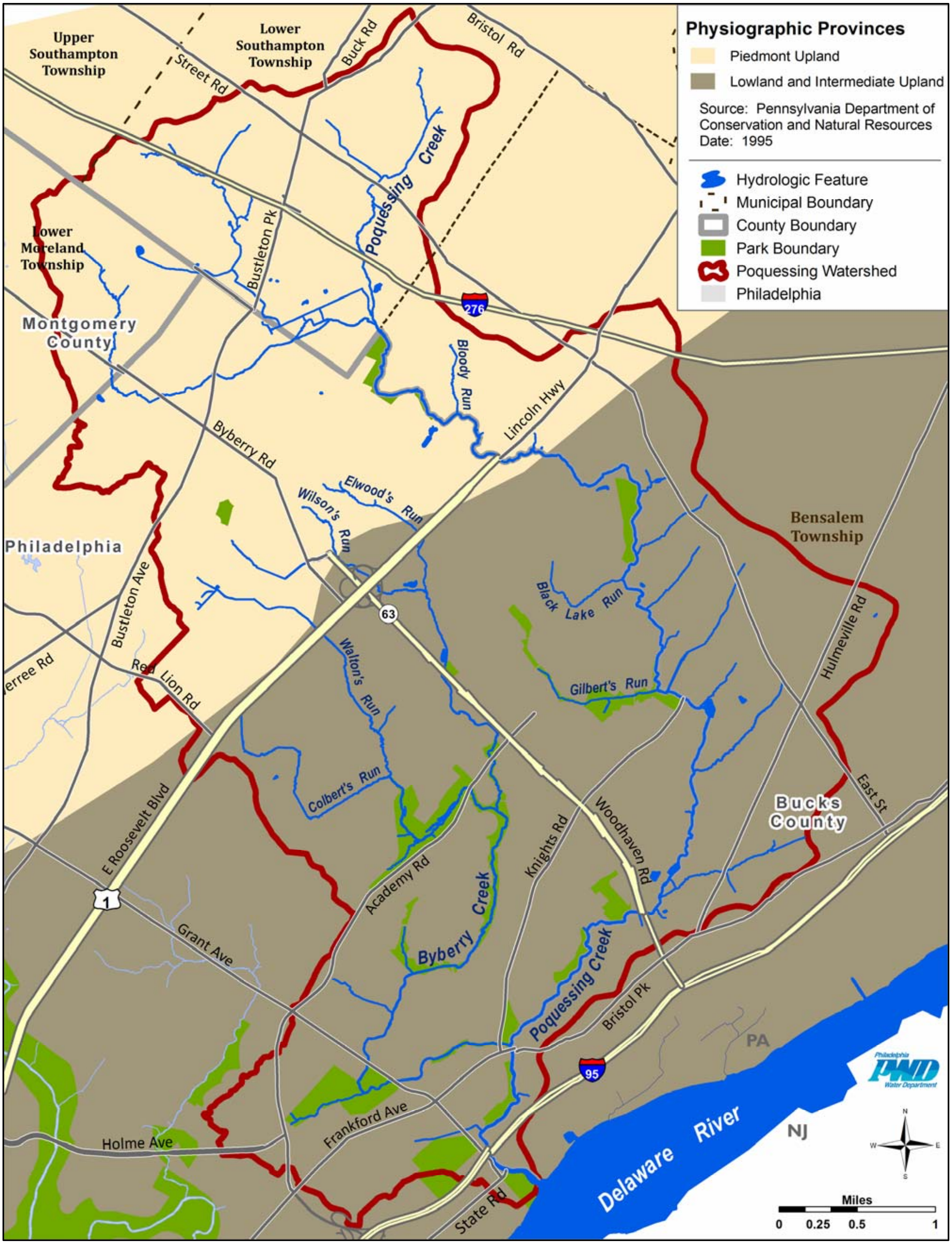
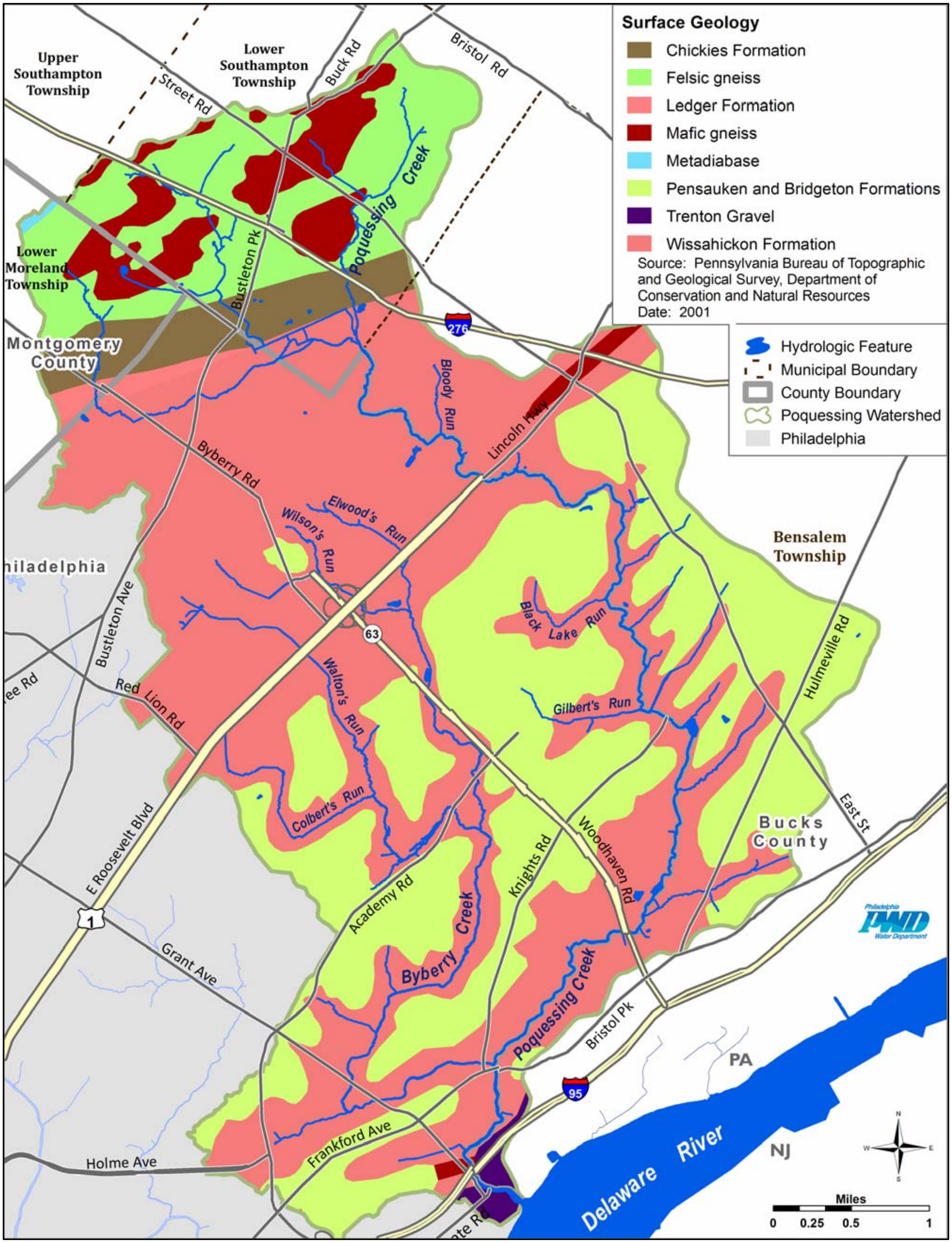


Figure 2.5 Poquessing Creek Watershed Physiographic Provinces

Table 2.5 Generalized descriptions of Geologic Formations within the Poquessing Creek Watershed

Formation	Description
Chickies Formation	This formation is created when sandstone is exposed to extreme heat and pressure. Composed of quartzite and quartz schist. This hard, dense rock weathers slowly. This formation has good surface drainage. A narrow band of quartzite extends westward across Bucks County from Morrisville. By virtue of its erosion-resistant nature it has formed a series of prominent ridges as seen along the Pennsylvania Turnpike in the eastern portion of the county.
Felsic Gneiss, Pyroxene Bearing	This formation consists of metamorphic rock units that yield small quantities of water due to the smallness of the cracks, joints, and other openings within the rock. This fine-grained granitic gneiss is resistant to weathering but shows good surface drainage.
Ledger Dolomite	This formation consists of limestone valley that extends eastward from Lancaster County through Chester County, tapering off within Abington Township. The limestone and dolomite formations yield good trap rock and calcium-rich rock which has been quarried for various industrial and construction uses. Sinkholes can form in the limestone formation when water dissolves portions of the rock, resulting in underground cavities. Care must be taken in the development of buildings and the management of stormwater in these locations.
Mafic Gneiss	This formation consists of medium- to fine-grained, dark-colored calcic plagioclase, hyperthene, augite, and quartz. It is highly resistant to weathering but shows good surface drainage.
Metadiabase	Dark-gray, fine-grained intrusives; locally, mineralogy is altered and unit has greenish color.
Pennsauken Formation	This formation consists of sand and gravel yellow to dark reddish-brown, mostly comprised of quartz, quartzite, and chert. It is a deeply weathered floodplain formation.
Wissahickon Schist	The Wissahickon Schist is composed of mica schist, gneiss and quartzite, in which the portions of mica, quartzite and feldspar vary from bed to bed. The schists are softer rock and are highly weathered near the surface. This formation consists mostly of metamorphosed sedimentary rocks but also includes rocks of igneous origin.
Trenton Gravel	Gray or pale reddish-brown, very gravelly sand interstratified with crossbedded sand and clay-silt beds; includes areas of Holocene alluvium and swamp deposits.

Source: Berg *et al.* 1980, modified, as found in Poquessing Creek River Conservation Plan, 2007



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

Figure 2.6 Poquessing Creek Watershed Surface Geology

Soils within the Poquessing Creek Watershed were classified according to the United States Department of Agriculture, Natural Resource Conservation Service (NRCS) Hydrologic Soil Groups (HSG). The assigned groups are listed in NRCS Field Office Technical Guides, published soil surveys, and local, state, and national soil databases. The Hydrologic Soil Groups, as defined by NRCS engineers, are A, B, C, D, and dual groups A/D, B/D, and C/D.

Table 2.6 USGS-NRCS Hydrologic Soil Group Descriptions

Hydrologic Soil Group	Description
A	Typically low runoff potential and a high rate of infiltration when thoroughly wet. The depth to any restrictive layer is greater than 100 cm (40 inches) and to a permanent water table is deeper than 150 cm (5 feet).
B	Soils that have a moderate rate of infiltration when thoroughly wet. The depth to any restrictive layer is greater than 50 cm (20 inches) and to a permanent water table is deeper than 60 cm (2 feet).
C	Have a slow rate of infiltration when thoroughly wet; water movement is moderate or moderately slow. They generally have a restrictive layer that impedes the downward movement of water. The depth to the restrictive layer is greater than 50 cm (20 inches) and to a permanent water table is deeper than 60 cm (2 feet).
D	Have a high runoff potential and a very slow infiltration rate when thoroughly wet. Water movement through the soil is slow or very slow. A restrictive layer of nearly impervious material may be within 50 cm (20 inches) of the soil surface and the depth to a permanent water table is shallower than 60 cm (2 feet).
Dual Hydrologic Soil Groups	Dual Hydrologic Soil Groups (A/D, B/D, and C/D) are given for certain wet soils that could be adequately drained. The first letter applies to the drained and the second to the un-drained condition. Soils are assigned to dual groups if the depth to a permanent water table is the sole criteria for assigning a soil to hydrologic group D.

Source: Neilsen *et al*. 1998.

The HSG rating can be useful in assessing the ability of the soils in an area to recharge stormwater, accept recharge of treated wastewater, or allow for effective use of septic systems. Most soils in Poquessing Creek Watershed are categorized as urban and made land. This generally means that soils have been sufficiently disturbed from their natural state as to preclude classification. Furthermore, due to this disturbance, urban soil infiltration characteristics may vary widely. This has implications for the design of stormwater infiltration systems and also affects the amount of water that needs to be infiltrated in newly developing areas to maintain predevelopment or natural infiltration rates.

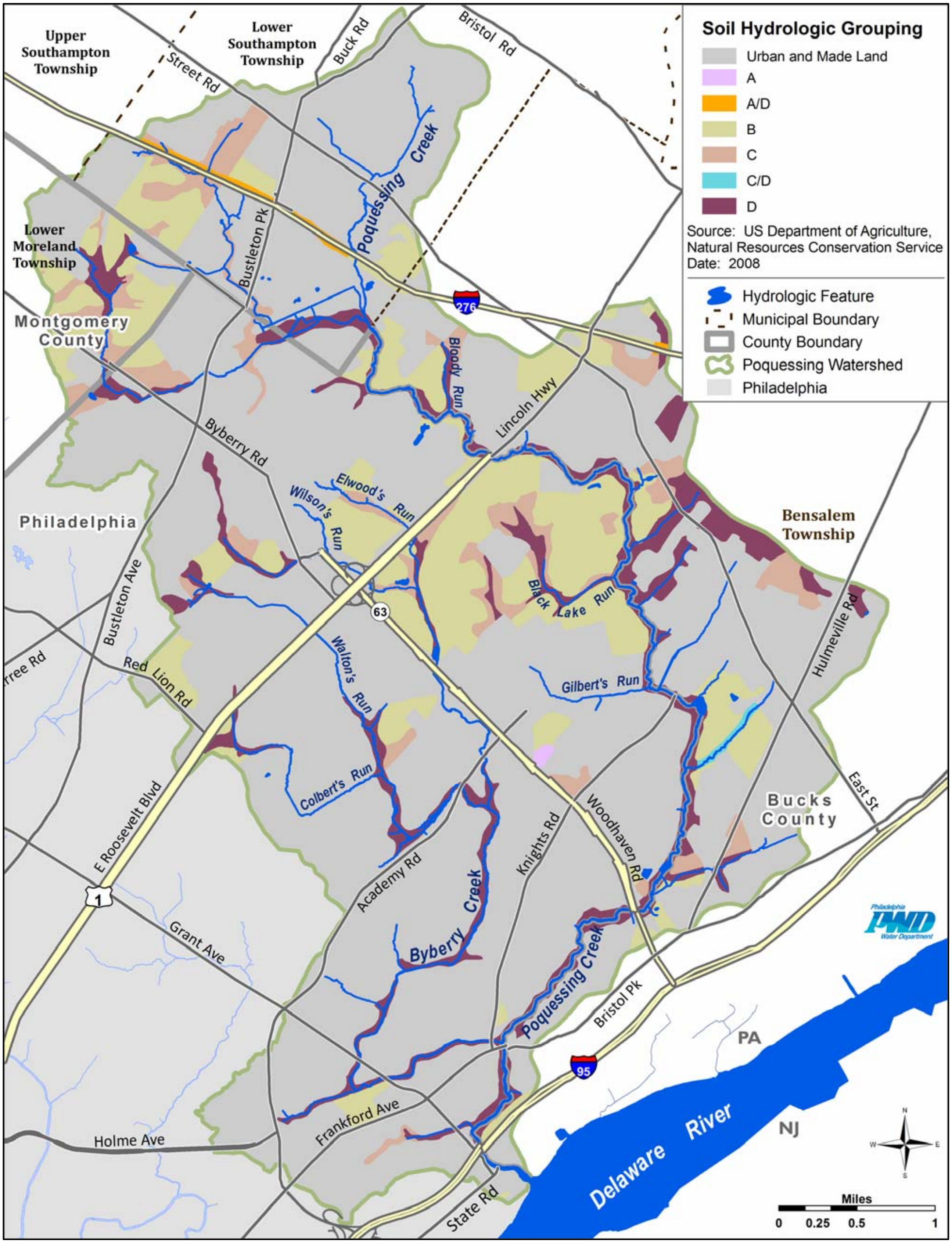


Figure 2.7 Soil Hydrologic Grouping within Poquessing Creek Watershed

2.5 DEMOGRAPHIC INFORMATION

Population density and other demographic information for the Poquessing Creek Watershed were estimated by PWD based on area-weighted census block group information from the 2000 U.S. Census (Table 2.7). Approximately 103,000 people reside within Poquessing Creek Watershed. The average population density of the watershed is approximately 7 persons per acre (Figure 2.8). The amount of impervious cover in a residential area is closely related to its population density, affecting both the quantity and quality of stormwater runoff.

Additional demographic analyses of 1930 to 1970 and 1970 to 2000 population changes are found in Section 2.2 of the Poquessing Creek Watershed River Conservation Plan (RCP) published in June 2007, citing data and population forecasts contained in DVRPC Bulletin #82 *Population Change in the Delaware Valley, 1930 – 2000* (DVRPC, 2006). However, the DVRPC report examined the municipalities in their entirety, not only the areas within the Poquessing Creek Watershed. Over this time frame, the greatest population change took place in Bensalem Township, where the population increased by 20 percent from 1990 to 2000. In Philadelphia during that same time period the population decreased by 4.2 percent, continuing a decades-long decline.

Table 2.7 Poquessing Creek Demographic Statistics

Municipality	Population	# of Households
Bucks County	**24,549**	**9,752**
Upper Southampton Township	23	6
Lower Southampton Township	7,903	3,079
Bensalem Township	16,623	6,667
Montgomery County	**1,862**	**644**
Lower Moreland Township	1,862	644
Philadelphia County	**76,896**	**29,008**
Total	**103,307**	**39,404**

Source: 2000 U.S. Census

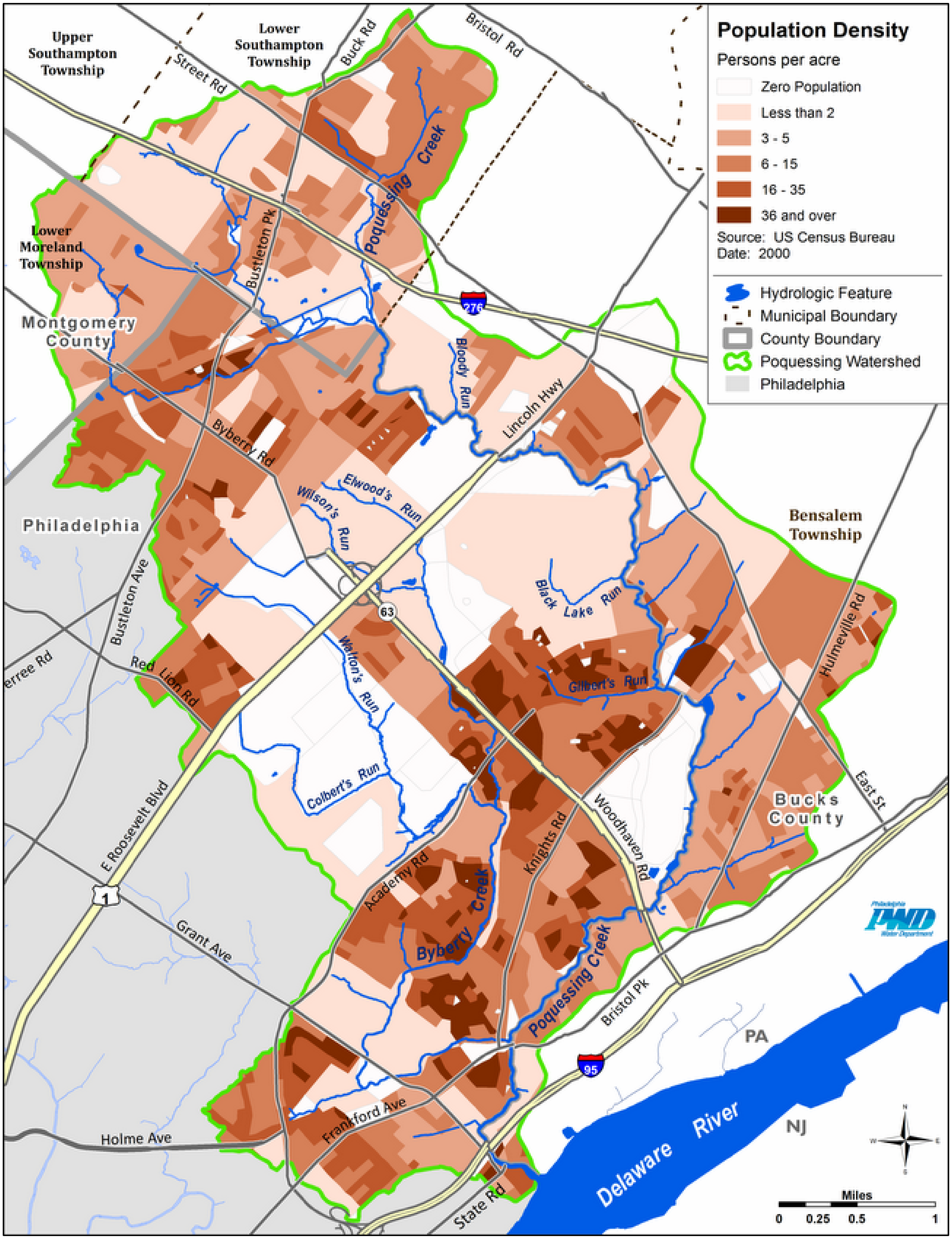


Figure 2.8 Poquessing Creek Watershed Population Density

2.6 IMPERVIOUS COVER AND WATERSHED HEALTH

One of the primary indicators of watershed health is the percentage of impervious cover within the watershed. Based on numerous research efforts, studies, and observations, a general categorization of watersheds has been widely applied to watershed management based on percentage of impervious cover (Schueler, 1995). The Poquessing Creek Watershed has an average of 37.24% impervious cover overall, placing it solidly in the "Non-Supporting" category of stream health (Tables 2.8 and 2.9). The City of Philadelphia portion of the watershed has a slightly greater relative amount of impervious cover, at 41.22%. The impacts that overall watershed impervious cover can have on stream health are described below in Table 2.9. Adverse changes in critical stream characteristics are listed, along with the levels of imperviousness typically associated with these changes.

Table 2.8 Estimated Impervious Cover in the Poquessing Creek Watershed

Location	Total Area of Watershed Square Miles	Total Impervious Area Square Miles	Percent Impervious
Bucks County	8.09	2.61	32.26%
Montgomery County	0.86	0.20	23.26%
Philadelphia County	13.15	5.42	41.22%
Total Watershed	**22.10**	**8.23**	**37.24%**

Source: PWD internal 2004 planimetrics data

Table 2.9 Impervious Cover as an Indicator of Stream Health (Schueler 1995)

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

Most impacts of traditional development on streams and watersheds can be attributed to increased impervious cover, but construction disturbance, non-point source pollution and other changes to the landscape also play an important role (Table 2.10). Poquessing-Byberry Watershed is unique among Philadelphia's small watersheds in that the watershed is not affected by treated wastewater discharge or combined sewer overflows, making it simpler to identify stormwater pollution as the primary stressor affecting the watershed.

Table 2.10 Impacts of Traditional Development on Watershed Resources (Scheuler 2005)

Changes in Stream Hydrology • Increased magnitude/frequency of severe floods • Increased frequency of erosive bankfull and sub-bankfull floods • Reduced groundwater recharge • Higher flow velocities during storm events	**Changes in Stream Morphology** • Channel widening and downcutting • Streambank erosion • Channel scour • Shifting bars of coarse sediments • Embedding of stream substrate • Loss of pool/riffle structure • Stream enclosure or channelization
Changes in Stream Water Quality • Instream pulse of sediment during construction • Nutrient loads promote stream and lake algae growth • Bacteria contamination during dry and wet weather • Higher loads of organic matter • Higher concentrations of metals, hydrocarbons, and priority pollutants • Stream warming • Trash and debris jams	**Changes in Stream Ecology** • Reduced or eliminated riparian buffer • Shift from external production to internal production • Reduced diversity of aquatic insects • Reduced diversity of fish • Creation of barriers to fish migration • Degradation of wetlands, riparian zones and springs • Decline in amphibian populations

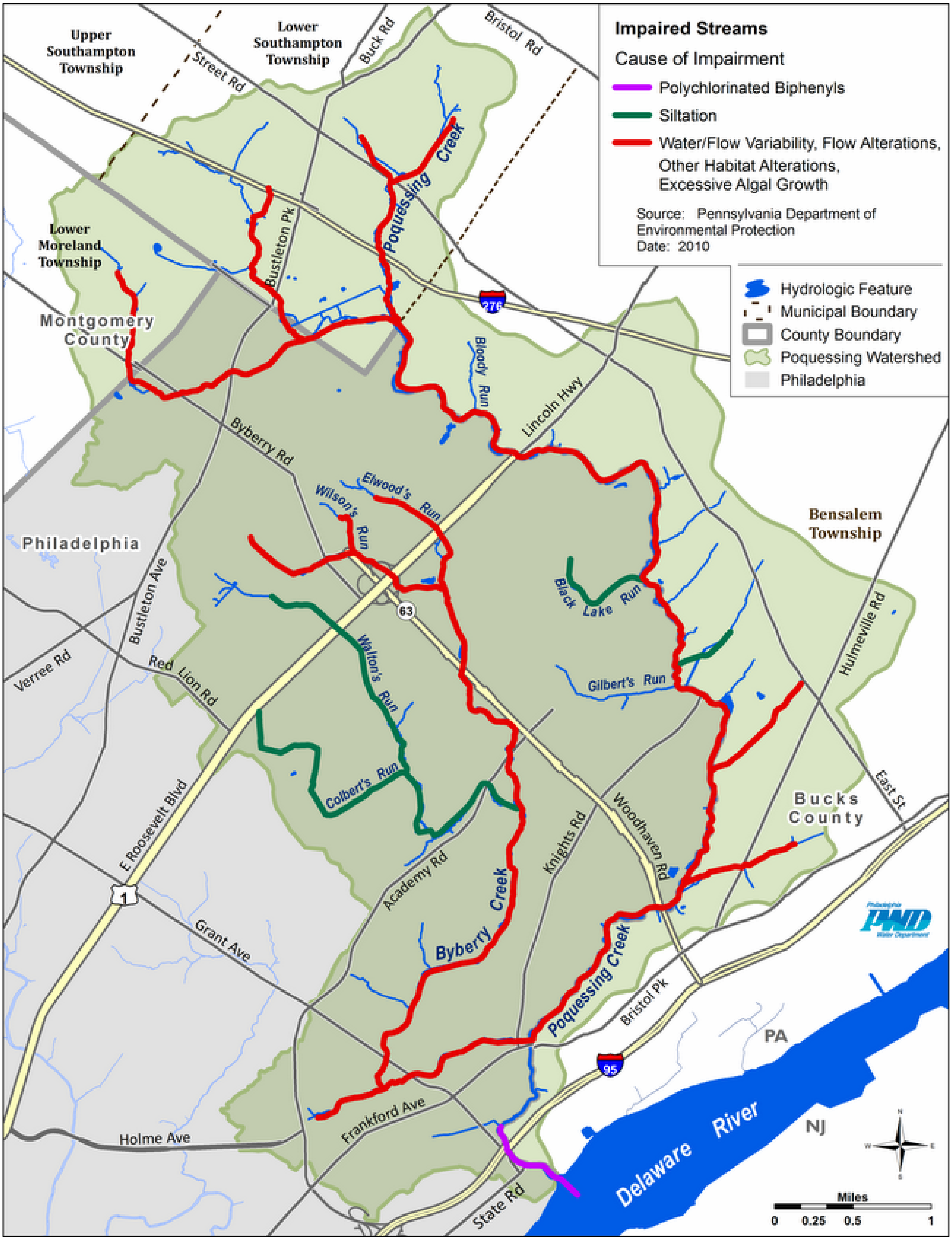
2.7 CLEAN WATER ACT SECTIONS 305B AND 303D

Under Section 305(b) of the Clean Water Act, states must assess the quality of water resources and document any stream segments that do not meet the numerical or narrative standards that constitute the designated use of a stream. The PADEP assesses waters according to four designated uses defined in Title 25 Pennsylvania Code Chapter 93 Section 93.3 Protected Water Uses; they are Aquatic Life, Water Supply, Fish Consumption, and Recreation. Segments that do not meet one or more specified designated uses are identified as impaired, and comprise the 303(d) list portion of the Pennsylvania Integrated Water Quality Monitoring and Assessment Report (PADEP, 2010).

In the Poquessing Creek Watershed, there are approximately 30 miles of streams included in the 303(d) list of impaired streams. A summary of impairments and the lengths of impaired stream segments are listed in Table 2.11 (minor differences exist between hydrography GIS data created by PWD and that used for the 303(d) list). As shown in Figure 2.9, the most extensive individual impairment category affects 23.08 miles of stream, including the entire mainstem Poquessing Creek within Bucks County and Philadelphia. The cause of impairment is listed as “water/flow variability, flow alterations, other habitat alterations, and excessive algal growth”; the source of impairment is “urban runoff and storm sewers.” In addition to this impairment, portions of Byberry Creek are listed as impaired due to siltation, the cause of which is listed as “urban runoff and storm sewers.” Also designated as impaired is the tidal portion of the Poquessing Creek mainstem, listed as such due to the presence of polychlorinated biphenyls (PCBs). The source of PCBs is listed as “unknown.”

Table 2.11 Summary of Impairments in the Poquessing Creek Watershed

Total Miles	Impairment Cause	Impairment Source
1.45	Polychlorinated biphenyls	Source Unknown
5.74	Siltation	Urban Runoff / Storm Sewers
23.08	Water/Flow Variability; Flow Alterations; Other Habitat Alterations; Excessive Algal Growth	Urban Runoff / Storm Sewers



Source: Pennsylvania Department of Environmental Protection
Date: 2010

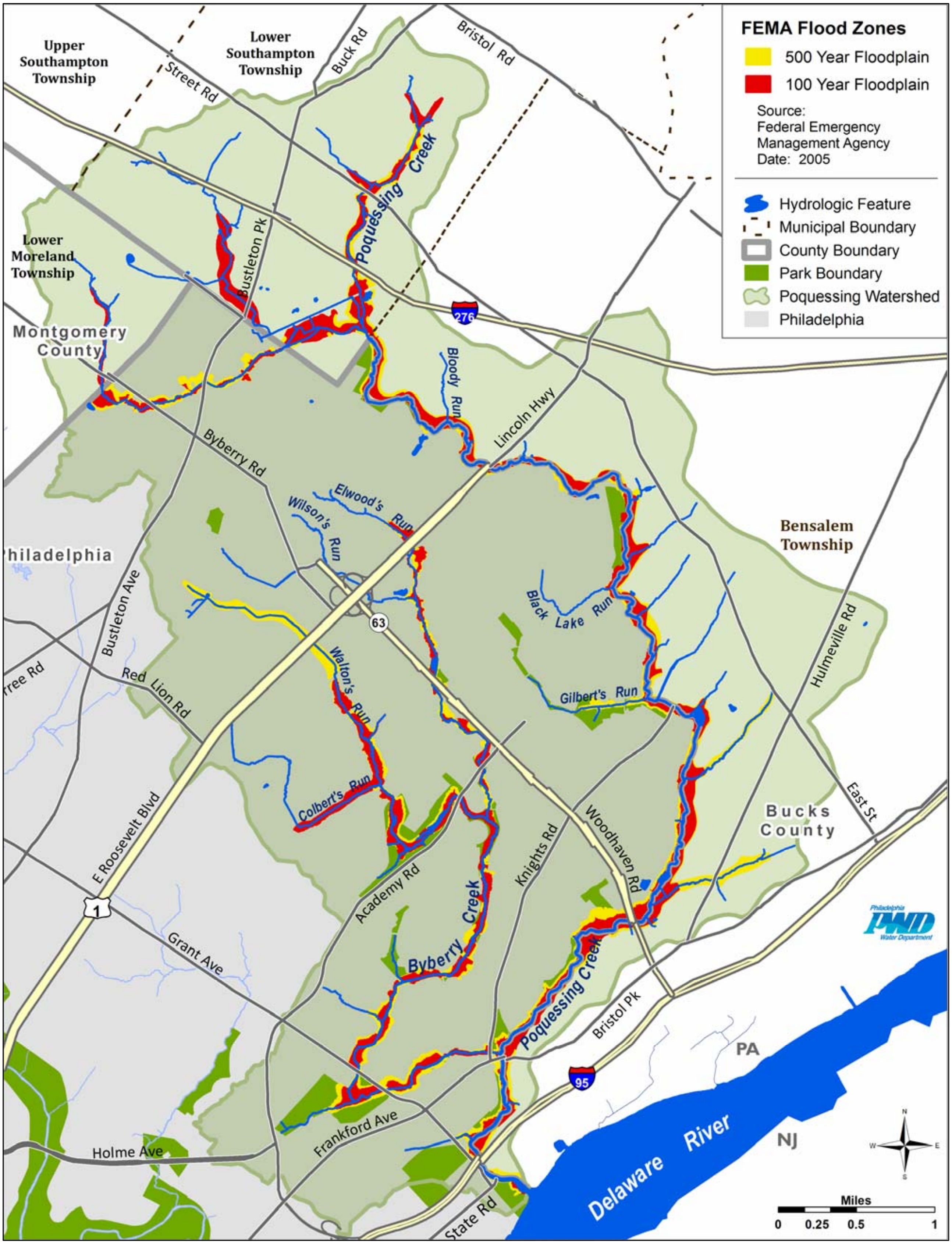
Figure 2.9 Poquessing Creek 303(d) List Stream Segments Not Attaining Designated Uses with Cause(s) of Impairment

2.7.1. TMDLS

The Pennsylvania Integrated Water Quality Monitoring and Assessment Report list of watersheds needing TMDLs includes additional segments of the Poquessing mainstem and tributaries. These segments are targeted for TMDL development in 2015 and 2019, though the PADEP has not committed to an implementation schedule for the remaining portion of the watershed.

2.8 FLOODING IN THE POQUESSING WATERSHED

As previously noted, considerable development and suburbanization within the Poquessing Creek Watershed has led to a number of problems; perhaps the most identifiable to residents is the increased incidence and severity of flooding. The frequency of flooding in the watershed has continued to increase as suburban development has sprawled within the upstream portions of the watershed. Within this watershed, the prevalence of development in the floodplain is problematic. Much of the development occurred prior to the enactment of municipal floodplain management ordinances. A few residential and commercial areas are located in or near floodplains in the upper portions of Poquessing Creek (Figure 2.10), but generally floodplains of the mainstem Poquessing Creek and Byberry Creek and its tributaries downstream are located in primarily wooded areas. Flooding will be the major focus of the Poquessing Creek Watershed Act 167 study presently under development by the Philadelphia Water Department.



Source:
Federal Emergency Management Agency
Date: 2005

Figure 2.10 Floodplains of the Poquessing Creek Watershed

2.9 FEDERAL MS4 AND NPDES PHASE II STORMWATER REGULATIONS

Federal regulations enacted in December 1999 required municipalities in urbanized areas to implement a five-year stormwater management program beginning in March 2003. (40 CFR §§ 122.26 – 123.35). These regulations, called National Pollution Discharge Elimination System (NPDES) Phase II Stormwater Regulations, apply to municipal separate storm sewer systems (MS4s) and mandate that MS4s adopt certain local legal requirements through an ordinance or other regulatory mechanism. The Phase II regulation requires NPDES permit coverage (mostly general permits) for stormwater discharges from most small urbanized areas (small MS4s) and construction activities that disturb from 1 to 5 acres of land.

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

These are:

1. Public Education and Outreach: Distributing educational materials and performing outreach to inform citizens about the impacts polluted stormwater runoff discharges can have on water quality.
2. Public Participation and Involvement: Providing opportunities for citizens to participate in program development and implementation, including effectively publicizing public hearings and/or encouraging citizen representatives to be part of a stormwater management panel.
3. Illicit Discharge Detection and Elimination: Developing and implementing a plan to detect and eliminate illicit discharges to the storm sewer system. Includes the development of a system map as well as informing the community about hazards associated with illegal discharges and improper waste disposal.
4. Construction Site Runoff Control: Developing, implementing, and enforcing an erosion and sediment control program for construction activities that disturb one or more acres of land. (Controls could include, for example, silt fences and temporary stormwater detention ponds.) Many communities choose to regulate smaller construction sites at the local level.
5. Post-Construction Runoff Control: Developing, implementing, and enforcing a program to address discharges of post-construction stormwater runoff from new development and redevelopment areas. Applicable controls could include preventative actions such as protecting sensitive areas (*e.g.*, wetlands) or the use of structural BMPs such as grassed swales or porous pavement.
6. Pollution Prevention/Good Housekeeping: Developing and implementing a program with the goal of preventing or reducing pollutant runoff from municipal operations. The program must include municipal staff training on pollution prevention measures and techniques (*e.g.*, regular street sweeping, reduction in the use of pesticides or street salt, and frequent catch-basin cleaning).

Since 2003, all Bucks and Montgomery County municipalities within the Poquessing Creek Watershed have been required to fulfill NPDES Phase II regulations and to adopt a stormwater ordinance, described in Section 2.11.

2.10 PENNSYLVANIA ACT 167 STORMWATER MANAGEMENT PLANNING

Recognizing the adverse effects of excessive stormwater runoff resulting from development, the Pennsylvania General Assembly approved the Stormwater Management Act, P.L. 864, No. 167 on October 4, 1978. Act 167 provides for the regulation of land and water use for flood control and stormwater management purposes. It imposes duties, confers powers to the Department of Environmental Protection (DEP), municipalities and counties, and provides for enforcement and appropriations. The Act requires the DEP to designate watersheds, develop guidelines for stormwater management, and model stormwater ordinances. The designated watersheds were approved by the Environmental Quality Board July 15, 1980, and the guidelines and model ordinances were approved by the legislature May 14, 1985. Pennsylvania's Stormwater Management Act (Act 167) of 1978 is administered by Pennsylvania Department of Environmental Protection (PADEP) and is designed to address the inadequate management of accelerated stormwater runoff resulting from development.

The Act requires Pennsylvania counties, in consultation with their municipalities, to prepare and adopt a stormwater management plan for each designated watershed. The plans are to provide for uniform technical standards and criteria throughout a watershed for the management of stormwater runoff from new land development and redevelopment sites. The county must review and revise such plans at least every five years when funding is available. Within six months of adoption and approval of a watershed stormwater plan, each municipality is required to adopt or amend stormwater ordinances as laid out in the plan. These ordinances must regulate development within the municipality in a manner consistent with the watershed stormwater plan and the provisions of the Act. Developers are required to manage the quantity, velocity, and direction of resulting stormwater runoff in a manner that adequately protects health and property from possible injury. They must implement control measures that are consistent with the provisions of the watershed plan and the Act. The Act also provides for civil remedies for those aggrieved by inadequate management of accelerated stormwater runoff.

This Act recognizes the interrelationship between land development, accelerated runoff, and floodplain management. An Act 167 plan must address a wide range of hydrologic impacts that result from land development on a watershed basis, and it must include such considerations as tributary timing, flow volume reduction, baseflow augmentation, water quality control, and ecological protection. Watershed runoff modeling is usually a critical component of the study, with modeled hydrologic responses to 2, 5, 10, 25, 50, and 100-year storms.

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

In fall 2009, PWD, in partnership with the Bucks County Planning Commission (BCPC), initiated an Act 167 Stormwater Management Plan for the Poquessing Creek Watershed. A Watershed Protection Advisory Committee (WPAC) was formed to provide a forum for municipalities and watershed stakeholders to participate in the planning process. At the conclusion of this planning process, municipalities of the Poquessing Creek Watershed will not only be presented with an updated stormwater ordinance, but also recommendations for BMP retrofits and installation locations specifically identified through this planning process.

2.11 EXISTING MUNICIPAL ORDINANCES

Many municipalities of the Poquessing Creek Watershed experienced extensive land development prior to the initiation of stormwater management controls required by the Pennsylvania Stormwater Management Act of 1978 (Act 167). Problems associated with years of increasing impervious cover and uncontrolled stormwater have been further exacerbated as additional development has taken place, especially in the headwater stream drainage areas, leading to increased flooding and other water quality and quantity issues for the Poquessing Creek and its tributaries. Ordinances and regulations have been passed in order to help reduce the impact of future development, but action is still needed to address the stormwater management of existing development.

2.11.1 CITY OF PHILADELPHIA ORDINANCES

2.11.1.1 §14-1603.1: STORMWATER MANAGEMENT CONTROLS

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

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

2.11.1.2 §14-1606: FLOODPLAIN CONTROLS

In the late 1970s, the City of Philadelphia City Council identified development along local rivers and streams as the cause of increased flooding within Philadelphia. To prevent further disruption of the floodplain and protect the health and safety of citizens and properties, City Council passed ordinance §14-1606 in 1979, which restricts and regulates development along rivers and creeks subject to flooding. The ordinance specifically targets the 100-year floodplain of all surface waters within Philadelphia, including the Poquessing Creek. The 100-year floodplain boundaries are based on the Flood Insurance Study by the United States Department of Housing and Urban Development, Federal Insurance Administration dated December 1978 (Figure 2.10).

Ordinance §14-1606 stipulates that no fill, new construction, or development is to take place within the 100-year floodplain, except for public utility projects that have shown no increase in 100-year flood levels. The ordinance also prohibits the storage of radioactive substances, industrial acids, pesticides, and additional chemicals detailed in §14-1606.5.a.3. The development of new structures or additions to existing structures of the following usage are prohibited within the 100-year floodplain: medical and surgical hospitals and medical centers, sanitaria; rest, old age, nursing or convalescent homes and nurseries; penal and correctional institutions; and mobile homes.

Within the areas immediately bordering the 100-year floodplain, called the floodway fringe, the ordinance permits development in accordance with the City of Philadelphia Zoning Code but mandates additional protections. Within the floodway fringe, the first floor of residences, including basements and cellars, must be one foot above the 100-year flood elevation. Non-residential structures must also be flood-proofed no less than one foot above the 100-year flood elevation. The ordinance also regulates the fill required to raise residential and non-residential structures. Lastly, the list of substances prohibited from being stored in the 100-year floodplain will be permitted to be stored in the floodway fringe only if the storage structure is flood-proofed up to one and a half feet above the 100-year flood elevation.

2.11.2 BUCKS COUNTY AND MONTGOMERY COUNTY ORDINANCES

2.11.2.2 STORMWATER MANAGEMENT ORDINANCES

Stormwater management is critical to reduce the flooding and erosion that is common throughout the Poquessing Creek Watershed. A comprehensive stormwater management ordinance controls erosion and sedimentation from construction sites, sets allowable post-development runoff to pre-development conditions, includes water quality and quantity requirements, and includes peak rate stormwater detention specifications. The PADEP Bureau of Watershed Protection has developed the Pennsylvania Model Stormwater Management Ordinance as a guide for municipalities interested in updating or enacting new stormwater management protections. The Pennsylvania Model Stormwater Management Ordinance can be found at www.depweb.state.pa.us under Water-Watershed Management-Topic-Stormwater Management-Announcements. A detailed description of stormwater management ordinances that govern the Bucks and Montgomery County portions of the Poquessing Creek Watershed will be included in the Poquessing Creek Watershed Act 167 Study.

2.11.2.1 FLOODPLAIN ORDINANCES

In both Bucks and Montgomery counties, all of the municipalities within the Poquessing Creek Watershed have floodplain protection ordinances that regulate development in these critical areas. The ordinances in these municipalities control and limit the types and extent of development within the 100-year floodplains, as delineated by FEMA. The floodplain boundaries recognized by FEMA are expected to change in these municipalities, as explained in Section 2.4.1, expanding the area of land protected by these ordinances. A detailed description of the floodplain ordinances that govern the Bucks and Montgomery County portions of the Poquessing Creek Watershed will be included in the Poquessing Creek Watershed Act 167 Study.

2.12 PENNSYLVANIA ACT 537 SEWAGE FACILITY MANAGEMENT

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

The main purpose of the plan is to correct existing sewage disposal problems, including malfunctioning on-lot septic systems, overloaded treatment plants or sewer lines, and improper sewer connections. The program is also designed to prevent future sewer problems and to protect groundwater and surface water quality.

Official plans contain comprehensive information, including:

- Planning objectives and needs
- Physical description of planning area
- Evaluation of existing wastewater treatment and conveyance systems
- Evaluation of wastewater treatment needs

Presently, all of the municipalities in the watershed have adopted an Act 537 plan; however, some plans are older than others and each vary in the level of detail (Figure 2.11). Bensalem and Lower Southampton Act 537 plans have not been updated since 1971, while the City of Philadelphia's Act 537 plan dates to 1993. Lower Moreland Township produced an Act 537 plan in 2007, making it the most up-to-date in the Poquessing Creek Watershed.

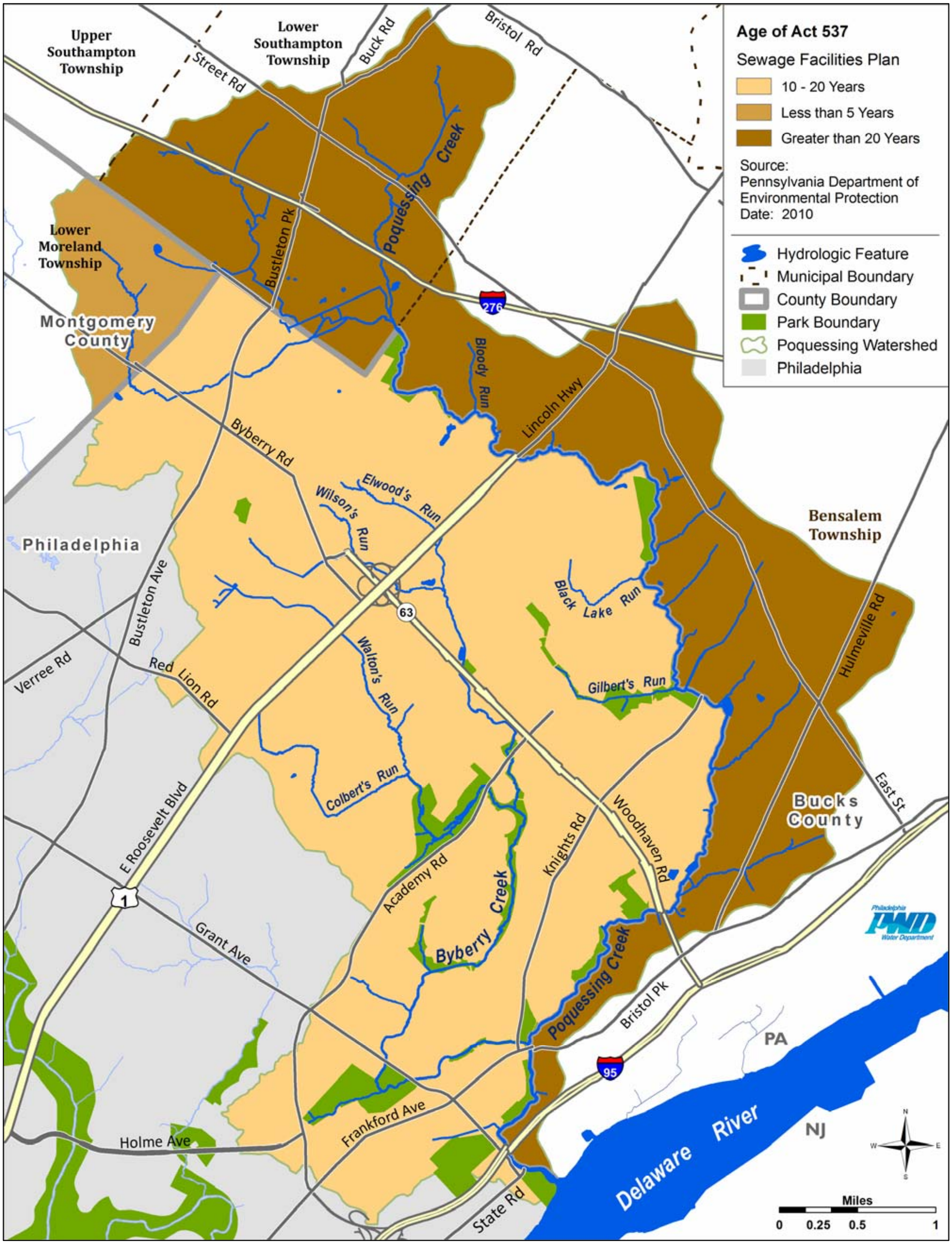


Figure 2.11 Age of Act 537 Municipal Sewage Facilities Plans

3 CHARACTERIZATION OF WATERSHED HYDROLOGY

This section examines the components of the hydrologic cycle for the Poquessing Creek Watershed.

3.1 COMPONENTS OF THE URBAN HYDROLOGIC CYCLE

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

For the purposes of this analysis, the water resources system is defined as flow in Poquessing Creek itself, the surface drainage area contributing flow to the creek, groundwater shallow enough to communicate with the creek, and manmade piping systems within the topographic watershed boundary. The system inflows and outflows can be split into a number of components. These are shown below as a simple, "input equals output" water balance with the many natural and anthropogenic components of a typical urban water cycle.

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

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

where:

P is the average precipitation recorded at the Philadelphia gages,

OPW is the outside potable water brought in,

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

EDR is the estimated domestic recharge from private septic systems,

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

RO is the surface water runoff component of precipitation,

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

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

EDW is the estimated domestic withdrawal of groundwater from private wells,

BF is the median baseflow of streams,

OWD is the discharge of wastewater to plants outside the watershed, and

ET is the evaporation and transpiration of water and is used to close the equation. It thus contains the sum of errors of the other terms as well as the estimated ET value.

3.1.1 PRECIPITATION

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

Precipitation data can be obtained from PWD's network of 24 rain gages throughout the City. This data is available in 15-minute increments from the early 1990s to the present. Three of the City gages are located in or near the Poquessing Creek Watershed, as shown in Figure 3.1. These gages provide precipitation data at a high level of spatial and temporal detail within the City of Philadelphia. Monthly and yearly summaries of rain gage data are located in Tables 3.1 and 3.2, respectively.

Table 3.1 Monthly Summary of Philadelphia Rain Gage Data (1990 – 2009)

Month	Rain Gage			Average
	4	20	24	
	(in)	(in)	(in)	(in)
January	3.04	3.15	2.84	3.01
February	2.09	2.05	1.90	2.01
March	3.86	3.74	3.70	3.77
April	3.65	3.66	3.40	3.57
May	3.46	3.51	3.34	3.44
June	3.82	4.06	3.94	3.94
July	4.35	4.46	3.95	4.25
August	3.47	3.96	3.87	3.77
September	4.02	4.25	4.14	4.13
October	3.35	3.51	3.50	3.45
November	2.83	3.03	2.84	2.90
December	3.77	3.90	3.68	3.78

Table 3.2 Yearly Summary of Philadelphia Rain Gage Data (1990 – 2009)

Year	Rain Gage			Average
	4	20	24	
	(in)	(in)	(in)	(in)
1990	41.41	38.67	38.12	39.40
1991	47.72	45.61	41.42	44.92
1992	46.75	40.27	38.63	41.88
1993	37.19	55.83	44.80	45.94
1994	43.84	48.73	42.48	45.02
1995	35.41	34.92	31.35	33.89
1996	55.20	58.56	53.12	55.62
1997	32.06	35.61	32.27	33.32
1998	34.89	34.49	31.36	33.58
1999	43.48	43.86	39.61	42.31
2000	40.27	45.25	40.37	41.96
2001	30.66	31.92	33.23	31.94
2002	35.67	38.18	35.71	36.52
2003	40.89	38.60	42.70	40.73
2004	44.99	43.49	46.72	45.07
2005	43.42	46.44	42.05	43.97
2006	45.65	49.84	56.07	50.52
2007	46.25	42.56	45.03	44.61
2008	40.78	45.36	38.51	41.55
2009	47.53	47.54	48.27	47.78
Mean	41.70	43.29	41.09	42.03
Max	55.20	58.56	56.07	55.62
Min	30.66	31.92	31.35	31.94
N	20	20	20	20
Std. Dev.	6.06	6.96	6.76	6.06

Average temperatures during the winter months are above the freezing point during the day and below the freezing point at night (Table 3.3). Snow and snowmelt events occur, but it is rare for a snow pack to accumulate and last through the season.

Table 3.3 Average Monthly Temperature and Potential Evaporation

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

*estimated

Additional precipitation data is available in portions of the watershed outside the City of Philadelphia. This information was not collected for the current study. Neither the Philadelphia Airport nor the Wilmington Airport weather stations record evaporation data. A site in New Castle County, Delaware has recorded daily evaporation data from 1956 through 1994. Average daily evaporation rates from this site were developed and are listed in Table 3.3 (City of Philadelphia Combined Sewer Overflow Program: System Hydraulic Characterization).

Figure 3.1 City of Philadelphia Rain Gages In and Around Poquessing Creek Watershed

3.1.2 OUTSIDE POTABLE WATER

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

Raw water from outside the watershed is supplied from three sources (the Philadelphia Water Department, Bucks County Water and Sewer Authority Southwest, and Aqua PA).

The Philadelphia Water Department operates three water treatment plants: Queen Lane Water Treatment Plant (WTP), Baxter WTP, and Belmont WTP. The Queen Lane and Belmont WTPs service areas are outside of the Poquessing Creek Watershed. Baxter Water Treatment Plant, which draws water from the Delaware River, is the sole source of potable water in Philadelphia portion of Poquessing Creek Watershed (PCW).

Bucks County Water and Sewer Authority Southwest and Aqua PA both obtain their water from a variety of sources throughout the region, and no information could be found on exactly which source is used for their service areas that lie in the PCW. However, by using the PADEP State Water Plan "Water Use Data Download" online tool, it was determined that all the drinking water for the PCW suburban customers is water that is transported from outside the PCW (confirmed via personal correspondence with PADEP staff, 7/19/10).

Based on the estimated population of Philadelphia, Bucks and Montgomery County residents in the PCW (U.S. Census), an assumption that none of those residents obtain drinking water from private wells, and an average use per person of 133 gallons per day (DRBC, 2008), a quantity for outside potable water was calculated.

Table 3.4 Estimated outside potable water use in PCW, by county.

County	Population	Estimated potable water use (MGY)
Philadelphia	76,896	3735
Bucks	24,549	1193
Montgomery	1862	90

3.1.3 WASTEWATER AND INDUSTRIAL RECHARGE TO GROUNDWATER

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

No information could be found on wastewater or industrial recharge into the groundwater within the Poquessing Creek Watershed; if any recharge is occurring it is likely to be insignificant compared with other water budget components.

3.1.4 ESTIMATED DOMESTIC RECHARGE

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

No information could be found on domestic recharge into the groundwater within the Poquessing Creek Watershed; if any recharge is occurring it is likely to be insignificant compared with other water budget components.

3.1.5 WASTEWATER DISCHARGES TO THE STREAM

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

This component represents water that has been used in homes or industry, has been treated, and is subsequently discharged back into the stream, thus making it an inflow component. The Poquessing Creek Watershed does not contain any publicly owned wastewater treatment plants.

3.1.6 RUNOFF

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

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

Baseflow separation was carried out following procedures similar to those found in the USGS "HYSEP" program (Sloto and Crouse, 1996). This baseflow separation technique uses an empirically defined relationship between drainage area and duration of surface runoff to aid in determining groundwater baseflow. The following excerpt explains this method:

> The duration of surface runoff is calculated from the empirical relation:
>
> $$N=A^{0.2}$$
>
> where N is the number of days after which surface runoff ceases, and A is the drainage area in square miles (Linsley and others, 1982, p. 210).
>
> The interval 2N* used for hydrograph separations is the odd integer between 3 and 11 nearest to 2N (Pettyjohn and Henning, 1979, p. 31). For example, the drainage area at the streamflow-measurement station French Creek near Phoenixville, Pa. (USGS station number 01472157), is 59.1 mi^2. The interval 2N* is equal to 5, which is the nearest odd integer to 2N, where N is equal to 2.26. The N and 2N* values used for the four gages in this analysis were listed in Table 3.5.
>
> The hydrograph separation begins one interval (2N* days) prior to the start of the date selected for the start of the separation and ends one interval (2N* days) after the end of the selected date to improve accuracy at the beginning and end of the separation. If the selected beginning and (or) ending date coincides with the start and (or) end of the period of record, then the start of the separation coincides with the start of the period of record, and (or) the end of the separation coincides with the end of the period of record.
>
> The sliding-interval method finds the lowest discharge in one half the interval minus 1 day [0.5(2N*-1) days] before and after the day being considered and assigns it to that day. The method can be visualized as moving a bar 2N* wide upward until it intersects the hydrograph. The discharge at that point is assigned to the median day in the interval. The bar then slides over to the next day, and the process is repeated.

Summary Statistics

During the USGS/PWD cooperative program in the 1960s-1970s, the USGS established streamflow gaging stations at five locations in Poquessing Creek Watershed. These locations are presented in Figure 3.2. Table 3.5 contains summary information at each of the gaging stations for their respective periods of record.

Table 3.5 USGS Gages and Periods of Record and Data Used for Baseflow Separation

Gage	Name	Period of Record	Period of Record (yrs)	Drainage Area (sq. mi.)	N (days)	2N* (days)
01465798	Poquessing Creek at Grant Avenue, Philadelphia, PA	7/1/1965 to Present	45	21.4	1.85	3
01465780	Poquessing Creek above Byberry Creek, Philadelphia, PA	7/1/1964 to 12/15/1970	6	13.2	1.68	3
01465790	Byberry Creek at Chalfont Road, Philadelphia, PA	6/1/1965 to 10/19/1978	13	5.34	1.40	3
01465785	Walton Run at Philadelphia, PA	6/1/1964 to 10/19/1978	14	2.17	1.17	3
01465770	Poquessing Creek at Trevose Road, Philadelphia, PA	6/1/1964 to 10/9/1981	17	5.08	1.38	3

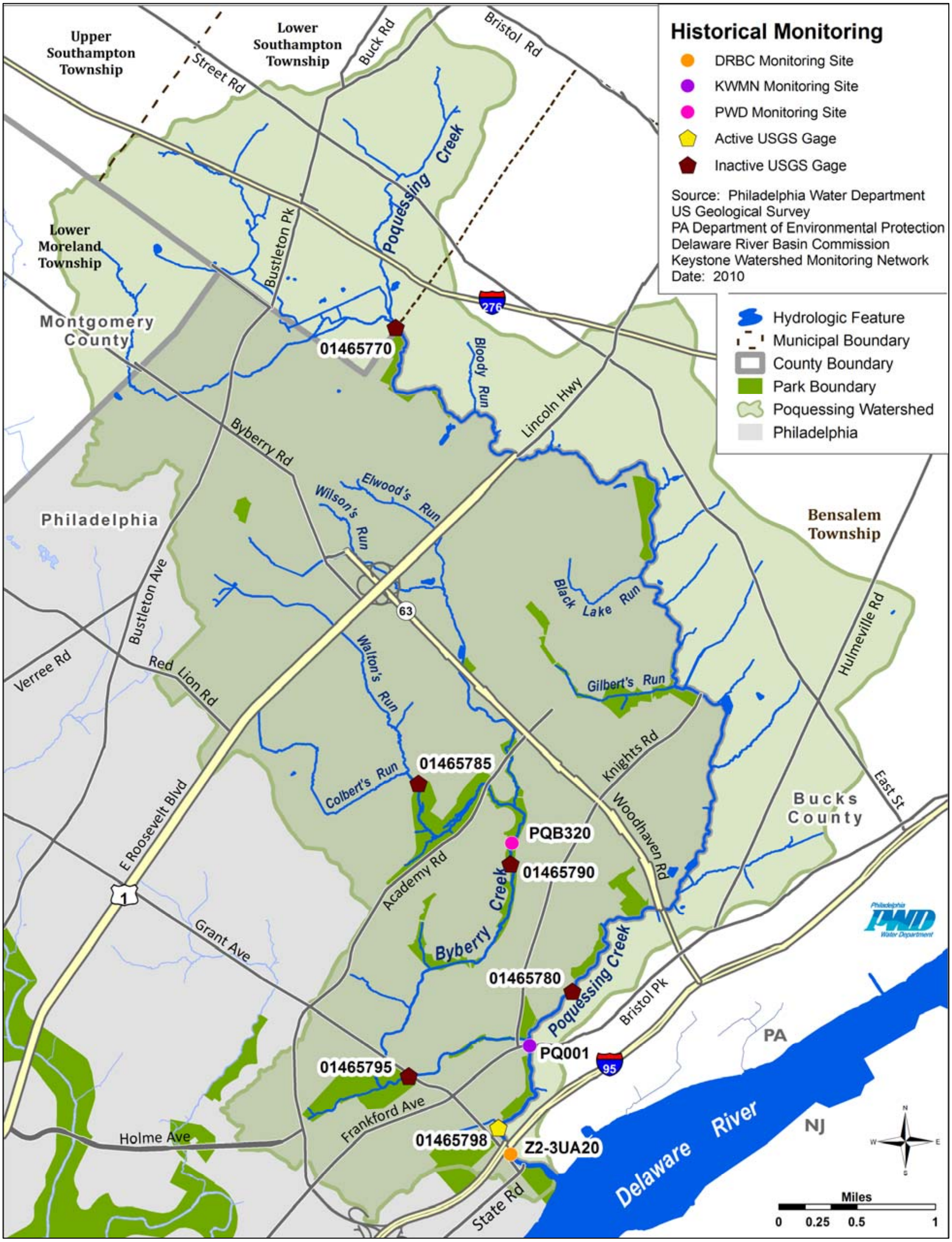
The interval 2N* used for hydrograph separations is the odd integer between 3 and 11 nearest to 2N. N is calculated based on watershed area.

At gage 01465798, a backwater effect can occur when Delaware River tides surpass 3.7 feet above Mean Sea Level. USGS adjusts daily discharge data for any tidal influence before approving the data. All daily discharge data at this gage that were utilized for the hydrograph decomposition were approved data, with the exception of the last 3 months of calendar year 2009, which is still considered preliminary data at the time of this report.

The results of the hydrograph decomposition exercise are summarized in Tables 3.6 and 3.7.

Table 3.6 Runoff Statistics For Poquessing Creek Watershed USGS Gages Compared to Other Area Streams.

Gage	Runoff (in/yr)			
	Mean	Max	Min	St.Dev.
01465798 Poquessing Creek at Grant Avenue	13.13	22.11	7.54	3.82
01465780 Poquessing Creek above Byberry Creek	8.36	12.69	4.49	2.83
01465790 Byberry Creek at Chalfont Road	13.40	22.44	7.82	4.46
01465785 Walton Run	14.43	23.95	6.16	5.10
01465770 Poquessing Creek at Trevose Road	10.69	17.84	4.32	3.95
01467048 Pennypack Creek at Lower Rhawn	12.71	22.01	6.88	3.93
01467045 Pennypack Creek at Verree Road	7.41	11.45	3.98	2.69
01467042 Pennypack Creek at Pine Road	10.42	19.24	4.00	3.89
01474000 Wissahickon Creek at Mouth, Philadelphia	10.40	22.30	5.10	3.90
014752157 French Creek near Phoenixville	7.40	15.40	2.90	3.10
01475550 Cobbs Creek at Darby, PA	10.70	15.60	5.20	2.70
01475510 Darby Creek near Darby, PA	8.90	15.60	3.60	2.90
01467087 Frankford Creek at Castor Avenue	11.40	20.30	6.20	3.50



Source: Philadelphia Water Department
US Geological Survey
PA Department of Environmental Protection
Delaware River Basin Commission
Keystone Watershed Monitoring Network
Date: 2010

Figure 3.2 USGS Gages and Other Historical Monitoring Locations

The results of the hydrograph decomposition exercise suggest differences in the degree of urbanization for watersheds in southeastern Pennsylvania. The flows in Table 3.6 are expressed as the mean of annual volumes divided by drainage area. Table 3.6 shows stream flow statistics for French Creek as representative of a minimally impaired stream. On a unit-area basis, runoff in Poquessing Creek Watershed is the highest in the Philadelphia area.

Expressing runoff as a percent of total measured flow provides an estimate of the degree to which the watershed is developed. Results from regional streams are on the order of 30%-40% for undeveloped and suburban watersheds (*e.g.*, French and Darby Creeks) and on the order of 60% for urban streams (Table 3.7). Results in Poquessing Creek Watershed range from 52%-68%, indicative of a highly urbanized stream. In addition, the high percent runoff values for gages that were only in operation in the 1960s-1970s illustrates that urbanization across the watershed has been present since at least that time period, particularly in the Byberry Creek subwatershed.

Table 3.7 Runoff as a Percentage of Annual Total Flow for Poquessing Creek Watershed USGS Gages Compared to Other Area Streams.

	Runoff (% of Annual Total Flow)			
	Mean	**Max**	**Min**	**St.Dev.**
01465798 Poquessing Creek at Grant Avenue	63%	76%	52%	6%
01465780 Poquessing Creek above Byberry Creek	57%	65%	49%	6%
01465790 Byberry Creek at Chalfont Road	60%	73%	51%	7%
01465785 Walton Run	68%	84%	57%	7%
01465770 Poquessing Creek at Trevose Road	52%	65%	43%	6%
01467048 Pennypack Creek at Lower Rhawn	57%	69%	46%	5%
01467045 Pennypack Creek at Verree Road	52%	59%	46%	5%
01467042 Pennypack Creek at Pine Road	49%	61%	38%	6%
01474000 Wissahickon Creek at Mouth, Philadelphia	61%	76%	51%	6%
01472157 French Creek near Phoenixville	36%	47%	25%	5%
01475550 Cobbs Creek at Darby, PA	58%	84%	46%	10%
01475510 Darby Creek near Darby, PA	38%	46%	25%	6%
01467087 Frankford Creek at Castor Avenue	62%	74%	51%	6%

Figure 3.3 provides some idea of trends in unit-area runoff from year to year. Although there is considerable variability between years, runoff flows at the five gages generally followed the same patterns when multiple gages were in operation.

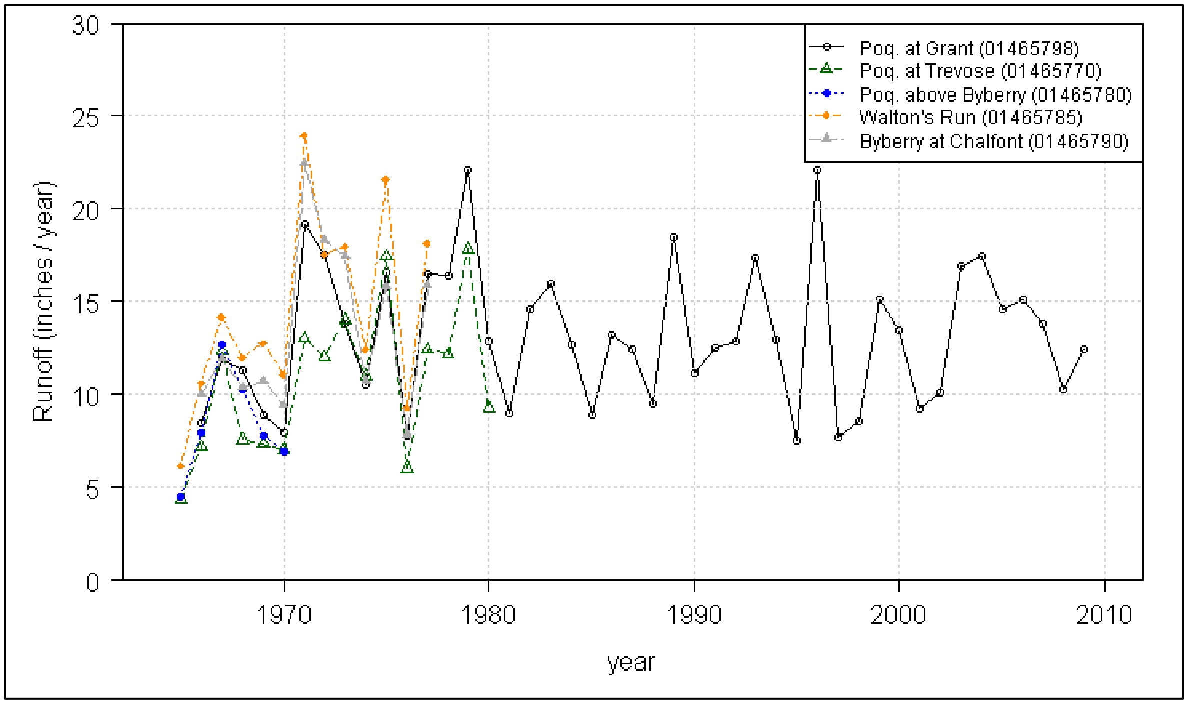


Figure 3.3 Runoff Trends at four USGS Stations in Poquessing Creek Watershed

The estimated stormwater runoff discharges by outfall within the City of Philadelphia are presented in Table 3.8. The period of record represented within Table 3.8 is 1902 to 2005.

Table 3.8 Philadelphia Stormwater Outfall Runoff

Outfall	Area (Acres)	Annual Flow (in/yr)
Q-101-03	163.7	11.12
Q-101-04	39.4	10.58
Q-101-05	78.5	12.64
Q-101-06	2.0	5.80
Q-101-07	28.3	8.81
Q-101-08	2.3	17.55
Q-101-09	221.5	8.25
Q-101-10	16.7	8.72
Q-101-11	57.3	4.99
Q-101-12	1.0	3.35
Q-101-13	5.4	14.72
Q-101-14	5.9	13.72
Q-101-15	3.5	16.03
Q-101-16	5.6	11.87
Q-101-17	24.4	15.35
Q-101-18	4.1	17.26
Q-101-19	17.8	9.59
Q-101-20	51.8	12.45
Q-102-01	14.6	13.37
Q-102-02	28.4	18.06
Q-102-03	27.2	16.29
Q-102-04	5.6	19.44
Q-102-05	6.8	6.02
Q-102-X	8.4	5.01
Q-106-03	44.8	12.73
Q-106-04	29.7	12.74
Q-106-05	31.2	8.99
Q-106-06	10.1	10.38
Q-101-03	163.7	11.12
Q-101-04	39.4	10.58
Q-101-05	78.5	12.64
Q-101-06	2.0	5.80
Q-106-07	4.0	9.25
Q-106-08	14.7	11.63
Q-106-09	8.4	14.87
Q-106-10	3.3	9.91
Q-106-11	5.1	11.48
Q-106-12	20.1	14.70
Q-106-13	19.9	13.63
Q-106-14	9.7	9.79
Q-106-15	0.7	506.65
Q-106-16	8.1	16.37
Q-106-17	7.1	16.39
Q-106-18	18.0	12.50
Q-106-19	5.1	7.66
Q-106-20	3.0	10.72
Q-106-21	75.0	12.98
Q-106-22	18.3	12.98
Q-107-01	15.1	11.02
Q-107-02	201.9	11.76
Q-107-03	5.9	14.38
Q-107-04	5.4	20.69
Q-107-05	30.5	9.47
Q-107-06	41.7	7.35
Q-107-07	32.2	15.30
Q-109-06	52.9	18.23
Q-109-07	237.0	10.03
Q-110-01	20.0	22.68
Q-110-02	39.0	7.24
Q-110-03	11.1	56.56
Q-110-04	21.6	11.56
Q-110-05	127.8	10.35
Q-110-06	47.4	11.62
Q-110-07	14.4	7.75
Q-110-08	10.3	12.60
Q-110-09	19.7	17.43
Q-110-10	7.6	14.14
Q-110-11	84.6	9.14
Q-110-12	5.5	17.50
Q-110-13	18.2	15.36
Q-110-14	37.1	13.71
Q-110-15	79.8	11.93
Q-110-16	25.4	12.76
Q-110-17	53.6	11.57
Q-110-18	14.5	9.26
Q-110-19	4.2	17.89
Q-110-20	42.8	12.89
Q-110-21	63.0	16.41
Q-113-09	132.1	9.53
Q-113-10	15.6	4.48
Q-113-11	10.8	18.22
Q-114-01	4.8	33.72
Q-114-02	3.3	283.69
Q-114-03	36.8	10.61
Q-114-04	15.2	38.85
Q-114-05	17.2	13.63
Q-114-06	50.3	10.68
Q-114-07	50.7	11.69
Q-114-08	22.8	8.53
Q-114-09	24.1	5.18
Q-114-10	26.3	13.43
Q-114-11	22.3	13.24
Q-114-12	48.4	12.47
Q-114-13	6.0	16.94
Q-114-14	4.1	11.90
Q-114-15	26.7	17.39
Q-114-16	14.5	24.12
Q-114-17	5.9	13.71
Q-114-18	17.2	38.32
Q-115-01	86.4	10.25
Q-115-02	15.6	13.55
Q-115-03	4.0	17.57
Q-115-04	16.2	12.16
Q-115-05	7.2	16.51
Q-115-06	11.0	11.56
Q-115-07	5.5	16.49
Q-115-08	27.5	2.09
Q-115-09	52.2	12.83
Q-115-10	16.2	15.23
Q-115-11	12.6	15.16
Q-115-12	116.0	12.55
Q-115-13	4.5	20.52
Q-115-14	11.2	16.94
Q-115-15	0.3	10.94
Q-115-16	3.4	10.81
Q-115-17	10.9	14.33
Q-115-18	7.8	17.36
Q-117-01	5.6	4.90
Q-117-02	222.2	9.45
Q-117-03	16.6	12.65
Q-117-04	135.9	8.88
Q-117-05	84.1	10.90
Q-118-01	16.3	29.33
Q-118-02	32.8	14.01
Q-118-03	34.0	13.61
Q-118-04	34.0	2.25
Q-118-05	6.2	31.13
Q-118-06	11.6	32.24
Q-118-07	13.0	18.28
Q-119-01	49.0	51.35
Q-120-01	6.8	5.08
Q-120-02	95.2	8.38
Q-120-03	35.7	15.86
Q-120-04	3.4	21.78
Q-120-05	28.8	5.45
Q-120-06	4.1	8.37
Q-120-07	2.7	21.70
Q-120-08	111.7	9.19
Q-120-09	5.7	14.84
Q-120-10	29.6	14.51
Q-120-11	70.1	12.50
Q-120-X	1.8	66.15
Q-120-Y	1.6	21.24
Q-120-Z	1.6	52.88
Q-121-01	50.3	7.71
Q-121-02	90.6	11.12
Q-121-03	4.4	8.52
Q-121-04	4.9	8.87
Q-121-05	48.3	10.66
Q-121-06	25.8	17.00

3.1.7 SURFACE WATER WITHDRAWALS

P + OPW + WW/IND Rech + EDR + WW Disch = RO + SWW+ GWW + EDW + BF + OWD + ET
There are no active surface water intakes located within the Poquessing Creek watershed (PADEP State Water Plan "Water Use Data Download" online tool).

3.1.8 GROUNDWATER WITHDRAWALS

P + OPW + WW/IND Rech + EDR + WW Disch = RO + SWW+ GWW + EDW + BF + OWD + ET
Only one groundwater withdrawal was located in the PCW via the PADEP State Water Plan "Water Use Data Download" online tool.

Table 3.9 Municipal Groundwater Withdrawals (PADEP State Water Plan "Water Use Data Download" online tool)

Names	Zip code	Million Gallons per Year Total	Average MGD
Bensalem Twp.	19020	1.2593	0.00345

Table 3.10 Summary of Groundwater Withdrawals

Category	Number of Withdrawals	Million Gallons per Year Total	Average MGD
Municipalities	1	1.2593	0.00345
Total	1	1.2593	0.00345

3.1.9 ESTIMATED DOMESTIC WITHDRAWALS

P + OPW + WW/IND Rech + EDR + WW Disch = RO + SWW+ GWW + EDW + BF + OWD + ET
No information could be found on domestic withdrawals from private wells in the PCW. If any domestic withdrawals are occurring it is likely to be insignificant compared with other water budget components.

3.1.10 BASEFLOW

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

The recharge and discharge areas of shallow groundwater systems generally correspond to the surface watershed area. This implies that infiltration entering the groundwater aquifer eventually flows to the surface to be discharged as stream baseflow. Given that infiltration is difficult to measure, infiltration was determined at stream gages through baseflow separation techniques on streamflow. The infiltration component is then directly balanced by the baseflow component if baseflow is assumed to equal infiltration.

Unit-area baseflow is greater at the upstream gage than at the downstream gage, but it is less than baseflow in French Creek and Darby Creek (Table 3.11). The Darby and Poquessing Creek Watersheds have a similar suburban character. Expressing baseflow as a percentage of total flow, the same pattern is evident (Table 3.12).

Table 3.11 Baseflow Statistics

	Baseflow (in/yr)			
	Mean	Max	Min	St.Dev.
01465798 Poquessing Creek at Grant Avenue	7.57	12.97	3.73	2.18
01465780 Poquessing Creek above Byberry Creek	6.16	8.62	4.13	1.69
01465790 Byberry Creek at Chalfont Road	8.53	12.43	5.84	2.20
01465785 Walton Run	6.61	9.36	3.38	1.72
01465770 Poquessing Creek at Trevose Road	9.61	13.95	5.71	2.94
01467048 Pennypack Creek at Lower Rhawn	9.88	18.21	4.42	3.46
01467045 Pennypack Creek at Verree Road	6.97	11.59	4.56	2.91
01467042 Pennypack Creek at Pine Road	10.79	17.79	4.57	4.28
01474000 Wissahickon Creek at Mouth, Philadelphia	6.90	12.90	2.20	2.70
01472157 French Creek near Phoenixville	12.90	20.80	5.80	3.80
01475550 Cobbs Creek at Darby, PA	8.10	16.10	1.80	3.60
01475510 Darby Creek near Darby, PA	14.50	21.40	7.60	4.00
01467087 Frankford Creek at Castor Avenue	7.10	13.00	4.50	2.20

Table 3.12 Baseflow Statistics as a Percentage of Total Flow

	Baseflow (% of Annual Total Flow)			
	Mean	Max	Min	St.Dev.
01465798 Poquessing Creek at Grant Avenue	37%	48%	24%	5%
01465780 Poquessing Creek above Byberry Creek	43%	48%	35%	5%
01465790 Byberry Creek at Chalfont Road	40%	49%	27%	7%
01465785 Walton Run	32%	43%	16%	7%
01465770 Poquessing Creek at Trevose Road	48%	57%	35%	6%
01467048 Pennypack Creek at Lower Rhawn	43%	54%	31%	5%
01467045 Pennypack Creek at Verree Road	48%	54%	41%	5%
01467042 Pennypack Creek at Pine Road	51%	62%	39%	6%
01474000 Wissahickon Creek at Mouth, Philadelphia	39%	49%	24%	6%
01472157 French Creek near Phoenixville	64%	75%	53%	5%
01475550 Cobbs Creek at Darby, PA	42%	54%	16%	10%
01475510 Darby Creek near Darby, PA	62%	75%	54%	6%
01467087 Frankford Creek at Castor Avenue	38%	49%	26%	6%

Although there was considerable interannual variation and the periods of record did not completely overlap, baseflows measured at the five gages generally followed the same patterns when multiple gages were in operation (Figure 3.4).

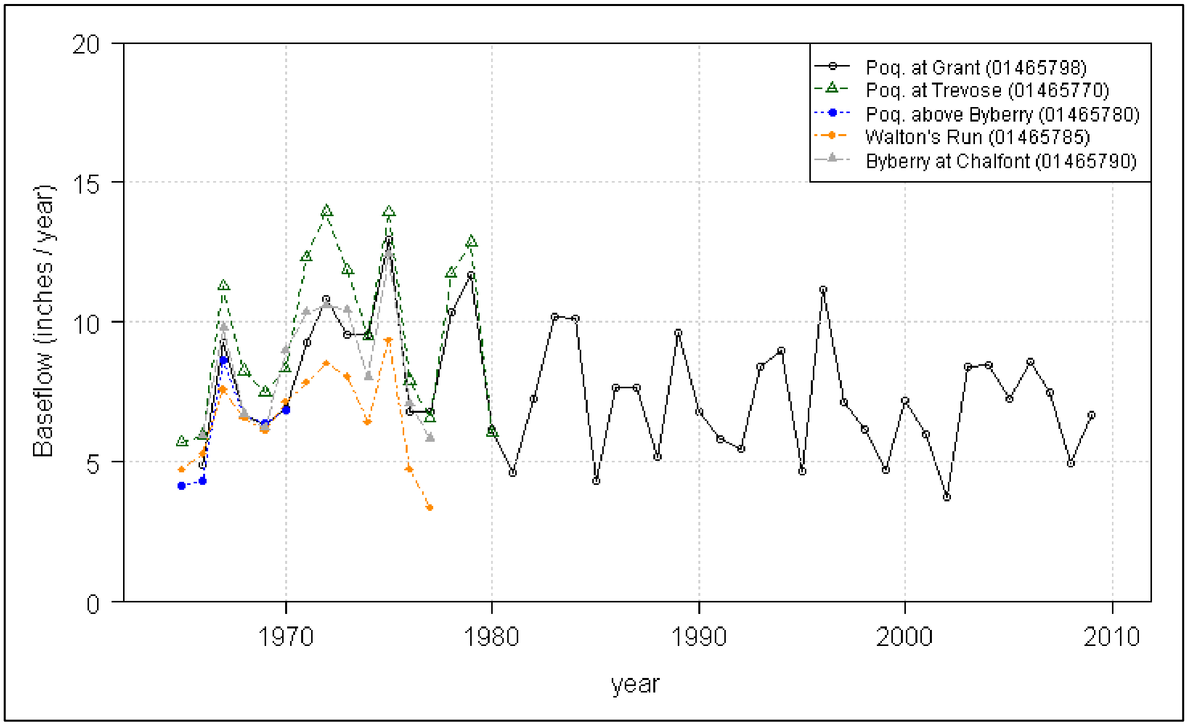


Figure 3.4 Baseflow Trends at Five USGS Gages in Poquessing Creek Watershed

Analysis of baseflow and runoff by month at the gage with the longest period of record (Poquessing Creek at Grant Avenue, 01465798) revealed a seasonal pattern. Baseflow is greatest in February-May and least in July-October, both in terms of magnitude and as a fraction of runoff (Figure 3.5).

At the farthest upstream Poquessing Creek gage (Trevose Road, 01465770), a similar pattern of seasonality was observed, with February-May as the months of strongest baseflow, and July-October as the months of weakest baseflow. Note that at this location, baseflow and runoff were much more balanced than at the most downstream gage; in February-May baseflow was even greater than runoff (Figure 3.6).

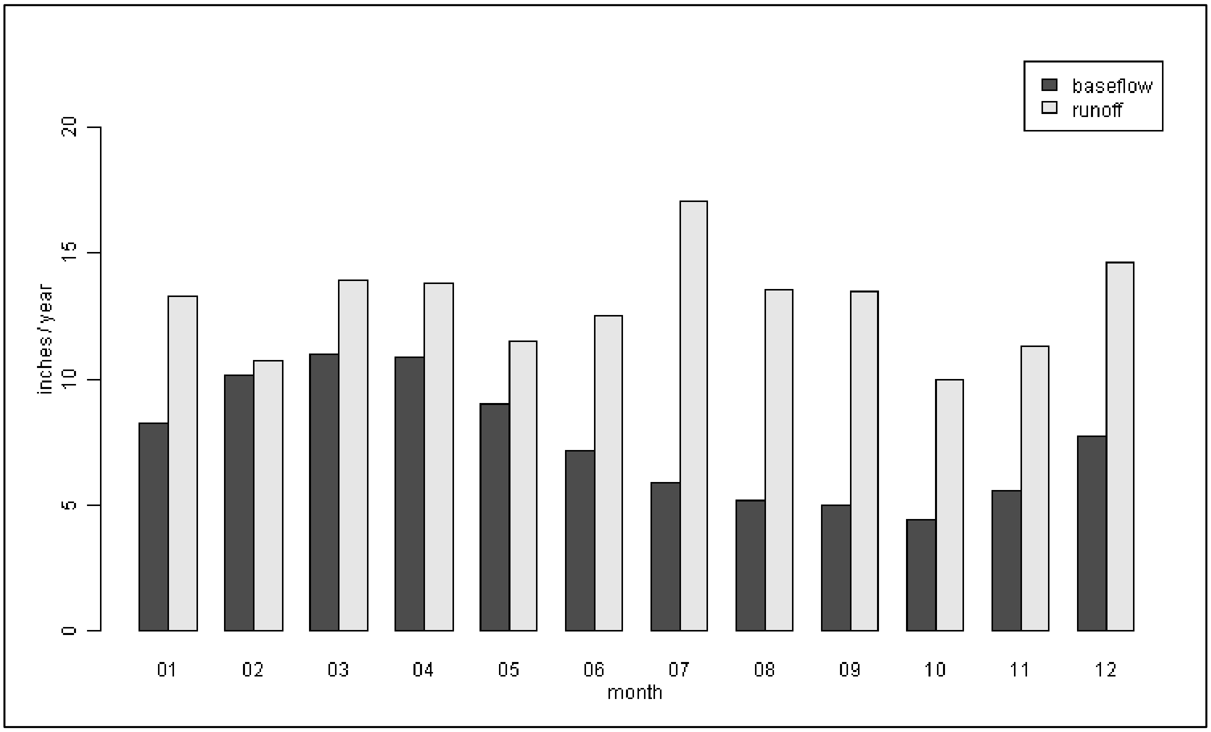


Figure 3.5 Monthly Distribution of Baseflow and Runoff at Poquessing Creek at Grant Avenue (01465798).

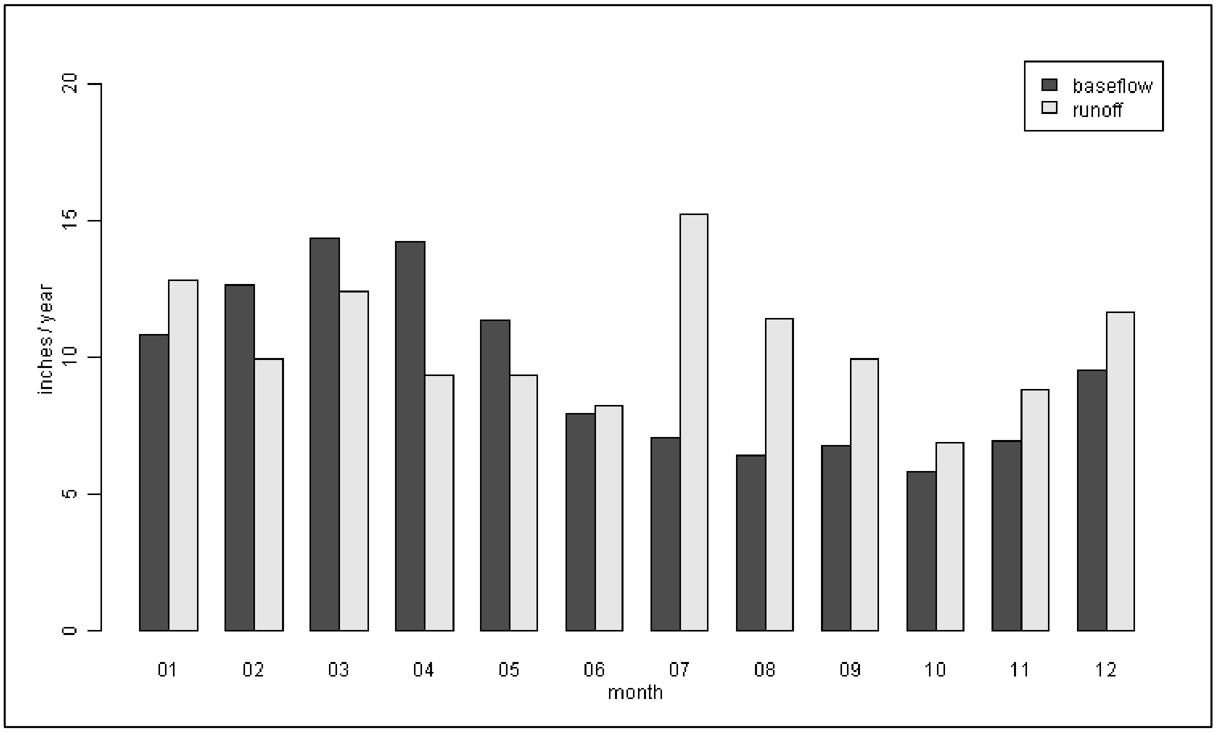


Figure 3.6 Monthly Distribution of Baseflow and Runoff at Poquessing Creek at Trevose Road (01465770).

3.1.11 OUTSIDE WASTEWATER DISCHARGES

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

Wastewater in the City of Philadelphia and the Bucks and Montgomery County portions of the PCW is exported to PWD's Northeast Water Pollution Control Plant. According to the 2000 U.S. Census, the population of Philadelphia, Bucks and Montgomery County within the PCW was 103,307. Assuming 100GPD per person (Great Lakes-Upper Mississippi Board of State and Provincial Public Health and Environmental Managers, 2004), it was estimated that within the Poquessing Creek watershed, a daily flow of 10.3 MGD of wastewater is exported to the Northeast Water Pollution Control Plant.

3.1.12 EVAPOTRANSPIRATION

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

One of the largest "outflows" of water from the system is evaporation and transpiration. Evapotranspiration includes evaporation, or loss of water to the atmosphere as water vapor, and transpiration, or loss of water to the atmosphere through plants. Evapotranspiration rates depend on temperature, wind speed, solar radiation, type of surface, type and abundance of plants species, and the growing season. Because of these factors, estimated evapotranspiration rates for the Philadelphia region vary seasonally. Neither the Philadelphia Airport nor the Wilmington Airport records evaporation data. A site in New Castle County, Delaware has recorded daily evaporation data from 1956 through 1994. Average daily evaporation rates from this site were developed and are listed in Table 3.3 (City of Philadelphia Combined Sewer Overflow Program: System Hydraulic Characterization).

3.2 POQUESSING CREEK WATER CYCLE SUMMARY

This section summarizes key components of watershed hydrology used as a basis for pollutant load estimates and as a baseline for evaluation of stormwater management practices.

Table 3.13 Average Annual Streamflow Components

Components of Streamflow	Poq. at Grant Ave.	Poq. above Byberry	Byberry at Chalfont	Walton Run	Poq. at Trevose Rd.
Drainage Area (sq.mi.)	21.4	13.2	5.34	2.17	5.08
Runoff (in/yr)	13.13	8.36	13.40	14.43	10.69
Baseflow (Groundwater) (in/yr)	7.57	6.16	8.53	6.61	9.61

3.2.1 ADDITIONAL ANALYSIS OF TOTAL FLOW

Figure 3.7 provides some idea of trends in unit area total flow from year to year. Although there is considerable variability between years, flows at the five gages followed the same patterns when multiple gages were in operation.

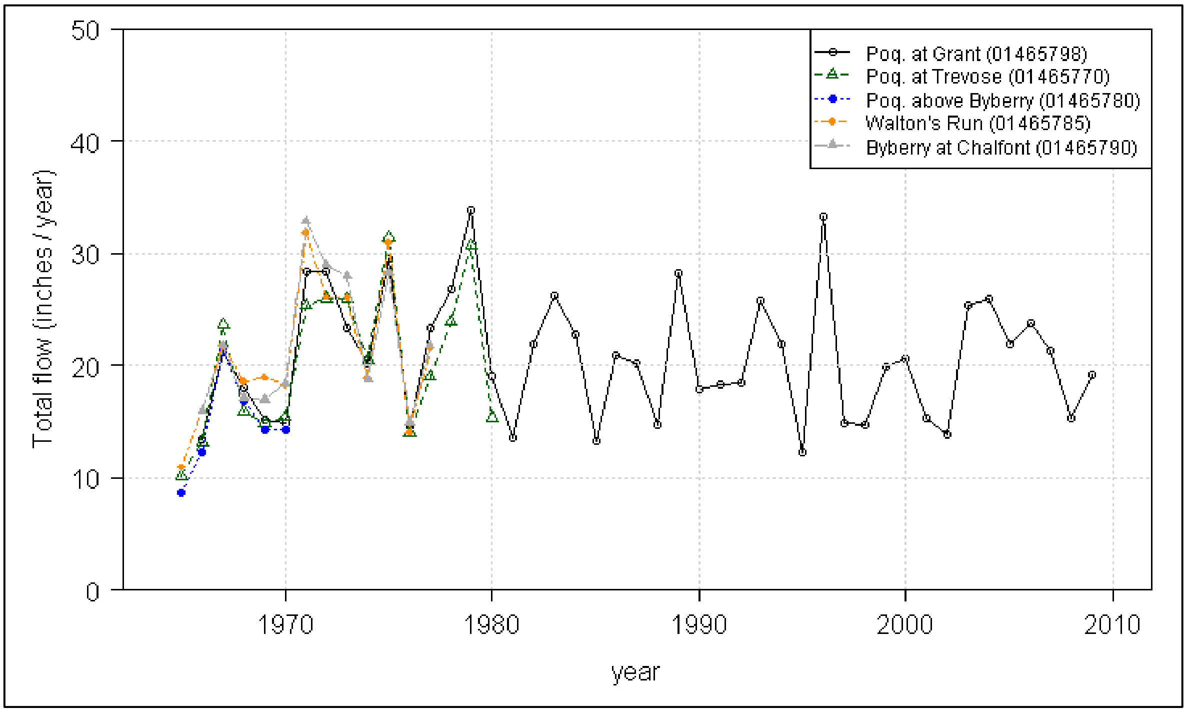


Figure 3.7 Unit Area Total Streamflow Trends at Five USGS Gages in Poquessing Creek Watershed

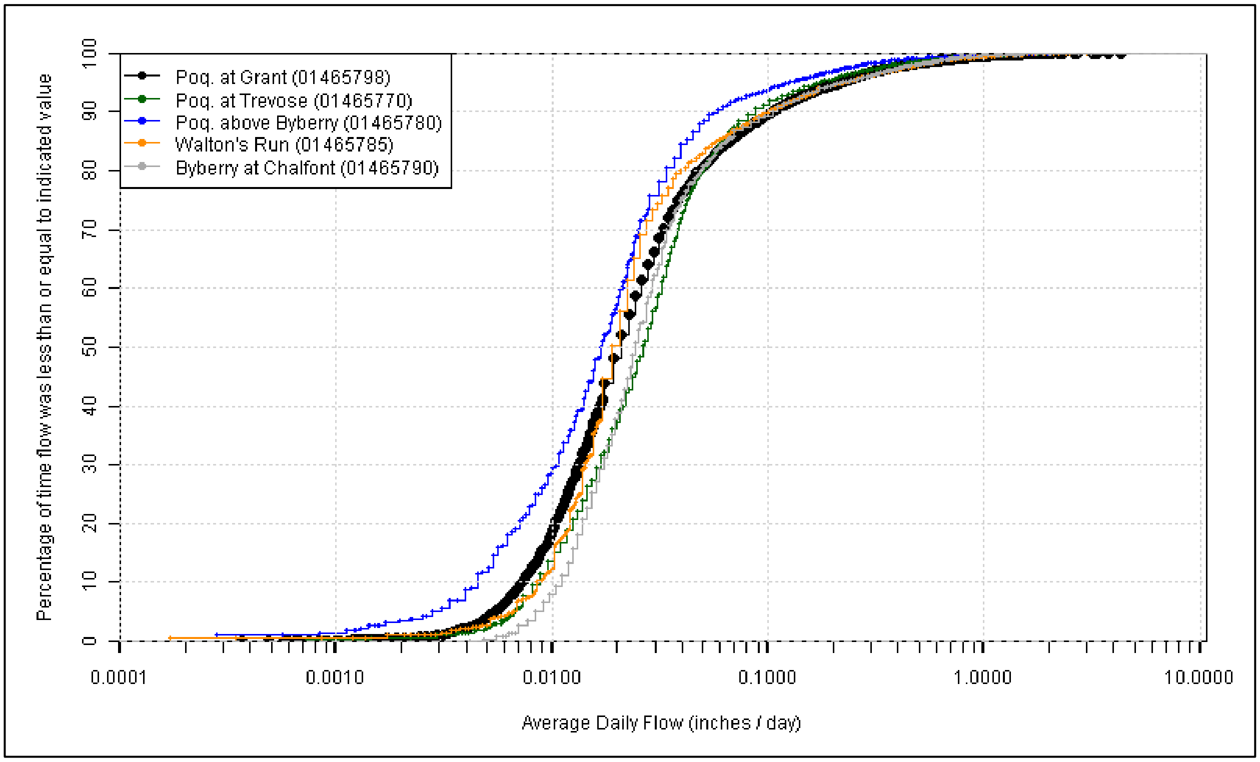


Figure 3.8 Cumulative Distribution of Unit Area Average Daily Flow

Cumulative Distribution

The cumulative distribution of unit area average daily flow, measured in inches/day, shows the percent of daily flow observations (vertical axis) that are equal to or less than a given value (on the horizontal axis). For example, unit area average daily flow in the Poquessing Creek at Grant Avenue was less than 0.1 inches/day on about 89% of days observed (Figure 3.8). The lowest distribution of unit area average daily flow was observed at the Poquessing Creek above Byberry Creek gage, where less than 0.1 inches/day occurred on about 94% of days observed (Figure 3.8).

4 WATER QUALITY

4.1 BACKGROUND

The Commonwealth of Pennsylvania, through the Pennsylvania Department of Environmental Protection (PADEP), is responsible for implementation of the Federal Water Pollution Control Act, or "Clean Water Act." Under the CWA, each state or authorized tribe must assess surface waters to determine whether the CWA objectives to "restore and maintain the chemical, physical, and biological integrity of the nation's waters" are being met. As described in section 303, Water Quality Standards and Implementation Plans, development of water quality standards is necessary to ensure that CWA objectives will be met.

This section describes methods and results of water quality sampling conducted by PWD for identification of water quality problems in the Poquessing Creek Watershed. Several criteria were relevant to the analysis, many of which provided specific numeric standards with which to comply. Others referred to as narrative standards were less specific, but were relevant nonetheless.

National water quality criteria specify aesthetic attributes that protect the quality of streams. The criteria define water that meets standards as:

"All waters free from substances attributable to wastewater or other discharges that:

(1) settle to form objectionable deposits;

(2) float as debris, scum, oil, or other matter to form a nuisance;

(3) produce objectionable color, odor, taste, or turbidity;

(4) injure or are toxic or produce adverse physiological responses in humans, animals or plants: and;

(5) produce undesirable or nuisance aquatic life." (EPA 2000).

Also, PADEP narrative water quality criteria state:

> (a) Water may not contain substances attributable to point or nonpoint source discharges in concentration or amounts sufficient to be inimical or harmful to the water uses to be protected or to human, animal, plant or aquatic life.
>
> (b) In addition to other substances listed within or addressed by this chapter, specific substances to be controlled include, but are not limited to, floating materials, oil, grease, scum and substances which produce color, tastes, odors, turbidity, or settle to form deposits." (PADEP Chapter 93 § 93.6.).

4.1.1 PENNSYLVANIA CODE TITLE 25, CHAPTER 93.4: STATEWIDE WATER USES

(a) *Statewide water uses.* Except when otherwise specified in law or regulation, the uses set forth in Table 4.1 apply to all surface waters. These uses shall be protected in accordance with this chapter, Chapter 96 (relating to water quality standards implementation) and other applicable state and federal laws and regulations.

Table 4.1 PA Statewide Water Uses

Symbol	Use
	Aquatic Life
WWF	Warm Water Fishes
	Water Supply
PWS	Potable Water Supply
IWS	Industrial Water Supply
LWS	Livestock Water Supply
AWS	Wildlife Water Supply
IRS	Irrigation
	Recreation
B	Boating
F	Fishing
WC	Water Contact Sports
E	Esthetics

4.1.2 PENNSYLVANIA CODE TITLE 25, CHAPTER 96.3: WATER QUALITY PROTECTION REQUIREMENTS

PADEP water quality standards are based on, in part, aquatic life habitat, human health requirements, and recreation use. Threshold chemical and biological characteristics and other stream conditions are required to be maintained for each designated use. PADEP periodically assesses water quality and identifies streams that do not meet water quality standards.

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

(a) Existing and designated surface water uses shall be protected.

(b) Antidegradation requirements in §§ 93.4a—93.4d and 105.1, 105.15, 105.17, 105.18a, 105.20a and 105.451 shall apply to surface waters.

(c) To protect existing and designated surface water uses, the water quality criteria described in Chapter 93 (relating to water quality standards), including the criteria in §§ 93.7 and 93.8a(b) (relating to specific water quality criteria; and toxic substances) shall be achieved in all surface waters at least 99% of the time, unless otherwise specified in this title. The general water quality criteria in § 93.6 (relating to general water quality criteria) shall be achieved in surface waters at all times at design conditions.

(d) As an exception to subsection (c), the water quality criteria for total dissolved solids, nitrite-nitrate nitrogen, phenolics, chloride, sulfate and fluoride established for the protection of potable water supply shall be met at least 99% of the time at the point of all existing or planned surface potable water supply withdrawals unless otherwise specified in this title.

(e) When a water quality criterion described in Chapter 93, including the criteria in §§ 93.7 and 93.8a (b), cannot be attained at least 99% of the time due to natural quality, as determined by the Department under § 93.7(d) based on water quality observations in that waterbody or at one or more reference stations of similar physical characteristics to the surface water, the natural quality that is achieved at least 99% of the time shall be the applicable water quality criterion for protection of fish and aquatic life.

(f) When the minimum flow of a stream segment is determined or estimated to be zero, applicable water quality criteria shall be achieved at least 99% of the time at the first downstream point where the stream is capable of supporting existing or designated uses.

(g) Functions and values of wetlands shall be protected pursuant to Chapters 93 and 105 (relating to water quality standards; and dam safety and waterway management).

Poquessing Creek is designated a Warm Water Fishery (WWF) with water quality appropriate for supporting fish and other life indigenous to a warm-water habitat. Based on biological assessments carried out by biologists from PADEP, Poquessing Creek is included on Pennsylvania's 2010 Integrated List of waters as an impaired waterbody, with all but a few small tributary segments failing to attain this aquatic life use (Section 2, Figure 2.9). With some exceptions, assessments that initially identified these impairments occurred from 1998-2001. Under the assessment protocol of that time, individual water pollution biologists were responsible for identifying causes and sources of impairment based primarily on a single site visit. Subjectivity inherent in this method resulted in some Philadelphia area stream segments being listed for various impairments (*e.g.*, excessive algal growth, siltation) when other segments ostensibly impaired by similar stressors were not listed as such.

Aside from the downstream-most segment of Poquessing Creek, all stream segments of Poquessing Creek Watershed in the City of Philadelphia and Bucks and Montgomery counties are listed as impaired due to urban runoff/storm sewers, with the causes of impairment listed as "excessive algal growth," "siltation," and "cause unknown." The downstream-most segment of Poquessing Creek is listed as impaired due to "source unknown," with the cause of impairment listed as "PCBs" (Section 2, Figure 2.9). Stream segments impaired due to a pollutant and thus requiring a TMDL (category 5) are described in section 4.1.3, below. Category 4c stream segments, considered impaired for pollution but not requiring a TMDL, are addressed in section 6.1.1.

4.1.3 PENNSYLVANIA CODE TITLE 25, CHAPTER 96.4: TOTAL MAXIMUM DAILY LOADS AND WATER QUALITY BASED EFFLUENT LIMITS

(a) The Department will identify surface waters or portions thereof that require the development of Total Maximum Daily Loads (TMDLs), prioritize these surface waters for TMDL development, and then develop TMDLs for these waters.
(b) The Department will develop Water Quality Based Effluent Limits (WQBELs) for point source discharges using applicable procedures described in this chapter when the Department determines that water quality protection requirements specified in § 96.3 (relating to water quality protection requirements) are or would be violated after the imposition of applicable technology based limitations required under sections 301(b), 306, 307 or other sections of the Federal Clean Water Act (33 U.S.C.A. §§ 1311(b), 1316 and 1317) and The Clean Streams Law (35 P. S. §§ 691.1—691.1001) to the point source.
(c) TMDLs and WQBELs shall be developed to meet the requirements of § 96.3.
(d) WLAs developed in accordance with this chapter shall serve as the basis for the determination of WQBELs for point source discharges regulated under Chapter 92 (relating to National Pollutant Discharge Elimination System permitting, monitoring and compliance). When WLAs are developed in accordance with this chapter, they shall serve as the basis for the development of nonpoint source restoration plans.
(e) In developing TMDLs and WQBELs, the Department will:
    a. As appropriate, consider relevant design factors, including, but not limited to: water quality criteria duration, flow duration and frequency, natural seasonal variability in water temperature, the natural variability of pH and hardness, the physical characteristics of a watershed, reserve factors, factors of safety and pollutant contributions from other sources.
    b. Treat all pollutants as conservative unless it finds based on scientifically valid information that the substance is not conservative and adequate information is available to characterize the substance’s fate or transformation, or both.

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

Twelve stream segments, including most of the length of Poquessing Creek, Byberry Creek, and their respective tributaries, were listed in 2002 due to excessive algal growth impairments (Section 2, Figure 2.9). Excessive algal growth is stimulated by conditions of abundant light and nutrients, and slow stream velocity. Excessive algal growth causes diel fluctuation in DO concentration and pH, which can lead to lethal conditions for fish and other aquatic life. Sources of excessive algal growth impairments include urban runoff/storm sewers. As of the 2010 Integrated list, the projected TMDL date for Excessive Algal Growth Impairments is 2015 (PADEP 2010a).

The tidal extent of Poquessing Creek, a small (1.45-mile) stream segment, was listed in 2006 as impaired for fish consumption due to polychlorinated biphenyls (PCBs). PCBs were used extensively in transformers and other industrial applications until their production was banned in

1979. Unfortunately, due to their persistence in the environment, ability to enter the atmosphere, volatility, and toxicity at very low levels, PCB pollution is one of the most difficult water pollution problems to solve. The projected TMDL date for PCB Impairments is 2019 (PADEP 2010a).

4.2 WATER QUALITY CRITERIA AND REFERENCE VALUES

Data collected from discrete wet and dry weather sampling in Poquessing Creek Watershed were compared to PADEP water quality standards. National water quality standards and reference values were used in instances when state water quality standards were not available (Table 4.2). Water quality parameters were evaluated with respect to attainment status according to the PADEP (2007c) Chemistry Statistical Assessment protocol, as described further in Section 4.6.

Table 4.2 Water Quality Standards and Reference Values

Parameter	Criterion	Water Quality Criterion or Reference Value	Source
Alkalinity	Minimum	20 mg/L	PA DEP
Aluminum	Aquatic Life Acute Exposure Standard	750 µg/L	PA DEP
Aluminum	Aquatic Life Chronic Exposure Standard	87 µg/L (pH 6.5-9.0)	53FR33178
Arsenic	Aquatic Life Acute Exposure Standard	340 µg/L	PA DEP
Arsenic	Aquatic Life Chronic Exposure Standard	150 µg/L	PA DEP
Chlorophyll *a*	Maximum	1.205 µg/L, (Spectrophotometric) ***	EPA 822-B-00-019
Dissolved Cadmium	Aquatic Life Acute Exposure Standard	2.01 µg/L *	PA DEP
	Aquatic Life Chronic Exposure Standard	0.25 µg/L *	PA DEP
Dissolved Chromium	Aquatic Life Acute Exposure Standard	16 µg/L	PA DEP
	Aquatic Life Chronic Exposure Standard	10 µg/L	PA DEP
Dissolved Copper	Aquatic Life Acute Exposure Standard	13 µg/L *	PA DEP
	Aquatic Life Chronic Exposure Standard	9 µg/L *	PA DEP
	Human Health Standard	1.3 mg/L****	EPA
Dissolved Iron	Maximum	0.3 mg/L	PA DEP
Dissolved Lead	Aquatic Life Acute Exposure Standard	65 µg/L *	PA DEP
	Aquatic Life Chronic Exposure Standard	2.5 µg/L *	PA DEP
Dissolved Zinc	Aquatic Life Acute Exposure Standard	120 µg/L *	PA DEP
	Aquatic Life Chronic Exposure Standard	120 µg/L *	PA DEP
	Human Health Standard	7.4 mg/L****	PA DEP
Dissolved Oxygen	Minimum Daily Average	5 mg/L	PA DEP
	Instantaneous Minimum	4 mg/L	PA DEP
E. coli	Maximum (Swimming season)	1851 CFU/100mL *****	EPA 440-5-86-001
E. coli	Maximum (Non-swimming season)	16,425 CFU/100mL *****	EPA 440-5-86-001
E. coli	Maximum (Swimming season)	409 CFU/100mL ‡	EPA 440-5-86-001
E. coli	Maximum (Non-swimming season)	4096 CFU/100mL ‡	EPA 440-5-86-001
Enterococci	Maximum (Swimming season)	107 CFU/100mL ‡	EPA 440-5-86-001
Enterococci	Maximum (Non-swimming season)	1070 CFU/100mL ‡	EPA 440-5-86-001
Fecal Coliform	Maximum (Swimming season)	200 CFU/100mL	PA DEP
Fecal Coliform	Maximum (Non-swimming season)	2000 CFU/100mL	PA DEP
Iron	Maximum	1.5 mg/L	PA DEP
Manganese	Maximum	1.0 mg/L	PA DEP
Ammonia Nitrogen (NH_3-N)	Maximum	pH and temperature dependent	PA DEP
$NO_{2\text{-}3}$-N	Nitrates – Human Health Consumption for water + organisms	0.995 mg/L ***	EPA 822-B-00-019
$NO_2 + NO_3$	Maximum (Public Water Supply Intake)	10 mg/L	PA DEP
Periphyton Chl-*a*	Maximum	Ecoregion IX – 20.35 mg/m^2	EPA 822-B-00-019
pH	Acceptable Range	6.0 - 9.0	PA DEP
TDS	Maximum	750 mg/L	PA DEP
Temperature		Varies w/ season. **	PA DEP
TKN	Maximum	0.30 mg/L ***	EPA 822-B-00-019
TN	Maximum	2.225 mg/L ***	EPA 822-B-00-019
TP	Maximum	40 µg/L ***	EPA 822-B-00-019
TSS	Maximum	25 mg/L	Other US states
Turbidity	Maximum	2.825 NTU ***	EPA 822-B-00-019

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

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

*** - Ecoregion IX, subregion 64 median of seasonal 25th percentile values

**** - Agency notes “organoleptic effect criterion is more stringent than the value for priority toxic pollutants.”

***** - Based on recommended standard for lightly used full body contact recreation freshwater, with site-specific log standard deviation of 0.87

‡ - Based on recommended standard for lightly used full body contact recreation freshwater, with log standard deviations of 0.4 for *E. coli* and enterococci

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

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

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

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

4.2.2 PWD – USGS COOPERATIVE PROGRAM

In the early 1970s, the Philadelphia Water Department began a study in cooperation with the U.S. Geological Survey (USGS) entitled "Urbanization of the Philadelphia Area Streams." (Radziul *et al.*, 1975) The purpose of this study was to quantify the pollutant loads in some of Philadelphia's streams and possibly relate degradation in water quality to urbanization. By 1965, USGS established four stream gaging stations in Poquessing Creek Watershed (Table 4.3). Water quality data was transcribed from a hard copy of the aforementioned report in the PWD Bureau of Laboratory Services (BLS) library and entered into a Microsoft Excel spreadsheet.

Table 4.3 USGS Gages and Periods of Record for Historic Water Quality Sampling by USGS/PWD

PWD Site	Gage	Name	Period of Record
PQ050	01465798	Poquessing Creek at Grant Avenue, Philadelphia, PA	10/4/1967 to 3/3/1980
PQ157	01465780	Poquessing Creek above Byberry Creek, Philadelphia, PA	10/4/1967 to 2/19/1970
PQB090	01465795*	Byberry Creek at Grant Avenue, Philadelphia, PA	10/16/1964 to 8/23/1970
PQB305	01465790	Byberry Creek at Chalfont Road, Philadelphia, PA	10/4/1967 to 10/1/1973
PQW120	01465785	Walton Run at Philadelphia, PA	10/3/1967 to 2/19/1970
PQ820	01465770	Poquessing Creek at Trevose Road, Philadelphia, PA	12/7/1970 to 3/3/1980

*Station used for water quality grab sampling only.

Overall, three stations on mainstem Poquessing Creek, one station on mainstem Byberry Creek, and one station on Walton's Run, a tributary to Byberry Creek, were instrumented with water level sensors and rated for discharge. These five gages, as well as station 01465795, were also used to collect water quality samples. Gage 01465798 is the only original station that remains operational today. Continuous water quality monitoring was implemented at USGS gage station 01465798 at Grant Ave. in 2008, with the responsibility for maintenance shared between PWD and USGS personnel. USGS staff maintain stream gaging and telemetry equipment and periodically make flow measurements and adjust the stage-discharge relation. PWD staff are responsible for maintenance of continuous water quality monitoring instruments.

PWD and USGS conducted water quality sampling in from 1964 to 1980 at the six gages listed in Table 4.3. PWD also collected samples at site PQB320, located 0.15 miles upstream of gage 01465790 from 11/9/1970 to 10/16/1978 (Figure 4.1). Samples were initially collected monthly, but sampling became less frequent as the study progressed. Furthermore, some chemical analytes were not consistently sampled (Table 4.4).

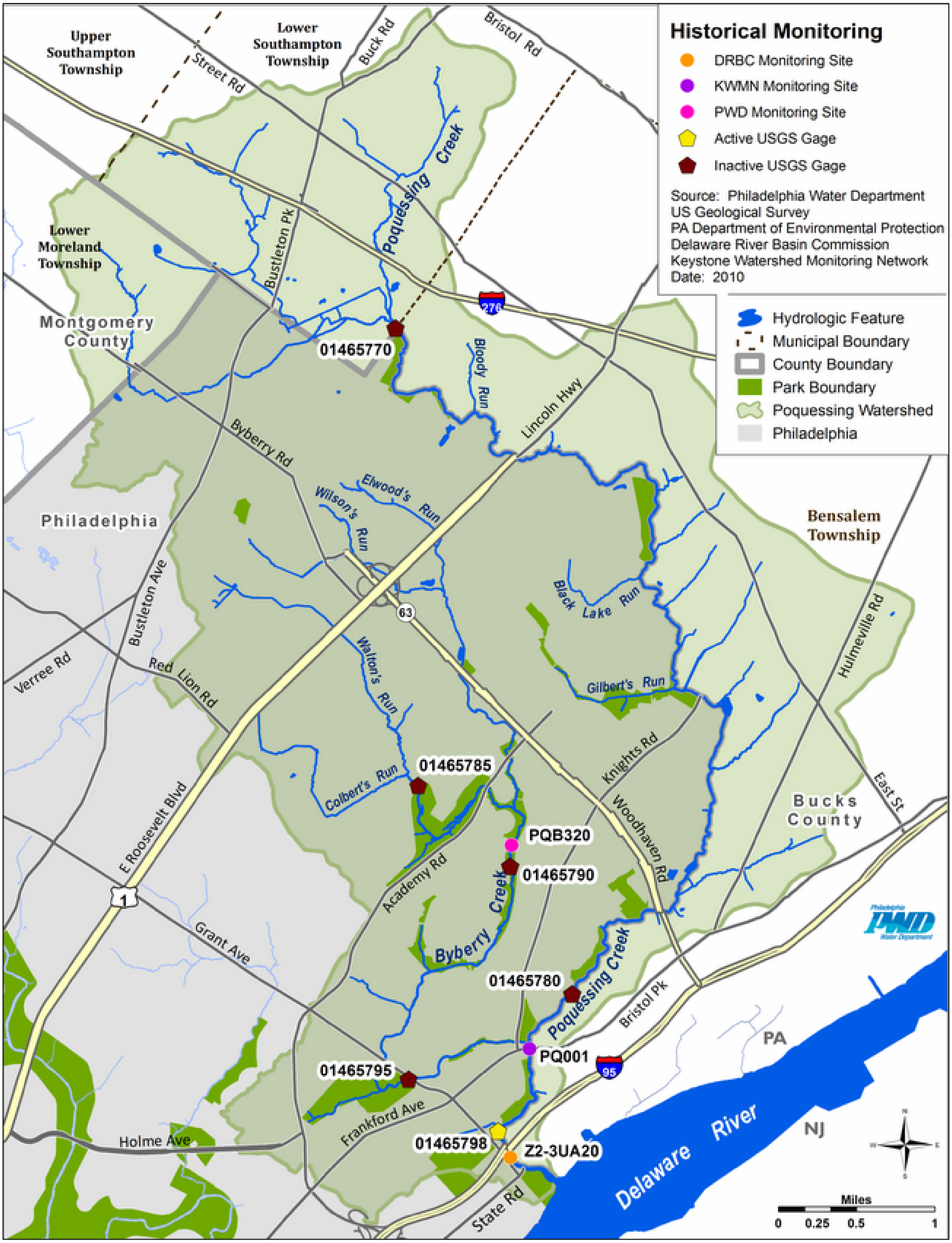


Figure 4.1 Historical Monitoring Locations in Poquessing Creek Watershed

Table 4.4 Number of Samples by Location for PWD/USGS Historical Water Quality Monitoring program, 1964-1980

Parameter	Units	1465798	1465780	1465795	1465790	1465785	1465770	PQB320	Parameter Total
BOD$_5$	mg/L	127	*0*	*0*	28	*0*	117	54	326
COD	mg/L	61	*0*	*0*	28	*0*	37	36	162
Dissolved Oxygen	mg/L	135	*0*	*0*	28	*0*	130	55	348
Fecal Coliform	mg/L	134	*0*	*0*	28	*0*	129	56	347
Ammonia	mg/L as N	120	*0*	*0*	17	*0*	125	55	317
Nitrite	mg/L	123	*0*	*0*	17	*0*	129	56	325
Nitrate	mg/L	123	*0*	14	17	*0*	129	56	339
pH	pH units	65	5	22	29	7	36	34	198
Orthophosphate	mg/L	15	2	3	15	3	*0*	*0*	38
Total Phosphorus	mg/L	15	*0*	*0*	16	*0*	*0*	*0*	31
Specific Conductance	µS/cm	140	5	22	33	7	126	52	385
Hardness	mg/L	8	5	22	5	7			47
Total Dissolved Solids	mg/L	13	*0*	*0*	*0*	*0*	15	13	41
Total Suspended Solids	mg/L	48	15	429	16	14	38	35	595
Temperature	°C	149	15	309	42	12	129	56	712
Total Organic Carbon	mg/L	30	*0*	*0*	*0*	*0*	33	30	93
Total Organic Nitrogen	mg/L	4	*0*	*0*	2	*0*	2	2	10
Turbidity	JTU	12	*0*	*0*	12	*0*	*0*	*0*	24
Site totals →		**1322**	**47**	**821**	**333**	**50**	**1175**	**590**	**4338**

4.2.3 USGS NATIONAL WATER INFORMATION SYSTEM

As described above, USGS established a total of 5 monitoring locations in Poquessing Creek Watershed. The National Water Information System (NWIS) (http://waterdata.usgs.gov/nwis) was queried in spring 2009 to retrieve all streamflow and water quality data from these sites, as listed in Table 4.4. The NWIS dataset was well-documented, listing water quality analytes by parameter code, and in many cases the method used. However, many water quality parameters were analyzed from filtered water quality samples, whereas present-day samples are generally unfiltered.

Data retrieved from NWIS was found to overlap with some of the data collected by PWD during the cooperative sampling program. Any duplicate records were removed, with the USGS data receiving preference. Wet and dry weather conditions were determined by a comparison of the sample date to daily rainfall measured at Philadelphia International Airport. If cumulative rainfall on the two days prior to and on the sample date measured greater than or equal to 0.05 inches, the sample was assumed to be collected under wet weather conditions.

4.2.4 DELAWARE RIVER BASIN COMMISSION (DRBC)

DRBC collected 17 samples on two separate days in July and September 1986 at a site 0.2 miles downstream of USGS gage 01465798. The DRBC site is labeled as ‘Z2-3UA20’ on Figure 4.1. Six different parameters (DO, temperature, pH, specific conductance, fecal coliform and *E. coli*) were represented in the dataset. The range of values in the samples collected by DRBC was well within that observed in the 1964-1980 PWD/USGS data and the PWD data from 2001-2009. Due to the small size of the DRBC dataset and its unexceptional results, it was not included in the subsequent analysis.

4.2.5 HISTORIC DATA PROCESSING

Historical records from the PWD/USGS Cooperative Study were formatted as plain text files and processed with R. Each sample was classified as wet or dry using the method described in section 4.2.3. Records without data values and water quality results from filtered samples were removed. The resulting dataset of approximately 4,000 records afforded an opportunity to make a meaningful comparison of historical water quality to present-day conditions. Data collected through 1980 were grouped as “historical,” while data from 2001-2009 were grouped as “modern,” though it should be noted that historical data were collected most frequently in the late 1960s and modern data were collected exclusively in 2001-2002 and 2008-2009 (Figures 4.2 and 4.3).

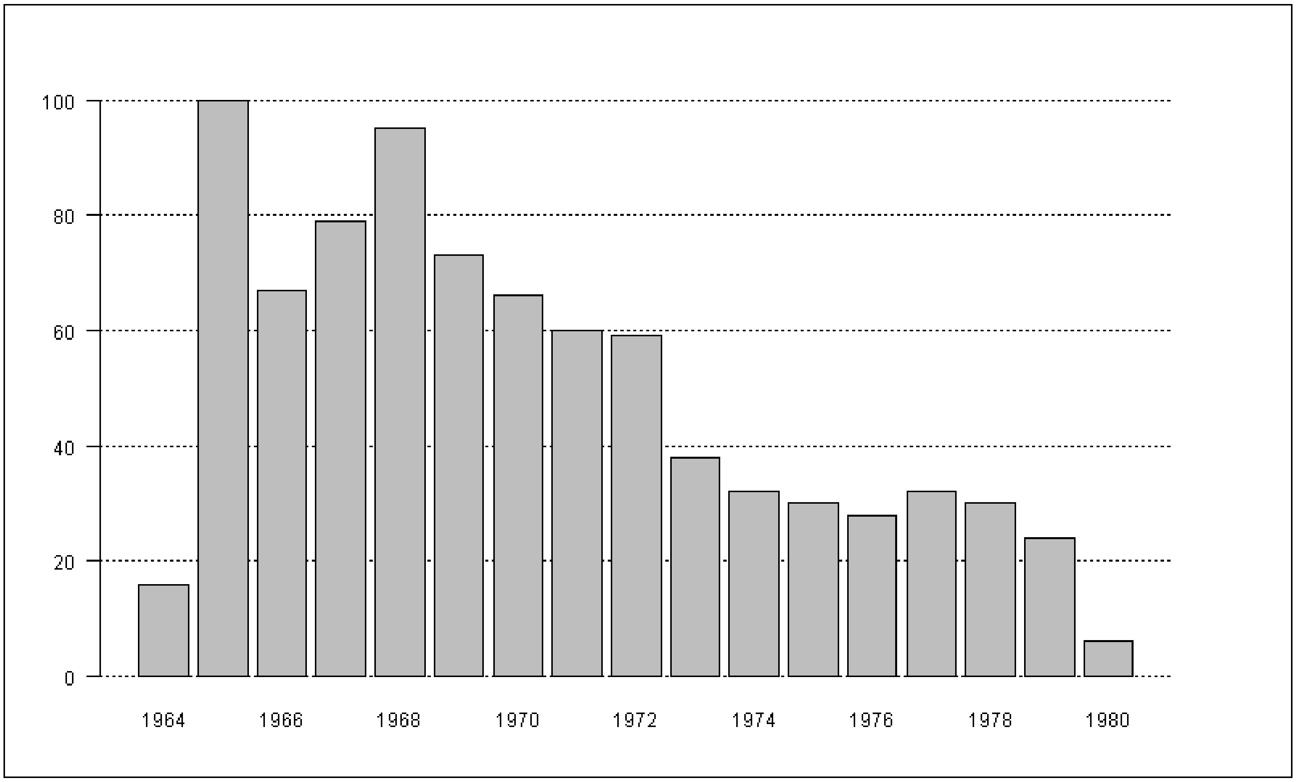


Figure 4.2 Number of Water Chemistry Sampling Events per Monitoring Period, 1964-1980, Conducted by USGS/PWD

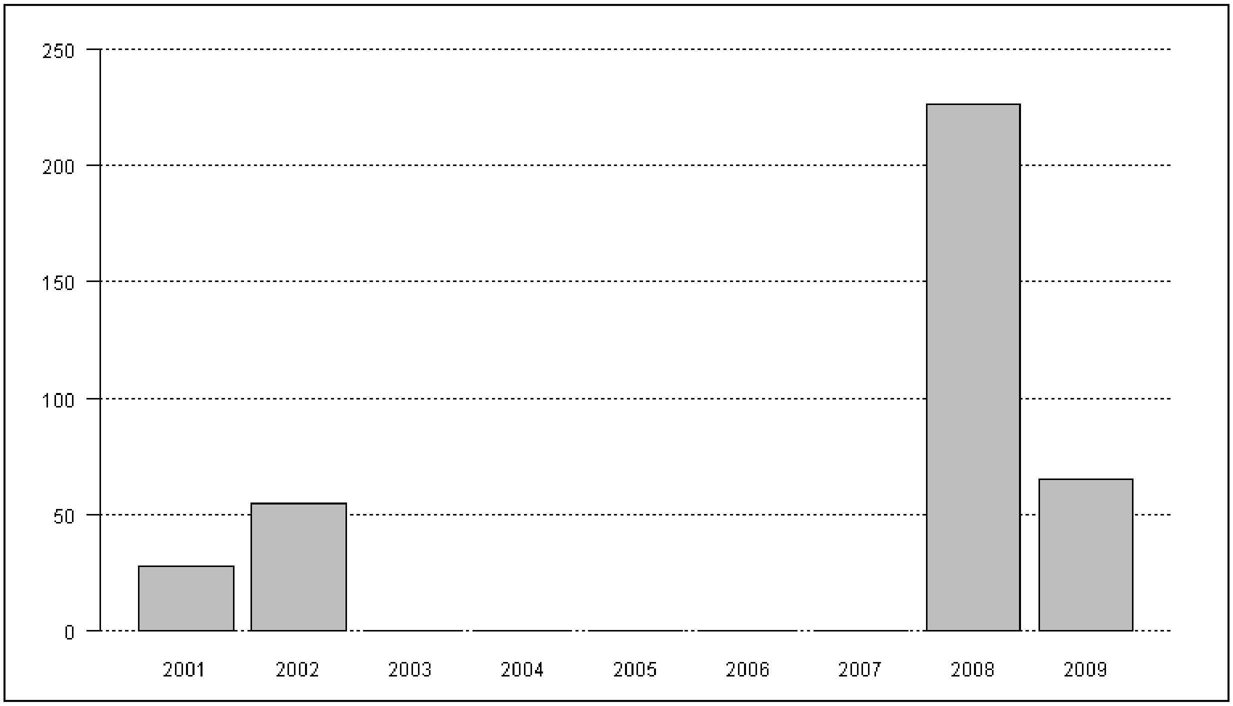


Figure 4.3 Number of Water Chemistry Sampling Events per Monitoring Period, 2001-2009, Conducted by PWD

Three historical monitoring locations were used in present-day monitoring (PQ050, PQ820, and PQB305). This enabled pairwise site-specific comparisons at three locations for several different parameters, categorized by wet or dry weather. The three locations in the pairwise site-specific analysis included the most upstream and downstream sites on the mainstem Poquessing Creek and one site on the mainstem Byberry Creek. A second analysis was done comparing data from mainstem Byberry Creek sites treated as a group. A grouping of historic data from PQB090, PQB305, and PQB320, and present-day data from PQB305 and PQB025 were compared, with categorization according to wet or dry weather. Results of these analyses are presented in Table 4.5.

Historic data used in the comparisons did not contain any samples below detection limits. However, the modern dataset contained numerous samples below detection limits, particularly for ammonia, BOD_5, fecal coliform, nitrate, and TSS. Non-detect samples can be a confounding factor in making statistical comparisons. To alleviate this obstacle, non-detect samples in the modern dataset were assigned a value of half the detection limit value.

4.2.6 HISTORIC DATA COMPARISON RESULTS

When a sufficient number of samples were available (n>14), comparisons were made between modern and historical data, grouped by site and weather (wet or dry). Significance was assessed at the 0.05 level. Significant differences were observed in dry weather for BOD_5 and fecal coliform, and at both wet and dry weather for nitrate and TSS (Table 4.5), with higher mean concentrations in the historical data. Observed decreases in dry weather fecal coliform and nitrate mean concentrations might be an indication that management strategies to reduce infrastructure failures are functioning properly during dry weather. Significant differences were observed for dry weather specific conductance, with higher mean concentrations in the modern data, possibly due to the cumulative effects of winter road salting.

Table 4.5 Comparison of 2001-2009 Water Quality Data and Historic Water Quality Data

Site	Parameter	Wet/ Dry	Test	*U-value	p-value	Historic valid n	Modern valid n	Historic mean	Modern mean
PQ050	BOD5	Dry	Mann Whitney U-test	1359	0.00**	46	31	2.97	1.04**
PQ050	Specific Conductance	Dry	Mann Whitney U-test	935.5	0.00	37	26	377	540
PQ050	Fecal coliform	Dry	Mann Whitney U-test	1420	0.00	50	34	2240	448
PQ050	Fecal coliform	Wet	Mann Whitney U-test	1377	0.07	57	60	4320	8352
PQ050	Nitrate	Dry	Mann Whitney U-test	1537	0.00	50	34	2.42	1.16
PQ050	TSS	Dry	Mann Whitney U-test	527	0.00**	22	31	7.9	3.4**
PQ820	Specific Conductance	Dry	Mann Whitney U-test	134	0.00	59	16	291	474
PQ820	Fecal coliform[1]	Dry	T-test	4.75	0.00**	61	16	8623	492**
PQ820	Nitrate	Dry	Mann Whitney U-test	898	0.00**	61	16	2.41	1.32**
PQB305	Specific Conductance	Dry	Mann Whitney U-test	71	0.00	18	18	319	440
All Byberry Creek Sites	Specific Conductance	Dry	Mann Whitney U-test	636	0.00	50	40	355	412
All Byberry Creek Sites	Specific Conductance	Wet	Mann Whitney U-test	516	0.69	57	17	361	279
All Byberry Creek Sites	Fecal coliform[1]	Dry	T-test	3.61	0.00**	42	40	10251	1753**
All Byberry Creek Sites	Fecal coliform	Wet	Mann Whitney U-test	944	0.00	42	67	8160	12401
All Byberry Creek Sites	Hardness	Wet	Mann Whitney U-test	451	0.09	18	68	67.6	81.0
All Byberry Creek Sites	Nitrate[1]	Dry	T-test	8.64	0.00**	39	40	3.57	1.52**
All Byberry Creek Sites	Nitrate	Wet	Mann Whitney U-test	2431	0.00	48	66	2.28	1.12
All Byberry Creek Sites	TSS	Dry	Mann Whitney U-test	4683	0.00**	138	40	22.5	4.1**
All Byberry Creek Sites	TSS	Wet	Mann Whitney U-test	14987	0.00**	341	63	564.6	45.3**

[1] Log (x + 1) transformation used to normalize data
* T-value where T-tests were used
** Non-detect samples in modern dataset were assigned a value of half the detection limit

4.2.7 WATER QUALITY SAMPLING 1990-PRESENT

4.2.7.1 PWD BASELINE BIOLOGICAL ASSESSMENT OF POQUESSING CREEK WATERSHED

PWD conducted a baseline assessment of Poquessing Creek Watershed in 2002. Water quality samples were collected from seven sites in Poquessing Creek Watershed, along with habitat and macroinvertebrate assessments from 13 locations and fish collections from seven sites. The primary differences between 2001-2002 and 2008-2009 water quality monitoring programs were that water quality samples were collected on a weekly basis without regard for weather or streamflow conditions in 2001-2002, while the 2008-2009 sampling schedule was adjusted to ensure that a sufficient number of grab samples be collected in dry weather (baseflow) conditions. The 2008-2009 water quality sampling effort was also more comprehensive, addressing wet weather and continuous effects.

4.2.7.2 KEYSTONE WATERSHED MONITORING NETWORK – VOLUNTEER MONITORING IN POQUESSING CREEK WATERSHED

The Keystone Watershed Monitoring Network (KWMN) is a statewide association of citizen monitors, agencies and organizations established to promote volunteer monitoring in Pennsylvania's watersheds. KWMN undertook monitoring from 1997-2001 in the Poquessing Creek at the site labeled 'PQ001' on Figure 4.1, located on the mainstem Poquessing Creek just downstream of the confluence with Byberry Creek. The site is located 0.4 miles upstream of USGS gage 01465798. PWD was not involved with KWMN monitoring activities. The number of samples collected by KWMN is shown in Table 4.6.

KWMN data were not included in the historic data comparison (Table 4.5) because there were no historic data collected at the KWMN sampling site. Mean values for nitrate and orthophosphate were observed at 0.78 mg/L and 0.27 mg/L, respectively.

Table 4.6 Number of Samples for KWMN Water Quality Monitoring Program at location PQ001, 1997-2001

Parameter	Units	n
Temperature	°C	88
Dissolved Oxygen	mg/L	92
pH	pH units	95
Nitrate	mg/L	91
Orthophosphate	mg/L	69
Site total		521

4.2.7.3 PWD 2008-2009 COMPREHENSIVE WATER QUALITY ASSESSMENT OF POQUESSING CREEK WATERSHED

4.2.7.3.1 SAMPLING BACKGROUND

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

Under the provisions of the Clean Water Act, the National Pollutant Discharge Elimination System (NPDES) requires permits for point sources that discharge to waters of the United States. In Poquessing Creek Watershed, stormwater outfalls are classified as point sources and are regulated by NPDES.

Regulation of stormwater outfalls under the NPDES program requires operators of medium and large municipal stormwater systems or MS4s, such as those found in Poquessing Creek Watershed, to obtain a permit for discharges and to develop a stormwater management plan to minimize pollution loads in runoff over the long term. In part due to administration of this program, PADEP assigns designated uses to water bodies in the state and performs ongoing assessments of the condition of the water bodies to determine whether the uses are met and to document any improvement or degradation. These assessments are performed primarily with biological indicators based on the EPA's Rapid Bioassessment Protocols (RBPs) for benthic invertebrates and physical habitat. Poquessing Creek is listed by the PADEP as impaired for excessive algal growth, siltation, and PCBs, requiring Total Maximum Daily Loads (TMDLs) for these pollutants.

Poquessing Creek and its tributaries are designated warm water fisheries. With the exception of a few small tributary reaches, all stream reaches in Poquessing Creek Watershed are classified by PADEP as not meeting all designated uses (Section 2, Figure 2.9). For this reason, the NPDES stormwater permit for the City of Philadelphia specifies that the state of the aquatic resource must be evaluated periodically. Because PADEP has endorsed biomonitoring as a means of determining attainment of uses, PWD periodically performs RBPs and collects water chemistry samples in Poquessing Creek Watershed.

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

4.2.8 SUMMARY OF PHYSICAL AND CHEMICAL MONITORING

PWD Office of Watersheds (OOW) and Bureau of Laboratory Services (BLS) have planned and carried out an extensive sampling and monitoring program to characterize conditions in Poquessing Creek Watershed. The program includes hydrologic, water quality, biological, habitat, and fluvial geomorphological components. Again, because the OOW has merged the goals of the city's stormwater, combined sewer overflow, and source water protection programs into a single unit dedicated to watershed-wide characterization and planning, it is uniquely suited to administer this program.

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

Tables 4.7 and 4.8 summarize the types, amounts, and dates of recent sampling and monitoring performed by PWD and USGS. A river mile-based naming convention is followed for sampling and monitoring sites located along waterways in the watershed. The naming convention includes two to four letters and three or more numbers which denote the watershed, stream, and distance from the mouth of the stream. For example, site PQB305 is named as follows:

- "PQ" an abbreviation of Poquessing Creek.
- "B" an abbreviation of Byberry Creek, a tributary to Poquessing Creek.
- "305" a series of digits to indicate the river mile distance in hundredths of a mile from the confluence of Byberry Creek and Poquessing Creek.

A series of individual site maps was created featuring 2008 color orthophotography, biological and chemical monitoring locations, and, in the case of fish assessment sites, fish physical habitat assessment stream channel boundaries. These 1:1,000 scale maps can be found in Appendix A.

Table 4.7 Summary of Physical, Chemical, and Biological Sampling and Monitoring

Site Name	Stream Name	USGS Gage Number	USGS		PWD		
			USGS Daily Flow	USGS Water Quality	PWD Water Quality	Invertebrates & Habitat*	Fish**
PQ050	Poquessing Creek	1465798	1965-present	1967-1973; 2008-present	1970-1980; 2001-2002; 2008-present	2001, 2008	2001, 2008
PQ115	Poquessing Creek				2008-present	2001, 2008	2001, 2008
PQ155	Poquessing Creek				2001-2002; 2008-present		
PQ157	Poquessing Creek	1465780	1964-1970	1967-1970			
PQ395	Poquessing Creek				2001-2002; 2008-present	2001, 2008	2001, 2008
PQ665	Poquessing Creek				2001-2002; 2008-present	2001, 2008	
PQ820	Poquessing Creek	1465770	1964-1981		1970-1980; 2001-2002; 2008-present		
PQB025	Byberry Creek				2001-2002; 2008-present	2001, 2008	2001, 2008
PQB090	Byberry Creek	1465795		1964-1970			
PQB305	Byberry Creek	1465790	1965-1978	1967-1973	2001-2002; 2008-present		
PQB320	Byberry Creek				1970-1978		
PQW120	Walton's Run	1465785	1964-1978	1967-1970			

* EPA Rapid Bioassessment Protocol III Benthic Macroinvertebrates

** EPA Rapid Bioassessment Protocol V Ichthyofaunal (Fish)

4.3 WATER QUALITY ASSESSMENT OF POQUESSING CREEK WATERSHED

4.3.1 BACKGROUND INFORMATION

In order to comply with the state-regulated stormwater permit obligations, water quality sampling was conducted in Poquessing Creek Watershed during 2008 and 2009. Samples were collected at six mainstem sites and two tributary sites in the watershed (Figure 4.4, Table 4.8). Water quality parameters (Table 4.9) were chosen based on state water quality criteria or because they are known or suspected to be important in urban watersheds.

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

Table 4.8 Summary of Water Quality Monitoring Activities at Various Sampling Locations in Poquessing Creek Watershed, 2008-2009

SITE	ASSESSMENT		
	Discrete	Continuous	Wet Weather
PQ050	X	X	X
PQ115	X		
PQ155	X		
PQ395	X		
PQ665	X	X	X
PQ820	X		
PQB025	X	X	X
PQB305	X		

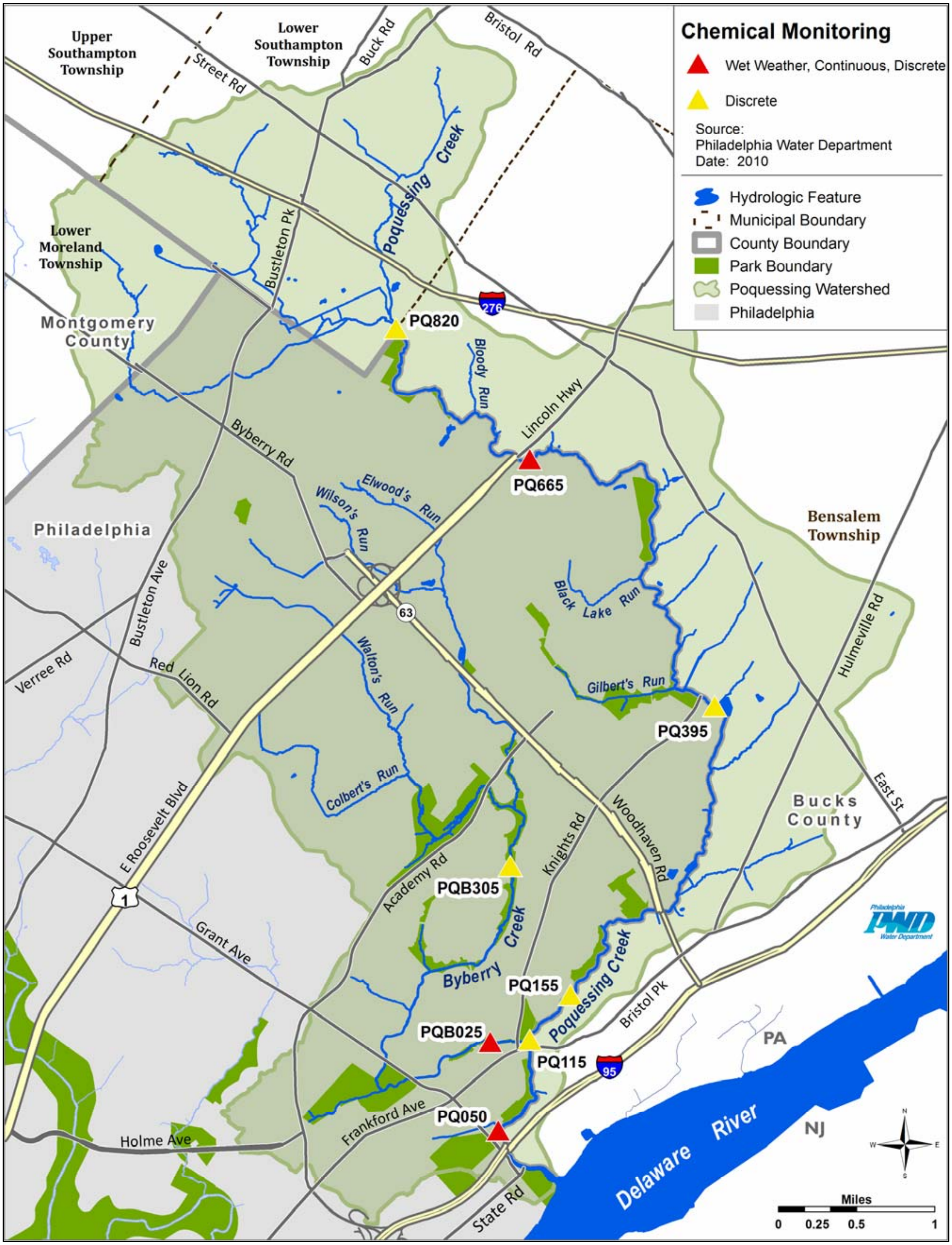


Figure 4.4 Water Quality Sampling Locations in Poquessing Creek Watershed, 2008-2009

Table 4.9 Water Quality Parameters Sampled in Comprehensive Water Quality Assessment of Poquessing Creek Watershed, 2008-2009

Parameter	Units	Discrete	Wet Weather	Continuous
Alkalinity	mg/L	X		
Aluminum	mg/L	X	X	
Dissolved Aluminum	mg/L	X		
Ammonia	mg/L	X	X	
Arsenic	mg/L	X	X	
Dissolved Arsenic	mg/L	X		
BOD_5	mg/L	X	X	
Cadmium	mg/L	X	X	
Dissolved Cadmium	mg/L	X		
Calcium	mg/L	X	X	
Chlorophyll-a	mg/m^2	X		
Total chlorophyll	mg/m^2	X		
Chromium	mg/L	X	X	
Dissolved Chromium	mg/L	X		
Specific Conductance	µS/cm	X		X
Copper	mg/L	X	X	
Dissolved Copper	mg/L	X		
E. coli	CFU/100mL	X	X	
Enterococci	CFU/100mL	X	X	
Fecal Coliform	CFU/100mL	X	X	
Hardness	mg/L	X	X	
Iron	mg/L	X	X	
Dissolved Iron	mg/L	X		
Lead	mg/L	X	X	
Dissolved Lead	mg/L	X		
Magnesium	mg/L	X	X	
Manganese	mg/L	X	X	
Dissolved Manganese	mg/L	X		
Nitrate	mg/L	X	X	
Nitrite	mg/L	X	X	
Orthophosphate	mg/L	X	X	
Dissolved Oxygen	mg/L	X		X
pH	pH units	X		X
Total Phosphorus	mg/L	X	X	
Suspended Solids	mg/L	X	X	
Total Solids	mg/L	X	X	
Temperature	°C	X		X
TKN	mg/L	X	X	
Turbidity	NTU	X	X	X
Zinc	mg/L	X	X	
Dissolved Zinc	mg/L	X		

4.3.2 DISCRETE INTERVAL SAMPLING

Bureau of Laboratory Services staff collected surface water grab samples at seven (n=7) locations within Poquessing Creek Watershed for chemical and microbial analysis (Figure 4.4**)**. (Site PQ115 was only used for periphyton sampling). Each site along the stream was sampled once during the course of a few hours, to allow for travel time and sample processing/preservation. Based on a new set of Water Quality Statistical Analysis guidelines provided by PADEP, PWD made adjustments to the discrete sampling program in order to ensure that a minimum of eight samples were collected in "dry" conditions (defined as less than 0.05" precipitation in the nearest rain gage in the previous 48 hours). While the statistical guidelines make no mention of the influence of stormwater on stream water quality, PWD considers identification of wet and dry conditions paramount to understanding urban water quality problems. Discrete sampling follows the BLS Standard Operating Protocol (SOP) "Field Procedures for Grab Sampling", which can be found in Appendix B. Samples that were rejected as not valid or outlier data are listed in Appendix D.

Sampling events were planned to occur at each site at weekly intervals for one month during four separate seasons. Actual sampling dates were as follows: "winter" samples collected 1/9/08, 1/17/08, 1/29/08, and 2/6/08; "spring" samples collected 4/23/08, 4/30/08, 5/7/08, 4/1-2/09, and 4/20-21/09 ; "summer" samples collected 7/31/08, 8/6/08, 8/14/08, 8/21/08, 8/27/08, 9/4/08, and 9/6-8/08; "fall" samples collected 10/23/08, 10/26-27/08, 11/12/08, and 11/14/08. A total of 125 discrete samples, comprising 4,297 chemical and microbial analytes, were collected and analyzed during the 2008-2009 assessment of Poquessing Creek Watershed. To add statistical power, additional discrete water quality samples from PWD's wet-weather chemical sampling program were included in analyses when appropriate. These data are most pertinent to Target A of the Poquessing Creek Watershed Management Plan being developed by PWD (Dry Weather Water Quality and Aesthetics). Chemical and microbial constituents that are influential in shaping communities of aquatic systems or that are indicative of anthropogenic degradation of water quality were specifically addressed.

4.3.3 CONTINUOUS MONITORING

Physicochemical properties of surface waters are known to change over a variety of temporal scales, with broad implications for aquatic life. Several important, state-regulated parameters (*e.g.*, dissolved oxygen, temperature, and pH) may change considerably over a short time interval, and therefore cannot be measured reliably or efficiently with grab samples. Self-contained data logging continuous water quality monitoring sondes (YSI Inc. Models 6600, 600XLM) (Appendix B) were deployed in Poquessing Creek Watershed at three sites (PQ050, PQ665, and PQB025) in order to collect DO, pH, temperature, conductivity, turbidity and depth data (Figure 4.4). The sonde at PQ050, a USGS gage location, was deployed from July-November 2008 and March-November 2009. At PQB025, the sonde was deployed from July-November 2008 and March-September 2009. The sonde at PQ665 was deployed from August-November 2008 and March-September 2009.

Sondes continuously monitored conditions and discretized the data in 15-minute increments at PQ665 and PQB025, and 30-minute increments at PQ050. The instrument measures parameters using optical, voltage and diffusion-based probes rather than physically collecting samples. Depending on the discretization increment, this method produces 48 or 96 measurements per parameter every 24 hours, but cost and quality control are more challenging compared to discrete sampling. The BLS SOP for continuous sampling (Appendix B) describes the extensive quality control and assurance procedures applied to the data. The data flagging protocol is described in Appendix C.

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

4.3.4 WET WEATHER EVENT SAMPLING

Target C of the Poquessing Creek Watershed Management Plan (in draft) addresses water quality in wet weather. Yet characterization of water quality at several widely distributed sites simultaneously over the course of a storm event presents a unique challenge. Automated samplers (Isco, Inc.) were used to collect samples from two mainstem sites (PQ050 and PQ665) and one tributary site (PQB025) during runoff-producing rain events in 2008 and 2009. Successful deployments during wet weather events took place on 9/6/08, 10/25/08, 11/13/08, 4/1/09, and 4/20/09. The data allow characterization of water quality responses to stormwater runoff.

The automated sampler system obviated the need for BLS team members to manually collect grab samples, thereby greatly increasing sampling efficiency. Automated samplers were equipped with vented instream pressure transducers that allowed sampling to commence beginning with a 0.1ft. increase in stage. Once sampling was initiated, a computer-controlled peristaltic pump and distribution system collected the first four grab samples at 30-minute intervals and the remaining samples at 60- to 150-minute intervals.

Use of automated samplers allows for a greater range of flexibility in sampling programs, including flow-weighted composite sampling based on a user-defined rating curve, but stage discharge rating curves at these sites were poorly defined for larger flows. Though some difficulties were encountered due to a combination of mechanical failure, individual site characteristics, and/or vandalism, the chosen intervals were found to be generally satisfactory in collecting representative samples over the course of a storm event.

4.3.5 BIOTIC LIGAND MODEL (BLM) ANALYSIS

The Biotic Ligand Model is a toxicity prediction tool that addresses the major constituents of water that may compete for ligand bonding sites of fish gills and respiratory apparatus of invertebrates. The model is built from empirical studies of the interactions of 12 separate water quality parameters on the toxicity of various toxic metals. Generally, these water quality parameters influence the solubility of toxic metals or function to bind or form organic complexes with toxic metals, thereby reducing toxicity. Biotic Ligand Model Version 2.2.3 for Microsoft Windows (Hydroqual 2007) was used to address toxicity effects of dissolved Cd, Cu, and Zn, though Cd was never measured above reporting limits.

Some model input parameters were not sampled or only a small number of results were available in the Poquessing Creek Watershed dataset. Input values for these parameters were substituted with conservative values (Table 4.10) as follows:

1.) When temperature or pH data were lacking, as was the case with wet weather data collected with automated samplers, the most conservative value (the value producing the most toxic result) from baseline, sampler check, or post-storm samples was used for all samples within the wet weather sampling deployment.
2.) Dissolved organic carbon and percent humic acids were never sampled from Poquessing Creek Watershed and were assumed to be 2.9 mg/L and 10%, respectively, based on sample results from other small streams in the Philadelphia region and recommendations in the model documentation (Hydroqual 2005).
3.) Some major ions were assigned different estimated values for wet and dry weather samples, based on sample results from Poquessing Creek or other small streams in the Philadelphia region. Other major ions did not have enough samples collected to use separate values for dry and wet weather.

Table 4.10 Reference Values Used for BLM Toxicity Calculations

Parameter (units)	Estimated Value	
	Dry weather	Wet weather
DOC (mg/L)	2.9	2.9
Humic Acid (%)	10	10
Ca (mg/L)	34.1	24.0
Mg (mg/L)	14.5	10
Na (mg/L)	30	21
K (mg/L)	3.13	3.13
SO_4 (mg/L)	33.9	23.7
Cl (mg/L)	23.8	23.8
SO_2* (mg/L)	0.001	0.001

*Sulfide is not currently used in the Biotic Ligand Model but requires a value for the model to run

The biotic ligand model was used to predict toxic levels of Cd for fathead minnow (*Pimephales promelas*) and a cladoceran, or water flea (*Ceriodaphnia dubia*). Toxic levels of Zn were predicted for *P. promelas* and the water flea *Daphnia magna*. With previous water chemistry investigations, PWD compared dissolved Cu to BLM-derived toxicity predictions for three target species. However, in 2007, EPA developed ambient freshwater quality recommendations for Cu, integrating the BLM with appropriate margins of safety for protecting aquatic life. Hydroqual revised the BLM computer interface with a module for calculating the EPA-recommended Cu water quality criteria (Hydroqual 2007). This module was thus used in lieu of species-specific toxic interactions for dissolved Cu samples collected from Poquessing Creek Watershed. When dissolved Cu data are provided, the model compares these results to the estimated water quality criterion and calculates acute toxicity units (TU) as the analytical result divided by the water quality criterion. Samples with TU >1.0 represent violations of recommended water quality criteria.

It should be noted that EPA ambient water quality criteria for Cu (EPA 2007) are not enforceable water quality standards, but rather should be considered guidelines for states and authorized tribes to use in developing water quality standards. These recommendations may be slow to be adopted by state water management agencies such as PADEP due to the relatively large number of water quality parameters that must be analyzed to supply BLM input data.

4.4 WATER CHEMISTRY RESULTS

4.4.1 DISSOLVED OXYGEN

Along with temperature, dissolved oxygen (DO) concentration may be the most important factor shaping heterotrophic communities in streams and rivers. As sufficient DO concentration is critical for fish, amphibians, crustacea, insects, and other aquatic invertebrates, DO 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. Poquessing Creek Watershed is designated a warm water fishery (WWF) that cannot support salmonid fish year-round. Furthermore, the stream is not considered appropriate for a put-and-take fishery (*i.e.*, stocking trout to provide recreational opportunities). PADEP water quality criteria require that minimum DO concentration in a WWF not fall below 4.0 mg/L and that daily averages remain at or above 5.0 mg/L.

As colder stream water has a greater capacity for dissolved oxygen and metabolic activity slows down in colder water, Philadelphia’s streams rarely experience DO problems in winter. Violations of DO criteria can occur in spring and summer when water temperatures are higher and biological activity increases. Furthermore, nutrient-enriched streams with excessive algal growth often experience severe diel fluctuations in DO that may result in violations of daily minimum criteria, and in a few cases, violation of the daily average requirement. Despite cooler water temperatures, DO violations may be more common in early spring at some sites because canopy cover is reduced prior to leaf-out and algal growth rates are high.

Continuous water quality monitoring instruments (YSI Model 6600 and 600XLM Sondes) were deployed at three sites throughout Poquessing Creek Watershed from 2008 to 2009 in order to collect data in 15- or 30-minute intervals. A total of 927 days of DO data were collected from these monitoring locations through November 2009 and are considered herein for the Poquessing Creek Watershed CCR. Beginning in 2008, PWD reports annual continuous water quality statistics from all stations in the PWD-USGS Water Quality Monitoring Network in the City of Philadelphia's Stormwater Annual Report. Installing, servicing, and repairing these instruments in an urban environment presented many challenges, as DO membranes were subject to fouling during and after storm events. Beginning in 2007, PWD began investigating the use of optical DO monitoring technology and deployed several optical/membrane probe pairs side by side in monitoring instruments throughout the PWD-USGS Water Quality Monitoring Network, including sites in Poquessing Creek Watershed. A protocol for evaluating and rejecting data from intervals when probe failure occurred was developed (Appendix C). Quality of recovered data was excellent, owing to procedures for cleaning and replacing sondes that were developed and refined over the course of four years of study in the nearby Tookany-Tacony/Frankford and Wissahickon Watersheds.

However, when interpreting continuous DO data, one must keep in mind that *in situ* DO probes can only measure dissolved oxygen concentration of water in the vicinity of the probe. Furthermore, to obtain accurate measurements with membrane-based probes, probes should be exposed to flowing water or probes themselves must constantly be in motion. While it was not always possible to situate instruments in ideal locations due to conditions found in urban areas (*e.g.*, severe flows, infrastructure effects, debris accumulation, vandalism, etc.), low-flow velocity measurements and channel geometry measurements indicated highly turbulent flow conditions at all mainstem sonde sites.

4.4.1.1 RESULTS

DO concentration in Poquessing Creek Watershed was found to be highly variable, both seasonally and spatially, but in general, DO was controlled by temperature, natural community metabolism and inputs of untreated stormwater. Overall, across the three continuously monitored sites, violations of the instantaneous minimum DO criterion occurred during 1.6% of total observed hours, and violations of the daily average DO criterion occurred on 2.1% of total days monitored (Table 4.11). These violations were almost exclusively restricted to site PQ665 in the warmer months. In late June and mid-July 2009, DO at site PQ665 was consistently observed at less than 2 mg/L, or less than 20% saturation, during two separate instances of four consecutive days at baseflow conditions (Figure 4.5), with some daily minima less than 1 mg/L. DO was not observed to be as severely low over the same period at PQ050 or PQB025 (Figure 4.6 and Figure 4.7, respectively). Water temperatures were also well below the criterion for that period, and were generally observed around 20°C at PQ665. Diel fluctuations of DO and pH at PQ665 were also low, therefore the violations cannot be attributed to algal activity. Field checks of the optical DO probe did not find any discrepancies with the instrumentation.

PWD discrete water chemistry sampling concluded in fall 2008, so no concurrent BOD, bacteria or ammonia data were available to investigate potential causes of the low DO conditions observed at site PQ665 in summer 2009. However, BOD_5 in the range of 2.27-4.56 mg/L was observed in August 2008 at site PQ665. A turbidity peak of 497 NTU was observed on 6/26/09, and a peak of 1934 NTU was observed on 7/16/09, although the latter peak occurred during a period of questionable turbidity data.

In addition to DO data, pollution concerns at site PQ665 are reinforced by BOD, turbidity, and total phosphorus data, as described in Sections 4.4.2, 4.4.6.2, and 4.4.8.1.4, respectively. While performing grab sampling and servicing the continuous water quality monitor, PWD BLS staff observed surface runoff coming down the left bank at PQ665, and subsequent thermal imaging data collection in January 2010 suggested a point source of dry weather pollution located in Bensalem Township. PWD has investigated the thermal anomaly in the vicinity of site PQ665 and forwarded information about a leaking sanitary sewer to the Bucks County Health Department.

The above case notwithstanding, the effect of algal activity on DO was evident at periods throughout 2008-2009 at all three sites. Pronounced diel fluctuations of DO and pH were observed during baseflow conditions in warm months, conditions favorable for periphyton growth. Storm events had a scouring effect that suppressed periphyton growth, but within a few days the characteristic diel fluctuation signal typically returned (Figure 4.8). Effects of stream metabolism on DO concentration are addressed further in section 4.5 (Stream Metabolism). Additional time series plots of continuous dissolved oxygen concentration and percent saturation levels are presented in Appendix E.

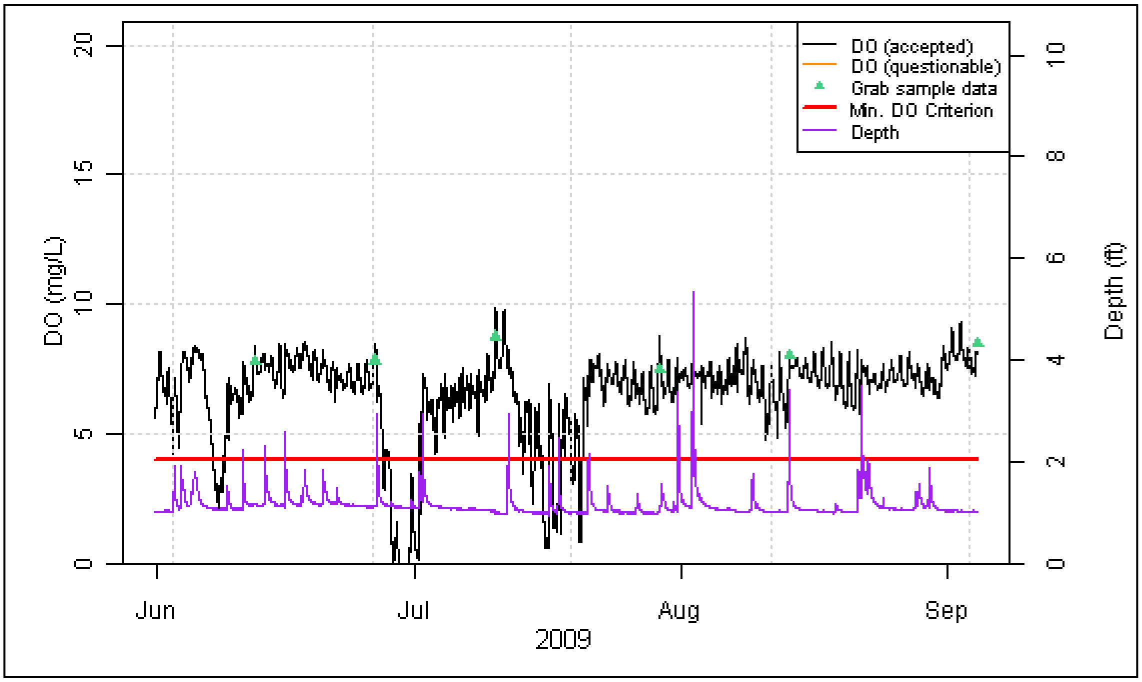


Figure 4.5 Dissolved Oxygen and Stream Depth at Site PQ665, 6/1/09 – 9/4/09

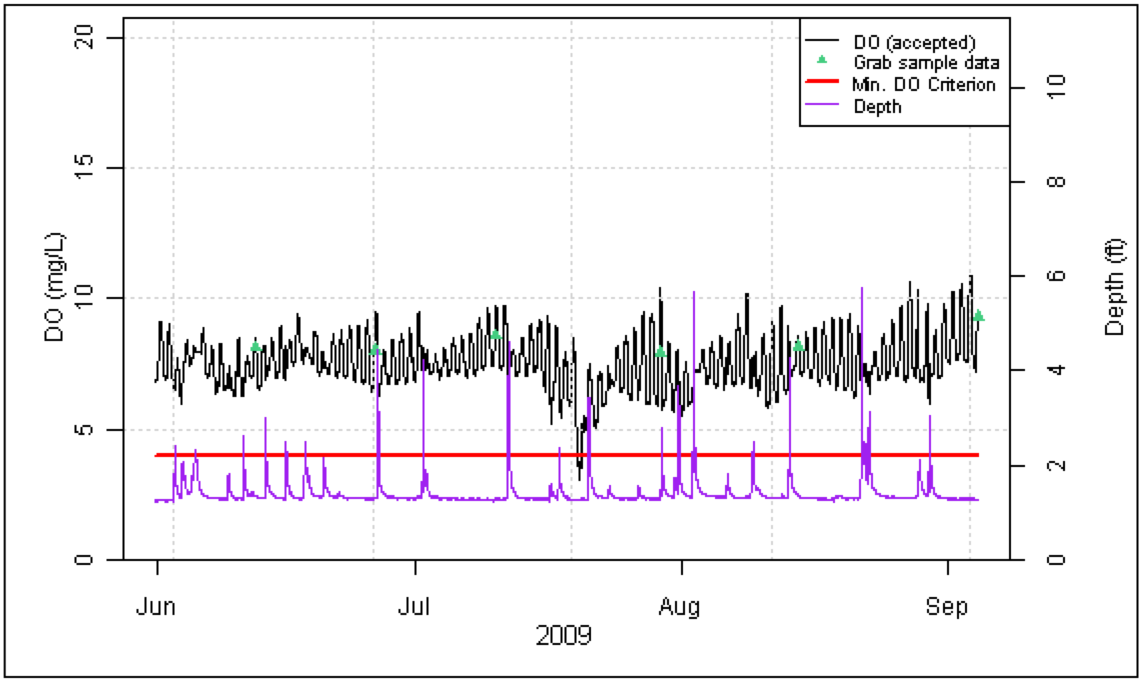


Figure 4.6 Dissolved Oxygen and Stream Depth at Site PQB025, 6/1/09 – 9/4/09

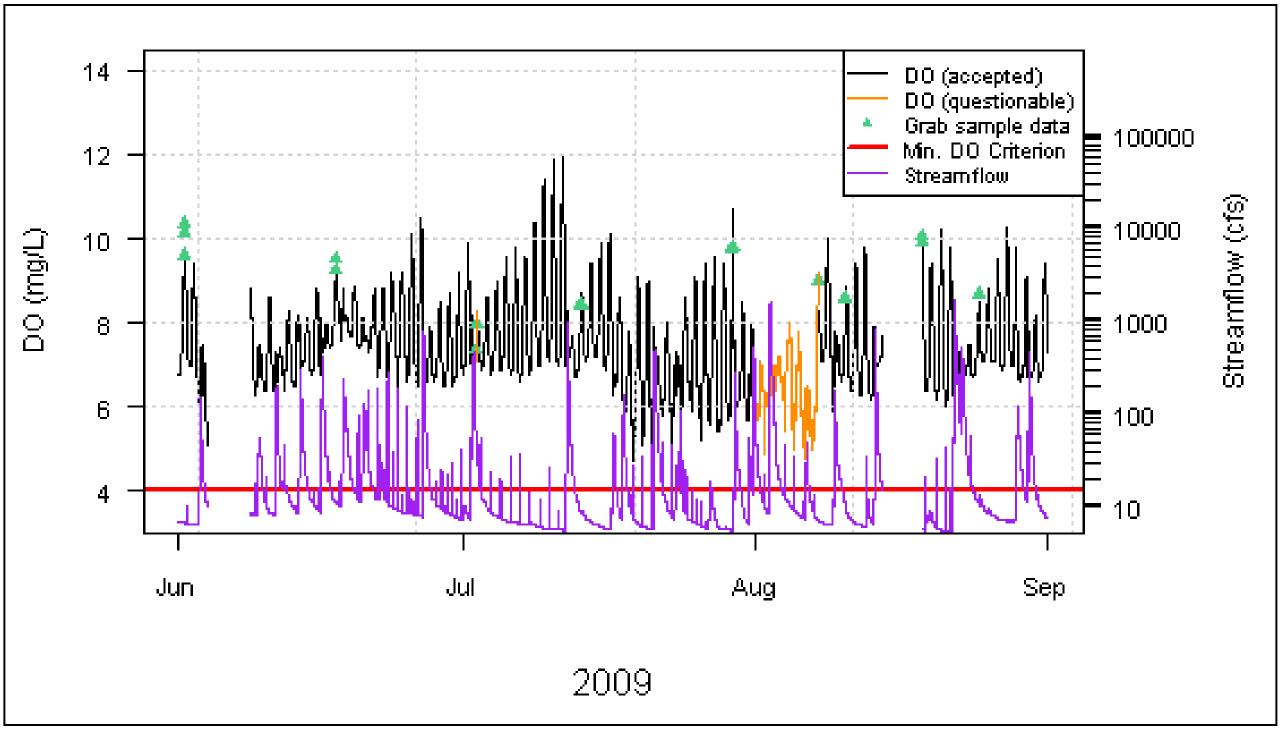


Figure 4.7 Dissolved Oxygen and Streamflow at Site PQ050, 6/1/09 – 9/1/09

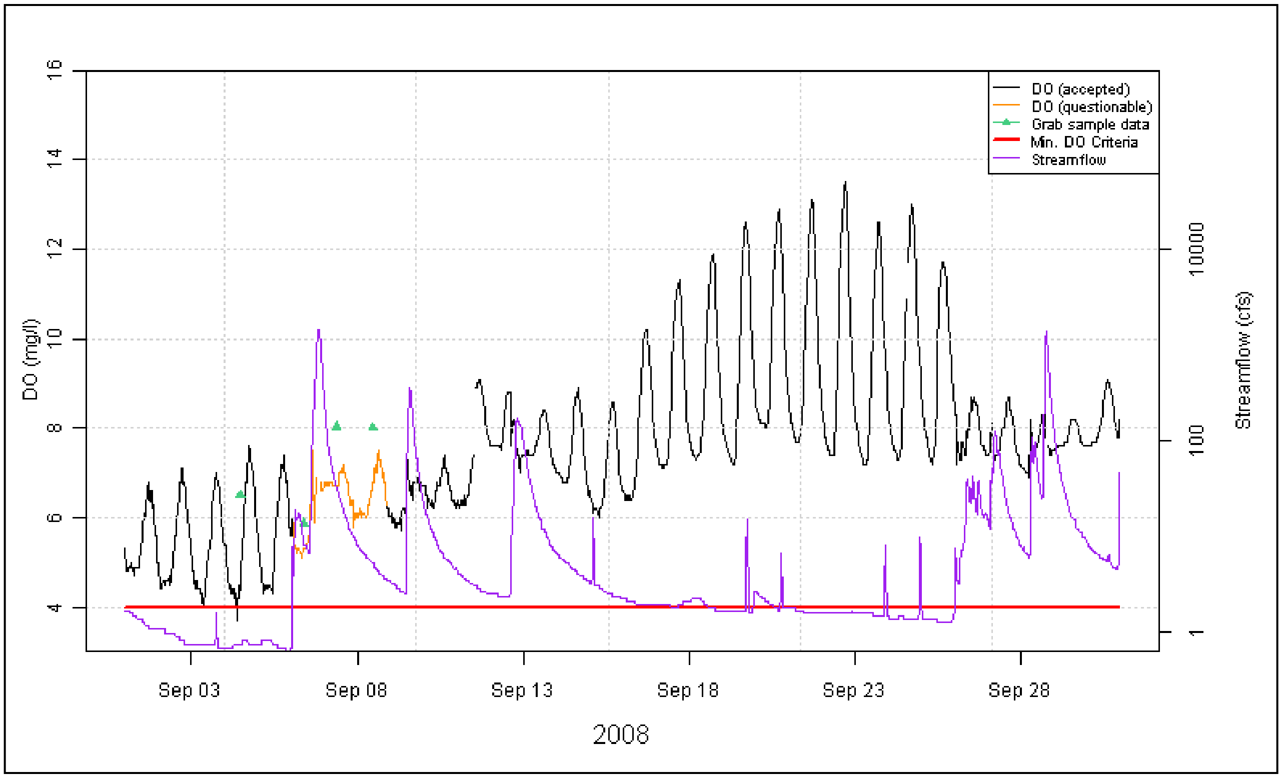


Figure 4.8 Dissolved Oxygen and Streamflow at Site PQ050, Sept. 2008

Table 4.11 Continuous Water Quality Data Meeting/Exceeding Standard by Site

Parameter	Standard	Site	Total hours accepted data	Total days accepted data	Percent hours flagged data	Percent hours violation	Percent hours compliance
Sonde DO	Instantaneous minimum	PQ665	5666.3	236.1	8.3	6.1	93.9
Sonde Temperature	Maximum		6179.5	257.5	0.0	10.3	89.7
Sonde Turbidity	Maximum (reference)		5783.0	241.0	6.4	63.9	36.1
Sonde pH	Maximum		5875.5	244.8	4.9	0.1	99.9
Sonde pH	Minimum		5875.5	244.8	4.9	0.0	100.0
Sonde DO	Instantaneous minimum	PQB025	7089.8	295.4	0.0	0.1	99.9
Sonde Temperature	Maximum		7091.5	295.5	0.0	10.8	89.2
Sonde Turbidity	Maximum (reference)		5749.3	239.6	18.9	33.2	66.8
Sonde pH	Maximum		6765.8	281.9	4.6	0.1	99.9
Sonde pH	Minimum		6765.8	281.9	4.6	0.0	100.0
Sonde DO	Instantaneous minimum	PQ050	9483.0	395.1	5.5	0.0	100.0
Sonde Temperature	Maximum		9727.5	405.3	3.0	10.2	89.8
Sonde Turbidity	Maximum (reference)		9075.0	378.1	9.5	42.7	57.3
Sonde pH	Maximum		9728.0	405.3	3.0	0.0	100.0
Sonde pH	Minimum		9728.0	405.3	3.0	0.0	100.0

Parameter	Standard	Site	Total days accepted data	Percent days flagged data	Percent days violation	Percent days compliance	
Sonde DO	Daily Average	PQ665	232	4.5	7.8	92.2	
		PQB025	294	1.3	0.3	99.7	
		PQ050	364	12.3	0.0	100.0	

4.4.2 BIOCHEMICAL OXYGEN DEMAND (BOD)

Biochemical oxygen demand is an empirical test that measures depletion of oxygen within a water sample over a period of time due to respiration of microorganisms, as well as oxidation of inorganic constituents (*e.g.*, sulfides, ferrous iron, nitrogen species) (Eaton *et al.*, 2005). Inhibitors may be used to prevent nitrification in a Carbonaceous Biochemical Oxygen Demand (CBOD) test, and the test may be carried out over the course of 30 or more days to yield ultimate BOD. The BOD_5 test, in which depletion of DO is measured over a five-day period, was applied most consistently to water samples from sites in Poquessing Creek Watershed. BOD is one of the most important input parameters for computer simulation of oxygen demand in water quality models. As warm stream water has a limited capacity for DO, excess BOD may preclude warmwater streams from meeting water quality criteria despite reaeration due to atmospheric diffusion and instream production of DO by algal photosynthesis.

Poquessing Creek Watershed is affected by permitted MS4 stormwater outfalls, non-point, and autochthonous (in-stream production) sources, which can introduce BOD to the stream. Stormwater discharges were believed to be the most important sources of BOD loading to Poquessing Creek Watershed. Elevated BOD_5 is a good indicator of the presence of organic material in stream water that may exert oxygen demand independently of algal metabolism.

The BOD_5 test provides little information when samples are dilute (MRL= 2 mg/L), which is often the case in dry weather samples from streams where point source discharges of BOD are regulated and there are no other major sources of organic enrichment. All dry weather BOD_5 samples collected in 2008 from Poquessing Creek Watershed were analyzed at reporting limits of 2 mg/L. Approximately 5% of wet weather BOD_5 samples were analyzed at a higher reporting limit of 10 mg/L, all associated with the 9/6/08 ISCO deployment. Overall, 96% of dry weather samples and 29% of wet weather samples had BOD_5 concentration below 2 mg/L reporting limits; 5% of wet weather samples had BOD_5 concentration below 10 mg/L reporting limits. In 99 dry weather samples, BOD_5 was only detected (*i.e.*, greater than 2mg/L) in the upper Poquessing Creek (site PQ665) or within the lower Byberry Creek (site PQB025). Dry weather BOD_5 was never detected at sites PQ050, PQ155, PQ395, PQ820, or PQB305. BOD_5 was detected in 13% and 7% of all dry weather samples at PQ665 and PQB025, respectively. The maximum observed dry weather BOD_5 was 4.56 mg/L, which occurred on 8/27/08 at PQ665. In 175 wet weather samples, BOD_5 was detected at all sites. Sites PQB025, PQ050 and PQ665 were each found to have more than 50% wet weather BOD_5 samples above reporting limits. The maximum observed wet weather BOD_5 was 11.14 mg/L, which occurred on 10/25/08 at PQB025.

As BOD_5 concentration data were affected by a large number of imprecise values, it was not possible to evaluate differences between sites or evaluate weather effects. Overall, BOD_5 concentration was greater in wet weather, and most frequently detected at sites PQB025, PQ050, and PQ665.

4.4.3 PH

Water quality criteria established by PADEP regulate pH to a range of 6.0 to 9.0 in Pennsylvania's freshwater streams (25 PA Code § 93). Direct effects of low pH on aquatic ecosystems have been demonstrated in streams affected by acid mine drainage (Butler *et al.*, 1973) and by acid rain

(Sutcliff and Carrick, 1973). Aquatic biota may also be indirectly affected by pH due to its influences on other water quality parameters, such as ammonia. As pH increases, a greater fraction of ammonia N is present as un-ionized NH_3 (gas). For example, ammonia is approximately 10 times as toxic at pH 8 as at pH 7. Extreme pH values may also affect solubility and bioavailability of metals (*e.g.*, Cu, Al), which have individually regulated criteria established by PADEP.

Fluctuations in pH generally occur most often at highly productive sites with abundant periphytic algae (Figure 4.9), primarily due to the relationship between algae and dissolved inorganic carbon (DIC). This relationship is further supported by observed dampening of diel pH fluctuations following scouring storm events (Figure 4.10). Moderate diel fluctuations in pH were observed at most sites along with DO fluctuations, yet pH violations were very rare, occurring on 0.1% of total hours monitored (Table 4.11). Algal densities and stream metabolism effects on stream pH are discussed further in section 4.5.2 (Relation of Algal Activity to stream pH). Additional time series plots of continuous pH are presented in Appendix G.

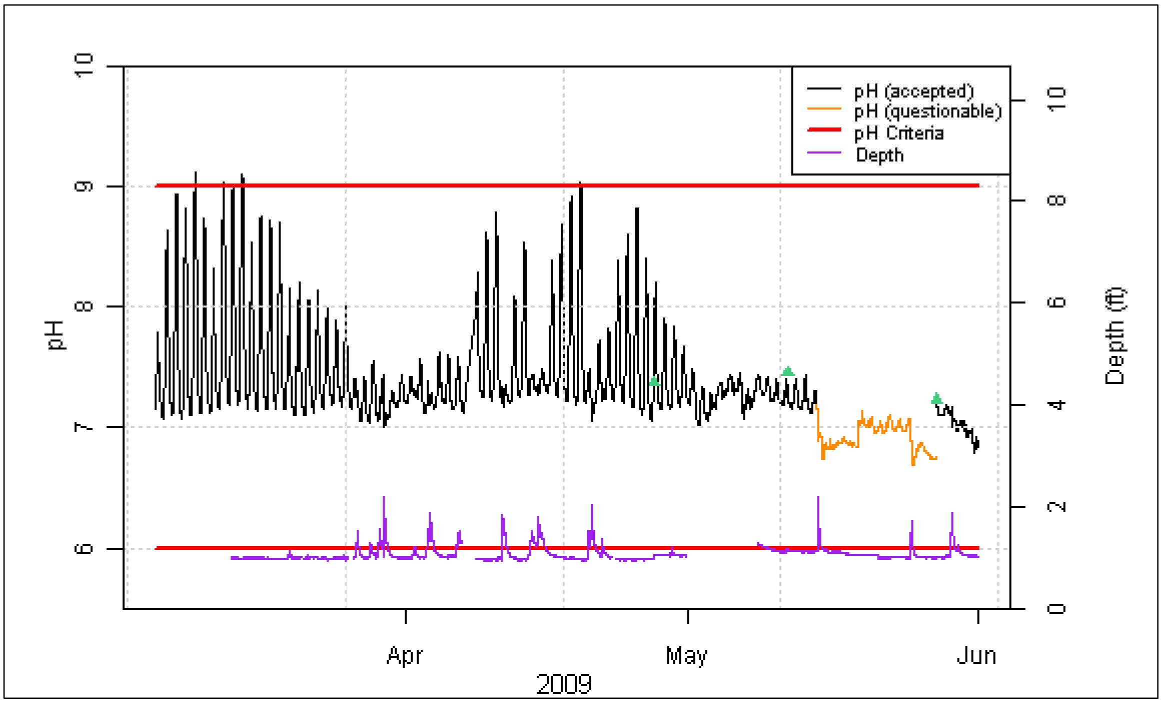


Figure 4.9 pH Fluctuations at Site PQ665, Mar-May 2009

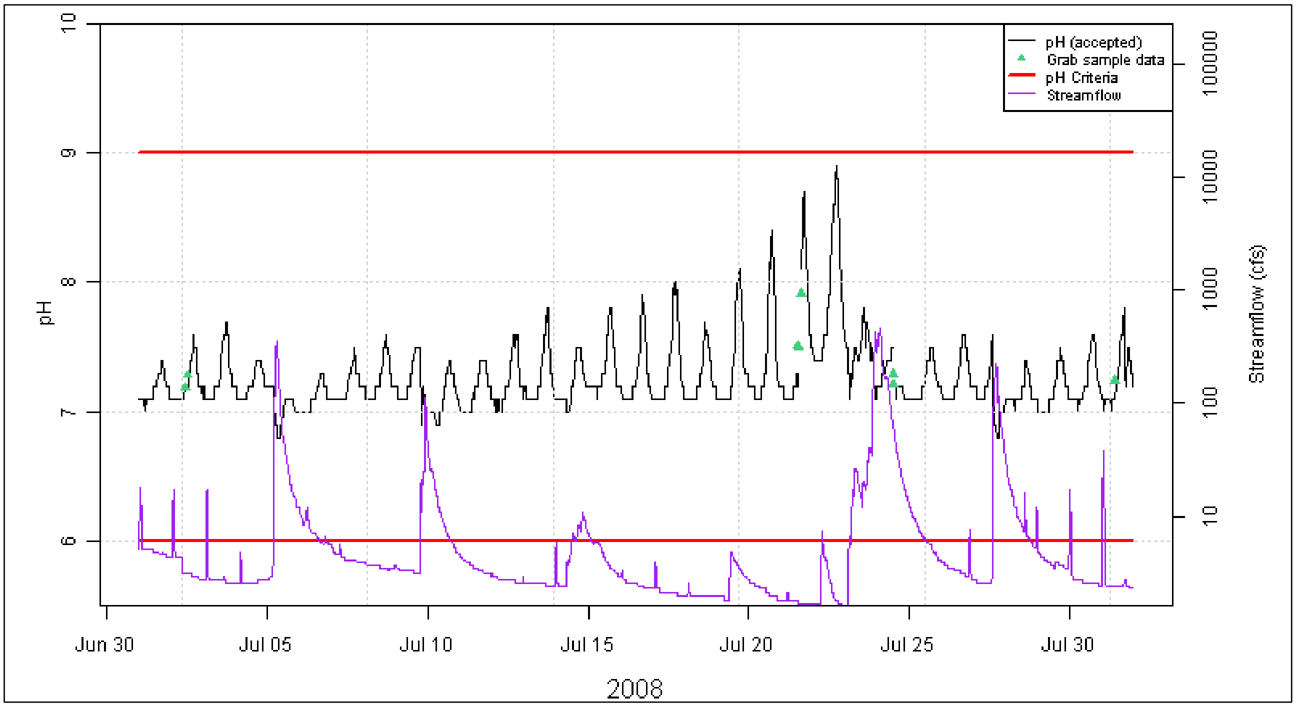


Figure 4.10 Dampening of pH Fluctuations at Site PQ050 Following a Wet Weather Event on 7/24/08

Poquessing Creek Watershed is not known to be directly affected by anthropogenic inputs of acids or bases (*e.g.*, acid mine drainage, industrial discharge) that would tend to change stream pH independently of the natural bicarbonate buffer system. Accordingly, the PCW Integrated Watershed Management Plan (IMWP) does not identify pH as a water quality concern. As pH fluctuations are directly related to algal metabolism and DO problems, remediation efforts intended to decrease excessive algal growth should generally decrease the likelihood of pH problems as well.

One important caveat, however, is that pH problems may occur at any time of the year when algal production is high. It is possible to have severe springtime fluctuations in DO that do not violate water quality standards due to the greater DO capacity of colder water. While there is a small compensatory effect of lower temperatures on pH toxicity, in general, pH effects may be present under high productivity conditions whenever they occur.

4.4.4 FECAL COLIFORM , *E. COLI*, AND ENTEROCOCCI BACTERIA

4.4.4.1 INTRODUCTION

Fecal coliform, *E. coli*, and Enterococci bacteria concentrations are positively correlated with point and non-point contamination of water resources by human and animal waste and are used as indicators of poor water quality. Bacteria samples collected from 2008-2009 indicate a strong correlation between fecal coliform and *E. coli* (r (278) = 0.96, $p < 0.001$), and moderate yet significant correlations between fecal coliform and enterococci (r (61) = 0.69, $p < 0.001$), and *E. coli* and enterococci (r (61) = 0.71, $p < 0.001$) (Figure 4.11).

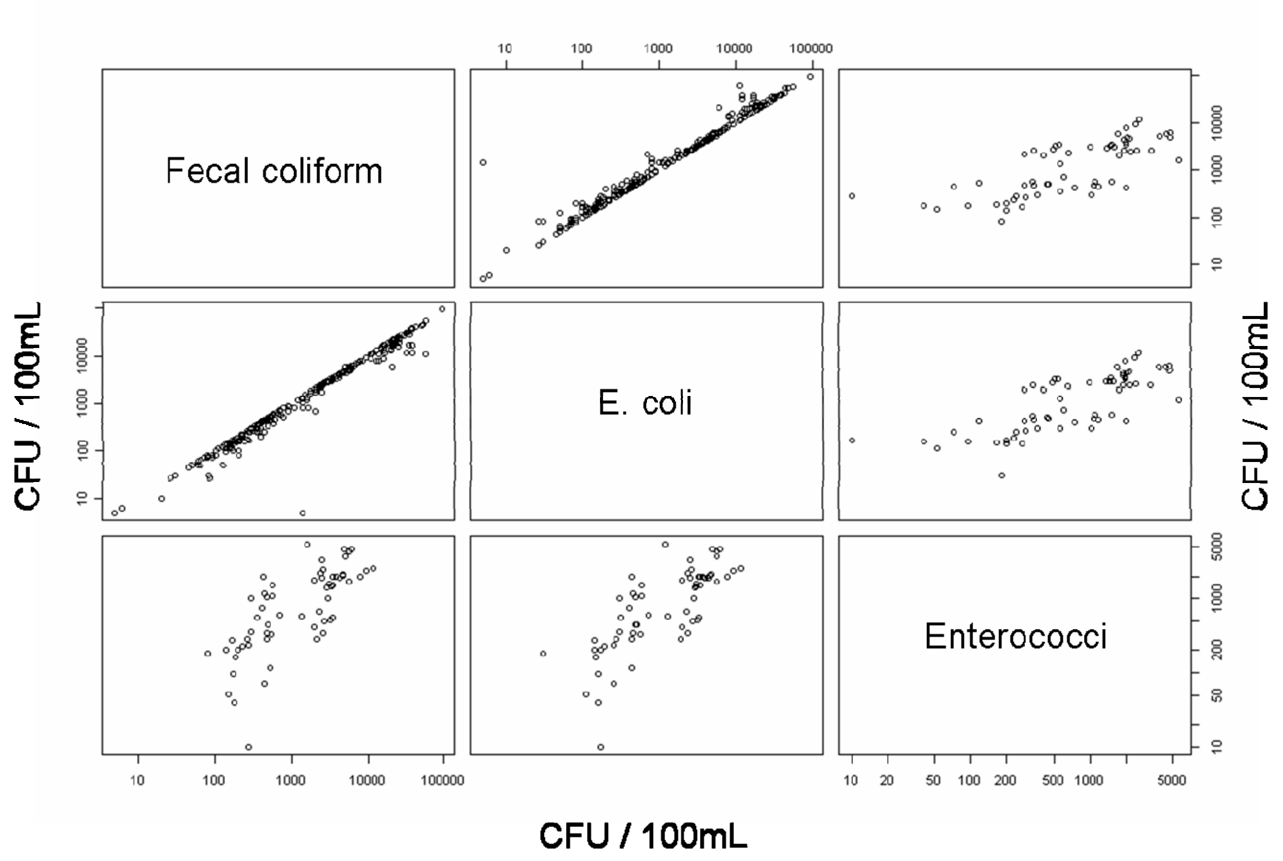


Figure 4.11 Scatterplot Matrix of 2008-2009 Bacteria Data (x-y axes plotted in $\log_{10}$ scale)

PADEP has established a maximum limit for fecal coliform of 200 colony forming units, or "CFU," per 100mL sample during the period 1 May – 30 Sept, the "swimming season" and a less stringent limit of 2,000 CFU/100mL for all other times. It should be noted that state criteria are based on the geometric mean of a minimum of five consecutive samples, each sample collected on different days during a 30-day period (25 PA Code § 93.7). As bacterial concentrations can be significantly affected by rain events and otherwise may exhibit high variability, individual samples are not as reliable as replicate or multiple samples taken over a short period. PADEP has not set water quality standards for *E. coli* or enterococci; instead, USEPA (1986) guidance was referenced in setting thresholds for these parameters in both swimming and non-swimming recreational seasons.

PWD has expended considerable resources toward documenting concentrations of fecal coliform bacteria, *E. coli*, and Enterococci in the Philadelphia regional watersheds. The sheer amount of data collected allows for more comprehensive analysis than does the minimum sampling effort needed to verify compliance with water quality criteria. In keeping with the organizational structure of PWD watershed management plans, fecal coliform bacteria analysis has been separated into dry (Target A) and wet weather (Target C) components. Wet weather sampling is conducted with the goal of characterizing a storm event at various locations along the river in its entirety (*i.e.*, rising limb, peak discharge, and descending limb of hydrograph). Wet weather was defined as a minimum rainfall of 0.05 inches in a 48-hour period. Note that any samples observed below the reporting limit (*i.e.,* non-detect) were assumed as half the reporting limit for the purposes of statistical analyses; this convention was also used for subsequent parameters described in this report (*e.g.,* TSS, metals, ammonia, nitrate, orthophosphate).

4.4.4.1.1 DRY WEATHER FECAL COLIFORM BACTERIA (TARGET A)

The geometric mean of 63 fecal coliform bacteria samples collected from Poquessing Watershed in dry weather during the non-swimming season from 2008-2009 did not exceed 2,000 CFU/100mL (Table 4.16, Figure 4.12). In fact, only one individual sample, measured at 2,100 CFU/100mL, had fecal coliform concentration greater than 2,000 CFU/100mL. Conversely, the geometric mean of 39 fecal coliform samples collected in dry weather exceeded water quality criteria of 200 CFU/100mL during the swimming season (Table 4.16, Figure 4.13).

A decrease in dry weather fecal coliform concentrations can be seen in both swimming and non-swimming seasons when data from 2008-2009 is compared to historical data from 1970-1980 (Table 4.16). The results from a two-way analysis of variance (ANOVA) test for effects of sampling group (historic and modern) and season (swimming and non-swimming) on mean fecal coliform concentrations were significant for both factors (F(1,252) = 121.1, $p<0.001$ and F(1,252) = 35.2, $p<0.001$, respectively). Post-hoc analysis of (ANOVA) results indicate that significant decreases in fecal coliform concentrations have occurred between the period from 1970-1980 and 2008-2009 during both the swimming ($p<0.001$) and non-swimming ($p<0.001$) seasons. However, there was a 53% increase in mean fecal coliform concentration at PQB305 during the swimming season (Table 4.16), although a Student's t-test did not find the increase to be significant (T(11.6) = 0.78, $p = 0.78$).

Table 4.12 Historic (1970-1980) Fecal Coliform Concentration (CFU/100mL) Dry Weather Non-swimming Season (1 Oct. - 30 Apr.)

Site	Valid N	Mean	Geo. Mean	Std. Dev.	Median	Min.	Max.
PQ050	31	1734.8	924.3	1898.9	1100	60	8400
PQ820	39	4662.4	1284.6	9613.8	1300	100	54000
PQB305	9	6458.9	1546.3	10955.4	1100	250	30300
PQB320	18	8305.6	1125.7	18230.8	675	10	73000
All Sites	97	4569.5	1147.9	10588.6	1100	10	73000

Table 4.13 Modern (2001-2009) Fecal Coliform Concentration (CFU/100mL) Dry Weather Non-swimming Season (1 Oct. - 30 Apr.)

Site	Valid N	Mean	Geo. Mean	Std. Dev.	Median	Min.	Max.
PQ050	22	354.2	193.3	557.8	181.5	30	2100
PQ155	8	88.3	63.5	60.6	85	6	210
PQ395	8	110.6	93.5	81.3	87	45	300
PQ665	20	280.0	164.6	365.6	140	30	1400
PQ820	7	266.4	90.2	426.2	110	5	1200
PQB025	11	588.5	197.9	717.9	160	5	2000
PQB305	8	304.5	208.2	233.8	255	26	710
All Sites	84	306.6	148.0	458.0	150	5	2100

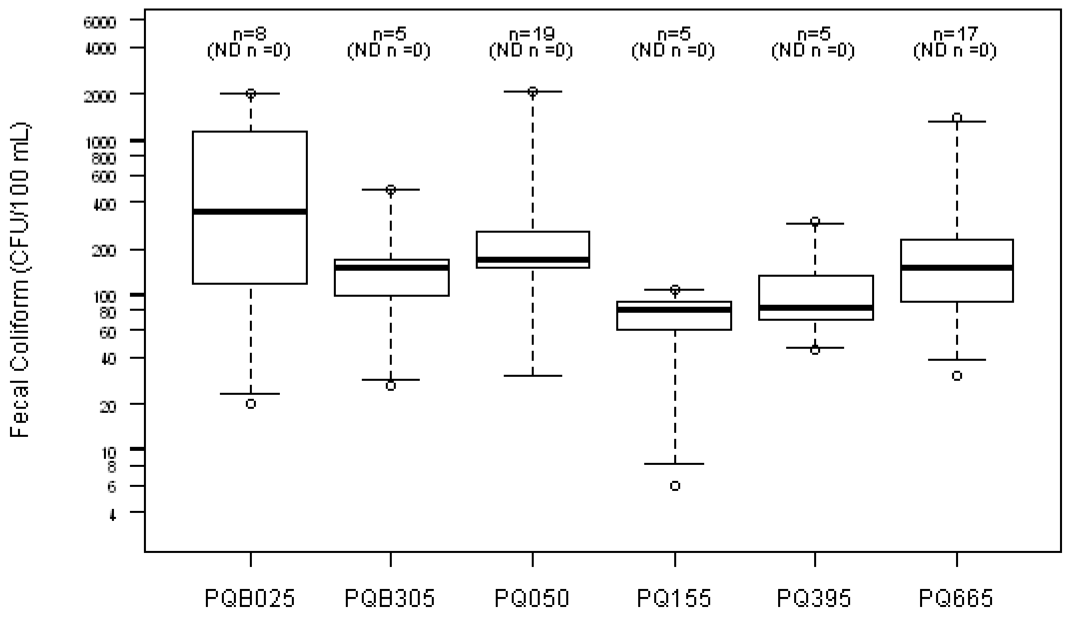


Figure 4.12 Dry Weather Fecal Coliform Concentrations During Non-swimming Season at Poquessing Creek Watershed Sites, 2008-2009[1]

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[1] All boxplots use the following conventions: only subsets with sample size > 4 are plotted; sample size and number of samples below reporting limits are listed above each subset; boxplot whiskers extend to 1st and 99th percentiles. Boxplots for other water quality parameters are contained in Appendix J.

Table 4.14 Historic (1970-1980) Fecal Coliform Concentration (CFU/100mL) Dry Weather Swimming Season (1 May - 30 Sept.)

Site	Valid N	Mean	Geo. Mean	Std. Dev.	Median	Min.	Max.
PQ050	19	3065.3	1714.3	3083.3	1700	100	9500
PQ820	22	15643.2	5326.0	23206.7	3900	300	91600
PQB305	4	3137.5	2882.8	1595.5	2600	1900	5450
PQB320	11	19124.5	8783.5	21962.4	11000	820	70000
All Sites	56	11166.3	3828.3	18564.0	2900	100	91600

Table 4.15 Modern (2001-2009) Fecal Coliform Concentration (CFU/100mL) Dry Weather Swimming Season (1 May - 30 Sept.)

Site	Valid N	Mean	Geo. Mean	Std. Dev.	Median	Min.	Max.
PQ050	12	619.2	330.9	1134.8	295	80	4200
PQ155	10	2842.0	623.4	6261.0	400	120	20000
PQ395	10	1442.1	665.0	1727.5	610	60	4900
PQ665	11	338.8	309.1	164.1	280	150	727
PQ820	9	667.8	441.3	733.9	380	130	2300
PQB025	11	1175.5	887.6	1157.7	670	420	4300
PQB305	10	4828.1	1857.2	7692.7	3050	81	26000
All Sites	73	1660.5	598.5	3913.8	440	60	26000

Table 4.16 Historic (1970-1980) and Current (2008-2009) Fecal Coliform Concentrations (CFU/100mL) During Dry Weather (Swimming and Non-swimming Seasons)

Sampling Period	Season	Valid N	Mean	Geo. Mean	Std. Dev.	Median	Min.	Max.
2008-2009	Swimming	39	953.6	456.9	1479.8	380	60	6000
2008-2009	Non Swimming	63	342.7	159.5	511.3	154	5	2100
1970-1980	Swimming	56	11166.3	3828.3	18564.0	2900	100	91600
1970-1980	Non Swimming	97	4569.5	1147.9	10588.6	1100	10	73000

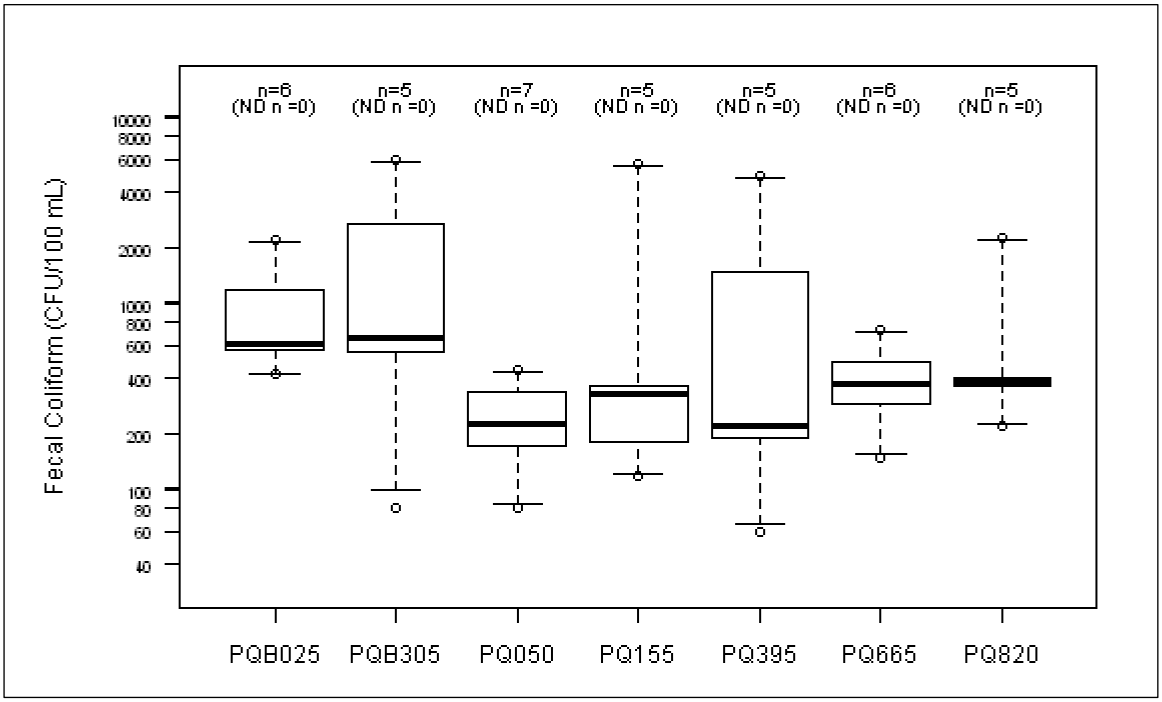

Figure 4.13 Dry Weather Fecal Coliform Concentrations During Swimming Season at Poquessing Creek Watershed Sites, 2008-2009

Spatial and temporal variability of 2001-2009 fecal coliform concentrations was also compared by performing a two-way analysis of variance (ANOVA). Location (*i.e.*, Byberry Creek, and Poquessing Creek upstream of Byberry-Poquessing confluence) and season (*i.e.*, swimming vs. non-swimming) served as the categorical predictors, and fecal coliform concentration was considered the dependent variable. Collectively, there was no significant difference in mean fecal coliform bacteria concentrations among Byberry and Poquessing sites upstream of their confluence (F(5,111) = 1.4, p>0.05), or interactions between season and location (F(5,111) = 1.4, p>0.05).

A more detailed investigation of variability between sites was performed via a one-way ANOVA of 2001-2009 fecal coliform concentrations during the swimming season (Table 4.15). Collectively, there was a significant difference in mean concentrations between sites (F(6,66) = 3.1, $p < 0.05$). However, a Tukey HSD test revealed that the only significant differences in mean fecal coliform concentration were between sites PQB305 and PQ665 (p<0.05), and sites PQB305 and PQ050 (p<0.05). A similar analysis of dry weather 2001-2009 data during the non-swimming season (Table 4.13) revealed no significant differences in mean concentrations between sites (F(6,77) = 1.5, $p > 0.05$).

The 2001-2009 data reflect that dry weather fecal coliform concentration in Poquessing Creek during swimming and non-swimming periods was significantly lower than wet weather concentration (Mann-Whitney U = 27847, $p < 0.001$). Moreover, the minimal effect of spatial variability on fecal coliform concentrations, and the significant decrease in concentrations from historical data implies that current management strategies to reduce point source discharges and/or infrastructure failures are functioning properly during dry weather. Research has shown that fecal coliform bacteria may adsorb to sediment particles and persist for extended periods in sediments (Van Donsel *et al*., 1967; Gerba, 1976). At sites where dry weather inputs of sewage are not indicated, presence of persistent background concentrations of bacterial indicators in dry weather may thus more strongly reflect past wet weather loadings than dry weather inputs (Dutka and Kwan, 1980). Evidently, there exist several possible sources of fecal coliform bacteria within the watershed, all or combinations of which may be acting within different spatial and temporal dimensions. PWD is piloting a Bacterial Source Tracking (BST) program that may eventually be useful in identifying the sources of fecal coliform bacteria collected in dry weather. Of particular interest is the relative proportion of the total bacterial load from human sources versus domestic and wildlife animal sources.

Table 4.17 Comparison of Historic (1970-1980) and Modern (2001-2009) Dry Weather Fecal Coliform Concentrations by Site

Site	Season	Valid N	Historic Mean	Historic Median	Valid N	Modern Mean	Modern Median
PQ050	S	19	3065.3**	1700	12	619.2	295
PQ050	NS	31	1734.8***	1100.0	22	354.2	181.5
PQ820	S	22	15643.2***	3900	9	667.8	380
PQ820	NS	39	4662.4*	1300.0	7	266.4	110
PQB305	S	4	3137.5	2600	10	4828.1	3050
PQB305	NS	9	6458.9*	1100.0	8	304.5	255

*p<0.01 **p<0.001 ***p<0.0001

4.4.4.1.2 WET WEATHER FECAL COLIFORM BACTERIA (TARGET C)

In the 2008-2009 period, 58 fecal coliform samples were collected in wet weather during the swimming season (*i.e.*, 5/1 - 9/30), and 120 samples were collected during the non-swimming season. Geometric means of all wet weather fecal coliform concentrations exceeded both swimming and non-swimming season criteria (Table 4.22, Figures 4.14 and 4.15).

Only three sites (PQ050, PQ665, and PQB025) had a meaningful sample size during the swimming season in the 2001-2009 period (Table 4.19); all other sites had n<5 during the swimming season, and the true distributions of fecal coliform concentration at those sites cannot be accurately estimated with such a limited sample size. Of the sites with meaningful sample sizes, geometric mean fecal coliform concentrations were between 30 (PQ665) and 96 (PQB025) times greater than PADEP water quality criteria during the swimming season. Application of the Mann-Whitney test found that wet weather fecal coliform concentrations are significantly higher during the swimming season than the non-swimming season (U = 5366, $p<0.001$).

Table 4.18 Historic (1970-1980) Fecal Coliform Concentration (CFU/100mL) Wet Weather, Swimming Season (1 May - 30 Sept.)

Site	Valid N	Mean	Geometric Mean	Std. Dev.	Median	Min.	Max.
PQ050	23	6783.0	3380.7	9010.3	3000	280	39000
PQ820	24	11258.3	4982.0	13718.9	3975	120	48000
PQB305	6	8805.0	4771.5	9898.4	3425	1380	23400
PQB320	9	22413.3	9605.0	27198.7	13000	1370	74000
All Sites	62	10980.0	4726.1	15222.3	3705	120	74000

Table 4.19 Modern (2001-2009) Fecal Coliform Concentration (CFU/100mL) Wet Weather, Swimming Season (1 May - 30 Sept.)

Site	Valid N	Mean	Geometric Mean	Std. Dev.	Median	Min.	Max.
PQ050	20	11786.0	5308.9	10620.5	6550	200	30000
PQ155	3	18216.7	3220.1	30124.1	1050	600	53000
PQ395	3	21966.7	9554.9	31214.8	4700	3200	58000
PQ665	20	17187.6	4526.8	17689.2	15611	100	57000
PQ820	3	14500.0	1294.1	24682.0	360	140	43000
PQB025	20	23120.0	15440.2	19789.0	21500	1700	93000
PQB305	3	12883.3	3464.4	20034.6	2100	550	36000
All Sites	72	17285.7	6351.7	17900.1	18000	100	93000

Table 4.20 Historic (1970-1980) Fecal Coliform Concentration (CFU/100mL) Wet Weather, Non-swimming Season (1 Oct. - 30 Apr.)

Site	Valid N	Mean	Geometric Mean	Std. Dev.	Median	Min.	Max.
PQ050	34	2653.5	1507.3	3129.8	1900	100	15000
PQ820	42	2552.4	996.1	5032.1	1100	40	29000
PQB305	9	1884.4	1415.2	1064.5	2000	120	3600
PQB320	18	3956.7	2073.9	6914.0	2345	120	31000
All Sites	103	2772.8	1338.7	4663.2	1600	40	31000

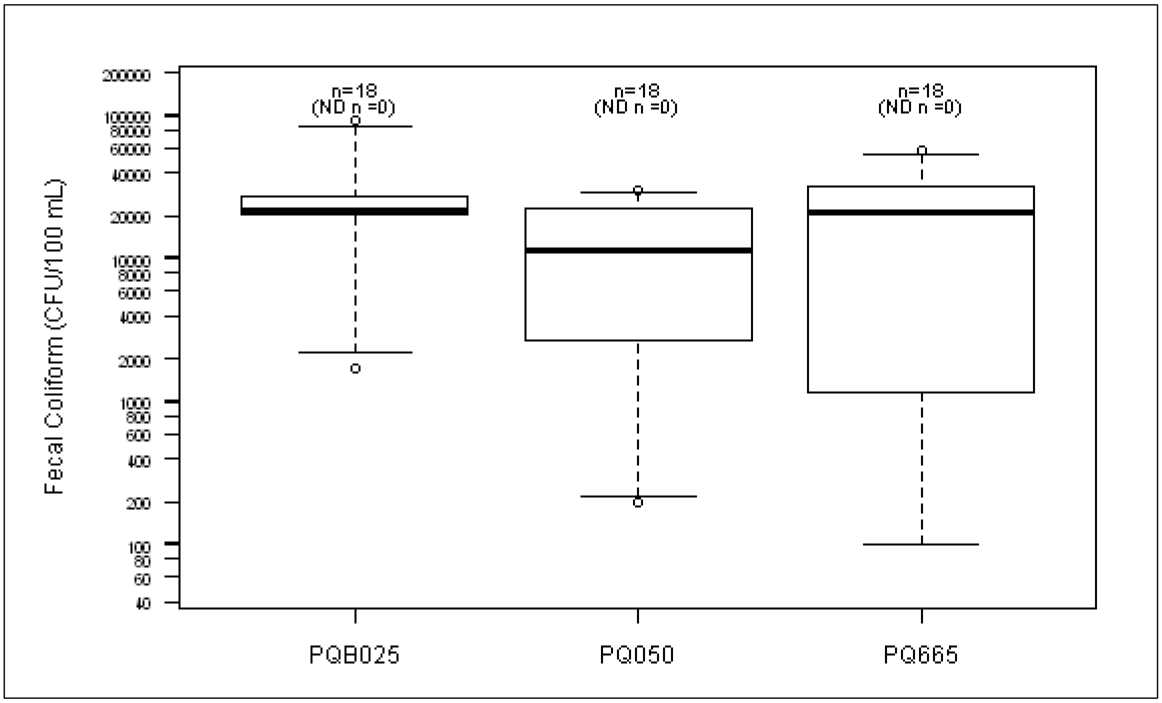

Figure 4.14 Wet Weather Fecal Coliform Concentration During Swimming Season at Poquessing Creek Watershed Sites, 2008-2009

Table 4.21 Modern (2001-2009) Fecal Coliform Concentration (CFU/100mL) Wet Weather, Non-swimming Season (1 Oct. - 30 Apr.)

Site	Valid N	Mean	Geometric Mean	Std. Dev.	Median	Min.	Max.
PQ050	40	6635.3	2448.9	9593.0	2550	100	52000
PQ155	3	2076.7	821.5	3051.3	330	300	5600
PQ395	3	2740.0	1124.3	3951.2	590	330	7300
PQ665	40	3188.8	1140.2	4529.8	1175	50	20000
PQ820	4	457.5	278.3	318.3	500	30	800
PQB025	41	7905.9	4392.5	9508.3	3500	430	38000
PQB305	3	1903.3	1394.7	1701.8	1400	510	3800
All Sites	134	5515.6	2068.4	8116.9	2650	30	52000

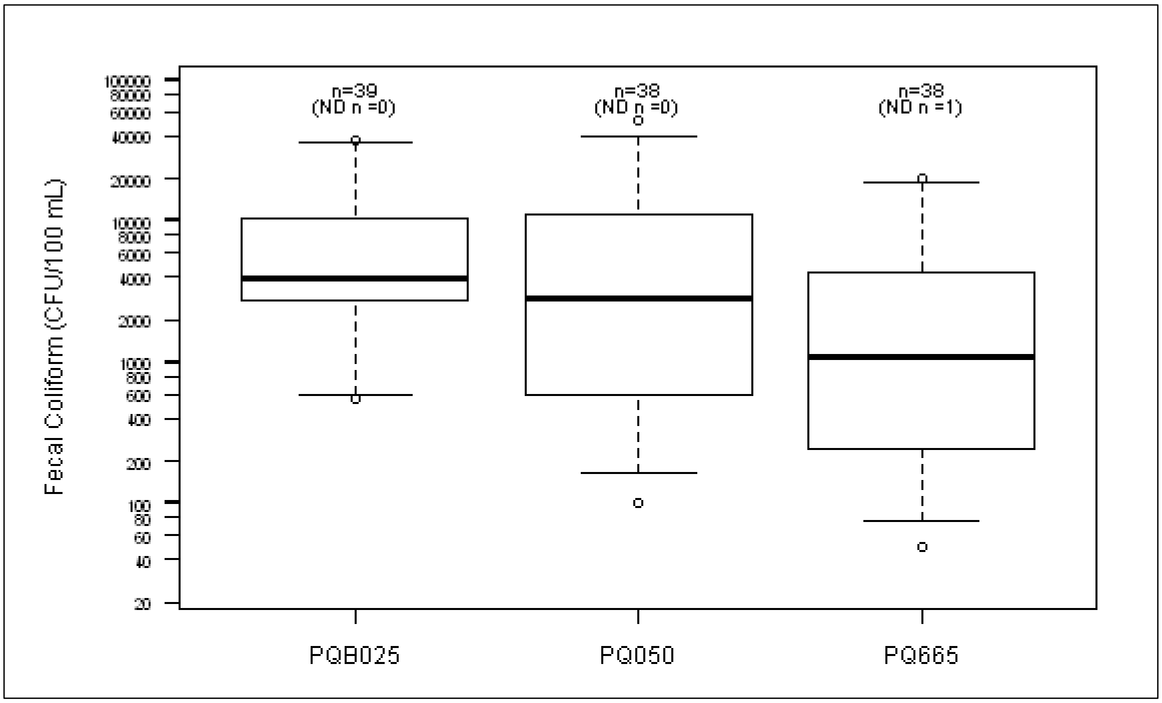

Figure 4.15 Wet Weather Fecal Coliform Concentration During Non-swimming Season at Poquessing Creek Watershed Sites, 2008-2009

Similarly, in the 2001-2009 period, geometric mean fecal coliform concentrations during the non-swimming season exceeded 2,000 CFU/100mL at sites PQ050 and PQB025, while meeting the standard at PQ665 (Table 4.21). Data from other sites had n≤ 4 and should be considered with discretion.

Variability of fecal coliform concentration between sites PQ050, PQ665, and PQB025 (*i.e.,* sites with n>3) was compared by performing a one-way analysis of variance (ANOVA) on data collected from 2001 through 2009 (Tables 4.19 and 4.21). Results indicate that the mean concentration of fecal coliform during wet weather was not significantly different between sites during the swimming season (F(2, 57), p>0.05), but was significantly different during the non-swimming season (F(2,118) = 5.69, p<0.01). During the non-swimming season, post-hoc tests confirm that site PQB025 had significantly higher mean fecal coliform concentrations than PQ665; there were no significant differences found between the mean fecal coliform concentrations of PQ050 and PQ665, and PQB025 and PQ050.

An increase in wet weather fecal coliform concentrations can be seen in both swimming and non-swimming seasons when data from 2008-2009 is compared to historical data from 1970-1980 (Table 4.22). The results from a two-way (ANOVA) test for effects of sampling group (historic and modern) and season (swimming and non-swimming) on mean fecal coliform concentrations were significant for both factors (F(1,340) = 63.8, p<0.001 and F(1,340) = 14.3, p<0.001, respectively). Post-hoc analysis of (ANOVA) results indicate that significant increases in fecal coliform concentrations have occurred between the period from 1970-1980 and 2008-2009 during both the swimming (p<0.001) and non-swimming (p<0.001) seasons. However, it must be noted that the 2008-2009 sampling program conducted by PWD specifically targeted wet weather events in their entirety. Sampling methods and equipment (*i.e.*, automated samplers) were more conducive to characterize fecal coliform concentrations at all points along the hydrograph and were more suitable to collect periods of peak fecal coliform concentrations.

Table 4.22 Historic (1970-1980) and Current (2008-2009) Fecal Coliform Concentrations (CFU/100mL) During Wet Weather (Swimming and Non-swimming Seasons)

Sampling Period	Season	Valid N	Mean	Geometric Mean	Std. Dev.	Median	Min.	Max.
2008-2009	Swimming	58	21064.2	9882.4	17996.9	21000	100	93000
2008-2009	Non Swimming	120	5950.8	2273.7	8441.4	3000	30	52000
1970-1980	Swimming	62	10980.0	4726.1	15222.3	3705	120	74000
1970-1980	Non Swimming	103	2772.8	1338.7	4663.2	1600	40	31000

These results do not specifically imply that fecal coliform loading to Poquessing Creek has been getting worse over time. The analysis was limited by the distribution of sites with historic data. There was only one site, PQ050, with sufficient data to allow for site-specific comparison of historic and modern data (Table 4.23). Student's t-tests found no significant difference in either recreational season (swimming season, *p*=0.23; non-swimming season, *p*=0.07) between historic and modern data at PQ050.

Table 4.23 Comparison of Historic (1970-1980) and Modern (2001-2009) Wet Weather Mean Fecal Coliform Concentrations by Site

Site	Season	Valid N	Historic Mean	Historic Median	Valid N	Modern Mean	Modern Median
PQ050	S	23	6783.0	3000	20	11786.0	6550
PQ050	NS	34	2653.5	1900	40	6635.3	2550
PQ820	S	24	11258.3	3975	3	14500.0	360
PQ820	NS	42	2552.4	1100	4	457.5	500
PQB305	S	6	8805.0	3425	3	12883.3	2100
PQB305	NS	9	1884.4	2000	3	1903.3	1400

4.4.5 TEMPERATURE

Temperature has a very strong influence on the structure of aquatic communities, determining the saturation concentration of dissolved oxygen and the rate of many biological and physicochemical processes. Though aquatic organisms generally have enzymes capable of working over a range of temperatures, and thus are able to acclimate to different conditions, thermal preferenda and tolerance ranges determine species' distributions. This effect is especially true of larger vertebrates, such as fish, but due to the close interaction with dissolved oxygen, it is difficult to isolate temperature related effects on species' distributions independent of dissolved oxygen. Thermal water quality criteria for Poquessing Creek Watershed are based on the warm water fishery (WWF) designation and reflect the fact that the watershed is not expected to have appropriate conditions to support populations of cold water fish (*e.g.*, trout species).

Maximum temperature criteria for warm water fisheries vary throughout the year, ranging from 4ºC (40ºF) in January-February to 30.5ºC (87ºF) in July-August.

Frequencies of stream temperature violations in Poquessing Creek Watershed were very similar across sites (Table 4.24), under both dry and wet weather conditions (Table 4.25). The vast majority of violations occurred in March-April 2009. The largest magnitude violation occurred at PQB025 on 4/27/09 when the temperature reached 25.0ºC (water quality standard=14ºC). This is most likely attributed to very high air temperatures that occurred during that period; the maximum air temperature on 4/27/09 was observed at 33.3ºC.

Table 4.24 Continuous Temperature Measurements Exceeding Maximum Standards by Site, 2008-2009

Parameter	Standard	Site	Total hours accepted data	Total days accepted data	Percent hours flagged data	Percent hours violation	Percent hours compliance
Temperature	Maximum	PQ665	6179.5	257.5	0.0	10.3	89.7
Temperature	Maximum	PQB025	7091.5	295.5	0.0	10.8	89.2
Temperature	Maximum	PQ050	9727.5	405.3	3.0	10.2	89.8

Table 4.25 Continuous Temperature Measurements Exceeding Maximum Standards by Site, Categorized as Dry or Wet Weather, 2008-2009

Site	DRY			WET		
	Total hours accepted data	Percent hours violation	Percent hours compliance	Total hours accepted data	Percent hours violation	Percent hours compliance
PQ665	2975.25	12.2	87.8	3204.25	8.4	91.6
PQB025	3484.75	12.2	87.8	3606.75	9.5	90.5
PQ050	4613.5	8.8	91.2	5113.5	11.5	88.5

As stream temperatures are most strongly related to ambient air temperature (Bartholow, 1989), it is recognized that patterns observed in the 2008-2009 dataset are not necessarily representative of other years. Stream temperatures for a given time period exhibit a great deal of interannual variation, and exceedances of water temperature criteria may occur at random due to climatic factors. Furthermore, relationships between weather events, streamflow, air temperature, and stream temperature were not simple. Stormwater demonstrated the ability to warm or cool the stream, depending on season and antecedent temperature states of the stream, air, and landscape (Appendix F).

Flow modifications and channel alterations (*i.e.*, incision) have probably reduced the influence of groundwater on baseflow water temperatures in Poquessing Creek Watershed. However, temperature did not appreciably increase in a downstream direction within the city of Philadelphia. One explanation for this could be the narrow but nearly contiguous forest canopy buffer along both stream banks in Poquessing Creek Park and other semi-wooded parcels adjoining the creek.

4.4.6 OTHER PHYSICOCHEMICAL PARAMETERS

4.4.6.1 TOTAL SUSPENDED SOLIDS

Sediment transport in small streams is dynamic and difficult to quantify. Numerous factors can affect a stream's ability to transport sediment, but sediment transport is generally related to streamflow and sediment particle size. Stable streams are generally capable of maintaining equilibrium between sediment supply and transport, while unstable streams may be scoured of smaller substrate particles or accumulate fine sediments. The latter effect is particularly damaging to aquatic habitats. PADEP has identified the cause of impairment in Poquessing Creek Watershed to be “siltation” in tributaries of Byberry Creek and one unnamed tributary to mainstem Poquessing Creek, with “urban runoff/storm sewers” listed as the source of siltation (Section 2, Figure 2.9).

Water sampling techniques that are adequate to characterize most water quality parameters (*e.g.*, grab samples, automated sampling) are not generally appropriate for evaluating sediment transport in fluvial systems (Edwards and Glysson, 1988; Ongley, 1996; Ferguson, 1986); errors related to sampling technique should preclude computation of sediment transport during severe storm events that mobilize large streambed particles. Traditional TSS analytical methods have been found to underestimate suspended sediment concentrations, especially as the proportion of sand in the sample increases. Due to the high rate of settling for sand, it has been shown that regardless of the amount of agitation, it is almost impossible to extract a comparable water-sediment subsample from the original sample as is done in TSS analysis (Gray *et al.*, 2000).

TSS and turbidity concentrations were measured from surface water grab samples collected prior to wet weather events and from samples collected by automated samplers during wet weather events. TSS concentration was significantly greater in wet weather than in dry weather (Mann-Whitney U = 22409, $p<0.001$).

A total of 269 TSS samples were collected from seven sites in the Poquessing Creek Watershed in 2008-2009, with 99 during dry weather and 170 during wet weather. Over this period, TSS exceeded the 25 mg/L reference value in only 3.0% of the dry weather samples compared to 30.6% of the wet weather samples. Overall, 30.3% of dry weather samples and 4.7% of wet weather samples had concentrations below the 1 mg/L reporting limit. A regression analysis of 2001-2009 data showed that TSS concentration was significantly positively correlated to turbidity (r (263) =0.83, $p<0.001$) (Figure 4.16). The minimum and maximum TSS concentrations observed were 0.5 and 1,028 mg/L, respectively. Minimum and maximum turbidity values in the discrete sample dataset were 0.554 and 191 NTU, respectively. (A maximum turbidity of 1,523.5 NTU was recorded with the sonde at PQB025 on 8/22/09). Strong correlations between TSS and turbidity support the future use of turbidity as an indicator of TSS concentration with the caveat that extrapolation is less reliable outside of the measured range.

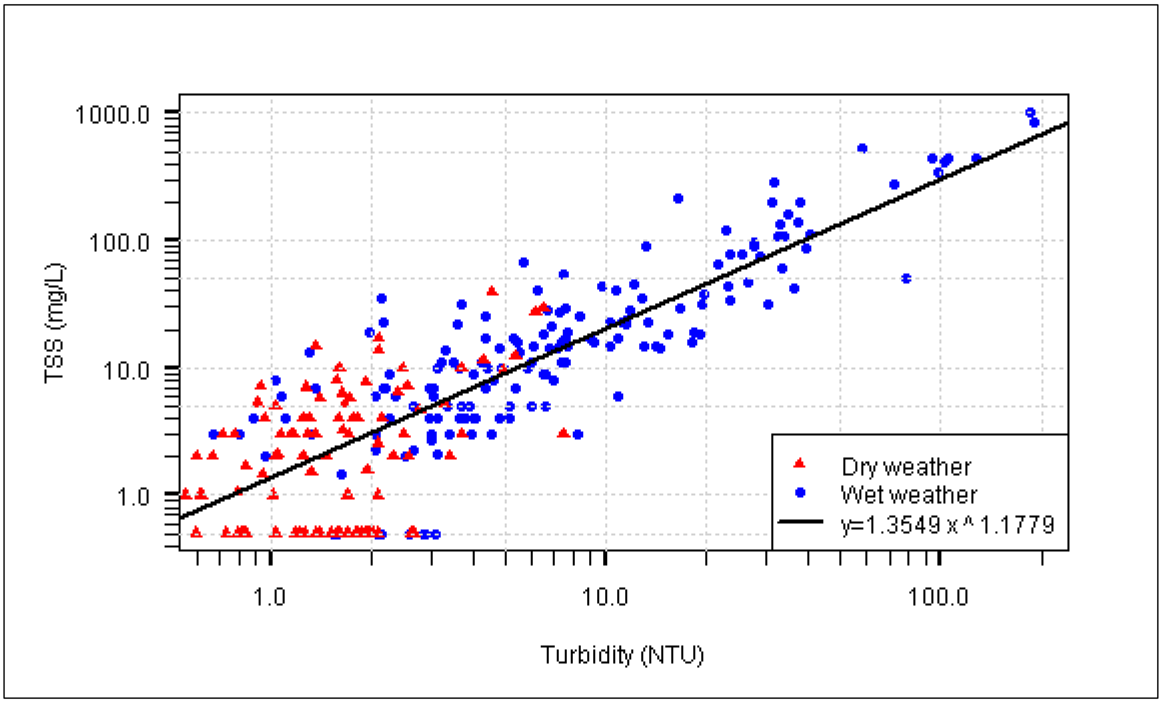

Figure 4.16 Scatterplot of Paired TSS and Turbidity Samples Collected from 7 Sites in Poquessing Creek Watershed (2001-2009 data)

4.4.6.2 TURBIDITY

Turbidity is a measure of the light-scattering properties of particles suspended in water. In streams, turbidity can come from many sources, but the chief cause of increased turbidity is suspended sediment. While a correlation between turbidity and TSS certainly exists, the relationship between turbidity and TSS may differ between water bodies and even among different flow stages/seasons in the same water body due to sediment characteristics. Consistently turbid waters often show impairment in aquatic communities. Light penetration is reduced, which may result in decreased algal production. Suspended particles can also clog gills and feeding apparatus of fish, benthic invertebrates, and microorganisms. Furthermore, feeding efficiency of visual predators may be reduced in consistently turbid waters.

PADEP has not established numeric water quality criteria for turbidity, though General Water Quality Criteria (25 PA Code §93.6) specifically prohibit substances attributable to any point or non-point source in concentrations inimical or harmful to aquatic life. Discharge of substances that produce turbidity are also specifically prohibited. As turbidity may vary considerably from stream to stream, a reference value of 2.825 NTU was used to define excess turbidity, based on an analysis of turbidity data from streams in EPA Region IX, subregion 64 (USEPA, 2000).

Turbidity was determined to be a problem in all sites in Poquessing Creek Watershed during wet weather based on 2008-2009 continuous sonde data (Appendix I). The worst site was PQ665, where turbidity exceeded the reference value during wet weather 78.6% of the time. At sites PQB025 and PQ050, continuous sampling data during wet weather exceeded the water quality reference value at a somewhat lower proportion compared to PQ665. PQB025 exceeded the turbidity threshold in 55.4% of wet weather continuous samples compared to 65.3% for PP1850. The difference between sites was greater during dry weather, when the turbidity threshold was exceeded 48.8% of the time at PQ665, compared to 7.8% and 17.2% at PQB025 and PQ050, respectively.

Discrete data from 2008-2009 reinforced the above findings while offering additional information on other sites. Using the PADEP protocol on statistical assessments of water chemistry data (PADEP, 2007c), both Byberry Creek sites (PQB025 and PQB305) and two Poquessing Creek sites (PQ155 and PQ395) did not exceed the turbidity reference value during dry weather. One site exceeded the reference value (PQ665) and two sites were inconclusive (PQ050 and PQ820) during dry weather. During wet weather, all sites with a sufficient number of samples were found to have exceeded the reference value. The failure to meet the reference value at PQ665 during dry weather may be related to the anomalous DO and BOD_5 phenomena observed at this site, as described earlier in those parameter subsections. Periodic runoff observed by PWD/BLS staff at PQ665 likely contributed to the higher turbidity exceedance rate at this site.

4.4.6.3 CONDUCTIVITY AND TOTAL DISSOLVED SOLIDS (TDS)

Conductivity and Total Dissolved Solids (TDS) are measures of the concentration of ions and solids dissolved in water. TDS is an empirical laboratory procedure in which a filtered water sample is dried to yield the mass of dissolved solids, while conductivity is a measure of the ability of water to conduct electricity over a given distance, expressed as microsiemens/cm (corrected to 25ºC, reported as specific conductance) (Eaton *et al*., 2005). With sufficient data, a good relationship between conductivity and TDS can be established. Waters containing large relative proportions of organic ions (*e.g.*, bog or wetland samples containing organic acids) generally have less conductivity for equivalent TDS concentration than waters containing primarily inorganic ions.

Dissolved ion content is perhaps most useful in determining the start of wet weather events at ungaged water quality monitoring stations. Conductivity probes are generally simple in design, robust, and very accurate. They are extremely sensitive to changes in flow, as stormwater (diluent) usually contains smaller concentrations of dissolved ions than stream baseflow. A notable exception to this rule concerns the application of ice-melt chemicals to roads (primarily sodium, magnesium, and potassium salts). When present in runoff or snowmelt, these substances can cause large increases in ionic strength of stream water. Some formulations may increase levels of chloride. Previously, the PADEP chloride criterion of 250 mg/L was intended to protect drinking water supplies and did not explicitly account for aquatic life. However, PADEP has recently drawn on USEPA (1988) guidance and proposed acute and chronic ambient water quality criteria for chlorides, in concentrations of 860 and 230 mg/L, respectively (PADEP 2010b). The new chloride standards would be intended to protect freshwater plant and animal species from chloride toxicity effects as summarized in USEPA (1988). In light of the newly proposed chloride criteria, PWD may consider adding chloride as an analyte for future watershed monitoring efforts or attempt to develop a chloride-specific conductance relation in order to monitor chloride effects with continuous water quality monitoring equipment.

A regression analysis of 2001-2009 data showed that conductivity and TDS were moderately correlated (r (103) = 0.59), $p< 0.001$) (Figure 4.17). The maximum TDS concentration observed in the 2008-2009 dataset was 550 mg/L, measured at PQ155 during a long stretch of dry weather on 8/27/08, the 12th consecutive day without rain at that site. The maximum specific conductance observed was 2,979 microsiemens/cm at 25ºC on 3/5/09 at PQB025. A slightly lower reading of 2,602 microsiemens/cm at 25ºC was observed the same day at PQ665. These extremely high observations occurred four days after a snowfall and during a period of very cold weather. It is likely that road salt runoff caused increases in specific conductance observed at multiple locations. The USGS gage conductivity probe at PQ050 was not in operation on 3/5/09, however when it began logging data on 3/10/09, 1,490 microsiemens/cm at 25ºC was recorded. A general decline in specific conductance was observed at all three sonde sites in early March 2009, corroborating the likelihood that the high values observed on 3/5/09 are valid (Figure 4.18). TDS samples were not taken on 3/5/09, but given the correlation between TDS and specific conductance, it is possible that TDS exceeded the 750 mg/L standard at that time. However, any extrapolation of TDS under such high values of specific conductance would go well beyond the range of the fitted regression equation. (Additional time series plots of continuous conductivity are presented in Appendix H).

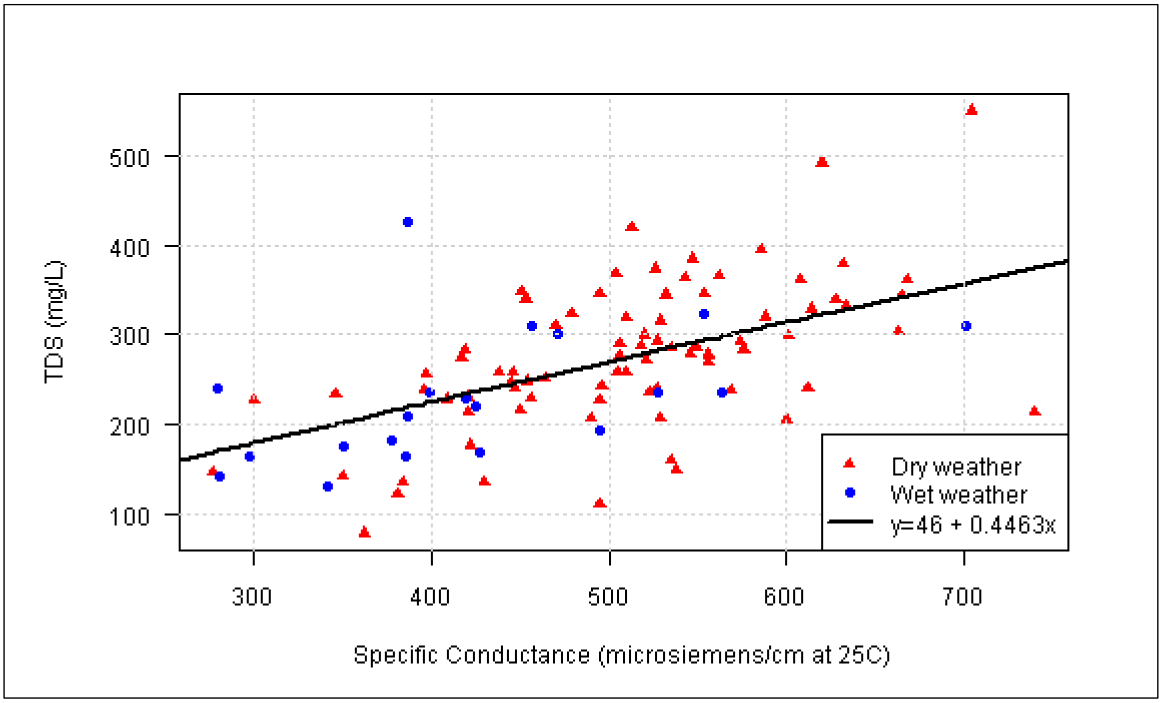

Figure 4.17 Scatterplot of Paired TDS and Specific Conductance Samples Collected from 7 Sites in Poquessing Creek Watershed (2001-2009 data)

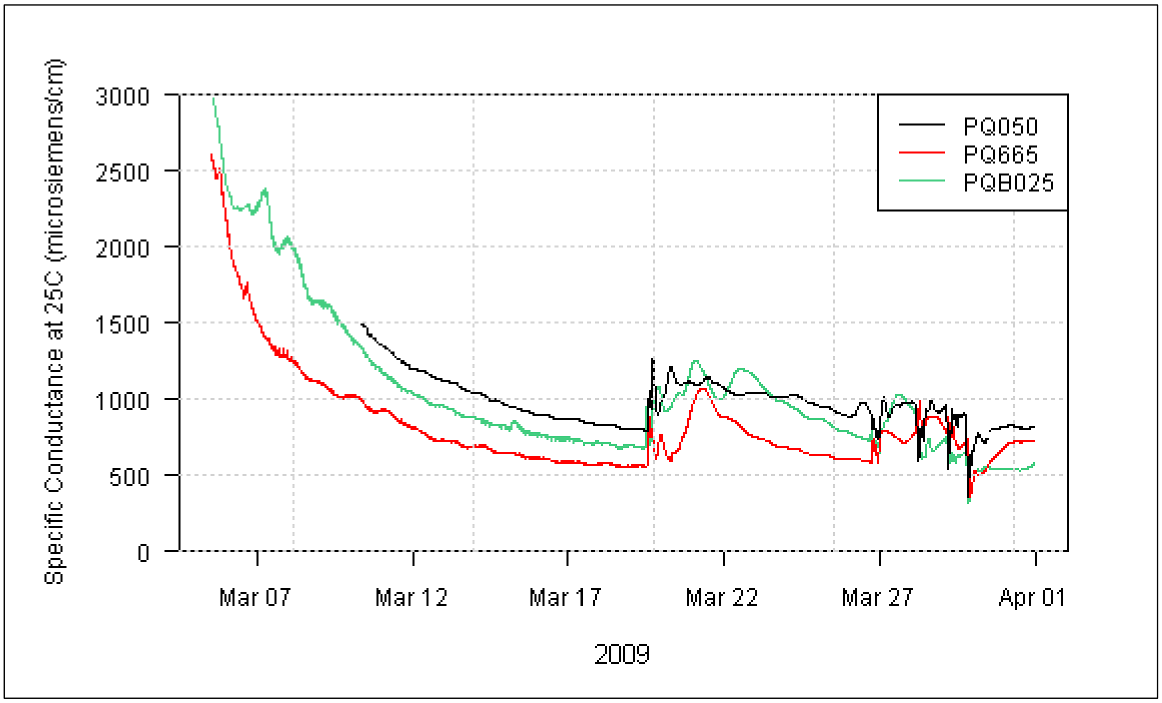

Figure 4.18 Specific Conductance at 3 Sites with Continuous Monitoring, March 2009

4.4.6.4 HARDNESS

Hardness is a calculated water quality parameter. Separate determinations of concentrations of calcium (Ca) and magnesium (Mg), which are the two primary cations in surface waters, are combined using the formula 2.497[Ca]+4.118[Mg], the result expressed as an equivalent concentration of $CaCO_3$ in mg/L. Waters of the Commonwealth of Pennsylvania must contain 20mg/L minimum $CaCO_3$ hardness concentration, except where natural conditions are less; however, there is no existing maximum criterion for this parameter. Hardness is important in the calculation of water quality criteria for toxic metals (25 PA Code § 16), as toxicity of most metals is inversely proportional to hardness concentration. Groundwater in Poquessing Creek Watershed is naturally moderately hard to hard, so streams usually have greater hardness in dry weather than in wet weather.

Dry weather samples collected in 2008-2009 at seven Poquessing Creek Watershed sites ranged from 92.5 – 201 mg/L $CaCO_3$ (n=98); wet weather samples ranged from 19 - 187 mg/L $CaCO_3$ (n=181). Wet weather samples had an exceedance rate of 1.1%, while all dry weather samples were above the minimum standard. It is unlikely that the few instances of water hardness criteria exceedance would be considered violations of water quality criteria, as they are not related to a particular discharge.

4.4.6.5 IRON AND MANGANESE

Iron (Fe) and manganese (Mn) are generally not toxic in natural streams, but certain conditions (*e.g.*, very low pH due to acid mine drainage) can result in increased toxicity of Fe and Mn. The typical mechanism of Fe toxicity in fish is asphyxiation due to accumulation of metal on gill surfaces (Dalzell and MacFarlane, 1999) though Fe[II] toxicity is not unknown. Dissolved Fe and total recoverable Mn are also regulated in waters of the Commonwealth of Pennsylvania for public water supply (PWS) protection (25 PA Code §93.7) because excess concentrations of these metals can cause color, taste, odor, and staining problems in drinking water and industrial applications. Both elements are essential nutrients for life and are relatively abundant in the soils and surface geology of Poquessing Creek Watershed.

Iron is a particularly abundant element (at approximately 5% of the Earth's crust, it is second only to aluminum in abundance among metals) and was detected in 273 of 278 samples collected from Poquessing Creek Watershed in 2008-2009. Manganese was detectable in all 279 samples. Presence of these metals in surface water samples may be naturally related to weathering of rock and soils or due to stormwater runoff. Ferrous materials in contact with the stream (*e.g.*, pipes and metal debris) and dry weather flows from ferrous pipes could also be potential sources of Fe loading to streams. This is supported by the strong correlation between TSS and total recoverable Fe (r(262) = 0.7489, $p<0.001$; 2001-2009 data) during dry weather. Furthermore, blooms of iron-fixing bacteria, which are indicators of the presence of oxidized Fe, were observed in some areas of the watershed during dry weather.

Total recoverable Mn criteria were never exceeded in 98 dry weather samples but were violated in 5.0% of 181 wet weather samples. Violations of total recoverable Fe water quality criteria were frequent in wet weather. During wet weather, levels of Fe exceeded the 1.5 mg/L standard in 45.3% of the samples collected, as opposed to only 7.2% during dry weather. However, Fe may not be toxic to aquatic life at the concentrations observed, as pH levels were typically neutral and conditions in Poquessing Creek Watershed do not favor accumulation of Fe on gill surfaces (Gerhardt, 1993). Nevertheless, Fe cannot be ruled out as a potential cause of observed impairments in aquatic communities. Unlike toxic metals (*e.g.*, lead, cadmium and copper), Fe and Mn are not regulated by 25 PA Code § 16 - Water Quality Criteria for Toxic Substances.

Dissolved iron was detected in 92 of 116 samples collected in 2008-2009. Dissolved manganese was detected in 113 of 117 samples from the same period. Dissolved iron criteria were violated in 7.3% of dry weather samples, but none of the wet weather samples. There is no criterion for dissolved manganese.

4.4.7 TOXIC METALS

Toxic metals have the potential to create serious environmental problems even in relatively small concentrations (Warnick and Bell, 1969; LaPoint *et al*., 1984; Clements *et al*., 1988). As such, their presence in waters of the Commonwealth, treatment plant effluents, and other permitted discharges is specially regulated by 25 PA Code § 16.24 - Toxic Metals Criteria. Considerable research over the past two decades has been directed at understanding the ecotoxicology of heavy metals (*e.g.*, biological pathways, physical and chemical mechanisms for aquatic toxicity, thresholds for safe exposure both acute and chronic, roles of other water quality constituents in bioavailability of toxic metals, etc.).

New guidelines for statistical analysis of water quality data issued by PADEP (2007c) state that when evaluating whether or not a water body is meeting water quality standards for a toxic parameter, the “5% rule” (*i.e.*, no more than one violation in 20 samples) is applied rather than the 10% rule that is applied to non-toxic parameters. Non-parametric statistical procedures and datasets containing fewer than 24 samples may be used to make the determination that a water body is impaired, but further evaluation (collecting at least 24 samples) is required to make the determination whether the water body is meeting water quality standards.

It is now widely accepted that dissolved metals best reflect the potential for toxicity to organisms in the water column, and many states, including Pennsylvania, have adopted dissolved metals criteria (40 CFR 22227-22236). As many metals occur naturally in various rocks, minerals, and soils, storm events can expose and entrain soil and sediment particles that naturally contain metals. These inert particles are removed when samples are filtered for dissolved metals analysis (Eaton *et al*., 2005). Total recoverable metals samples are digested and acidified to liberate organically bound and complexed metals, but this process may also solubilize metals in inorganic and particulate states that are stable and inert under normal stream conditions, overestimating the potential for toxicity.

However, since it is not possible to filter samples collected with automatic sampling equipment immediately after collection, PWD has collected a greater number of total metals samples than dissolved metals samples in general. Water quality sampling data from the Philadelphia metropolitan area suggests that urban streams without point sources of treated municipal waste typically experience increases in toxic metal concentrations due to stormwater and soil erosion. Metals in stormwater runoff may consist of predominantly large inert inorganic particulates, such as ores and minerals, or metals adsorbed to soil particles or complexed with other constituents such that the ratio of dissolved metal to total recoverable metal decreases with increasing total metal concentration. This relationship is consistent among many toxic metal constituents in urban streams studied by PWD.

Sediment and pore water conditions may result in greater concentrations or otherwise contribute to increased potential for toxicity to benthic organisms within stream sediment microhabitats, but these effects remain poorly defined and are difficult to measure. For example, Borgmann and Norwood (1997) found *Hyalella azteca* (Amphipoda:Hyalellidae) demonstrated increased sensitivity to sediment pore water Zn, but no observable increase in toxicity with increases in sediment pore water Cu concentration.

With the exception of aluminum and hexavalent chromium, Pennsylvania water quality criteria are based on hardness (as $CaCO_3$) to reflect inverse relationships between hardness and toxicity that exist for most metals (Figures 4.19 and 4.20). This relationship becomes especially important in streams where stormwater tends to dilute the ionic content of water while possibly concurrently increasing concentrations of toxic metals. Poquessing Creek tends to experience decreased conductivity and hardness during storm events.

While hardness-based criteria are much improved over simple numeric criteria, they fail to describe the complex interactions between dissolved metals and other water constituents and physicochemical properties (*e.g.*, Dissolved Organic Carbon, pH, temperature, and ions other than Ca and Mg,). Hardness-based criteria may represent an intermediate step between simple numeric criteria and criteria based on more complex water quality models (*i.e.*, Biotic Ligand Model) (Di Toro *et al*., 2001; USEPA, 2003).

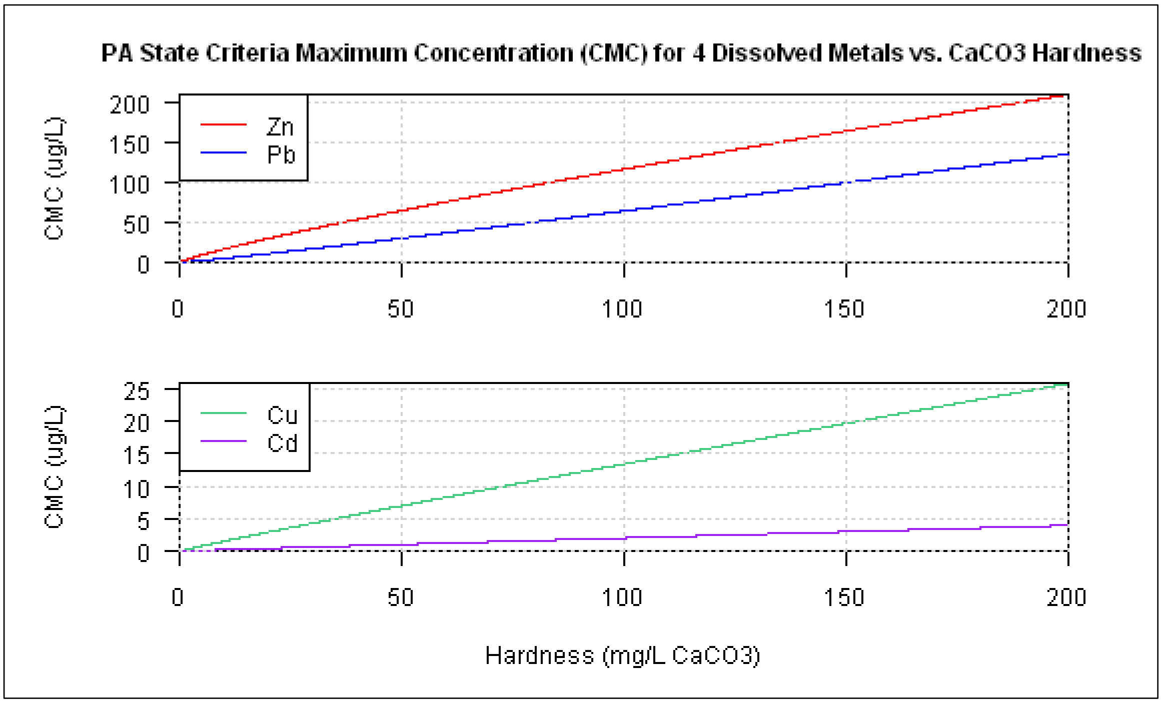

Figure 4.19 PADEP Hardness-based Criteria Maximum Concentrations for 4 Toxic Metals

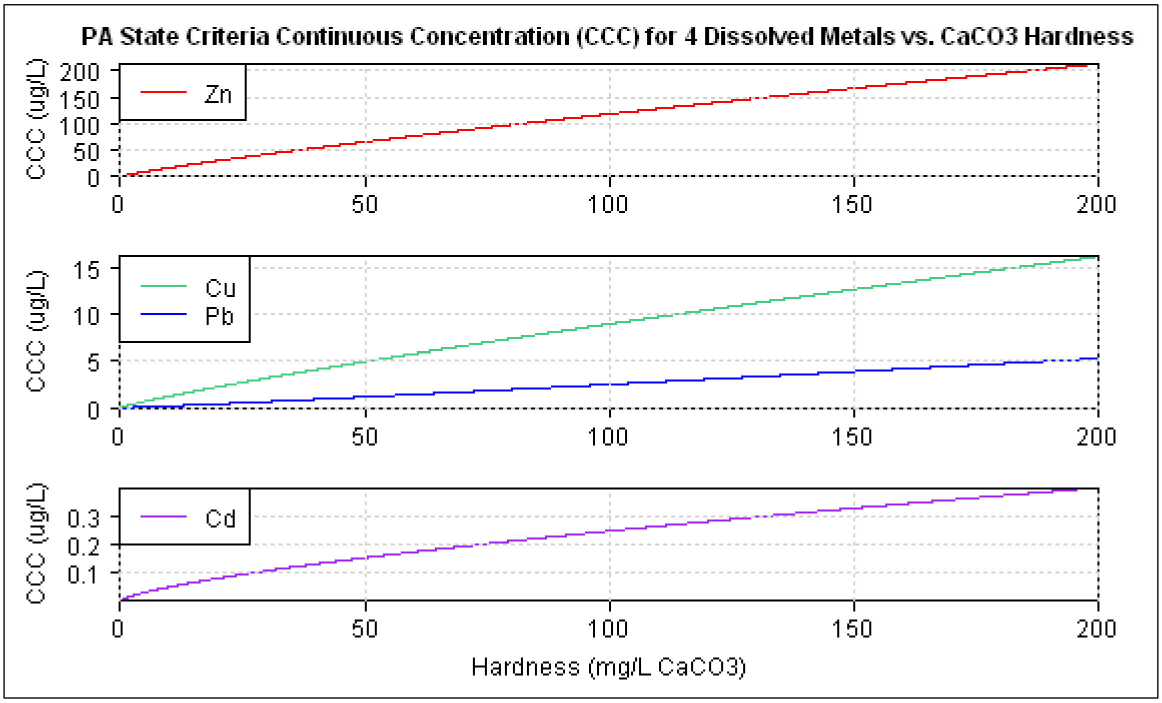

Figure 4.20 PADEP Hardness-based Criteria Continuous Concentrations for 4 Toxic Metals

4.4.7.1 ALUMINUM

Aluminum (Al) is the most abundant metal in the Earth's crust at approximately 8.1% by mass. As Al is a component of many rocks and minerals, particularly clays, weathering of rocks and soil erosion may contribute Al to natural waters. As described in section 4.3 (Water Quality Sampling and Monitoring Protocols), the 2008-2009 Poquessing water quality database contains results from numerous sampling programs with varying objectives. Considering all samples, water column Al concentrations were significantly higher in wet weather than in dry weather (U = 15608, $p<0.001$). Examination of paired dissolved and total recoverable Al concentrations from discrete interval grab samples collected from Poquessing Creek Watershed showed that while total recoverable Al concentrations may often have exceeded 100 µg/L in wet weather, dissolved Al was rarely present in similar concentrations (Figure 4.21). While no discernible correlation was found between dissolved and total recoverable Al, a good correlation (r(113) = 0.82, $p<0.001$) was found between the dissolved fraction (*i.e.*, dissolved Al divided by total recoverable Al) and total recoverable Al (Figure 4.22). The positive correlation between Al and TSS (r(262) = 0.80, $p<0.001$) also suggested that Al was usually present in particulate form, such as clay, during storm events (Figure 4.23).

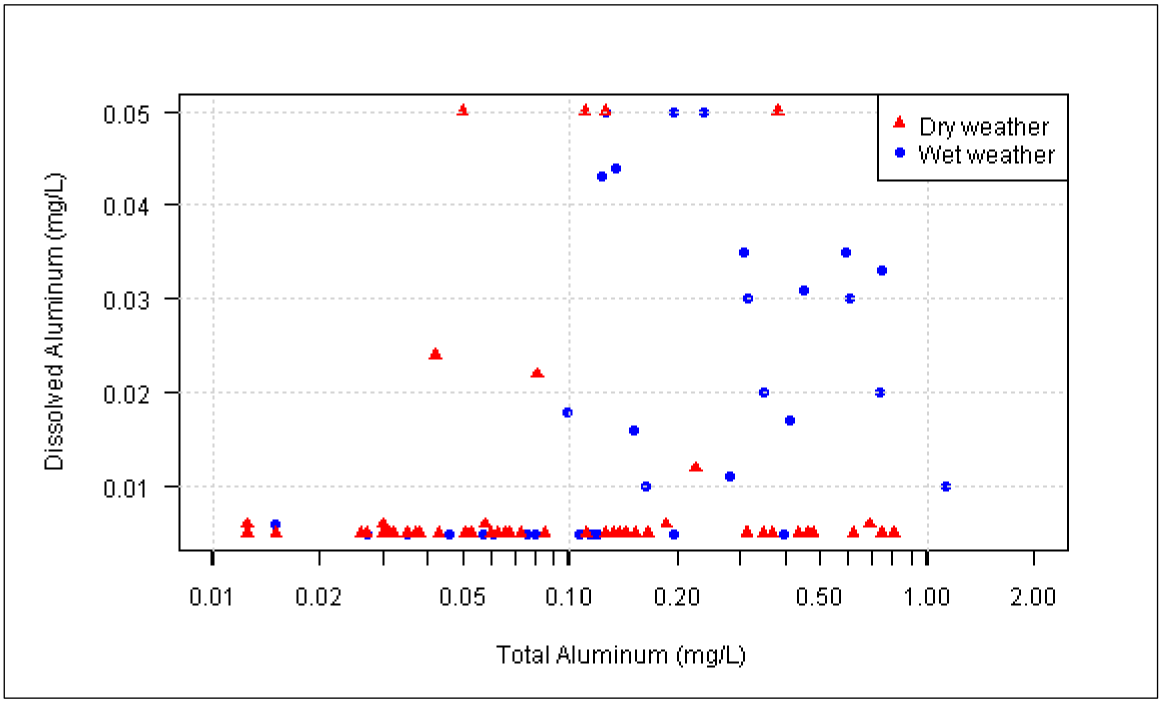

Figure 4.21 Scatterplot of Paired Total Recoverable Aluminum and Dissolved Aluminum Samples Collected from 7 Sites in Poquessing Creek Watershed (2008-2009 data)

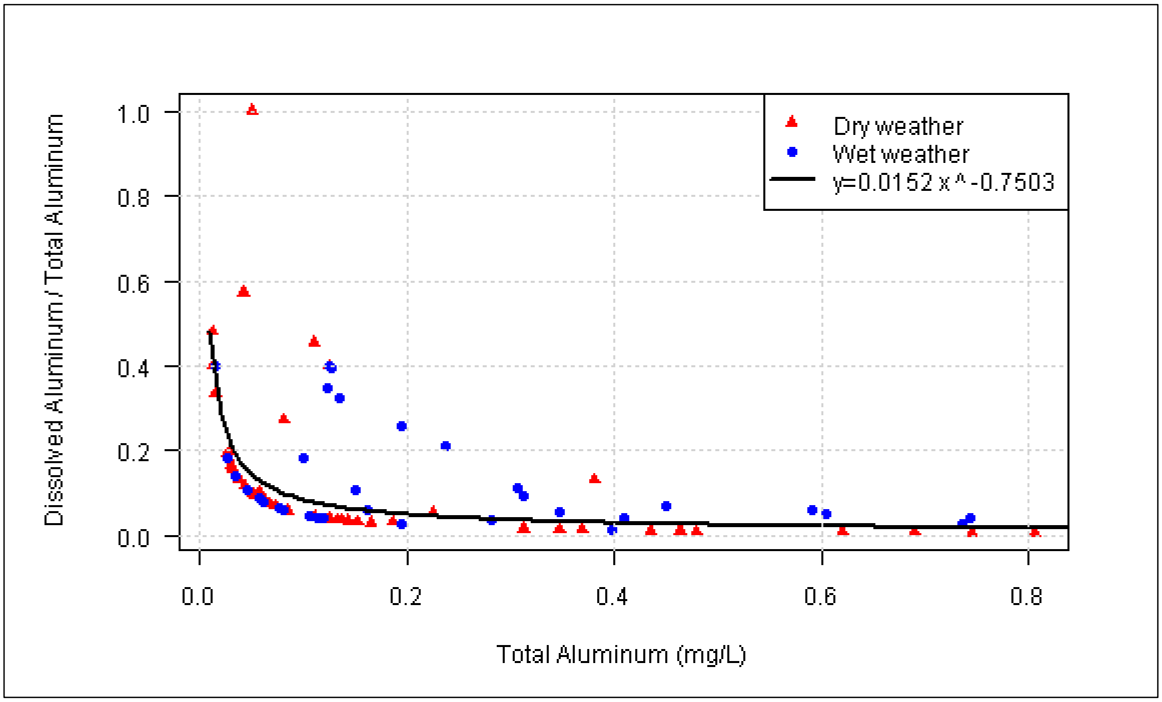

Figure 4.22 Scatterplot of Paired Dissolved Fraction and Total Recoverable Aluminum Samples Collected from 7 Sites in Poquessing Creek Watershed (2008-2009 data)

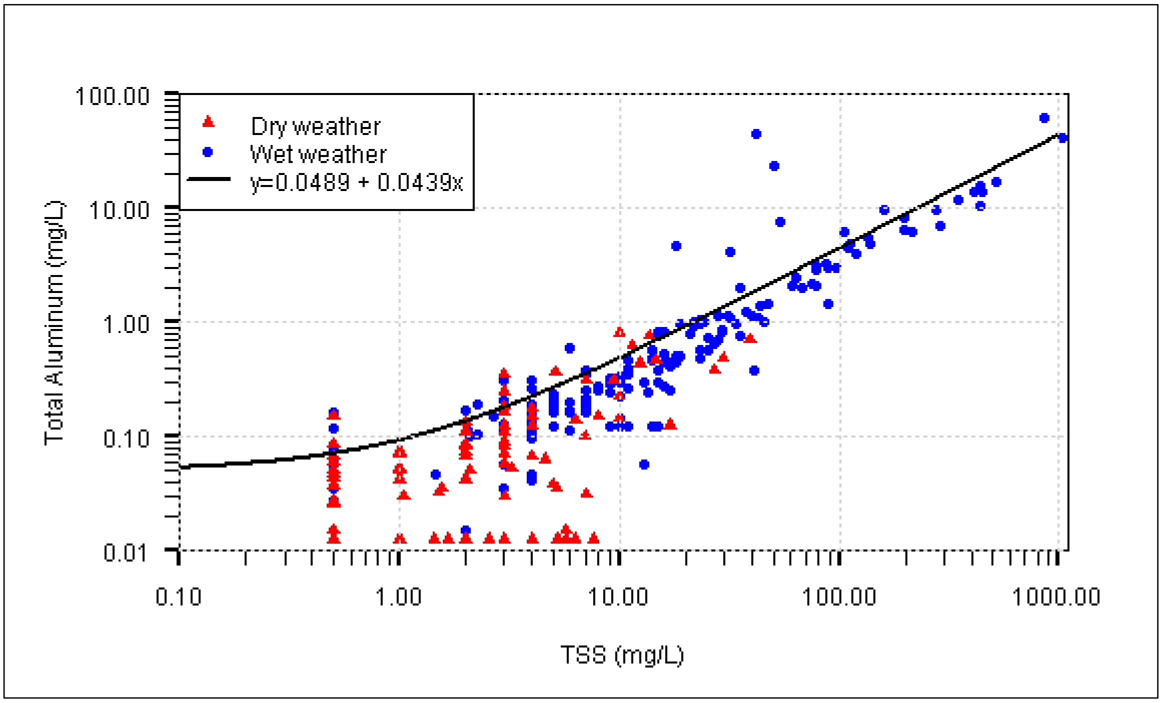

Figure 4.23 Scatterplot of Paired TSS and Total Recoverable Aluminum Samples Collected from 7 Sites in Poquessing Creek Watershed (2008-2009 data)

Al was detected in 234 of 278 water samples from Poquessing Creek Watershed in 2008-2009 (Table 4.26); violations of the PADEP acute exposure criterion were observed in 1.0% and 37.2% of samples collected in dry weather and wet weather, respectively. Violations of the PADEP chronic exposure criterion were observed in 29.6% and 88.9% of samples collected in dry weather and wet weather, respectively. Wet weather suspended solids loads consist of a mixture of urban/suburban stormwater, eroded upland soils, and streambank particles. It is thus impossible to determine individual Al contributions of these sources.

PA water quality criteria for Al are based on total recoverable fractions rather than dissolved, partially because under experimental conditions, brook trout (*Salvelinus fontinalis*) experienced greater mortality with increased total Al concentration despite constant levels of dissolved Al. The form of particulate Al present in this experiment was Aluminum hydroxide, and experimental pH was low. Furthermore, EPA has recognized that total recoverable Al in stream samples may be due to clay particles and documented many high-quality waters that exceed water quality standards for total recoverable Al (USEPA 1988, 53FR33178). As Poquessing Creek Watershed is rich in both mica and clay soils, and rarely experiences pH < 6.0, other factors should probably be ruled out before attributing biological impairment in Poquessing Creek Watershed to Al toxicity.

Table 4.26 Summary of Toxic Metals Samples Collected in Dry and Wet Weather and Corresponding Number of Samples Found to have Concentrations Below Reporting Limits

Parameter	Number of Dry Samples	Percent Detected	Number of Wet Samples	Percent Detected
Total Aluminum	98	63.3	180	95.6
Dissolved Aluminum	83	4.8	34	47.1
Total Arsenic	98	0.0	181	19.3
Dissolved Arsenic	82	6.1	34	11.8
Total Cadmium	95	1.1	181	7.2
Dissolved Cadmium	82	0.0	34	0.0
Total Chromium	98	5.1	181	37.6
Dissolved Chromium	83	0.0	34	0.0
Total Copper	98	62.2	180	92.2
Dissolved Copper	82	80.5	33	97.0
Total Lead	98	7.1	181	51.9
Dissolved Lead	81	0.0	34	0.0
Total Zinc	89	93.3	178	90.4
Dissolved Zinc	76	94.7	31	93.5

4.4.7.2 ARSENIC

Arsenic (As) is a heavy metal that is unevenly distributed in the earth's crust in soil, rocks, and minerals. Arsenic is easily adsorbed by iron and manganese and reacts with clay particles, increasing its likelihood of presence in sediments. Industries that use inorganic As and its compounds include nonferrous metal alloys and electronic semiconductor manufacturing. Until recently, As was used in the U.S for manufacturing wood preservatives and glass production. As is also found in agricultural pesticides and coke oven emissions associated with the smelting industry. In the U.S., the use of As in consumer products was discontinued for residential and general consumer construction on December 31, 2003.

Little is known about the mechanisms of As toxicity to aquatic organisms; however, As readily forms stable bonds to sulfur and carbon in organic compounds. Like mercury, As (III) reacts with sulfhydryl groups of proteins; enzyme inhibition by this mechanism may be the primary mode of toxicity (USEPA, 1984). PA water quality criteria for As (CMC = 340 µg/L; CCC = 150 µg/L) are based upon total recoverable fractions rather than dissolved.

As was detected in 35 of 279 water samples from Poquessing Creek Watershed in 2008-2009 (Table 4.26). There were no violations of water quality criteria; the maximum observed concentration was 7 µg/L .

4.4.7.3 CADMIUM

Cadmium (Cd) is a heavy metal that is widely but sparsely distributed in the earth's crust. Cd is often associated with zinc (Zn) but may also be found with other metals such as copper (Cu) and lead (Pb). For this reason, smelting and other industrial uses of nonferrous metals may be sources of Cd pollution. Other industrial sources include battery, pigment, and plastics manufacturing. Atmospheric deposition and some types of agricultural fertilizers may also contribute Cd to the environment. Cd has no known biological function and may be toxic in very small concentrations. In aquatic environments, toxicity is assumed to be due to uptake of dissolved Cd, so PADEP water quality criteria are based on dissolved concentrations. Dissolved Cd was never detected in 116 water samples, so it is unlikely that Cd toxicity is responsible for observed biological impairment in Poquessing Creek Watershed.

Though concentrations were always below reporting limits, water quality criteria for dissolved Cd reflect the fact that this metal may be toxic in very small concentrations. Water quality criteria for dissolved Cd are calculated based on hardness, and dissolved Cd concentrations less than 1ug/L may be in violation of water quality criteria in very soft water. Dissolved Cd was never detected in 34 wet weather samples, nor in 82 dry weather samples (Table 4.26). At the paired hardness concentration of each sample, only all dissolved Cd samples below reporting limits could have possibly exceeded the Continuous Criteria Concentration, and six wet weather samples could have possibly exceeded the Criteria Maximum Concentration. At the minimum observed hardness concentration of 19 mg/L, reporting limits would have to be less than 0.4 µg/L and 0.077 µg/L in order to determine true exceedances of the CCC and CMC, respectively.

Water chemistry parameters accompanying cadmium results below detection limits were also compared to BLM-derived toxicity values for fathead minnow (*P. promelas*) and a cladoceran, or water flea (*Ceriodaphnia dubia*). Due to uncertainty in cadmium concentration and the fact that many of the BLM input parameters were estimated, resulting toxicity values were multiplied by a conservative measure of safety (MOS) factor of 10. Even with the 10x MOS, cadmium at a concentration 0.5 times the reporting limit (*i.e.*, 0.5µg/l) was not predicted to be toxic to either *P. promelas* or *C. dubia* at any site in Poquessing Creek watershed in either wet or dry weather.

4.4.7.4 CHROMIUM

Chromium (Cr) is commonly used in alloys of stainless steel and as chromate salts in other metallurgical and industrial applications. Of the two predominant naturally occurring forms, only hexavalent chromium (Cr[VI]) is toxic, while trivalent Cr (Cr[III]) is an essential trace nutrient. Separate water quality standards exist for Cr[III] and Cr[VI]. Toxic Cr[VI] is much more soluble at normal stream pH than Cr[III] (Rai *et al.*, 1989), so at the extremes, dry weather dissolved Cr samples probably more closely reflect actual water column concentrations of Cr[VI], while wet weather total recoverable Cr samples will contain a much greater proportion of insoluble, nontoxic Cr[III]. Despite the influence of other water quality constituents on the speciation and bioavailability of Cr, water quality criteria for Cr[VI] are absolute (CCC=10ug/L, CMC=16ug/L, dissolved fraction only).

Determinations of Cr described herein were obtained with ICP-MS equipment following acid digestion, a method that does not allow for speciation of Cr in either dissolved or total recoverable samples; concentrations were conservatively assumed to be Cr[VI], though the ratio of Cr[III] to Cr[VI] is very likely to be much greater in total recoverable samples as well as in wet weather samples. Dissolved Cr was not detected in any of 117 samples (Table 4.26), and there were no violations of water quality criteria.

4.4.7.5 COPPER

Copper (Cu) occurs naturally in numerous forms and is present to some degree in most soils and natural waters. Cu is also used industrially for copper pipes, electrical wires and coils, as well as in building materials such as roofing and pressure-treated lumber. Cupric ion (Cu^{2+}) is the bioavailable form of Cu in aquatic systems, and its mode of toxicity involves ligand bonding with the gill surface of fish or similar structures of invertebrates. As such, water quality criteria are based on dissolved Cu concentration, which is a better predictor of Cu toxicity than total recoverable metal concentration.

Dissolved concentrations of Cu are smaller than total recoverable concentrations in natural waters due to the presence of Cu in particulate form or adsorbed to large particles that are trapped by filtering surface water grab samples. Cu forms complexes and ligand bonds with various water column constituents (Morel & Hering 1993) which can reduce bioavailability, and thus toxicity, of the metal.

Cu and dissolved Cu were usually detectable above reporting limits in Poquessing Creek Watershed (Table 4.26). Paired samples of total recoverable Cu and dissolved Cu were significantly positively correlated ($r(114) = 0.89$, $p < 0.001$) (Figure 4.24). Violations of the PADEP acute exposure criterion (CMC) were observed in none of the 82 dry weather samples, and in 2 of 33 (6.1%) wet weather samples. Violations of the more stringent PADEP chronic exposure criterion (CCC) were observed in 1 of 82 (1.2%), and 4 of 33 (12.1%) samples collected in dry weather and wet weather, respectively.

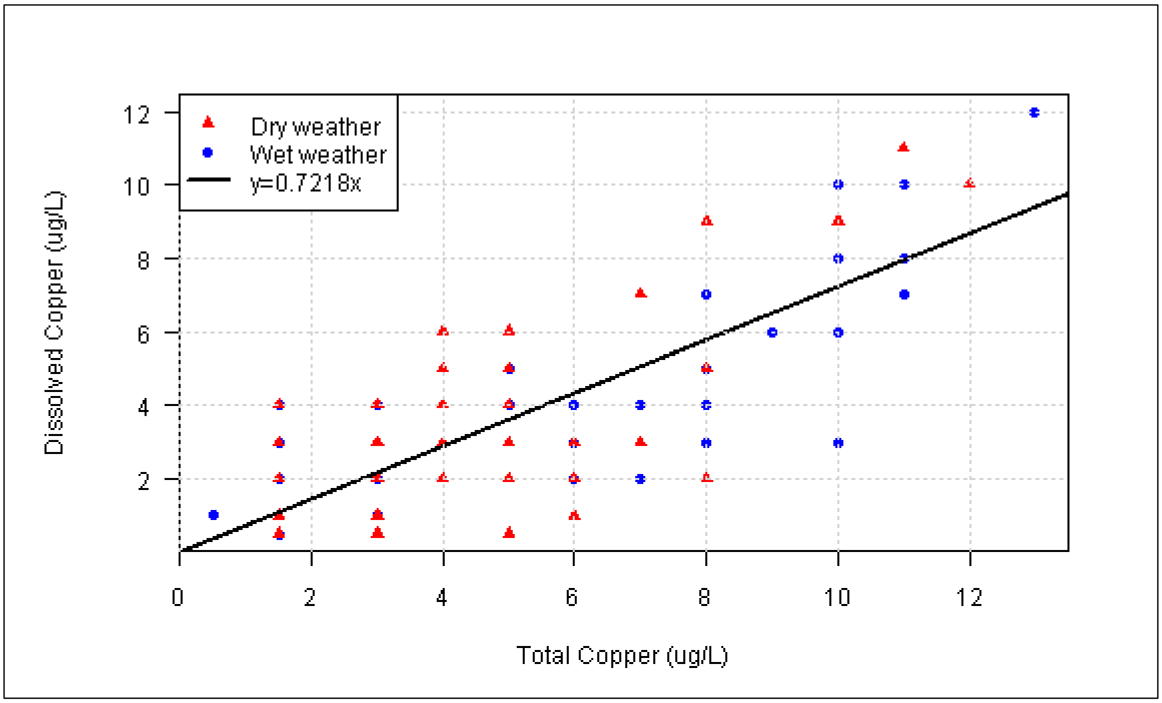

Figure 4.24 Scatterplot of Paired Total Recoverable Copper and Dissolved Copper Samples Collected from 7 Sites in Poquessing Creek Watershed (2008-2009 data)

As Cu may adsorb to sediment, pore water and sediment toxicity should not be ignored as a potential stressor to benthic invertebrates. The only sensitive taxon that was consistently collected throughout the watershed (though densities were low) were cranefly larvae (*Tipulidae*), which were collected at all sites. Tipulid larvae, sometimes called "leather jackets," are relatively large shredders that enshroud themselves in leaf packs. A diet and microhabitat rich in organic acids may confer resistance to heavy metal pollution. Mayflies, on the other hand, have been characterized as very sensitive to heavy metal pollution (Clements *et al*., 1988; Warnick and Bell, 1969) and the obvious disparity between Poquessing Creek Watershed sites and reference sites with respect to the number and abundance of mayfly and other sensitive taxa may be partially attributable to heavy metal pollution. No mayflies or stoneflies were collected from Poquessing Creek watershed in 2008 macroinvertebrate sampling. Sediment metals concentrations and reference site chemistry data are needed before any definitive conclusions can be drawn.

4.4.7.5.1 BIOTIC LIGAND MODEL ANALYSIS OF DISSOLVED COPPER

Cu toxicity was also investigated using the Biotic Ligand Model (BLM) (Hydroqual 2005), as many water chemistry parameters can affect Cu toxicity. Other ions and organic molecules tend to compete with gill ligand bonding sites for available Cu. BLM data were used to address the question of whether Cu toxicity could be affecting the biology of Poquessing Creek Watershed. Each model input case consisted of water quality data from a single sample from Poquessing Creek Watershed, though some parameters were estimated due to lack of availability in the 2008-2009 data set. Parameters for which estimates were used included: dissolved organic carbon (DOC), percent of DOC contributed by humic acids; Cl, K, SO_4 and SO_2. DOC competes for Cu with gill ligand sites and is positively correlated to the LC_{50} of Cu, therefore a conservative estimate of 2.9 mg/L was used. Due to the lack of DOC characterization data, 10% was used for the relative proportion of DOC made up by humic acids as recommended by the model documentation (DiToro *et al.*, 2001).

As described in section 4.3.5, the BLM Windows computer interface includes a module to calculate the recommended EPA ambient freshwater criteria for copper. Acute toxicity criteria were violated more frequently (5 of 33 samples) in wet weather, with only 2 of 82 dry weather samples exceeding the criterion. Though BLM-derived acute water quality criteria were slightly more stringent, results were similar to the PADEP water quality standards comparison. Both methods indicate possible metals toxicity in a relatively small number of samples.

4.4.7.6 LEAD

Lead (Pb) is a toxic heavy metal that was once commonly used in paints (as recently as 1978) and in automotive fuels (until being phased out in the 1980s). Pb is still used industrially in solder and batteries. Some areas have banned the use of lead in shotgun pellets and fishing weights, as chronic toxicity results when these items are ingested by waterfowl. Chronic toxicity of Pb to aquatic life is considerably less than acute toxicity, as evidenced by the large difference in CCC and CMC criteria (2.5 and 65μg/L, respectively, at 100mg/L $CaCO_3$ hardness) (25 PA Code § 16.24). Dissolved Pb was never detected in 115 Poquessing samples from 2008-2009 (Table 4.26). At the paired hardness concentration of each sample, only three dissolved Pb samples below reporting limits could have possibly exceeded the Continuous Criteria Concentration. The three possible exceedances were observed at hardness concentrations of 32 and 36 mg/L $CaCO_3$, respectively, during wet weather on 9/7/08 and 10/26/08 at PQB025, and 31 mg/L $CaCO_3$ at PQ050 during wet weather on 9/7/08.

4.4.7.7 ZINC

Zinc (Zn) is a common element present in many rocks and in small concentrations in soil. Zn is a micronutrient needed by plants and animals, but when present in greater concentrations in surface water, it is moderately toxic to fish and other aquatic life. Toxicity is most severe during certain sensitive (usually early) life stages. Zn is a component of common alloys such as brass and bronze and is used industrially for solders, galvanized coatings, and in roofing materials. Zn is usually present in surface waters of Poquessing Creek Watershed, and dissolved zinc was detected in 101 of 107 samples in 2008-2009 (Table 4.26). Dissolved zinc concentrations were significantly positively correlated with total recoverable zinc ($r(103) = 0.94$, $p<0.001$) (Figure 4.25). There were no violations of acute or chronic exposure water quality criteria.

Spatial variability of dissolved zinc under dry and wet weather conditions were investigated separately with one-way ANOVAs. Mean concentrations of dissolved zinc were significantly different among sites under both dry and wet weather conditions ($F(6,70) = 7.67$, $p<0.001$ and $F(2,19) = 5.39$, $p= 0.014$, respectively) (Figures 4.26 and 4.27). Post-hoc analysis of dry weather results revealed that mean concentrations were each significantly greater at PQB025 than at PQ155, PQ395, PQ665, and PQ820. Similarly, mean concentrations were each significantly greater at PQB305 than at PQ155, PQ395, PQ665, and PQ820. Post-hoc analysis of wet weather results showed that mean concentrations were significantly greater at PQB025 than PQ665.

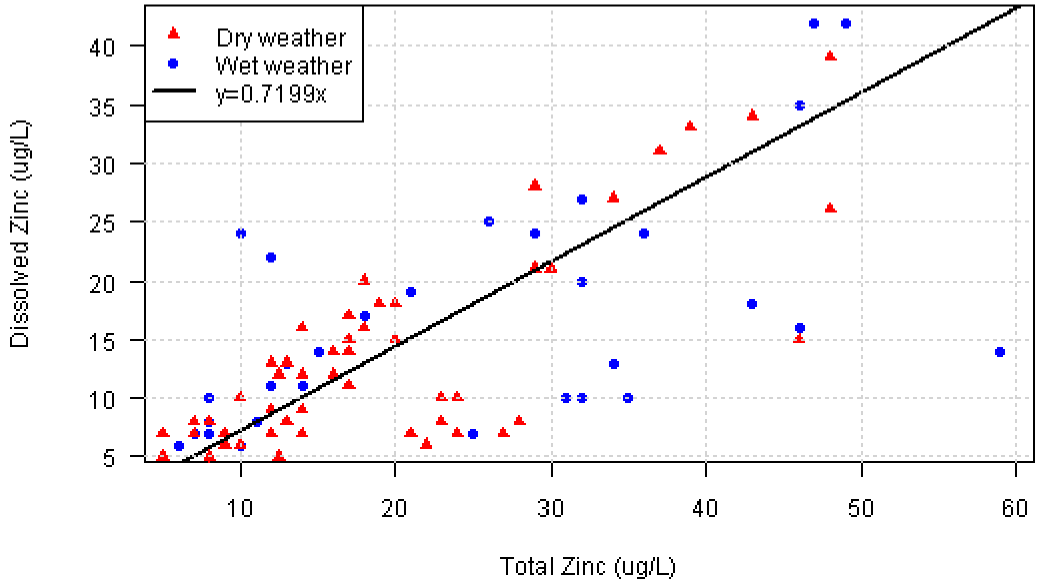

Figure 4.25 Scatterplot of Paired Total Recoverable Zinc and Dissolved Zinc Samples Collected from 7 Sites in Poquessing Creek Watershed (2008-2009 data)

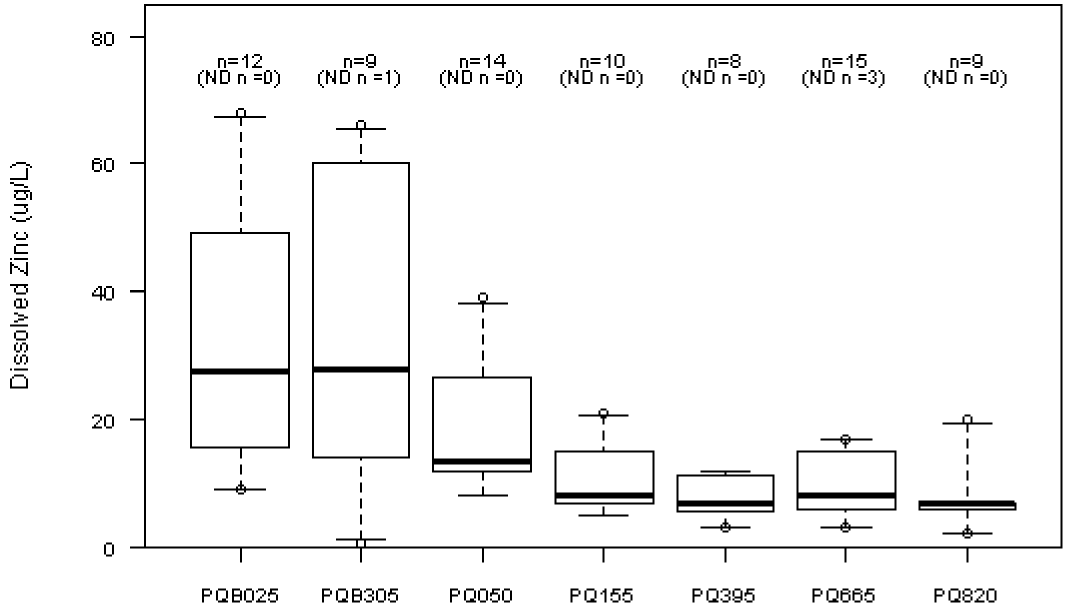

Figure 4.26 Dissolved Zinc Concentrations by Site in Dry Weather Conditions, 2008-2009

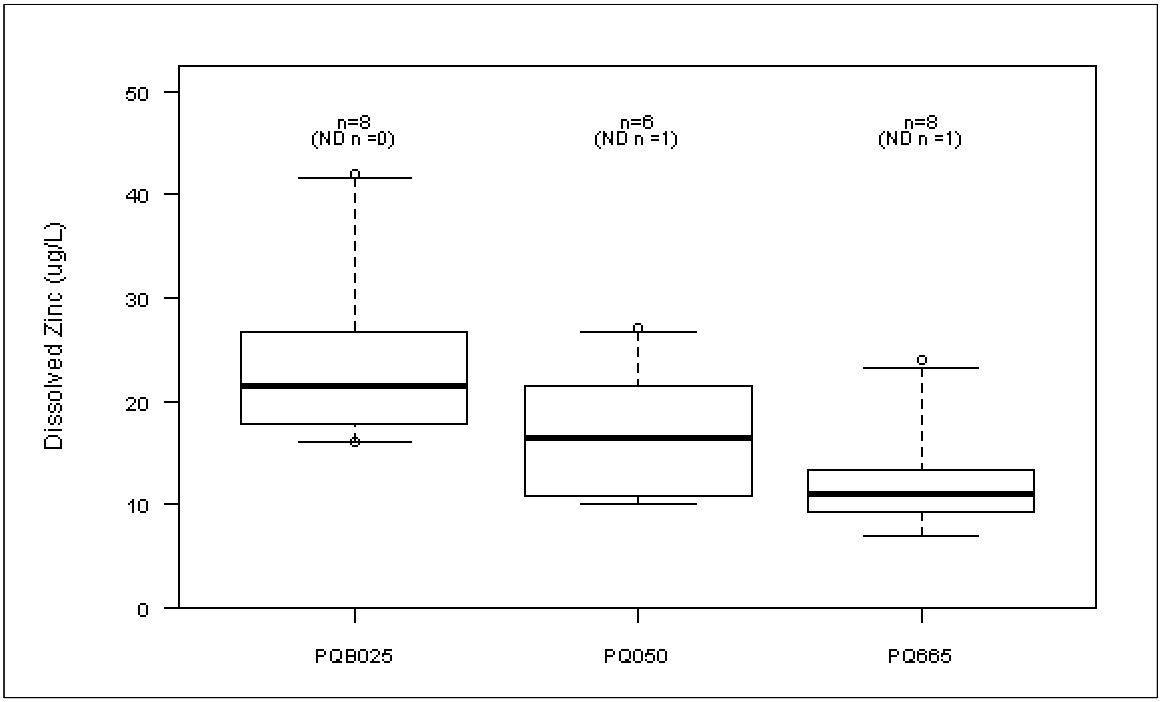

Figure 4.27 Dissolved Zinc Concentrations by Site in Wet Weather Conditions, 2008-2009

Discrepancies have occurred in the relative concentrations of dissolved and total recoverable zinc from water quality samples processed by PWD BLS. When different aliquots of sample are analyzed it may be expected that occasionally a dissolved metal result may be slightly higher than a total recoverable result, but samples for which the dissolved result greatly exceeds the total recoverable result are suspected to have been contaminated and should probably be considered outliers. As samples were preserved and stored, the PWD Bureau of Laboratory Services (BLS) was able to re-analyze these samples, obtaining similar results. The analyst visually confirmed the presence of settled solids in sample containers used for total recoverable metal, while sample containers used for dissolved metals were visually clear. A series of subsequent filter blank trials showed filters used to prepare dissolved metals samples may have leached a small amount of Zn, but the magnitude of the difference in total and dissolved concentrations was much too great to be explained by filter contamination. The source of contamination remains unknown, but airborne zinc particles in dust are another potential source. Only two wet weather samples from Poquessing Creek showed this pattern (Figure 4.25)

The BLM was used to estimate the toxicity of dissolved Zn to fathead minnows (*Pimephales promelas*), and a cladoceran water flea (*Daphnia magna*). Input data were compiled or estimated in the same manner as dissolved copper model input data. Due to the fact that many of the BLM input parameters were estimated, an order of magnitude (10x) MOS factor was applied to the LC_{50} concentrations generated by the model and the resulting concentration was compared with dissolved zinc data collected from Poquessing Creek Watershed. With this safety margin, observed dissolved Zn concentrations exceeded the calculated LC_{50} for *P. promelas* in 4 of 76 (5%) dry weather samples, but none of the 31 wet weather samples. The invertebrate target organism, *D. magna*, however, was much more sensitive to Zn and calculated LC_{50} was exceeded in 34 of 76 (45%) dry weather samples and 9 of 31 (29%) wet weather samples.

4.4.8 NUTRIENTS

4.4.8.1 PHOSPHORUS

4.4.8.1.1 PHOSPHORUS BACKGROUND INFORMATION

Phosphorus (P) concentrations are often correlated with algal density and are used as a primary indicator of cultural eutrophication of water bodies. Most segments of mainstem Poquessing and Byberry Creeks have been listed by PADEP as impaired due to excessive algal growth (Section 2, Figure 2.9). While several TMDLs have been completed and revised for aquatic life use impairments due to nutrients, Pennsylvania does not have phosphorus water quality standards for protection of aquatic life. Numerous water quality standards or reference values for phosphorus as TP (total phosphorus) and, less frequently, for orthophosphate have been proposed for various types of water bodies (Dodds and Welch, 2000; Dodds and Oakes, 2004; USEPA 2000).

Total P concentrations in Poquessing Creek Watershed were evaluated against reference stream data in EPA Ecoregion IX, subregion 64 (75th percentile of observed data=0.040 mg/L) as recommended in USEPA 2000. This reference value is considerably less than the mesotrophic/eutrophic boundary for TP suggested by Dodds *et al*. (1998) (*i.e.*, 0.075 mg/L). While total phosphorus accounts for all forms of P that may be available through various decomposition scenarios, release from sediments upon desorption under anoxic conditions, and other biochemical pathways, orthophosphate is the form of phosphorus that is directly usable by producers and thus most strongly related to the potential for algal growth in small, shallow, oxygenated streams.

4.4.8.1.2 PHOSPHORUS TRENDS IN POQUESSING CREEK WATERSHED 1969-1973

Historic mean concentrations of TP at sites PQ050 and PQB305 were 0.11 and 0.17 mg/L, respectively (Figure 4.28). Unfortunately, historic observations of orthophosphate reflect filtered samples, whereas the current dataset contains unfiltered orthophosphate samples, therefore the two orthophosphate datasets are not directly comparable. Nevertheless, it is worth noting that the historic mean orthophosphate concentration, based on 38 samples from five sites in 1969-1971, was 0.55 mg/L (Figure 4.29). The 1969-1971 mean orthophosphate concentration is greater than the 1971-1973 TP mean concentration because the data are from non-overlapping periods, and because the former subset has three additional sites and appears to have captured a small number of very high concentration events. The 1969-1971 median orthophosphate concentrations from PQ050 and PQB305 are 0.17 and 0.19 mg/L, respectively, and are within 70% of 1971-1973 median TP concentrations at those sites. The maximum observed orthophosphate concentration in samples collected from Poquessing Creek Watershed 2008-2009 was 0.106 mg/L, based on 277 samples from seven sites. Furthermore, 259 of 277 samples in 2008-2009 were below 0.05 mg/L reporting limits. Given that the current dataset reflects unfiltered samples, and thus reflects both particulate and dissolved orthophosphate, whereas the historic dataset reflects only dissolved orthophosphate, it seems that current concentrations of orthophosphate have decreased. A Mann-Whitney test of historic and current orthophosphate found the historic mean concentration to be significantly greater ($U = 10234$, $p<0.001$). To account for the possible skewing effect of extreme events, the four historic orthophosphate samples that exceeded 2 mg/L were removed and the Mann-Whitney test was redone; the outcome was similar ($U = 9403$, $p<0.001$).

It is difficult to draw definitive conclusions given the disparity in historic data between TP and orthophosphate mean concentrations. Nevertheless, it is highly likely that orthophosphate trends in the watershed have not worsened over time, and may have possibly improved.

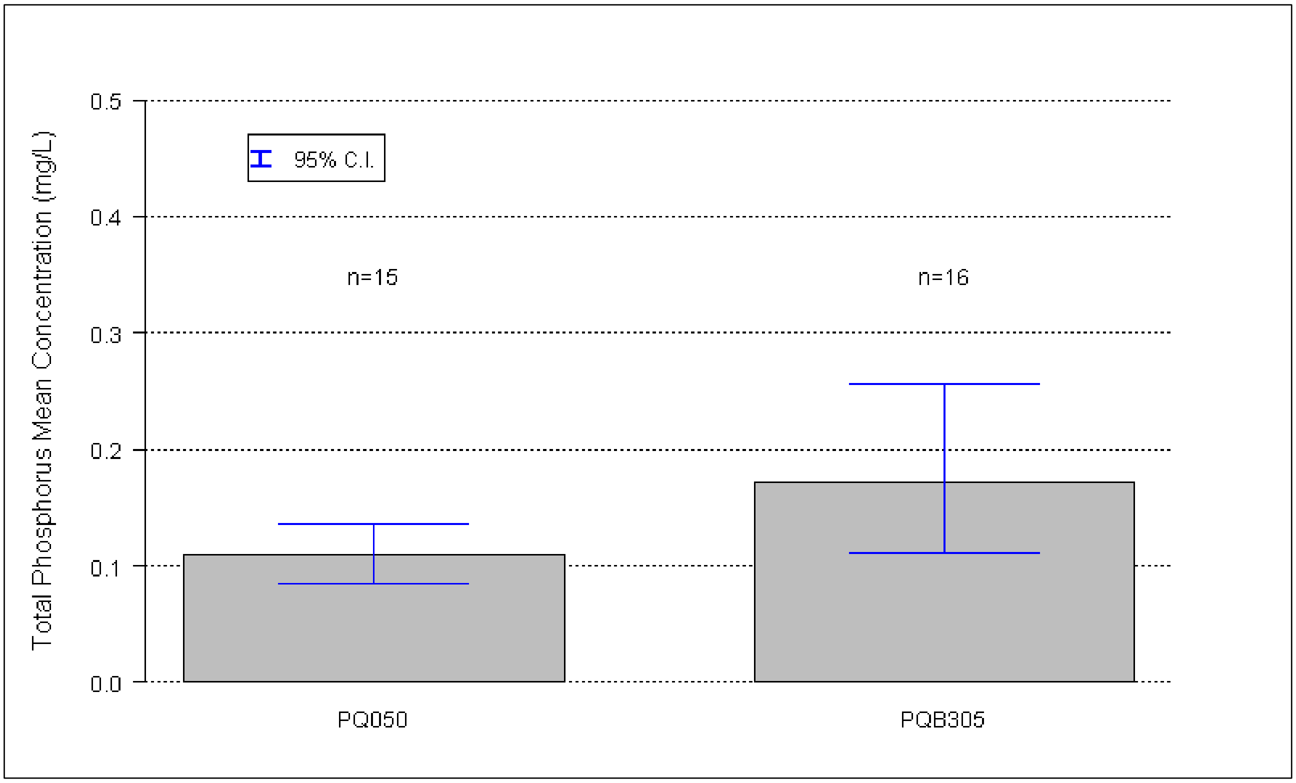

Figure 4.28 Mean TP Concentration of Historic Water Quality Samples by Site, 1971-1973

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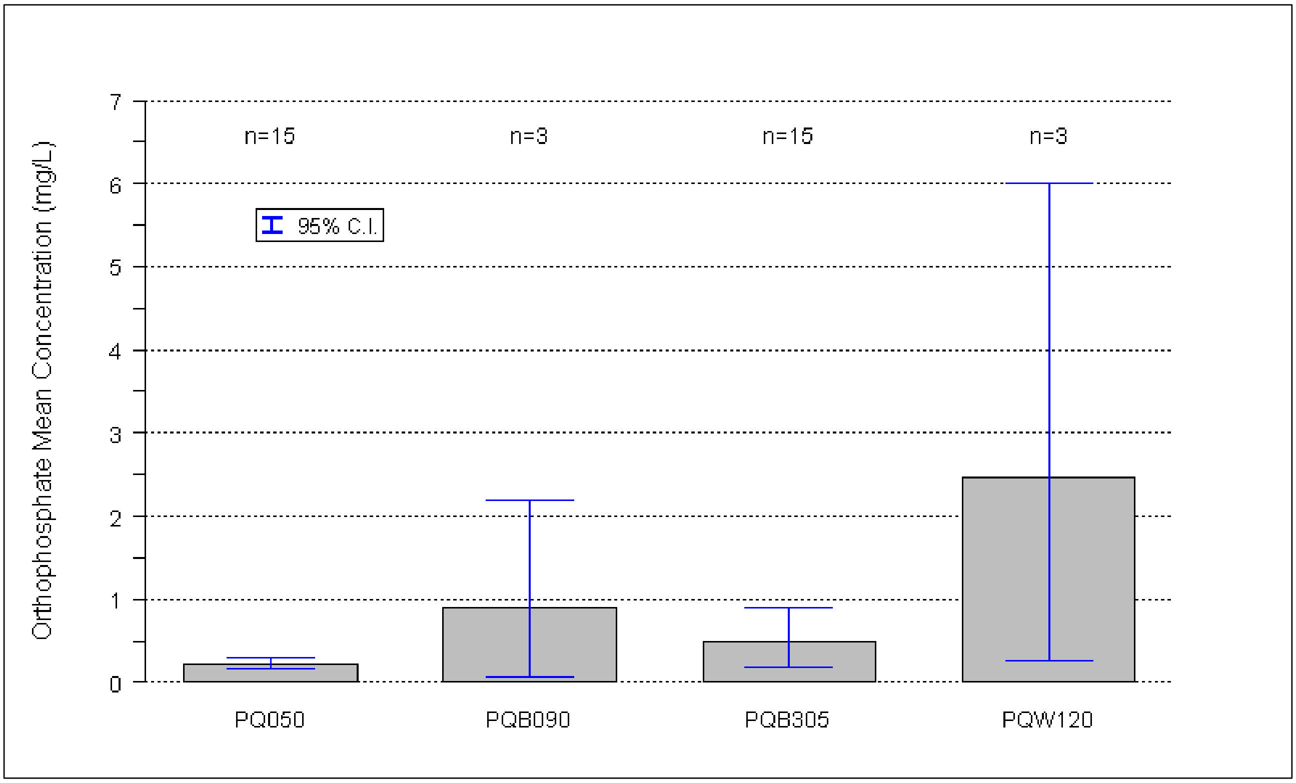

Figure 4.29 Mean Orthophosphate Concentration of Historic Water Quality Samples by Site, 1969-1973 (all samples were filtered)

4.4.8.1.3 ORTHOPHOSPHATE RESULTS

As stated above, the maximum observed orthophosphate concentration in 2008-2009 was 0.106 mg/L, based on 277 samples from seven sites. Of the 277 samples, 259 samples were less than a reporting limit of 0.05 mg/L, and eight samples were less than a 0.1 mg/L reporting limit. The USEPA Ecoregion IX sub-ecoregion 64 recommended maximum limit for orthophosphate (0.026 mg/L) (USEPA 2000) is less than reporting limits, therefore all orthophosphate samples in 2008-2009 were potential exceedances.

4.4.8.1.4 TOTAL PHOSPHORUS RESULTS

The USEPA Ecoregion IX subecoregion 64 recommended maximum limit for TP is 0.040 mg/L, which was exceeded in 51.0% and 89.0% of dry and wet weather samples, respectively. The wet weather mean concentration of 0.24 mg/L was significantly greater than the dry weather mean concentration of 0.046 mg/L (U = 14903, $p<0.001$). All sites had median TP concentrations less than 0.020 mg/L in both dry and wet weather conditions (Figures 4.30 and 4.31).

A Kruskall-Wallis ANOVA procedure was used to determine if any sites were statistically different during both wet and dry weather. TP mean concentrations were significantly different among sites in dry weather ($X^2(6,98) = 18.0$, $p<0.01$), but not in wet weather ($X^2(2,172) = 1.6$, $p>0.05$). ANOVA was performed at all sites for dry weather and at three sites for wet weather, due to sample size constraints. Post-hoc analyses of dry weather results found that the dry weather mean TP concentration at PQB025 was significantly greater than at PQB305, PQ050, and PQ155 ($p<0.05$ in each case), and the dry weather TP mean concentration at PQ665 was significantly greater than at PQ050, PQ155, PQ395, PQ820, and PQB305 ($p<0.05$ in each case). These site-specific trends were not observed in dry weather fecal coliform, nitrate, or organic nitrogen data, so it is unclear what is contributing higher TP concentrations at upstream sites in both Poquessing Creek and Byberry Creek during dry weather. Further investigation of this phenomenon is warranted.

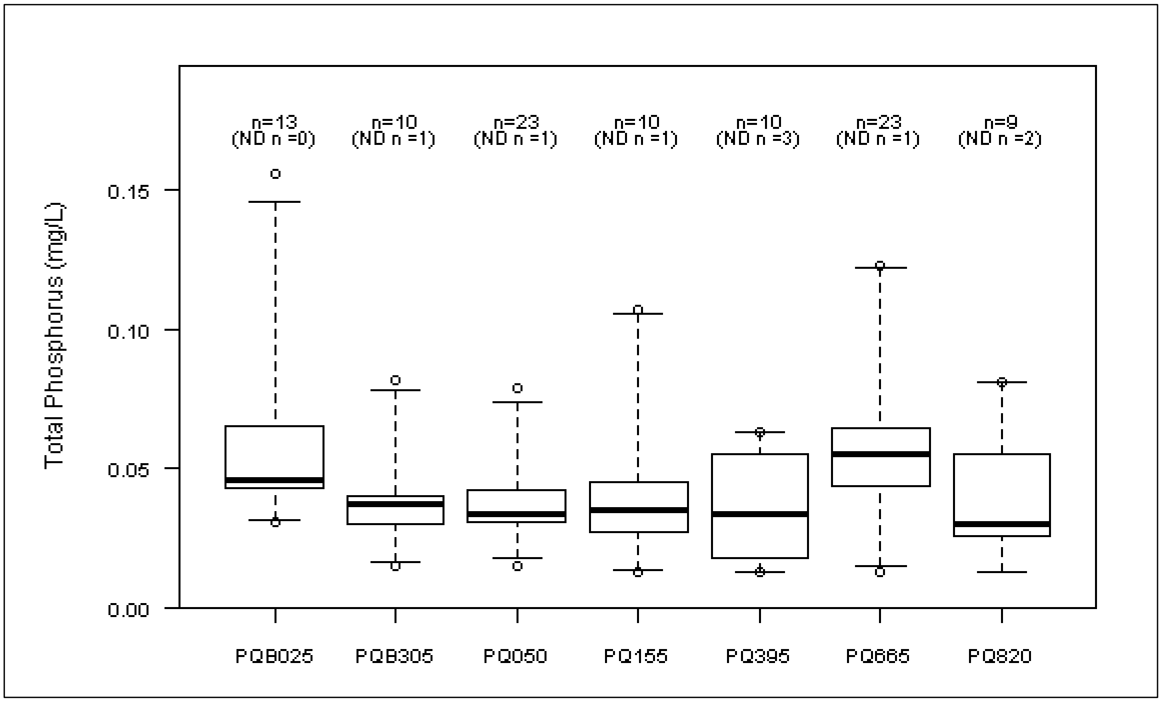

Figure 4.30 TP Concentrations by Site in Dry Weather Conditions, 2008-2009

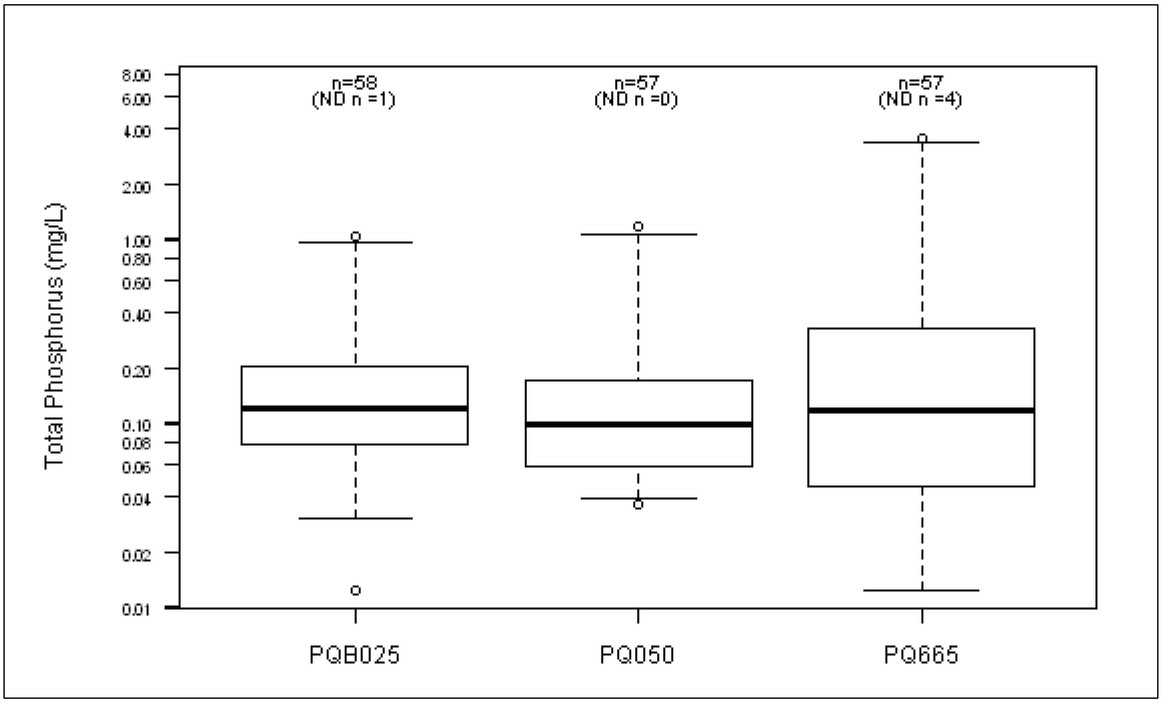

Figure 4.31 TP Concentrations by Site in Wet Weather Conditions, 2008-2009

4.4.8.2 AMMONIA

4.4.8.2.1 AMMONIA BACKGROUND INFORMATION

Ammonia, present in surface waters as un-ionized ammonia gas (NH_3), or as ammonium ion (NH_4^+), is produced by deamination of organic nitrogen-containing compounds, such as proteins, and also by hydrolysis of urea. In the presence of oxygen, ammonia is converted to nitrate (NO_3^-) by a pair of bacteria-mediated reactions, together known as the process of nitrification. Nitrification occurs quickly in oxygenated waters with sufficient densities of nitrifying bacteria, effectively reducing ammonia concentration, although at the expense of increased NO_3^- concentration. Ammonia is a primary form of nitrogen produced from excretory waste products and other organic material in sewage, thus, presence of ammonia can be an indicator of sewage pollution. As ammonia is converted to nitrate in oxygenated streams, ammonia is a non-conservative pollution indicator that tends to decrease in concentration with increasing distance from the source of pollution.

PADEP water quality criteria for NH_3 reflect the relationship between stream pH, temperature, and ammonia dissociation. Ammonia toxicity is inversely related to hydrogen ion [H+] concentration (*e.g.*, an increase in pH from 7 to 8 increases NH_3 toxicity by approximately an order of magnitude). At pH 9.5 and above, even background concentrations of NH_3 may be considered potentially toxic.

4.4.8.2.2 AMMONIA TRENDS IN POQUESSING CREEK WATERSHED 1970-2009

Based on analysis of historic ammonia data dating back to 1970, ammonia concentrations in Poquessing Creek Watershed have remained relatively constant. Ammonia toxicity does not generally appear to have been a potential water quality problem (Figure 4.32), notwithstanding a small subset of historic samples (n=9) that ranged from 1.05 to 6 mg/L. Most historic ammonia samples (n= 291) had ammonia concentration less than 1 mg/L.

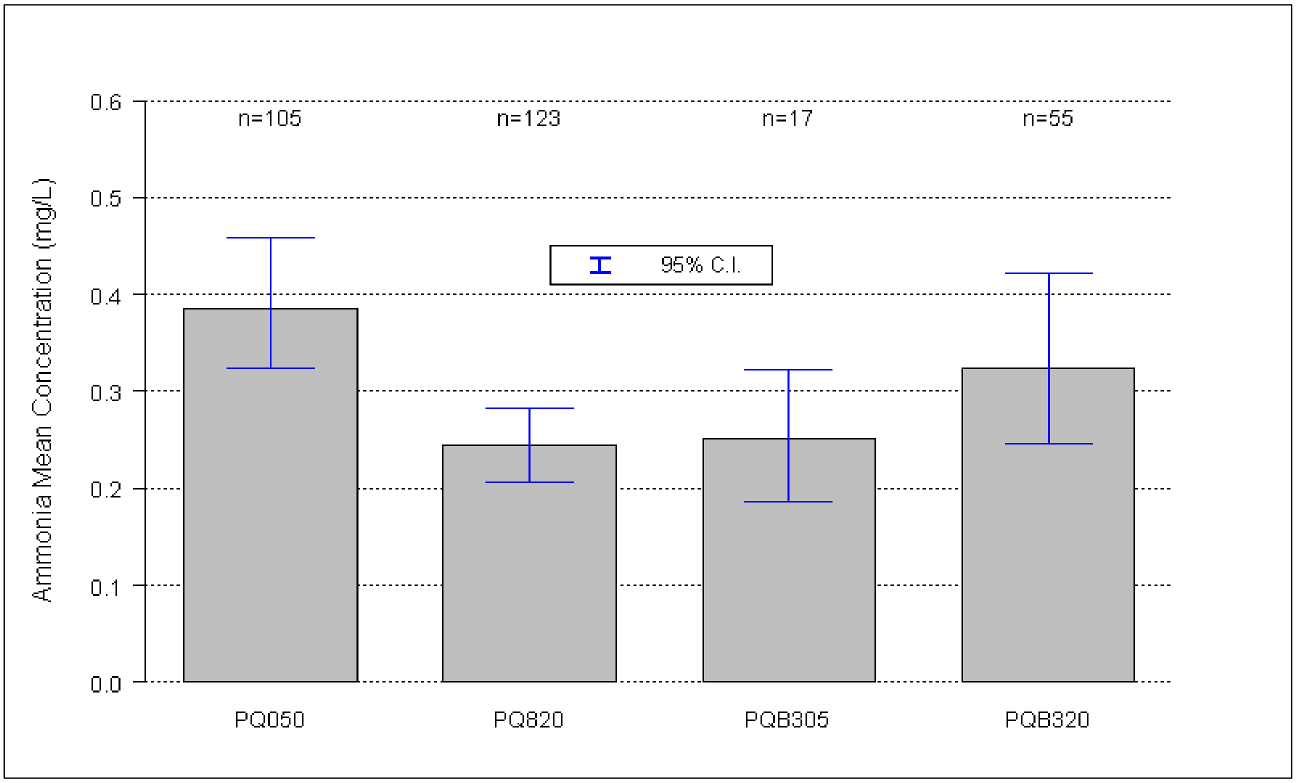

Figure 4.32 Mean NH_3 Concentrations of Historic Water Quality Samples by Site, 1970-1980

4.4.8.2.3 AMMONIA RESULTS

PWD laboratory reporting limits for ammonia fluctuated based on the performance of lab analytical equipment with spiked and blank samples. Ammonia concentration reporting limits were usually 0.5 mg/L, however some sample results had reporting limits of 0.1mg/L. Ammonia concentration in samples collected from Poquessing Creek Watershed exceeded 0.5 mg/L in only 1 of 175 wet weather samples and 2 of 98 dry weather samples. Maximum observed concentrations were 0.575 and 0.585 mg/L in dry and wet weather, respectively.

Ammonia may be introduced to streams through fertilizers, breakdown of natural organic material, stables and livestock operations, stormwater runoff, and in some cases from more serious anthropogenic sources of untreated sewage such as defective laterals, crossed/illicit connections, and sanitary sewer overflows (SSOs). PWD has established intensive field infrastructure trackdown, infrared photography, sewer camera monitoring, and dye testing programs to identify and correct these problems where and when they occur.

There were no observed violations of ammonia water quality criteria in Poquessing Creek Watershed in the 2008-2009 sample dataset. However, the sampling regime was not ideally suited for identifying possible violations of water quality standards as discrete interval grab samples were collected in the morning, while daily pH maxima were typically reached in afternoon/early evening hours due to algal activity (Section 4.4.3). In order to explore whether these circumstances had the potential to obscure violations, when pH and temperature were recorded continuously at a site or nearby site (*i.e.,* July 2008-November 2009), daily maxima of pH and temperature were subsequently used to calculate toxicity levels and compared to measured NH_3 concentrations. In the absence of continuous data (*i.e.,* January-June 2008), paired grab sample measurements of pH and temperature were utilized. Application of this method found that none of the samples had the potential to violate water quality criteria.

4.4.8.3 NITRITE

As an intermediate product in the oxidation of organic matter and ammonia to nitrate, nitrite (NO_2) is seldom found in unimpaired natural waters in great concentrations provided that oxygen and nitrifying bacteria are present. For this reason, NO_2 may indicate sewage leaks from illicit connections, defective laterals, or storm sewer overflows and/or anoxic conditions in natural waters. NO_2 was detected in none of the 46 wet weather samples, and in 4 of 60 dry weather samples collected from Poquessing Creek Watershed. Contribution of NO_2 to total inorganic nitrogen was usually small, and concentrations of all samples below detection limits samples were estimated to be half the detection limit for the purpose of evaluating nutrient ratios.

4.4.8.4 NITRATE

4.4.8.4.1 NITRATE BACKGROUND INFORMATION

Concentrations of nitrate (NO_3^-) are often greatest in watersheds impacted by (secondary) treated sewage and agricultural runoff, but elevated NO_3^- concentrations in surface waters may also be attributed to runoff from residential and industrial land uses, atmospheric deposition and precipitation (*e.g.*, HNO_3 in acid rain), decomposing organic material of natural or anthropogenic origin, and inputs of groundwater with elevated NO_3^- concentration. Nitrate is very mobile in groundwater, whereas phosphorus tends to be adsorbed by clay particles and iron. For this reason, sources of nitrogen pollution can be difficult to characterize based on water sampling. Surface-applied fertilizers have the ability to contribute nitrate to local waterways both through leaching into the groundwater and via overland runoff. Nitrogen from human wastes can be introduced to streams diffusely through septic systems or from point sources of treated wastewater. Groundwater in and around Poquessing Creek Watershed generally has elevated nitrate levels (median NO_3^- concentration of groundwater samples from monitoring wells in PADEP groundwater monitoring network zones 77 and 78 = 3.41 and 3.11 mg/L, respectively, Reese 1998), while rainwater tends to be more dilute.

Nitrification of ammonia in oxygenated streams produces nitrate, a practically non-toxic form of inorganic nitrogen that serves as a source of the essential nutrient for photosynthetic autotrophs. Availability of inorganic N can be a growth-limiting factor for producers, though in the Eastern United States this is usually only the case in oligotrophic (nutrient-poor) lakes and streams or acidic bogs. Temporary nitrogen limitation may also occur in the epilimnion of stratified lakes and reservoirs during summer, resulting in blooms of nuisance blue-green algae that have the ability to fix nitrogen.

PADEP has established a limit of 10mg/L for oxidized inorganic nitrogen species (NO_3^- + NO_2) (25 PA Code § 93.7). This limit is based on public water supply use (PWS) and intended to prevent methemoglobinemia, or "blue baby syndrome." Methemoglobinemia is a condition caused by excessive concentrations of nitrate in the blood where nitrate begins to bind to red blood cells instead of oxygen because hemoglobin, which is the protein that transports oxygen in the body, has a higher affinity for NO_3^- than oxygen. This condition can be fatal or cause serious illness in infants and small children due to diminished oxygen transport. As described in 25 PA Code § 96.3, this standard applies only at the point of existing or planned water supply intakes.

4.4.8.4.2 NITRATE TRENDS IN POQUESSING CREEK WATERSHED 1964-2009

Historical (*i.e.*, 1964-1980) mean NO_3^- concentrations at five sites are shown in Figure 4.33. As described in section 4.2.6, a statistical comparison of historical to modern (*i.e.*, 2001-2009) data demonstrated that significant decreases in nitrate have been observed in dry weather at multiple Poquessing and Byberry Creek sites, and in wet weather at Byberry Creek sites. Further site-specific comparisons were hindered by a lack of sufficient samples. Observed decreases in dry weather fecal coliform and nitrate mean concentrations might be an indication that management strategies to reduce infrastructure failures are functioning properly during dry weather.

4.4.8.4.3 NITRATE RESULTS

Twelve stream segments, comprising most of the length of Poquessing Creek, Byberry Creek, and their respective tributaries, were listed by PADEP in 2002 as not meeting their designated aquatic life use due to excessive algal growth impairments, which are often associated with nutrient enrichment (Section 2.7, Figure 2.9). The USEPA (2000) Ecoregion IX, sub-ecoregion 64 recommended maximum limit for NO_2 +NO_3 concentration in surface waters is 0.995 mg/L, which is the median of seasonal 25th percentile values of observed data. As mentioned above in section 4.4.8.4.1, groundwater nitrate concentration in and around Poquessing Creek Watershed is considerably greater than surface water concentrations in streams used to compile these data (USEPA 2000).

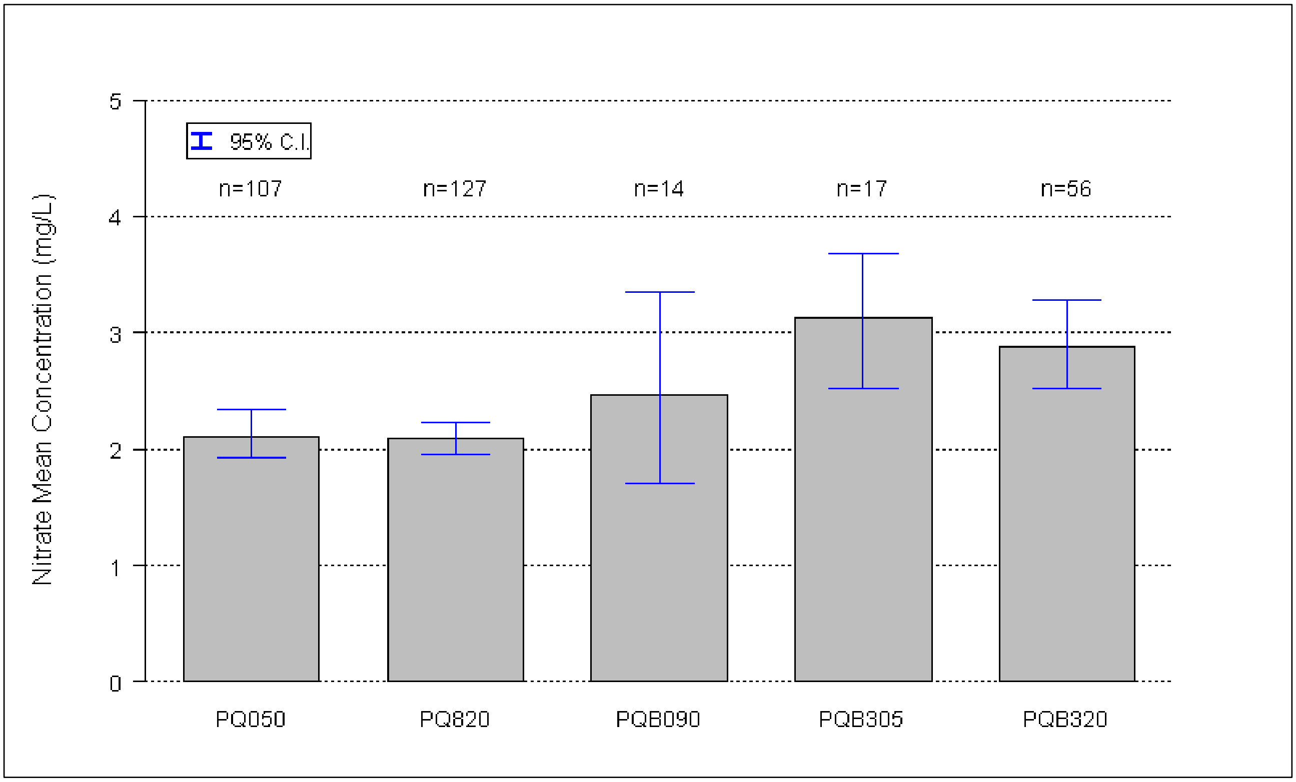

Figure 4.33 Mean NO_3^- Concentrations of Historic Water Quality Samples by Site, 1964-1980

The reference value of 0.995 mg/L was exceeded in 140 of 277 (50.5%) samples from Poquessing Creek Watershed. The exceedance rate was greater in dry weather (66.7%) compared to wet weather (41.1%), and mean concentration was significantly greater in dry weather than wet weather (U = 12798.5, $p<0.001$). Dry and wet weather mean concentrations were 1.34 and 0.90 mg/L, respectively. Only one site, PQ665, was found to have a dry weather median nitrate concentration value less than 0.995 mg/L (Figure 4.34).

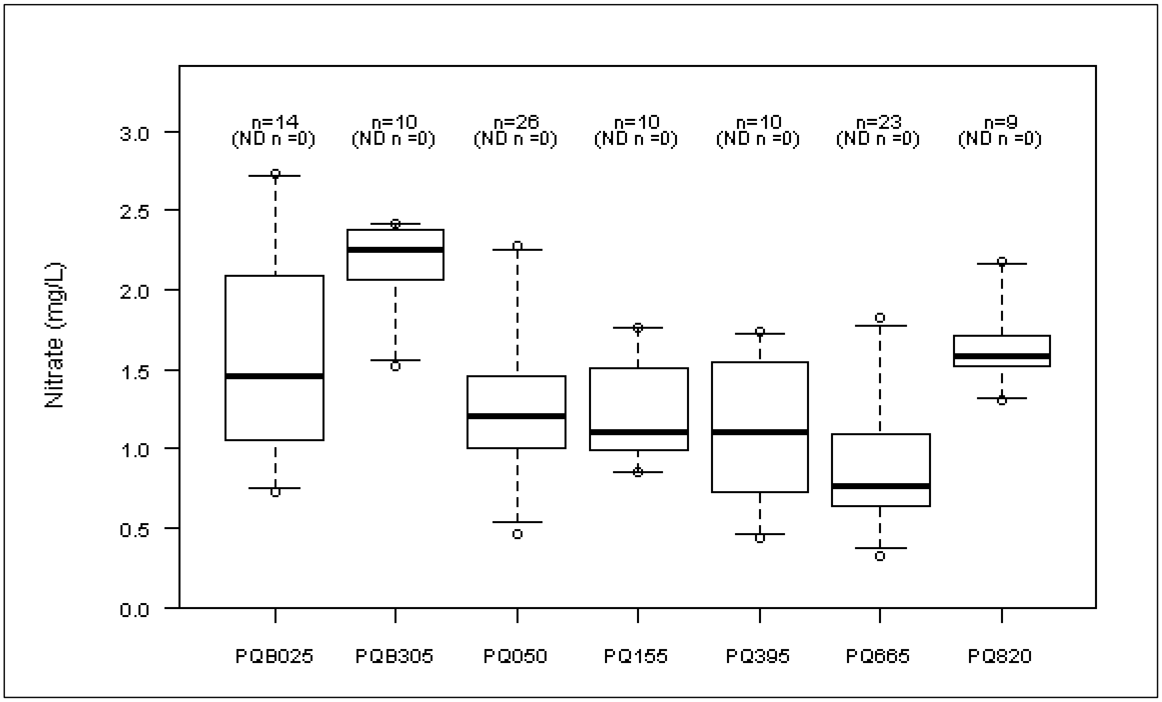

Figure 4.34 NO_3^- Concentrations by Site in Dry Weather Conditions, 2008-2009

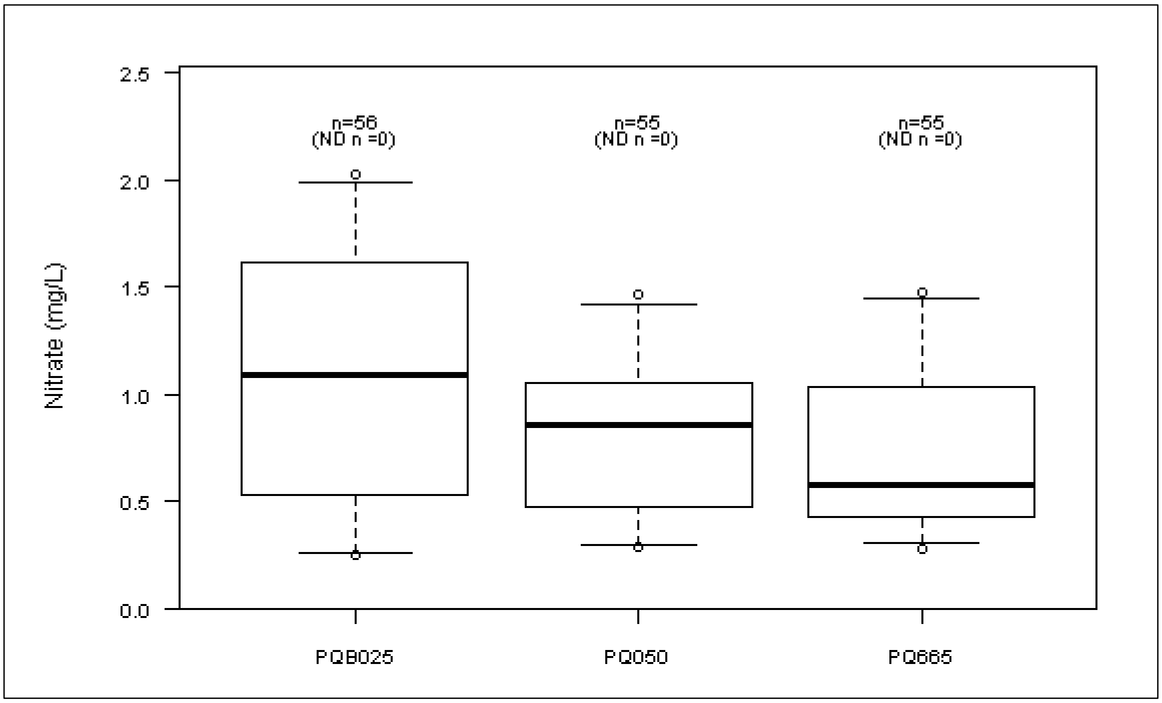

Figure 4.35 NO_3^- Concentrations by Site in Wet Weather Conditions, 2008-2009

One-way ANOVA was used to determine if any sites were statistically different in either dry or wet weather. NO_3^- mean concentrations were significantly different among sites in dry weather ($F(6,95) = 11.56$, $p<0.001$), and in wet weather ($F(2,163) = 10.34$, $p<0.001$). ANOVA was performed for all sites for dry weather, and at three sites for wet weather, due to sample size constraints. Tukey HSD analysis of dry weather results found that the dry weather NO_3^- mean concentration at PQ665 was significantly less than at PQB025 ($p<0.001$), PQB305 ($p<0.001$), and PQ820 ($p=0.001$). The dry weather mean NO_3^- concentration at PQ050 was found to be significantly less than at: PQB025 ($p=0.04$); PQB305 ($p<0.001$), and PQB820 ($p<0.001$). The dry weather mean NO_3^- concentration at PQB025 was also significantly greater than at PQ395, PQ155, PQ050 and PQB025 ($p<0.001$ in all three cases). Tukey HSD analysis of wet weather results found that the wet weather NO_3^- mean concentration at PQB025 was significantly greater compared to sites PQ665 and PQ050 ($p<0.001$ and $p=0.003$, respectively).

In summary, PQB305 dry weather NO_3^- mean concentration was significantly greater than all other sites except PQ820. In both Poquessing and Byberry Creeks, the most upstream site (*i.e.*, PQB305 and PQ820) had the greatest dry weather NO_3^- concentrations in terms of median and all other quartile values. This phenomenon is possibly attributed to the greater percentage of baseflow in upstream sites, in which the effect of a 3 mg/L groundwater mean nitrate concentration would be stronger than in downstream sites with a lower baseflow fraction.

4.4.8.5 TOTAL KJELDAHL NITROGEN

The Total Kjeldahl Nitrogen (TKN) test provides an estimate of the concentration of organically-bound N, or nitrogen that is not dissolved in the water column as nitrate (or nitrite) ions; however, the method actually measures all N present in the trinegative (-III) oxidation state. Ammonia must be subtracted from TKN values to give the organically bound fraction. (Ammonia samples below reporting limits were assumed at half the reporting limit when calculating organic nitrogen). TKN analysis also does not account for several other N compounds (*e.g.*, azides, nitriles, hydrazone); these compounds are rarely present in surface waters.

Sampling results suggest the most important source of organic N in Poquessing Creek Watershed is natural and anthropogenic organic material washed into the stream during storm events. However, sewage inputs from failed septic systems and defective laterals are another possible source, as are SSO discharges where and when they occur. There was a significant positive correlation, $r(271) =0.521$, $p<0.001$) between paired TKN and fecal coliform samples (Figure 4.36), which supports the assumption that fecal matter is a contributing source of organic nitrogen input into the watershed. Organic N concentration was significantly greater in wet weather than in dry weather ($U=13764$, $p<0.001$) (Figures 4.37 and 4.38). Organic N was also significantly positively correlated with fecal coliform bacteria concentration, $r(271) = 0.510$, $p<0.001$ (Figure 4.39), suggesting that fecal material (whether from domestic animals, wildlife or human waste) is a component of the organic N load.

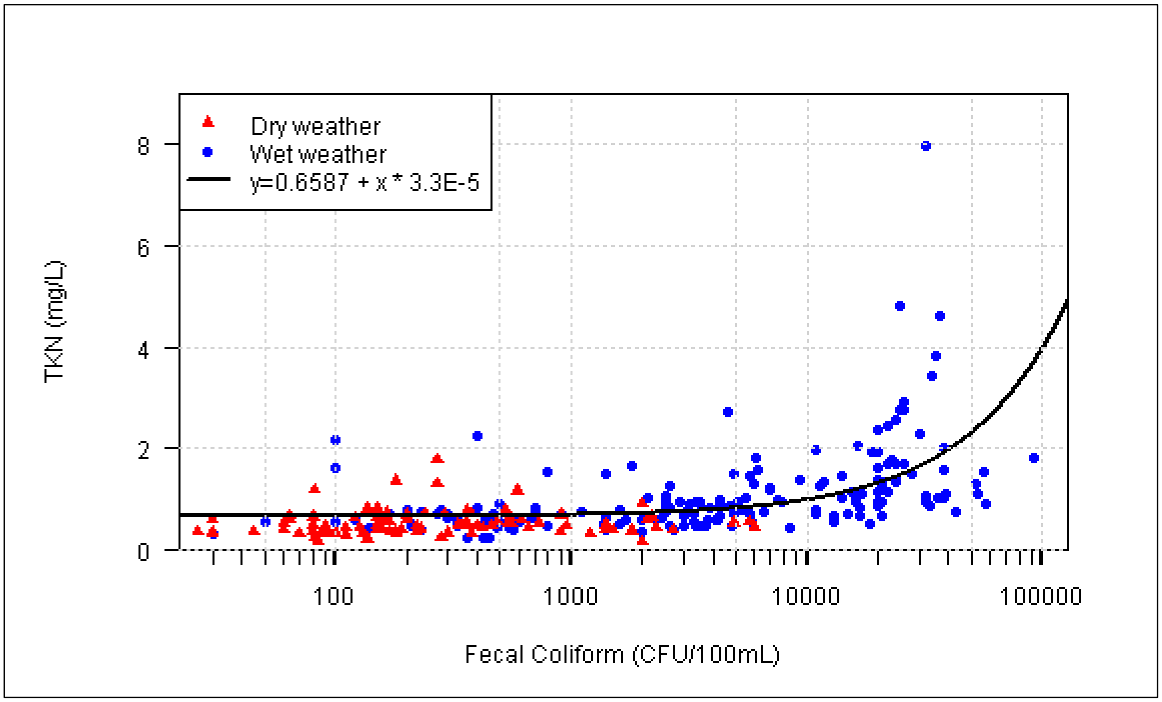

Figure 4.36 Scatterplot of Paired Fecal Coliform and TKN Samples Collected from 7 Sites in Poquessing Creek Watershed (2008-2009 data)

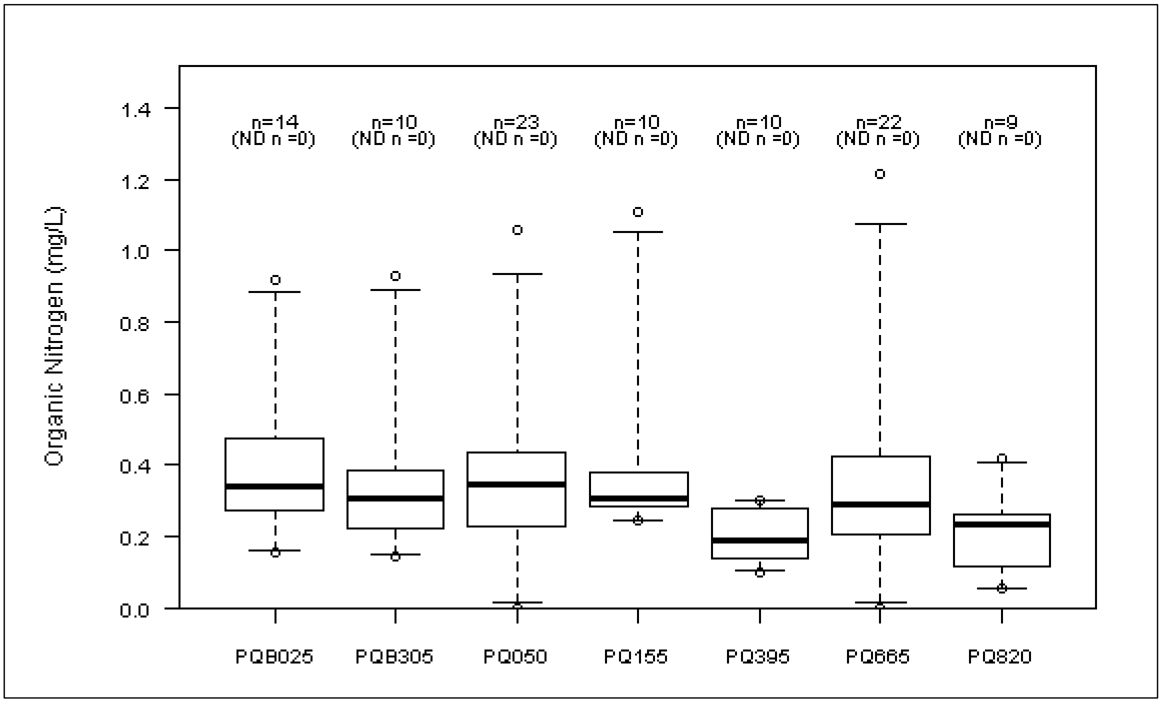

Figure 4.37 Total Organic Nitrogen Concentrations by Site in Dry Weather Conditions, 2008-2009

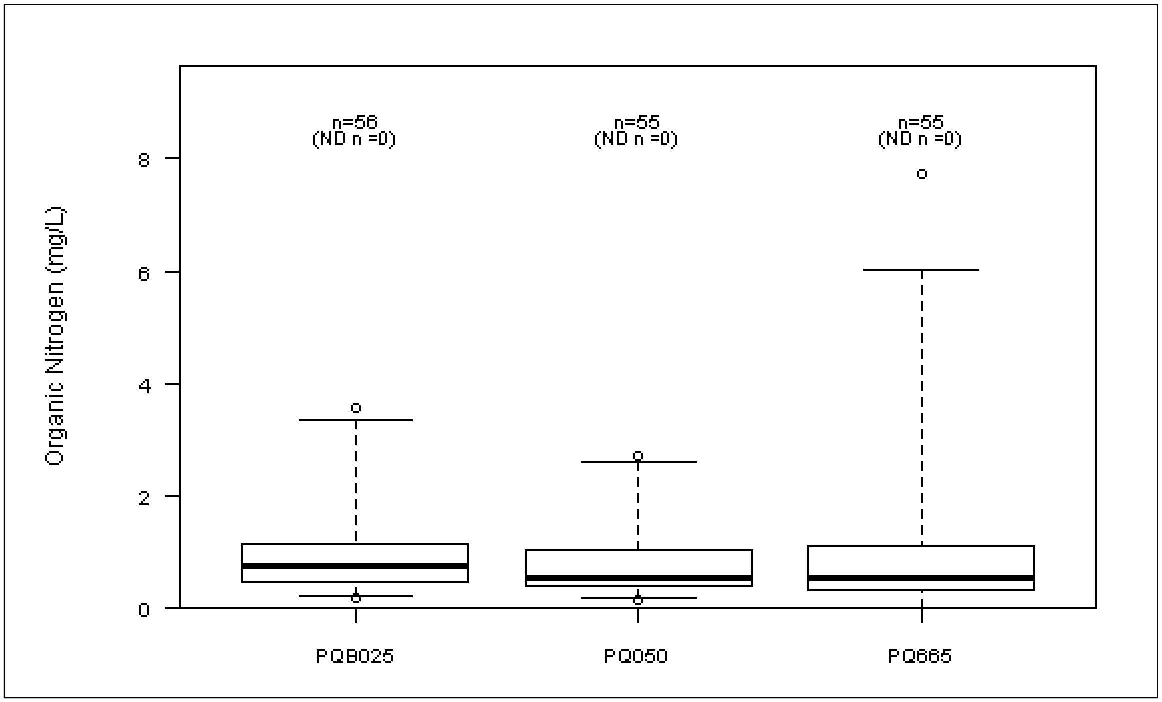

Figure 4.38 Total Organic Nitrogen Concentrations by Site in Wet Weather Conditions, 2008-2009

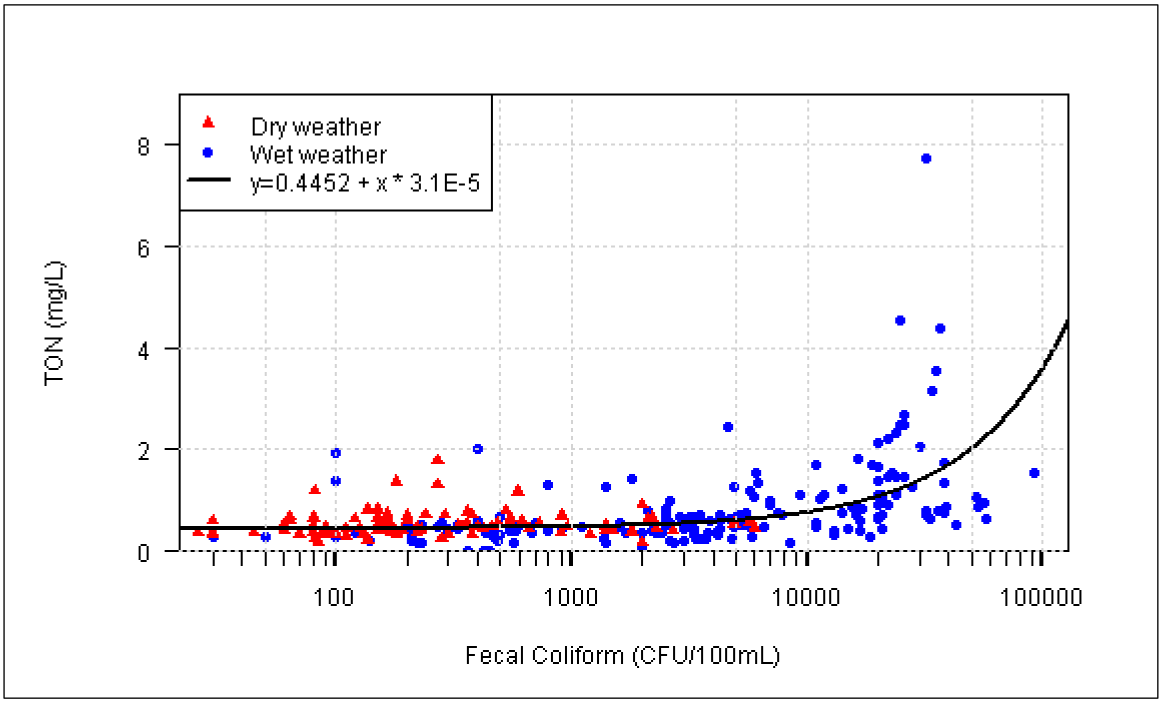

Figure 4.39 Scatterplot of Paired Fecal Coliform and TON Samples Collected from 7 Sites in Poquessing Creek Watershed (2008-2009 data)

4.5 STREAM METABOLISM

4.5.1 OVERVIEW OF STREAM METABOLISM

Stream metabolism is a measure of the basic ecosystem processes of primary productivity and community respiration. Primary productivity measures the total energy fixed by plants in a community by photosynthesis, and community respiration quantifies the use of reduced chemical energy by autotrophs as well as heterotrophs (Odum, 1956). Benthic algae are important primary producers in aquatic systems and are often the greatest source of energy in shallow mid-order streams with less than complete tree canopy. Periphyton communities may strongly influence water column dissolved oxygen concentration, pH, and inorganic carbon speciation.

As Poquessing Creek Watershed was not found to have large dry weather concentrations of chlorophyll in the water column that would be indicative of suspended phytoplankton, these fluctuations in continuous water quality parameters are due largely to periphytic algae (Section 5.3.3.3.1). Also supporting this conclusion are observed reductions in the magnitude of dissolved oxygen and pH fluctuations during and immediately after storm events, indicating scouring away and rapid subsequent recolonization of attached algae.

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

4.5.2 RELATION OF ALGAL ACTIVITY TO DISSOLVED OXYGEN CONCENTRATION

DO concentrations often strongly reflect autotrophic community metabolism, and in turn, affect the heterotrophic community structure as a limiting factor for numerous organisms. Stream sites that support abundant algal growth often exhibit pronounced diel fluctuations in dissolved oxygen concentration (Figure 4.40). Algal photosynthesis infuses oxygen during the day (often to supersaturation), while respiration by algae and heterotrophic organisms removes oxygen throughout the night. Diel fluctuations are more pronounced in the spring and summer months than the autumn and winter months as colder water has a greater capacity for DO and biological metabolic activity is generally regulated by temperature.

Dissolved oxygen concentration fluctuations at continuously monitored sites in Poquessing Creek Watershed were observed to decrease immediately following storm events. While some of this effect is due to reduced insolation, scouring and flushing effects of high flows are assumed to have reduced periphyton and phytoplankton algal biomass, thereby decreasing production of oxygen via photosynthesis. Daily maximum DO concentrations and range of diel fluctuations subsequently returned to pre-flow conditions (Figure 4.40) rather quickly, often in three days. This phenomenon was assumed to be due to accrual of algal biomass following scouring events.

The Poquessing Creek Watershed experienced pronounced diel fluctuations in dissolved oxygen (DO) concentration. When biological activity was high, DO concentrations were observed to violate the state regulated WWF minimum of 4.0 mg/L, although violations of these standards were limited almost exclusively to site PQ665. Dry weather dissolved oxygen suppression tended to occur at night and was likely caused by respiration of algae and heterotrophic organisms, as well as microbial decomposition of organic constituents in the absence of photosynthetic oxygen production. As noted in section 4.4.1, diel fluctuations in dissolved oxygen were not always severe (Figure 4.6) and did not always result in afternoon supersaturation during episodes of violation of DO water quality standards; water quality data suggest that neither BOD nor NBOD is problematic in the watershed. These findings suggest that another source of DO flux is also a major factor in the DO impairment observed at this site.

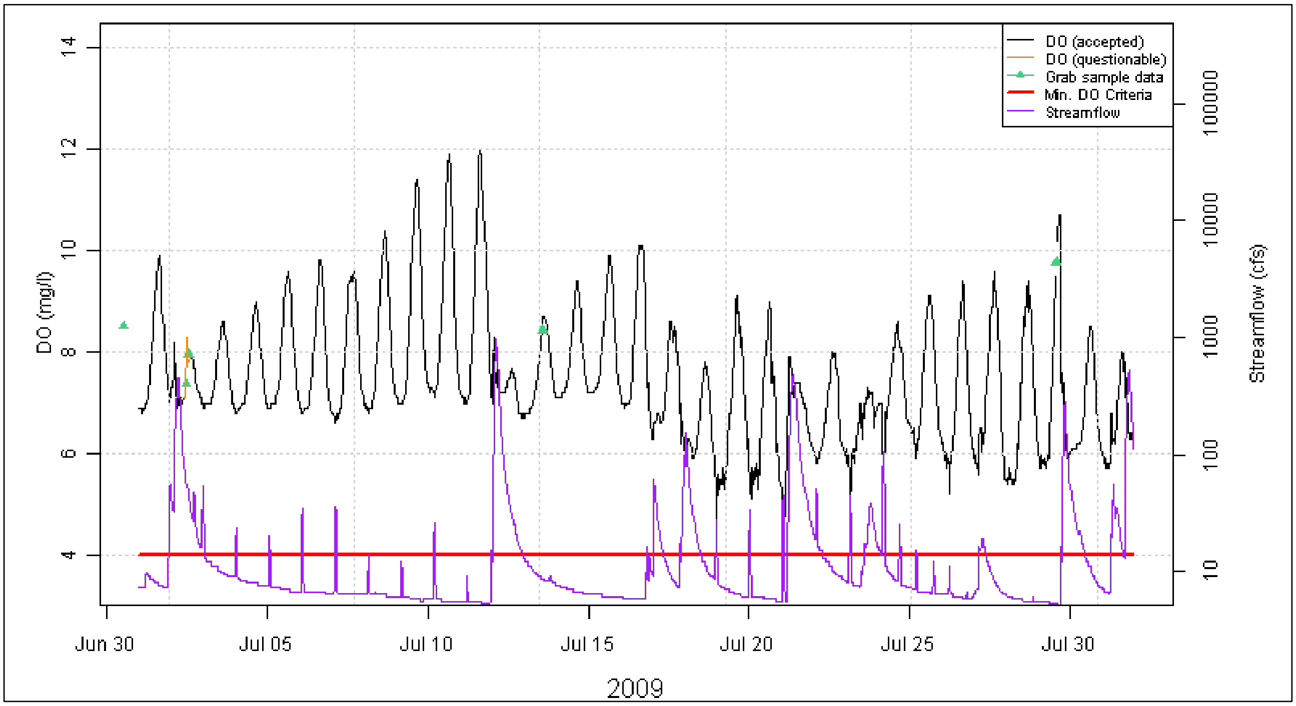

Figure 4.40 Example of Severe Dissolved Oxygen Fluctuations (7/9/09 -7/11/09) at PQ050, with Dampening Due to 7/12/09 Storm Event

4.5.3 RELATION OF ALGAL ACTIVITY TO STREAM PH

Fluctuations in pH can occur in freshwater systems as a result of natural and anthropogenic influences. Interplay between inorganic carbon species, known as the bicarbonate buffer system, generally maintains pH within a range suitable for aquatic life. pH affects aquatic biota directly and also influences ionization of NH_3 and solubility/bioavailability of toxic metals. Fluctuations in pH driven by algal activity (*i.e.*, respiration and photosynthesis) thus have the potential to exacerbate toxic conditions or even create toxic conditions where none previously existed.

The bicarbonate buffer system describes the equilibrium relationship between carbon dioxide (CO_2) and carbonic acid (H_2CO_3), as well as bicarbonate (HCO_3^-) and carbonate (CO_3^{2-}) ions. In natural waters, the predominant source of hydrogen ions is carbonic acid. Biochemical metabolism of carbon throughout the day continually shifts the equilibrium equation, causing fluctuations in pH.

As plants and algae consume carbon dioxide during photosynthesis, carbonic acid dissociates to replenish the CO_2 and maintain equilibrium. Decreasing carbonic acid concentration causes elevated pH, as hydrogen ions are taken up with the increased consumption of CO_2, thereby raising pH. As photosynthetic rates decline after peak sunlight hours, respiratory activities of aquatic biota replenish carbon dioxide to the system and release hydrogen ions which in turn decreases pH. pH in Poquessing Creek Watershed is chiefly determined by metabolic activity as the watershed is not heavily influenced by anthropogenic inputs, such as acid mine drainage. Diel fluctuations of pH were observed at all continuously monitored sites in Poquessing Creek Watershed, with the magnitude of daily fluctuations approaching 2.0 pH units. As described in section 4.4.8.2.3, these fluctuations may have exacerbated ammonia toxicity, but there were no observed violations of ammonia water quality standards.

4.5.4 NUTRIENT LIMITATION EFFECTS ON PRIMARY PRODUCTION

4.5.4.1 NUTRIENT LIMITATION BACKGROUND INFORMATION

Nutrients are arguably the most important factor dictating algal standing crop, primary production, and community composition. Examination of the nutrient-algae relationship requires both an autecological and community-level approach (Borchardt, 1996).

Nutrients can limit algal growth. In any given scenario, only one nutrient can limit algal growth for a given species at a time, although at the community level this rule does not apply where different species might be limited by different nutrients. Growth rates are not affected by nutrient concentrations alone. Light and temperature can affect nutrient uptake rates (*e.g.*, Faulkner *et al.*, 1980; Wynne and Rhee, 1988), and more nutrients are often needed when light and temperature conditions are less than ideal (Goldman, 1979; Rhee and Gotham, 1981a,b; Wynne and Rhee, 1986; van Donk and Kilham, 1990). Additionally, nutrient uptake rates can vary depending on nutrient conditions. In steady-state growth conditions, the rate of nutrient uptake is equivalent to the rate at which nutrients are used in growth. However, cells may take up fewer or greater amounts of nutrients (for example, during nutrient pulses) and alter the nutrient ratios within the cell (Borchardt, 1996).

The relationship between nutrients and algal biomass is complicated by numerous factors, and findings are not consistent across ecoregions and water body types. Typically, nutrient enrichment stimulates periphyton growth in lotic systems and many studies have shown strong relationships between nutrient concentrations and algal biomass (*e.g.*, Jones *et al.*, 1984; Welch *et al.*, 1988; Kjeldsen, 1994; Chetelat *et al.*, 1999; Francouer, 2001). However, other studies have shown no relationship between biomass and nutrient concentration (Biggs and Close, 1989; Lohman *et al.*, 1992). Periphyton standing crop can be highly variable (Morin and Cattaneo, 1992) and other factors (described in subsequent sections) may override nutrient effects.

Of the necessary components for algal growth, nitrogen and phosphorus are likely to be growth-limiting in aquatic systems (Wetzel, 2001) although carbon (Fairchild *et al.*, 1989; Fairchild and Sherman, 1993), trace metals (Winterbourn, 1990), organic phosphorus (Pringle, 1987) and silicates (Duncan and Blinn, 1989) have also been implicated in limiting algal growth. Based on periphyton-nutrient studies, phosphorus is typically the limiting nutrient in the northern U.S. (see Borchardt, 1996 for review) while nitrogen has been shown to be limiting in the southwest (Grimm and Fisher, 1986; Hill and Knight, 1988a; Peterson and Grimm, 1992) and Ozark (Lohman *et al*., 1991).

4.5.4.2 CLASSIFYING STREAM NUTRIENT CONDITION

In an effort to develop a practical system of stream classification based on nutrient concentrations similar to those used for lakes, Dodds *et al*. (1998) examined the relationship between chl-*a* (mean and maximum benthic chl-*a* and sestonic chl-*a*) and total nitrogen (TN) and total phosphorus (TP) in a large, global dataset. They defined the oligotrophic-mesotrophic boundary by the lower third of the distribution of values with mean and maximum benthic chl-*a* concentrations of 20 mg/m^2 and 60 mg/m^2, respectively; and TN and TP concentrations of 0.7 mg/L and 0.025 mg/L, respectively. The mesotrophic-eutrophic boundary was represented by the upper third of the distribution of values with mean and maximum benthic chl-*a* concentrations of 70 mg/m^2 and 200 mg/m^2, respectively; and TN and TP concentrations of 1.5 mg/L and 0.075 mg/L, respectively. Other recent studies examining specific chl-*a*-nutrient relationships include Dodds *et al*. (1997), Biggs (2000), Francouer (2001), Dodds *et al*. (2002a, b), Kemp and Dodds (2002).

4.5.4.3 ROLE OF NUTRIENT LIMITATION IN AQUATIC RESOURCES MANAGEMENT

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

However, the most appropriate target values for periphyton chlorophyll-*a* and corresponding phosphorus concentrations expected to achieve them in Poquessing Creek Watershed probably can be taken from a series of local studies of nutrients and TMDL endpoints conducted by H.J. Carrick and C. Godwin of Penn State University (Carrick, 2004; Carrick and Godwin, 2005; Carrick and Godwin, 2006). The researchers applied three established chlorophyll-a to phosphorus regressions to Wissahickon Creek Watershed data and estimated target P concentrations that might be expected to achieve different periphytic algal densities (*i.e.*, 50 and 100 mg/m^2). In addition to being geographically very close to Wissahickon Creek watershed, Poquessing Creek shares other common factors as well, such as land use. Two of the three regressions applied to Wissahickon Creek watershed were originally derived by Dodds, *et al*. (2002) for assumed periphyton N:P ratio 15:1 and 4:1 (Table 4.27). The target TP concentration 0.074 mg/L predicted to result in 50 mg/m^2 chlorophyll-a appears to be currently met in dry weather conditions in Poquessing Creek Watershed. The target 0.205 mg/L predicted to result in 100 mg/m^2 chlorophyll-a is 15% below the current wet weather TP mean concentration, and should be an achievable management goal.

Table 4.27 Regression Models Applied Toward Estimating Target TP Concentrations in Wissahickon Creek to Achieve Periphyton Biomass of 50 and 100 mg/m², Respectively

Citation	Regression Model	Scope of Study, r^2 or R^2	Target TP (mg/L) to achieve 50, 100 mg/m^2 chl-a
Cattaneo 1987	Chl=3.6 (TP)$^{0.61}$	Canadian lakes r^2=0.31	0.075, 0.233
Dodds *et al*., 2002 **N:P Ratio 15:1**	logChl=log(TN) 0.236 + log(TP) 0.443 + 0.155	N. America, New Zealand R^2=0.40	0.074, 0.205
Dodds *et al*., 2002 **N:P Ratio 4:1**	logChl=log(TN) 0.236 + log(TP) 0.443 + 0.156	N. America, New Zealand R^2=0.40	0.110, 0.305

*Adapted from (Carrick 2004, Carrick and Godwin 2005, Carrick and Godwin 2006)

Nutrient limitation analysis for Poquessing Creek Watershed was based on periphyton samples collected approximately 36 hours after a rain event that was observed at 0.1 to 0.35 inches at proximate rain gages. However, dry weather steady state conditions are the conditions under which dissolved oxygen suppression effects are greatest and also when nutrient limitation is most likely to affect periphyton communities. Therefore, results in this section may not be representative of steady state conditions. Algal biomass, estimated as chlorophyll-a, was greatest at site PQB025. Of the three sites where periphyton biomass was sampled, PQ115 and PQ820 had intracellular N:P ratios of 6.2:1 and 5.6:1, respectively, which are slightly less than the Redfield mass ratio 7:1. The intracellular N:P ratio at site PQB025 was slightly higher at 7.8:1. Given the propensity of some periphytic algal taxa to store excess P, intracellular P concentrations may be different than measurements from water column samples, especially during the growing season. Periphyton biomass estimates are a widely accepted means of biomonitoring but are not normalized to microhabitat parameters such as stable substrate availability and the availability of light; however, they do provide a framework for further investigation through intensive chemical sampling.

4.5.4.4 N:P RATIO

Although nitrogen and phosphorus are the nutrients commonly limiting algal growth, the concentrations required to limit growth are less clear. Concentrations of phosphorus ranging from 0.3-0.0006 mg PO_4-P/L have been shown to maximize growth of benthic diatoms (Bothwell, 1985), but higher concentrations have been needed in filamentous green algal communities (Rosemarin, 1982), and even higher concentrations (0.025-0.050 mg PO_4-P/L) as algal mats develop (Horner *et al*., 1983; Bothwell, 1989). Nitrogen has been shown to limit benthic algal growth at 55 µg NO_3-N/L (Grimm and Fisher, 1986) and 100 µg NO_3-N/L (Lohman *et al*., 1991). In the past, the Redfield ratio (Redfield, 1958) of cellular carbon, nitrogen, and phosphorus at 106:16:1 (atomic ratio) has been used to determine nutrient limitation. In benthic algae studies, ambient N:P ratios greater than 20:1 are considered phosphorus limited, whereas those less than 10:1 are considered nitrogen limited.

Combining the above frameworks, the samples collected from sites in mainstem Poquessing in dry weather were determined to be limited by phosphorus. It should be noted that periphyton was observed to grow to nuisance densities throughout the watershed and nutrients may not be limiting algal growth as strongly as physical factors such as substrate size and stability, light availability, or disturbance. Ignoring these physical factors, of 98 samples collected during dry weather, 84 were considered phosphorus limited and none were considered nitrogen limited. Using the mesotrophic-eutrophic boundary 0.075 mg/L for TP and 1.5 mg/L for TN (Dodds, 1998), only 11.2% of dry weather samples were considered eutrophic with respect to TP, whereas 69.6% of dry weather samples were eutrophic for TN. This further supports the conclusion that algal growth in dry weather conditions are limited by phosphorus.

Periphyton intracellular nutrient ratios were slightly skewed from the Redfield ratio toward an overabundance of P (Section 5.3.3.4.3, Table 5.17), with N:P ratios ranging from 5.6:1 at PQ820 to 7.8:1 at PQB025. These results alone might suggest that P is not limited, however the intracellular N:P ratios are based on samples from a single day in wet weather conditions. As described above, the weight of evidence is greater with respect to ambient N:P ratios from dry weather samples collected from 2008-2009 which suggest that P is limited. Given the propensity of periphytic algae and other primary producers to store excess P as biomass, watershed-wide P availability is likely to be much higher than measured in water column samples, especially during the growing season.

4.5.4.5 FLOW EFFECTS ON STREAM NUTRIENT CONCENTRATIONS

Stream nutrient concentrations in Poquessing Creek Watershed are dynamic. The macronutrient of greatest concern, P, exhibited somewhat different responses to dry and wet weather. The wet weather mean TP concentration of 0.240 mg/L was significantly greater than the dry weather mean concentration of 0.046 mg/L ($U = 14903$, $p<0.001$). All sites had median TP concentrations less than 0.020 mg/L in both dry and wet weather conditions (Figures 4.30 and 4.31).

4.6 PROBLEM SUMMARY

Water quality parameters were evaluated with respect to attainment status according to the PADEP (2007c) Chemistry Statistical Assessment protocol. A slight enhancement was added to the protocol to handle cases where samples below reporting limits could have been a potential exceedance, whereby a definitive assessment (*i.e.*, attainment or non-attainment) was withheld if the number of possible exceedances was great enough to change the assessment had they all been true exceedances.

The results are presented below in four general categories: recreation (*i.e.*, bacteria), aquatic life acute criteria, aquatic life chronic criteria, and stream trophic criteria. Note that PADEP does not stipulate water quality criteria for all the parameters in the tables below. Where PADEP criteria are absent, a reference value was used (Table 4.2).

In previous watershed CCRs, a color-coding system based on IWMP developed for the Cobbs and Tookany-Tacony/Frankford Watersheds was used to indicate problems (red) and potential problems (yellow). Problems were identified if more than 10% of samples exceeded the applied water quality standard or criterion. Potential problems were identified if between 2% and 10% of samples exceeded the standard or criterion. However, in light of the PADEP (2007c) Chemistry Statistical Assessment protocol and its more thorough consideration of sample size, sample distribution, and exceedance rate, the color-coding system of previous watershed CCRs was not used in this report. Rather, this report uses a color-coding system based on the range of possible PADEP statistically based assessments: Attaining (green); Non-attaining (red); Insufficient data due to fewer than eight samples, or Needs further evaluation (grey). The latter assessment may arise from several different possibilities, including a fraction of non-detected samples greater than half the sample size, passage of a parametric test coupled with an exceedance rate greater than 10% (or 5% for toxics), passage of a nonparametric test for a toxic pollutant without enough samples to perform the parametric test, and uncertainty due to an elevated number of potential exceedances.

4.6.1 RECREATION

Table 4.28 Summary of Fecal Coliform Recreation Criteria Exceedances

Season	Site	No. Obs.	No. Exceed	Percent Exceedance	PADEP criterion
Non Swimming	PQB025	47	34	72.3	non-attaining
	PQB305	6	0	0	ID n<8
	PQ050	57	26	45.6	non-attaining
	PQ155	6	0	0	ID n<8
	PQ395	6	0	0	ID n<8
	PQ665	55	17	30.9	non-attaining
	PQ820	6	0	0	ID n<8
Swimming	PQB025	24	24	100	non-attaining
	PQB305	6	5	83.3	ID n<8
	PQ050	25	21	84	non-attaining
	PQ155	6	4	66.7	ID n<8
	PQ395	6	4	66.7	ID n<8
	PQ665	24	21	87.5	non-attaining
	PQ820	6	6	100	ID n<8

ID n <8: Insufficient Data to make an assessment due to fewer than 8 samples

Table 4.29 Summary of *E. coli* Recreation Criteria Exceedances

Season	Site	No. Obs.	No. Exceed (site-specific guideline)	No. Exceed (General guideline)	Percent Exceedance (site-specific guideline)	Percent Exceedance (General guideline)	Site-specific guideline	notes	General guideline
Non Swimming	PQB025	47	4	19	8.5	40.4	Needs more eval.	5	non-attaining
	PQB305	6	0	0	0	0	ID n<8		ID n<8
	PQ050	57	5	14	8.8	24.6	attaining		non-attaining
	PQ155	6	0	0	0	0	ID n<8		ID n<8
	PQ395	6	0	0	0	0	ID n<8		ID n<8
	PQ665	55	2	10	3.6	18.2	attaining		non-attaining
	PQ820	6	0	0	0	0	ID n<8		ID n<8
Swimming	PQB025	24	18	23	75	95.8	non-attaining		non-attaining
	PQB305	6	3	5	50	83.3	ID n<8		ID n<8
	PQ050	25	13	16	52	64	non-attaining		non-attaining
	PQ155	6	2	2	33.3	33.3	ID n<8		ID n<8
	PQ395	6	2	3	33.3	50	ID n<8		ID n<8
	PQ665	24	11	17	45.8	70.8	non-attaining		non-attaining
	PQ820	6	2	2	33.3	33.3	ID n<8		ID n<8

ID n <8: Insufficient Data to make an assessment due to fewer than 8 samples
Notes: 5 = Number of possible exceedances precludes definitive assessment

Table 4.30 Summary of Enterococci Recreation Criteria Exceedances

Season	Site	No. Obs.	No. Exceed	Percent Exceedance	Reference criterion
Non Swimming	PQB025	20	13	65	non-attaining
	PQ050	22	9	40.9	non-attaining
	PQ665	20	7	35	non-attaining

4.6.2 AQUATIC LIFE

Table 4.31 Summary of Aquatic Life Acute Criteria Exceedances

Parameter	Criteria	Dry			Wet		
		No. Obs.	No. Exceed	Percent Exceedance	No. Obs	No. Exceed	Percent Exceedance
Al	Acute Maximum	98	1	1	180	67	37.2
As	Acute Maximum	98	0	0	181	0	0
Cd	Acute Maximum	82	0	0	34	0	0
Cr	Acute Maximum	83	0	0	34	0	0
Cu	Acute Maximum	82	0	0	33	2	6.1
Pb	Acute Maximum	81	0	0	34	0	0
Zn	Acute Maximum	76	0	0	31	0	0
DO* (continuous samples)	Minimum	10715	263.75	2.5	11524	90.25	0.8
DO (discrete)	Minimum	85	1	1.2	31	0	0
Ammonia	Maximum	98	0	0	175	0	0
Fe	Maximum	97	2	2.1	181	60	33.1
Alkalinity	Minimum	83	0	0	31	0	0

* Number of observations and exceedances refers to hours monitored

Table 4.32 Aquatic Life Acute Criteria Exceedances by Site

Parameter	Site	Dry					Wet				
		No. Obs.	No. Exceed	Percent Exceedance	PADEP Criterion	Notes	No. Obs.	No. Exceed	Percent Exceedance	PADEP Criterion	Notes
Al	PQ050	23	0	0	Needs more eval.	4	56	18	32.1	non-attaining	
	PQ155	10	1	10	Needs more eval.	3,4	2	0	0	ID n<8	
	PQ395	10	0	0	Needs more eval.	4	2	0	0	ID n<8	
	PQ665	23	0	0	Needs more eval.	4	57	25	43.9	non-attaining	
	PQ820	9	0	0	Needs more eval.	4	3	0	0	ID n<8	
	PQB025	13	0	0	Needs more eval.	4	58	24	41.4	non-attaining	
	PQB305	10	0	0	Needs more eval.	4	2	0	0	ID n<8	
As	PQ050	23	0	0	Needs more eval.	1	57	0	0	Needs more eval.	1
	PQ155	10	0	0	Needs more eval.	1	2	0	0	ID n<8	1
	PQ395	10	0	0	Needs more eval.	1	2	0	0	ID n<8	1
	PQ665	23	0	0	Needs more eval.	1	57	0	0	Needs more eval.	1
	PQ820	9	0	0	Needs more eval.	1	3	0	0	ID n<8	1
	PQB025	13	0	0	Needs more eval.	1	58	0	0	Needs more eval.	1
	PQB305	10	0	0	Needs more eval.	1	2	0	0	ID n<8	1
Cd	PQ050	15	0	0	Needs more eval.	1	8	0	0	Needs more eval.	1
	PQ155	10	0	0	Needs more eval.	1	2	0	0	ID n<8	1
	PQ395	10	0	0	Needs more eval.	1	2	0	0	ID n<8	1
	PQ665	15	0	0	Needs more eval.	1	8	0	0	Needs more eval.	1
	PQ820	9	0	0	Needs more eval.	1	3	0	0	ID n<8	1
	PQB025	13	0	0	Needs more eval.	1	9	0	0	Needs more eval.	1
	PQB305	10	0	0	Needs more eval.	1	2	0	0	ID n<8	1
Cr	PQ050	15	0	0	Needs more eval.	1	8	0	0	Needs more eval.	1
	PQ155	10	0	0	Needs more eval.	1	2	0	0	ID n<8	1
	PQ395	10	0	0	Needs more eval.	1	2	0	0	ID n<8	1
	PQ665	15	0	0	Needs more eval.	1	8	0	0	Needs more eval.	1
	PQ820	9	0	0	Needs more eval.	1	3	0	0	ID n<8	1
	PQB025	14	0	0	Needs more eval.	1	9	0	0	Needs more eval.	1
	PQB305	10	0	0	Needs more eval.	1	2	0	0	ID n<8	1

Cu	PQ050	15	0	0	Needs more eval.	4	8	0	0	Needs more eval.	4
	PQ155	10	0	0	Needs more eval.	4	2	0	0	ID n<8	
	PQ395	10	0	0	Needs more eval.	4	2	0	0	ID n<8	
	PQ665	15	0	0	Needs more eval.	4	7	1	14.3	ID n<8	
	PQ820	9	0	0	Needs more eval.	4	3	0	0	ID n<8	
	PQB025	13	0	0	Needs more eval.	4	9	1	11.1	Needs more eval.	3,4
	PQB305	10	0	0	Needs more eval.	4	2	0	0	ID n<8	
Pb	PQ050	15	0	0	Needs more eval.	1	8	0	0	Needs more eval.	1
	PQ155	10	0	0	Needs more eval.	1	2	0	0	ID n<8	1
	PQ395	9	0	0	Needs more eval.	1	2	0	0	ID n<8	1
	PQ665	15	0	0	Needs more eval.	1	8	0	0	Needs more eval.	1
	PQ820	9	0	0	Needs more eval.	1	3	0	0	ID n<8	1
	PQB025	13	0	0	Needs more eval.	1	9	0	0	Needs more eval.	1
	PQB305	10	0	0	Needs more eval.	1	2	0	0	ID n<8	1
Zn	PQ050	14	0	0	Needs more eval.	4	6	0	0	ID n<8	
	PQ155	10	0	0	Needs more eval.	4	2	0	0	ID n<8	
	PQ395	8	0	0	Needs more eval.	4	2	0	0	ID n<8	
	PQ665	15	0	0	Needs more eval.	4	8	0	0	Needs more eval.	4
	PQ820	9	0	0	Needs more eval.	4	3	0	0	ID n<8	
	PQB025	11	0	0	Needs more eval.	4	8	0	0	Needs more eval.	4
	PQB305	9	0	0	Needs more eval.	4	2	0	0	ID n<8	
DO* (continuous samples)	PQ050	4568	1	0	attaining		4915	0.5	0	attaining	
	PQ665	2664	253.5	9.5	non-attaining		3002.25	89.75	3	attaining	
	PQB025	3483	9.25	0.3	attaining		3606.75	0	0	attaining	
DO (discrete samples)	PQ050	18	0	0	attaining		8	0	0	attaining	
	PQ155	10	0	0	attaining		2	0	0	ID n<8	
	PQ395	10	0	0	attaining		2	0	0	ID n<8	
	PQ665	14	1	7.1	attaining		7	0	0	ID n<8	
	PQ820	9	0	0	attaining		3	0	0	ID n<8	
	PQB025	14	0	0	attaining		7	0	0	ID n<8	
	PQB305	10	0	0	attaining		2	0	0	ID n<8	

Ammonia	PQ050	23	0	0	Needs more eval.	1	55	0	0	Needs more eval.	1
	PQ155	10	0	0	Needs more eval.	1	2	0	0	ID n<8	
	PQ395	10	0	0	Needs more eval.	1	2	0	0	ID n<8	
	PQ665	22	0	0	Needs more eval.	1	55	0	0	Needs more eval.	1
	PQ820	9	0	0	Needs more eval.	1	3	0	0	ID n<8	
	PQB025	14	0	0	Needs more eval.	1	56	0	0	Needs more eval.	1
	PQB305	10	0	0	Needs more eval.	1	2	0	0	ID n<8	
Fe	PQ050	23	0	0	attaining		57	15	26.3	non-attaining	
	PQ155	10	1	10	attaining		2	0	0	ID n<8	
	PQ395	10	0	0	attaining		2	0	0	ID n<8	
	PQ665	23	1	4.3	attaining		57	25	43.9	non-attaining	
	PQ820	8	0	0	attaining		3	0	0	ID n<8	
	PQB025	13	0	0	attaining		58	20	34.5	non-attaining	
	PQB305	10	0	0	attaining		2	0	0	ID n<8	
Alkalinity	PQ050	15	0	0	attaining		7	0	0	ID n<8	
	PQ155	10	0	0	attaining		2	0	0	ID n<8	
	PQ395	10	0	0	attaining		2	0	0	ID n<8	
	PQ665	15	0	0	attaining		7	0	0	ID n<8	
	PQ820	9	0	0	attaining		3	0	0	ID n<8	
	PQB025	14	0	0	attaining		8	0	0	attaining	
	PQB305	10	0	0	attaining		2	0	0	ID n<8	

* Number of observations and exceedances refers to hours monitored
ID n <8: Insufficient Data to make an assessment due to fewer than 8 samples
Notes: 1 = Greater than half of samples were below reporting limits; 3 = Failed 5% rule; 4 = Passed nonparametric test

Tables 4.32 and 4.33 list parameters subject to aquatic life chronic criteria. Since these are chronic, and thus long-term exposure limits, they are not split into dry weather and wet weather results.

Table 4.33 Summary of Aquatic Life Chronic Criteria Exceedances

Parameter	Criterion	No. Obs.	No. Exceed	Percent Exceedance
Al	Chronic Maximum	278	189	68
As	Chronic Maximum	279	0	0
Cd	Chronic Maximum	116	0	0
Cr	Chronic Maximum	117	0	0
Cu	Chronic Maximum	115	5	4.3
Pb	Chronic Maximum	115	0	0
Zn	Chronic Maximum	107	0	0
DO (continuous observations)	Min. Daily Average	890	19	2.1

Table 4.34 Summary of Aquatic Life Chronic Criteria Exceedances By Site

Parameter	Criterion	Site	No. Obs.	No. Exceed	Percent Exceedance	PADEP Criterion	notes
Al	Chronic Maximum	PQ050	79	57	72.2	non-attaining	
		PQ155	12	3	25	non-attaining	
		PQ395	12	3	25	non-attaining	
		PQ665	80	60	75	non-attaining	
		PQ820	12	4	33.3	non-attaining	
		PQB025	71	59	83.1	non-attaining	
		PQB305	12	3	25	non-attaining	
As	Chronic Maximum	PQ050	80	0	0	Needs more eval.	1
		PQ155	12	0	0	Needs more eval.	1
		PQ395	12	0	0	Needs more eval.	1
		PQ665	80	0	0	Needs more eval.	1
		PQ820	12	0	0	Needs more eval.	1
		PQB025	71	0	0	Needs more eval.	1
		PQB305	12	0	0	Needs more eval.	1

Cd	Chronic Maximum	PQ050	23	0	0	Needs more eval.	1
		PQ155	12	0	0	Needs more eval.	1
		PQ395	12	0	0	Needs more eval.	1
		PQ665	23	0	0	Needs more eval.	1
		PQ820	12	0	0	Needs more eval.	1
		PQB025	22	0	0	Needs more eval.	1
		PQB305	12	0	0	Needs more eval.	1
Cr	Chronic Maximum	PQ050	23	0	0	Needs more eval.	1
		PQ155	12	0	0	Needs more eval.	1
		PQ395	12	0	0	Needs more eval.	1
		PQ665	23	0	0	Needs more eval.	1
		PQ820	12	0	0	Needs more eval.	1
		PQB025	23	0	0	Needs more eval.	1
		PQB305	12	0	0	Needs more eval.	1
Cu	Chronic Maximum	PQ050	23	1	4.3	Needs more eval.	4
		PQ155	12	0	0	Needs more eval.	4
		PQ395	12	0	0	Needs more eval.	4
		PQ665	22	2	9.1	Needs more eval.	4
		PQ820	12	0	0	Needs more eval.	4
		PQB025	22	2	9.1	Needs more eval.	4
		PQB305	12	0	0	Needs more eval.	4
Pb	Chronic Maximum	PQ050	23	0	0	Needs more eval.	1
		PQ155	12	0	0	Needs more eval.	1
		PQ395	11	0	0	Needs more eval.	1
		PQ665	23	0	0	Needs more eval.	1
		PQ820	12	0	0	Needs more eval.	1
		PQB025	22	0	0	Needs more eval.	1
		PQB305	12	0	0	Needs more eval.	1
Zn	Chronic Maximum	PQ050	20	0	0	Needs more eval.	4
		PQ155	12	0	0	Needs more eval.	4
		PQ395	10	0	0	Needs more eval.	4
		PQ665	23	0	0	Needs more eval.	4
		PQ820	12	0	0	Needs more eval.	4
		PQB025	19	0	0	Needs more eval.	4
		PQB305	11	0	0	Needs more eval.	4
DO	Min. Daily Avg.	PQ050	232	18	7.8	attaining	
		PQ665	294	1	0.3	attaining	
		PQB025	364	0	0.0	attaining	

Notes: 1 = Greater than half of samples were below reporting limits; 4 = Passed nonparametric test

4.6.3 STREAM TROPHIC STATUS

Table 4.35 Summary of Stream Trophic Criteria Exceedances

Parameter	Criterion	Dry			Wet		
		No. Obs.	No. Exceed	Percent Exceedance	No. Obs	No. Exceed	Percent Exceedance
Chlorophyll-*a* ‡	Maximum	0	0	n/a	9	9	100
pH* (continuous samples)	Range	10748.25	14	0.1	11621	0	0
pH (discrete)	Range	85	0	0	31	0	0
Temperature* (continuous samples)	Maximum	11073.5	1194.75	10.8	11924.5	1201	10.1
Temperature (discrete)	Maximum	85	25	29.4	31	0	0
NO23-N ‡	Maximum	102	68	66.7	175	72	41.1
TDS	Maximum	99	0	0	175	0	0
TKN ‡	Maximum	99	93	93.9	175	172	98.3
TN ‡	Maximum	102	24	23.5	175	56	32
TP ‡	Maximum	98	50	51	181	161	89
TSS ‡	Maximum	99	3	3	170	52	30.6
Turbidity* ‡ (continuous samples)	Maximum	9793.5	2332.5	23.8	10813.75	7147.75	66.1
Turbidity ‡ (discrete)	Maximum	101	12	11.9	175	144	82.3

* Number of observations and exceedances refers to hours monitored

Table 4.36 Summary of Stream Trophic Criteria Exceedances by Site

Parameter	Site	Dry					Wet			
		No. Obs.	No. Exceed	Percent Exceedance	PADEP (or reference) Criterion	notes	No. Obs.	No. Exceed	Percent Exceedance	PADEP (or reference) Criterion
Chlorophyll-*a* ‡	PQ115	n/a	n/a	n/a	n/a		3	3	100	ID n<8
	PQ820	n/a	n/a	n/a	n/a		3	3	100	ID n<8
	PQB025	n/a	n/a	n/a	n/a		3	3	100	ID n<8
pH (continuous samples)	PQ050	4610	0	0	attaining		5118	0	0	attaining
	PQ665	2785.75	8.5	0.3	attaining		3089.75	0	0	attaining
	PQB025	3352.5	5.5	0.2	attaining		3413.25	0	0	attaining
pH (discrete)	PQ050	18	0	0	attaining		8	0	0	attaining
	PQ155	10	0	0	attaining		2	0	0	ID n<8
	PQ395	10	0	0	attaining		2	0	0	ID n<8
	PQ665	14	0	0	attaining		7	0	0	ID n<8
	PQ820	9	0	0	attaining		3	0	0	ID n<8
	PQB025	14	0	0	attaining		7	0	0	ID n<8
	PQB305	10	0	0	attaining		2	0	0	ID n<8
Temperature (continuous samples)	PQ050	4613.5	406.5	8.8	attaining		5113.5	590	11.5	non-attaining
	PQ665	2975.25	363	12.2	non-attaining		3204.25	271	8.5	attaining
	PQB025	3484.75	425	12.2	non-attaining		3606.75	342.75	9.5	attaining
Temperature (discrete)	PQ050	18	4	22.2	non-attaining		8	0	0	attaining
	PQ155	10	4	40	non-attaining		2	0	0	ID n<8
	PQ395	10	3	30	non-attaining		2	0	0	ID n<8
	PQ665	14	3	21.4	non-attaining		7	0	0	ID n<8
	PQ820	9	3	33.3	non-attaining		3	0	0	ID n<8
	PQB025	14	4	28.6	non-attaining		7	0	0	ID n<8
	PQB305	10	4	40	non-attaining		2	0	0	ID n<8

NO23-N ‡	PQ050	26	19	73.1	non-attaining		55	17	30.9	non-attaining
	PQ155	10	7	70	non-attaining		2	1	50	ID n<8
	PQ395	10	5	50	non-attaining		2	0	0	ID n<8
	PQ665	23	7	30.4	non-attaining		55	18	32.7	non-attaining
	PQ820	9	9	100	non-attaining		3	3	100	ID n<8
	PQB025	14	11	78.6	non-attaining		56	31	55.4	non-attaining
	PQB305	10	10	100	non-attaining		2	2	100	ID n<8
TDS	PQ050	23	0	0	attaining		55	0	0	attaining
	PQ155	10	0	0	attaining		2	0	0	ID n<8
	PQ395	10	0	0	attaining		2	0	0	ID n<8
	PQ665	23	0	0	attaining		53	0	0	attaining
	PQ820	9	0	0	attaining		3	0	0	ID n<8
	PQB025	14	0	0	attaining		53	0	0	attaining
	PQB305	10	0	0	attaining		2	0	0	ID n<8
TKN ‡	PQ050	23	21	91.3	non-attaining		55	55	100	non-attaining
	PQ155	10	10	100	non-attaining		2	2	100	ID n<8
	PQ395	10	8	80	non-attaining		2	2	100	ID n<8
	PQ665	23	22	95.7	non-attaining		55	52	94.5	non-attaining
	PQ820	9	8	88.9	non-attaining		3	3	100	ID n<8
	PQB025	14	14	100	non-attaining		56	56	100	non-attaining
	PQB305	10	10	100	non-attaining		2	2	100	ID n<8
TN ‡	PQ050	26	4	15.4	Needs more eval.	2	55	9	16.4	non-attaining
	PQ155	10	1	10	Needs more eval.	5	2	0	0	ID n<8
	PQ395	10	0	0	attaining		2	0	0	ID n<8
	PQ665	23	2	8.7	Needs more eval.	5	55	9	16.4	non-attaining
	PQ820	9	1	11.1	Needs more eval.	5	3	0	0	ID n<8
	PQB025	14	7	50	non-attaining		56	37	66.1	non-attaining
	PQB305	10	9	90	non-attaining		2	1	50	ID n<8

TP ‡	PQ050	23	7	30.4	non-attaining		57	56	98.2	non-attaining
	PQ155	10	4	40	non-attaining		2	1	50	ID n<8
	PQ395	10	4	40	non-attaining		2	1	50	ID n<8
	PQ665	23	19	82.6	non-attaining		57	44	77.2	non-attaining
	PQ820	9	3	33.3	non-attaining		3	1	33.3	ID n<8
	PQB025	13	10	76.9	non-attaining		58	57	98.3	non-attaining
	PQB305	10	3	30	non-attaining		2	1	50	ID n<8
TSS ‡	PQ050	23	0	0	attaining		55	14	25.5	non-attaining
	PQ155	10	1	10	attaining		2	0	0	ID n<8
	PQ395	10	0	0	attaining		2	0	0	ID n<8
	PQ665	23	1	4.3	attaining		53	20	37.7	non-attaining
	PQ820	9	0	0	attaining		3	0	0	ID n<8
	PQB025	14	1	7.1	attaining		53	18	34	non-attaining
	PQB305	10	0	0	attaining		2	0	0	ID n<8
Turbidity ‡ (continuous samples)	PQ050	4267	734	17.2	non-attaining		4808	3139.5	65.3	non-attaining
	PQ665	2847.25	1389.5	48.8	non-attaining		2935.75	2307.5	78.6	non-attaining
	PQB025	2679.25	209	7.8	attaining		3070	1700.75	55.4	non-attaining
Turbidity ‡ (discete)	PQ050	25	3	12	Needs more eval.	2	55	47	85.5	non-attaining
	PQ155	10	1	10	attaining		2	2	100	ID n<8
	PQ395	10	0	0	attaining		2	0	0	ID n<8
	PQ665	23	5	21.7	non-attaining		55	49	89.1	non-attaining
	PQ820	9	1	11.1	Needs more eval.	2	3	0	0	ID n<8
	PQB025	14	1	7.1	attaining		56	45	80.4	non-attaining
	PQB305	10	1	10	attaining		2	1	50	ID n<8

* Number of observations and exceedances refers to hours monitored
‡ PADEP criterion does not exist; parameter was evaluated with respect to reference value.
ID n <8: Insufficient Data to make an assessment due to fewer than 8 samples
Notes: 2 = Failed 10% rule; 5 = Number of possible exceedances precludes definitive assessment

4.6.4 PROBLEM PARAMETER SUMMARY

Problem parameters are those constituents at a given site for which a "non-attainingment" status was determined through application of the PADEP (2007c) Chemistry Statistical Assessments protocol. Parameters without PADEP criteria were evaluated with respect to the appropriate reference value listed in Table 4.2.

In Table 4.37, the problem parameters are listed by category. They are also categorized as either wet or dry weather problems, if applicable.

Table 4.37 Summary of Problem Parameters

Parameter	**Standard**	**Weather Condition**	
	RECREATION	***ALL WEATHER***	
Fecal Coliform	Maximum Swimming Season	PQB025	
		PQ050	
		PQ665	
E. coli*		PQB025	
		PQ050	
		PQ665	
Fecal Coliform	Maximum Non-Swimming Season	PQB025	
		PQ050	
		PQ665	
Enterococci*		PQB025	
		PQ050	
		PQ665	
	AQUATIC LIFE-ACUTE	***DRY***	***WET***
Al	Acute Maximum		PQ050
			PQ665
			PQB025
Fe	Maximum		PQ050
			PQ665
			PQB025
DO	Minimum Instantaneous	PQ665	

	AQUATIC LIFE-CHRONIC	*ALL WEATHER*	
Al	Chronic Maximum	PQ050	
		PQ155	
		PQ395	
		PQ665	
		PQ820	
		PQB025	
		PQB305	
	TROPHIC CRITERIA	*DRY*	*WET*
Temperature	Maximum	PQ155	PQ050
		PQ395	
		PQ665	
		PQ820	
		PQB025	
		PQB305	
NO23-N*	Maximum	PQ050	PQ050
		PQ155	PQ665
		PQ395	PQB025
		PQ665	
		PQ820	
		PQB025	
		PQB305	
TKN*	Maximum	PQ050	PQ050
		PQ155	PQ665
		PQ395	PQB025
		PQ665	
		PQ820	
		PQB025	
		PQB305	
TN*	Maximum	PQB025	PQ050
		PQB305	PQ665
			PQB025

TP*	Maximum	PQ050	PQ050
		PQ155	PQ665
		PQ395	PQB025
		PQ665	
		PQ820	
		PQB025	
		PQB305	
TSS*	Maximum		PQ050
			PQ665
			PQB025
Turbidity*	Maximum	PQ050	PQ050
		PQ665	PQ665
			PQB025

*PADEP criterion does not exist; parameter was evaluated with respect to reference value.

5 BIOLOGICAL CHARACTERIZATION

5.1 SUMMARY OF HISTORICAL AND EXISTING INFORMATION

As described in Section 2, Poquessing-Byberry Watershed is unique among Philadelphia's small watersheds in that the watershed is not affected by treated wastewater discharge or combined sewer overflows, making it simpler to identify stormwater pollution as the primary stressor affecting the watershed. Although Poquessing Creek Watershed has the greatest density of stormwater management practices and largest relative area draining to these features among Philadelphia's watersheds, most of these stormwater management structures are detention basins aimed at flood control rather than protection of receiving stream channels. Furthermore, much of the suburban development within the Poquessing Creek Watershed occurred prior to wide-scale adoption of effective stormwater controls and protection of wetlands and riparian corridors, causing widespread degradation of natural habitats and ecosystems. Nutrients from stormwater runoff and other sources cause excessive growth of stream algae. Increased imperviousness due to land development has reduced infiltration of stormwater, accelerated erosion and sedimentation throughout the basin, and produced a deleterious effect on natural communities.

The ecological value of wetlands and headwater streams was not recognized until only recently in land development practices, and one could argue that these resources are still not adequately protected in Pennsylvania, especially with regard to riparian buffer zones. Many first- and zero-order streams (springs, ephemeral streams, and small streams without tributaries) in Poquessing Creek Watershed have been buried or encapsulated in storm sewers to facilitate development. These small streams may lack fish and certain other attributes that are valued in larger rivers, but they are an important link in aquatic food webs and are critical to sustaining populations of certain sensitive macroinvertebrates.

As development has progressed, infrastructure needs have grown. While some portions of the land directly abutting Poquessing Creek Watershed and its major tributaries are protected as parkland or protected open space, infrastructure easements for roads, sewers, rail lines and utilities often intrude into or cross riparian lands, causing local destabilization of stream channels and interrupting important habitat corridors for aquatic and terrestrial wildlife. Several mill dams were also constructed along Poquessing Creek and its tributaries, but with the possible exception of the dam near Grant Ave and State Rd, there are relatively few extant dams on the mainstem compared to other local watersheds.

5.1.1 NLREEP MASTER PLAN

In 1999 and 2000, the Academy of Natural Sciences of Philadelphia (ANS) submitted reports to the Fairmount Park Commission's Natural Lands Restoration and Environmental Education Program (NLREEP) that summarized a comprehensive review of historical biological data from sampling efforts conducted by the Pennsylvania Fish and Boat Commission (PFBC), Pennsylvania Department of Environmental Protection (PADEP), and historical records of collections by ANS biologist Dr. Richard Horwitz. In addition to being the most complete review of historical biological information available, the ANSP report also documented original macroinvertebrate and fish sampling data from collection efforts in 1998 and 2000.

As described in Volume II Chapter 7, Poquessing Creek was one of the last watersheds within the City of Philadelphia to be developed (ANS 2000). Until the early 20th century, the dominant land use was agriculture. As a result, many upland woodlands were cleared to make room for farmsteads. Starting in the 17th century and continuing into the mid-19th century, there was a proliferation of private and commercial mills and their associated impoundments on the lower reaches of Poquessing Creek.

There is scant historical information about aquatic life in Poquessing Creek Watershed prior to industrialization and suburban development. Some of the earliest-known records of aquatic life in the watershed come from the observations of Henry Weed Fowler, who was the fish curator (1898-1930) at the Academy of Natural Sciences of Philadelphia. A resident of Holmesburg, he documented occurrence of fish species in Poquessing Creek (Fowler 1914). Fowler noted 17 species, 16 of which are considered to be widespread native stream species naturally supported by the creek, and one introduced species, the common carp. One anadromous species, the alewife, was reported from Poquessing Creek. Some of the native species reported by Fowler have apparently been extirpated from the stream, as evidenced by subsequent collections by ANS. Bridle shiner and creek chubsucker are associated with vegetated streams and have been decreasing regionally (ANS 2000).

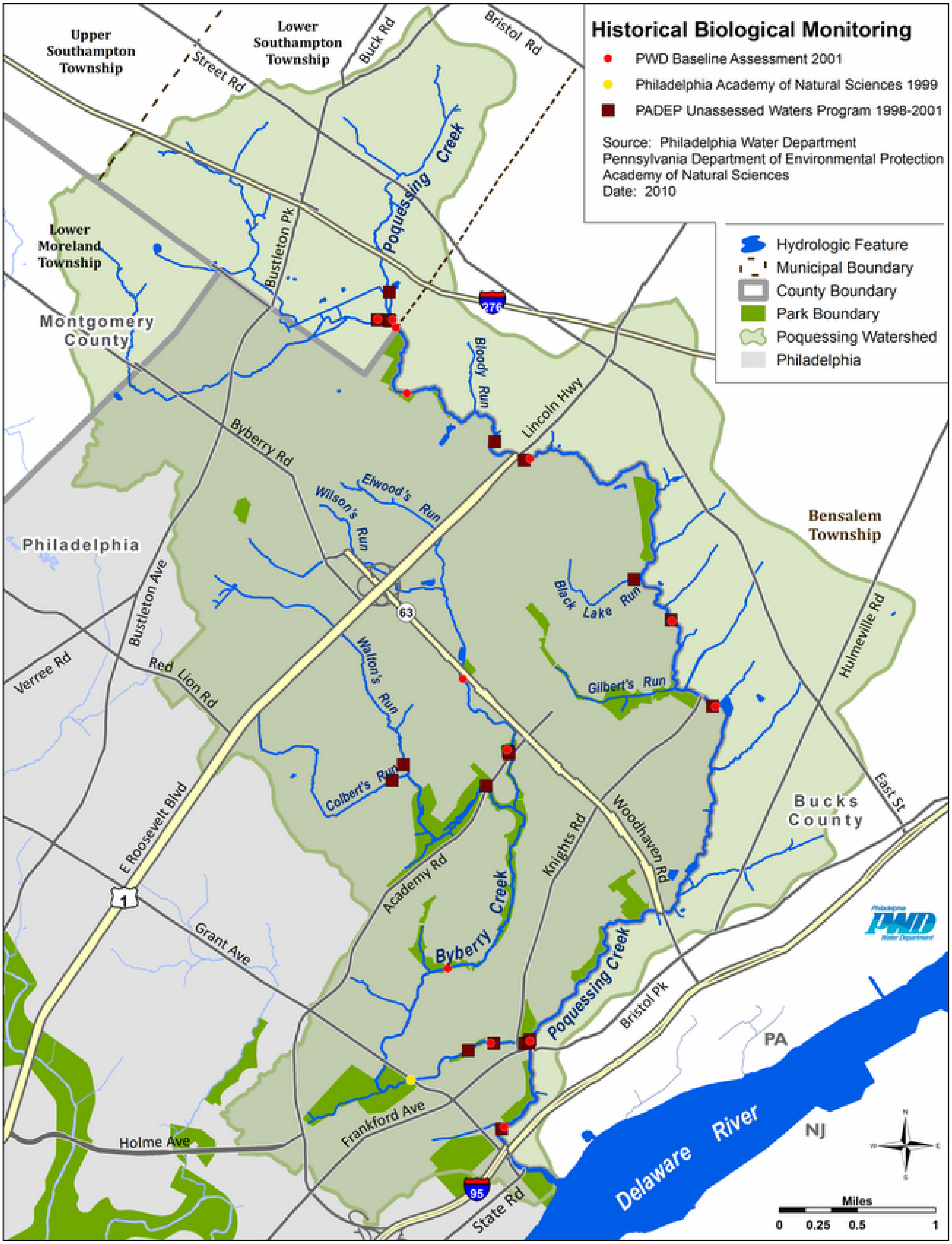

Figure 5.1 Historical Biological Monitoring Sites in Poquessing Creek Watershed, 1998-2001

ANS (2000) conducted qualitative fish monitoring with electrofishing techniques at several Philadelphia park sites in the 1998 NLREEP Assessments but did not collect any qualitative fish samples from Poquessing Creek. ANS collected macroinvertebrates from three riffles within one site on Byberry Creek using a fixed area Surber sampler (1ft^2). Quantitative estimates of density (number of individuals/cm^2) were derived by sub-sampling one of the three replicates. Numerous metrics were reported, including measures of benthic community diversity, tolerance to stress, and trophic relationships. These Byberry sample results were generally among the worst observed in all of Philadelphia Park system samples (n=32). Unfortunately, only aggregate macroinvertebrate data were presented, and the report lacks documentation of the actual taxa collected (with the exception of craneflies, which were collected in the adult stage in a more widespread study that also considered terrestrial and semi-aquatic species).

5.1.2 PADEP UNASSESSED WATERS PROGRAM

As a result of a Memorandum of Understanding reached between PADEP and US EPA in response to a lawsuit brought by Widener University Law Clinic on behalf of the American Littoral Society and the Public Interest Research Group of Pennsylvania, PADEP began a program to assess all waters of the Commonwealth within 10 years (PADEP 1998). Due to the sheer number of stream miles to be assessed, PADEP conducted non–quantitative, field-based rapid bioassessment protocols (modified Rapid Bioassessment Protocol II) and habitat assessments (Barbour *et al.,* 1999) to determine whether aquatic life designated uses were being met. Assessments were conducted at 17 locations in Poquessing Creek Watershed in 1998.

Biomonitoring data were used to determine where biological impairment was present and identify potential sources and causes of impairment. Based on this study, the majority of Poquessing Creek Watershed was listed on Pennsylvania’s 303(d) list as not attaining aquatic life uses. While listings for individual segments varied, impairments were identified as primarily due to runoff and storm sewers. Byberry Creek and tributaries are listed as impaired due to siltation and excessive algal growth in 2002. Most segments of Poquessing Creek were also listed for excessive algal growth, but not siltation, in 2002. Downstream segments in Philadelphia were listed for more serious pollution impairments such as priority organic pollution (PCBs) due to fish consumption advisories. PADEP presently reports stream segments not attaining their designated aquatic life uses in an “Integrated List of Waters” as described in Section 5.1.4 PADEP Integrated List of Waters (PADEP 2010).

5.1.3 PWD 2001 BASELINE ASSESSMENT OF THE POQUESSING CREEK WATERSHED (PUBLISHED 2002)

In 2001, through a joint effort between the Philadelphia Water Department’s Bureau of Laboratory Services and Office of Watersheds, EPA Rapid Bioassessment Protocols (RBP) III and V as well as physical and chemical assessments were used to evaluate the ecological health of Poquessing Creek Watershed. Physical habitat, benthic macroinvertebrates and fish were sampled from eight mainstem Poquessing Creek sites, four Byberry Creek sites, and one Poquessing Creek tributary site. Water quality data was collected at five mainstem Poquessing Creek sites and two Byberry Creek sites (PWD 2002).

Water quality, habitat and bioassessment data were evaluated in conjunction to both diagnose the degree of impairment and identify potential stressors in the watershed. Results of the RBP III and V biotic assessments, as well as the EPA RBP habitat assessment, were compared to reference sites in the French Creek Watershed in Chester County, Pennsylvania (Appendix H), allowing for comparison of macroinvertebrate and fish communities in Poquessing Creek Watershed to regional reference conditions. In comparison to previous work, PWD 2001 macroinvertebrate sampling site dispersion was comparable to the PADEP unassessed waters program, but samples were identified to genus in the laboratory. ANSP macroinvertebrate samples from 1998 had the advantage of being semi-quantitative, but that study was restricted to Philadelphia only. PWD fish surveys of 2002 were quantitative, unlike earlier studies conducted by ANS.

A total of 1,789 benthic macroinvertebrate individuals from 22 taxa were identified during the 2001 Poquessing Creek Baseline Assessment. Subsequent analysis of the benthic macroinvertebrate community structure and relevant biodiversity metrics observed in Poquessing Creek Watershed sites indicated severe impairment based on the combination of poor taxa richness, elevated Hilsenhoff Biotic Index (HBI) scores, trophic structures dominated on average by generalist feeders (86.71%), and the lack of sensitive mayfly (Ephemeroptera), stonefly (Plectoptera), and caddisfly (Trichoptera), collectively known as EPT taxa; and other intvertebrate taxa considered sensitive to pollution. Furthermore, in terms of proportional abundance, most communities were dominated by either Chironomidae (41.28%) or net-spinning caddisflies (39.02%) from the genera *Hydropsyche* and *Cheumatopsyche.* These taxa are relatively tolerant of adverse environmental conditions, and, as such, their proportional dominance within a community serves as an indicator of moderate inputs of organic pollution and hydrologic disturbance.

A total of 11,649 individuals of 24 species representing 7 families were collected throughout Poquessing Creek Watershed in the 2001 fish assessment. The fish community was dominated by a small number of taxa, as six species contributed over 80% of the abundance. Similarly, three species made up 64% of total biomass, with American eel (*Anguilla rostrata*) contributing approximately 32% of total fish biomass. 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 downstream-most sites had higher biological integrity than upstream sites. The mean Index of Biotic Integrity (IBI) score for Poquessing Creek Watershed was 36 (out of 50), placing it in the “fair” category.

5.1.4 PADEP INTEGRATED LIST OF WATERS

In 2004, PADEP began publishing results of aquatic biology assessments and lists of aquatic life impairments in biennial reports combining the former 303(d) listing and 305(b) reporting requirements into an “Integrated List of Waters” (PADEP 2004). Most use-attainment designations for Poquessing Creek watershed were completed in 2002, with segments on list 5 (impaired for a pollutant, requiring a TMDL) listed with the TMDL date as 2015. PADEP published Integrated Lists again in 2006, 2008, and 2010, listing downstream segments of Poquessing Creek Watershed as Impaired for the Aquatic Life Designated Use based on Fish consumption advisory for PCBs in 2006. The 2010 Integrated List of waters is thus the most up-to-date report on the listing status of Poquessing Creek Watershed for federal Clean Water Act reporting purposes.

5.1.5 SUMMARY OF HISTORIC BIOLOGICAL INFORMATION

Results of all historical studies have been consistent and clear; impairment was evident in both macroinvertebrate and fish communities, whether measured as taxa richness, ecosystem function, or various numeric criteria used to evaluate aquatic communities (*e.g.*, HBI, EPT, Fish MIwb, etc.). The 2001 PWD study integrated extensive physical habitat and chemical datasets in an attempt to determine the primary stressors on aquatic communities. However, when assessing an urban stream system that has been impaired for many years, particularly one that lies at the center of a region with widespread impairment, it may be difficult to determine whether observed effects are the result of antecedent or ongoing impairments. Water quality and stream physical habitats have been deteriorating over the past 40 years, generally following a pattern seen in urbanized watersheds worldwide.

Depauperate benthic macroinvertebrate assemblages and highly skewed fish communities present throughout the watershed are primarily a response to physical habitat impairments. Perpetuated by extensive development (*i.e.*, impervious surfaces, modification and piping of headwater and first-order streams) and infrastructure (*i.e.*, stormwater outfalls), physical impairments to the habitat structure within the Poquessing Creek Watershed were manifested through increased stream temperatures, alternating areas of scouring and deposition of sediment, accentuation of hydrologic extremes, and overabundance of algal periphyton and fine particulate organic material. Consequently, the resulting assemblages of aquatic life that are present in the watershed are those able to cope with extensive degradation to the watershed’s physical habitat.

The reduction of both assemblage diversity and species abundance is problematic to aquatic ecosystems, because as particular niches are lost following degradation of habitat and water quality, so too are stream functions and services such as processing and transport of leaf litter and particulate organic matter; grazing of periphyton leading to nuisance densities of periphyton and possible eutrophication (following periphyton senescence); control of pest and nuisance species (*e.g.*, blackflies, deer flies, mosquitos) by predators; and reaeration of the hyporheic zone and benthic sediments by bioturbators (*e.g.*, crayfish).

5.2 BIOLOGICAL MONITORING BACKGROUND INFORMATION

5.2.1 USE OF BIOLOGICAL COMMUNITIES AS INDICATORS

Though Poquessing Creek Watershed fish and benthic macroinvertebrate community data suggest that many taxa have been extirpated or nearly extirpated in the past century, historical information to support these findings is generally lacking. There are simply no data to indicate what the biological communities of Poquessing Creek Watershed looked like prior to changes wrought by man. While some measures of community structure (*e.g.*, diversity indices) may provide meaningful information alone, conclusions of most analyses and metrics are enhanced by, or require, comparison to an unimpaired reference site. These unimpaired reference sites are often difficult to identify in southeast Pennsylvania due to extensive development and agricultural land uses. The most robust application of the reference site approach is a pair of sites located upstream and downstream of a suspected source of impairment. The downstream site in this scenario can be assumed to have a rather constant source of colonists, or "drift" from the upstream site, as all life stages of fish and macroinvertebrates are prone to displacement from the upstream site to the downstream site.

Reference site-based biological indexing methods assume that all similar habitats within a given ecoregion will have similar communities (absent major stressors). The use of reference-site based metrics as a short-term periodic assessment tool assumes that recovery of biological communities, particularly benthic macroinvertebrate communities, occurs quickly once stressors are removed. However, in regions where impairments occur watershed-wide and most first-order streams have been eliminated, one cannot assume that impacted sites have a constant source of colonists. Recent studies have challenged the assumption that benthic invertebrates disperse frequently and widely, at least over the short-term (*ca.* 5 years) assessment and permitting intervals characteristic of water resources management (Blakely *et al.* 2006, Petersen *et al.* 1999, Bond & Lake 2003, Bohonak & Jenkins 2003). Other factors affecting re-colonization by macroinvertebrate taxa may include:

1.) Geographic factors (*e.g.*, number and relative size of undisturbed first-order tributaries within the watershed, distance to sources of colonists, predominant land cover and topographic features separating target sites from sources of colonists, prevailing winds and climatic factors, natural and anthropogenic barriers to passive and active dispersal),
2.) Life history strategies (*e.g.*, propensity of the taxon to actively disperse, behaviors that increase the likelihood of passive dispersal, seasonal timing of oviposition and propensity to disperse prior to oviposition, duration of life cycle stages that are more prone to passive dispersal),
3.) Population factors (*e.g.*, stability and population dynamics of local populations representing potential colonists), and
4.) Miscellaneous factors, such as natural and anthropogenic mechanisms of passive dispersal (*i.e.*, phoresis).

Poquessing Creek Watershed is at the center of a region of widespread impairment due to urbanization. Some areas of the watershed, tributaries in particular, may have water quality suitable for re-establishment of sensitive EPT taxa; PWD supports reintroduction of macroinvertebrates combined with stream restoration and stormwater BMPs for these areas.

5.2.2 RBP III BENTHIC MACROINVERTEBRATE ASSESSMENT REGIONAL REFERENCE SITE APPROACH

From 1999 to 2007, PWD exclusively used local reference reaches to evaluate the biotic integrity of monitoring locations within study watersheds in accordance with prevailing practice in stream assessment and published guidelines from US EPA. Reference reaches in French Creek Watershed (Chester County, PA) (Appendix I) were selected for comparison based on stream order. In cases where reference reaches were not "pristine," they were assumed to represent the best attainable conditions within the region, because (carefully chosen) target and reference sites can be reasonably assumed to be subject to the same coarse scale climatic (*e.g.*, temperature, rainfall) and regional (*e.g.*, landforms, underlying geology) factors that influence the distribution and structure of benthic macroinvertebrate communities.

Biotic index scores at monitoring sites were based on their percent similarity to the reference reach (Table 5.1). Using this protocol, reference reaches were used to set "benchmarks" for management and planning programs within the watershed, particularly Integrated Watershed Management Plans (IWMP). Targets for improvement and possible strategies within these plans were derived with the goal of attaining or approaching reference reach conditions within impacted or impaired reaches. As such, PWD intends to continue evaluating data from biological assessments against local reference conditions for the foreseeable future in parallel with the revised PADEP Benthic Index of Biotic Integrity (Section 5.2.3) rather than amending existing Watershed Management Plans and supporting documentation.

It is important to note that while reference reaches represent the "best attainable" or "least disturbed" conditions, they are still subject to adverse impacts from local or regional stressors. Thus, a site classified as a reference reach may experience change over time; however, the range of regional reference conditions can still be a reliable approximation of "best attainable" conditions regionally.

Table 5.1 RBP III Benthic Macroinvertebrate Assessment Regional Reference Site Condition Categories

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

*Biologists are directed to use additional sources of information and best professional judgment in cases when scores are intermediate between biological condition categories.

5.2.3 PADEP BENTHIC INDEX OF BIOTIC INTEGRITY FOR WADEABLE FREESTONE STREAMS IN PENNSYLVANIA

Acquiring and processing reference site data can be time-consuming and expensive, especially if reference site data must be collected very frequently. Moreover, when reference site data are used to administer regulatory programs, assessment conditions will vary from year to year, raising concerns over whether the regulations are being applied fairly to all streams and regulated entities from year to year. To address these concerns and others, PADEP undertook a rigorous study of the highest quality first-through third-order streams statewide (PADEP 2007a). This study was conducted in 2005-2006 with assistance from several other natural resource agencies and academic institutions, and used to develop a set of reference metrics and an Index of Biotic Integrity (IBI) (Tables 5.3 and 5.2, respectively).

PADEP and other participating agencies sampled a large number of stations statewide in a probabilistic study design (PADEP 2007a). The research and peer review teams consisted of representatives from USEPA, Stroud Water Resource Center, the Western PA Conservancy, Pennsylvania Fish and Boat Commission, Tetra-Tech, Inc. and EcoAnalysts, Inc. In creating this new IBI, the concept of localized reference reaches has been eliminated for stream assessment and listing purposes and replaced by a statewide standard reference condition for all wadeable freestone riffle-run type streams. The standard reference condition represents a composite of the conditions exhibited by streams across the state that were deemed to be of superior biotic integrity. The criteria used to select reference reaches for index development included land use, physical habitat, and water quality. Target site classification is based on percent comparability of the IBI index to a reference value; however, the statewide reference condition does not account for local climatic variation or regional stressors. With the exception of limestone streams, underlying geology is not considered.

At the larger scale, standardization of reference conditions allows for increased comparability of biotic integrity and stream function between freestone streams across the state regardless of region; furthermore, this approach obviates the need for PADEP water pollution biologists to identify regional reference reaches (and re-sample existing reference reaches to confirm that they are still in good condition) in order to classify sampling sites. It is important to note that samples for IBI development were collected from relatively small, wadeable, freestone, riffle-run type streams; therefore, there is a possibility that some site-specific exceptions to any thresholds may exist because of local scale natural limitations (*e.g.*, habitat availability) on biological condition (Hughes 1995).

This issue could have relevance locally in a situation where the IBI at a sample site may improve to a certain level but is limited by anthropogenic stressors. Even though habitat quality may improve significantly, the site may still be deemed stressed and accordingly not be classified as capable of supporting the optimal community assemblage for that habitat type. Pennsylvania Code (2006: Title 25, Chapter 93.3) recognizes four categories of protected ALUs, including: (1) cold water fishes (CWF); (2) warm water fishes (WWF); (3) migratory fishes (MF); and (4) trout stocking (TSF). The CWF, WWF, and TSF uses all include protection of fish as well as additional flora and fauna (*e.g.*, benthic macroinvertebrates, macrophytes and periphyton) indigenous to a cold (CWF) or warm water (TSF and WWF) habitat. Pennsylvania also recognizes two antidegradation water uses: high quality waters (HQ) and exceptional value waters (EV).

In reviewing the available data, PADEP Biologists and the research team explored whether significant differences existed between streams with different designated uses as well as streams in different ecoregions. The researchers did not find sufficient evidence to support regionalization of the reference standards or applying different standards to streams with different designated uses (*e.g.*, a lower standard for WWF streams than CWF streams) (PADEP 2007a). This approach contrasts with Pennsylvania's policy in assigning separate Protected Water Uses to WWF and CWF streams, (used for development of water quality criteria) specifically to protect "additional flora and fauna which are indigenous to a [coldwater/warmwater] habitat". In response to public comments on the 2006 Integrated List of waters, PADEP did note that this issue could be revisited at a later time (PADEP 2007b).

The Biological Condition Gradient (BCG) is a conceptual model relating stages of biological responses to an increasing stressor gradient. It serves as a universal benchmark by which the condition of a sampling site can be classified; thus, the BGC model does not directly correspond to PA Tiered Aquatic Life Use (TALU) attainment thresholds, but rather it serves to distinguish sites of biotic integrity from those that are stressed. Thus, the BCG has no policy implications nor does it evaluate the potential of a water body to improve or degrade further. The BCG is arranged in tiers of condition, from communities that are equivalent to natural and undisturbed (BCG Tiers 1 and 2) to completely disrupted (BCG Tier 6) (Figure 5.2).

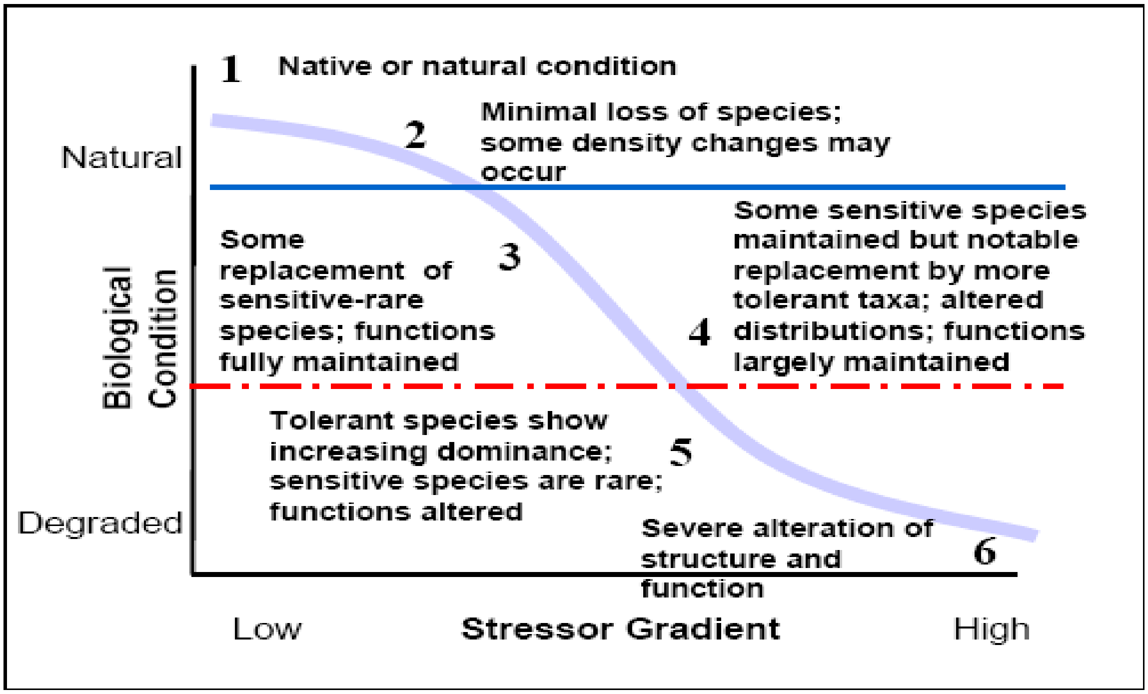

Figure 5.2 The Biological Condition Gradient (as adapted from Davies & Jackson 2006, in PADEP 2007a)

BCG Tier 1 sites met stringent “minimally disturbed” criteria (outlined in Stoddard *et al.*, 2006) and subsequent tiers of biotic integrity classifications were determined by IBI benchmark thresholds (Table 5.2) based on 10 levels of assessment that have been noted to change with increasing human-related disturbance: I.) historically documented, sensitive, long-lived or regionally endemic taxa; II.) sensitive and rare taxa; III.) sensitive but ubiquitous taxa; IV.) taxa of intermediate tolerance; V.) tolerant taxa; VI.) non-native taxa; VII.) organism condition; VIII.) ecosystem function; IX.) spatial and temporal extent of detrimental effects, and X.) ecosystem disturbance. IBI scores of reference and stressed scores were plotted, and clear breaks were observed in biological condition corresponding to approximately 80% and 63% comparability to reference condition (Figure 5.3). These thresholds were used to set standards for attainment of designated aquatic life uses for Antidegradation (Tiers 1 & 2) waters and other designated uses, respectively (Table 5.2).

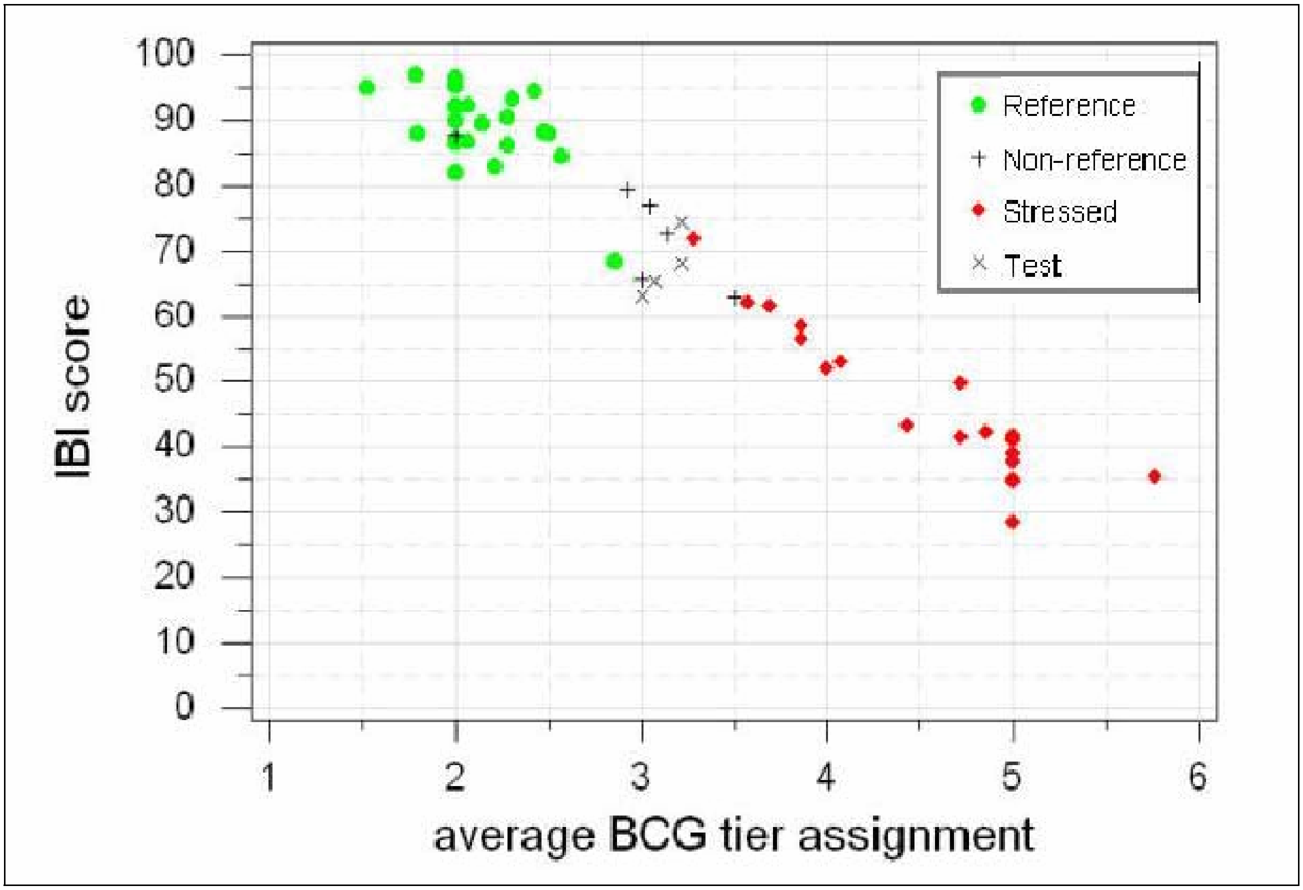

Figure 5.3 Benthic IBI score vs. Biological Condition Gradient Tier Assignment for 53 sites in Pennsylvania (PADEP 2007)

For urbanized watersheds, which dominate the landscape of Southeastern Pennsylvania, this could have severe implications on the attainability of TALU thresholds. Streams previously classified as being of "best attainable" condition locally may be classified as stressed and not attaining designated aquatic life use according to the revised PADEP IBI guidelines. For example, macroinvertebrate community data collected from French Creek Watershed 2000-2005 do not meet 63% comparability with revised IBI reference standards. Re-sampling these sites with the PADEP Instream Comprehensive Evaluation (ICE) protocol (six riffle samples and picking 200 +/-20% individuals in subsamples) might perhaps resolve the first issue and find that these sites formerly used as reference sites are indeed attaining their designated use. But the second, more important problem of whether these IBI benchmarks are achievable in warmwater streams in Southeastern Pennsylvania with cost-effective BMPs would remain unresolved.

Table 5.2 PADEP IBI Benchmarks for PA Designated Uses

Protected Use	IBI Scoring Benchmark	Corresponding percentile		
		IBI development sample types		
		Reference	Non-reference	Stressed
EV, HQ*	≥80.0	21	88	---
CWF	≥ 63.0 Supporting use	---	9	63
TSF				
WWF				

*Additional factors are considered when determining antidegradation candidacy and to distinguish between EV and HQ uses.

5.3 BIOLOGICAL ASSESSMENT OF POQUESSING CREEK WATERSHED

PWD assessed biotic integrity of Poquessing Creek Watershed by collecting macroinvertebrates (RBP III), fish (RBP V) and periphyton in 2008. Macroinvertebrates were collected from 12 sites in Poquessing Creek Watershed and two reference sites on French Creek, Chester County, PA in March 2008. EPA RBP Physical habitat assessment was also conducted at all macroinvertebrate assessment locations, results of which are presented in Section 6.3. Fish were collected from six sites in Poquessing Creek Watershed in June 2008, and periphyton was collected from three sites in May 2008.

Overall, year 2008 monitoring sites were similar to those sites sampled in the 2001 PWD Baseline bioassessment of Poquessing Creek Watershed. However, after publication of the 2001 bioassessment, PWD reviewed available hydrography data and discovered that the headwaters of Poquessing Creek had been misidentified. Site ID codes (Section 4.2.8) in the 2008 assessment were thus revised to reflect the fact that the site originally referred to as the upstream-most mainstem Poquessing Creek site was actually an unnamed tributary to Poquessing Creek. Monitoring site PQU013 in the 2008 assessment corresponds to site PQ840 in the 2001 baseline assessment. The site originally identified in the 2001 baseline assessment as PQU020, an unnamed tributary to Poquessing Creek, was actually the mainstem Poquessing Creek. This site is referred to as site PQ845 in the 2008 assessment (Figure 5.4)

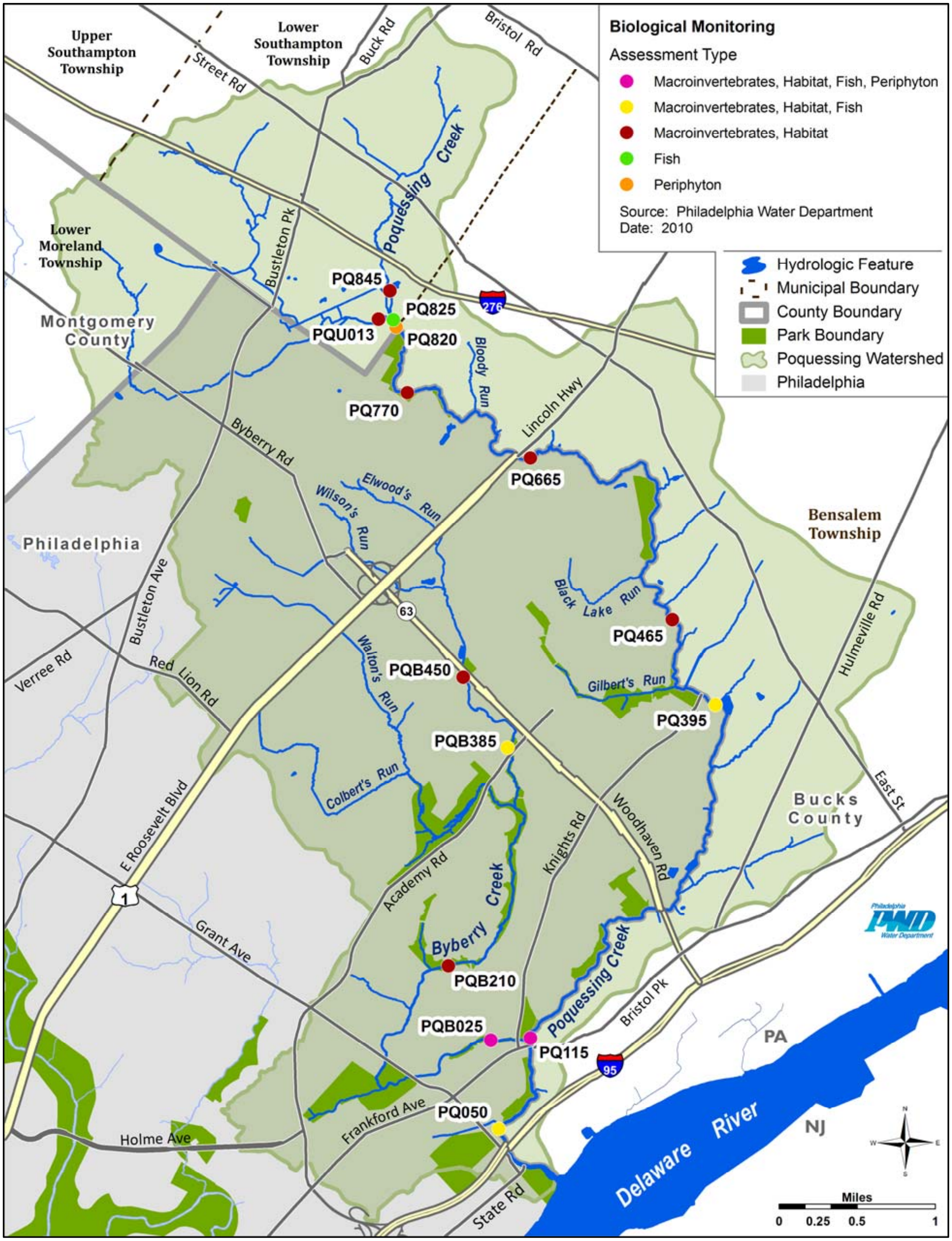

Figure 5.4 Biological Monitoring Locations in Poquessing Creek Watershed, 2008

5.3.1 BENTHIC MACROINVERTEBRATE ASSESSMENT

5.3.1.1 MONITORING LOCATIONS

From 3/7/08 to 3/18/08, PWD conducted Rapid Bioassessment Protocols (RBP III) at 12 (n=12) locations within Poquessing Creek Watershed. Surveys were conducted at seven mainstem locations and five tributary locations. Five of the seven mainstem sites were located within the City of Philadelphia (Figure 5.5). At six of the 12 monitoring locations, only macroinvertebrate and EPA RBP physical habitat assessments were conducted. Additional biological or chemistry monitoring occurred at the remaining six sites (Figure 5.4)

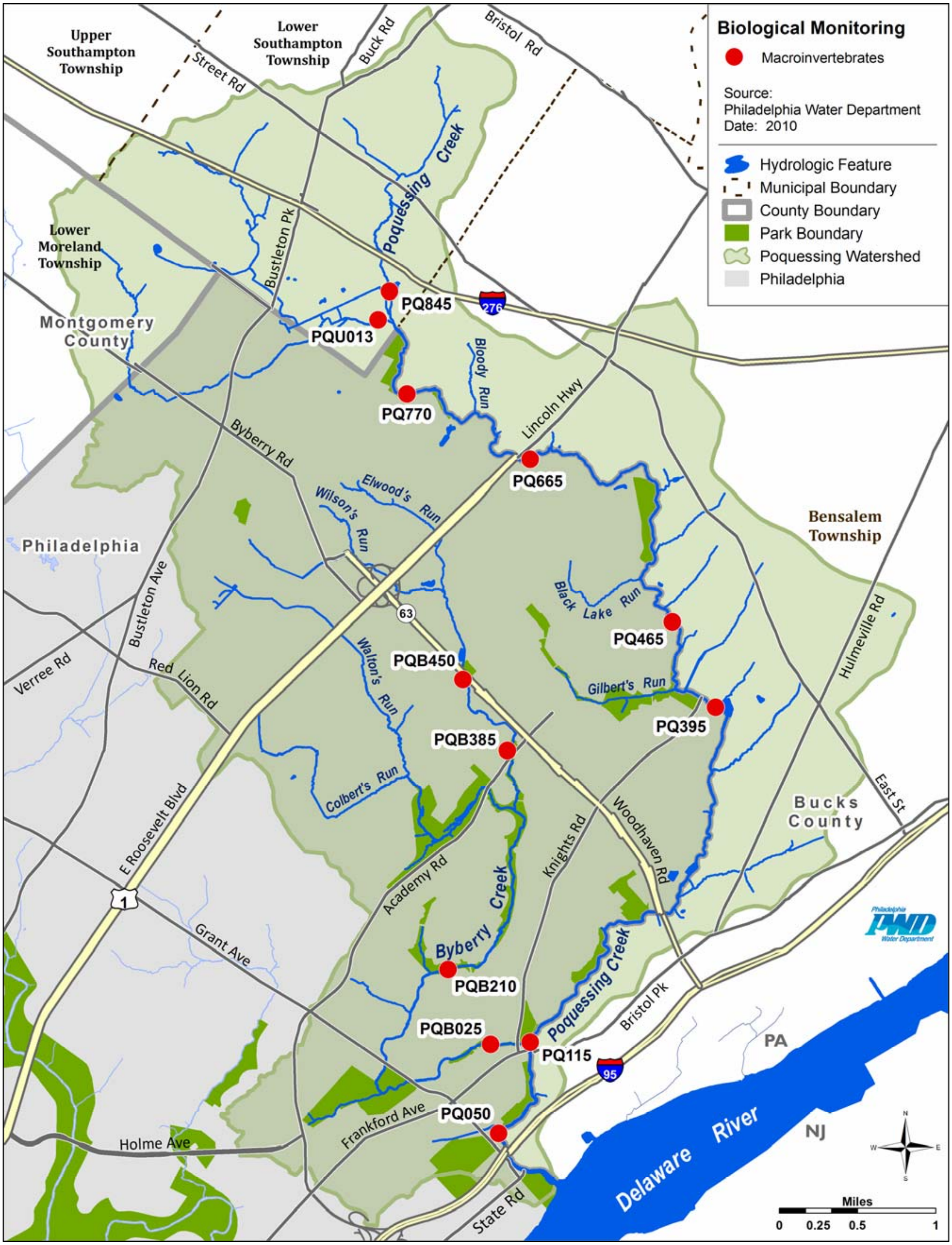

Figure 5.5 Benthic Macroinvertebrate Assessment Sites in Poquessing Creek Watershed, 2008

5.3.1.2 FIELD STANDARD OPERATING PROCEDURES

Using the PADEP Instream Comprehensive Evaluation (ICE) protocol (PADEP 2006c), macroinvertebrate samples were collected by placing a handheld D-frame net (500µm) at the downstream portion of a riffle. Stream substrate directly upstream of the D-frame net was then disturbed for approximately one minute to a depth of approximately 10 cm as substrate allowed. This procedure was repeated at other riffle locations of variable flow within the 100-m reach such that the sample at each station was a composite of six riffle samples. Composited samples from each biological monitoring location were then preserved in 95% ETOH (ethyl alcohol) and returned to the laboratory in polyethylene containers.

The ICE protocol differs from the previous PWD RBP III protocol in that: a D-frame net has replaced the standard 1 m^2 kicknet (500 µm); samples are a composite of six riffles instead of two; and finally, large substrate is no longer scrubbed manually by hand. When comparing protocols, increasing the number of riffles sampled from two to six should be expected to increase the likelihood that rare and patchily distributed taxa are collected, while refraining from manually scrubbing substrates should be expected to decrease the likelihood of collecting invertebrates that firmly attach to substrates (*e.g.*, Hydroptilidae, Glossosomatidae).

5.3.1.3 LABORATORY STANDARD OPERATING PROCEDURES

The laboratory component of PADEP ICE protocol required only minor changes to preexisting laboratory procedures. Each composited sample was placed into an 18 x 12 x 3.5-inch pan marked with 28 four-square-inch grids. Debris from four grids was randomly selected from the pan, extracted using a four-square-inch circular "cookie cutter," and placed into another identical empty pan. From this second pan, organisms were picked from randomly selected grids or “plugs” until a minimum of 200, but not more than 240, individuals were subsampled. This procedure was a misinterpretation of the actual technique, which stipulates a count of 200 (+/- 20%) individuals. For this reason, PWD results from 2007 should be compared to other samples collected with the PADEP ICE protocol with caution and careful examination of whether the additional invertebrate abundance in PWD samples has a significant effect on biological metrics.

When picking either the four initial “plugs” or additional plugs results in subsampling more than 240 individuals, the PADEP ICE protocol outlines a procedure for redistributing the subsample into a clean, gridded pan and “back counting” grids until a subsample consisting of 200 (+/-20%) is obtained. PWD RBP III laboratory protocols used 1999-2006 were generally similar, but required a minimum of 100 individuals in a subsample taken from an 11 x 14-inch pan with 20 grids or “plugs.”

Stream substrates are irregular, and for this reason, it is extremely difficult, if not impossible, to obtain quantitative samples of macroinvertebrates from natural streams. Even invertebrate samplers that are designed to be placed directly on or pushed into the stream substrate in order to isolate a sampling area cannot cope with large rocks along the periphery of the sampling area. Insect density estimates from non-quantitative sampling protocols are thus subject to large errors and, in the case of comparing results from macroinvertebrate samples collected in Poquessing Creek Watershed in 2001 and 2008, further confounded by differences in field and laboratory methods.

Organisms picked from subsamples were identified and counted using a Leica dissecting microscope. Midges were identified to the family level of Chironomidae. Roundworms and proboscis worms were identified to the phylum levels of Nematoda and Nemertea, respectively. Flatworms were identified to the class level of Turbellaria. Segmented worms, aquatic earthworms, and tubificids were identified to the class level of Oligochaeta. All other macroinvertebrates were identified to genus.

5.3.1.4 DATA ANALYSIS

As described in Sections 5.2.3 and 5.3.1.2, PWD adopted the "Freestone" sampling and sample processing techniques for 2007 and 2008 monitoring activities in Pennypack Creek and Poquessing-Byberry Creek Watersheds (PADEP 2006). It was deemed necessary, however, to consider the new assessment metrics alongside metrics formerly used in the 2001 baseline assessment of Poquessing Creek Watershed for clarity and in order to retain compatibility with previous studies and ongoing Integrated Watershed Management Plan (IWMP) initiatives. Analyses based upon the 2001 RBPIII Baseline Assessment metrics and 2007 PADEP ICE assessment metric frameworks are presented in Sections 5.3.1.5.2 and 5.3.1.5.3, respectively. It should be noted that due to minor differences in Pollution Tolerance values (PTV) used between the two assessments, Hilsenhoff Biotic Index results are not directly comparable.

Baseline PWD macroinvertebrate assessments in Poquessing Creek (PWD 2001) were compared to reference sites in French Creek Watershed, Chester County, PA. Data for five scoring metrics and three supplementary metrics (Table 5.3) were used to compare sites and assign total biological condition scores (Table 5.5). 2008 Poquessing Creek watershed data were compared to these same metrics to facilitate a comparison between these assessments. As 2001 samples had minimum 100 individual sample size, PWD investigated the effect of sample size, finding significant differences between the 2001 and 2008 assessments (Mann-Whitney U = 143, p = 0.0008876). 12 of 13 sites sampled in 2001 had fewer than 160 individuals per sample, and at 124, the average number of individuals was considerably less than the PADEP ICE protocol range of 160-240. Historical data comparisons are presented herein with the caveat of unequal sample sizes, which are assumed to affect richness and other count-based metrics more strongly than weighted metrics. An historical comparison of macroinvertebrate metrics between the 2001 and 2008 datasets based on 100 individual randomized subsamples has been included in appendix X.

Between the publication of the Pennypack Creek Watershed CCR and Poquessing Creek Watershed macroinvertebrate data analysis, PADEP revised the benthic invertebrate IBI to exclude from the Ephemeroptera Plecoptera Trichoptera (EPT) index any taxa with pollution tolerance value (PTV) of 5 or higher (PADEP 2009) and made adjustments to the metric scoring. PADEP had originally chosen the unmodified EPT index (all EPT taxa included regardless of PTV) to reduce reliance on pollution tolerance value scores in the final compiled metric. In practice, this eliminates from the metric score the contribution of two very common moderately tolerant caddisfly taxa (*Hydropsyche* and *Cheumatopsyche*), and scores at most sites decrease by 10%. Mayflies of the genus *Baetis* (PTV 6) would also have been excluded had they been found at Poquessing Creek Watershed sites. Poquessing Creek Watershed was thus the first wadeable stream assessed in Philadelphia with the revised IBI metrics, and findings are not directly comparable to earlier assessments in Pennypack Creek Watershed.

Table 5.3 RBP III Macroinvertebrate Community Metrics used in PWD 2001 Baseline Assessment of Poquessing Creek Watershed

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

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

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

(*) 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.

Table 5.4 PADEP ICE Protocol IBI Macroinvertebrate Metrics

Metric	Reference Standard
Taxa Richness	33
EPT Taxa Richness (PTV 0-4 only)	19
Beck's Index	38
Shannon Diversity Index	2.86
Hilsenhoff Biotic Index	1.89
Percent Sensitive Taxa (PTV 0-3 only)	84.5

5.3.1.5 RESULTS

5.3.1.5.1 WATERSHED OVERVIEW

A total of 2,547 individuals from 30 taxa were identified during the 2008 macroinvertebrate survey of Poquessing Creek Watershed. Some individual subsamples were observed to contain relatively few individuals, and 9 of 12 samples required sorting of more than the minimum 4 subsamples, or “plugs”, in order to count the required number of invertebrates. Samples from sites PQ665, PQ050 and PQ395 were particularly sparse, requiring more than 15 plugs to be counted (Figure 5.6). As the 2008 assessment was only the second year in which PWD performed macroinvertebrate assessments with the PADEP ICE protocol, it is difficult to draw conclusions about whether this represents an actual trend in invertebrate density or whether the observed decrease in invertebrate density is a by-product of the sampling technique.

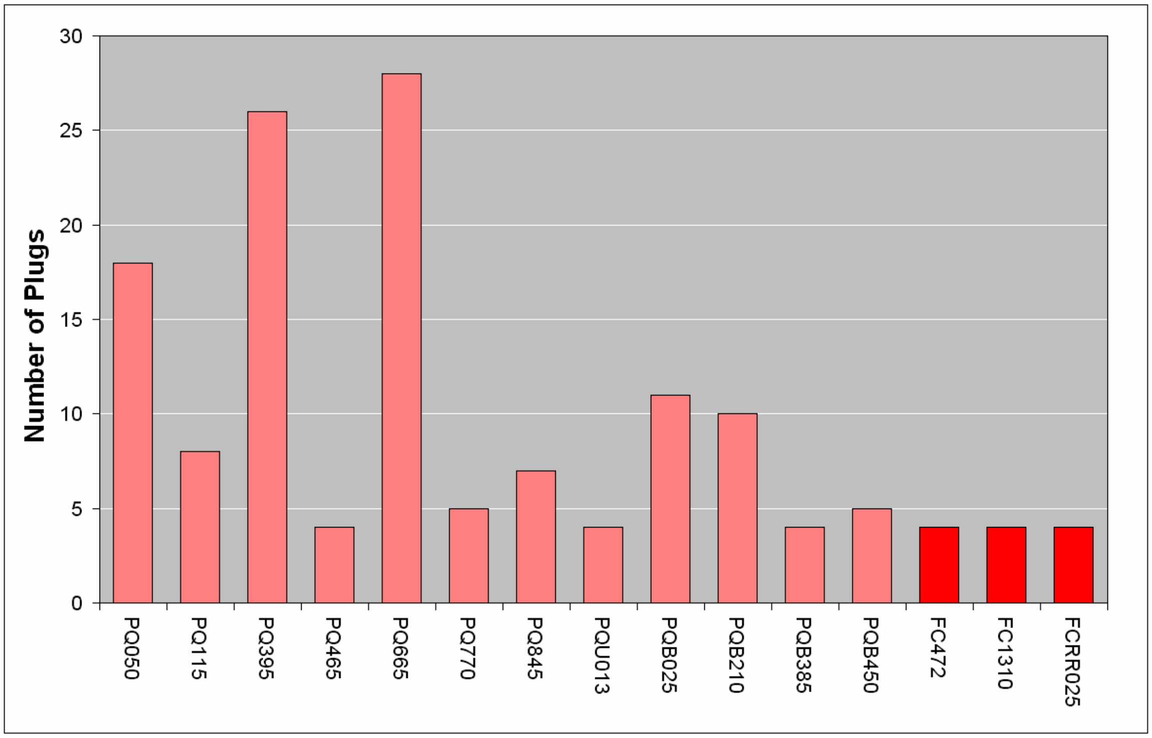

Figure 5.6 Number of Subsamples, or "Plugs" Sorted for Poquessing Creek Watershed and French Creek Reference Sites, 2008

The most notable finding from the macroinvertebrate assessment was a complete lack of any mayfly (Ephemeroptera) or stonefly (Plecoptera) taxa. Even relatively tolerant common mayfly taxa (*e.g.*, Baetidae) were not found at any of the 12 assessment sites. Average taxa richness of sites within Poquessing Creek Watershed was 11.5 (n=11.5) taxa. Overall, moderately tolerant (77.58%) and generalist feeding taxa (96.07%) dominated the watershed. The average Hilsenhoff Biotic Index (HBI) of all assessment sites was 6.43. The most common pollution-sensitive taxon observed in the macroinvertebrate assessments was the Tipulid *Antocha* spp., which was found at 11 sites (seven mainstem and four tributary sites). Modified EPT taxa are Ephemeroptera, Plecoptera, and Trichoptera (EPT) taxa with an HBI score of four or less. Poquessing Creek Watershed averaged 0.42 Modified EPT taxa per site. Only one Modified EPT taxon, the Fingernet spinning caddisfly (*Chimarra* spp.), was found in the Poquessing Creek Watershed, collected from sites PQ395, PQ465, PQ770, PQ845, and PQU013.

Chironomidae (non-biting midges) dominated the benthic macroinvertebrate assemblage of the watershed. The percent contribution of Chironomid midges ranged from 36.8% to 80% at mainstem sites and 30.9% to 49% at tributary sites. Oligochaetes and net-spinning caddisflies (Hydropsychidae) were the most numerically abundant taxa after Chironomidae, with the exceptions of sites PQB210 and PQB385, where the assemblages were dominated by Oligochaeta (53.92%) and Cheumatopsyche (36.69%), respectively. Isopods, amphipods, tipulids, gastropods, riffle beetles, *Corbicula*, water pennies, and planaria were also present throughout the watershed but in very low abundance.

Stormwater runoff can affect habitat quality such that sedimentation/siltation, poor water quality (due to pollution, turbidity, and low dissolved oxygen) and extremely variable flow regimes create conditions that can only be tolerated by the hardiest of taxa. The dominance of the benthic macroinvertebrate communities in the Poquessing Creek Watershed by midges and complete lack of sensitive mayflies or stoneflies indicated that a stressor (or stressors) was limiting the ability of other taxa to survive. There was also a sizable contribution from net-spinning caddisflies, which averaged 24.7% of taxa in the watershed and reached a maximum percent contribution of 44.95% (site PQB385). These taxa are reliable indicators of organic or nutrient pollution, as their abundance indicates elevated levels of suspended organic matter on which they feed. Of particular concern was the lack of representation by other tolerant invertebrate taxa, such as Black Fly larvae (*Simulium* spp.), which are often abundant in moderately polluted waters. Taxa in this family are relatively tolerant of pollution; however, they cannot persist in polluted waters with low dissolved oxygen or where substrate has become embedded with fine sediment or covered by algae.

Feeding measures comprise functional feeding groups and provide information on the balance of feeding strategies in the benthic community (Barbour *et al*., 1999). The trophic composition of macroinvertebrate communities within the watershed was skewed toward generalist feeding gatherers (71.06%) and filterers (25.01%). Scrapers (1.92%), predators (1.88%), and shredders (0.12%) were very rare in the Poquessing Creek Watershed, with omnivores being completely absent from all samples. In general, these more specialized feeding groups are more sensitive to perturbation than generalist feeders. The unbalanced feeding structure could suggest that the watershed has an overabundance of fine particulate organic matter (FPOM) and/or reduced retention of coarse particulate organic matter (CPOM) such as leaf litter and detritus, or that nutrient enrichment has altered the periphyton community favoring large filamentous green algae and thick brown algal scums (addressed in Section 5.3.3). Limitation of food sources hinders the ability of specialized feeders to flourish and ultimately reduces the diversity and abundance of predator species.

For example, shredders were found to be very uncommon throughout the watershed, possibly as a response to lack of leaf pack stability and the scouring effects of storm flows. In natural streams, it is not uncommon for leaf packs to persist throughout the year. Through a process called "conditioning," hyphomycete fungi colonize the surface of individual leaves and use special enzymes to break down the large chemical components of leaves. This process makes leaves softer, more palatable and more easily assimilated by macroinvertebrates; moreover, microbes on the leaf surface actually increase the nutritional content of leaves, adding essential nutrients such as proteins and lipids. Leaves from a diverse tree and shrub canopy can potentially provide greater nourishment as leaves from individual species decompose at different rates. Some tree and shrub species produce leaves that break down quickly, while leaves with higher tannin (organic acid) content are more slowly decomposed (Cummins *et al.,* 1989).

In urbanized streams with "flashy" flow regimes, lack of leaf pack retention in a reach may decrease time available for microbial colonization and thus have effects that extend beyond the availability of food resources for taxa at a particular site. Leaf litter transported downstream from upstream reaches and sub-catchments may be degraded to fine particulate organic matter (FPOM) through physical fragmentation by stream flow; however, reduced microbial colonization and activity may decrease the nutritional content of particulate organic matter for invertebrates living downstream.

Tolerance/intolerance measures are intended to be representative of relative sensitivity to perturbation and may include numbers of pollution tolerant and intolerant taxa or percent composition (Barbour *et al*., 1999). Moderately tolerant individuals (taxa with pollution tolerance values 4-7) dominated the macroinvertebrates collected in Poquessing Creek Watershed (79.9%). Sensitive taxa were poorly represented (3.26 %), and their rarity suggests a response to watershed-wide perturbation, such as water quality degradation. Other potential explanations for the rarity of sensitive taxa are habitat degradation caused by fine sediment delivered to the stream channel via bank erosion or stormwater runoff and changes in seasonal baseflow and temperature that tend to accompany urbanization.

The Hilsenhoff Biotic Index (HBI) is a metric used to determine the overall pollution tolerance of a site's benthic macroinvertebrate community. Oriented toward the detection of organic pollution, HBI can range from 0 (very sensitive) to 10 (very tolerant). The mean HBI score for Poquessing Creek Watershed was 6.45. Dominance of moderately tolerant individuals and general lack of pollution-sensitive taxa contributed to elevated HBI. In comparison, the mean HBI score of the French Creek reference sites was 3.35, which suggests severe impairment in Poquessing Creek. As noted in section 5.3.1.4, differences in Pollution Tolerance Values between the 2001 and 2008 assessments preclude a direct comparison of HBI trends.

In practice, the only meaningful difference in HBI scores pertained to non-insect taxa Oligochaeta (worms) and *Corbicula fluminea*, the invasive Asian clam. In the 2001 assessment, worms were identified to the level of Lumbriculidae and assigned PTV 8, while in 2008 they were identified to the level of Oligochaeta and assigned PTV 10, in accordance with PADEP ICE protocol documentation. Corbicula was assigned PTV 8 in 2001 and PTV 4 in 2008. *Corbicula* was found at four of 13 sites in 2001 and six of 12 sites in the 2008 assessment, but aside from site PQ465, at which eight Corbicula individuals were collected in 2001, most sites had only a single individual and no sites had greater than two individuals. Even given the large discrepancy in PTV, the small number of individuals collected meant that differences in HBI methods for *Corbicula* made only minor changes to the interpretation of HBI between assessment years. The differences in HBI score methods from 2001 to 2008 thus primarily affected impaired sites with a relatively large proportion of tolerant worms. HBI scores for sites with a large proportion of worms collected in 2001 would be higher if the 2008 method of computing HBI was applied to 2001 samples.

5.3.1.5.2 POQUESSING CREEK WATERSHED RESULTS COMPARISON TO REGIONAL REFERENCE CONDITION

A total of 2,547 individual macroinvertebrates were collected from the seven mainstem Poquessing Creek sites (PQ050, PQ115, PQ395, PQ465, PQ665, PQ770, and PQ845), four Byberry Creek sites (PQB025, PQB210, PQB385, and PQB450), and one Poquessing Creek unnamed tributary site (PQU013) assessed during the 2008 PWD benthic macroinvertebrate survey of Poquessing Creek Watershed (Table 5.5). The majority of sites surveyed received a total Biological Condition score of zero (0) out of a possible 30. PQ050, PQ115, and PQB385 received a score of 4 out of 30 due to the generally lower percentage of dominant taxa found at these sites relative to their respective reference sites. Nevertheless, all sites were designated "severely impaired" and were characterized by low taxa richness (n=8 to n=15), low or absent modified EPT taxa, and elevated Hilsenhoff Biotic Index score (5.77 to 8.09) when compared to reference reach standards (Figures 5.10 and 5.11; Table 5.7). The reference site approach has been used extensively in aquatic science because matching subject sites with unimpaired, geologically similar sites should account for localized macroinvertebrate population distribution patterns and life history chronology. Furthermore, closely spaced sites can be expected to be subject to similar climatic factors.

Table 5.5 Macroinvertebrate Community Metric Results from Poquessing Creek Watershed Sites Compared to Regional Reference Conditions, 2008

Site	Taxa Richness	Modified EPT Taxa	Hilsenhoff Biotic Index (Modified)	Percent Dominant Taxa	Percent Modified Mayflies	Total Biological Condition Score	Biological Assessment
PQ050 [a]	14	0	6.67	44.66 (CHIRONOMIDAE)	0	4	Severely Impaired
PQ115 [b]	9	0	6.71	36.79 (CHIRONOMIDAE)	0	4	Severely Impaired
PQ395 [b]	15	1	7.00	45.63 (CHIRONOMIDAE)	0	0	Severely Impaired
PQ465 [b]	10	1	5.90	71.01 (CHIRONOMIDAE)	0	0	Severely Impaired
PQ665 [b]	13	0	6.38	57.35 (CHIRONOMIDAE)	0	0	Severely Impaired
PQ770 [b]	14	1	6.11	54.83 (CHIRONOMIDAE)	0	0	Severely Impaired
PQ845 [b]	13	1	5.84	56.07 (CHIRONOMIDAE)	0	0	Severely Impaired
PQB025 [b]	10	0	6.97	46.37 (CHIRONOMIDAE)	0	0	Severely Impaired
PQB210 [b]	8	0	8.09	53.92 (OLIGOCHAETA)	0	0	Severely Impaired
PQB385 [b]	13	0	5.77	36.69 (CHEUMATOPSYCHE)	0	4	Severely Impaired
PQB450 [b]	8	0	6.01	49.05 (CHIRONOMIDAE)	0	0	Severely Impaired
PQU013 [c]	11	1	5.91	80.0 (CHIRONOMIDAE)	0	0	Severely Impaired
FC472	27	12	4.00	29.27 (CHIRONOMIDAE)	29.27	------	------
FC1310	29	14	3.37	23.11 (EPHEMERELLA)	31.51	------	------
FCRR025	21	12	2.68	32.48 (EPHEMERELLA)	36.32	------	------

[a] FC472 used as reference
[b] FC1310 used as reference
[c] FCRR025 used as reference

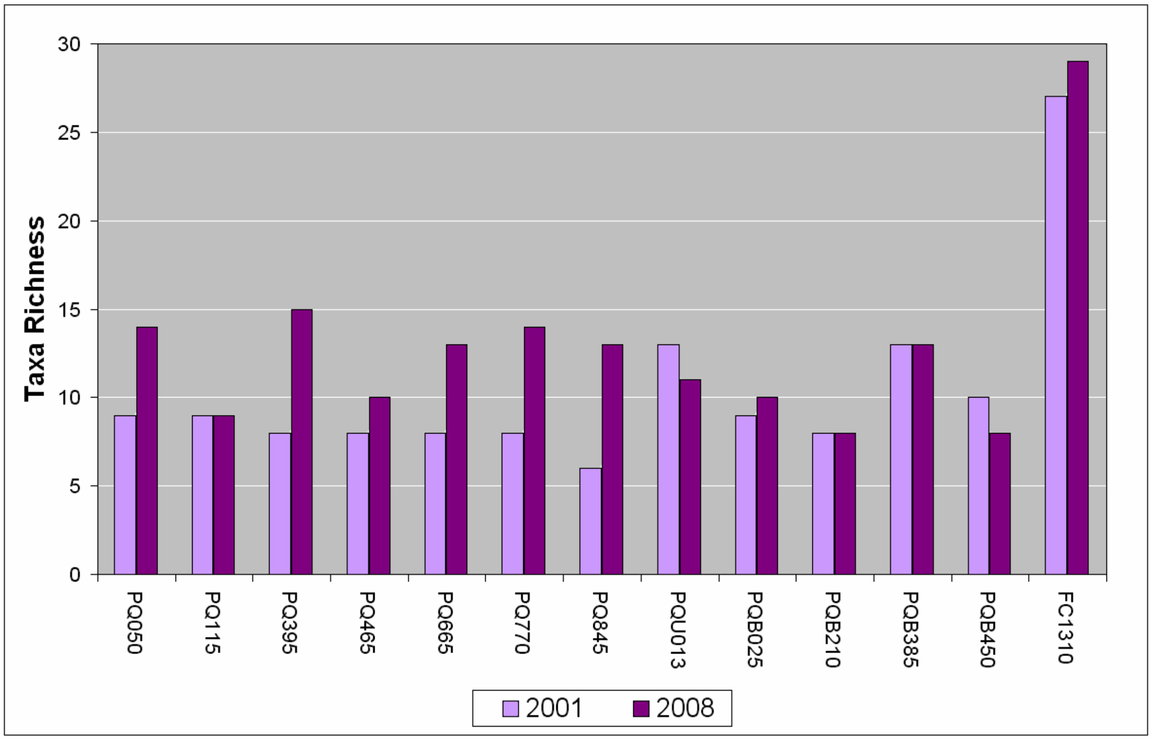

Figure 5.7 Taxa Richness at Poquessing Creek Watershed and French Creek Reference Sites, 2001 and 2008

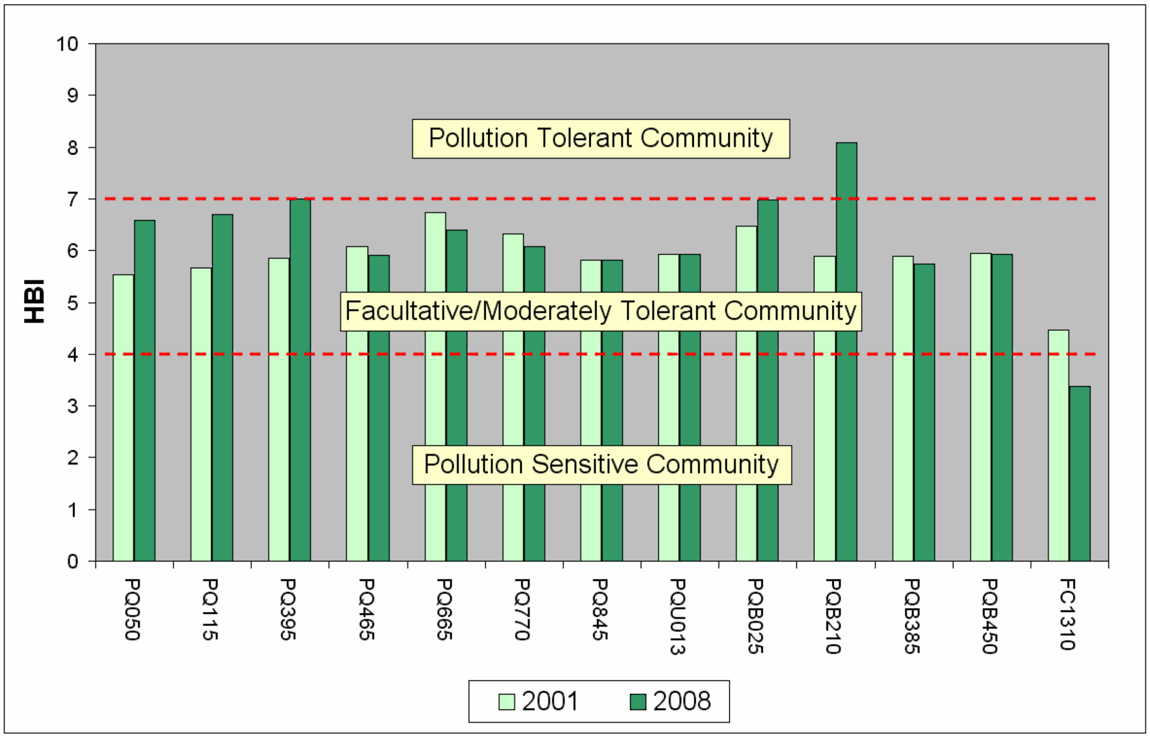

Figure 5.8 Hilsenhoff Biotic Index Scores of Poquessing Creek Watershed and French Creek Reference Site, 2001 and 2008*

*Due to differences in Pollution Tolerance Values (PTV), HBI scores are not directly comparable. See section 5.3.1.4

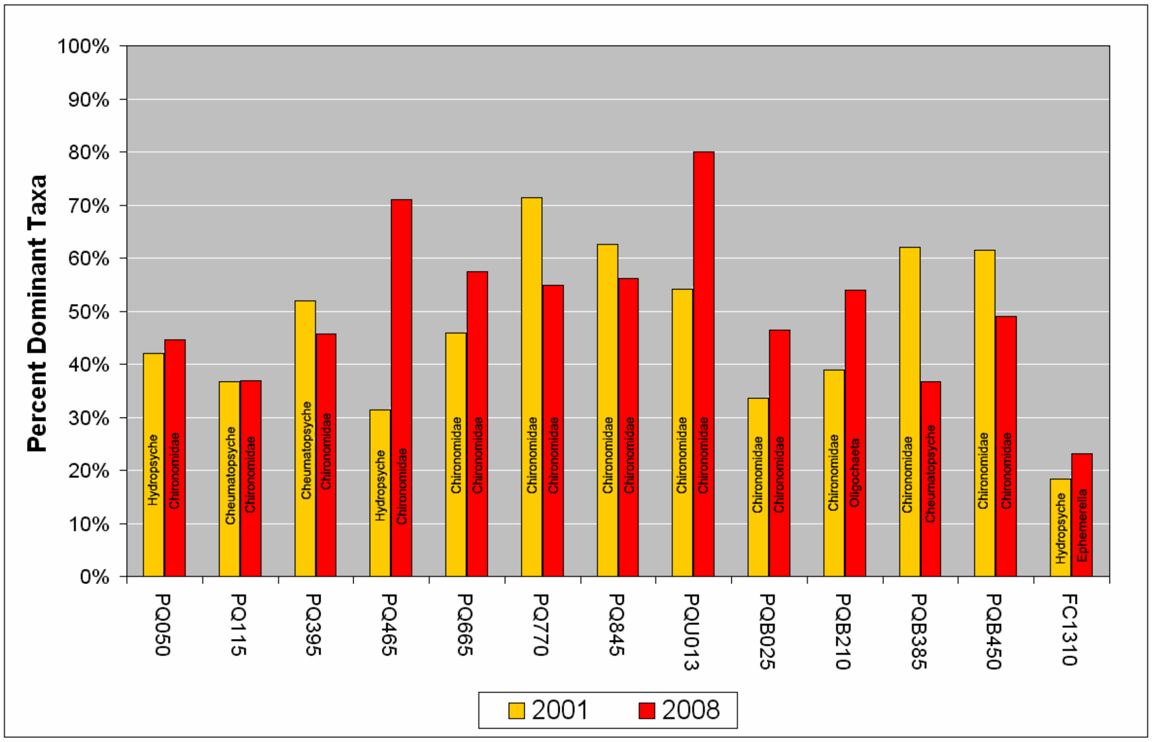

Figure 5.9 Percent Dominant Taxa at Poquessing Creek Watershed and French Creek Reference Sites, 2001 and 2008

Overall, Chironomids, which are moderately tolerant of pollution, were the dominant taxon at all mainstem Poquessing Creek assessment locations (36.7% to 80%). Chironomids were also found in high abundance at all Byberry Creek locations (30.88% to 49.06% dominance) (Table 5.5). The proportional dominance of Chironomids is evidence of increasingly homogenous community assemblages in Poquessing Creek Watershed. Chironomids and other pollution-tolerant, generalist species increase in proportional dominance with increased disturbance due to the loss of optimal habitat conditions for less tolerant, more specialized species.

Habitat impairments such as hydrologic extremes (*i.e.*, low base flow and accentuated flow during storm events), physical obstructions, and sedimentation/siltation appear to be the major environmental stressors on the aquatic ecosystem. Accumulation of sediment in the interstitial spaces of riffles has been shown to limit available habitat and possibly smother benthic invertebrate life stages (Runde & Hellenthal 2000). Most mainstem assessment locations scored in the sub-optimal to poor ranges for both embeddedness and sediment deposition (Section 6.3.1) in the 2008 EPA RBP Physical Habitat assessment.

Macroinvertebrate assessment data collected in 2001 for the Poquessing Baseline Assessment was compared to 2008 assessment data in order to assess changes in macroinvertebrate community structure. There was a relatively large change in all metrics between the 2001 and 2008 surveys for most sites. By direct comparison of the two different survey methods, taxa richness increased at all mainstem Poquessing Creek sites between the 2001 and 2008 assessments, except site PQ115, which showed no change in taxa richness (Figure 5.7). These results suggest an increase in biodiversity; however, there were large increases in percent dominant taxa from 2002 to 2008, which suggest that taxa within Poquessing Creek assemblages are becoming less evenly distributed. It also should be noted that the change to PADEP ICE field and laboratory protocols may have increased the likelihood that rare taxa would be collected. Six different riffle sites were sampled in 2008 rather than two riffle sites in 2001, and the taxonomist generally counted a greater number of "plugs" and macroinvertebrate individuals in the 2008 study. Appendix K addresses the imbalance in the sample sizes by comparing 100 randomly selected individual subsamples from 2001 and 2008 and concludes the difference in taxa richness is likely due to the disparity in sample size.

Table 5.6 Macroinvertebrate Community Metric Results from Poquessing Creek Watershed Sites Compared to Regional Reference Condition, 2001 and 2008

Site	2001 Taxa Richness	2008 Taxa Richness	2001 Modified EPT Taxa	2008 Modified EPT Taxa	2001 Hilsenhoff Biotic Index (Modified)*	2008 Hilsenhoff Biotic Index (Modified)	2001 Percent Dominant Taxa	2008 Percent Dominant Taxa	2001 Percent Modified Mayflies	2008Percent Modified Mayflies
PQ050[a]	9	14	0	0	5.53	6.67	41.95 (HYDROPSYCHE)	44.66 (CHIRONOMIDAE)	0	0
PQ115[b]	9	9	0	0	5.67	6.71	36.65 (CHEUMATOPSYCHE)	36.79 (CHIRONOMIDAE)	0	0
PQ395[b]	8	15	0	1	5.86	7.00	51.88 (CHEUMATOPSYCHE)	45.63 (CHIRONOMIDAE)	0	0
PQ465[b]	8	10	0	1	6.08	5.90	31.37 (HYDROPSYCHE)	71.01 (CHIRONOMIDAE)	0	0
PQ665[b]	8	13	0	0	6.74	6.38	45.87 (CHIRONOMIDAE)	57.35 (CHIRONOMIDAE)	0	0
PQ770[b]	8	14	0	1	6.32	6.11	71.32 (CHIRONOMIDAE)	54.83 (CHIRONOMIDAE)	0	0
PQ845[b]	6	13	0	1	5.82	5.84	62.59 (CHIRONOMIDAE)	56.07 (CHIRONOMIDAE)	0	0
PQB025[b]	9	10	0	0	6.48	6.97	33.66 (CHIRONOMIDAE)	46.37 (CHIRONOMIDAE)	0	0
PQB210[b]	8	8	0	0	5.89	8.09	38.83 (CHIRONOMIDAE)	53.92 (OLIGOCHAETA)	0	0
PQB385[b]	13	13	0	0	5.89	5.77	62.07 (CHIRONOMIDAE)	36.69 (CHEUMATOPSYCHE)	0	0
PQB450[b]	10	8	0	0	5.94	6.01	61.39 (CHIRONOMIDAE)	49.05 (CHIRONOMIDAE)	0	0
PQU013[c]	13	11	0	1	5.93	5.91	54.05 (CHIRONOMIDAE)	80.0 (CHIRONOMIDAE)	0	0
FC472**	---	27	---	12	---	4.00	-----	29.27 (CHIRONOMIDAE)	---	29.27
FC1310	27	29	7	14	4.47	3.37	18.31 (HYDROPSYCHE)	23.11 (EPHEMERELLA)	58.72	31.51
FCRR025**	---	21	---	12	---	2.68	-----	32.48 (EPHEMERELLA)	---	36.32

*Due to differences in Pollution Tolerance Values (PTV), HBI scores are not directly comparable

[a] FC472 used as reference

[b] FC1310 used as reference

[c] FCRR025 used as reference

**2001 data not collected for these reference sites

Excluding the uppermost sites of the Poquessing Creek mainstem (PQ845 and PQ770), all Poquessing Creek sites were found to have a marked increase in the percent contribution of Chironomids from the 2001 assessment. Percent contribution of Chironomids at sites PQ665, PQ465, PQ395, PQ115, and PQ050 increased by an average of 28.8%. At four of these five locations, Chironomidae surpassed the net spinning caddisflies (*Hydropsyche* and *Cheumatopsyche*) to become the new dominant taxa at those sites relative to the 2001 assessment. However, the most extreme change was seen at Byberry Creek site PQB210, where the dominant taxon changed from Chironomidae (38.83%) in 2001 to Oligochaeta (53.92%) in 2008. Incidentally, no specimen representatives of the order Oligochaeta were collected at this site or the rest of the upper Byberry Creek sites during the 2001 assessment. This change in dominant taxon corresponds to a large increase in HBI at the site, from 2001 (5.89) to 2008 (8.09). This may be evidence of an increased frequency or magnitude of disturbance from organic pollution at the site given the large shift in community structure.

At the downstream-most sites on mainstem Poquessing Creek, a similar yet smaller change in HBI corresponded to a shift in dominant taxon from 2001. For example, HBI decreased by 1.14 from 2001 to 2008 at site PQ050, while the dominant taxon shifted from Hydropsyche (41.95%) in 2001 to Chironomidae (44.66%) in 2008. This change exemplifies how small differences in HBI tolerance values for moderately tolerant taxa such as Hydropsyche (HBI 5) and Chironomidae (HBI 6) strongly affect total HBI score when a major shift in relative abundance occurs, even between two common, moderately tolerant taxa. It also demonstrates how weighted metrics like HBI add to the overall usefulness of a multimetric approach and why metrics based strictly on the presence or absence of a taxon (such as total taxa richness) are best considered in light of other measures of community structure.

5.3.1.5.3 POQUESSING CREEK WATERSHED RESULTS COMPARISON TO PADEP INDEX OF BIOTIC INTEGRITY (IBI)

As described in Section 5.3.1.4, 2008 Poquessing Creek Watershed macroinvertebrate data were also compared to PADEP ICE reference conditions IBI. All assessment sites in Poquessing Creek Watershed were classified as stressed. No mainstem sites achieved 63% comparability of reference IBI for attaining the WWF designated use. Percent comparability with IBI scoring metrics were very poor, ranging from 14.9-26.7% (Table 5.7). Furthermore, no site met the PADEP reference value for any individual metric (Table 5.5, Figures 5.10 and 5.11). Taxa richness ranged (n=8 to n=15) compared to the reference value of n=33. Poquessing sites also performed poorly when measured against the Ephemeroptera, Plecoptera, Trichoptera (EPT) taxa richness metric, as the range of values (n=0-1) fell far below the reference value of (n=19). Of the EPT taxa found on the mainstem, few were classified as sensitive to pollution, a fact that is further illustrated by the low values of Beck's Index (n=0-1) when compared to the reference value of (n=38). Beck's index (also known as the Florida index) is a weighted index of all sensitive macroinvertebrates rather than just the EPT orders.

Diversity was also very low among mainstem sites. The Shannon Diversity Index scores for mainstem sites ranged from (H=0.86 to H=1.68) compared to the reference value of (H=2.86). The average HBI of mainstem sites was 6.42 and HBI values ranged from 5.74-8.09, suggesting aquatic communities in Poquessing Creek Watershed are exposed to elevated levels of organic pollution.

Mainstem scores for the Percent Intolerant Taxa metric (0.83-10.55%) differed from the metric scoring value (84.5%) by the largest margin, proportionally, of all PADEP metrics. The combination of poor water quality (evident in elevated HBI values), low diversity and the reduced abundance and distribution of sensitive taxa classify all sites in Poquessing Creek Watershed as severely impaired, corresponding to BCG Tiers 5 or 6.

Table 5.7 Summary of PADEP IBI Metric Scores for Poquessing Creek Watershed Sites, 2008

2008 Poquessing Creek Watershed Assessment	Taxa Richness	EPT Richness	Beck's Index	Hilsenhoff Biotic Index	Shannon Diversity index	Percent Intolerant Taxa	Percent Comparability
PQ050	14	0	1	6.67	1.68	5.83	25.31
PQ115	9	0	1	6.71	1.55	4.25	21.65
PQ395	15	1	1	7.00	1.48	0.97	23.86
PQ465	10	1	1	5.90	1.09	4.35	22.02
PQ665	13	0	0	6.38	1.43	4.41	23.20
PQ770	14	1	1	6.11	1.50	1.38	25.40
PQ845	13	1	1	5.84	1.43	0.93	24.98
PQB025	10	0	0	6.97	1.43	1.93	19.97
PQB210	8	0	0	8.09	1.18	0.00	14.86
PQB385	13	0	0	5.77	1.60	10.55	26.70
PQB450	8	0	1	6.01	1.15	3.77	20.14
PQU013	11	1	0	5.91	0.86	0.83	25.31
PADEP Reference	33	19	38	1.89	2.86	84.5	------

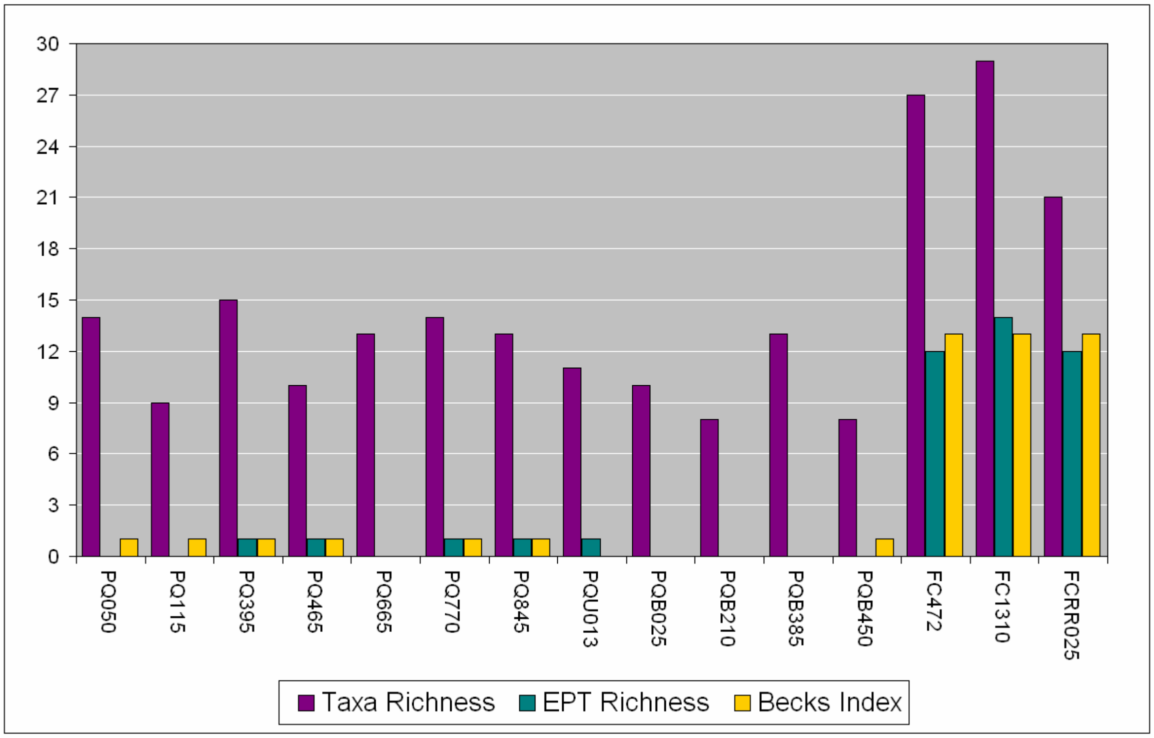

Figure 5.10 PADEP IBI Metrics for Sites in Poquessing Creek Watershed and French Creek Reference Sites, 2008

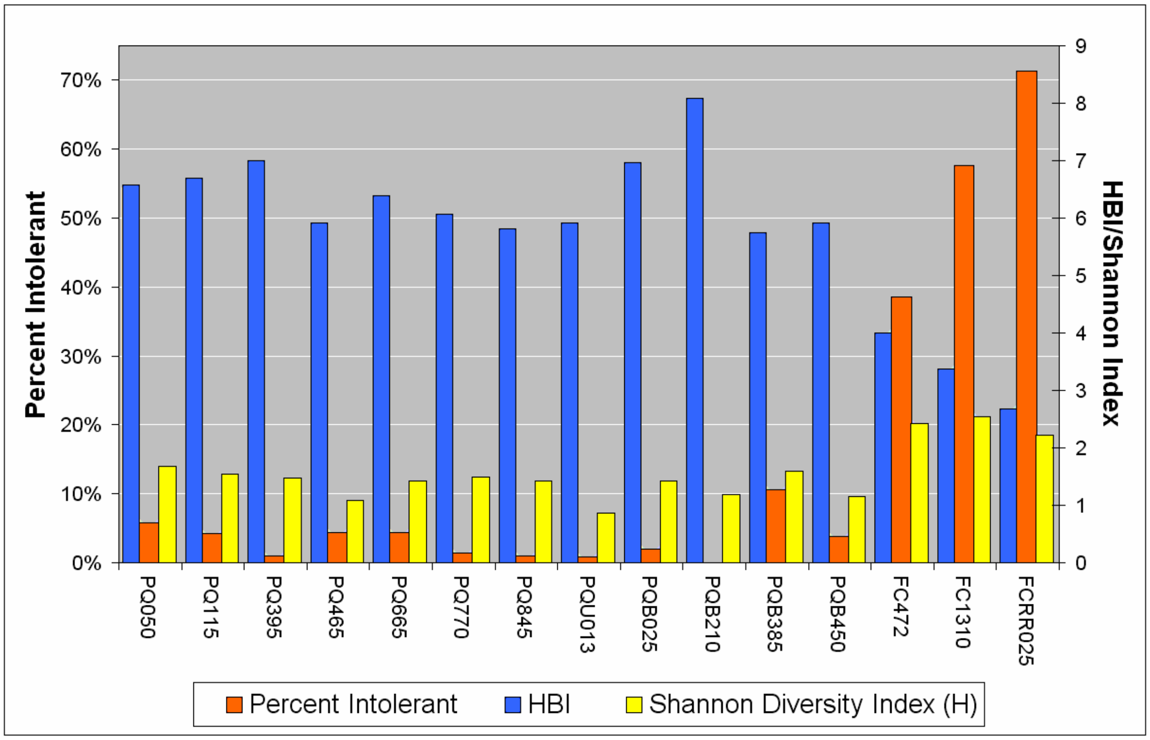

Figure 5.11 PADEP IBI Metrics for Poquessing Creek Watershed and French Creek Reference Sites, 2008

5.3.1.5.4 INDIVIDUAL SITE RESULTS

5.3.1.5.4.1 PQ050

Located behind Holy Family University (40° 3' 27.906" N, 74° 59' 3.732" W) and upstream of Stevenson Lane, this site is the farthest downstream location sampled on the Poquessing Creek above the tidal influence of the Delaware River. The macroinvertebrate community had a taxa richness of n=14 with zero EPT taxa and an HBI score of 6.67. A total of 206 macroinvertebrates were obtained after sorting 18 plugs, and the dominant taxon was Chironomidae at 45%. The trophic structure was primarily made up of generalist feeders (gatherers 72% and filterers 21%) due to the abundance of Chironomidae, Oligochaeta, and Hydropsychidae (*Hydropsyche* and *Cheumatopsyche*). The two most sensitive macroinvertebrate taxa collected at this site were Tipulidae *Antocha* and Elmidae *Ancyronyx*. Relative pollution sensitivity values at site PQ050 were 7% intolerant, 71% moderately tolerant and 22% tolerant. Based on the Index of Biotic Integrity assessment criteria, PQ050 received an IBI metric score of 25.3%, which classifies it as impaired.

5.3.1.5.4.2 PQ115

This site is located upstream of PQ050 (40° 3' 56.134" N, 74° 58' 51.282" W) and had a taxa richness of n=9 with zero EPT taxa and an HBI score of 6.71. A total of 212 macroinvertebrates were obtained after sorting eight plugs, and the dominant taxon was Chironomidae at 37%. The trophic structure was primarily made up of generalist feeders (gatherers 66% and filterers 33%) due to the majority of the macroinvertebrates in the sample belonging to the taxa Chironomidae, Oligochaeta, and Hydropsychidae (*Hydropsyche*). The two most sensitive macroinvertebrate taxa collected at this site were Tipulidae *Antocha* and Elmidae *Ancyronyx*. Relative pollution sensitivity values at site PQ115 were 4% intolerant, 71% moderately tolerant and 25% tolerant. Based on the Index of Biotic Integrity assessment criteria, PQ115 received an IBI metric score of 21.7%, which classifies it as impaired.

5.3.1.5.4.3 PQ395

This site is located upstream of PQ115 (40° 5' 45.334" N, 74° 57' 25.589" W) and had a taxa richness of n=15 with one EPT taxon (Philopotamidae *Chimarra*) and an HBI score of 7.00. A total of 206 macroinvertebrates were obtained after sorting 26 plugs, and the dominant taxon was Chironomidae at 46%. The trophic structure was primarily made up of generalist feeders (gatherers 77% and filterers 14%) due to the majority of the macroinvertebrates in the sample belonging to the taxa Chironomidae, Oligochaeta , and Hydropsychidae (*Hydropsyche* and *Cheumatopsyche*). The least tolerant macroinvertebrate taxa collected at this site were Elmidae *Ancyronyx*, Tipulidae *Antocha* and Philopotamidae *Chimarra*. Relative pollution sensitivity values at site PQ395 were 2% intolerant, 67% moderately tolerant and 31% tolerant. Based on the Index of Biotic Integrity assessment criteria, PQ395 received an IBI metric score of 23.9%, which classifies it as impaired.

5.3.1.5.4.4 PQ465

This site is located upstream of PQ395 (40° 6' 14.239" N, 74° 57' 42.927" W) and had a taxa richness of n=10 with one EPT taxa (Philopotamidae *Chimarra*) and an HBI score of 5.90. A total of 207 macroinvertebrates were obtained after sorting four plugs, and the dominant taxon was Chironomidae at 71%. The trophic structure was heavily skewed toward generalist feeders (gatherers 83% and filterers 15%) and contained only one scraper taxon Elmidae *Stenelmis*. The least tolerant macroinvertebrate taxa collected at this site were Elmidae *Ancyronyx*, Tipulidae

Antocha and Philopotamidae *Chimarra*. Relative pollution sensitivity values at site PQ465 were 8% intolerant, 85% moderately tolerant and 7% tolerant. Based on the Index of Biotic Integrity assessment criteria, PQ465 received an IBI metric score of 22.0%, which classifies it as impaired.

5.3.1.5.4.5 PQ665

This site is located upstream of PQ465 (40° 7' 10.030" N, 74° 58' 42.100" W) and had a taxa richness of n=13 with zero EPT taxa and an HBI score of 6.38. A total of 204 macroinvertebrates were obtained after sorting 28 plugs, and the dominant taxon was Chironomidae at 57%. The trophic structure was heavily skewed toward generalist feeders (gatherers 80% and filterers 17%). The only sensitive macroinvertebrate taxon collected at this site was Tipulidae *Antocha*. Relative pollution sensitivity values at site PQ665 were 5% intolerant, 78% moderately tolerant and 17% tolerant. Based on the Index of Biotic Integrity assessment criteria, PQ665 received an IBI metric score of 23.2%, classifying it as impaired.

5.3.1.5.4.6 PQ770

This site is located upstream of PQ665 (40° 7' 33.332" N, 74° 59' 34.587" W) and had a taxa richness of n=14 with one EPT taxa (Philopotamidae *Chimarra*) and an HBI score of 6.11. A total of 217 macroinvertebrates were obtained after sorting five plugs, and the dominant taxon was Chironomidae at 55%. The tropic structure was heavily skewed toward generalist feeders (gatherers 67% and filterers 29%). The most sensitive macroinvertebrate taxa collected at this site were Tipulidae *Antocha* and Elmidae Ancyronyx. Relative pollution sensitivity values at site PQ770 were 9% intolerant, 80% moderately tolerant and 11% tolerant. Based on the Index of Biotic Integrity assessment criteria, PQ770 received an IBI metric score of 25.4%, classifying it as impaired.

5.3.1.5.4.7 PQ845

This site is located upstream of PQ770 (40° 8' 7.589" N, 74° 59' 40.554" W) and had a taxa richness of n=13 with one EPT taxa (Philopotamidae *Chimarra*) and an HBI score of 5.84. A total of 214 macroinvertebrates were obtained after sorting seven plugs, and the dominant taxon was Chironomidae at 56%. The trophic structure was heavily skewed toward generalist feeders (gatherers 59% and filterers 36%). Other sensitive macroinvertebrate taxa collected at this site were Tipulidae *Antocha* and Elmidae *Ancyronyx*. Relative pollution sensitivity values at site PQ845 were 7% intolerant, 90% moderately tolerant and 3% tolerant. Based on the Index of Biotic Integrity assessment criteria, PQ845 received an IBI metric score of 25.0%, classifying it as impaired.

5.3.1.5.4.8 PQB025

This was the farthest downstream site sampled on the Byberry Creek before it combines with the Poquessing Creek. A benthic sample was collected downstream of Morrell Avenue where it intersects with Crestmont Avenue (40° 3' 55.927" N, 74° 59' 8.486" W). The macroinvertebrate community had a taxa richness of n=10 with zero EPT taxa and a calculated Hilsenhoff Biotic Index (HBI) score of 6.97. A total of 207 macroinvertebrates were obtained after sorting 11 plugs, and the dominant taxon was Chironomidae at 46%. The trophic structure was primarily made up of generalist feeders (gatherers 76% and filterers 21%) due to the abundance of Chironomidae, Oligochaeta, and Hydropsychidae (*Hydropsyche* and *Cheumatopsyche*). The most sensitive macroinvertebrate taxon collected at this site was the Tipulidae *Antocha* spp. Relative pollution sensitivity values at site PQB025 were 3% intolerant, 69% moderately tolerant and 28% tolerant.

Based on the Index of Biotic Integrity (IBI) assessment criteria, PQB025 received an IBI metric score of 20.0%, which classifies it as impaired.

5.3.1.5.4.9 PQB210

This site is located upstream of PQB025 (40° 4' 21.293" N, 74° 59' 25.753" W) and had a taxa richness of n=8 with zero EPT taxa. This location had the highest HBI value of all benthic sites sampled with an HBI score of 8.09. A total of 204 macroinvertebrates were obtained after sorting 10 plugs, and the dominant taxa was Oligochaeta (54%), followed by Chironomidae (31%) and Hydropsychidae 12% (*Hydropsyche* and *Cheumatopsyche*). This site's benthic community trophic structure was dominated by generalist feeders (gatherers 85% and filterers 12%). Relative pollution sensitivity values at site PQB210 were 1% intolerant, 46% moderately tolerant and 54% tolerant. Based on the Index of Biotic Integrity assessment criteria, PQB210 received an IBI metric score of 14.9%, which classifies it as impaired.

5.3.1.5.4.10 PQB385

This site is located upstream of PQB210 (40° 3' 55.927" N, 40° 3' 55.927" N) and has a taxa richness of n=13 with zero EPT taxa and an HBI score of 5.77. A total of 218 macroinvertebrates were obtained after sorting four plugs with Hydropsychidae *Cheumatopsyche* (37%) and Chironomidae (34%) dominating the benthic assemblage. The least tolerant macroinvertebrate collected was Tipulidae *Antocha*, which accounted for 11% of the total sample. This benthic community trophic structure was dominated by generalist feeders (gatherers 49% and filterers 45%). Relative pollution sensitivity values at site PQB385 were 11% intolerant, 85% moderately tolerant and 3.67% tolerant. Based on the Index of Biotic Integrity assessment criteria, PQB385 received an IBI metric score of 26.7%, which classifies it as impaired.

5.3.1.5.4.11 PQB450

This site is located upstream of PQB385 (40° 5' 57.548" N, 74° 59' 14.767" W) and has a taxa richness of n=8 with zero EPT taxa and an HBI score of 6.01. A total of 212 macroinvertebrates were obtained after sorting five plugs with Chironomidae (49%) and Hydropsychidae *Cheumatopsyche* (39%) dominating the benthic assemblage. This site's benthic community trophic structure was dominated by generalist feeders (gatherers 57.08 % and filterers 41.98%). Relative pollution sensitivity values at site PQB450 were 4.25% intolerant, 91.51% moderately tolerant and 4.25% tolerant. Three sensitive taxa, Tipulidae *Tipula* and *Antocha*, and Ceratopogonidae *Atrichopogon* were collected for a combined total of nine macroinvertebrates. Based on the Index of Biotic Integrity assessment criteria, PQB385 received an IBI metric score of 20.1%, which classifies it as impaired.

5.3.1.5.4.12 PQU013

This site is located approximately 700 ft upstream of the confluence where this tributary creek combines with the Poquessing Creek near PQ825. PQU013 (40° 7' 58.364" N, 74° 59' 45.920" W) had a taxa richness of n=11 with one EPT taxa (Philopotamidae *Chimarra*) and an HBI score of 5.91. A total of 240 macroinvertebrates were obtained after sorting four plugs with the dominant taxon being Chironomidae at 80%. The trophic structure was heavily skewed toward generalist feeders (gatherers 83% and filterers 15%). Other sensitive macroinvertebrate taxa collected at this site were Tipulidae *Antocha* and Tipulidae *Tipula*. Relative pollution sensitivity values at site PQU013 were 5% intolerant, 93% moderately tolerant and 2% tolerant. Based on the Index of

Biotic Integrity assessment criteria, PQU013 received an IBI metric score of 20.0%, classifying it as impaired.

5.3.1.5.5 POQUESSING CREEK MACROINVERTEBRATE SUPPLEMENTARY RESULTS

In addition to applying metrics in order to classify sites as being impaired with respect to regional or statewide reference conditions, additional attributes of macroinvertebrate community structure were also addressed. With regard to trophic structure, or the distribution of feeding strategies, generalist feeders (71.06%) and filterers (25.01%) dominated at all mainstem Poquessing Creek assessment sites (Figure 5.12). Specialized feeders were absent or found in low abundance at nearly all sites, with the only minor exception being site PQ395, where scrapers represented 7.77% of taxa collected. The scrapers at this site were dominated by moderately tolerant riffle beetles (*Stenelmis* spp.), as well as two types of pollution-tolerant aquatic snails (Ancylidae and Physidae). However, on average scrapers made up only 1.92% of all taxa collected in the watershed. Other functional feeding groups were observed in the macroinvertebrate assessment at much lower proportions, including predators (1.88%) and shredders (0.12%), as well as a complete absence of omnivores (0%). Analysis of trophic structure can serve to indicate potential stressors (*e.g.*, sedimentation/siltation, eutrophication) and identify food resource limitations.

As described in section 5.2.3, relative abundance of tolerant taxa increases in response to physical and chemical degradation of the stream environment (Figure 5.2). Most sites assessed by PWD would be assigned to level 5 of the Biological Condition Gradient. Identification of severely impaired sites (BCG level 6) is useful for watershed planning initiatives, particularly Integrated Watershed Management Plan Target A - Dry Weather Water Quality. The relative proportion of tolerant taxa is somewhat more useful than HBI in comparing trends compared to the 2001 assessment, because, as noted in section 5.3.1.4, there were differences in the Pollution Tolerance Values (PTV) assigned to worms (Oligochaeta) in the 2001 and 2008 assessments. Despite the difference in PTV, oligochaetes were considered equally tolerant in each assessment. Trends in relative proportion of tolerant taxa were unusual, showing a pattern of impairment that alternated between upstream and downstream sites. The three downstream-most Poquessing Creek sites experienced increases in relative proportion of tolerant taxa from 2001 to 2008, while the opposite trend was observed at upstream sites (Figure 5.14).

Overall, tolerant taxa accounted for 17.22% of all taxa collected in the watershed and the proportion of tolerant taxa at each monitoring site ranged from 2.08-53.92% (Figure 5.13). Site PQB210 had the highest proportion of tolerant taxa (53.92%), showing a considerable increase from the 2001 assessment (16.5%, Figure 5.14) by direct comparison of two different survey methods. For a discussion of the disparity in sample sizes between the 2001 and 2008 assessments and an alternate method of comparison, see Section 5.3.1.4 and Appendix K, respectively. This was also the only site at which no (n=0) pollution intolerant taxa were collected.

The proportion of moderately tolerant individuals at all Poquessing Creek Watershed sites averaged 79.51% (range 46.08% to 97.08%). The site that had the greatest proportion of moderately tolerant taxa was PQU013 with 97.08% dominance, a slight increase from 2001 (95.95%) by direct comparison of two different survey methods. For a discussion of the disparity in sample sizes between the 2001 and 2008 assessments and an alternate method of comparison, see Section 5.3.1.4 and Appendix K, respectively. Generally speaking, intolerant taxa were poorly represented at all

Poquessing Creek Watershed sites, as on average they accounted for only 3.27% of taxa collected in the 2008 assessment.

Table 5.9 lists the locations where sensitive taxa were collected during the 2008 macroinvertebrate assessment. Sensitive taxa (pollution tolerance values ≤ 3) were collected at every monitoring location on the mainstem except for Byberry Creek site PQB210.

Another metric that employs macroinvertebrates as indicators of biotic integrity is the unique taxa metric. Unique taxa are those that are exclusive to one site within a watershed or group of assessment sites. The presence of resident unique taxa within a site can offer insight to the biotic integrity of a site because the distribution of aquatic macroinvertebrates is often a product of the patchy nature of habitat and food resources. Essentially, the presence of unique taxa signifies that the site in which it was found has an array of environmental conditions that makes it more suitable to inhabit than other reaches within the watershed given the species in question is moderately motile.

Reference reaches (FC472, FC1310, FCRR025) contained greater numbers of unique taxa (Table 5.8) than Poquessing Creek study sites. This may be due to the fact that urbanized streams tend to be physically (*e.g.*, homogenous depth distributions, reduced or absent low flow channels) and chemically (*e.g.*, eutrophic, contaminated by point/non-point source pollution) impaired, therefore reducing the amount and types of microhabitats they can support. Besides supporting more unique taxa, reference reaches contained more sensitive unique taxa than assessment sites.

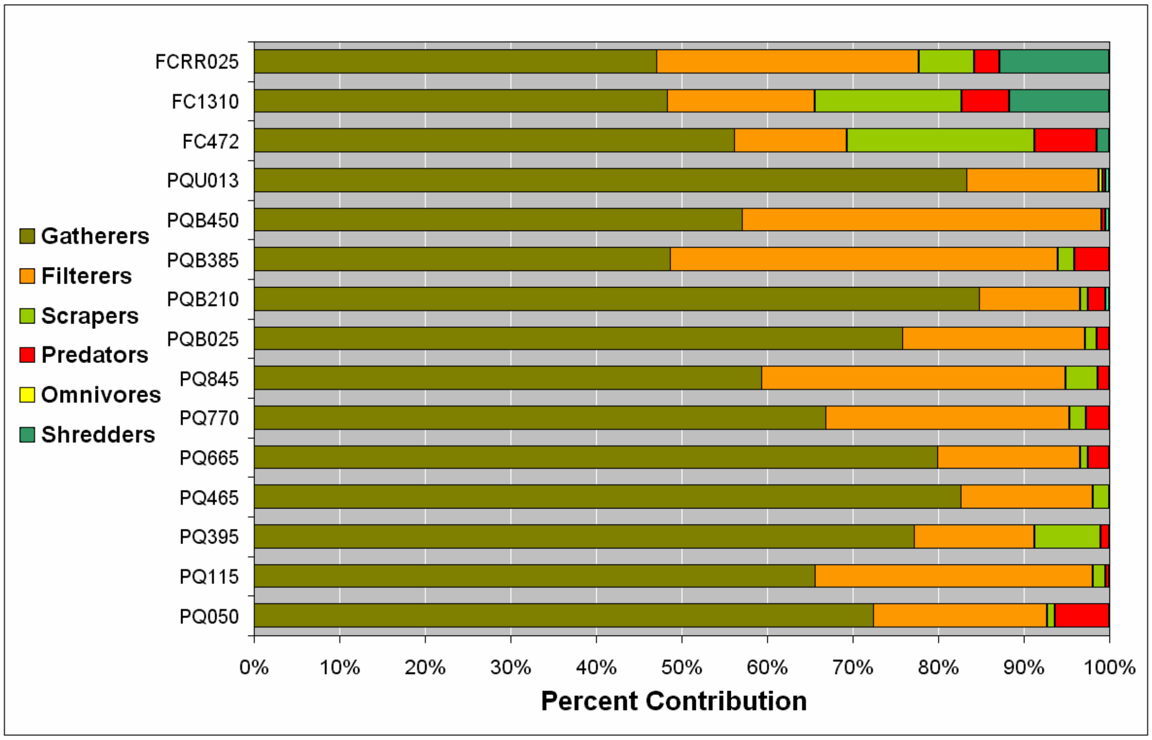

Figure 5.12 Benthic Macroinvertebrate Community Trophic Composition at Poquessing Creek Watershed and French Creek Reference Sites, 2008

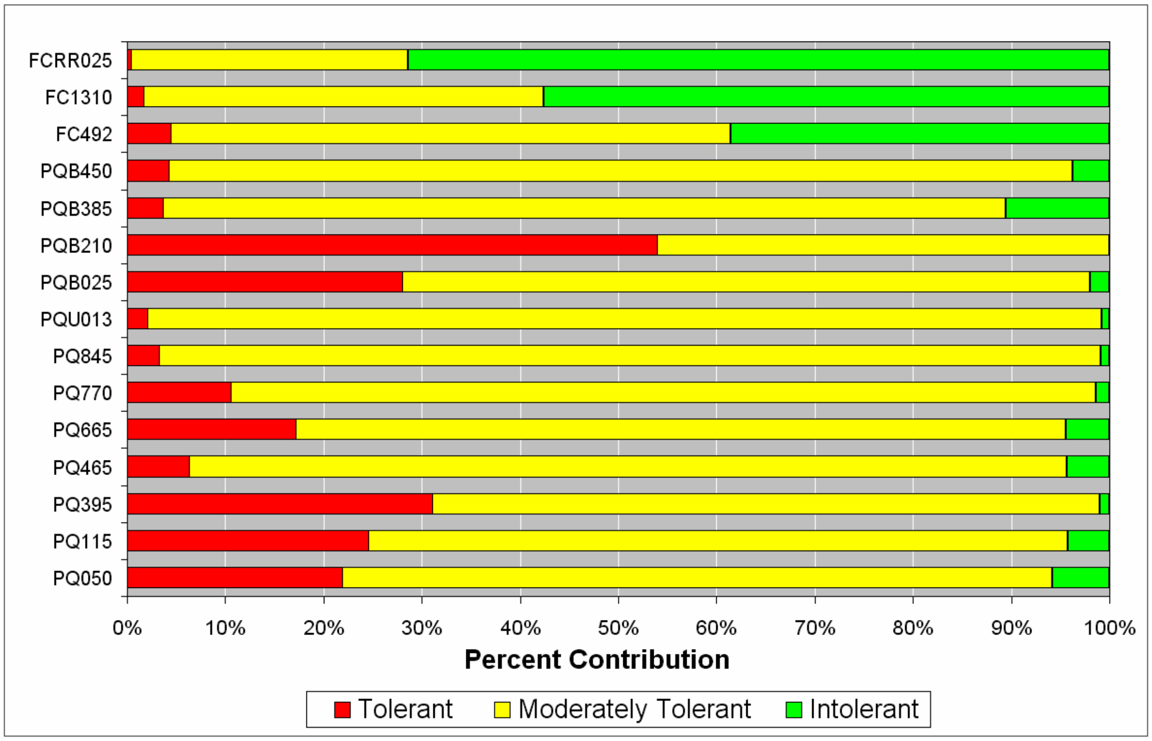

Figure 5.13 Tolerance Designations of Benthic Macroinvertebrate Communities at Poquessing Creek Watershed Sites and French Creek Reference Sites, 2008

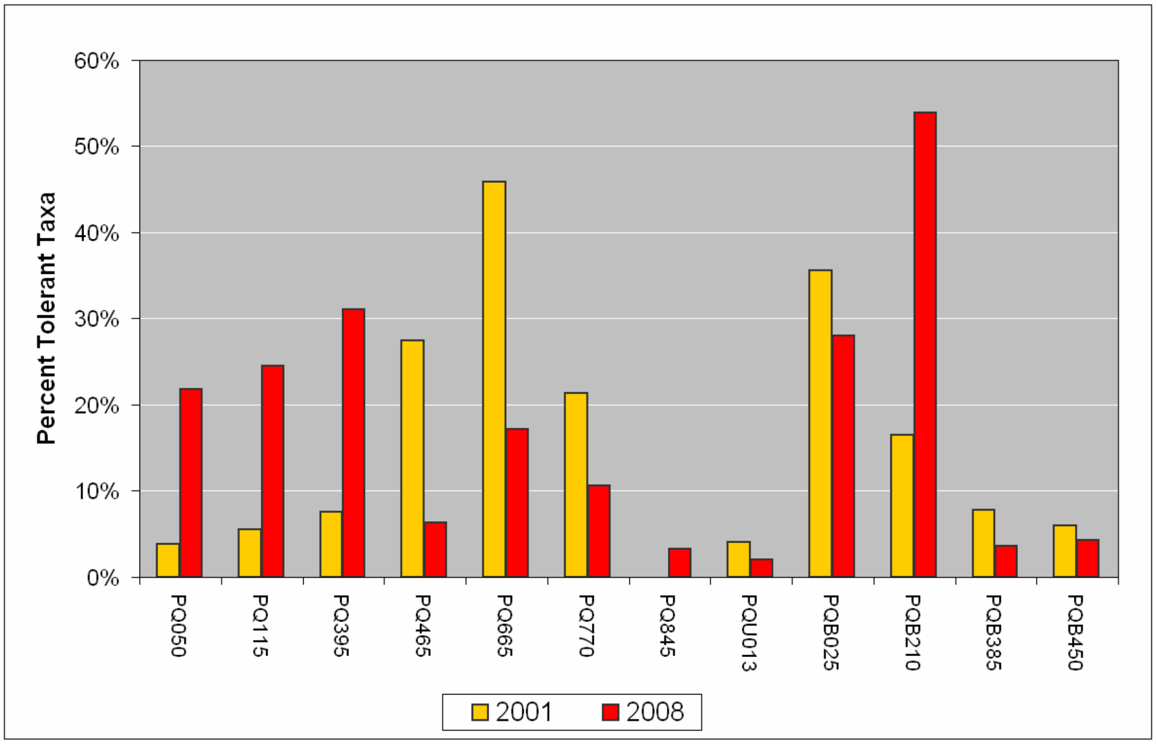

Figure 5.14 Percent Tolerant Taxa at Poquessing Creek Watershed Sites, 2001 and 2008.

Table 5.8 Unique Taxa of Poquessing Creek Watershed and French Creek Reference Sites, 2008

Site	Site HBI	Order	Family	Genus	Taxon HBI
FC1310	3.37	Coleoptera	Elmidae	Oulimnius	5
FC1310	3.37	Coleoptera	Elmidae	Promoresia	2
FC1310	3.37	Diptera	Chironomidae	Tanytarsini	6
FC1310	3.37	Ephemeroptera	Baetidae	Acentrella	4
FC1310	3.37	Ephemeroptera	Ephemerellidae	Eurylophella	4
FC1310	3.37	Ephemeroptera	Ephemerellidae	Serratella	2
FC1310	3.37	Hoplonemertea	Tetrastemmatidae	Prostoma	6
FC1310	3.37	Trichoptera	Psychomyiidae	Psychomyia	2
FC472	4.00	Coleoptera	Dryopidae	Helichus	5
FC472	4.00	Coleoptera	Elmidae	Microcylloepus	2
FC472	4.00	Diptera	Chironomidae	Eukiefferiella	6
FC472	4.00	Diptera	Chironomidae	Microtendipes	6
FC472	4.00	Diptera	Chironomidae	Rheotanytarsus	6
FC472	4.00	Diptera	Empididae	(undetermined)	6
FC472	4.00	Ephemeroptera	Caenidae	Caenis	7
FC472	4.00	Oligochaeta	Lumbriculidae	(undetermined)	8
FC472	4.00	Plecoptera	Perlodidae	Isoperla	2
FCRR025	2.68	Diptera	Chironomidae	Sympotthastia	6
FCRR025	2.68	Ephemeroptera	Ameletidae	Ameletus	0
FCRR025	2.68	Trichoptera	Uenoidae	Neophylax	3
PQ050	6.58	Amphipoda	Gammaridae	Gammarus	4
PQ050	6.58	Trichoptera	Hydroptilidae	Leucotrichia	6
PQ665	6.39	Diptera	Ceratopogonidae	Culicoides	10
PQ665	6.39	Zygoptera	Coenagrionidae	Enallagma	8
PQ770	6.07	Zygoptera	Calopterygidae	Calopteryx	6
PQB450	5.92	Diptera	Ceratopogonidae	Atrichopogon	2

Table 5.9 Sensitive Taxa Collected from Poquessing Creek Watershed Sites, 2008

Site	Order	Family	Genus	HBI
PQ050	Coleoptera	Elmidae	Ancyronyx	2
PQ050	Diptera	Tipulidae	Antocha	3
PQ115	Coleoptera	Elmidae	Ancyronyx	2
PQ115	Diptera	Tipulidae	Antocha	3
PQ395	Coleoptera	Elmidae	Ancyronyx	2
PQ395	Diptera	Tipulidae	Antocha	3
PQ465	Coleoptera	Elmidae	Ancyronyx	2
PQ465	Diptera	Tipulidae	Antocha	3
PQ665	Diptera	Tipulidae	Antocha	3
PQ770	Coleoptera	Elmidae	Ancyronyx	2
PQ770	Diptera	Tipulidae	Antocha	3
PQ845	Coleoptera	Elmidae	Ancyronyx	2
PQ845	Diptera	Tipulidae	Antocha	3
PQU013	Diptera	Tipulidae	Antocha	3
PQB025	Diptera	Tipulidae	Antocha	3
PQB385	Diptera	Tipulidae	Antocha	3
PQB450	Diptera	Ceratopogonidae	Atrichopogon	2

Table 5.10 Unique Taxa Collected from Poquessing Creek Watershed Sites, 2008

Site	Site HBI	Order	Family	Genus	Taxon HBI
PQ050	6.58	Amphipoda	Gammaridae	Gammarus	4
PQ050	6.58	Trichoptera	Hydroptilidae	Leucotrichia	6
PQ665	6.39	Diptera	Ceratopogonidae	Culicoides	10
PQ665	6.39	Zygoptera	Coenagrionidae	Enallagma	8
PQ770	6.07	Zygoptera	Calopterygidae	Calopteryx	6
PQB450	5.92	Diptera	Ceratopogonidae	Atrichopogon	2

5.3.2 ICHTHYOFAUNAL ASSESSMENT

5.3.2.1 MONITORING LOCATIONS

Between 6/2/08 and 6/11/08, PWD biologists conducted fish assessments at six (n=6) locations on mainstem Poquessing Creek (Figure 5.15). Data from these assessments were used to compile biotic integrity metrics as well as to estimate fish biomass used in correlational analyses in conjunction with habitat suitability models (Section 6.3.2)

5.3.2.2 FIELD STANDARD OPERATING PROCEDURES

Fish were collected by electrofishing as described in EPA's Rapid Bioassessment Protocol V (RBP V) (Barbour *et al*., 1999). Depending on stream conditions, Smith-Root backpack or tote barge electrofishers were used to stun fish. A 100-m reach of the stream was blocked at the upstream and downstream limits with nets to prevent immigration or emigration from the study site. Each reach was uniformly sampled, and all fish captured were placed in buckets for identification and counting. An additional pass without replacement was completed along the reach to ensure maximum likelihood population and biomass estimates.

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

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

5.3.2.3 DATA ANALYSES

5.3.2.3.1 FISH IBI METRICS

The health of fish communities in Poquessing Creek Watershed was assessed based on the technical framework of the Index of Biological Integrity (IBI) developed by Karr (1981). The analysis entailed the definition of "ecoregional-specific" metrics pertinent to the fish assemblages located in the lower Schuylkill River Drainage. Standardized metrics (*i.e.*, indices) were then integrated to provide an overall indication of the condition of fish assemblages at each assessment location. Individual metrics within the fish IBI framework were also used to provide quantitative information regarding a specific attribute of the respective assessment location (*e.g.*, pollution tolerance values). In addition to IBI metrics, other metrics were incorporated into the design to evaluate the overall ecological health of fish assemblages and as a means of comparison of each assessment site. Tables 5.11 and 5.12 describe the various indices and scoring criteria used for the IBI metrics in Poquessing Creek Watershed. Additional metrics used in the analysis are displayed in Table 5.13.

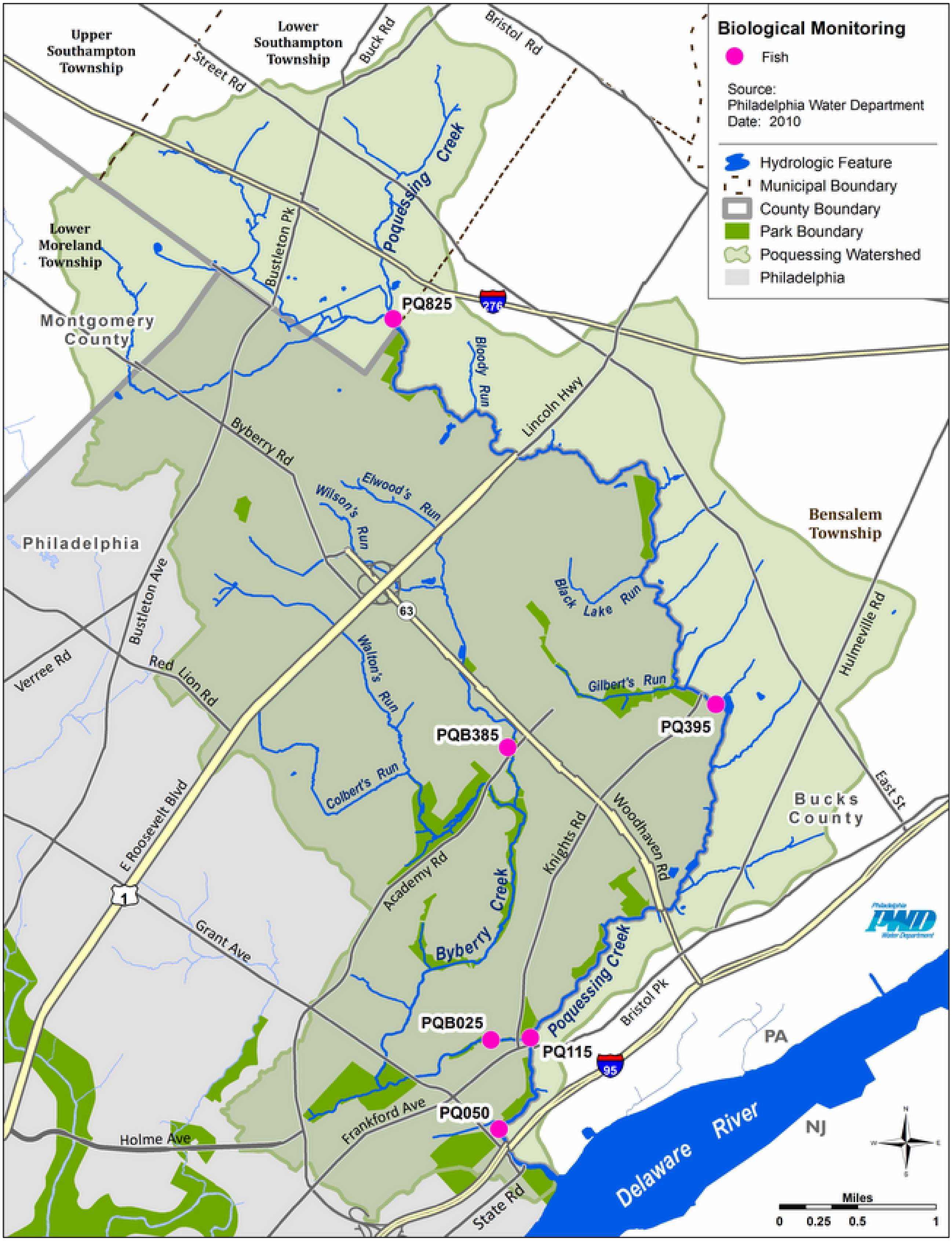

Figure 5.15 Fish Monitoring Sites in Poquessing Creek Watershed, 2008

Table 5.11 Metrics Used to Evaluate Index of Biological Integrity (IBI) at Representative Sites *

Metric	Scoring Criteria		
	5	3	1
1. Number Of Native Species	>67%	33-67%	<33%
2. Number Of Benthic Insectivore Species	>67%	33-67%	<33%
3. Number Of Water Column Species	>67%	33-67%	<33%
4. Percent white sucker	<3%	3-15%	>15%
5. Number Of Sensitive Species	>67%	33-67%	<33%
6. Percent Generalists	<20%	20-45%	>45%
7. Percent Insectivores	>50%	25-50%	<25%
8. Percent Top Carnivores	>5%	1-5%	<1%
9. Proportion of diseased/anomalies	0%	0-1%	>1%
10. Percent Dominant Species[a]	<40%	40-55%	>55%

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

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

Table 5.12 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 5.13 Additional Metrics Used to Evaluate Fish Assemblage Condition

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

5.3.2.3.2 SPECIES DIVERSITY

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

$$\mathbf{H' = -\Sigma\, n_i/N * ln\, (n_i/N):} \qquad \text{(Eq. 5.1)}$$

where n_i is the relative number of the *i*th taxon and N is the total number of all species.

5.3.2.3.3 TROPHIC COMPOSITION AND TOLERANCE DESIGNATIONS

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

5.3.3.3.4 MODIFIED INDEX OF WELL-BEING (MIWB)

Modified Index of Well-Being (MIwb) is a metric that incorporates two abundance and two diversity measurements. Modifications from the Ohio EPA (1987), which eliminate pollution tolerant species, hybrids and exotic species, were incorporated into the study in order to increase the sensitivity of the index to a wider array of environmental disturbances. MIwb is calculated using the following formula (Equation 5.2):

$$\mathbf{MIwb = 0.5*lnN + 0.5*lnB + H_N + H_B} \qquad \text{(Eq. 5.2)}$$

where:

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

5.3.2.4 RESULTS

5.3.2.4.1 WATERSHED OVERVIEW

During the 2008 Poquessing/Byberry watershed fish assessment, PWD surveyed six sites and collected a total of 4,099 fishes representing 19 species in seven families (Tables 5.14). Banded killifish (*Fundulus diaphanus)* and American eel (*Anguilla rostrata),* two taxa tolerant of poor stream conditions, were most abundant and accounted for 31.4% of all fish collected. Other common species included white sucker (*Catostomus commersonii*), satinfin shiner (*Cyprinella analostana*), tessellated darter (*Etheostoma olmstedi*), and blacknose dace (*Rhinichthys atratulus*). Of 19 species collected in the watershed, the six aforementioned species made up 75.1% of the entire fish assemblage. Similarly, three species made up 78.6% of the total fish biomass, with American eel contributing 42.0% of the biomass.

The overall fish diversity in Poquessing/Byberry watershed decreased from 24 species in 2001 (seven survey sites) to 19 species in 2008 (six survey sites) (Table 5.15). Diversity is typically one of the first ecological attributes to change in response to stream degradation. There were declines (61.3%) in watershed fish abundance (*i.e.*, total number of fish collected) from 11,649 fishes collected in 2001 to only 4,099 fishes collected in 2008 (Figure 5.16); however, the declines in biomass were much less pronounced (Figures 5.21 and 5.22). There was a shift in dominant species, with satinfin shiner most abundant in 2001 (n=1,966) and banded killifish (n=671) most abundant in 2008. The most notable change in community composition was a very sharp decline (80.6%) in the number of swallowtail shiners from 2001 (n= 1,710) to 2008 (n=290) (Figure 5.18). The importance of this trend should be noted, as swallowtail shiner is only moderately tolerant of pollution and their numbers decrease in response to increased stream degradation. The only species to increase in abundance from 2001 to 2008 were brown bullhead and American eel. Five of the six most common fishes (satinfin shiner, white sucker, banded killifish, tessellated darter, and blacknose dace) were similar from 2001 to 2008; however, the abundance of swallowtail shiner was reduced and replaced by the pollution-tolerant American eel.

Although most findings from the 2008 fish survey of Poquessing Creek Watershed were negative, documenting undesirable changes to the fish community as compared to reference conditions, positive observations were made regarding the persistence of longnose dace and American eels. While neither species is classified as sensitive to pollution, longnose dace has specific habitat requirements for fast riffles of adequate depth and American eel populations are experiencing a downward trend in many areas of their distribution. Longnose dace declined in number from the 2001 assessment but relative abundance increased slightly due to the overall decrease in fish abundance observed in the watershed. Longnose dace thus did not decline as severely as was the case in recent Wissahickon or Pennypack Creek Watershed Assessments conducted by PWD (PWD 2007, PWD 2009).

In 2007, the U.S. Fish and Wildlife Service (USFWS) released its finding that, despite observed population declines, listing American eel as a Threatened or Endangered species was not warranted (USFWS 2007). Due to its pollution tolerance, American eels can be viewed as less desirable than other piscivorous species. However, tidal creeks, including Poquessing Creek and other tributaries to the Delaware River in the Philadelphia region, are important habitats for eels and contribute to continued survival of this species.

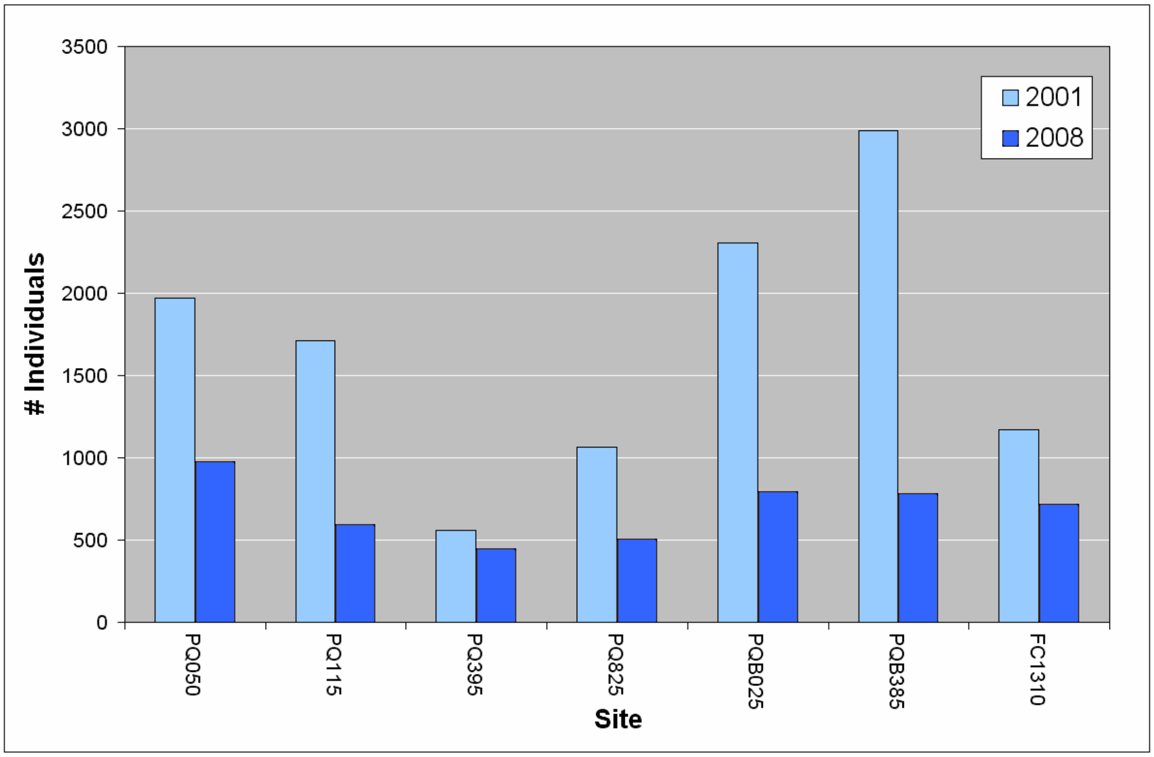

Figure 5.16 Total Fish Abundance at Poquessing Creek Watershed and French Creek Reference Sites, 2001 and 2008

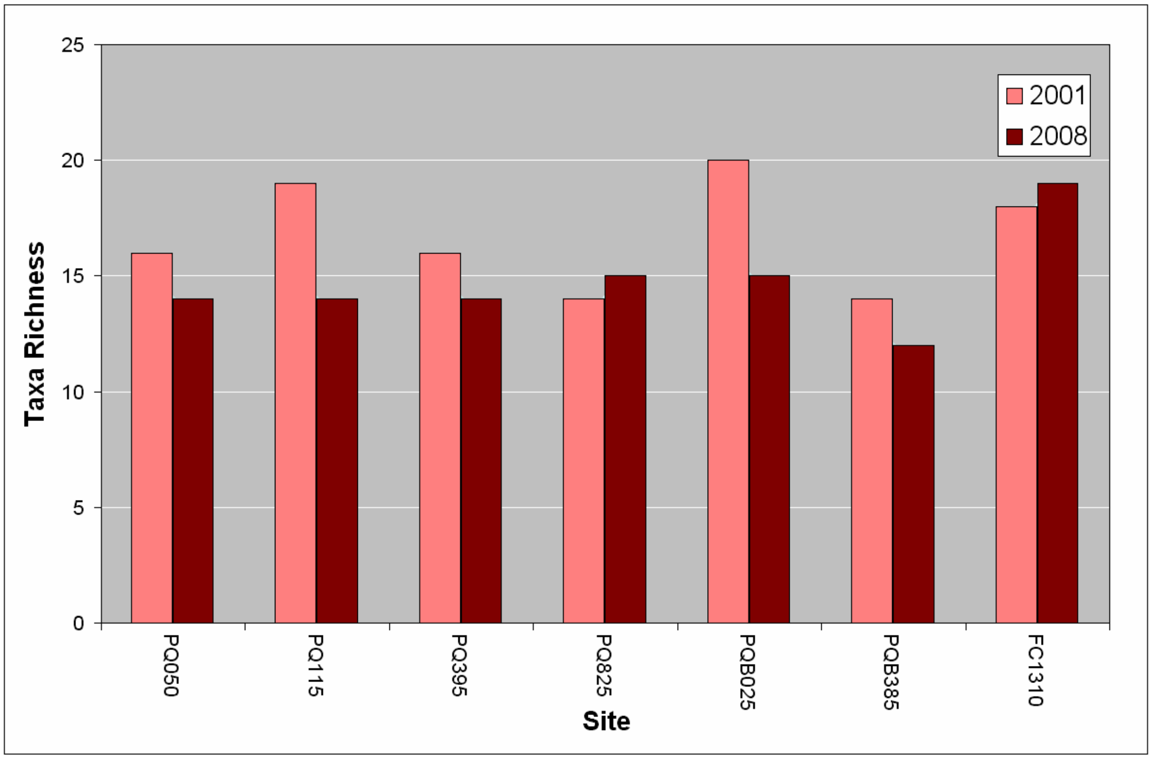

Figure 5.17 Fish Taxa Richness at Poquessing Creek Watershed and French Creek Reference Sites, 2001 and 2008

Table 5.14 List of Fish Species Collected from Poquessing Creek Watershed Sites with Abundance, 2008

Common Name	Scientific Name	PQ050	PQ115	PQ395	PQ825	PQB025	PQB385	Totals
American Eel	*Anguilla rostrata*	172	165	65	21	149	43	615
Banded Killifish	*Fundulus diaphanus*	196	58	13	15	258	131	671
Blacknose Dace	*Rhinichthys atratulus*	24	28	9	134	15	293	503
Brown Bullhead	*Ameiurus nebulosus*	0	0	0	2	0	2	4
Comely Shiner	*Notropis amoenus*	0	0	1	0	0	0	1
Common Shiner	*Luxilus cornutus*	0	0	14	20	3	0	37
Creek Chub	*Semotilus atromaculatus*	0	1	0	131	0	0	132
Eastern Silvery Minnow	*Hybognathus regius*	26	0	0	0	0	0	26
Golden Shiner	*Notemigonus crysoleucas*	4	1	0	1	35	0	41
Green Sunfish	*Lepomis cyanellus*	2	0	11	1	6	0	20
Hybrid Sunfish	*Lepomis hybrid*	0	0	3	0	2	0	5
Longnose Dace	*Rhinichthys cataractae*	35	51	21	10	13	4	134
Mummichog	*Fundulus heteroclitus*	2	1	0	0	27	7	37
Pumpkinseed Sunfish	*Lepomis gibbosus*	1	1	5	6	1	0	14
Redbreast Sunfish	*Lepomis auritus*	94	17	33	0	41	29	214
Satinfin Shiner	*Cyprinella analostana*	78	50	53	15	36	105	337
Spottail Shiner	*Notropis hudsonius*	34	15	6	3	10	1	69
Swallowtail Shiner	*Notropis procne*	65	22	56	41	20	86	290
Tessellated Darter	*Etheostoma olmstedi*	122	153	105	53	105	50	588
White Sucker	*Catostomus commersonii*	121	31	50	55	72	32	361
	TOTAL:	**976**	**594**	**445**	**508**	**793**	**783**	**4099**

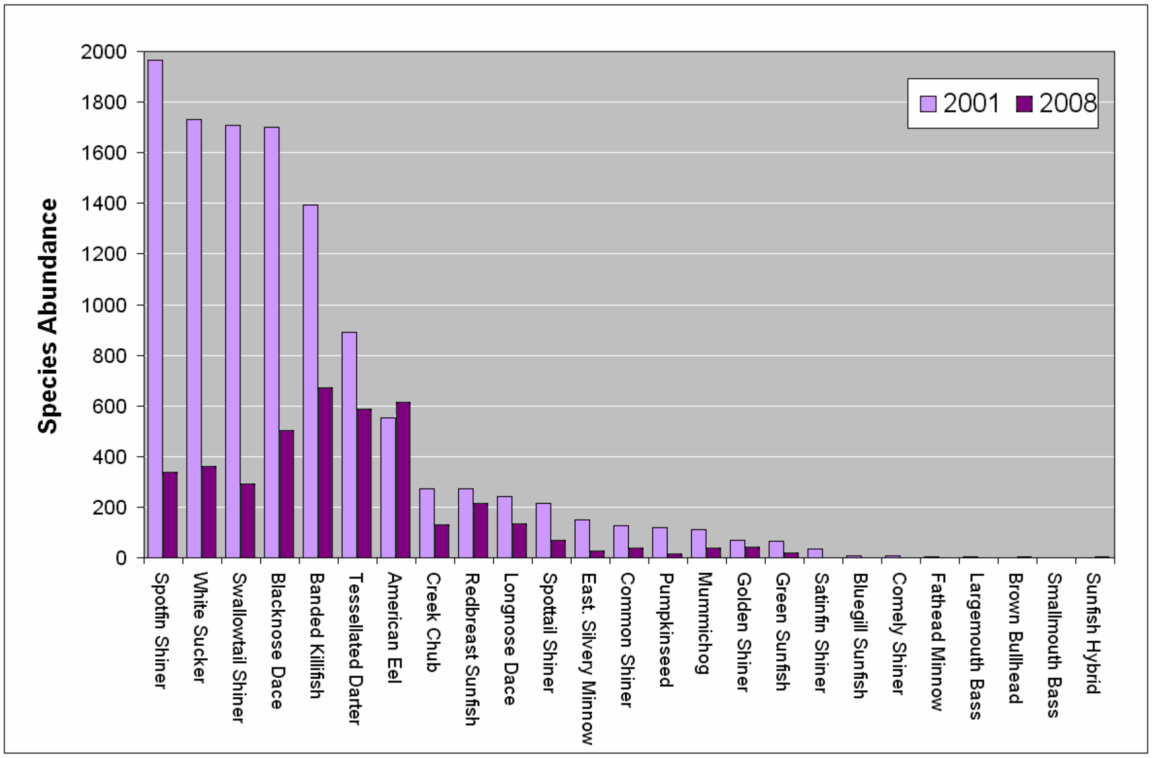

Figure 5.18 Abundance of Individual Fish Species Collected in Poquessing Creek Watershed Sites, 2001 and 2008

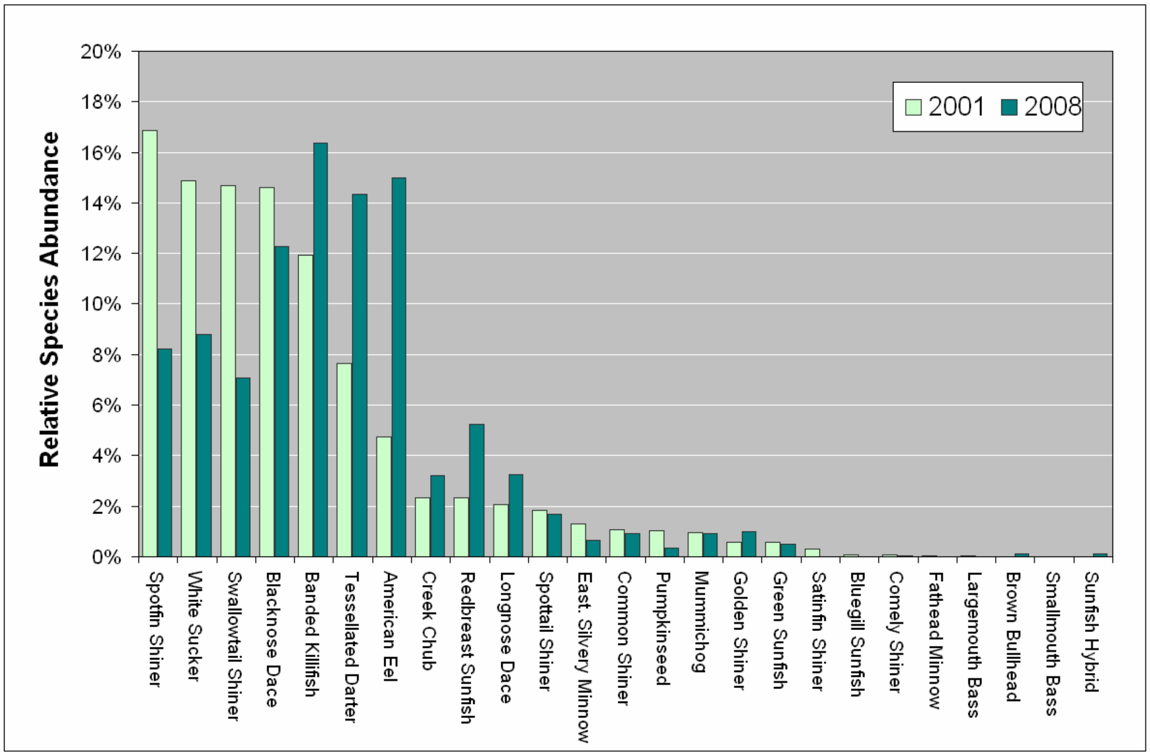

Figure 5.19 Relative Abundance of Fish Species Collected in Poquessing Creek Watershed, 2001 and 2008

Table 5.15 Fish Abundance and Biomass of 6 Poquessing Creek Sites, 2001 and 2008

Poquessing Creek Watershed Fish Assessment	2001 Abundance	2008 Abundance	2001 Density (individuals/m²)	2008 Density (individuals/m²)	2001 Biomass (g)	2008 Biomass (g)	2001 Biomass/m²	2008 Biomass/m²
PQB385	2987	783	6.35	1.80	9617.49	6501.64	20.43	14.98
PQB025	2307	793	2.88	0.96	6984.04	8168.40	8.72	9.94
PQ825	1067	508	2.44	0.93	3959.26	3631.29	9.04	6.66
PQ395	561	445	0.64	0.37	7267.08	9621.85	8.31	7.89
PQ115	1711	594	2.58	0.73	13310.27	6203.88	20.11	7.60
PQ050	1969	976	1.64	0.78	10432.99	11378.34	8.71	9.10

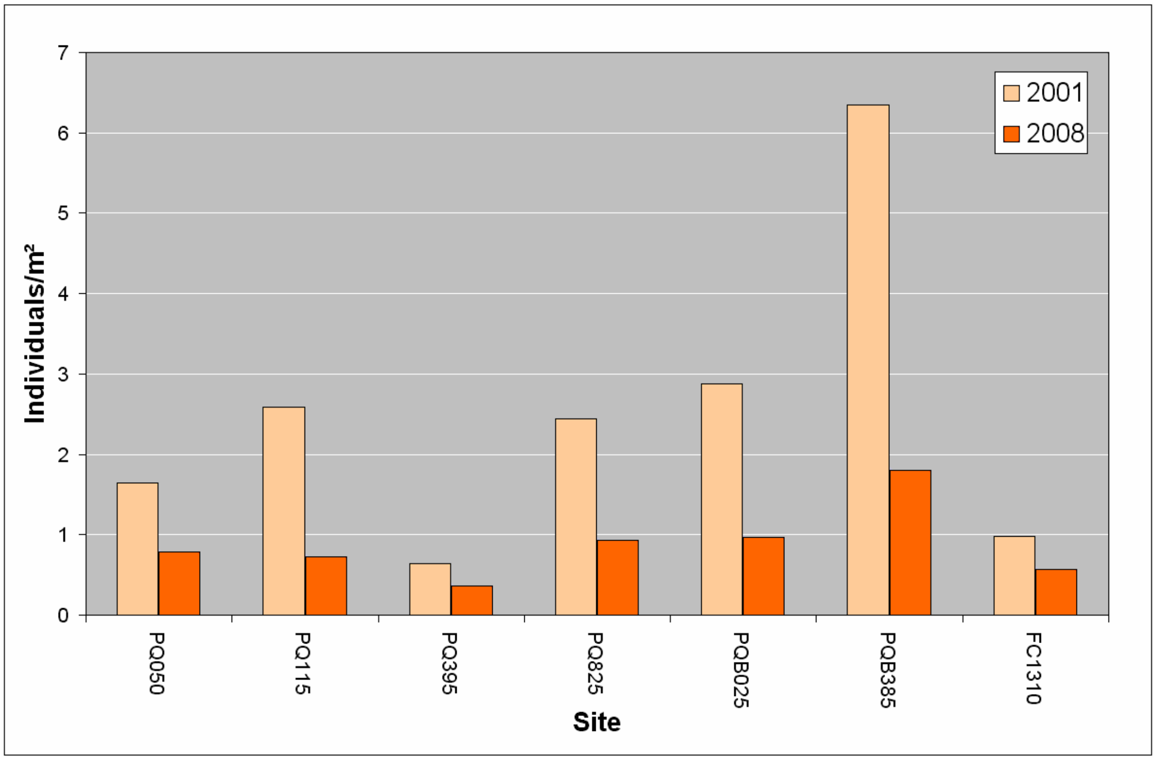

Figure 5.20 Fish Density (Abundance per Unit Area) at Poquessing Creek Watershed and French Creek Reference Site, 2001 and 2008

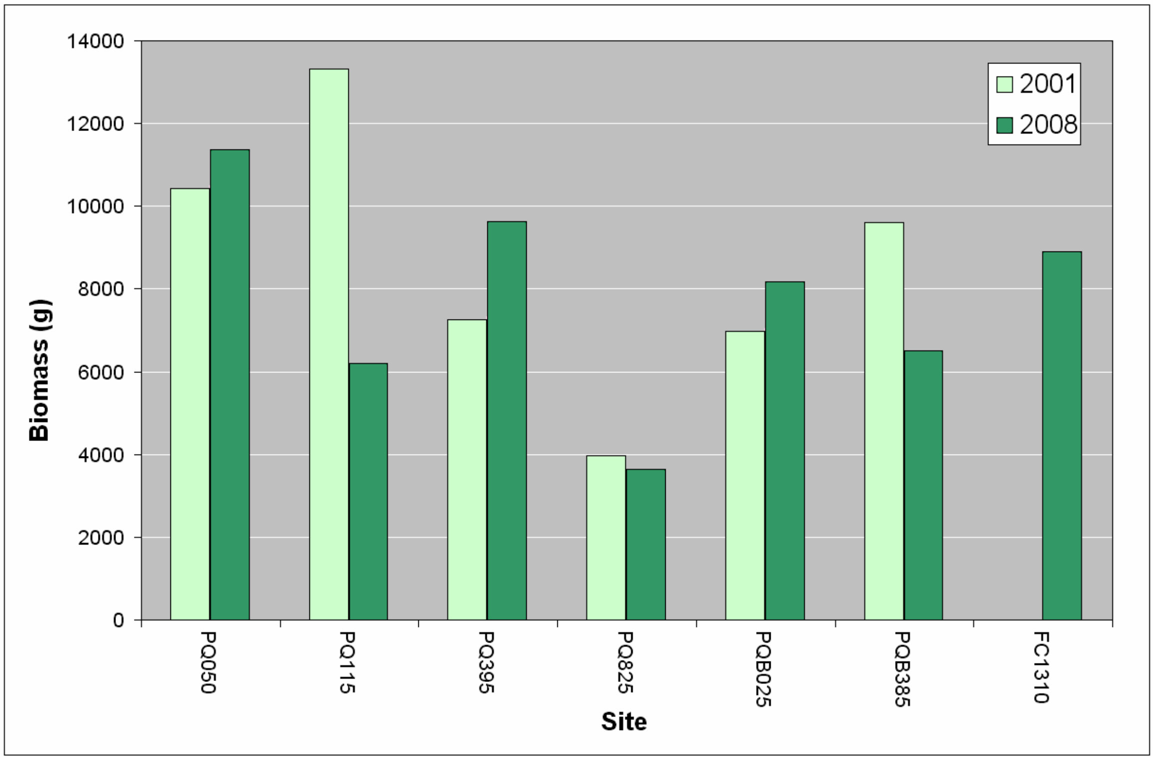

Figure 5.21 Total Fish Biomass at Poquessing Creek Watershed and French Creek Reference Site, 2001 and 2008

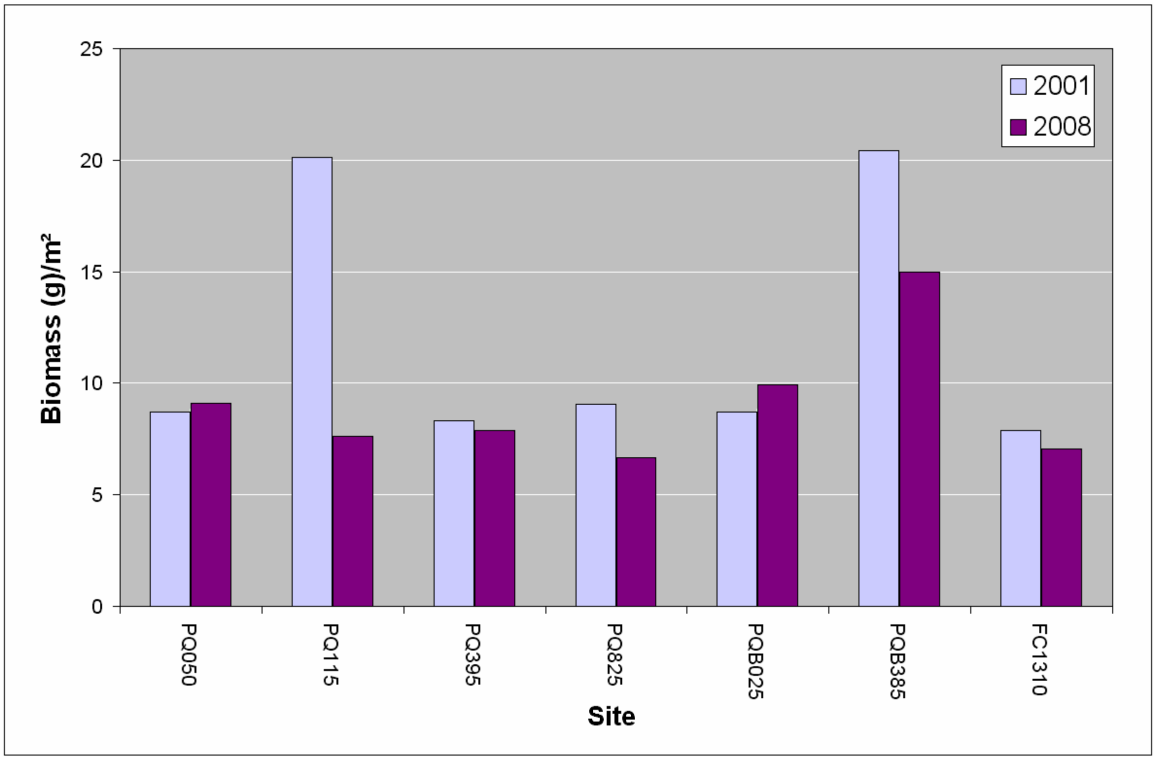

Figure 5.22 Fish Density (Biomass per Unit Area) at Poquessing Creek Watershed and French Creek Reference Site, 2001 and 2008

Trophic composition evaluates the quality of the energy base and foraging dynamics of a fish assemblage. As applied to urban streams, the trophic composition of a fish assemblage is an effective means of evaluating the shift toward more generalized foraging that typically occurs with increased degradation of the physicochemical habitat (Barbour, *et al*., 1999). Poquessing/Byberry watershed contained fair-quality trophic composition with 51.0% insectivores, 33.4% generalist feeders, 15.0% top carnivores (all American eels), and 0.6% herbivores (all Eastern silvery minnow) (Figure 5.23). These results were similar to the 2001 bioassessment, except for decreased herbivore abundance (and concurrent increased top carnivores) in 2008. Generalists become dominant and top carnivores become rare when certain components of the food base become less reliable (Halliwell, *et al*., 1999). Relative abundance of insectivores decreases with degradation in response to availability of the insect supply, which reflects alterations of water quality and instream habitat (Daniels, *et al*., 2002). The decreased percentage of insectivores at the upstream-most stations of Poquessing Creek and Byberry Creek illustrates this point. Trophic composition at the majority of stations was good compared to reference sites, which have more insectivores than generalists. Although community composition varied between sites, the fish assemblage in Poquessing/Byberry watershed was acceptably representative of reference stream conditions.

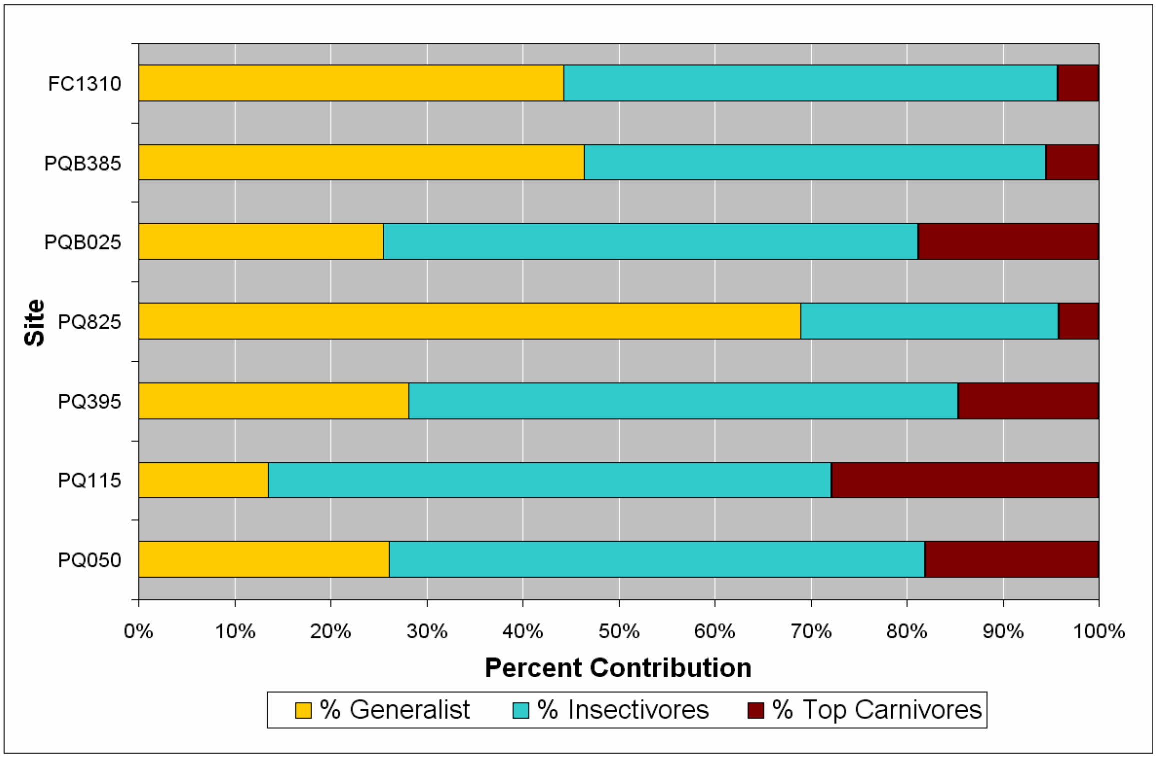

Figure 5.23 Fish Community Trophic Composition of Poquessing Creek Watershed and French Creek Reference Site, 2008

Tolerance designations describe the susceptibility of a species to chemical and physical perturbations. Intolerant species are typically first to disappear following a disturbance (Barbour, *et al*., 1999). For example, Byberry Creek was found to be completely lacking intolerant taxa and Poquessing Creek had only one intolerant species (Eastern silvery minnow) found at a single site, signifying high levels of chemical and physical disturbances. More specifically, Eastern silvery minnow was collected at three monitoring sites and at higher abundance in 2001, therefore its absence seven years later from two monitoring sites and its decreased abundance implies increased stream degradation. The percentage of fishes tolerant of poor stream quality was relatively stable from 68.0% in 2001 to 66.5% in 2008, while the percentage of intolerant fishes decreased from 1.3% in 2001 to 0.6% in 2008, again adding to the evidence that environmental quality of Poquessing/Byberry watershed is declining. It should be noted that only one monitoring station (PQ395) had more moderately tolerant individuals than pollution tolerant.

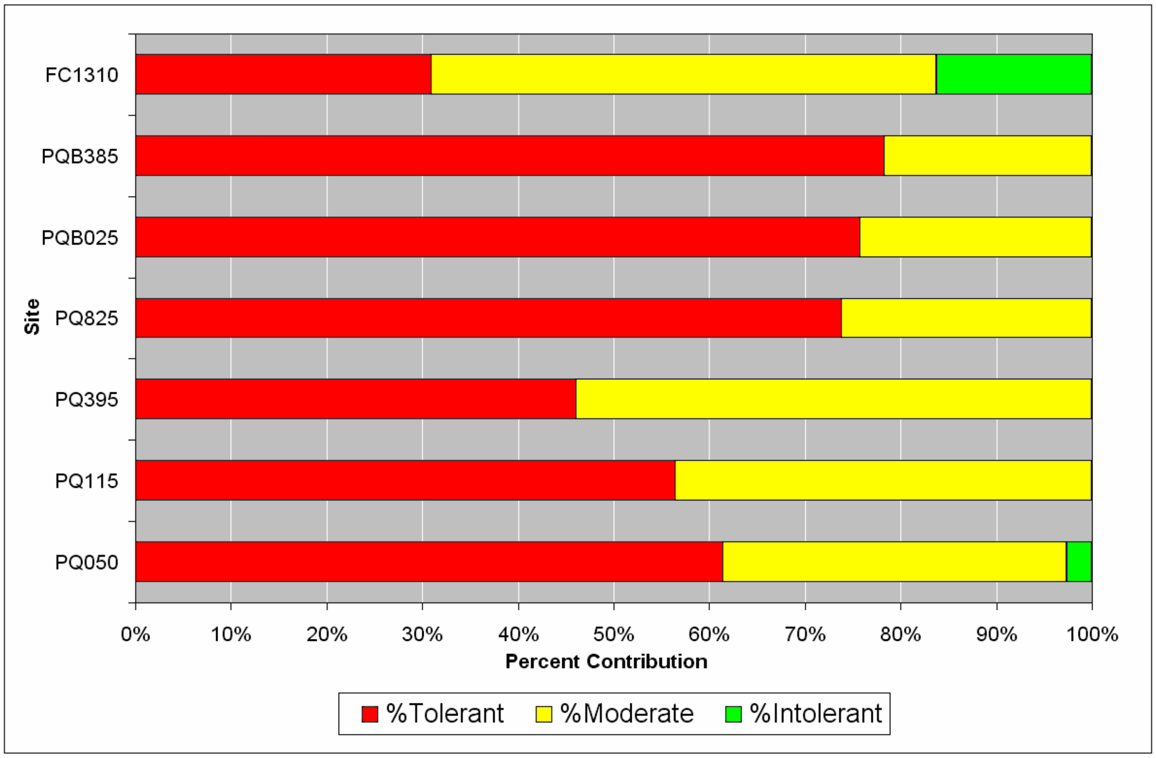

Figure 5.24 Fish Community Tolerance Designations of Poquessing Creek Watershed Sites and French Creek Reference Site, 2008

The Index of Biotic Integrity (IBI) is useful in determining long-term effects and coarse-scale habitat conditions because fish are relatively long-lived and mobile. A site with high integrity (*i.e.*, high score) is associated with communities of native species that interact under natural community processes and functions (Karr, *et al.* 1986). Since biological integrity is closely related to environmental quality, assessments of integrity can serve as a surrogate measurement of health (Daniels, *et al*. 2002). Mean IBI score for the Poquessing/Byberry watershed was 34 (out of 50), placing it in the "fair" category for biotic integrity. Low diversity, absence of benthic insectivorous species, absence of intolerant species, skewed trophic structure dominated by generalist feeders, high percentage of pollution tolerant taxa, and high percentage of dominant species are characteristics of a fish community with "fair" biotic integrity. Spatial trends showed that sites in the lower sections of the watershed received better IBI scores than sites farther upstream in the watershed (Figure 5.25). Modified Index of Well-Being values, which are measures of diversity and abundance, were well below reference site values at all monitoring sites and did not show spatial trends.

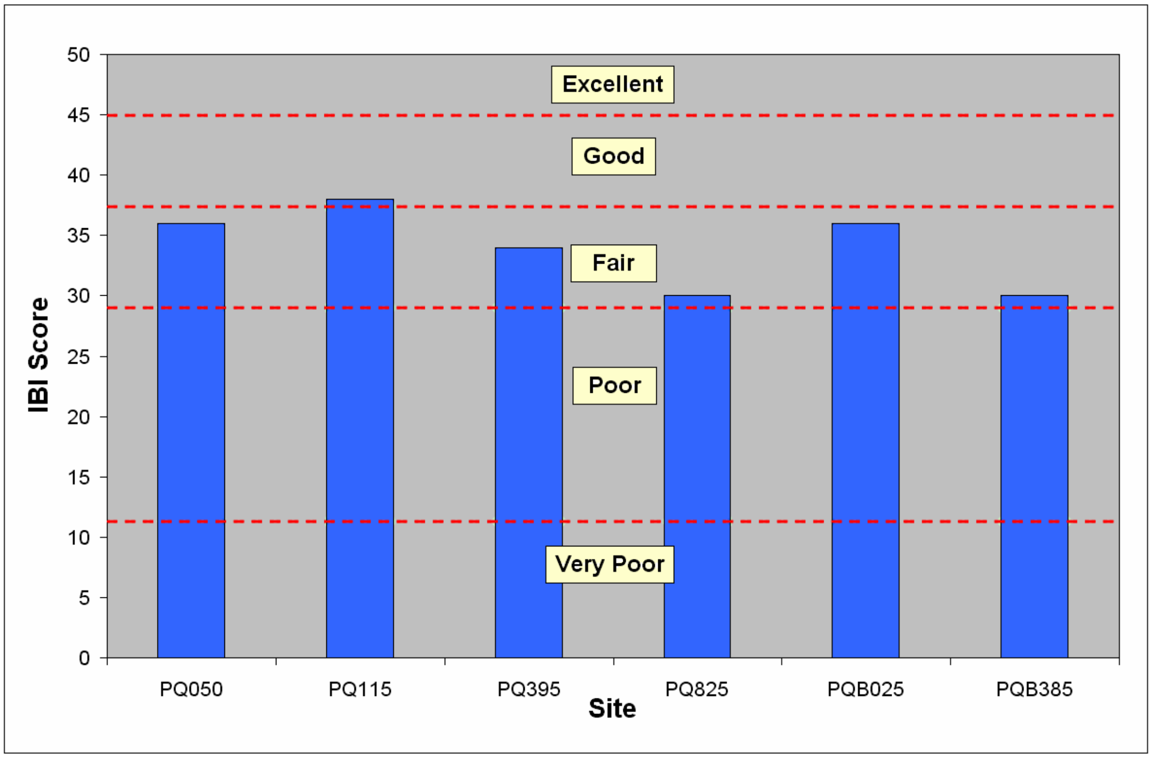

Figure 5.25 Fish Index of Biotic Integrity (IBI) for six Poquessing Creek Watershed Sites, 2008

Another general metric used to assess stream health, the percentage of fish with deformities, lesions, tumors, or anomalies (DELTA), revealed that the fish found at both Byberry Creek sites were more impacted than those found at the Poquessing Creek sites (Figure 5.26). With a range from 2.53-11.1%, the incidence of DELTA in the Poquessing Creek Watershed was not as severe as in other watersheds surveyed by the PWD, and some sites, particularly those in Poquessing Creek, were similar to reference conditions. The sites with the highest percentage of DELTAs in the Poquessing Creek Watershed were those located on Byberry Creek. Site PQB025 (11.1%) held the highest percentage of DELTAs in the watershed, followed by PQB385 (7.02%). Furthermore, when compared to the 2001 baseline assessment data, these Byberry Creek sites exhibited an increase of 6.4% (PQB385) to 6.9% (PQB025) in percent of DELTA occurrences. These were by far the greatest DELTA increases recorded in the entire Poquessing Creek Watershed. Overall, monitoring stations in the downstream portion of the watershed had higher biological integrity, and thus environmental quality, than upstream stations.

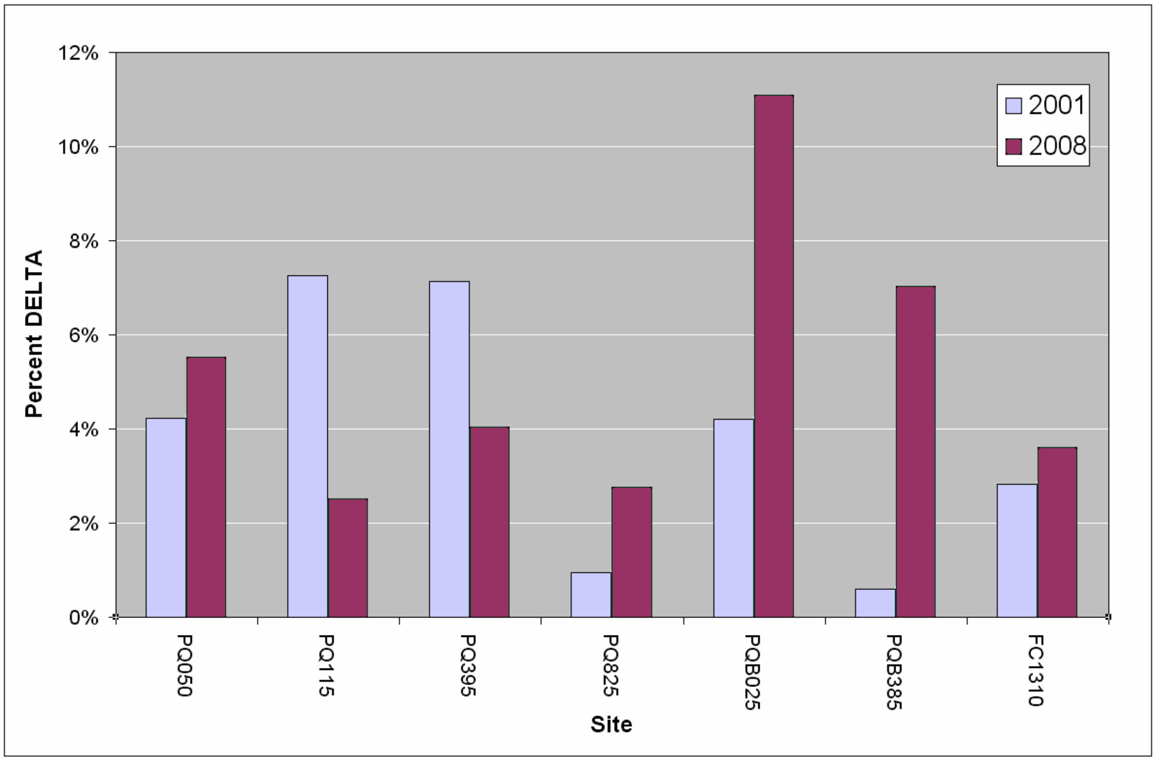

Figure 5.26 Percentage of Fish with Disease, Tumors, Fin Damage, or Anomalies (DELTA) at Poquessing Creek Watershed Sites and French Creek Reference Site, 2001 and 2008

5.3.2.4.2 Individual Site Results

5.3.2.4.2.1 PQ050

A total of 976 fishes represented by 14 species yielded a biomass of 11.4 kg during 82 minutes of electrofishing. This site had the greatest fish abundance (*i.e.*, number of fish) and total biomass in the watershed. However, there was a two-fold decrease (50%) in overall fish abundance at PQ050 from 2001 (n = 1,969) to 2008 (n = 976), with nearly 1,000 fewer fish collected. The species with the most dramatic decline in numbers included Eastern silvery minnow (75.5% decrease), blacknose dace (79.7% decrease), longnose dace (73.5% decrease), and satinfin shiner (69.1% decrease). The decline of Eastern silvery minnow (the only species intolerant of pollution) and longnose dace (a benthic insectivore) suggests this site has been further degraded over the seven-year study period. In contrast, total biomass and standing crop increased at PQ050. Based on a stream surface area of 1,250 m^2, a density of 0.78 fish per m^2 and a standing crop of 9.1 grams per m^2 were calculated; these values were below average for this watershed. However, this site had the highest catch per unit effort (CPUE) at 11.8 fish per minute of electrofishing.

Three species collected in 2001 (spotfin shiner, bluegill sunfish, and common shiner) were not collected in 2008, while two species collected in 2008 (green sunfish and golden shiner) were not found in 2001. Banded killifish, a pollution tolerant insectivore, was most abundant; whereas American eel, a pollution tolerant piscivore, dominated total biomass at this site. Trophic composition was well-balanced, with a low percentage of generalist feeders and a high percentage of insectivores, making this site comparable to reference conditions. The main difference from the reference site was the high percentage of top carnivores, which was made up entirely of American eels. The elevated percentage of American eels was closely related to the proximity to the tidal Delaware River and Estuary.

PQ050 received the second highest Index of Biotic Integrity (IBI) score in Poquessing Creek (36 out of 50), representing a "fair" quality fish assemblage and therefore fair environmental health. Since the IBI utilizes multiple biological metrics, several other characteristics of the fish community account for the fair score: the presence of two benthic insectivore species; four water column species; a pollution intolerant species; low percentage of generalist feeders; high percentage of top carnivores and insectivores; and low percentage of dominant species. The Modified Index of Well-Being (11.94) was the best among all sites in Poquessing/Byberry watershed, as was the Shannon-Weiner Diversity Index. Nonetheless, the 2001 IBI score from this site was higher (40 out of 50) than in 2008 and, consequently, dropped from the “good” to “fair” biotic integrity condition category. The biologic characteristics responsible for the decline are related to changes in diversity, abundance, and community composition.

5.3.2.4.2.2 PQ115

In 816 m^2 of stream surface area, a total of 594 individuals of 14 species were collected during 74 minutes of electrofishing. American eel contributed most to overall biomass (62.1%), followed by white sucker (11.5%), and redbreast sunfish (9.7%). This site had the second lowest density (0.73 fish/m^2) and CPUE (8.02 fish/minute) in the watershed, as well as below-average fish abundance. This represents an approximately three-fold decrease (65.3%) in total fish abundance at PQ115 from 2001 (n=1,711) to 2008 (n=594). The species with the most dramatic decline in numbers include swallowtail shiner (95.6% decrease), spottail shiner (85.1% decrease), satinfin shiner

(77.7% decrease), and white sucker (83.7% decrease). These decreases correspond to a major shift in the dominant fish species (*i.e.*, assemblage percent contribution) from 2001 to 2008. Swallowtail shiner, satinfin shiner, and white sucker were the three dominant species in 2001, however, American eel, tessellated darter, and banded killifish dominated in 2008. This suggests stream quality degradation during the seven-year period because of the reduction in insectivores and increase in generalist feeders. Generalized foraging typically occurs with increased degradation of the physicochemical habitat (Barbour, *et al*., 1999).

Fish species richness (*i.e.*, diversity) decreased from 19 species in 2001 to 14 species in 2008. Eight species collected during the 2001 survey (spotfin shiner, Eastern silvery minnow, green sunfish, bluegill sunfish, common shiner, smallmouth bass, largemouth bass, and comely shiner) were absent in 2008, whereas only three species documented in 2008 (mummichog, golden shiner, creek chub) were absent in 2001. Each of these three species was represented only by a single individual. Undesirable changes included disappearance of the only pollution intolerant species, the loss of two top predator game-fishes, as well as the displacement of moderately tolerant species by pollution tolerant taxa over the seven-year period.

PQ115 had the highest percentage of top carnivores (27.8%) and insectivores (58.8%), and lowest percentage of generalist feeders (13.5%) in the watershed and relative proportions of insectivores and top carnivores exceeded those found in the reference site. Two benthic insectivorous as well as four water column species were collected. This site had more pollution tolerant (56.4%) than moderately tolerant fishes (43.6%), and no intolerant species. The IBI score of 38 (out of 50) was the highest in the watershed and the only station that contained a fish assemblage with "good" biotic integrity. Despite changes in diversity and abundance, the 2001 IBI score was lower (36 out of 50) than in 2008 and, consequently, IBI score atsite PQ115 improved from “fair” to “good” biotic integrity. The biologic characteristics responsible for the slight improvement are related to the change in trophic structure, which received the best scores for surpassing reference conditions.

5.3.2.4.2.3 PQ395

PQ395 contained the fewest number of individuals (*i.e.*, total fish abundance) in the watershed with 445 fishes of 14 species, resulting in the lowest density (0.37 fish/m^2) and lowest catch per unit effort (6.19 fishes/minute electrofishing) in the Poquessing-Byberry Watershed. Again, there was a decline (20.7%) in total fish abundance from 2001 (n=561) to 2008 (n=445), mostly from a decrease in the cyprinid (minnow) family representation. One positive sign was a seven-fold increase in tessellated darter abundance from 2001 (n=15) to 2008 (n=105). A moderately tolerant benthic insectivore, tessellated darter was the most abundant species at this site and made up 23.6% of all fish collected. Another good indication was a four-fold increase in the number of swallowtail shiner from 2001 (n=13) to 2008 (n=56), The swallowtail shiner is a moderately tolerant insectivore that declined in abundance at all other monitoring locations, but represented 12.6% of all fish documented at PQ395. The increased abundance of insectivores positively impacted scoring criteria for trophic structure, which was comparable to reference conditions, and resulted in 57.3% insectivores, 28.1% generalist feeders, and 14.6% top carnivores; these results were slightly better than the 2001 survey. These factors also favorably influenced tolerance designations, in that this was the only monitoring location in the watershed with more moderately tolerant fishes (53.9%) than pollution tolerant fishes (46.1%). This was a major shift from the 2001 survey that documented 83.1% pollution tolerance.

Three species collected in 2001 (spotfin shiner, bluegill sunfish, and creek chub) were absent in 2008, whereas only one species documented in 2008 (comely shiner) was missing in 2001. Several common species included American eel, white sucker, and satinfin shiner, which are pollution tolerant and formed 37.8% of the fish assemblage. Similarly, three species made up 84.8% of the total fish biomass, with American eel contributing 40.0% of the biomass. Despite improvements in trophic composition and tolerance designation, this site received an IBI score of 34 (out of 50), which represents “fair” biotic integrity and was similar to results from the 2001 bioassessment. The loss of diversity, elevated percentage of white sucker, lack of intolerant species, and high percentage of individuals with disease and anomalies were factors that decreased scoring for biotic integrity.

5.3.2.4.2.4 PQ825

A total of 508 fishes representing 14 species were collected in 545 m^2 of stream surface area in 57 minutes of electrofishing at site PQ825. This site had the lowest total biomass (3.6 kg) and standing crop (6.6 g/m^2) in the entire watershed. The declining trend in total fish abundance (52.4%) from the 2001 survey (n=1,067) to 2008 (n=508) continued at PQ825. Not only did the totals change, but also the proportional community composition; most notably, the 68.5% decrease in swallowtail shiner, 49% decrease in tessellated darter, and 82.4% decrease in pumpkinseed sunfish abundance. There were two species collected in 2008 (brown bullhead and golden shiner) that were absent in 2001, while only one species collected in 2001 (bluegill sunfish) was missing in the 2008 survey.

Ultimately, the result was a fish community heavily dominated by generalist feeders (68.9%) and with a poor representation by insectivores (27.0%) and top carnivores (4.1%). This was the highest percentage of generalist, lowest percentage of insectivores, as well as fewest top carnivores in the entire Poquessing/Byberry watershed. Generalists become dominant and top carnivores become rare when certain components of the food base become less reliable (Halliwell *et al.* 1999). Relative abundance of insectivores decreases with degradation in response to availability of the insect supply, which reflects alterations of water quality and instream habitat (Daniels, *et al*. 2002). Also, this site had the second greatest percentage of dominant species in the watershed, with the pollution tolerant, generalist-feeding blacknose dace making up 26.4% of all fish collected. Of the 14 species found here, four species composed 73.4% of all individuals documented and 80.4% of the total biomass. With undesirable scores for abundance, diversity, trophic structure, and pollution tolerance, this monitoring location received an IBI score of 30 out of 50 and was characterized as a "fair" quality fish assemblage. This IBI score was tied with site PQB385 for lowest score in the watershed, while Modified Index of Well-Being and Shannon-Weiner Diversity Index values were the lowest in the Poquessing/Byberry system.

5.3.2.4.2.5 PQB025

Site PQB025 had the greatest percentage of individual fishes with deformities, eroded fins, lesions, and other anomalies (DELTA), with 11.1% of the assemblage affected. This is an excellent measure of the sub-acute effects of chemical pollution and aesthetic value of nongame fishes (Barbour *et al.* 1999), and is symptomatic of an impacted assemblage downstream of point source pollution or in areas where toxic chemicals are concentrated (Barbour *et al.* 1999). There was further evidence of increased degradation due to the disappearance of Eastern silvery minnow, the only pollution intolerant species, which was collected in 2001 but absent in 2008. Furthermore, six species collected in 2001 (brown bullhead, spotfin shiner, Eastern silvery minnow, comely shiner, fathead minnow, and creek chub) were missing in 2008, whereas only one species found in 2008 (green sunfish) was absent in 2001. Again there was a decline (65.6%) in total fish abundance from 2001 (n=2,307) to 2008 (n=793), with the largest decreases occurring among swallowtail shiner (94.7%), spottail shiner (65.5%), and satinfin shiner (91.3%).

This location had a biomass of 8.2 kg and standing crop of 9.9 g/m^2, with four of 14 species making up 73.4% of all individuals collected and 80.4% of total fish biomass. Furthermore, 75.7% of all fishes collected were tolerant of pollution. There were two benthic insectivorous species, four water column species, and no pollution intolerant species found in 822 m^2 of stream surface area. Catch per unit effort (10.7 fish/minute) and density (0.96 fish/ m^2) were second highest in the Poquessing/Byberry watershed. The trophic structure was relatively well-balanced and representative of reference stream conditions with 55.7% insectivores, 25.5% generalist feeders, and 18.8% top carnivores.

The Modified Index of Well-Being (10.2) was the second highest in the watershed and the Shannon Diversity Index (1.94) was close to average. PQB025 received a "fair" IBI score of 36 out of 50, reflective of fair environmental quality.

5.3.2.4.2.6 PQB385

The fish assemblage at PQB385 contained only 12 species, which was the worst species richness (*i.e.*, least diverse) in the watershed. There was a net loss of two species from 2001 to 2008, as well as a 73.8% decrease in total fish abundance, primarily from declines of cyprinids and white sucker. Also, this site was devoid of pollution intolerant taxa. Species richness typically decreases with increased stream degradation. Pollution tolerant blacknose dace, banded killifish and satinfin shiner made up 67.6% of all fish collected at this location, while American eel, redbreast sunfish, and blacknose dace contributed 80% of total fish biomass.

With 46.4% generalist feeders, 48.2% insectivores, and 5.5% top carnivores, there was little change in trophic structure of the fish community at site PQB385 from 2001 to 2008, and site PQB385 had the highest fish density (1.8 fish/ m^2) and standing crop (14.9 g/m^2) of all sites surveyed in Poquessing Creek Watershed in 2008. However, this site had the greatest percentage of pollution tolerant fishes in the watershed, with nearly 80% of the entire fish assemblage tolerant of stream pollution. The Modified Index of Well-Being (9.42) and Shannon Diversity Index (1.86) were the second worst in the watershed. This site was tied for worst IBI score (30 out of 50) in the watershed, which signifies borderline “fair” biotic integrity. Low species richness and trophic composition metrics combined with poor tolerance and condition metrics yielded a fish assemblage reflective of degraded stream quality.

5.3.3 PERIPHYTON ASSESSMENT

5.3.3.1 INTRODUCTION

PWD's 2008 periphyton monitoring activities in Poquessing Creek Watershed were enhanced by a partnership with the Academy of Natural Sciences of Philadelphia (ANSP). The Phycology section of the Patrick Center for Environmental Research provided taxonomic expertise, identifying and enumerating diatoms and soft algae collected at each site. ANSP was also responsible for determining intracellular C: N: P ratios of periphyton samples. PWD's role was thus limited to field collection and laboratory processing of samples as well as estimates of periphyton biomass by chlorophyll-*a* fluorometric assay.

5.3.3.2 MONITORING LOCATIONS

Periphyton communities were sampled from sites PQ115, PQ820, and PQB025, chiefly to assess the role of periphyton in regulating stream metabolism (Section 4.5). Two survey sites were conducted at Poquessing Creek mainstem locations (PQ115 and PQ820). A total of two sites were located within Philadelphia County (PQ115 and PQB025) (Figure 5.27). Sites were chosen based on proximity to continuous water quality monitoring stations, but some adjustments were made in order to situate the periphyton sampling locations in areas with sufficient depth and substrates and to attempt to control for differences in canopy cover. Site PQ820 was chosen as more representative of the upper Poquessing Creek than the continuous monitoring station at PQ665, which is located downstream of Roosevelt Blvd. Similarly, site PQ115 was chosen instead of site PQ050 due to the fact that site PQ050 is occasionally affected by tide. Periphyton was sampled from all sites on 5/29/2008. This date was classified as wet weather by rain gage analysis (Section 4.5.4.3) and stream discharge was observed to increase to only 112 cfs , so it was determined that this would not be a scouring flow that should preclude collection of algae samples.

5.3.3.3 METHODS

5.3.3.3.1 FIELD STANDARD OPERATING PROCEDURES

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

Substrate particles were placed in white plastic lab trays in the same orientation they had been found and debris such as gravel, leaves, and large macroinvertebrates were removed. Substrate particles (particularly sides and undersides of rocks) typically contained caddisfly nets that were removed as part of the periphyton sampling procedure. If the substrate particle had extensive coverage of macroalgae, filaments were trimmed to the profile of the substrate particle as viewed from above and portions of filaments that extended beyond the substrate particle were removed.

Three replicate samples were collected at each site. Depending on the size of the substrate particles collected, one to three particles were used for each replicate sample at each site. Each member of the three-person sampling team was assigned a different replicate letter ("A", "B", or "C") and sample containers were pre-labeled with site and replicate information. Periphyton was removed from the upper surface of each substrate particle using firm bristle toothbrushes that had one half the brush length trimmed away. Substrate particles were irrigated with stream water and scraped to remove periphyton until the rock surface became noticeably rough and not slimy. All scraped material for each replicate sample was composited into 250mL Nalgene sample bottles by rinsing the plastic tray with stream water. (Poquessing Creek stream water was previously characterized as having very low phytoplankton density, with water column chlorophyll-*a* <5µg/L.) Samples were stored on ice in a darkened cooler and exposure to sunlight was minimized throughout the sample handling procedure.

All substrate particles used for a given replicate were wrapped with aluminum foil, which was folded, trimmed, and/or notched, as appropriate, to carefully match the surface of the substrate particle that was scraped to collect periphyton (Figure 5.28). All substrate particle foil molds for each replicate were stored in pre-labeled Ziploc bags.

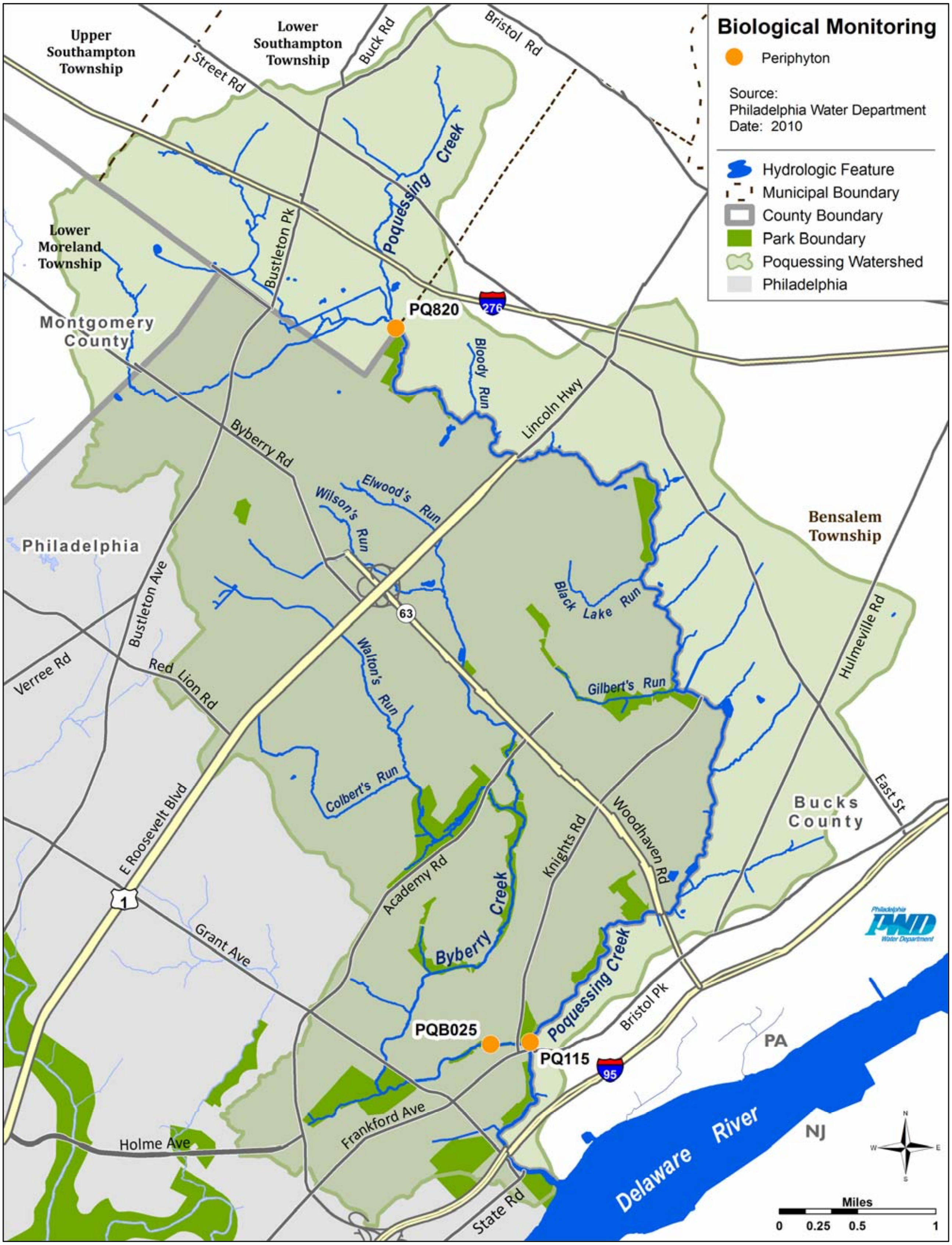

Figure 5.27 Periphyton Monitoring Locations in Poquessing Creek Watershed, 2008

Figure 5.28 Cutting Foil to Algal Periphyton Sampling Surface Area

5.3.3.3.2 PERIPHYTON SAMPLING SUBSTRATE PARTICLE SURFACE AREA DETERMINATION

Foil molds were scanned and digitized using a Microtek Scanmaker 4900 scanner. The scanner was modified with a dense black light-absorbing background to increase contrast in the resulting images, which were saved as 8-bit (256 levels of greyscale) TIFF files. Surface area was measured using ImageJ version 1.43. Differences in color between the foil and background were used to select and count the number of foil pixels, which was converted to square meters based on a calibration to the scanned image. For replicates in which more than one substrate particle was scraped to obtain the periphyton sample, the total surface area of all substrate particles sampled for each replicate was calculated by summing the individual areas of each particle used for the sample.

5.3.3.3.3 LABORATORY STANDARD OPERATING PROCEDURES

Periphyton samples were brought to the Bureau of Laboratory Services and processed in the Wastewater Laboratory using a modified version of EPA Method 445.0. Each replicate sample was homogenized using a laboratory blender (Waring, Inc.). The sample was transferred to a large beaker and the blender was rinsed with deionized water multiple times. Deionized water was added to the sample to make volume up to 1 L for ease of filtration and to simplify volumetric calculation of algal density.

5.3.3.3.4 CHLOROPHYLL-A FLUOROMETRIC ASSAY

5-mL aliquots of diluted sample were vacuum filtered through a 0.45 µm glass fiber filter (Whatman, Inc.) to concentrate algae. As many as three 5-mL aliquots were filtered through the filters to ensure that enough material was collected by the filter. A laboratory vacuum manifold was used to process multiple samples simultaneously. Total volume filtered was recorded on a data sheet and the sample label. Filters were individually wrapped in aluminum foil and stored for up to 21 days in a laboratory freezer at -20°C.

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

5.3.3.3.5 PERIPHYTON INTRACELLULAR NUTRIENT CONCENTRATION ASSAY

Intracellular nutrient concentration assays were performed by the Biogeochemistry Section of the Patrick Center for Environmental Research at ANSP. Algal material was concentrated from aliquots of algal slurry by centrifugation. Carbon and Nitrogen were determined with a CN analyzer, while Phosphorus was determined by acid digestion and colorimetric techniques. More specific information on laboratory procedures related to the nutrient ratio analysis is available from the Patrick Center.

The Redfield ratio (Redfield 1958) is an empirical relationship that describes the molecular ratio or the relative mass of C, N and P found in the tissues of aquatic autotrophs. This relationship can be used to determine the extent to which C, N or P is limited within an organism, and thus the availability of nutrients within the system in which that organism lives can be inferred. The stoichiometric ratio (106:16:1) describes the relationship between the number of atoms of C, N and P respectively, taken up in the cells of autotrophs. The mass ratio expression (41:7:1) was used, as this method was more compatible with observed periphyton nutrient data (*i.e.*, mass C, N, P per unit area).

5.3.3.3.6 DIATOM IDENTIFICATION AND ENUMERATION

The Phycology section of the Patrick Center for Environmental Research provided taxonomic expertise, identifying and enumerating diatoms and soft algae collected at each site. A minimum of 600 valves were counted for each sample. Voucher specimens were stored in the ANSP diatom herbarium and duplicate specimens were provided to PWD.

5.3.3.3.7 DIATOM AUTECOLOGICAL INDICES

Diatom taxa from the relative abundance estimates provided by ANSP were classified according to diatom autecological attributes and indices (Porter 2008). This reference compiles diatom autecological attributes and derived indices from several sources, including the USGS National Water Quality Assessment Program (NAWQA), in a series of tables available as tab-delimited text files. These files were retrieved from the USGS website and imported, along with algal abundance data, into a Microsoft Access database. Algal taxa collected in Poquessing Creek Watershed were classified according to seven attributes (Table 5.16).

Table 5.16 Algal Periphyton Autecological Classification

Classification	Description	Reference	Categories
MOTILITY	Motile or non-motile algae	None	2
DIATCOND	High or Low Conductivity indicator taxon	Potapova and Charles 2007	2
TROPHIC	Trophic classification	van Dam *et al.* 1994	7
POLL_CLASS	Pollution tolerance	Bahls 1993	3
POLL_TOL	Pollution tolerance	Lange-Bertalot 1979	5
DIATASTN	High or Low TN indicator taxon	Potapova and Charles 2007	2
DIATASTP	High or Low TP indicator taxon	Potapova and Charles 2007	2

5.3.3.3.8 DATA ANALYSIS

Periphyton chlorophyll-*a* biomass was determined with a volumetric calculation based on the amount of diluted sample that was filtered onto the glass fiber filter and results were expressed as mg/m^3 using the appropriate conversion factors. Periphyton sample diversity was analyzed with the Shannon (H') (Shannon 1948, Equation 5.1, Section 5.3.2.3.2), and Simpson's (1949, Equation 5.3) diversity indices:

$$D = 1 - \left(\frac{\Sigma\, n(n-1)}{N(N-1)} \right) \qquad \text{(Eq. 5.3)}$$

where *n* = the total number of individuals of a particular taxon in a given sample, and *N* = the total number of individuals of all taxa in a given sample. Pairwise periphyton community similarity was analyzed for all combinations of sites using Sørensen's coefficient of community (Brower *et al.,* 1990):

$$CCs = \frac{2c}{s_1 + s_2} \qquad \text{(Eq. 5.4)}$$

where *c* is the number of species common to both samples and s_1 and s_2 are the number of species in the two samples, respectively. Abundance estimates in each pairwise comparison were used to calculate proportional similarity (Brower *et al.,*1990):

$$PS = \Sigma_{i\text{-}z}\, [p_i \text{ or } q_i\text{, whichever is lower}] \qquad \text{(Eq. 5.5)}$$

where, for all species, *i* through *z*, p_i = proportion of species *i* in sample 1 and q_i = proportion of species *i* in sample 2. The advantage of proportional similarity is that it considers not only presence/absence data but also the relative abundance of each taxon.

5.3.3.4 RESULTS

5.3.3.4.1 WATERSHED OVERVIEW

Brown algae, and pennate diatoms in particular, were found to be ubiquitous at all sites and the dominant form of periphyton in Poquessing Creek Watershed overall (discussed further in Section 5.3.3.4.4). Mats of branched filamentous green macroalgae were found patchily distributed, with filaments as long as 1 m attached to stable substrate particles. Aquatic mosses were also locally abundant at some sites. Algal mats and odors may detract from the aesthetic value of Poquessing Creek, located in a popular urban park. Though storm events tend to scour and remove algal biomass, nutrient conditions favor rapid re-establishment of pre-disturbance algal densities, as evidenced by observed patterns of diel dissolved oxygen fluctuations (Section 4.4.1.1, Figure 4.8).

On some occasions, periphyton layers appeared to be very loosely attached and subject to releasing from the substrate and creating floating mats of brown algae and decomposing organic matter. This phenomenon may be related to self-shading (*i.e.*, as the mat becomes thicker and more opaque, less sunlight is available for cells near the lower surfaces of the mat and these lower cells die and decompose), or entrainment of gas bubbles in the algal-detrital matrix.

Periphytic algae grew to nuisance densities within many of the Poquessing Creek assessment sites, causing pronounced fluctuations in dissolved oxygen concentration. Nevertheless, these fluctuations generally did not result in exceedance of instantaneous minimum or daily average DO water quality criteria, with the exception of site PQ665. (Section 4.4.1.1, Table 4.11). pH fluctuations were also observed, causing very infrequent (0.1% of hours) violations of water quality standards at sites PQ665 and PQB025 (Table 4.10). Dense algal growths may also be partially responsible for the biological impairment that was observed throughout the watershed (Sections 5.3.1 and 5.3.2). In some locations, nearly every stable substrate particle (approximately the size of a small boulder, or 10 in/256 mm) in sufficient depth of flow was covered with brown algae or filamentous green algae, while smaller particles generally appeared scoured and cleaner.

5.3.3.4.2 PERIPHYTON BIOMASS

Mean periphyton chlorophyll-*a* density ranged from 91.06 mg/m² at site PQ115 to 124.64 mg/m² at site PQB025 (Figure 5.29). At each monitoring site, mean periphyton chlorophyll-*a* exceeded the EPA Ecoregion IX water quality reference value of 20.35 mg/m² (USEPA 2000), and one or more samples from each site exceeded 100 mg/L, which is within the range of values suggested as a threshold value for "nuisance" growth (Dobbs *et al*. 1997, Welch *et al*. 1988). As noted in Section 5.3.3.2, a small rain event occurred early in the morning one day prior to the algae sampling, causing stream discharge to increase briefly, peaking as high as 112 cfs. Flows of this magnitude do not usually result in notable scour (Section 4.5.2, Appendix E) as evidenced by continuous DO data, however it is possible that these algal biomass values may be slightly less than they would have been without this flow.

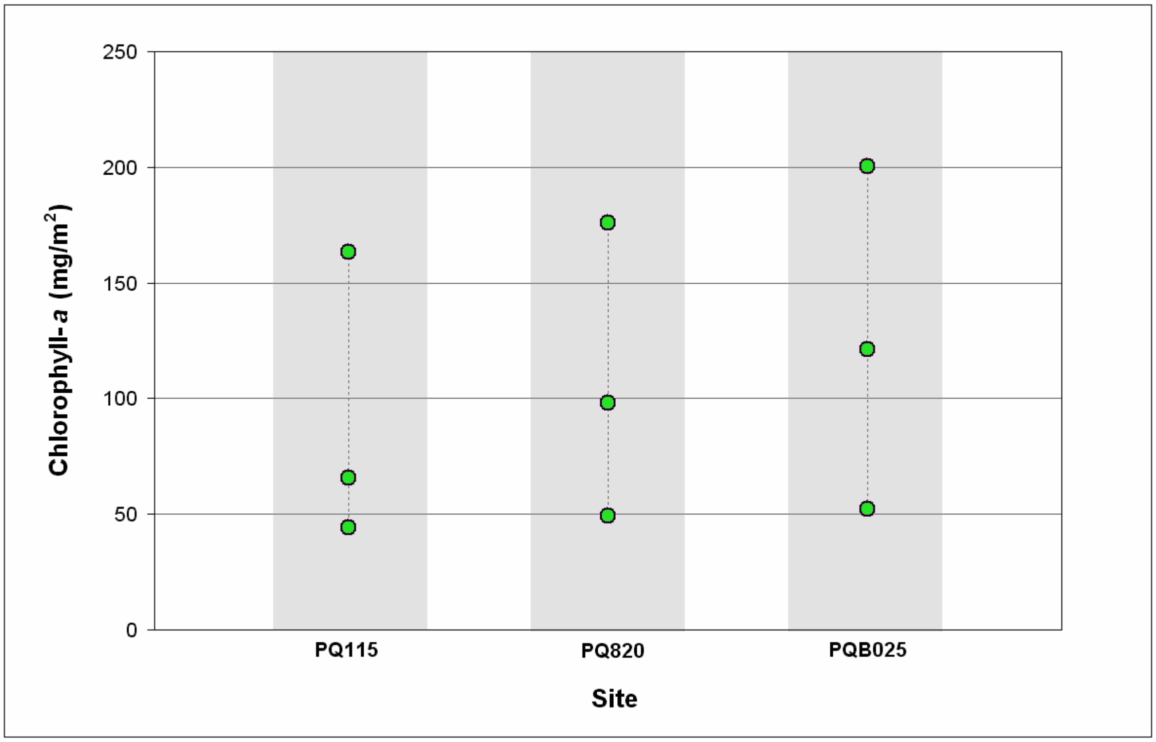

Figure 5.29 Mean Periphyton Biomass Estimates (Chl-*a*) at Three Sites in Poquessing Creek Watershed, 2008

Periphyton biomass accrued in high densities (as chlorophyll-*a*) throughout the watershed, including site PQ820, the upstream-most sampling site. In natural systems, periphyton biomass generally is greatest in mid-order streams, such as the downstream-most reaches of Poquessing Creek, because these reaches are wider and less shaded than narrower upstream reaches. The presence of dense algal growths at site PQ820 demonstrated that Poquessing Creek is not a well-shaded forested natural stream system with low productivity. There are numerous factors that determine periphyton abundance within a stream, such as grazing pressure or light, nutrient and substrate availability, and for this reason estimates of periphyton biomass and abundance may change dramatically within a short distance.

The presence of an adequate riparian buffer is an important factor governing light availability to instream autotrophs and thus periphyton distributions. Sufficiently wide riparian buffers, especially those with mature canopies, will limit periphyton growth during the late spring and summer months. All periphyton sampling sites were similar in having a relatively complete high tree canopy but less dense shrub and riparian vegetation layer. It is likely that light is not the most important factor governing periphyton distribution and abundance in the Poquessing Creek Watershed. Substrate particle size and substrate stability also govern the biomass of periphyton. On rocks sampled for periphyton analysis, many sites were observed to have obvious differences in algal mat thickness or extent of macroalgae coverage, which could have been a result of discrepancies in substrate size distributions at periphyton sampling sites.

5.3.3.4.3 PERIPHYTON INTRACELLULAR NUTRIENT RATIOS

Analysis of C:N:P mass ratios from Poquessing Creek periphyton samples revealed that N:P nutrient ratios were slightly less than the Redfield Ratio (7:1) at two of three sites (Table 5.17) but generally did not show extreme divergence from the Redfield ratio, as exhibited by other nutrient enriched sites sampled by PWD (*i.e.*, Wissahickon Creek).

Table 5.17 Mean C, N, P, and Chl-*a* Concentrations of Periphyton Samples from 3 Poquessing Creek Sites, 2008

Site ID	River Mile	C (g/m²)	N (g/m²)	P (g/m²)	C:N:P	Chl-a (mg/m²)
PQB025	0.25	14.55	2.03	0.26	56:8:1	124.636
PQ820	8.2	7.11	0.95	0.17	42:6:1	107.781
PQ115	1.15	8.01	1.06	0.173333	46:6:1	91.056
Redfield Ratio	---	---	---	---	41:7:1	---

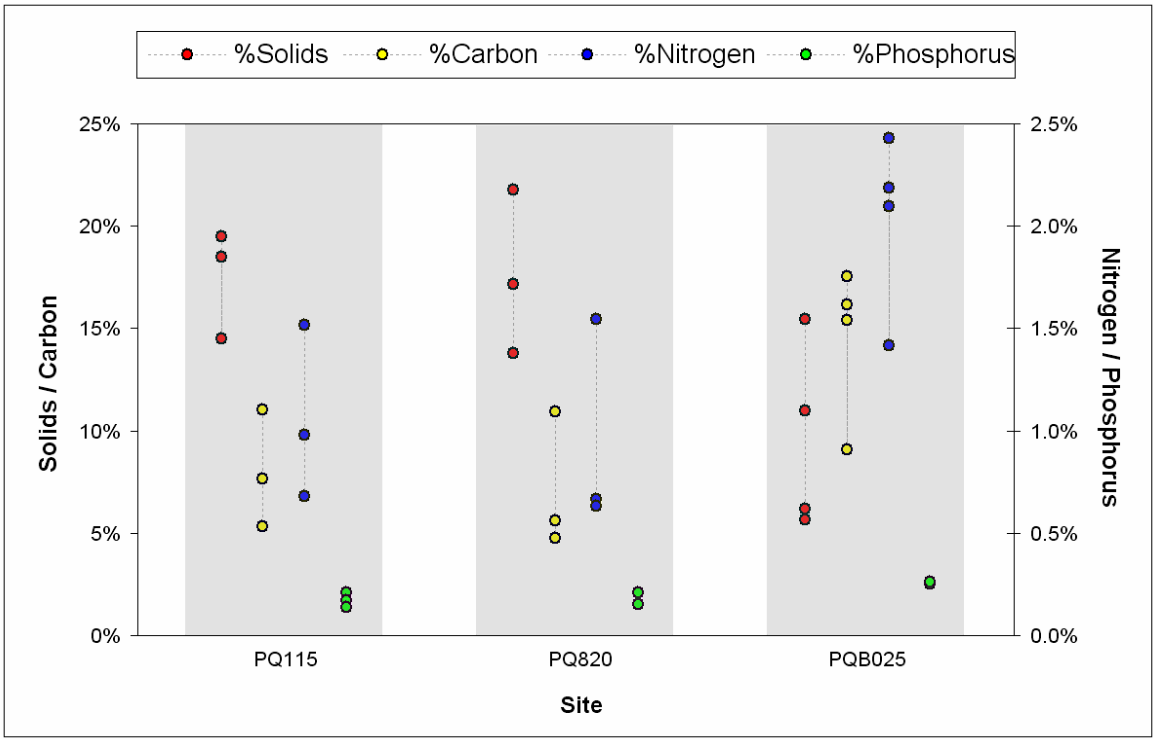

Figure 5.30 Relative Concentrations of Solids, Carbon, Nitrogen and Phosphorus at 3 Poquessing Creek Watershed Sites, 2008

5.3.3.4.4 PERIPHYTON COMMUNITY STRUCTURE

Algal periphyton samples were also examined taxonomically by the Phycology Section of the Patrick Center for Environmental Research of the Academy of Natural Sciences of Philadelphia (ANSP). Algal communities at the three Poquessing watershed sites were generally dominated by the genera *Achnanthidium*, *Nitzschia,* and *Navicula*, which together contributed 84% (45%, 24%, and 14%, respectively) of the total abundance. Although the individual species within these genera varied somewhat from site to site, with each dominated by a different species (Table 5.18), sites were relatively similar to one another as measured by the Sørensen and proportional similarity indices (Table 5.19). Taxonomic richness was greatest at site PQ115, which has the greatest drainage area of all sites sampled.

Table 5.18 Diatom Community Taxonomic Results

Metric	PQ115	PQ820	PQB025
Number of Individuals	623	626	629
Taxa Richness	38	22	26
Shannon H'	1.09	0.84	0.79
Simpson D	0.14	0.19	0.27
% Dominant taxon (genus)	41.41 *Achnanthidium* spp.	41.37 *Achnanthidium* spp.	54.53 *Achnanthidium* spp.
% Dominant taxon (species)	28.90 *Achnanthidium minutissimum* (Kutzing)	28.60 *Nitzschia inconspicua* (Grunow)	46.10 *Achnanthidium rivulare* (Potapova et Ponader)

Table 5.19 Sørensen and Proportional Similarity Indices for Paired Algal Periphyton Community Samples From 2 Poquessing Creek and 1 Byberry Creek Site, 2008

Site pair	Sørensen Community Coeff.	Proportional similarity
PQ115 & PQ820	0.63	0.67
PQ115 & PQB025	0.56	0.47
PQ820 & PQB025	0.50	0.52

5.3.3.4.5 PERIPHYTON AUTECOLOGICAL INDICES

Periphytic algal communities, and diatoms in particular, have been used as indicators of water quality (Stevenson and Pan 1999, Lowe 1974, Charles *et al*., 2006). However, as most water chemistry parameters (*e.g.*, nutrients, BOD, etc.) within Poquessing Creek Watershed have been fully characterized through extensive sampling, PWD considers the use of periphyton communities to infer an ecological condition and corroborate results of water chemistry assessments. Periphyton community assemblage data is presented here for the sake of inter-site comparison and comparison to algal indices that have been developed for diatom communities in Europe and different regions of the U.S., including the USGS NAWQA program.

Algal taxonomy is a changing field limited to a relatively narrow field of experts. PWD data follow taxonomic organization as practiced by ANSP. Algal responses to water quality or other environmental gradients derived from large-scale studies combining datasets over broad geographic areas may be clouded by confounding factors of inconsistent taxonomic schemes used by different practitioners, or possibly by the presence of regional ecotypes or yet-undescribed species. Differences in response to environmental gradients are not limited to comparisons between North American and European indices. For example, taxa exhibit different patterns of response to nutrients, pH, or conductivity at regional and national scales (Potapova and Charles 2007, Ponader and Potapova 2007, Potapova *et al.,* 2005). Motility classification also may differ among authorities, as it is difficult to classify some taxa as either motile or non-motile, rather than having degrees of motility.

Given these caveats, periphyton relative abundance data were found to be generally in accordance with conclusions drawn from water quality sampling and other biological assessments. Diatom community data indicated that Poquessing Creek sites can be characterized as moderately nutrient enriched, of neutral pH, and moderately affected by increases in conductivity and organic pollution. NAWQA national diatom nutrient indicators showed slightly different responses for TN and TP, with Poquessing sites having similar proportion of taxa characterized as having low TP (<0.01mg/L) and TN (<0.2mg/L) optima, but more taxa characterized as high TP optima (>0.1mg/L) than high TN optima(>3mg/L) (Table 5.20, Figures 5.31 and 5.32). These results generally agree with observed water quality sampling results.

Table 5.20 NAWQA Conductance, Total N, and Total P Indicator Classification of Algal Taxa Collected From 3 Poquessing-Byberry Watershed Sites, 2008

Site	CONDUCTANCE OPTIMA			NITROGEN OPTIMA			PHOSPHORUS OPTIMA		
	Low	*High*	*NC**	*Low*	*High*	*NC**	*Low*	*High*	*NC**
PQ115	<1%	13%	86%	50%	30%	20%	40%	42%	18%
PQ820	<1%	23%	77%	58%	18%	24%	55%	41%	4%
PQB025	0%	47%	53%	43%	7%	50%	38%	53%	9%

*NC – Not Classified

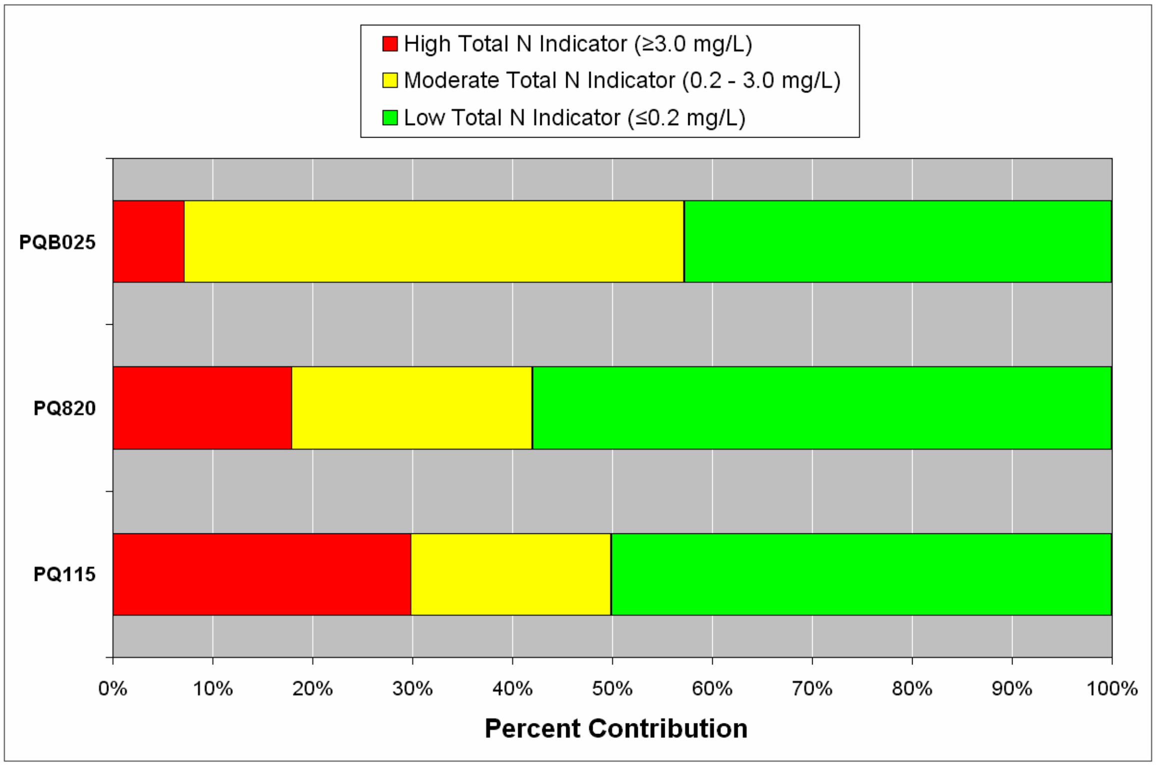

Figure 5.31 NAWQA Total Nitrogen Indicator Classification of Algal Taxa Collected From 3 Sites in Poquessing Byberry Watershed, 2008

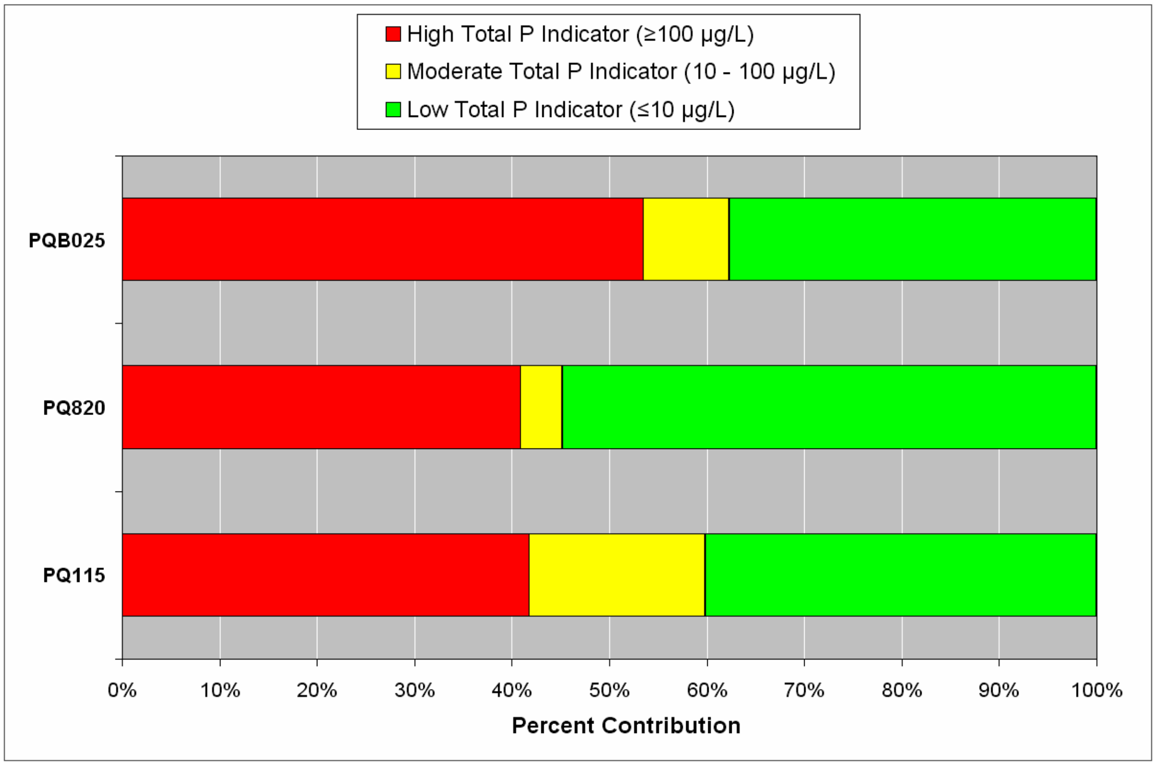

Figure 5.32 NAWQA Total Phosphorus Indicator Classification of Algal Taxa Collected From 3 Sites in Poquessing Byberry Watershed, 2008

All Poquessing sites had less than 1% of taxa considered characteristic of low conductivity (<200µS/cm) conditions and the greatest proportion of taxa were not classified indicative of high or low conductivity (Table 5.20, Figure 5.33). Despite the fact that conductivity tends to increase in a downstream direction within urbanized watersheds, site PQ115 had the smallest proportion (13%) of high conductance (>500µS/cm) indicator taxa and Site PQB025 contained the greatest relative proportion of high conductance indicator taxa. Excluding spring 2009, which was affected by freeze-thaw conditions and use of road salts, dry weather conductivity was observed to reach a maximum of approximately 500µS/cm in most Poquessing Creek sites (Section 4.4.6.3, Appendix H), thus suggesting good agreement between the diatom conductivity index and continuous water quality data.

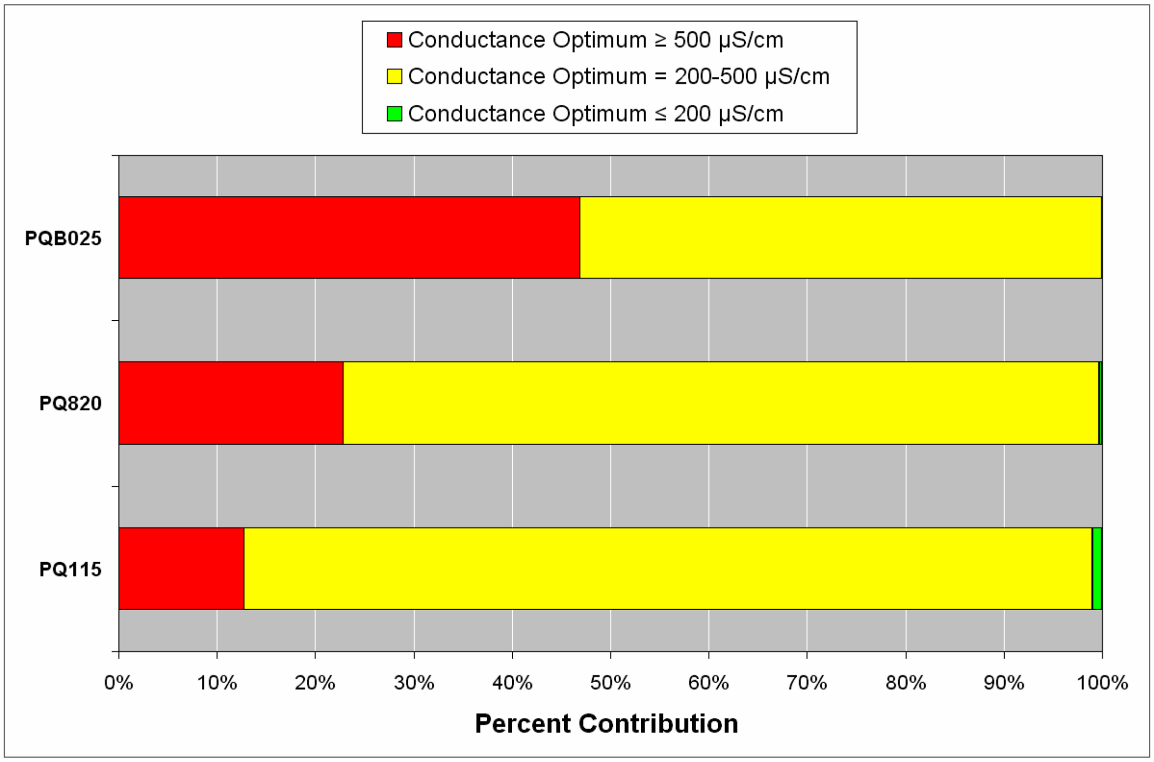

Figure 5.33 NAWQA National Specific Conductance Indicator Classification of Algal Taxa Collected From 3 Sites in Poquessing Byberry Watershed, 2008

The relative proportion of motile diatoms has been used as an indicator of siltation in freshwater streams (Bahls 1993, Kutka and Richards 1996, Stevenson and Bahls 1999). Poquessing sites generally had a large proportion of the total abundance made up by motile taxa (Table 5.21, Figure 5.34), indicating siltation of stream substrates may be a problem. Some *Navicula* taxa are classified as non-motile in Porter (2008), but the % Motile diatoms siltation index , as it appears in The USEPA Rapid Bioassessment Protocol manual (Stevenson and Bahls 1999) groups entire genera and the index is calculated as the sum of *Navicula* + *Nitzchia* + *Surirella*. Notably, *Navicula minima*, which was proportionally abundant at site PQB025 (19%) was not listed as motile in Porter 2008. If this taxon is considered mobile, then the siltation index for site PQB025 would have increased accordingly. Motility in diatoms may be directly observed from living material, or inferred from structural anatomy, including production of polysaccharides and other exudates associated with motility. PWD lacks expertise in this area, but lacking information to the contrary, we assume that the classifications in Porter 2008 represent more current species-level understanding.

Algal communities of Poquessing Creek Watershed respond to hydrologic disturbance in a somewhat predictable way, as evidenced by continuous DO and pH monitoring (Sections 4.4.1.1 4.4.3, 4.5.2, 4.5.3). Scouring and siltation are complementary processes that take place during the transition from baseflow conditions, to scouring storm flow, and then as the stream returns to baseflow conditions. In addition to the relative proportion of motile diatoms as indicators of hydrologic disturbance, certain other community attributes and particular taxa may also support the conclusion that the watershed experiences a high degree of hydrologic disturbance. While developing periphyton protocols for the state of Montana, Bahls (1993) observed that *Achnanthidium minutissimum* was not strongly influenced in its distribution by nutrients or acid mine drainage and was often the first species to colonize sites following disturbance. He suggested that relative abundance of *A. minutissimum* could be used as an indicator of disturbance. *A. minutissimum* and other *Achnanthidium* species were very abundant in Poquessing Creek Watershed sites. While diatoms as a group vary in size over a large range, most diatom taxa found in Poquessing Creek Watershed samples are relatively small, ~10µm, which may also be an indicator of frequent hydrologic disturbance.

Table 5.21 Motility and Trophic Composition Indicator Classification of Algal Taxa Collected From 3 Sites in Poquessing Byberry Watershed, 2008

Site	MOTILITY			TROPHIC COMPOSITION				
	Motile	*Non-Motile*		*Oligotrophic-Mesotrophic Groups***	*Eutrophic*	*Polytrophic*	*Indifferent*	*NC**
PQ115	29%	71%		4%	47%	<1%	34%	14%
PQ820	32%	68%		<1%	56%	<1%	21%	23%
PQB025	16%	84%		<1%	38%	<1%	13%	49%

*NC – Not Classified
**This category encompasses Oligotrophic, Oligotrophic-Mesotrophic, Mesotrophic, and Mesotrophic-Eutrophic Groups (van Dam 1994).

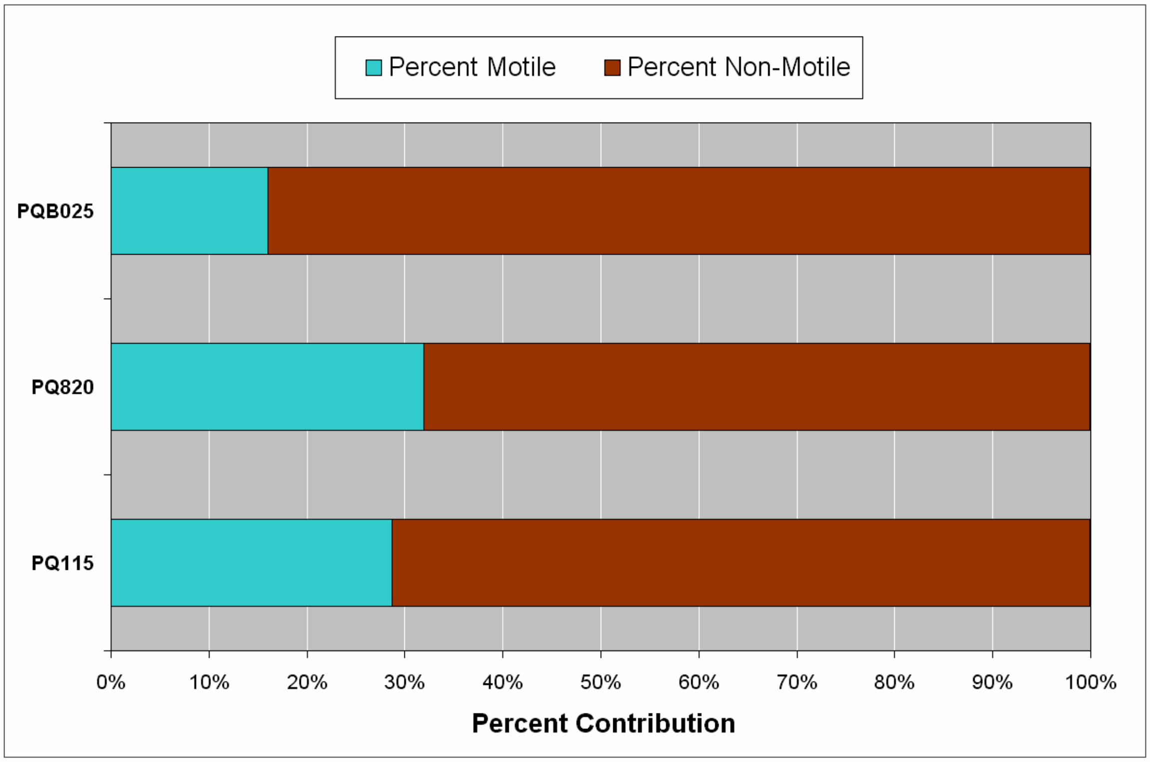

Figure 5.34 Motility Classification of Algal Taxa Collected From 3 Sites in Poquessing Byberry Watershed, 2008

Diatom relative abundance data were also compared to a trophic classification index (van Dam 1994) as well as two pollution indicator indices (Bahls 1993, Lange-Bertalot 1979). van Dam's trophic classification index was developed in the Netherlands but has been shown to correlate with trophic conditions in North American streams as well (Porter 2008). Most diatoms that were classified as having a relationship to nutrients were classified as "Eutrophic" species, the proportions of which ranged from 38% at site PQB025 to 56% at site PQ115 (Figure 5.35). Relative abundance of diatom species that were unable to be classified and the number of diatoms classified as indifferent to nutrients exhibited an inverse relationship to one another at sites PQB025 and PQ115, while site PQ820 had relatively similar proportions of taxa that were unable to be classified and classified as indifferent to nutrients. This phenomenon was primarily due to varying abundance of *Achnanthidium rivulare*.

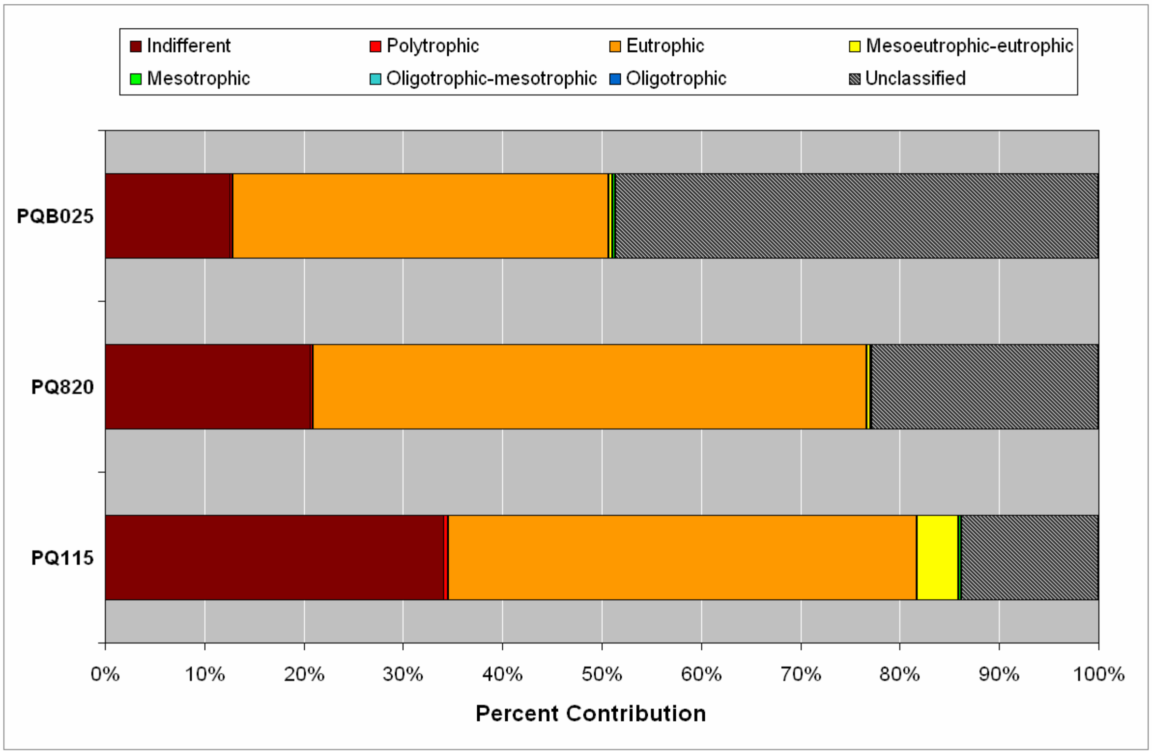

Figure 5.35 Trophic Composition Indicator Classification of Algal Taxa Collected From 3 Sites in Poquessing Byberry Watershed, 2008

Diatom Pollution tolerance metrics developed in Montana (Bahls 1993) and Europe (Lange-Bertalot 1979) showed reasonably good agreement with one another. Relative abundance of taxa classified as sensitive versus tolerant of pollution suggest that while Poquessing Creek Watershed is far from pristine, diatom communities do not indicate severe organic pollution (Table 5.22, Figures 5.36 and 5.37). In both indices, site PQ115 was found to be the least affected by organic pollution and site PQB025 was found to be the most affected by organic pollution. Relative abundance of taxa that were not classified showed a similar, yet even more pronounced effect of increasing from site PQ115 to site PQB025, as the two most abundant taxa (*A. rivulare* and *Nitzschia inconspicua*) were not classified.

Table 5.22 Pollution Tolerance Indicator Classifications of Algal Taxa Collected From 3 Sites in Poquessing Byberry Watershed, 2008

Site	POLLUTION CLASS				POLLUTION TOLERANCE					
	Sensitive	*Less Tolerant*	*Most Tolerant*	*NC**	*Less Tolerant*	*Somewhat Tolerant*	*Tolerant*	*Very Tolerant*	*Extremely Tolerant*	*NC**
PQ115	43%	35%	7%	16%	1%	43%	2%	6%	6%	42%
PQ820	34%	39%	4%	24%	<1%	37%	<1%	4%	4%	55%
PQB025	11%	20%	20%	49%	<1%	9%	0%	4%	20%	67%

*NC – Not Classified

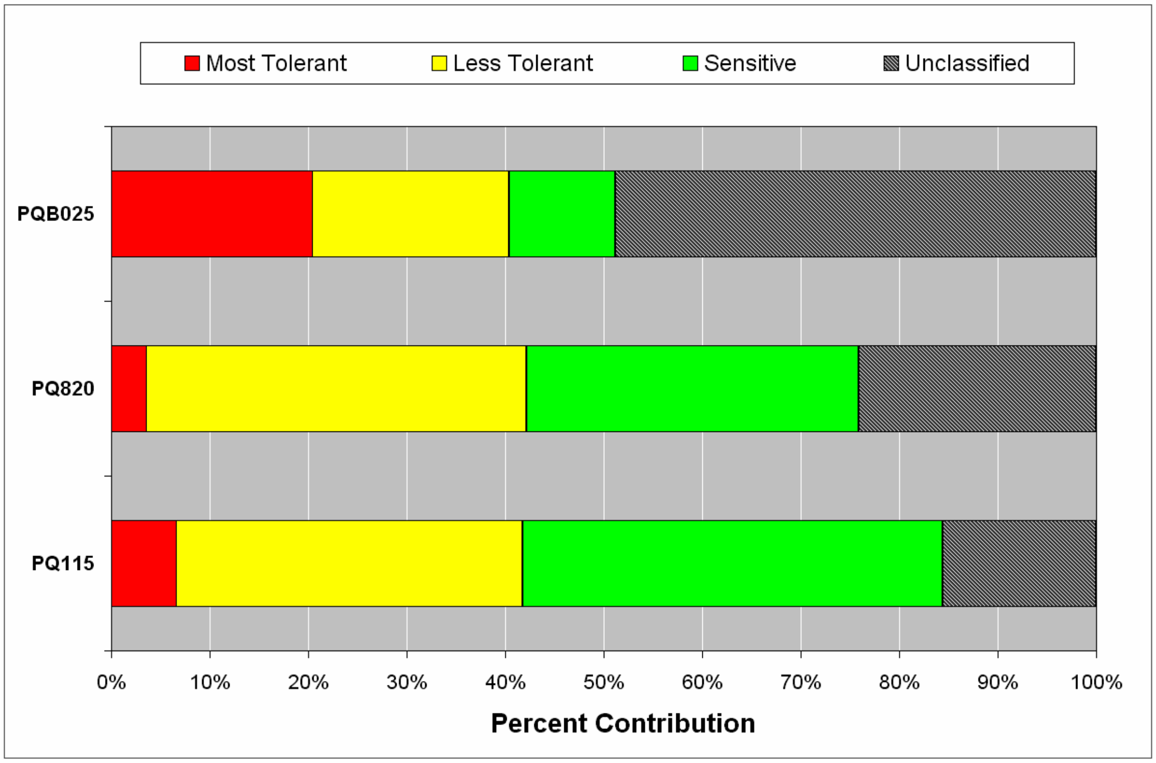

Figure 5.36 Pollution Indicator Classification of Algal Taxa Collected From 3 Sites in Poquessing Byberry Watershed, 2008

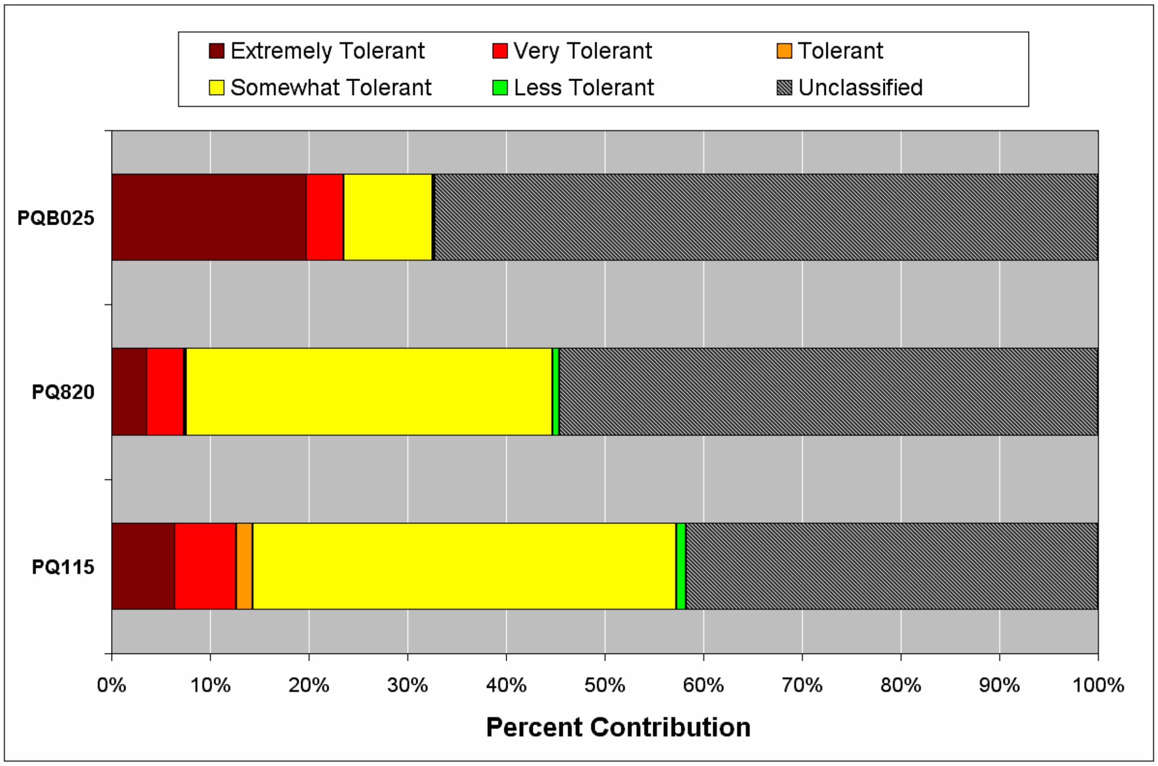

Figure 5.37 Pollution Tolerance Indicator Classification of Algal Taxa Collected From 3 Sites in Poquessing Byberry Watershed, 2008

While taxonomic periphyton data for the Poquessing Creek Watershed were limited with respect to the number of samples and number of sites, PWD continues to share results of other monitoring activities, such as physical habitat, water chemistry, and particularly continuous water quality, with researchers from the Academy of Natural Sciences. PWD sampling locations represent a valuable resource with respect to the amount of additional background information available for the site, especially when compared to locations that may have only a single water chemistry grab sample to accompany the periphyton data. It is hoped that through this continued partnership, PWD water quality data may assist local efforts to develop regionally-calibrated periphyton indices for use in regulatory programs. Degraded sites usually contain more species of diatoms than macroinvertebrates or fish, so it is possible that through mining these data, scientists may be able to identify trends and impairments that are difficult to characterize through other monitoring techniques (*e.g.*, siltation impairments).

5.3.4 SUMMARY OF BIOLOGY BY SITE

This summary is intended to highlight results from the Poquessing Creek Watershed assessment of 2008 that may have implications for watershed planning activities, including identification of possible sources of dry weather water quality pollution and prioritization of stream reaches for stream restoration and other stormwater management practices.

In assessing impaired urban streams, PWD primarily encounters sites that have been physically and chemically degraded by stormwater runoff to exclude sensitive fish and invertebrates, resulting in a moderately tolerant benthic invertebrate and fish communities. Applying the Hilsenhoff Biotic Index, or HBI, a weighted index of benthic invertebrate pollution tolerance values (PTV), most sites typically score between 5 and 6, as most moderately tolerant common taxa (*e.g.*, chironomid midges, hydropsychid caddisflies) have PTV 5 or 6. Very few individual sites among the 100+ sites assessed by PWD in the Philadelphia region have been distinguished as being healthier or more severely degraded than this general level of impairment caused by stormwater runoff and hydrologic disturbance due to urbanization.

Rarely, PWD encounters sites experiencing a more severe level of water pollution, causing conditions to deteriorate to the point where even moderately tolerant invertebrates such as midge larvae and net spinning caddisflies are suppressed. At these severely impacted sites, the benthic invertebrate community becomes dominated by pollution-tolerant (and primarily non-insect) invertebrates (*e.g.*, worms, leeches, planaria, and snails). Severely impacted sites may be degraded to the point where density of invertebrates in the stream benthos is reduced, as estimated by PADEP ICE sample collection and subsampling methods. These methods are not intended to be quantitative (*i.e.*, number of individuals per unit stream area), but can be used for relative comparisons of sites when very large discrepancies exist between the density of insects in subsamples from individual sites.

While several different physical, chemical and biological components of the 2008 assessment of Poquessing Creek Watershed are summarized herein, HBI and, in some cases, estimated relative invertebrate density, were the most consistent factors that allowed PWD to distinguish between the typical pattern of urban stream degradation from stormwater and signs of more serious water quality pollution. Additional evidence was provided in some cases where neighboring sites, assumed to be exposed to similar hydrologic disturbance, showed markedly better biological quality for these factors as compared to impaired sites.

5.3.4.1 PQ050 and Tidal Portions of Poquessing Creek

Site PQ050, located behind Holy Family College and approximately 700 ft upstream from the Delaware Expressway (I-95) bridges, was the downstream-most PWD monitoring site assessed in Poquessing Creek Watershed in 2008 (Appendix A, Figure A.1). A small dam, located downstream of this site and approximately 200 ft upstream of State Rd., is occasionally overtopped by the Delaware River tide, causing tidal influence at site PQ050. USGS filters these tidal excursions from stream discharge data when compiling annual flow statistics (Section 3.1.6).

No tidal (affected by daily tides on a regular basis) sites were assessed in Poquessing Creek Watershed, but PWD has, however, conducted qualitative fish sampling via boat electroshocking in tidal reaches of Frankford, Pennypack and Poquessing Creek in order to document the presence and relative size of spawning runs of native anadromous fish and native semi-migratory fish, such as white perch (*Morone americana*) and the desirable, recreationally-sought striped bass (*M. saxatilis*). Based on these infrequent, qualitative surveys, Poquessing Creek does not appear to have spawning runs of anadromous fish. The tidal portion of Poquessing Creek does serve as a nursery habitat for juvenile fish, and limited numbers of adult striped bass have been documented, which may suggest a very small remnant population of striped bass spawning in this tributary. The relatively unobstructed nature of Poquessing Creek is likely partially responsible for the abundance of American eels, which were found throughout the watershed.

Site PQ050 itself was one of the better quality sites assessed in Poquessing Creek Watershed, tied with site PQ770 for the highest comparison to invertebrate IBI and second-highest fish IBI comparison score. Site PQ050 was also found to have relatively high (for the watershed) proportions of intolerant fish and invertebrate species, though in the case of fish, this effect was due solely to the presence of Eastern silvery minnow (*Hybognathus regius*), a planktivorous species that is common in the tidal Delaware River. Habitat was among the better Poquessing Creek mainstem sites and the site experienced an increase in invertebrate taxa richness when compared to the 2001 PWD Baseline assessment of Poquessing Creek Watershed. While these are positive scores and attributes when compared among assessment sites in the Poquessing Creek Watershed, site PQ050 is in very poor condition compared to regional reference conditions.

Both invertebrate and fish communities showed undesirable changes when compared to baseline 2001 conditions. Overall fish abundance decreased 50% between assessment years, and 18 “plugs” were required to be sorted in order to count 200 individuals in the invertebrate subsample. The decrease in fish abundance, however, was countered by an increase in fish biomass, indicating that the site has fewer, but larger fish. One of the small fish notably reduced in number was the aforementioned Eastern silvery minnow, which decreased 75% in abundance from 2001 to 2008. Abundance shifts in this species must be considered alongside interactions with the tidal Delaware River, as this species forms schools and may move between the tidal and non-tidal portions of the creek and the main Delaware River.

Major invertebrate community structure changes were also observed, as *Hydropsyche* (the dominant taxon in 2001) decreased from 41.95% (2001) to 11.17% (2008); Chironomidae (the dominant taxon in 2008) increased from 8.64% (2001) to 44.66% (2008), with an accompanying increase in HBI from 5.53 to 6.58. Furthermore, oligochaetes (worms) made up 20% of the subsample in 2008. HBI values in excess of 6 and increasing numbers of oligochaetes and other tolerant invertebrate taxa are signs that this site may be experiencing additional stressors than typically found at stormwater-impacted sites.

5.3.4.2 PQ115

Site PQ115 is the downstream-most site on mainstem Poquessing Creek upstream of the Byberry Creek confluence. Similar to many other sites appearing to have reasonably good forest canopy coverage when viewed from land use maps or aerial photography (Appendix A, Figure A.2), site PQ115 was actually found to be rather poorly protected from local impacts such as steeply eroding banks and construction disturbance along the left bank. These factors, combined with in-channel sedimentation and embeddedness, yielded the worst habitat score among all mainstem Poquessing creek sites and the second-worst score overall. Despite poor habitat, biological effects were mixed, with the fish community at site PQ115 having the greatest IBI comparison score within the entire watershed and most periphyton metrics were best in the watershed. However, the benthic invertebrate community at site PQ115 had the lowest taxa richness and IBI comparison score within the watershed. It is not unusual for macroinvertebrate and fish community data to indicate different effects at a monitoring site, as different biota respond to different aspects of the physical habitat template and disturbance regime on different time scales. It is, however, somewhat unusual for the results of two assessments to be so different.

As was the case with site PQ050, tolerant oligochaetes (worms) were abundant, making up 25% of the invertebrates collected from this site, and more sensitive philopotamid caddisflies, found at most Poquessing Creek mainstem sites upstream, were not found at site PQ115. These factors caused an increase in HBI to 6.7, second highest among mainstem Poquessing Creek sites. PQ115 was also the only site not to experience an increase in invertebrate taxa richness from 2001 to 2008, though these observed increases in taxa richness at other sites may be more attributable to the PADEP ICE sample collection method, which increases the likelihood of collecting rare taxa. Overall, the results of biological assessments suggest that this site is affected by more serious sources of pollution, such as point source discharge, than sites that are primarily affected by stormwater runoff and habitat degradation only.

5.3.4.3 PQ395

Unlike Philadelphia's other watersheds, Poquessing Creek does not enjoy a widespread park system of protected riparian land along its length in Philadelphia. Site PQ395 is located upstream of the Franklin Mills mall within a relatively unbroken, if narrow, riparian corridor. Physical habitat conditions at this site were tied with site PQ050 for third best among mainstem Poquessing sites, but biological condition scores were generally poor. Most notably, site PQ395 required 26 "plugs" in order to pick the required number of invertebrates from the subsample. Only site PQ665 required more "plugs" be sorted. While this collection and processing method is not intended to be quantitative, it suggests a low overall abundance of insects due to perturbation. Site PQ395 also had the lowest fish abundance of all fish sites assessed. Trends in fish abundance, however, were the reverse, with site PQ395 being the only assessment site to experience a modest decline in overall fish abundance between the 2001 and 2008 assessments.

Site PQ395, like each of the four downstream-most Poquessing Creek sites, experienced a shift in dominant taxon from a hydropsychid caddisfly (Cheumatopsyche) to Chironomidae between 2001 and 2008. Continuing the trend at site PQ115, tolerant worms (Oligochaeta) made up 30% of the sample, which was the highest relative abundance for worms in the watershed. Although there were numerous other tolerant taxa collected at this site, they were not numerically abundant and worms were primarily responsible for the increase in HBI to 7.0, worst in the watershed. Similar to site PQ115, these findings suggest more serious sources of pollution, such as point source discharge, may be affecting site PQ395.

Site PQ395 did have two invertebrate taxa classified as sensitive, the cranefly genus *Antocha* (HBI=3), and riffle beetle *Ancyronyx* (HBI=2) which were collected alongside the philopotamid *Chimarra* (HBI=4) at site PQ395. Site PQ395 was thus the downstream-most site at which philopotamid caddisflies, more sensitive than the Hydropsychidae, were found. Both sensitive invertebrates were represented by a single individual in the subsample and there were two *Chimarra* individuals. *Chimarra* was found at the remaining sites upstream with the exception of site PQ665, which, like PQ395, appears to be more severely impaired due to pollution than other mainstem sites.

5.3.4.4 PQ465

This site had the highest habitat score of all POQ watershed sites (139.5), placing just into the range of "suboptimal," the only site in watershed to be placed in to this category. While only benthic invertebrates were assessed at this site, which is classified as severely impaired relative to reference conditions, PQ465 appears to be in better biological condition than either the immediately upstream (PQ665) or downstream (PQ395) sites. While site PQ465 had the highest relative proportion of dominant taxon (Chironomidae, 71%) and lowest Shannon diversity score of all mainstem Poquessing Creek sites, only four "plugs" were required to obtain an invertebrate subsample versus 26 and 28 at sites PQ395 and site PQ665, respectively. The number of "plugs" in an invertebrate sample collected with the PADEP ICE techniques is not intended to be a quantitative metric. However, such great differences between samples (collected the same day) may suggest that total insect abundance at site PQ465 was within the range of "normal," whereas the upstream and downstream sites have unusually low total insect density, perhaps due to acute toxicity or physical scouring of the streambed.

Site PQ465 was one of only two mainstem Poquessing Creek sites to have an HBI score less than 6, indicating a smaller contribution of pollution tolerant taxa. Furthermore, worms (Oligochaeta) represented only 6% of the invertebrates collected at site PQ465, but made up 30% and 15% of the invertebrate subsample at sites PQ395 and PQ665, respectively. Taken together, these findings strongly suggest that the impairment observed at sites upstream and downstream of site PQ465 may be due to localized factors, rather than widespread factors, such as drought, which would tend to generally affect all sites in a similar way. As suggested by the superior habitat score when compared to other mainstem Poquessing sites, site PQ465 may be more resilient against scouring disturbance from high flows on the stream bed, at least in the riffles that were targeted for sampling.

5.3.4.5 PQ665

Echoing the trend of very low overall insect abundance (as indicated by the density of insects in the subsamples) observed at site PQ395 (but notably not at site PQ465), all 28 "plugs" in the site PQ665 subsample were sorted in order to obtain the required number of invertebrates. Site PQ665 is thus one of many sites, along with downstream Poquessing Creek sites and Byberry site PQB210, that appears to be more seriously affected by point source pollution. Tolerant worms (Oligochaeta) made up 15% of the subsample, HBI was greater than 6, and site PQ665 was the only upstream assessment site on Poquessing Creek where *Chimarra* (Philopotamidae) was not found. Unlike the other sites ostensibly affected by point source pollution, site PQ665 actually experienced a decrease in HBI (*i.e.*, improvement in biological condition) when compared to the 2001 assessment.

While collecting water chemistry samples, PWD aquatic biologists noted an intermittent source of untreated raw sewage discharge to Poquessing Creek along the left bank in the vicinity of site PQ665. Site PQ665 was the only continuous water chemistry monitoring station to have exhibited periods of severely low dissolved oxygen, which occurred during dry weather in July 2008. Subsequent thermal imaging analysis and follow-up in May 2010 later confirmed this illicit discharge as active. PWD staff contacted PADEP and the Bucks County Health Department regarding this apparently intermittent sewage leak.

5.3.4.6 PQ770

Site PQ770 was one of only two sites, along with site PQ465, where only benthic macroinvertebrate and habitat assessments were conducted on mainstem Poquessing Creek in the 2008 watershed assessment. This site had the second highest habitat score of all mainstem POQ sites and fourth highest habitat score of the entire watershed, though this score represents a 15% decrease from 2001 conditions. Taxa richness, HBI and percent dominant taxon metrics all improved slightly from 2001 to 2008. Overall the results of the benthic invertebrate and physical habitat assessment suggest an impaired site, but impairment at site PQ770 appears mostly a result of stormwater runoff and habitat degradation. Similar to site PQ465, this site generally did not show signs of reduced total invertebrate density, unlike site PQ665, which is located downstream and appears to be more heavily impacted by pollution.

5.3.4.7 PQ820/PQ825/PQ845

Site PQ845 was the upstream-most monitoring location on mainstem Poquessing Creek and the only monitoring location outside the City of Philadelphia where all major types of biological assessment were conducted in the 2008 assessment of Poquessing Creek Watershed. Each form of biological monitoring, however, occurred at a slightly different location, and locations were sufficiently distant from one another (or separated by tributaries or other potential influences) such that it was necessary to assign each biological assessment site its own site ID (Appendix A, Figures A.7 and A.8). Physical habitat conditions at site PQ845, located nearer to Philmont Ave. were found to be unsuitable for fish assessment due to lack of any pool habitat. Fish were collected approximately 1,000 ft downstream, at site PQ825. The periphyton assessment location was located downstream farther still, south of Trevose Rd. (Appendix A, Figure A.7). Sites PQ845 and 825 were very well shaded, so the periphyton site was moved in order to match more closely the moderately shaded canopy cover at other periphyton monitoring sites. Conclusions from biological assessments have been grouped together as site PQ845 for convenience, but when interpreting the results one should keep in mind that these assessments occurred at different physical locations (particularly with respect to sites PQ845 and PQ825).

The physical habitat score of PQ845, where benthic invertebrates were collected, was second lowest of the mainstem POQ sites, but it was noted that this habitat score did not decrease as much between the 2001 and 2008 assessments as did the score at most other sites in the watershed. Site PQ825 had the lowest fish IBI score of all mainstem POQ sites (30) and showed a 52% decrease in total fish from 1,067 (2001) to 508 (2008). One expects that fish IBI scores and other metrics should change along the river continuum, decreasing in the upstream direction due to a decrease in overall size of fish and diminishing proportion of top predators. This effect is somewhat well supported as a potential explanation for the observed poor fish community IBI score at site PQ825 by the fact that site PQ845 had the greatest fish taxa richness and density (number of fish per unit area) of all mainstem sites, yet the lowest biomass per unit area. The Modified Index of well being was also the lowest in Poquessing Creek Watershed. However, site PQ825 is not representative of a small headwater stream. Drainage area was approximately 2 mi^2. and streams of this size in Southeastern PA are capable of supporting very high quality fish assemblages.

Invertebrate density (though based on a non-quantitative metric) showed signs of impairment as seven "plugs" were sorted, though this effect was not as severe as that observed at other impacted sites. Taxa richness increased (more than doubled) from 6 (2001) to 13 (2008), which is likely at least partially due to the PADEP ICE protocol, which increases the likelihood of rare taxa being collected. PQ845 had the lowest HBI score of all Poquessing watershed sites; the 2001 & 2008 HBI scores for this site were identical. Overall, the biological indicators at sites PQ820 through PQ845 indicate typical "urban stream syndrome" symptoms rather than acute pollution effects.

5.3.4.8 PQU013

Site PQU013 was the only tributary site assessed in the 2008 assessment of Poquessing Creek Watershed that was not located on Byberry Creek. This unnamed tributary originates in Lower Moreland Township and flows into Northeast Philadelphia. The stream's course is strongly influenced by the underlying geography, as this stream is located at the Eastern terminus of the Ledger formation (Section 2 Figures 2.2. and 2.6). The juxtaposition of easily eroded Ledger dolomite and relatively hard-wearing quartzite of the Chickies Formation is responsible for similar stream channel patterns in nearby Pennypack, Tookany, and Wissahickon Creek Watersheds.

Benthic invertebrates and habitat were the only types of assessment conducted at Site PQU013, and the site had the second highest habitat score of all sites assessed in the watershed. However, unlike sites PQ845 and site PQB450 (upstream-most assessment sites on the three respective streams), habitat quality decreased at site PQU013 compared to the 2001 assessment. The other two upstream sites were similar to the reference site FC1310 in experiencing only a small degradation in habitat score between the 2001 and 2008 assessments. The benthic invertebrate community at site PQU103 was the least diverse in the watershed, with the lowest Shannon Diversity index value and highest relative proportion of dominant taxon (Chironomidae). Taxa richness and proportion of dominant taxon metrics showed negative trends as compared to the 2001 assessment, however HBI remained nearly constant. Site PQU013 was also the upstream-most site at which the invasive Asian clam (*Corbicula fluminea*) was collected, perhaps indicating that the species has invaded most portions of Poquessing Creek watershed.

Although biological condition was poor, tied for second worst comparison to IBI conditions, the site had a very small proportion of tolerant taxa and required only the minimum of four "plugs" to sort invertebrate subsamples. Overall, assessment results suggest a site that is primarily affected by stormwater runoff and hydrologic disturbance rather than acute pollution.

5.3.4.9 PQB025

In many ways, observed biological indicator data at site PQB025 represent a measure of recovery from the undesirable ecological condition observed upstream at site PQ210, as the dominant taxa reverted to Chironomidae rather than Oligochaeta, which was the dominant taxon at site PQB210. That said, oligochaetes were still well represented at site PQB025 (27% of all invertebrates collected) and site PQB025 also required more than 10 plugs sorted to obtain the subsample. The modest level of improvement observed between sites PQB210 and PQB025 further reinforces the conclusion that severe impairment observed at site PQB210 is the result of a localized pollution source rather than general stormwater-related effects.

5.3.4.10 PQB210

By most measures, Site PQB210 was the most impaired site assessed in Poquessing Creek Watershed in 2008, with the lowest observed scores for physical habitat, benthic invertebrate IBI score, and taxa richness. Site PQB210 also had the highest HBI score and relative proportion of invertebrates classified as tolerant in the watershed and was the only site at which the dominant taxon was classified as tolerant (Oligochaeta).

Benthic invertebrate community impairment at site PQB210 indicates a more serious water pollution problem than that related to stormwater runoff and hydrologic disturbance due to urbanization. Biologists conducting habitat and benthic invertebrate assessments noted evidence of dry weather pollution coming from a stormwater outfall on the left bank of Byberry Creek in the vicinity of site PQ210. This leak was reported to the PWD Industrial Waste Unit which is responsible for tracking down sources of pollution, including identifying crossed and illicit connections to storm sewers.

5.3.4.11 PQB385

Site PQB 385 was the only site where the benthic invertebrate community was found not to be dominated by midge larvae (Chironomidae), indicating a positive aspect of the macroinvertebrate community (site PQ210, located downstream was dominated by Oligochaetes). Scores for most biological indicators at site PQB385 reflect general stormwater runoff related impairment, and thus provide support for the theory that a point source of pollution is responsible for the severe impairment present at site PQB210.

5.3.4.12 PQB450

PQB450 was the upstream-most assessment site located on Byberry Creek. The site is not representative of a small headwater stream, however, having upstream drainage area ~2 mi^2 heavily influenced by industrial land uses along the Roosevelt Blvd. transportation corridor. Site PQB450 is located approximately 0.5 mi downstream of the confluence of Wilson's Run and Elwood's Run.

Though habitat quality of site PQB450 decreased somewhat from the 2001 assessment and the decrease may have been responsible for a change in biological condition from "suboptimal" to "marginal," the decrease in habitat score observed at site PQ450 was minor relative to most other sites in the watershed, with the exception of site PQ845, which is also the upstream-most assessment location on its respective stream. In this way, sites PQ450 and PQ845 were most similar to the reference site FC1310, which experienced only a small decrease in habitat quality from 2001 to 2008. This observation suggests, first, that habitat assessment scores may not have been affected by a temporal bias in biologists' interpretation or differences between protocols used. Second, the less severe change in habitat quality from 2001 to 2008 observed at upstream sites perhaps suggests that upstream sites may not have been subject to hydrologic disturbance-induced habitat degradation as severely as downstream sites. Very few sites were assessed overall, and the upstream-most assessment sites still represent large drainage areas, so it is difficult to draw conclusions from such a limited amount of data.

Benthic invertebrate community data from site PQB450 were similar to other upstream sites, such as site PQU013, with poor overall taxa richness, relatively low proportional abundance of tolerant invertebrates, and relatively high proportional abundance of the dominant taxon, Chironomidae. The laboratory subsampling procedure did not suggest unusually low invertebrate density, with five "plugs" sorted for the subsample. These findings overall suggest site PQB450 is impacted by stormwater runoff and hydrologic disturbance, but perhaps not affected by more serious water pollution problems, which are more evident at many downstream Poquessing and Byberry sites.

6 PHYSICAL CHARACTERIZATION

6.1 INTRODUCTION

Habitat and water quality are the two most important factors determining what types of living things may be found occupying a given aquatic habitat. Unfortunately, aquatic habitats are subject to severe destabilization and destruction due to land development and increases in the human population. Assessing habitat for a watershed, a stream, or even a small segment of stream in a meaningful way can be difficult, as habitat attributes that are more suitable for one species or group of species may be less suitable for another species; different life stages of the same organism may require different habitat conditions; and habitats can change rapidly following a disturbance. Habitats also change seasonally due to climate and biological growth, particularly in temperate climates. Furthermore, some habitat attributes may be compensatory, in that a deficiency in one attribute can be partially compensated for by one or more unrelated factors.

The most severe destabilizing force affecting aquatic habitats is the modification of natural flow patterns, volume, and timing that accompanies land development. Impervious surfaces such as roads, roofs, and driveways shed water, allowing for very little infiltration. The type of drainage that is common in the City of Philadelphia – that of roof downspouts, parking areas and streets directly connected to a storm sewer system – has an even greater capacity to change flow patterns. Traditional stormwater management practices, such as the numerous stormwater detention basins that were constructed in the Poquessing Creek Watershed since stormwater regulations were implemented in the 1970s, are capable of “shaving peaks” but usually do not provide for infiltration. In 2009, PWD conducted a GIS analysis to inventory stormwater management facilities in the city built prior to digital records management being implemented. It was found that most (96 of 182) of the development projects requiring stormwater management (such as detention basins) constructed in Philadelphia through 2000 were located in Poquessing Creek Watershed.

A conceptual diagram of the change in hydrograph with increased impervious surface is depicted in Figure 6.1. Negative impacts of this flow modification are twofold – more water volume and velocity during rain events, and diminished baseflow during dry weather. While severe erosion may be the more obvious effect of hydrologic modification, baseflow diminution may also be important in explaining the extirpation of sensitive taxa from the watershed.

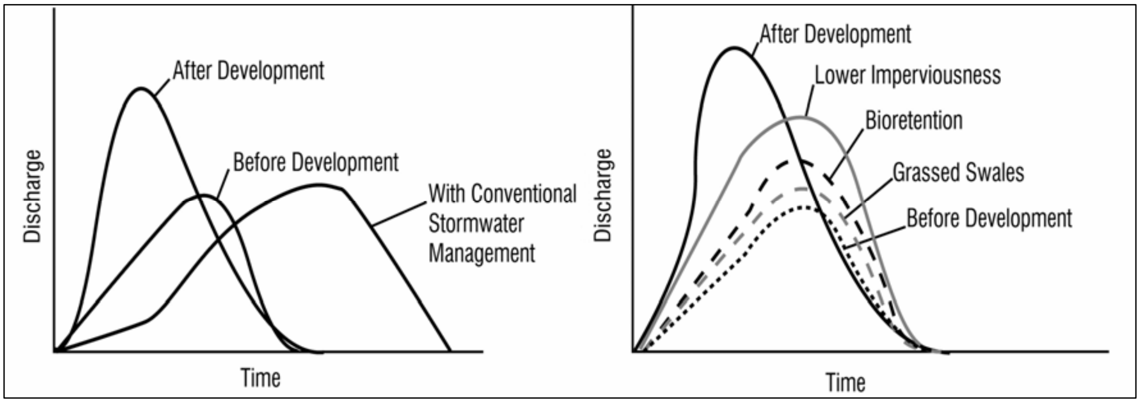

Figure 6.1 Comparison of Volume and Duration of Stormwater Runoff Before and After Land Development, and Reductions in Runoff from BMPs.
Source: Prince George's County Department of Environmental Resources *et al.*, undated.

Other anthropogenic factors lead to destabilization of natural stream flow patterns and habitat destruction. Human activity has indirectly altered the stream channels through changes in flow volume and timing, but also directly through construction of infrastructure such as culverts, channelization and dams. Culverts and other features often constrain flow, causing increased velocity, headcutting, and scour at knickpoints and sediment deposition in channel bars downstream. Channelization may be effective at reducing erosion on a small area, but it often exacerbates erosion problems downstream.

Dams can block upstream migration of fish and invertebrates, disrupt sediment transport, and alter natural microhabitat (*i.e.*, pool, riffle, run) sequences by creating impoundments of stagnant water that may have suitable conditions for algal blooms, oxygen depletion, and nutrient release from stream substrates. Dams were not found to be very prevalent along Poquessing or Byberry creeks (see section 6.5.2).

6.1.1 PADEP 2008 INTEGRATED LIST OF WATERS

According to the 2010 PA Integrated List of Waters (PADEP 2010), stream segments within the Poquessing Creek Watershed are listed by PADEP as being impaired due to "siltation" as well as water/flow variability, flow alterations, and other habitat alterations caused by urban runoff from storm sewers (section 2.7, Table 2.11, Figure 2.9). Deposition of fine sediment can be especially detrimental to aquatic macroinvertebrates that depend on interstitial spaces under and between rocks and fish that spawn over gravelly substrates. Two tributaries to Byberry Creek, Watson's Run and Colbert's Run; as well as Black Lake Run and a second unnamed tributary to Poquessing Creek, are listed in category 5 as impaired due to "siltation," which is considered a pollutant requiring a TMDL. More information is available in section 4.1.2.

Aside from these tributaries impaired by siltation and the downstream-most segment of Poquessing Creek (which is listed due to PCBs), all remaining stream segments of the Poquessing Creek Watershed in the City of Philadelphia and Bucks and Montgomery counties are listed as impaired due to various effects of urban runoff/storm sewers, but these are category 4 stream listings not requiring a TMDL. Effects of urbanization on streams are complex and defy simple identification of individual stressors, such as pollutants, that can be regulated and controlled. Physical habitat impairments in the Poquessing Creek Watershed are directly related to the way in which the land has been developed and thus are difficult to address with the TMDL framework, which is directed at identifying a pollutant and establishing wasteload allocations for that pollutant. A small number of TMDLs have been developed elsewhere to address urbanization in a more holistic fashion.

6.2 HISTORICAL PHYSICAL HABITAT INFORMATION

6.2.1 NLREEP ANSP STREAM QUALITY INDEX

As part of a grant from the William Penn Foundation to restore natural areas within the Fairmount Park system, the Academy of Natural Sciences of Philadelphia (ANS) created Natural Lands Restoration Master Plans for the Fairmount Park System (ANS 2000). In an effort to appraise the current status of stream channels as well as guide future restoration projects, ANSP developed an assessment program with two levels: “screening” and “detailed.”

The screening level assessment culminated in a Stream Quality Index (SQI) score for tributaries to mainstem Poquessing Creek. SQI was based on geomorphology, aquatic habitat, and riparian condition. Stream morphology data included observed bed morphology, planform, bar type, floodplain morphology, and channel cross-sectional area. Aquatic habitat assessments were composed of both the physical habitat as well as (qualitative) benthic macroinvertebrate community attributes. Finally, riparian condition was based on vegetation type and condition, width of vegetated corridor, and level of human disturbance. The resulting scores for each category were scaled to 100 and the three equally weighted components were combined to yield a final SQI score (0-300) that allowed for comparison of the relative condition of all reaches within the Fairmount Park system.

According to ANS,

> “There are a total of 20 stream reaches in Poquessing Park. The majority of reaches (80%) are classified as impaired. The other 20% of reaches are either severely impaired or moderately impaired.”(ANS 2000)

Table 6.1 Stream Quality Index Categories and Results* (reproduced from ANS 2000)

Stream Quality	Stream Quality Index Range	Number and % of Reaches - Fairmount Park System	Number and % of Reaches - Poquessing Creek Park
Severely Impaired	0 to 75	24 (6%)	1 (5%)
Impaired	76 to 150	155 (36%)	16 (80%)
Moderately Impaired	151 to 225	239 (56%)	3 (15%)
Slightly or Non-impaired	226 to 300	8 (2%)	0 (0%)
Totals	0 to 300	426 (100%)	20 (100%)

*Index and number of stream reaches do not include FDR Park

In addition to Stream Quality Index, ANS completed a detailed analysis of selected stream reaches. Detailed analysis was completed for channel geomorphology, cross-sectional area, sinuosity, meander wavelength, belt width, slope, pool/riffle structure, and substrate particle size distribution. One of the main goals of the survey was to determine the level of impairment within the Fairmount Park system due to urbanization, thus the number of reaches assessed per site (watershed) was a function of the total stream length in each park. Poquessing Creek, Tacony, and Fairmount East-West Parks had a total of two sites each, compared to four for Cobbs Creek Park and five for both Pennypack and Wissahickon Creek Park systems. In each stream, several reaches were selected for more detailed analysis and longitudinal profile, and five cross sections were surveyed. These cross sections, along with 14 others from streams within Fairmount Park, were compared to 16 reference reaches in Chester County, PA and Cecil County, MD. Results showed that urbanization had significantly changed the morphology of the stream segments (ANS 2000, Pizzuto *et al*., 2000).

6.2.2 PWD BASELINE BIOASSESSMENT OF POQUESSING CREEK WATERSHED 2001-2002

In 2001, the Philadelphia Water Department conducted EPA Rapid Bioassessment Protocols, including physical habitat assessments (Barbour *et al*. 1999) at 13 sites within the Poquessing Creek Watershed and its tributaries (PWD 2002). Locations were similar to the 2008 sampling effort, with the exception of sites identified as having changed (see section 5.3 for more information). The PWD Baseline assessment documented numerous signs of undesirable changes to the watershed’s natural communities and identified many occurrences of habitat degradation. The impairments observed were due primarily to the negative effects associated with stormwater runoff.

6.2.3 POQUESSING CREEK WATERSHED RIVERS CONSERVATION PLAN

The Pennsylvania Rivers Conservation Program is funded by the Pennsylvania Department of Conservation and Natural Resources (DCNR). The program provides funding and technical assistance to watershed stakeholders in order to carry out planning, implementation, land acquisition, and development activities packaged in a watershed River Conservation Plan (RCP). The Philadelphia Water Department received a grant from the DCNR to lead the development of an RCP for the Poquessing Creek Watershed in 2005 (completed 2007), with assistance from Borton Lawson Engineering and Forbes Environmental and Land Use Planning. Other participants included Fairmount Park Commission, Benjamin Rush State Park, Bucks County Conservation District, Montgomery County Conservation District, Friends of Poquessing, Delaware River Greenway Partnership, Lower Southampton Township Environmental Advisory Council, and Bensalem Township Environmental Advisory Board.

An RCP aims to identify natural and cultural resources within the watershed, identify sources of degradation, and recommend restoration techniques as well as other action items to conserve the landscape. The planning process includes forming a diverse group of watershed stakeholders to act as a steering committee for the plan, engaging the public in the planning process through outreach and educational events, and researching current and projected environmental and cultural conditions in the watershed. The RCP team compiled a list of 12 Goals and Recommendations for the watershed. One of the strongest recommendations was a push for more stringent stormwater management controls, which are presently being addressed by a watershed-wide Act 167 plan and revised stormwater regulations in the City of Philadelphia.

6.2.4 CITY OF PHILADELPHIA STORMWATER MANAGEMENT CONTROLS

As described in Section 2.11.1.1, as of January 2006, the City of Philadelphia's Stormwater Regulations provide more stringent controls for managing runoff from development occurring throughout Philadelphia. The Regulations are applicable to both new and redevelopment projects disturbing more than 15,000 ft^2 of earth. Specific stormwater requirements include Water Quality and Channel Protection components. The Water Quality criterion requires infiltration of the first inch of rainfall from all directly connected impervious area (DCIA). Should infiltration not be feasible, in part or in whole, then the stormwater must be treated before being released to the storm sewer. The Channel Protection criterion requires slow release of the one-year, 24-hour storm, a depth of 2.6 inches over the DCIA.

PWD and the Montgomery and Bucks county planning commissions are currently leading the development of an Act 167 Stormwater Management Plan for the Poquessing Creek Watershed, with an expected completion date of December 2010. Upon completion of this process, a model stormwater ordinance will be produced and provided to the municipalities within the Poquessing Creek Watershed for approval and adoption.

6.3 PHYSICAL HABITAT ASSESSMENT OF POQUESSING CREEK WATERSHED

Habitat conditions in the Poquessing Creek Watershed were assessed with a variety of techniques. Some assessment methods were evaluated with comparison to unimpaired reference streams (French Creek and Rock Run in Chester County, PA) selected for good habitat conditions. Other habitat metrics were based on models or comparison to literature datasets.

6.3.1 DEP INSTREAM COMPREHENSIVE EVALUATION (ICE) PROTOCOL HABITAT ASSESSMENT

6.3.1.1 FIELD STANDARD OPERATING PROCEDURES

Immediately following benthic macroinvertebrate sampling procedures, habitat assessments were completed at 12 sites (Figure 6.2) based on Pennsylvania DEP Instream Comprehensive Evaluation (ICE) protocols (PADEP 2009). Reference sites in French Creek, Chester County, PA were assessed and used to normalize assessment of the Poquessing Creek Watershed to the "best attainable" regional condition. It should be noted that both physical habitat assessment and benthic macroinvertebrate sampling followed PADEP ICE field and laboratory protocols.

6.3.1.2 DATA ANALYSIS

Habitat parameters were separated evenly into three principal categories. The first category includes those parameters that evaluate stream section conditions in the immediate vicinity of the benthic macroinvertebrate sampling point. The parameters of the second category evaluate a larger area surrounding the sampled riffle, generally defined by how far upstream and downstream the investigator can see from the sample point. The third and final category characterizes a larger area, defined as the length of stream that was typically electroshocked for fish, approximately 300 ft (PADEP 2009). Table 6.2 lists parameters addressed during habitat assessments.

Table 6.2 PADEP ICE Protocol Habitat Assessment Parameters

Condition Parameter	Condition			
	Optimal	**Suboptimal**	**Marginal**	**Poor**
Instream Fish Cover	16-20	11-15	6-10	0-5
Epifaunal Substrate	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
Channel Alteration	16-20	11-15	6-10	0-5
Sediment Deposition	16-20	11-15	6-10	0-5
Frequency of Riffles	16-20	11-15	6-10	0-5
Channel Flow Status	16-20	11-15	6-10	0-5
Condition of Banks	16-20	11-15	6-10	0-5
Bank Vegetative Protection	16-20	11-15	6-10	0-5
Grazing or Other Disruptive Pressure	16-20	11-15	6-10	0-5
Riparian Vegetative Zone Width	16-20	11-15	6-10	0-5

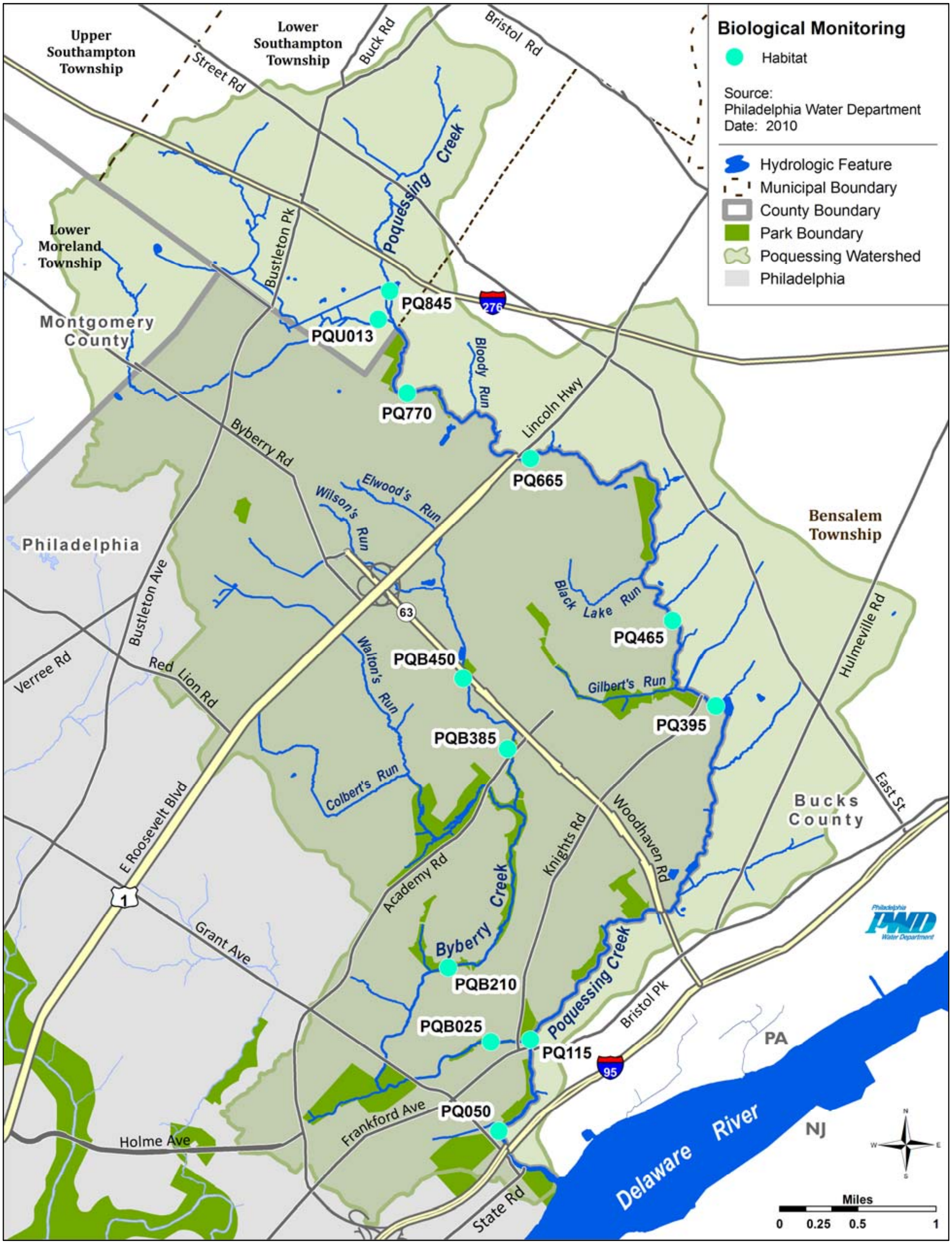

Figure 6.2 PWD Physical Habitat Assessment Sites in Poquessing Creek Watershed, 2008

6.3.1.3 RESULTS

Most sites in the Poquessing Creek Watershed were classified as "marginal," as scores ranged from a high of 139.5 at site PQ465, the only site with a habitat score in the "suboptimal" category, to a score of 63.5 at site PQB210, the only site appropriate for the "poor" category. There was no general longitudinal trend of improvement or degradation of physical habitat along either mainstem Poquessing Creek, as the aforementioned site PQ465 was located intermediate between sites with poorer scores, and scores did not appreciably increase or decrease consistently along the stream channel. Along mainstem Byberry Creek, habitat assessment scores generally decreased longitudinally from upstream to downstream within the City of Philadelphia with the exception of the downstream-most station PQB025, which improved slightly over the score at site PQB210 (Figure 6.3). A similar pattern was observed in mainstem Poquessing Creek, as the downstream-most site PQ050 score was greater than that of the upstream site PQ115.

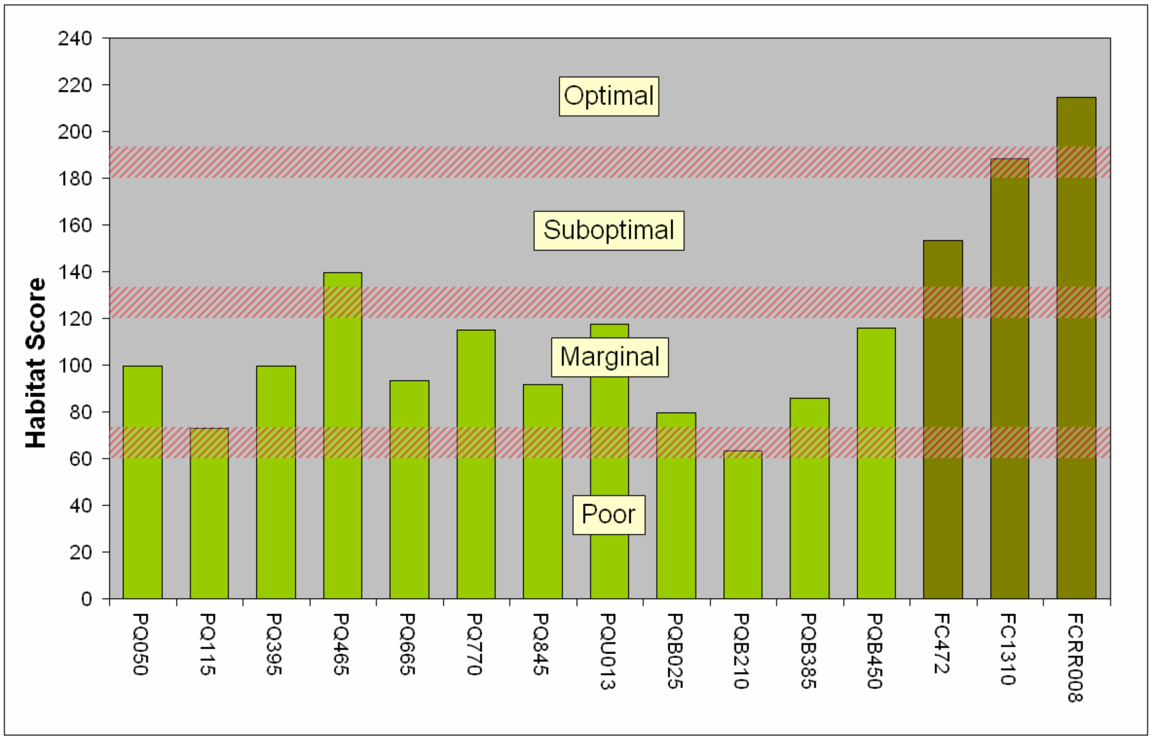

Figure 6.3 PADEP ICE Protocol Total Habitat Quality Score for Poquessing Creek Watershed and French Creek Reference Sites, 2008

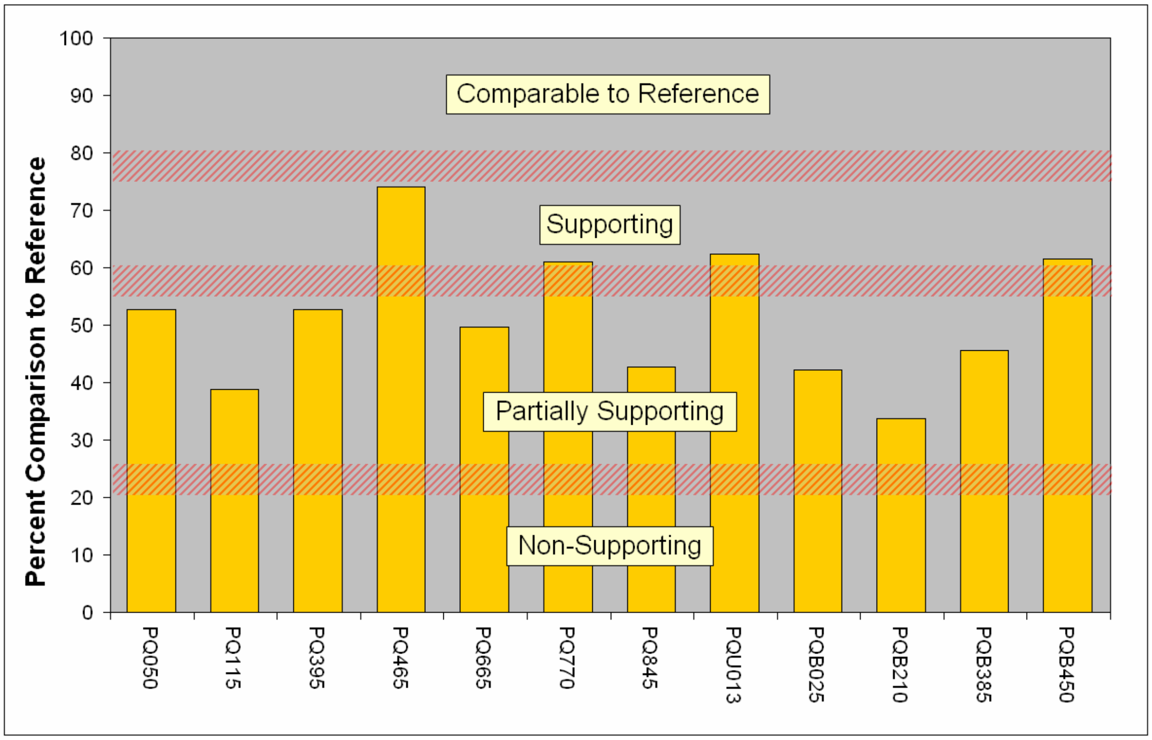

Figure 6.4 PADEP ICE Protocol Habitat Score Percent Comparison of Poquessing Creek Watershed Sites to French Creek Reference Sites, 2008

6.3.1.4 COMPARISON TO HISTORICAL RESULTS

Of the 12 physical habitat monitoring locations assessed in Poquessing Creek Watershed in 2008, 11 were also surveyed in 2001. The 2001 PWD Baseline assessment used USEPA Rapid Bioassessment Protocols (RBP) (Barbour *et al*. 1999), which are similar to the PADEP ICE methods used in 2008. However, the protocol used in 2008 contains 12 habitat scoring metrics, some of which are different from USEPA RBP metrics. The PADEP ICE protocol is clearly based on the USEPA RBP protocol, retaining the 0-20 scoring system for individual metrics as well as condition category descriptions for interpretation of the multimetric habitat index. Many of the habitat assessment metrics are identical, or at least analogous, to EPA scoring metrics.

USEPA RBP Physical Habitat assessments conducted by PWD in 2001 contained 13 metrics, as PWD biologists at the time elected to include three additional habitat metrics from the "low gradient streams" protocol along with the high gradient streams metrics. PWD did not attempt to make pairwise comparisons between similarly named or analogous individual habitat scoring metrics in the two assessment periods. Given the caveats of different assessment methods, a coarse comparison to historic data was performed by normalizing habitat scores to a percentage of the total possible habitat score (Figure 6.4). Maximum total score for RBP assessments was 260 (13*20) and 240 (12*20) for PADEP ICE protocols.

Habitat scores, as normalized to percentage of maximum possible habitat score, decreased very consistently across all sites, with the exception of the upstream-most (PQ845, PQB450) and reference (FC1310) sites. All other sites demonstrated decreases in habitat score of approximately 20% between assessment periods. The fact that upstream-most sites and the reference site did not experience deterioration in habitat score provides some support for the theory that habitat has declined by a similar amount watershed-wide. However, even when working with normalized data, one should use caution when making comparisons of this type, as differences in scores from year to year may not be due to an actual change in habitat conditions. Even with the same field crew of experienced biologists performing the assessments, it is probably more appropriate to compare sites to other sites assessed within the same year than to compare scores at the same site from year to year.

Some habitat parameters (or parameter groups) might be expected to change rapidly at a single site, such as a local disturbance of removing riparian buffer for a housing development, while other parameter scores might decrease consistently across many sites, such as a series of destabilizing flood events that caused erosion and sedimentation watershed-wide. Conversely, differences may reflect a change in perception or interpretation of the habitat condition categories on the part of the observers, or perhaps a subtle difference in the particular segment to which the assessment was directed, rather than a real change. Habitat conditions in Poquessing Creek Watershed may be deteriorating overall, but comparison of 2008 habitat assessment results to 2001 EPA RBP habitat data is not conclusive proof that this is the case.

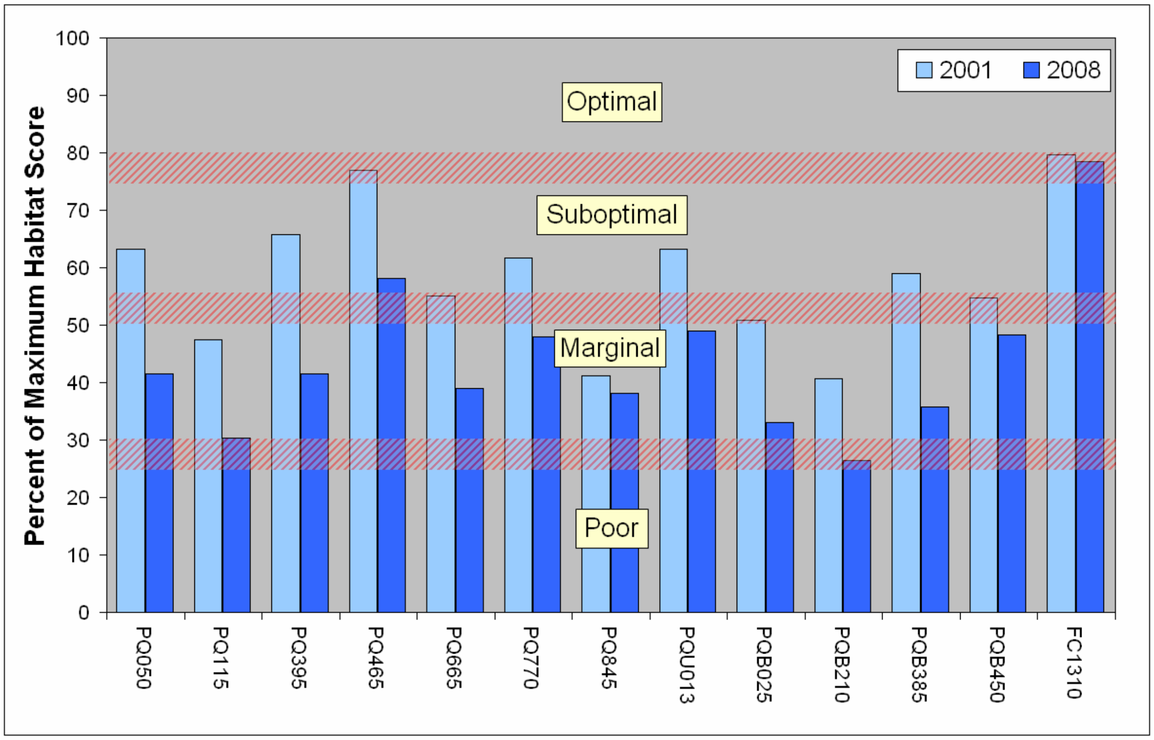

Figure 6.5 Normalized Habitat Scores for Poquessing Creek Watershed and French Creek Reference Sites, 2001 and 2008

6.3.2 FISH HABITAT SUITABILITY MODELING

6.3.2.1 BACKGROUND INFORMATION

From 2003 to 2008, PWD employed Habitat Suitability Index (HSI) models developed by the U.S. Fish and Wildlife Service (USFWS) (Edwards *et al.* 1983b, Aho *et al.* 1986, Edwards *et al.* 1983a, Trial *et al.* 1983c, McMahon 1982, Trial *et al.* 1983a, Raleigh *et al.* 1986, Raleigh *et al.* 1984) in order to explore relationships between physical habitat and populations of individual fish species. The last HSI modeling effort took place in 2008 for the Pennypack Creek Watershed Comprehensive Characterization Report (PWD 2009), when HSI models for eight species were completed. Although in some cases HSI models produced satisfactory results in predicting abundance or biomass of fish species, these models were generally found to be too simplistic (taking into account too few variables), too complicated (too many variables, many of which were co-varying or not helpful in predicting suitability), or contained variables with suitability curves that could not be effectively applied to subject Philadelphia area streams due to data incompatibility or observed effects that were the opposite of those predicted by the models.

HSI models available for common fish species in the Philadelphia region differ greatly in the extent to which they incorporate physicochemical variables such as temperature, turbidity, dissolved oxygen, and pH. These factors clearly may influence suitability of conditions at a site for various species of fish, however, PWD typically conducts continuous water quality monitoring at a subset of fish assessment sites for a given watershed. With the exception of turbidity, each of these parameters has applicable water quality standards with which to evaluate whether water quality is supportive of aquatic life. For the Poquessing Creek Watershed Comprehensive Characterization Report, PWD made the decision to discontinue use of HSI models in order to focus on basic habitat characteristics of depth, velocity, and substrate. This approach has two benefits: First, the data processing tasks associated with assembling the disparate datasets required for each individual species' HSI model was eliminated. Second, the new modeling strategy is more compatible with PWD stream restoration monitoring methods.

Moving forward, PWD has chosen to focus on aspects of the physical habitat that can be surveyed accurately and quantitatively. With considerable effort, very accurate stream channel geometry data can be obtained, from which measures of habitat heterogeneity and total habitat area with certain combinations of physical factors can be calculated. These habitat attributes are then compared not to individual species' habitat requirements, but to generalized habitat "guilds," or groups of species for which the interaction with aspects of the physical habitat are similar (Bovee *et al.* 2007). As our understanding of the relationships between habitat features and fish community metric response grows, these relationships can be calibrated to the effects observed.

It is not our intention to state that the HSI modeling philosophy, or any individual HSI models, are themselves faulty or contain fallacious logic; PWD recognizes that our application of these models was primarily to impaired urban streams with, in most cases, a greater level of data availability than cases used for development of the models (*e.g.*, continuous water chemistry datasets). Furthermore, model developers recommended that in any application of the models, individual model assumptions and data relationships should be examined for local effects and modelers should exercise professional judgment, consult with regional experts when necessary, and consider the possible effects of other factors when interpreting model output.

6.3.2.2 HABITAT SUITABILITY MODEL SELECTION

As described above, PWD uses traditional surveying methods to obtain, albeit in a labor-intensive fashion, a very large series of channel geometry data for each target site. It was not feasible to measure velocity at thousands of instream points, so site hydrodynamics were modeled using the two-dimensional (2D) depth-averaged finite element hydrodynamic model River2D. The model was developed at the University of Alberta by Peter Steffler and Julia Blackburn in 2002 and has been widely used in fish habitat evaluation studies. The River2D model suite consists of four programs (R2D_Bed, R2D_Ice, R2D_Mesh and River2D) generally used in succession. River2D_Ice is used to model ice-covered domains, thus it was not necessary to use this program for the fish habitat assessment.

Numerous assumptions are inherent with use and interpretation of habitat suitability models. First and foremost is the assumption that habitat features are responsible, at least in part, for determining some measurable environmental response, such as abundance or biomass of the species of interest at the study site. As stated above, one of the primary reasons for selecting River2D as a modeling tool was the decision to eliminate physicochemical variables from consideration and focus on the physical habitat. In practice, for urban streams, the process of habitat degradation can be generalized as a gradient of decreasing habitat heterogeneity and increased hydrologic disturbance (Schlosser 1987, Resh *et al.* 1988). Fish assessments and physical habitat surveys were conducted in June and July, respectively, under baseflow conditions. Physical habitat was modeled such as to evaluate conditions present during the actual fish surveys. PWD recognizes that disturbance likely plays a major part in structuring biological communities in small urban streams such as Poquessing Creek, and other flows may be more influential, in fact, than the baseflow conditions that were modeled. PWD is in the process of evaluating additional measures of hydrologic disturbance due to urbanization, such as “flashiness” indices, in order to take these effects into account in future modeling efforts.

6.3.2.3 HABITAT SUITABILITY MODELING FIELD METHODS

The first and ultimately the most crucial step involved in 2D finite element modeling is the representation of the stream channel bathymetry. Channel bathymetry data was collected during the summer of 2008 using a TOPCON® Model GTS 235 Total Station. The x- and y-coordinates were taken as eastings and northings, respectively, based on the Pennsylvania State Plane South datum of 1983, and the z-coordinates (elevations) were based on the City of Philadelphia vertical datum.

Point coordinates were collected at baseflow conditions at both the right and left edges of flow and within the stream channel, both at about 1.0 m resolution. With respect to the downstream direction of flow, stream margins were coded as either (REW) or (LEW), for right edge of water and left edge of water, respectively. Points taken within the stream channel were coded (SB) for streambed or (RCK) for boulders. Other features of interest consisted of point bars, bankfull elevations, stream banks and top of banks coded as (PBR), (BKF), (BNK) and (TOB), respectively. As these features were not within the wetted channel, data points were distributed throughout the domain at a lower resolution. Care was taken to distribute the acquisition of bathymetry coordinates in direct proportion to channel bed heterogeneity and complexity. Coordinates surveyed in homogenous areas (*i.e.*, flat, shallow runs) were distributed farther apart than coordinates surveyed in more heterogeneous areas such as steep gradient cobble-boulder riffles. At the upstream-most riffle, stream discharge (ft^3/s) was recorded at each site using a FlowTracker® Handheld ADV.

Following the collection of channel bathymetry data, substrate data was collected at approximately 1 m^2 resolution. Using a raster of the bed topography dataset, the channel was surveyed visually and lithofacies or “facies” were drawn onto the raster map using appropriate symbology to represent all sediment classes between silt and boulder. Scanned versions of these maps are presented in Appendix M. Lithofacies refer to groupings of channel-bed alluvium of similar grain-size (Kondolf and Piegay 2003) such as sand, coarse gravel, or cobble.

6.3.2.4 RIVER 2D MODEL INPUT DATA PROCESSING

6.3.2.4.1 RIVER 2D BED

River2D_Bed, a graphical bed topography preprocessor, allows for graphical representation and editing of the model domain. The normal modeling process involves creating a preliminary bed topography file (tab- or comma- delineated text file) from the raw field data in the form of x-, y-, and z-coordinates, then editing and refining raw data using R2D_Bed (Steffler and Blackburn 2002). In R2D_Bed, bed topography files were edited and finalized following the collection of bathymetry data nodes. During the editing process, nodes were transformed into a triangulated irregular network (TIN), which allowed for appropriate bed topography editing and quality assurance measures. It is generally recommended that “elements,” which form the triangles in TINs, maintain a size distribution such that adjacent elements never differ in size by more than a factor of 1.5 (Steffler and Blackburn 2002). In instances where element sizes exceeded this threshold, nodes in the vicinity of the element of interest were deleted or new nodes were added to increase or decrease the size of an adjacent element, respectively. The model also requires a minimum of eight to ten elements to span the width of the channel throughout the model domain. Where nodes were added to the domain, the easting, northing and elevation values were interpolated by River2D_Bed. When element distribution criteria were satisfied, the channel thalweg was defined by connecting bathymetry nodes with break-lines. Break-lines were also used to define stream margins (REW and LEW), top of banks (TOB) and other prominent linear features such as the precipices of steep, undercut banks.

6.3.2.4.2 RIVER 2D SUBSTRATE ROUGHNESS DERIVATION

The next step in the bed topography editing process was the assignment of roughness values to each node in the domain. R2D_Bed allows the user to insert roughness values globally, regionally via polygons, or at an individual node throughout the model domain. Roughness values in this assessment were inserted using irregularly-shaped polygons that corresponded to the respective lithofacies observed at each site. Roughness values were assigned to each of the eight sediment classes (*i.e.*, silt, sand, coarse sand, fine gravel, gravel, coarse gravel, cobble and boulder) using a modified version (Arcement and Schneider/USGS, 1989) of the Cowan Method (Equation 6.1), which incorporates factors such as the shape of the channel and the size and type of materials that compose the channel bed and stream banks when estimating Manning’s n values.

$$\mathbf{n = (n_b + n_1 + n_2 + n_3 + n_4)m} \qquad \text{(Eq. 6.1)}$$

where:

n_b = a base value of Manning's n
n_1 = a correction factor for the effect of surface irregularities in the stream channel
n_2 = a value for variations in shape and size of the stream channel's cross-sectional dimension
n_3 = a value for obstructions in the channel
n_4 = a value for vegetation in the channel
m= a correction factor for sinuosity of the channel

In R2D_Bed, Manning's n values corresponding to the respective lithofacies were converted to a roughness height (k_s) according to the formula (Equation 6.2):

$$\mathbf{k_s = (12H)/e^m} \qquad \text{(Eq.6.2)}$$

where "H" equals flow depth and "m" is equal to:

$$\mathbf{m = H^{1/6}/(2.5n\sqrt{g})} \qquad \text{(Eq. 6.3)}$$

where "g" equals acceleration due to gravity.

It was necessary to develop multiple classes of roughness values for sites PQ845 and PQB385, as the hydraulic radius varied dramatically between segments of the respective assessment sites. Once all roughness values were entered, the computational boundary was created around the model domain (wetted channel). The final step needed to prepare bed topography files for the mesh editor involved extending the model domain upstream and downstream of inflow and outflow boundaries, respectively. This was done to ensure the constructed meshes created in the next program would fall within the defined topography. Without this step, it was observed that portions of constructed meshes near inflow and outflow boundaries would extend slightly outside the prescribed computational boundaries. In these situations, the mesh would not have topographic data to reference, causing the model to crash. These modifications had no effect on flow calculations; they merely allowed for improved mesh quality. Following this step, each file was saved with a ".bed" extension. Bed topography files for each site are presented in Appendix M.

6.3.2.4.3 RIVER 2D MESH

The next step in the process was to create a computational mesh in River2D_Mesh, which is the second model-preprocessor. Creation of computational meshes for each of the finished bed topography files involved the same process. Each bed topography file was first imported into the R2D_Mesh application and boundary nodes were generated at 15-m spacing around the computational boundary and triangulated. Next, the inflow and outflow mesh boundaries were parameterized. In R2D_Mesh, inflow boundaries are determined by setting the inflow discharge (Q_{in}) along the boundary nodes that comprise the inflow portion of the computational boundary. A similar process is used for the outflow boundary, except that an outflow elevation is used instead of discharge. The program allows parameters for both types of boundaries to be set at all nodes simultaneously using the "set inflow/outflow by area" command. To ensure that River2D would compute an accurate flow solution at the inflow and outflow boundaries, existing boundary segments were bisected such that both boundaries comprised at least 15-20 boundary nodes.

Using the "uniform fill" command, mesh nodes were added to the entire mesh at 1.0-m to 2.5-m resolution and triangulated. These mesh node densities were determined empirically, based on the degree to which different resolutions of computational meshes could capture flow field variations within the channel. In general, finer meshes with node spacing between (1.0-2.5 m) performed better than coarser meshes in capturing flow variations, as determined by comparison of velocity vectors. Conversely, mesh node densities below 1.0/m^2 offered no additional capacity to capture variations in the flow-field yet made the model run much slower. In areas where the bed topography exhibited increased spatial heterogeneity, additional mesh nodes were added to ensure variations in the flow field would be fully captured.

The positioning and size of mesh elements were then modified such that all elements were close to uniform in shape. Special attention was given to mesh nodes near lateral boundaries, as the non-linear planform of natural channels often causes elements to form irregular shapes (*i.e.*, scalene triangles) in areas where the channel boundary begins to meander or is extremely curvilinear. In instances when irregular triangles formed near boundaries, either additional nodes were added or boundary segments were bisected to allow for smaller, more regular elements that could better capture variations in channel boundary forms. Once mesh nodes were added and elements were triangulated, the file was saved with a ".msh" extension.

Additional modifications to meshes were based on several quality control parameters that govern the computational success of created meshes. To ensure that mesh elements capture variations in bed elevation, an elevation difference threshold parameter can be set. This parameter specifies the maximum allowable elevation difference between bed topography nodes and mesh elements; any elements that are above the prescribed threshold are highlighted. This threshold ultimately depends on the scale of the project. Considering the size of the reach, it was necessary to capture as much small-scale variation as possible, thus a 0.03-m threshold was used for each mesh. Elements displaying elevation differences greater than the threshold were altered by decreasing the size of both the highlighted element and adjacent elements such that none of them would be positioned between two areas of the channel that had rapidly changing elevations. There were, however, some instances where mesh nodes were added or deleted to remove highlighted elements.

Another parameter, the Quality Index (QI), measures the size uniformity of each mesh element such that the QI increases as irregularly-shaped (obtuse or scalene) elements are modified to a more equilateral shape. A perfectly straight channel would have a completely uniform element size distribution and a QI of 1.0. Given that natural channels are not straight, values this high are not possible and QI values between 0.35-0.50 are considered acceptable. Meshes created for each of the bed topography files had QI values between 0.45-0.53 (Table 6.3).

Table 6.3 River2D Model Information for 5 Sites in Poquessing Creek Watershed, 2008

	River2D_Bed		River2D_Mesh		
SITE	Nodes	Density (nodes/m²)	Nodes	Elements	QI
PQ050	882	0.75	3701	7354	0.53
PQ115	983	1.20	1265	2509	0.51
PQ825	1689	3.01	4059	8095	0.53
PQB025	1320	1.61	2450	4884	0.45
PQB385	1565	2.22	1996	3963	0.46

Computational meshes were considered ready for input into the hydrodynamic component of the model (River2D) once all quality control parameters reached satisfactory values. At this point, mesh files were saved with a ".cdg" extension, which is the file format used by the River2D hydrodynamic model. Upon saving, it was necessary to enter an approximate inflow water surface elevation. Steffler and Blackburn (2003) recommended using the elevation along the inflow boundary that is halfway between the elevations of the inflow boundary nodes at the right and left banks.

6.3.2.5 FLOW CALIBRATION

At several sites, the stream discharges measured at the upstream cross sections were not high enough to fully inundate the observed wetted channel throughout the modeled domain. In all instances, the modeled wetted channel was between 5-10% of the observed wetted channel. This phenomenon was likely due to the generally over-widened channel morphology present in the Byberry and Poquessing Creek stream networks, which in turn produce very shallow riffle depths. In instances where flow depths reach the minimal allowable depth of 0.01 m, River2D essentially "turns off" non-inundated elements and routes flow through these elements as groundwater. It may have been possible to increase flows to the shallow margin areas of the domain by adjusting the groundwater transmissivity and storativity parameters throughout the model domain, however the availability of data needed to re-parameterize these components was limited. As such, it was difficult to obtain flow field solutions at the margins of the observed wetted channel throughout the entire domain. Characteristic baseflow discharges were evaluated using a Microsoft® Excel-based cross-sectional flow model developed by Dan Mecklenburg of the Ohio Department of Natural Resources. Water surface elevations were scaled to the elevation of the edge of water within inflow cross sections. The resulting discharge values were then used in place of the field-measured discharge values.

6.3.2.6 RIVER 2D MODEL EXECUTION

Once imported into River2D, steady-state flow field solutions to each ".cdg" file were computed. The default values for steady-state flow parameterization were used as these were all suitable for the relatively small streams with non-supercritical flow found in the Poquessing Creek Watershed. Each flow solution took a maximum of 1,000 time steps before reaching steady state. After flow solutions (spatial distribution of depth and velocity) were computed, it was then possible to begin the habitat evaluation process. The River2D hydrodynamic model also has the capability to output spatial distributions of shear stress, shear velocity, and Froude number as well as water surface elevation.

6.3.2.7 RIVER2D MODEL FISH HABITAT SUITABILITY PREFERENCE FILES

The River2D model uses the Physical Habitat Simulation (PHABSIM) methodology to quantify the physical habitat available within the stream according to a species-specific habitat suitability index (HSI). A given species-specific HSI contains information on the biological preference (based on probability of use) for the habitat variables depth, velocity, and substrate. Through multivariate analysis, the River2D habitat component uses the HSI criterion and the model's hydrodynamic output to compute the metric weighted usable area (WUA). WUA represents the proportion of stream area predicted to be available to a given species weighted by the probability of use as determined by the HSI. The habitat component of the River2D hydrodynamic model also has the capacity to produce spatial distributions of depth, velocity and substrate suitability individually. The metric Habitability (H) (Equation 6.4) was created to allow comparison between the different reach given they differ in surface area. This metric provides the proportion of each fish assessment site that could serve as suitable habitat for each of the respective guilds.

$$\mathbf{H} = \frac{\mathbf{WUA}}{\mathbf{Surface\ Area}} \qquad \text{(Eq. 6.4)}$$

In order to make predictions about a wider range of fish species, WUA was compared between fish habitat guilds instead of individual species. Guilds represent a way to classify or group species based on the physiological structures, adaptations or behavioral mechanisms used to acquire food. The guilds evaluated were riffle-specialists, *e.g.*, longnose dace (*Rhinichthys cataractae)* and margined madtom (*Noturus insignis*); pool-specialists, *e.g.*, smallmouth bass (*Micropterus dolomieui*) and large sunfish (*Lepomis sp*.); and habitat generalists, *e.g.*, blacknose dace (*Rhinichthys atratulus*), American eel (*Anguilla rostrata,* sunfish (*Lepomis sp*.) and creek chub (*Semotilus atromaculatus*). Figures 6.6-6.8 represent the guild-specific habitat suitability relationships for depth, velocity, and substrate respectively. Values for depth, velocity, and substrate were based on existing U.S. Fish and Wildlife Service (USFWS) HSI models and best professional judgment, as there is currently a paucity of fish habitat-guild suitability data.

The riffle guild is intended to represent the habitat requirements of longnose dace and margined madtom, fish that live within the fastest areas of current within the stream channel. While these small fish are not recreationally important, they occupy the same habitat as the most sensitive stream invertebrates (pollution-sensitive mayflies stoneflies and caddisflies). Where suitable conditions exist for these fish, physical habitat suitability for sensitive invertebrates is expected to be high. Conversely, if hydrodynamic conditions indicate insufficient depth, velocity, or substrate size for riffle guild fish, suitability of habitat for sensitive invertebrates is also assumed to be poor. Stream channels have the smallest cross sectional area at riffle features and, due to their relative stability and tendency to also have the greatest substrate diameter, riffle cross-sectional profiles are commonly used in fluvial geomorphological studies. No habitat suitability information was available for margined madtom, so the habitat suitability preference file for the riffle guild was based on the USFWS longnose dace HSI model velocity and depth suitability curves (Trial 1983) with the exception of extrapolating the tail of the depth curve to SI = 0 at 2 m depth (Figures 6.6 and 6.7). Best professional judgment was used to estimate riffle guild substrate suitability, assuming that larger substrates are required given the greater shear stress present in riffle microhabitats (Figure 6.8).

Habitat generalist preference curves are not intended to represent the habitat needs of any one particular species, rather to create a composite set of relationships expected to be positively correlated with fish abundance and biomass. Generalist fish can be viewed as occupying a continuum of conditions, in which a few species can exist or even thrive at the extremes. Small cyprinids, notably blacknose dace, are often found near the headwaters of small streams, and can even survive in disconnected shallow pools with no surface flow. At the opposite end of the depth spectrum, some detritivore and omnivore fish species such as carp, white suckers, and catfish may be found in the deepest, slowest pools within a stream segment where they attain very large size. But overall, deep pool habitats tend to be depositional areas with reduced light penetration and small substrate size. These characteristics make them low primary productivity areas unsuitable for growth of algal periphyton.

Extensive areas of deep water are not suitable for many lotic minnow species, and stream fish communities will generally exhibit greater diversity and productivity when depth conditions are heterogeneous. The generalist guild depth and velocity suitability curves (Figures 6.6 and 6.7) are thus relatively broad, but depth suitability decreases as depth approaches 2 m. Depth suitability has not been extrapolated to zero, in order to represent the fact that many of the aforementioned generalist omnivore and detritivore species will still be found in very deep pools. In interpreting the results of habitat suitability modeling, PWD intends to represent smaller, more generalist feeding life stages of fish, particularly some Centrarchids, as generalists, while larger piscivorous life stages of these fish are considered pool specialists.

The pool specialist guild is intended to represent large piscivorous centrarchids, such as smallmouth bass, rock bass, and green and redbreast sunfish. These fish can be described as “sit and wait” predators, exhibiting the greatest preference for deep, slow water where energy expenditures associated with prey acquisition are kept to a minimum. Smallmouth bass are often found in large rivers, so for the purpose of evaluating habitat suitability for small streams, no upper limit was set for depth suitability and all depths greater than 1 m were considered perfectly suitable (SI = 1, Figure 6.6). Many large piscivorous pool specialist fish are very strongly associated with cover features, however assessing cover in a quantitative fashion is a difficult task. PWD hopes to eventually be able to incorporate an adjustment to pool suitability scores to account for the amount and quality of associated cover.

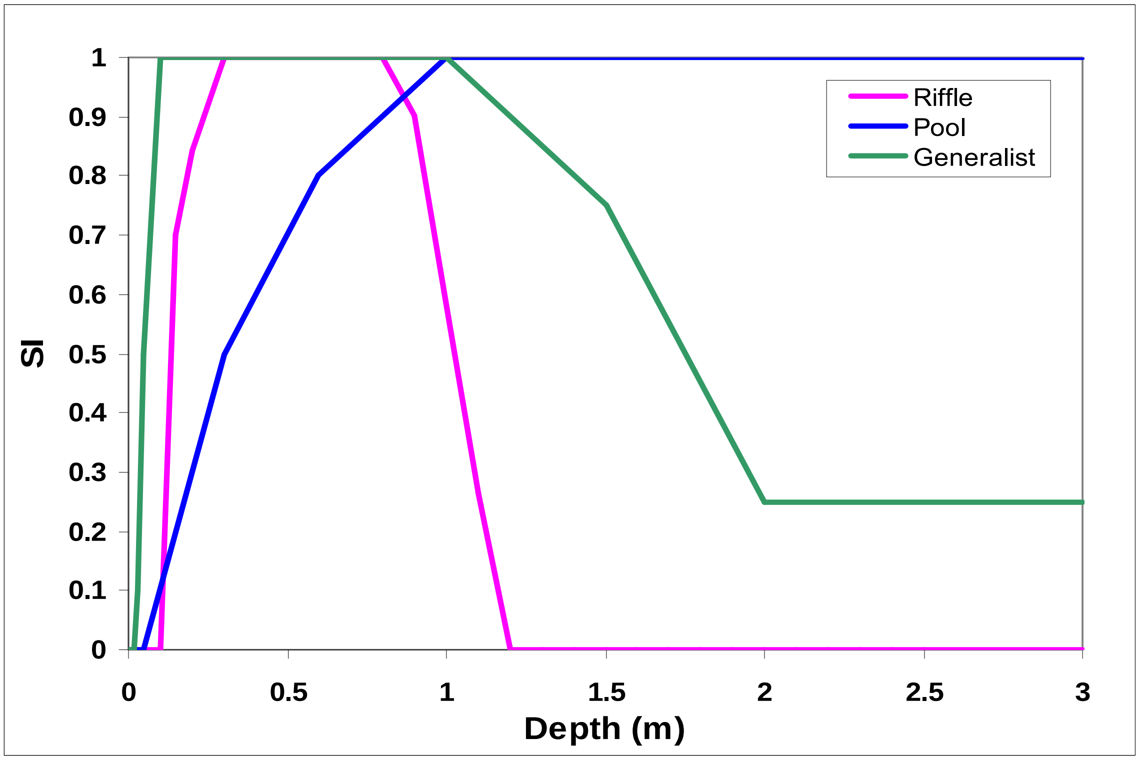

Figure 6.6 River2D Fish Habitat Depth Preference Curves for Three Generalized Species Guilds

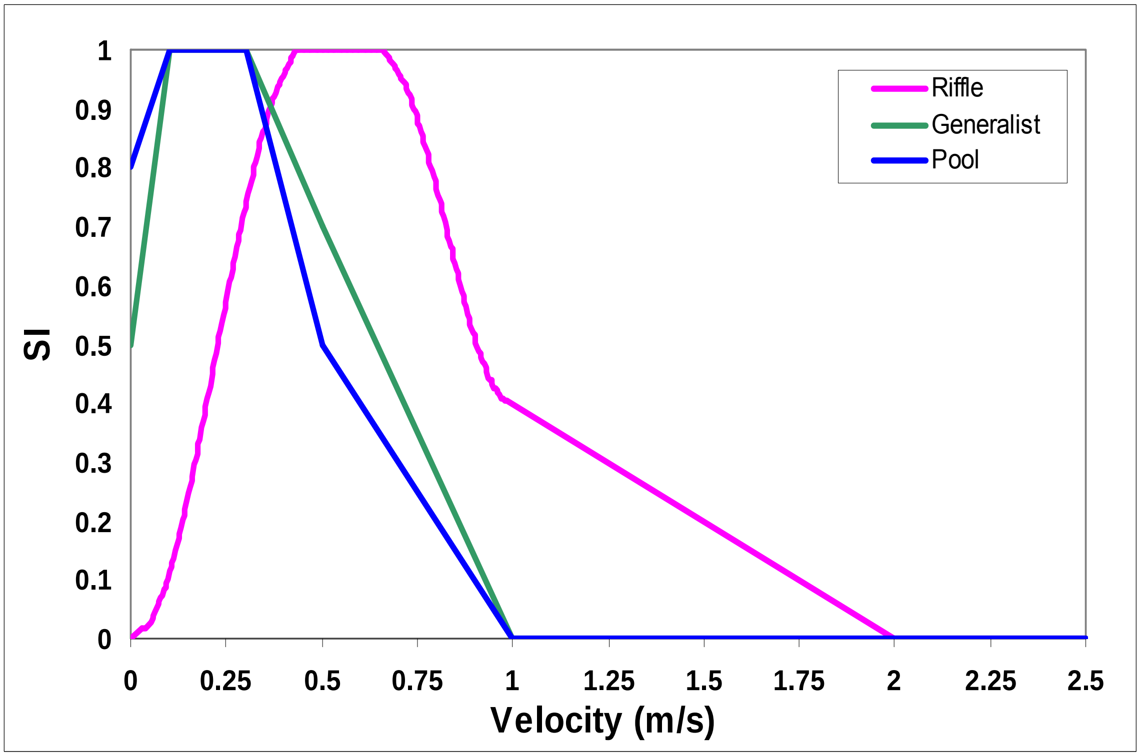

Figure 6.7 River2D Fish Habitat Velocity Preference Curves for Three Generalized Species Guilds

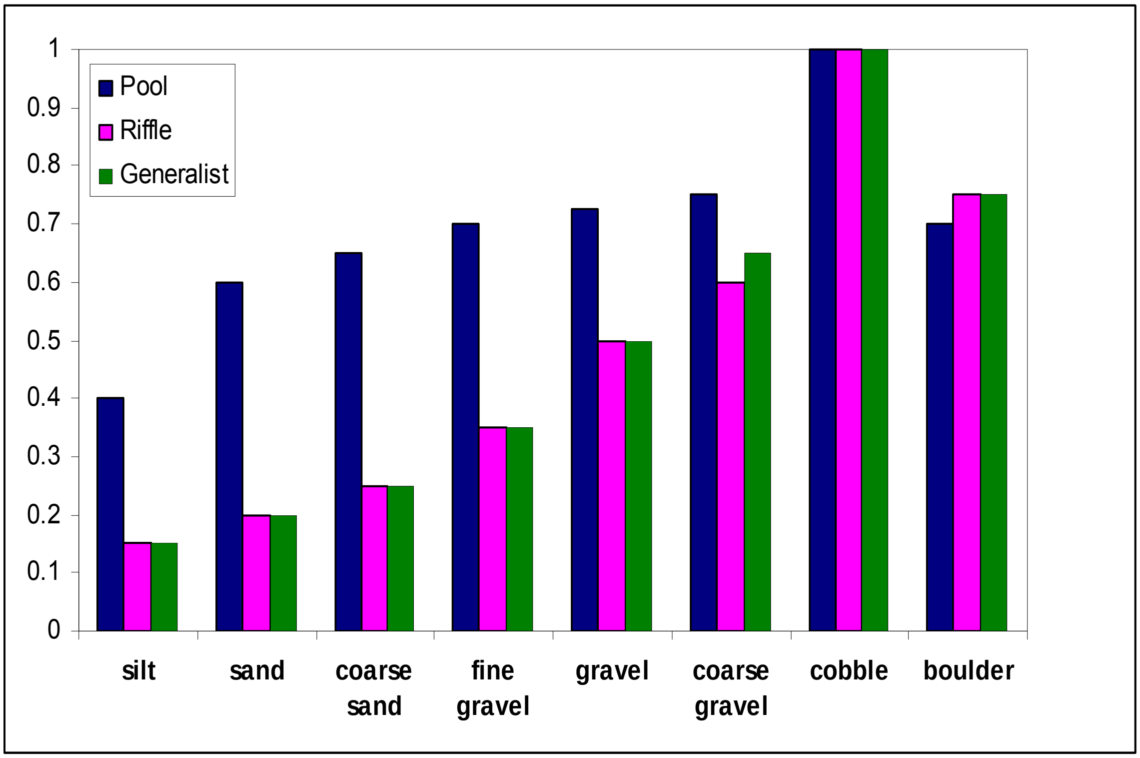

Figure 6.8 River2D Fish Habitat Substrate Preference Relationships for Three Generalized Species Guilds

6.3.2.8 RESULTS

Within the fish habitat assessment sites, WUA ranged from18.93 – 84.08 m² for the riffle-specialist guild (WUA_r), 90.78 – 162.89 m² for the pool-specialist guild (WUA_p) and 197.39 – 284.74 m² for the habitat-generalist guild (WUA_g). Values of H ranged from 2.32% – 11.92% for the riffle-specialist guild (H_r), 11.54% – 21.53% for the pool-specialist guild (H_p), and 24.14% – 43.50% for the habitat-generalist guild (H_g) (Table 6.4). Overall, habitat-generalist guild maintained the highest WUA and H at each site assessed with the pool-specialist guild maintaining the second highest WUA and H at all sites. Riffle habitat suitability was generally limited at all sites although at PQB385, WUA_r (84.08 m²) and H_r (11.92%) were somewhat comparable to WUA_p (90.78 m²) and H_p (12.87%). PQ825 presented the most optimal array of suitable habitat for all three guilds as H ranged from 7.94% – 43.50% (mean 24.32%); whereas PQ050 presented the least amount of usable habitat area among the sites assessed as H ranged from 2.56% – 24.14% (mean 13.12%).

In general, HSI model output rendered by the model did not agree completely with the results of field data collected at the fish assessment sites, although there were several relationships that exhibited positive responses. Models that aim to predict habitat suitability for small minnows (*i.e.* Longnose Dace) that inhabit riffles might be expected to have a strong relationship with fish abundance per unit surface area. This positive relationship (r = 0.88) was observed in correlation analyses between H_r and density (*i.e.* abundance per unit area); however, there was a relatively weak positive correlation (r = 0.64) between mean WUA and total abundance at each site. The metric (H_g) had a moderately high correlation (r = 0.71) with the percentage of generalists species collected during fish abundance assessments; although most relationships between modeled habitat data and the results of field data were not in accordance with expected results. There was a strong negative relationship between site scores for Shannon Diversity Index (SDI) – a measure of species diversity – and the mean H (-0.92) at each site. This result was not in accordance with the expected relationship between the datasets given the number of species observed tends to increase with increased area (*i.e.* species-area effect). Similarly, relationships between respective values of H for each guild and measures of species diversity (*e.g.* SDI) were found to be strongly negative (*e.g.* r = -0.70 and r = -0.83 for H_r and H_g respectively).

This may be an indication that physical habitat may not be the most critical factor in structuring the distribution and abundance of fish species in the Poquessing Creek Watershed. Other factors such as water quality, frequency of disturbance and the availability of food items are also known to be critical factors that influence the ecology of fish communities. These results may also be limited by the small sample size (n=5) given the limited number of fish assessment sites. As such, the most informative results were comparisons made between sites as well as evaluations of both composite habitat suitability (*i.e.* WUA) and the suitability of each respective HSI component (*i.e.* depth, velocity, and substrate) with respect to each site. PWD is currently exploring other statistical tools and data collection methods to study fish and macroinvertebrate habitat relationships.

Table 6.4 River 2D Weighted Usable Area for 3 Generalized Fish Guilds at 5 Sites in Poquessing Creek Watershed, 2008

SITE	Q (m^3/s)	Length (m)	Area (m^2)	$Depth_{max}$ (m)	$Velocity_{max}$ (m/s)	WUA_p (m^2)	WUA_r (m^2)	WUA_g (m^2)	H_p (%)	H_r (%)	H_g (%)
PQ050	0.15	114.91	1179.42	0.73	0.62	149.34	30.27	284.74	12.66	2.56	24.14
PQ115	0.10	115.21	816.16	0.64	0.45	94.17	18.93	255.71	11.54	2.32	31.33
PQ825	0.146	109.12	545.09	0.74	0.65	117.34	43.26	237.52	21.53	7.94	43.5
PQB025	0.25	106.07	822.04	1.69	0.96	162.89	60.84	250.46	19.82	7.40	30.47
PQB385	0.146	110.95	705.37	0.63	1.47	90.64	84.08	197.36	12.87	11.92	27.98

6.3.2.8.1 PQ050

Site PQ050 was the largest of the five fish assessment sites, with a surface area of 1,179.42 m^2. Like many streams in highly impervious watersheds, the stream channel was excessively widened due to the effects of hydrograph "flashiness." The wetted channel exhibited characteristics of a Rosgen type F4 channel, with steep vertical banks and a high width:depth ratio. The dominant mesohabitat was characteristic of a shallow run, with slow velocity and fine to intermediate grain-size sediment distribution. The riffle morphology of the wetted channel was typical of excessively widened (Figure 6.10) channels as the three riffle segments were characterized by low depth and a rather homogenous velocity distribution; however there were large boulders in each riffle that provided a more heterogeneous velocity distribution where flow was diverted around their respective locations. These obstructions also created velocity refugia directly downstream of their location. Velocity refugia are crucial habitat features as they serve as important resting areas for fish when foraging in riffles. The three largest boulders at the site were in the downstream-most segment of the reach and are represented as large irregularly shaped white circles. A TIN of the site georeferenced to orthophotography is depicted in Appendix A, Figure A.1.

This site was determined to have the most limiting habitat template among the fish habitat sites assessed, as (H) at PQ050 had the lowest range (2.56%-24.14%). The generalist guild had the highest WUA (284.74 m^2), followed by the pool-specialist guild (149.34 m^2) and the riffle-specialist guild (30.27 m^2). (Table 6.4) With respect to WUA, PQ050 had the largest amount of usable habitat space for all guilds among all sites assessed—although it must be noted that PQ050 had a much larger surface area than any other site. Conversely, WUA_r was among the lowest values observed in the habitat assessment. Velocity suitability at the site was highest for the pool-specialist guild (approximately 95%) followed by the habitat-generalist (approximately 90%) and riffle-specialist guild (approximately 10%) respectively; however, the increased depths required by pool-specialists rendered large areas of the wetted channel unsuitable as less than 20% of the channel had unsuitable depth. Depth suitability for both the riffle-specialist and habitat-generalist guilds was estimated at 90%. Substrate suitability was highest for the pool-specialist (approximately 85%) guild followed by the habitat-generalist (approximately 65%) and riffle-specialist (approximately 15%) guilds. The substrate distribution throughout much of the channel was dominated by coarse sand and coarse gravel, although large patches of cobble and boulder clusters were present in distinct patches throughout the reach. A scanned image of the field substrate assessment for site PQ050 is presented in Appendix M, Figure M.3.

Suitable habitat for the riffle-specialist guild was present within only two of the three riffle units, however these habitat patches were relatively small and severely isolated (Appendix M Figure M.6). The small percentage of the wetted channel exhibiting suitable habitat for the riffle-specialist (2.56%) was attributed to the lack of sufficient substrate and velocity suitability throughout much of the reach. Substrate and velocity suitability were estimated at 15% and 10%, respectively. Stable substrate in the form of cobble and boulders were present only within the riffle and pool habitat units as runs were dominated by sand and gravel. Along much of the stream margin areas of PQ050 and the areas directly adjacent, values of velocity were near zero. These areas were characterized by flat gravel bars with intermittent or no flow during field surveys. Depths were highly suitable (90% of channel) throughout much of the reach, even within the large pool at the downstream end of the reach. In general, areas of suitable depth rarely had sufficient velocity, which was what limited the distribution of WUA_r to the head of the two upstream-most riffles. The downstream-most riffle was one of the only other locations where velocity was suitable but this area lacked suitability for both depth and substrate in the vicinity of the two large boulder clusters.

Suitable habitat for the habitat-generalist guild was present in three large, contiguous patches distributed throughout the majority of the channel with the exception of channel margins and the areas between and directly upstream of the large boulder clusters (Appendix M Figure M.7). Segments of the stream channel that were not suitable habitat space were characterized by low depths and high velocity, although the depth and velocity suitability for this guild were estimated at 90% for both depth and velocity. The most optimal habitat patches were located in run units and the shallowest areas of the large downstream pool. In the large pool depth, velocity and substrate (cobble and boulders) were highly suitable.

Areas of suitable depth were sparsely distributed for the pool-specialist guild, which attributed to the limited habitat availability for the pool-specialist guild at PQ050 (H_p = 12.66%). Suitable habitat for the pool-specialist guild (Appendix M Figure M.8) was distributed among four distinct and isolated patches throughout the reach. The areas with the majority of suitable depth were in two large pools, although these habitat units were isolated by a shallow 45-m riffle-run complex. There were small areas with suitable depth in run habitat units but these were isolated by broad areas of the channel where depths were unsuitable. The most optimal habitat was concentrated in the large pool at the downstream extent of the reach, which ranged in depth from 0.20 m to 0.73 m. Given the low to intermediate depths (0-0.37 m) characteristic of the majority of the wetted channel, suitable depths were sparsely distributed for the pool-specialist guild throughout the site (estimated 20%) with the exception of the two large pools present within the reach.

Figure 6.9 Upstream view of PQ050, 2008

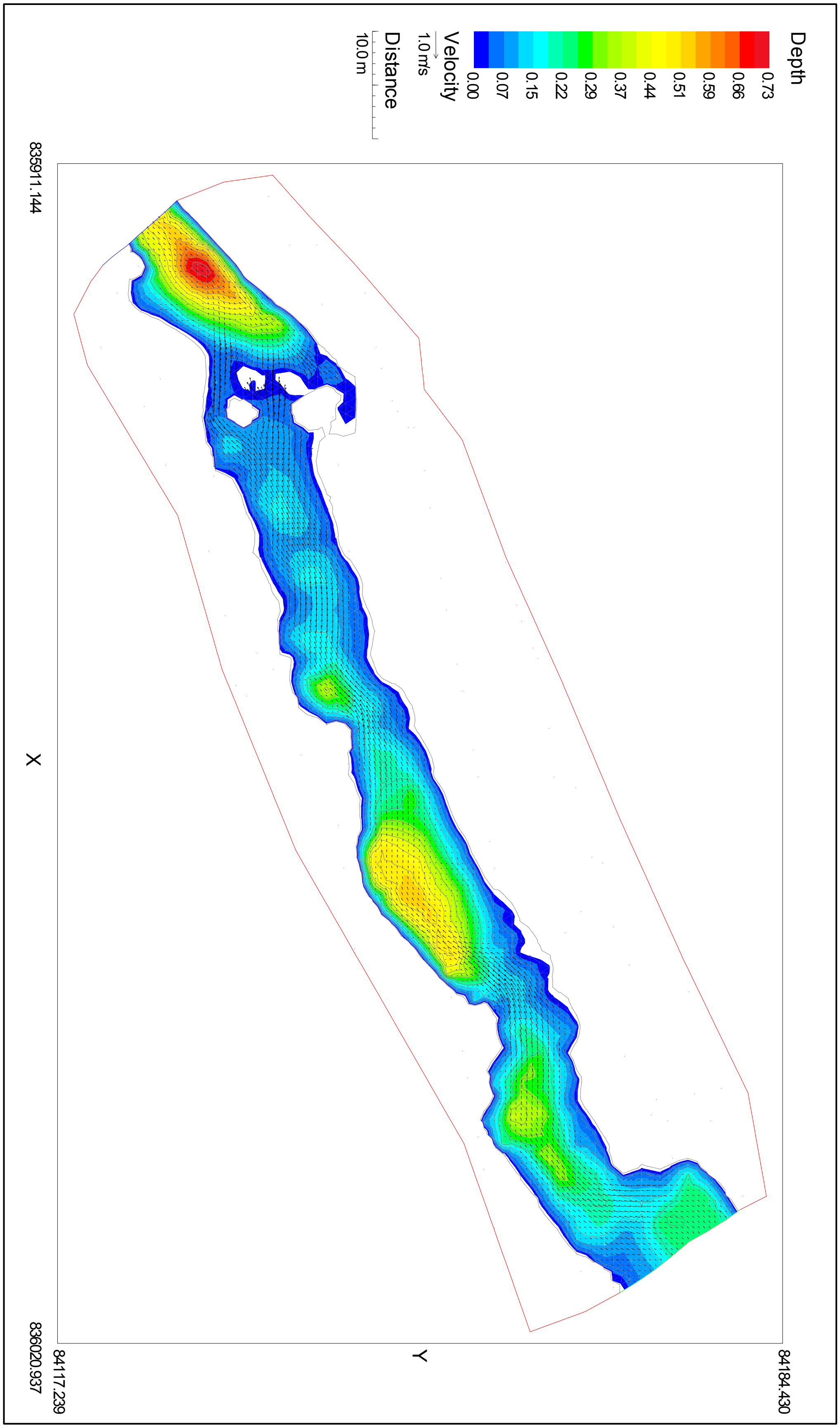

Figure 6.10 River2D Modeled Depth and Velocity Profile of Poquessing Creek Site PQ050

6.3.2.8.2 PQ115

Site PQ115 had the longest segment length of all the sites assessed (115.21 m). There were two noteworthy pool features with maximum depths of 0.64 m and 0.45 m. Similarly, there were two riffles in the reach, each characterized by shallow depths and a homogenous distribution of velocity (note velocity vectors in Figure 6.11). The upstream-most riffle was actually composed of a run-riffle-run-riffle complex approximately 40 m long. This segment was characteristic of the divergence from the expected riffle-run-pool-glide-riffle habitat unit morphology exhibited in less impacted stream channels. Such poorly defined habitat units are characteristic of impacted, overwidened stream channels. Riffle and pool features were separated by very shallow runs that ranged in depth from 0.01 m to 0.26 m in depth. At the top of the reach were two large boulder clusters that had considerable localized effects on the magnitude and direction of flow velocity. The impact of these flow obstructions can be observed as a large area (approximately 30 m^2) of diminished velocity magnitude immediately downstream of the boulder clusters (Figure 7.11). This area was observed to be suitable habitat space for the habitat-generalist guild. The minimal depths in this area precluded habitat suitability for the pool-specialist guild, whereas the reduced velocity magnitude limited habitat suitability in this area for the riffle-specialist guild. A TIN of the site georeferenced to orthophotography is depicted in Appendix A Figure A.2.

The substrate distribution at site PQ115 was dominated by fine to intermediate grained sediment (*i.e.* sand, fine gravel and coarse gravel). There were limited amounts of stable cobble and boulder substrate. Most cobble-sized sediment was present in a patchy distribution throughout the channel with the exception of a 30-m patch of cobble along the downstream left (DSL) margin of the channel in the downstream-most segment of the reach (Appendix M Figure M.11). Substrate suitability was highest for the pool-specialist (approximately 85%) guild followed by the habitat-generalist (approximately 30%) and riffle-specialist (approximately 25%) guilds.

Areas of suitable depth were sparsely distributed for the pool-specialist (approximately 10%) guild although suitable depths were more widely distributed for the riffle-specialist guild (approximately 65%) and habitat-generalist guilds. Due to the shallow depths prevalent throughout the site, more than 90% of the channel had depths suitable to the habitat-generalist guild. The maximum velocity observed throughout the reach was 0.45 m/s, which was the lowest magnitude of maximum velocity observed among all the fish assessment sites (Table 6.4). As such, only 25% of the channel had suitable velocities for the riffle-specialist guild compared to approximately 90% velocity suitability for the both habitat-generalist and pool-specialist guilds.

Given the patchy distribution of mesohabitat units (*i.e.* riffle, run and pool) throughout the reach, WUA for each habitat guild was likewise distributed in distinct patches throughout the reach (Appendix M, Figures L.14 –L.16). The habitat-generalist guild had the highest WUA (255.71 m^2) followed by the pool-specialist guild (94.93 m^2) and the riffle-specialist guild (18.93 m^2). Both WUA_r and H_r were the lowest values observed among all assessment sites. The (H) metric at PQ115 had a range (2.32%-31.33%) most comparable to that of PQ050 (Table 6.4). A relatively moderate quantity of suitable habitat was observed at PQ115, as all other sites had proportionally higher habitat suitability metrics than PQ115 for the pool-specialist and riffle-specialist guild although (H_g) at PQ115 (31.33%) was the second highest value observed among all the assessment sites. The combination of both unsuitable depths and velocity severely limited the composite suitability of most areas within PQ115, as H_p had the lowest value of all sites assessed.

The distribution of WUA for the riffle-specialist guild was limited to areas within the thalweg, which was located in the center of the channel throughout much of the reach with the exception of the upstream-most riffle, where the thalweg migrated to the DSL bank (Appendix M Figure M.14). The most optimal habitat patches were located within run habitat units as well as immediately upstream and downstream of the large pool although these patches were rather small and isolated. The velocity distribution throughout the site was the most limiting factor for the riffle-specialist guild. Areas of highly suitable velocity were located only within three riffle segments; however, the shallow depths were highly unsuitable and not conducive to composite habitat suitability. Furthermore, large areas of unsuitable velocities were located within several pools; however, the velocity distribution within these pools were highly unsuitable. Consequently, composite habitat suitability was reserved to run segments with poor substrate suitability and moderately suitable depths and velocities.

Suitable habitat for the habitat-generalist guild was distributed throughout the entire channel although the most optimal patches were sparely distributed (Appendix M Figure M.15). These patches were observed in areas of moderately shallow depth, which were most frequently observed in the run and glide units. Both depth and velocity suitability were very high for the habitat-generalist guild with the exception of areas with riffles. Substrate suitability was the most limiting habitat suitability factor, as only 30% of the channel contained suitable substrate. There were small, isolated patches of stable cobble and boulder substrate; however, the majority of the channel was dominated by highly unstable sand and gravel.

The most optimal habitat patch for the pool-specialist guild was located in the large pool on the outside of the first meander (Appendix M Figure M.16). The radius of curvature for both meanders was very small given the low sinuosity of the channel. This may explain the paucity of pool units within the channel. There were three other habitat patches in the reach, but all were of low quality. The largest was located in the downstream third of the reach. Composite habitat suitability for this guild was most limited by depth suitability. The lack of suitable depths can be attributed to both channel morphology and the low sinuosity of the reach. Ultimately, these factors are a product of impaired hydrodynamic (“flashy” flow regime) and fluvial conditions (i.e. high supply of fine sediment), which have resulted in a very wide, straight channel. In such channels baseflow is distributed across a large surface area such that the thalweg does not form large, deep pools on the outsides of meanders and bends as observed in natural channels.

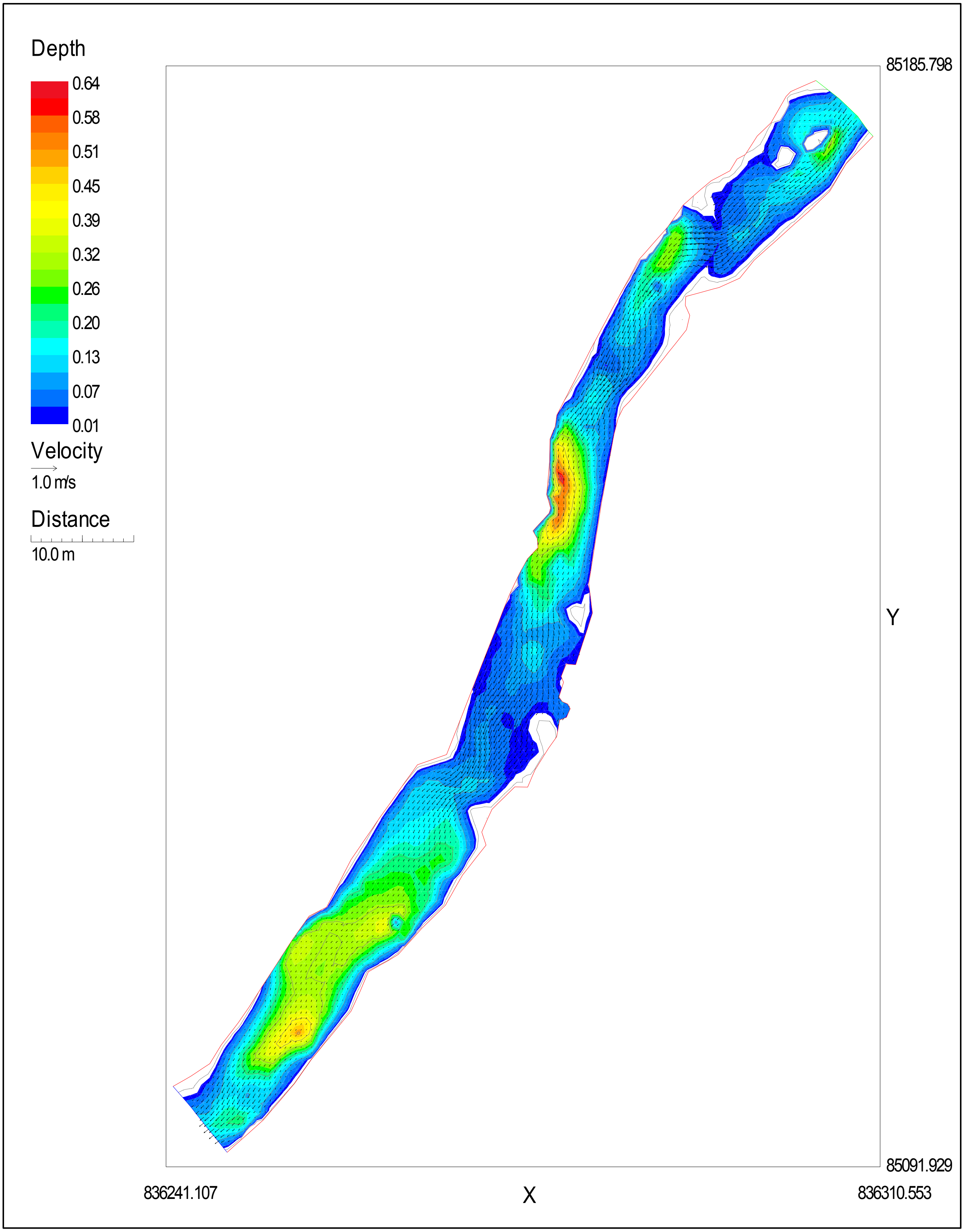

Figure 6.11 River2D Modeled Depth and Velocity Profile of Poquessing Creek Site PQ115

6.3.2.8.3 PQ825

Site PQ825 was the smallest reach among the fish assessment sites in terms of surface area (545.09 m²) as well as the second shortest reach (109.12 m) after PQB025. The disparity in surface area between PQ825 and the other sites can be attributed to the lateral confinement of the wetted baseflow channel. The velocity magnitude distribution throughout the channel remained consistently homogenous in the upper and lower run segments, but maintained considerable variability in the vicinity of the meander at the center of the reach (Appendix M Figure M.20). Near this meander, the channel was constricted laterally as it flowed around a relatively stable point bar composed of large cobble and coarse gravel on the inside of the meander. The banks and stream channel on the outside of the meander were composed of highly cohesive clay material (Appendix M Figure M.19). Clay is highly resistant to erosive shear stress usually observed on the outside of meander bends, which likely prevented the large-scale channel widening observed in PQ050, PQ115, and PQB025.

The combined effects of these factors on stream channel morphology likely contributed to the highly heterogeneous depth and velocity distributions within the central segment of the reach. As such, the physical habitat template (i.e. depth, velocity and substrate distributions) observed within PQ825 was among the most heterogeneous observed in the habitat assessment. Depths were observed to be relatively shallow throughout the reach, even within the pool habitat units (maximum depths were 0.56 m and 0.74 m); however, in most locations throughout the reach there was considerable variation in the distribution of depth laterally. A maximum velocity of 0.65 m/s was observed in this segment, which ultimately conferred a high degree of velocity suitability for the riffle-specialist and generalist guilds but precluded velocity suitability for the pool-specialist guild.

At the upstream end of the reach there was a small pool (0.56 m maximum depth) along the downstream right (DSR) bank followed by a shallow riffle-run complex 30 m in length that comprised the meander bend at the center of the reach. Following the riffle complex there was another pool (0.74 m maximum depth) that was much deeper and larger than the upstream pool. In the downstream-most segment of the reach there was another shallow riffle-run complex, which provided the aforementioned contiguous habitat patches for both the riffle-specialist and habitat-generalist guilds (Figure 6.12). Depths were highly suitable for the riffle-specialist throughout the majority of the wetted channel (approximately 80%) with the exception of the deep pool at the downstream end of the first meander. Depth suitability was distributed throughout an even larger proportion of the channel for the habitat-generalist guild (approximately 95%). Optimal depths were observed in the upstream-most segment of the reach; however, throughout the shallow 30 m riffle-run complex, there were only isolated patches of suitable depth. Beyond the riffle-run complex, highly suitable depths for the riffle-specialist guild were observed in the majority of the channel, with the exception of the channel margins. The pool-specialist guild was severely limited in the availability of suitable depths (approximately 20%). There was considerable overlap in the areas of the channel that contained optimal depths for the pool-specialist and habitat-generalist guilds. However, these areas were much smaller patches than the patches that were optimal for the riffle-specialist guild. Areas of suitable depth were severely isolated for the pool-specialist guild, as suitable patches were separated by a series of very shallow riffle-run-riffle complexes immediately upstream and downstream of the large pool at the center of the channel.

The majority of the channel substrate was composed of sand and coarse gravel. There were also large clay lithofacies distributed along considerable lengths of the margin on both the DSL and DSR sides of the channel. Stable habitat in the form of cobble-sized particles was distributed in three distinct patches in the upstream, central and downstream-most segments of the reach. These patches were rather isolated, although they were long and relatively contiguous. The longest patch (20 m) was located within the two meanders in the central and downstream segments of the reach. There were no large boulders located within the channel. The substrate distribution at site PQ825 provided the highest degree of suitability for the pool-specialist guild as approximately 80% of the channel bed was composed of suitable substrate. Suitable substrate for the riffle-specialist and habitat-generalist guilds was distributed throughout less than 25% of the channel bed. The distribution of suitable substrate was most limiting for the riffle-specialist (approximately 35%) and habitat-generalist guilds (approximately 45%); however, suitable substrate was widely distributed for the pool-specialist guild (approximately 80%).

The values of the H metric at site PQ825 (7.94% - 43.50%) were among the highest observed among all fish assessment sites for each of the three habitat guilds. Both H_g (43.50%) and H_p (21.53%) were the highest values observed in the assessment and H_r (7.94%) was the second highest aside from PQB385. WUA at PQ825 ranged from 43.26 m^2 - 237.52 m^2 (Table 6.4). WUA was highest for the habitat-generalist guild (237.52 m^2) followed by the pool-specialist guild (117.34 m^2) and riffle-specialist guild (43.26.18 m^2).

Suitable habitat for the riffle-specialist guild was distributed in isolated although contiguous linear patches mostly within the channel thalweg (Appendix M Figure M.22). The most optimal patches were located at the head of the large riffle upstream of the deep pool as well as the shallow downstream portion of the deep pool (*i.e.* glide). Suitable habitat had a rather limited distribution for the pool-specialist guild as well (Appendix M Figure M.24). The most optimal habitat for the pool-specialist guild was concentrated in a small isolated patch in the widest part of the channel within a run habitat unit. The second habitat patch was considerably larger and occupied the entire lower half of the reach, although the quality of this habitat patch was greatly exceeded by the smaller, upstream patch. These two patches were isolated by a long (25 m) riffle-run-riffle complex of insignificant habitat quality and quantity for the pool-specialist guild. Suitable habitat for the habitat-generalist guild was distributed in large, contiguous patches throughout the entire reach (Appendix M Figure M.23). The most optimal habitat patch was located in the upstream-most run unit, which contained optimal depth, velocity and substrate suitability for this guild.

The comparably higher degree of habitat suitability observed at PQ825 was attributed to the large amount of stable substrate present within the channel as well as the well-distributed depth regime (Appendix M Figure M.21). Unlike PQ050, PQB025 and PQ115, site PQ825 had a relatively high degree of sinuosity and had diverse channel morphology throughout the reach. These factors likely promoted a larger array of depth-velocity combinations than the straighter, less sinuous reaches PQ050 and PQ115. At the upstream extent of the reach, channel morphology most resembled a Rosgen type F stream, which is characterized by very wide (width to depth ratio greater than 12.0) and high entrenched (entrenchment ratio less than 1.4) channels. The central and downstream segments were characteristic of Rosgen type C channels, which have a better connection with the adjacent floodplain (*i.e.* not severely entrenched), lower width to depth ratios such and greater depths than similar order F type channels. A TIN of the site georeferenced to orthophotography is depicted in Appendix A, Figure A.7.

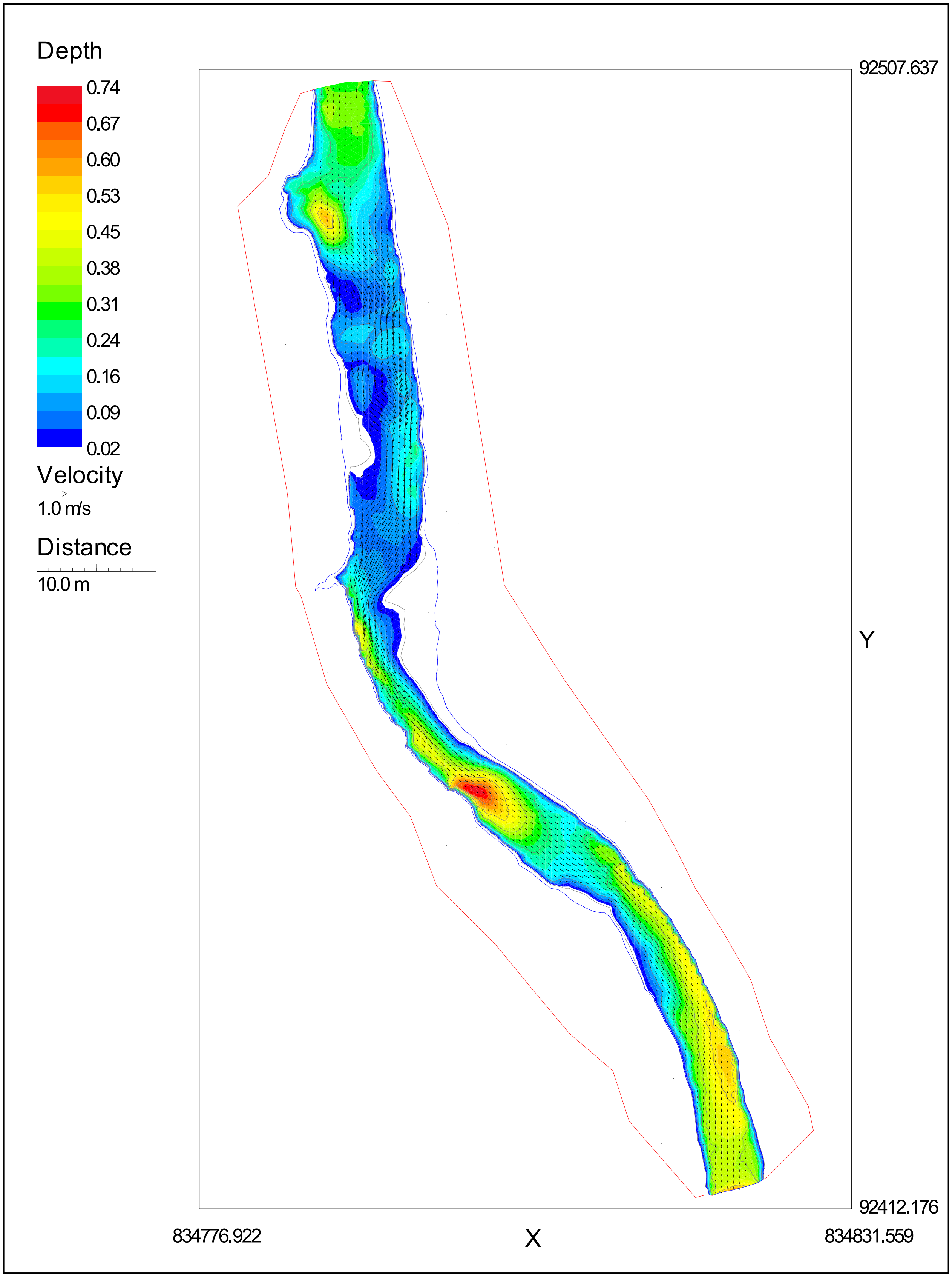

Figure 6.12 River2D Modeled Depth and Velocity Profile of Poquessing Creek Site PQ845

6.3.2.8.4 PQB025

Site PQB025 had a hydrodynamic regime and channel morphology similar to that of site PQ050. The wetted channel at PQB025 was over-widened and likewise characterized by a homogenous depth and velocity regime; however, there were two large boulder clusters in the upstream and downstream segments of the reach that decreased velocity magnitude upstream of their location thereby producing a more heterogeneous flow regime in the vicinity of their respective locations. PQB025 had the largest supply of boulder among all sites assessed. Although PQB025 had similar hydraulic conditions as PQ050, it differed substantially from PQ050 in that a larger proportion of suitable habitat was present for all three guilds as H ranged from 7.40% - 30.47%. WUA at PQB025 ranged from 60.84 m² - 250.46 m² (Table 6.4), with the habitat-generalist guild having the highest WUA (250.46 m²) followed by the pool-specialist guild (162.89 m²) and the riffle-specialist guild (60.84 m²). WUA_p was ranked first among all sites assessed and WUA_r was the second highest after PQB385. The large amount of WUA for each riffle-specialist guild was attributed to both the large surface area (surface area of PQB025 was 822.04 m²) and extremely shallow depths at PQ025. The large amount of WUA for the pool-specialist guild was attributed to the large pool (maximum depth = 1.69 m) at the upstream extent of the reach, which was by far the deepest pool observed among all sites; however, depths remained much lower throughout the majority of the reach, ranging from 0 – 0.44 m. A TIN of the site georeferenced to orthophotography is depicted in Appendix A Figure A.10.

The location of the thalweg at PQB025 conferred a high degree of composite suitability for both the riffle-specialist and habitat-generalist guilds. The thalweg at this site, which can be distinguished by the high magnitude of flow vectors along the DSR side of the channel, was located along the DSR side of the channel throughout most of the reach (Figure 6.13). The large pool at the upstream extent of the reach and the areas directly upstream and downstream of it were also highly significant features of PQB025. Depths within the pool were too deep for the habitat-generalist and riffle-specialist guilds, although the run immediately upstream and the glide immediately downstream were highly suitable habitat patches. Sand and gravel dominated the substrate distribution throughout the channel although along the thalweg there were long, contiguous patches of cobble and boulder lithofacies that provide very stable and highly suitable substrate for all guilds. Substrate suitability was 25%, 45% and 30%, respectively, for the pool-specialist, habitat-generalist and riffle-specialist guilds. Within the channel thalweg, the majority of the substrate was composed of cobble (Appendix M Figure M.27). The combination of stable substrate in the vicinity of the thalweg as well as a highly suitable depth regime produced a physical habitat template highly suited to these two guilds.

Suitable habitat for the riffle-specialist guild was distributed in four distinct patches. The first was a small patch in the run upstream of the deepest pool, although this area was isolated from other highly suitable areas by the highly unsuitable depths in the vicinity of the pool. The second and largest area was a highly contiguous although moderate quality segment that began downstream of the large pool at a cluster of boulders located near the center of the channel. This patch extended downstream along the thalweg for approximately 50 m. Nested within this area was a significant area of optimal habitat created as flow diverted around the boulder cluster forced high velocity flows toward the DSR bank, creating a scour-pool of moderate depth. The fourth patch for the riffle-specialist guild was located downstream of the large boulder cluster at the downstream-most segment of the reach at the head of a shallow run (Appendix M Figure M.30).

There was considerable overlap in the distribution of suitable habitat for the habitat-generalist guild with respect to the distribution of suitable riffle-specialist habitat, although habitat patches for the habitat-generalist guild were present in the shallow areas outside of the thalweg. Suitable depth distributions were highly abundant throughout the majority of the channel for both the habitat-generalist (approximately 80%) and riffle-specialist (approximately 70%) guilds. Furthermore, highly suitable cobble lithofacies in the vicinity of the thalweg were highly suitable to both guilds. The only areas exploited by riffle-specialists and not habitat-generalists were areas that reached velocities (maximum velocity = 0.96 m/s) that exceeded the suitability threshold of the habitat-generalist guild. These areas were located within the thalweg as well as downstream of the second boulder cluster. In the downstream-most segment of the reach, the two aforementioned pools had depths that exceeded the depth threshold for the generalist guild, thus suitable habitat patches were small and isolated within the downstream pools (Appendix M Figure M.31).

Suitable habitat for the pool-specialist guild was severely limited by the distribution of suitable depths throughout the channel as areas of suitable depth were present in three distinct patches isolated by shallow riffles (Appendix M Figure M.32). The largest and most highly suitable habitat patch was located upstream of the deep pool in the upstream segment of the reach. Downstream of the pool, there were small patches of moderate suitability within a larger, less suitable patch in the riffle-run-riffle complex downstream of the first boulder cluster. Directly upstream of the last boulder cluster there were two small pools on the DSL and DSR, both with maximum depths of approximately 0.67 m. Substrate suitability was much higher within the DSR pool, thus WUA was concentrated within the pool nearest the DSR bank.

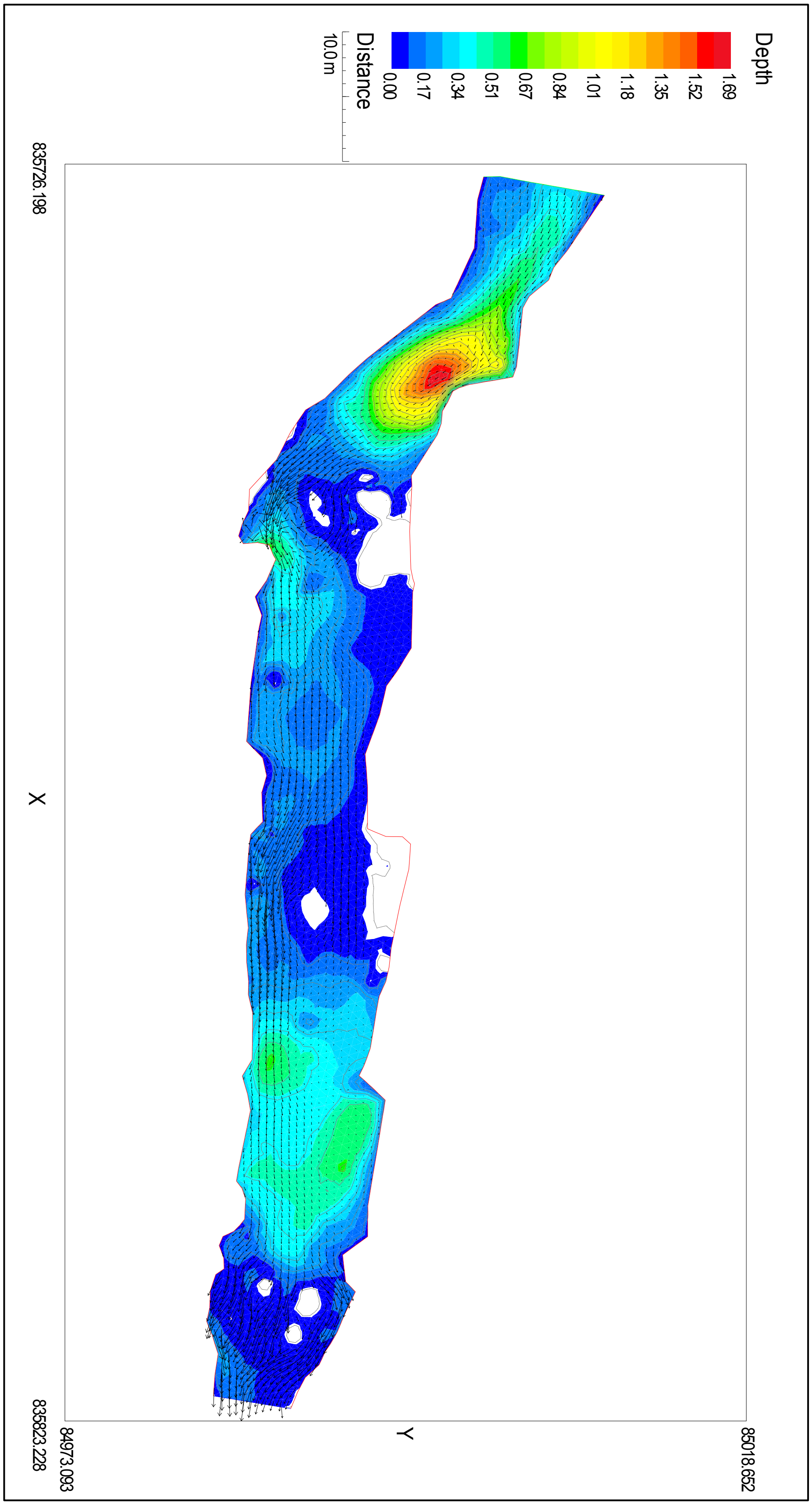

Figure 6.13 River2D Modeled Depth and Velocity Profile of Byberry Creek Site PQB025

6.3.2.8.5 PQB385

PQB385 had the most complex and heterogeneous depth and velocity regimes of all sites assessed. The range of hydraulic conditions was evidenced by the maximum velocity (1.47 m/s) and depth (0.63 m) observed at PQB385. These values were the highest and lowest, respectively, among all sites. There were large segments of the channel where both depth and velocity magnitude were highly variable both laterally and longitudinally. The assortment of depth-velocity combinations produced favorable distributions of hydraulic conditions with respect to the partitioning of habitat patches throughout the reach. Such conditions allow species with similar or overlapping niche and habitat requirements to coexist within the same habitat patch given differences in the utilization of respective depth-velocity microhabitats.

Stable cobble and boulder substrate was distributed widely throughout the channel although silt, clay, sand and coarse gravel lithofacies were relatively abundant as well. A scanned image of the field substrate assessment for site PQB385 is presented in Appendix M Figure M.35. Large boulder clusters distributed across the channel can be observed throughout the upstream two-thirds of the channel. These features were critical to the high velocity suitability in both the upstream riffle as well as the riffle located within the meander at the center of the reach. The boulders dissipated a significant portion of the high velocity flows in these riffles. In the downstream-most riffle the maximum velocity reached 1.49 m/s, most likely in response to constriction and narrowing of the channel. Similar to PQ825, the DSR streambank was composed of clay material, which is highly resistant to scour and erosion. This lateral confinement on the outside of the meander in effect transferred shear stress from the DSR bank back into the channel, producing the high velocity flows observed in the third riffle. In these locations, Froude number reached values greater than 1.0, indicating extremely turbulent flow. In these locations flow velocity ranged from 1.17 m/s to 1.49 m/s and were highly unsuitable to all guilds.

WUA at PQB385 ranged from 84.08 m^2 to 197.36 m^2.The habitat-generalist guild had the highest WUA (197.36 m^2) followed by the pool-specialist (90.78 m^2) and riffle-specialist (84.08 m^2) guild (Table 6.4). Unlike all other assessment sites, WUA and H for the riffle-specialist guild approached the WUA available to the pool-specialist guild. This was attributed to the preponderance of shallow pools throughout the channel, most of which were highly suitable to the depth specifications of the riffle-specialist guild but not the pool-specialist guild. As such both WUA_r (84.08 m^2) and H_r (11.92%) were the highest values observed among all sites. WUA_p, H_p and H_g were the lowest values observed among all sites.

Both velocity and depth suitability for the riffle-specialist guild were relatively high. Suitable velocities and depths were present throughout approximately 65% and 85% of the channel, respectively. The large proportion of sand, gravel and clay distributed throughout the reach limited the availability of suitable substrate to approximately 50% of the channel for this guild. The most optimal habitat patches for the riffle-specialist guild were observed in locations directly downstream of the two largest boulder clusters near the center of the reach (Appendix M Figure M.38). There was another patch of highly suitable habitat located at the head of the run among a deposit of large cobble and boulder substrate. Moderately suitable habitat was observed throughout the entire reach in long contiguous patches, especially in the upstream-most and central segments of the reach.

Suitable habitat for both the habitat-generalist and riffle-specialist guilds were generally distributed in the same areas of the channel (Appendix M Figure M.39) although the high velocities observed in the riffle segments were most favorable to the riffle-specialist guild. The most limiting habitat variable was substrate suitability (approximately 60%) although velocity suitability was rather high for the habitat-generalist guild as 65% of the channel had suitable velocity. Velocities downstream of all of the large boulder clusters were highly suitable for the habitat-generalist guild. As such, suitable habitat for the habitat-generalist guild was distributed throughout the entire channel with the exception of the very high velocity areas located within riffles and the downstream-most segment of the reach dominated by clay and gravel substrate.

Suitable habitat for the pool-specialist guild was very limited within the PQB385 stream channel (Appendix M Figure M.40). H_p (12.87%) was one of the lowest values observed aside from PQ115 and PQ050. Suitable habitat for the pool-specialist guild was limited by low depth suitability as favorable substrate and velocity distributions were present throughout the channel. Approximately 90% of the channel contained suitable substrate and close to 80% of the channel had a suitable velocity regime for this guild. Less than 10% of the channel had depths suitable for the pool-specialist guild, thus suitable habitat was limited to two relatively small pools. The maximum depth observed in the largest pool was 0.63 m, which was the lowest value of maximum pool depth observed among all fish assessment sites.

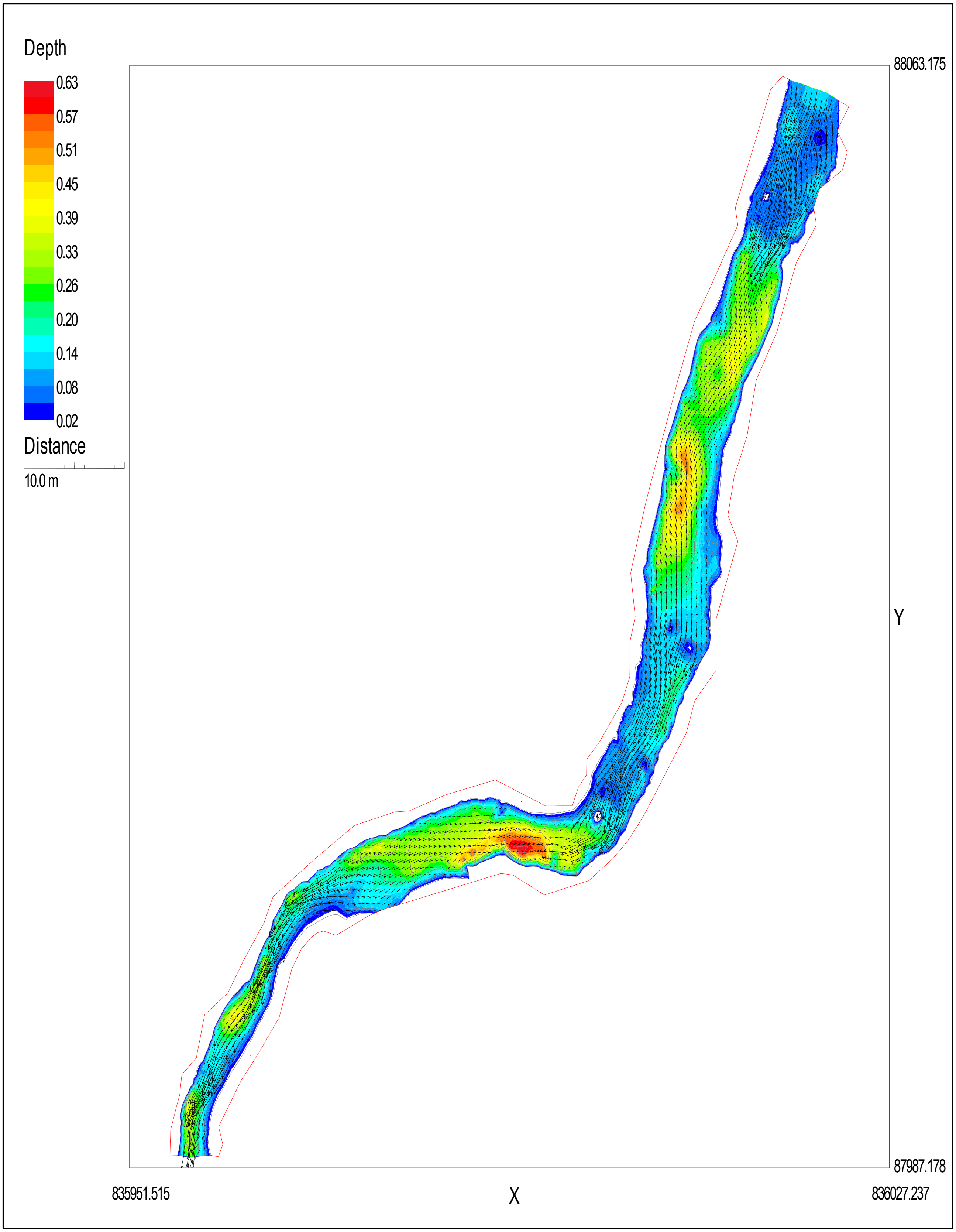

Figure 6.14 River2D Modeled Depth and Velocity Profile of Byberry Creek Site PQB385

6.3.2.9 PROBLEM SUMMARY

The stream network of the Byberry-Poquessing Watershed has been considerably impacted by the effects of unabated stormwater runoff and its associated constituents – with the most prevalent being sediment. Many of the channels were much wider, less sinuous and contained more fine sediment than regional reference channels of similar orders. The channel morphology and substrate conditions are a direct result of the dynamic relationship between sediment transport and the dominant channel forming discharge (*i.e.* bankfull discharge), which has been commonly defined as the discharge that occurs at the 1.5 year flow event.

The level to which a stream channel is impacted by stormwater runoff can be assessed by calculating the value of its Runoff Response Index (RRI). The RRI is defined as the ratio of the 1.5 year flow event to the average daily baseflow. This index provides a dimensionless, independent measure of a stream's flashiness using readily available flow data provided by most USGS stream gages. Using flow data recorded at USGS stream gage 01465798 located at Grant Avenue, the 1.5 year return interval was estimated at 2,194 ft^3/s compared to an average daily baseflow of 11 ft^3/s, producing a RRI of 183. In comparison, at French Creek (USGS gage 014722157), a regional reference stream, the 1.5 year return interval was estimated at 1,866 ft^3/s compared to an average daily baseflow of 57 ft^3/s, producing a RRI of 33. Based upon the RRI metric, Poquessing Creek is 5.5 times flashier than French Creek.

The disparity between these two flows at Poquessing Creek resulted in a wetted channel at baseflow that is tremendously oversized to convey a relatively small discharge; therefore, these channels had limited depth and capacity to transport bedload sediment during the descending limb of the hydrograph. The lack of sediment transport competency results in excessive deposition of fine sediment throughout the channel. Excessive fine sediment deposition adversely impacts habitat quality by filling in the interstitial spaces between larger cobble and boulder substrate (*i.e.* embeddedness) while also reducing hyporheic gas exchange, which is critical to respiration and the transport of metabolic byproducts in benthic organisms.

Reaches PQ050, PQ115 and PQB025 exhibited the aforementioned widening and excessive fine sediment deposition characteristic of impacted urban streams. These channels were dominated by fine sediment (*i.e.* silt, sand, gravel) throughout. Larger, coarser sediment (cobble and boulder) was distributed sporadically, often in pools where only large storm events could generate the power to transport them further downstream. These streams also lacked sinuosity, which affected the distribution of riffle, run and pool mesohabitat units throughout these reaches. The traditional riffle-run-pool-glide-riffle habitat unit morphology was not observed in these reaches As a result, many habitat units were poorly developed or not present such that riffle-run-riffle complexes were commonly observed. Pools were very infrequent and were often extremely shallow. Pools are usually formed largely by the channel thalweg as it migrates across the stream channel in response to sinuosity and changes in slope. In wide, reduced-sinuosity channels, the thalweg does not migrate in the same manner and therefore does not create scour pools on the outside of meander bends as in more natural systems.

PQB385 and PQ825 had the most stable channel morphology of all the reaches assessed. For both of these reaches, the upstream portion resembled the over-widened morphology of PQ050, PQ115 and PQB025, however these streams had narrow, more stable channels in the downstream portions of the reach. In both of these reaches, the downstream stream banks consisted mostly of clay, which is highly resistant to erosion. In both PQB385 and PQ825, these banks were along the channel thalweg, which prevented the excessive widening observed in the other three reaches. The combination of clay material along the thalweg and depositional features (*i.e.* point bars and channel bars) on the opposite bank constricted the channel and prevented excessive bank erosion and subsequent lateral migration of the channel.

6.4 TREE CANOPY ANALYSIS

6.4.1 HERITAGE CONSERVANCY RIPARIAN BUFFER ASSESSMENT OF SOUTHEASTERN PENNSYLVANIA

Heritage Conservancy, a land trust organization in Doylestown, PA, received funding from Pennsylvania Coastal Zone Management and the PA Stream ReLeaf Program to document the presence or absence of forested riparian buffers throughout Southeastern PA. The project was completed in two phases of grant funding: an initial study of tree canopy in the Perkiomen, Neshaminy, Valley, and Chester Creek Watersheds, and a second, more detailed inventory of the remaining watersheds in the five-county region, including the Darby-Cobbs, French, Namaan, Pennypack, Pickering, Ridley-Crum, Tookany/Tacony-Frankford, and Poquessing creeks, as well as the Lower Schuylkill and Delaware rivers (Heritage Conservancy 2002). More than 1,200 miles of stream were mapped using digital orthophotography and helicopter flight video analysis.

Of 25.5 linear miles assessed in Poquessing Creek, approximately 25% of the riparian land was found to be lacking a forested buffer (defined as at least 50 ft. wide with at least 50% canopy closure) on one or both banks (Heritage Conservancy 2002). These results indicate that most riparian problems in the Poquessing Creek Watershed are located in areas where lands are managed as mown lawns or fields. This most notably includes golf courses, sports fields, local parks, cemeteries, and residential properties.

The Heritage Conservancy study was conducted with an incomplete watershed hydrology dataset, and extensive areas of the watershed were not assessed. The source base hydrology data set was cited only as “USGS Hydrography.” For the purpose of the PWD analysis of the dataset, the National Hydrography Dataset (NHD) was used. As the NHD includes approximately 22 miles of hydrologic features in the Poquessing Creek Watershed, there may be errors related to the exact extent that was assessed.

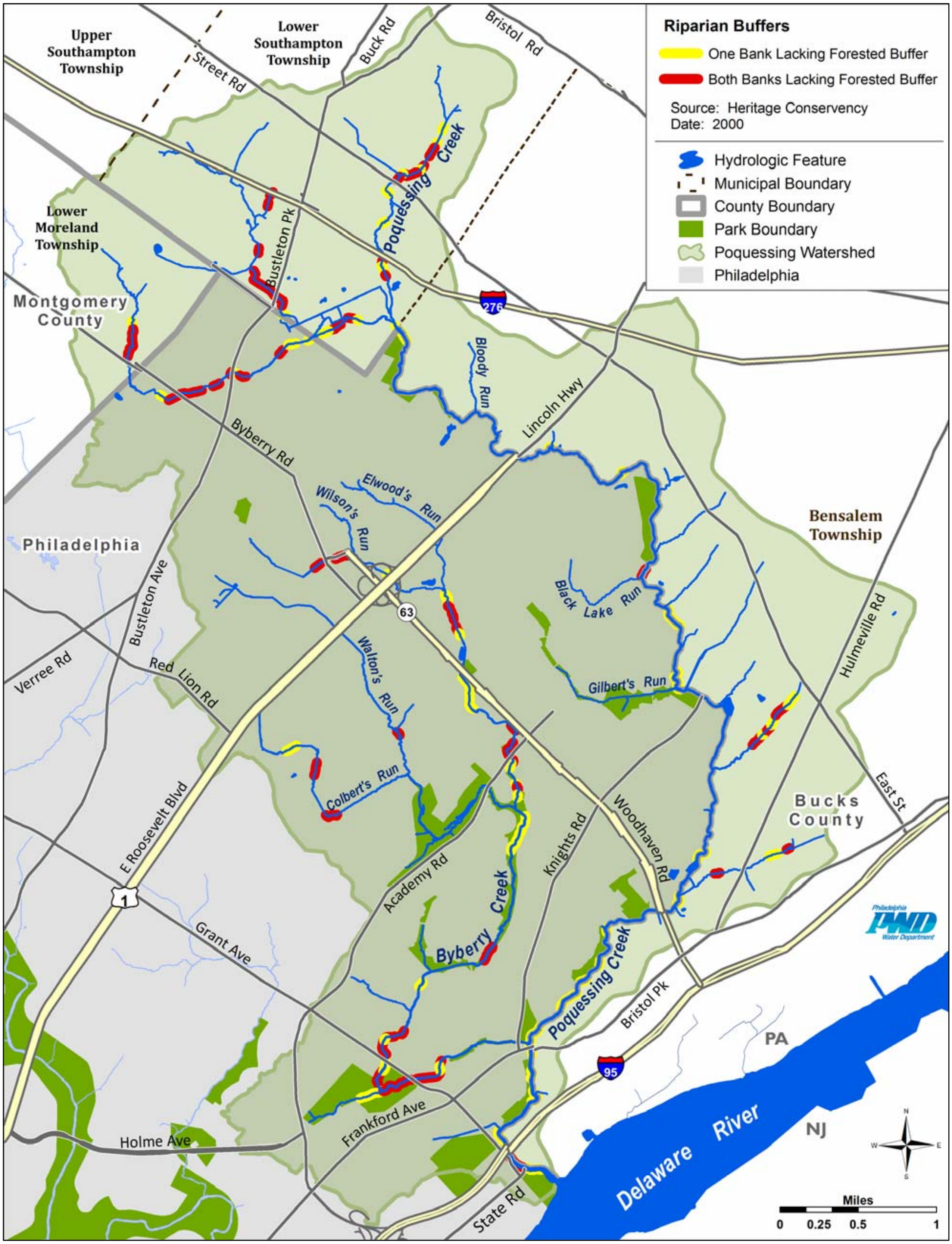

Figure 6.15 Poquessing Creek Watershed Stream Segments Lacking a Forested Riparian Buffer on One or Both Banks (Redrawn from Heritage Conservancy 2000)

6.5 DOCUMENTATION OF INFRASTRUCTURE IMPACTS IN FLOODPLAINS OF POQUESSING CREEK WATERSHED

6.5.1 INTRODUCTION

As an extension of the fluvial geomorphological (FGM) investigation of stream channels within the Poquessing Creek Watershed during 2007, an infrastructure assessment was conducted. In order to document infrastructure throughout the basin, PWD staff and trained consultants walked along stream segments with GPS, digital photography, and portable computer equipment, compiling an inventory of each infrastructure feature encountered. These features included bridges, culverts, dams, stormwater outfalls and drain pipes greater than 8" in diameter, sewers, pipe crossings, confluences, manholes, and areas where one or more of the streambanks were artificially channelized. All field work was completed in 2008, and results are included herein to better integrate the results with the findings of other assessments (*e.g.*, to help explain observed impairments found in the biological assessments). Due to the large number and spatial distribution of the features, infrastructure maps (Figures 6.16 and 6.17) were prepared at a finer resolution than the watershed scale maps presented in other sections of the Comprehensive Characterization Report.

6.5.2 INFRASTRUCTURE IN POQUESSING CREEK WATERSHED

6.5.2.1 STORMWATER OUTFALLS

The Poquessing Creek Watershed was developed in distinct stages of differing land use patterns, but unlike most of Philadelphia's watersheds, much of the Poquessing Creek Watershed was developed after modern-day wetlands protection and stormwater management regulations. Numerous wetlands, small tributaries and stormwater conveyance flow paths were drained and encapsulated in the stormwater collection system. Unlike most other streams in Philadelphia where the city had the foresight to acquire riparian lands for parkland and to protect drinking water sources, the Poquessing Creek Watershed generally suffers from a lack of riparian buffers along most of its length. Stormwater outfalls in the watershed thus tend to be located along the mainstem as well as along tributaries.

The 2008 survey documented a total of 328 outfalls in Philadelphia County, 143 in Bucks County, and 14 in Montgomery County, for a total of 485 in the Poquessing Creek Watershed. Due to the prevalence of large stormwater outfalls, Poquessing Creek and its tributaries were found to be severely affected by localized erosion, and geomorphic instability caused by stormwater outfalls was determined to be a serious problem throughout the watershed. Stormwater outfalls and natural surface runoff flow paths (*i.e.*, gullies) have been scoured and enlarged as a result. Throughout this process, tributaries and gullies have contributed much sediment to the mainstem.

6.5.2.2 STORMWATER DETENTION BASINS

As noted in section 6.1, much of the land area within the Poquessing Creek Watershed was developed subject to traditional stormwater management regulations. The watershed thus contains a large number of stormwater management facilities, the majority of which are surface detention basins. Based on a stormwater detention basin inventory and inspection program carried out by PWD in 2009, very few of these facilities were constructed in order to enhance infiltration to groundwater. Rather, they were designed to "shave peaks" of large flood events. Flow rates from these facilities in smaller, more frequent events are considerably higher than desirable for protection of stream channels. These facilities generally serve as collection points for stormwater over large parcels and thus present good opportunities for retrofitting with newer stormwater management techniques.

Additionally, many light industrial and other large parcels in the watershed have extensive areas of lawn, providing opportunities for stormwater treatment in swales, rain gardens, infiltration galleries, and other management strategies. New PWD stormwater-based billing charges should provide a good incentive for landowners with large parcels of impervious cover to take additional steps to protect the Poquessing Creek from damaging stormwater flows. PWD is presently evaluating options for stormwater charge credits in these situations.

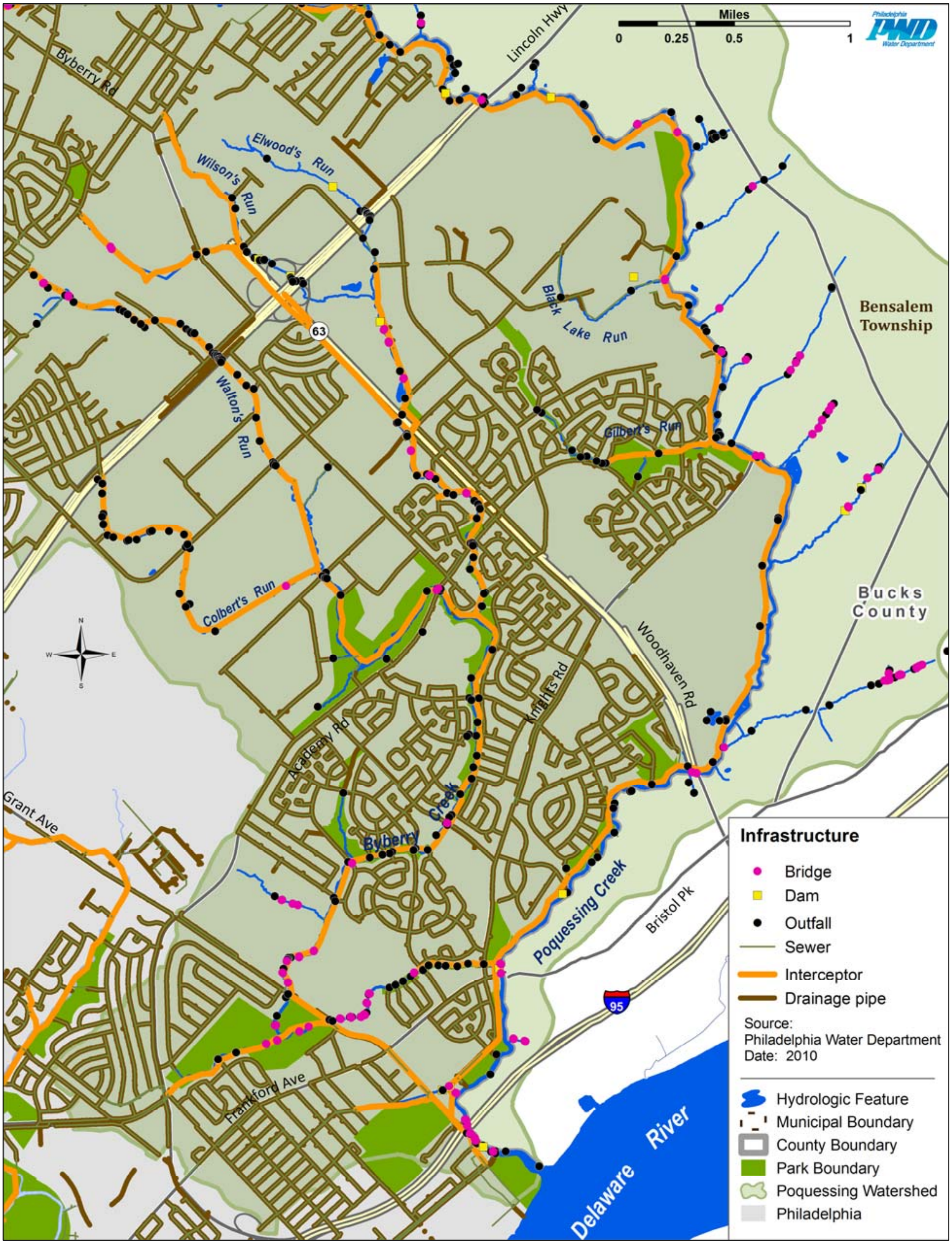

Figure 6.16 Infrastructure Locations in Poquessing Creek within the City of Philadelphia and Bucks County, 2010

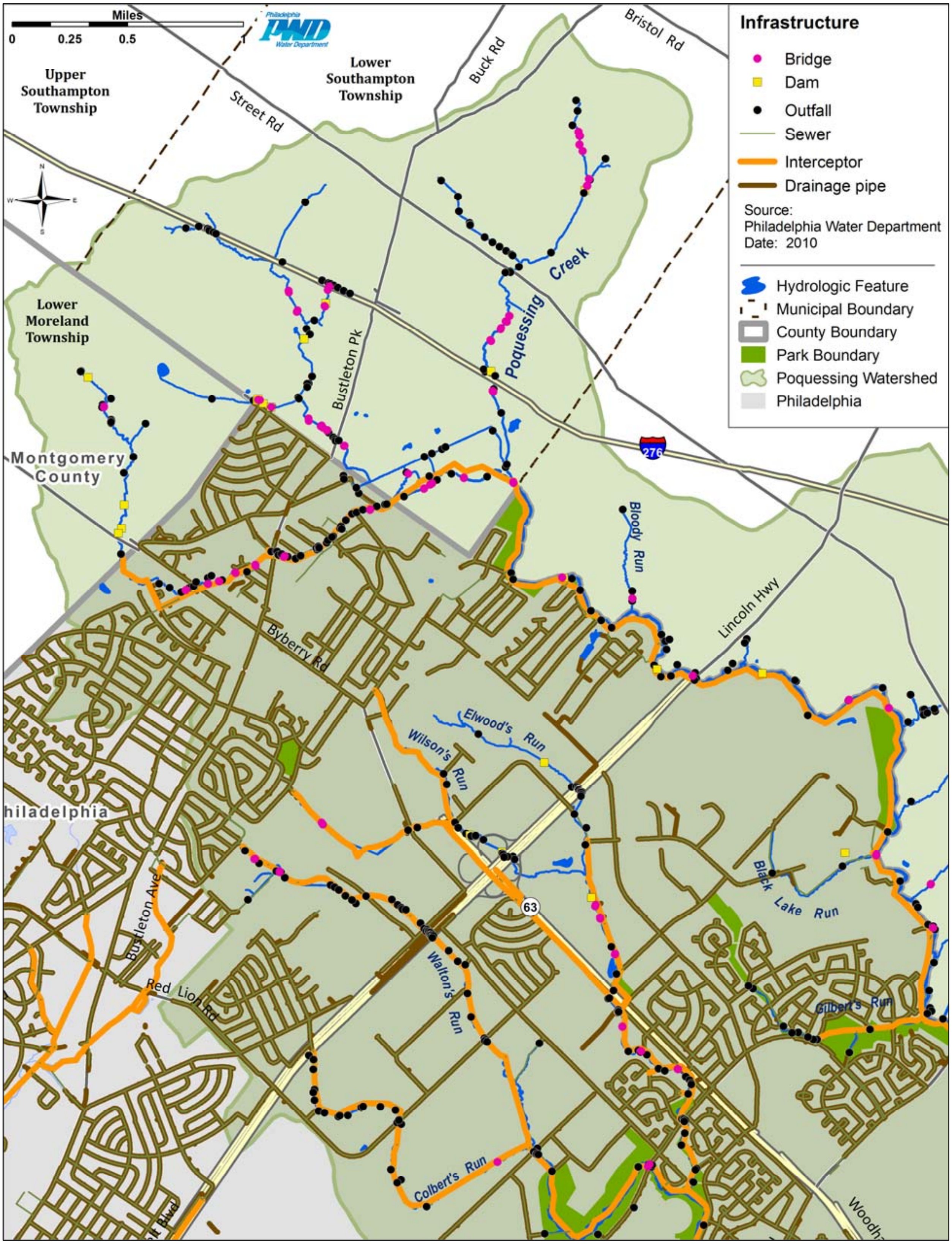

Figure 6.17 Infrastructure Locations in Poquessing Creek within the City of Philadelphia, Bucks County, and Montgomery County, 2010

6.5.2.3 CULVERTS, BRIDGES, AND CHANNELIZATION

The 2008 survey of infrastructure in the Poquessing Creek Watershed documented a total of 155 culverts, totaling 3.34 river miles. Culverted streams do not perform the same ecological functions as natural streams and promote the process of stream erosion, particularly at locations where the stream enters and flows out of the culvert. In addition to this extensive system of culverts, a total of 253 instances of channelization were observed, accounting for 7.18 river miles. Many private landowners install revetments along stream banks in order to arrest bank failure and property loss or damage associated with stream erosion. Though these features may protect individual properties, the aggregate effect of restricting the stream from its floodplain confines more erosive forces within the stream channel, and erosion problems may be exacerbated downstream. Altogether, more than 23% of all stream segments in the Poquessing Creek Watershed were found to be either culverted or channelized. PWD is addressing data quality control of the locations and dimensions of bridges and culverts in preparation for the Poquessing Creek Watershed Act 167 plan, slated for completion in 2011.

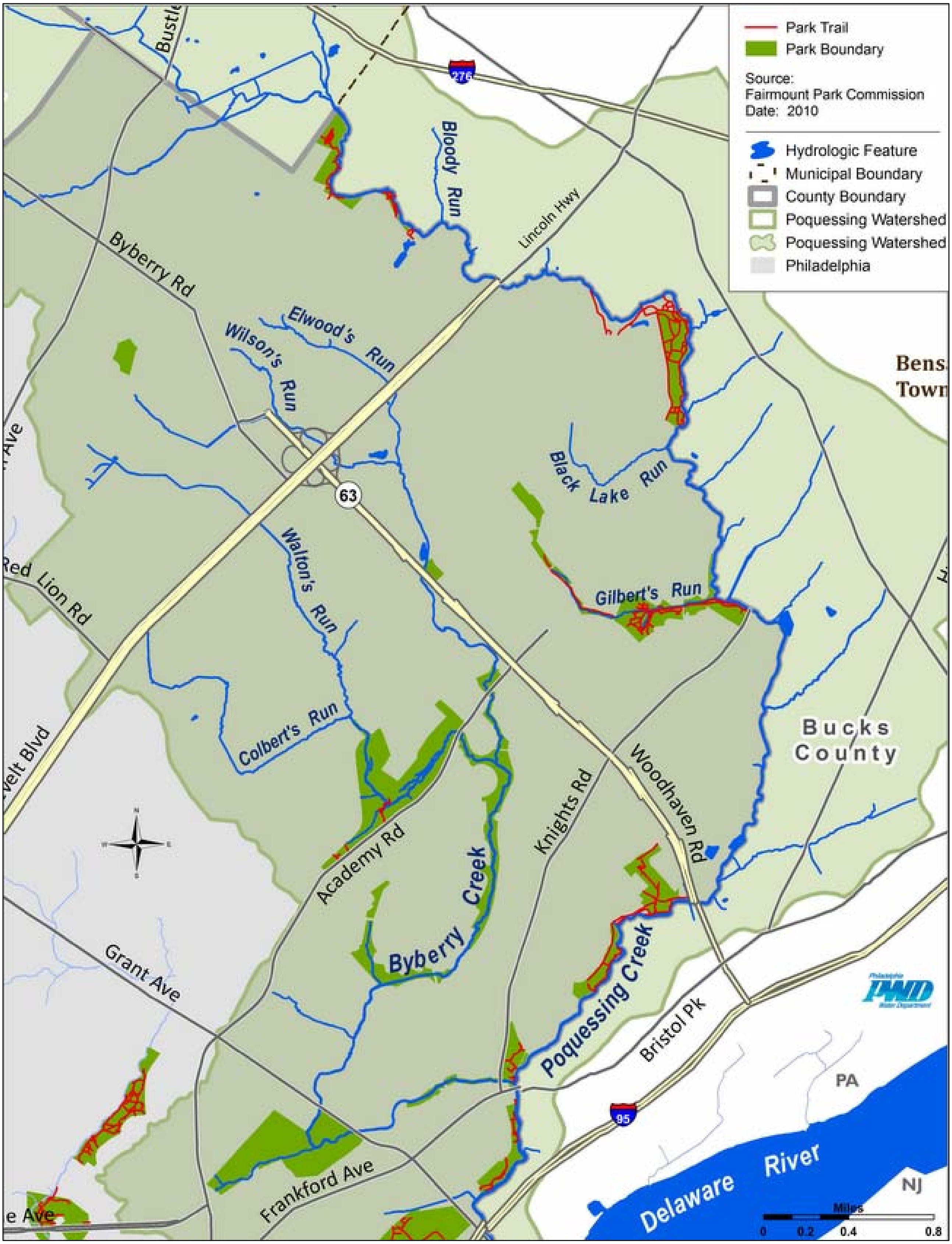

Figure 6.18 Recreational Trails in Poquessing Creek Park, 2010

6.5.2.4 DAMS

The Poquessing Valley within Philadelphia remained primarily large tracts of farmland until development accelerated in the 1950s and 1960s. The watershed probably once had a greater number of mill dams, however only one major dam remains, approximately 400 ft. downstream of the Delaware Expressway (I-95). Smaller dams (n=27) are found throughout the watershed, none of which impound major areas of stream channel.

6.5.2.5 MAN-MADE PONDS AND IMPOUNDMENTS

Approximately 23 ponds and impoundments have been created in the Poquessing Creek Watershed, typically by damming up a small spring or stream, and constructing berm(s) to raise water surface elevation (Table 6.5, Figure 6.19). Small man-made ponds have primarily been constructed in residential developments, farms, and golf courses, with discharge to streams via standpipes, other overflow control structures, or weirs. Like run-of-river dams, these ponds generally do not have any flood storage capacity. While these ponds do serve as wetland habitat for waterfowl, resident Canada geese (*Branta canadensis*) are often attracted to these ponds in large numbers, creating a nuisance. Ponds may increase water temperature, though PWD research suggests that this heating effect may not directly impact receiving streams when ambient air temperatures are high.

Table 6.5 Man-Made Ponds in Poquessing Creek Watershed within Philadelphia, Bucks, and Montgomery Counties

County	Total Number of Ponds	Connected	Disconnected	Headwaters	Total Pond Area (acres)
Philadelphia	12	12	0	0	5.63
Bucks	11	9	1	0	4.58
Montgomery	1	0	0	1	1.15

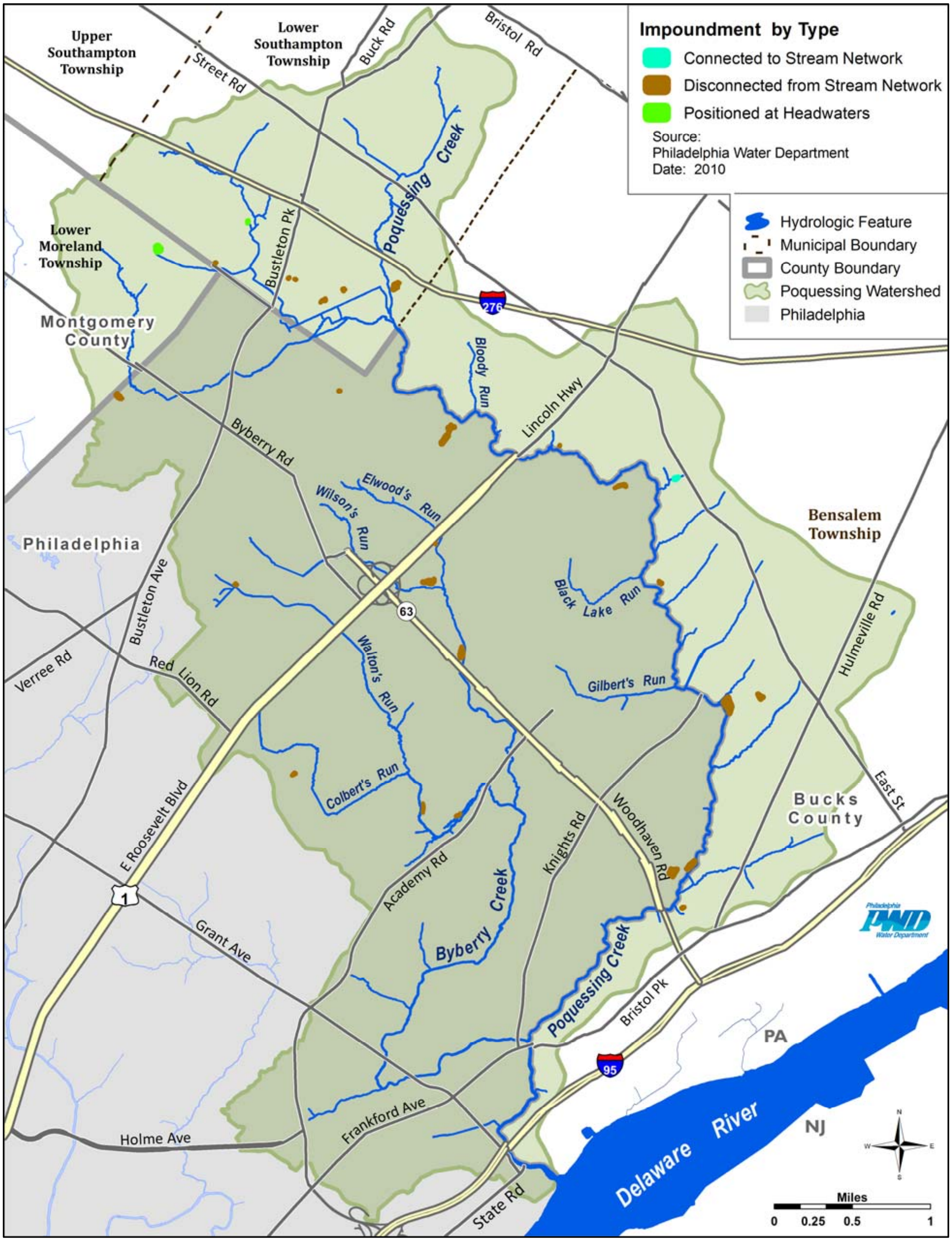

Figure 6.19 Man-Made Ponds and Impoundments in Poquessing Creek Watershed, 2010

6.6 PROBLEM SUMMARY

Poquessing Creek is an urbanized stream system that has been adversely affected by development and land use practices over the past century. Impervious cover is estimated at 37% of the watershed in total and 41% within the City of Philadelphia. Impervious cover, especially directly connected impervious cover, decreases groundwater recharge and the percent of annual streamflow represented by baseflow. Streams in the watershed are "flashy"– increases in streamflow and erosive forces occur quickly during storm events. Both maximum discharge and total runoff volume are increased compared to an undeveloped watershed.

Changes in hydrology have resulted in destabilization of much of the watershed. Urbanization promotes a cumulative, self-reinforcing pattern of streambank erosion. As stream channels become physically larger and further disconnected from their historic floodplains, more stormwater forces are restricted to the stream channel, where compromised, heavily eroded banks are least suited to dissipate them. These overwidened stream segments deficient in baseflow make very poor habitats for all but the most tolerant generalist species. Signs of habitat impairment were present in the watershed's biological communities; the Poquessing Creek Watershed is nearly devoid of sensitive macroinvertebrates and fish taxa, while unstable streambanks have been extensively colonized by invasive species, especially Japanese knotweed (*Polygonum cuspidatum*).

Other habitat effects include widespread sedimentation in runs and pools as well as along channel and lateral bars. Many historic first-order tributaries and wetlands within the watershed have been filled in and/or piped into storm sewers. Erosion has exposed, threatened and, in some cases, destroyed valuable infrastructure and private property. Unfortunately, traditional solutions for addressing erosion and flooding problems may increase instability overall, exacerbating problems they are intended to solve. Philadelphia's 2006 stormwater ordinance and the Poquessing Creek Integrated Watershed Management Plan (PCIWMP, in preparation) outline several options for detaining, infiltrating, and treating stormwater to reduce stream channel impacts. Healthy ecosystems require healthy habitats, and healthy habitats cannot be restored without addressing stormwater impacts.