Pennypack Creek Watershed

Comprehesive Characterization Report

Prepared by Philadelphia Water Department
June 2009

Philadelphia PWD Water Department

TABLE OF CONTENTS

Appendices

EXECUTIVE SUMMARY

Problems faced by the Pennypack Creek Watershed stem from many sources. The watershed suffers from physical disturbance due to urbanization and excess nutrient input from municipal wastewater and 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 treated municipal wastewater that does not maintain healthy stream chemistry. This report forms a technical basis for the forthcoming Pennypack Creek Integrated Watershed Management Plan (PCIWMP), a plan for restoration and enhancement of the creek and its watershed.

With impervious cover making up over 30% of the land area in many subsheds, stormwater flows have de-stabilized most stream channels of Pennypack Creek Watershed. Erosion and sedimentation effects are very severe in small tributary streams. Though many stream channels are protected within parkland, most either originate as stormwater outfalls or otherwise accept large volumes of urban stormwater. Throughout the watershed, many small ephemeral streams and first order tributaries have been lost to development. Moreover, destabilizing infrastructure features, such as culverts, bridges, channelization, and small dams are omnipresent in Montgomery County. Urbanization promotes a cumulative, self-reinforcing pattern of streambank erosion. As stream channels become physically larger and further disconnected from their historic floodplains, more stormwater forces are restricted to the stream channel, where compromised, heavily eroded banks are least suited to dissipate them.

Widespread urbanization, as present in the Pennypack 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 43% of total mean annual flow at the Rhawn St. Pennypack Creek USGS gauge. Effects of urbanization and physical habitat degradation are evident in biomonitoring data throughout the basin. The Pennypack Creek Integrated Watershed Management Plan (PCWIMP, in preparation) will contain several options for detaining, infiltrating, and treating stormwater to reduce its impact on the stream channel and aquatic habitats. The watershed simply cannot be restored without addressing stormwater impacts.

While all urban watersheds have severe problems with erosion and sedimentation in wet weather, bacterial contamination and other pathogens are also an important concern, particularly in a stream, such as Pennypack Creek, which contributes to public water supplies and is used extensively for various recreational activities. Of particular concern is the relative proportion of the pathogen load contributed by human vs. wildlife and domestic animal sources. Although bacterial contamination in the Pennypack 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 Pennypack Creek Watershed, dry weather (baseflow) conditions should not be overlooked as sources of impairment. Municipal treated sewage comprises a large proportion of baseflow in Pennypack Creek, and the monitoring station immediately downstream from the primary point source discharge frequently exceeded dissolved oxygen water quality criteria (21% of days monitored). 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. Significant reductions of instream phosphorus concentration are needed to reduce algal density, severity of DO fluctuations, and support a more diverse and healthy aquatic ecosystem overall.

All invertebrate communities sampled in Pennypack Creek Watershed were characterized as "severely impaired" when compared to unimpaired regional reference sites. Most sites sampled have a very simplified invertebrate community nearly completely dominated by midge fly larvae (chironomids), and a small number of other moderately tolerant invertebrates with generalized food requirements. These invertebrates are tolerant of low dissolved oxygen conditions and frequent disturbance of their habitat. It is unknown whether Pennypack 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 2002 and 2007. 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 Pennypack 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. Pennypack Creek is dominated by moderately tolerant fish with generalized feeding habits and life history strategies, while species that have specialized habitat, food or reproductive needs are largely missing. Fish that require firm, stable, well oxygenated substrates for spawning are also generally not found in the basin. Though the watershed supports a put-and-take trout fishery, there is some evidence that native fish may be adversely affected by high trout densities. Efforts to restore spawning runs of historically-occurring anadromous fish have thus far been unsuccessful despite removal of several obstructions to fish passage and extensive stocking of Hickory shad fry.

Pennypack Creek Watershed exemplifies contrasts in history and changing environmental attitudes. While acquisition and protection of the Pennypack Creek Valley to protect Philadelphia's source water in the 19th century is an example of very progressive forward thinking, most of the remainder of the basin was developed without effective stormwater management. The current unstable physical and ecological state of the Pennypack 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 Pennypack Watershed Partnership are working to ensure that watershed improvements are cost-effective and based on sound science. We believe this report will serve as a solid foundation for defining reachable goals and developing a roadmap to attaining them in the in the forthcoming Pennypack Creek Integrated Watershed Management Plan.

List of Figures	Page

1 INTRODUCTION

The Philadelphia Water Department (PWD) has embraced a comprehensive watershed characterization, planning, and management program for the Pennypack 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. The Wissahickon Creek planning effort was the third planning process to be initiated and shall be completed in 2009. The Pennypack Creek Integrated Watershed Management Plan was initiated in Winter 2007 and shall be completed alongside the watershed-wide Act 167 Stormwater Management Planning process – due Winter 2010.

This Comprehensive Characterization Report (CCR) for the Pennypack Creek forms the scientific basis for the Pennypack 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 the spring of 2008, 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

2.1 WATERSHED DESCRIPTION

The Pennypack Creek Watershed (PCW) covers a roughly 56 square mile drainage area of southeastern Pennsylvania. The headwaters of the Pennypack Creek originate in Horsham and Warminster Townships within Montgomery and Bucks Counties respectively, and the creek flows roughly 25 miles southeastwardly to its confluence with the Delaware River in the City of Philadelphia.

2.1.1 DRAINAGE AREA

The Pennypack Creek Watershed drains eleven municipalities and portions of northeast Philadelphia before reaching the Delaware River (Table 2.1, Figure 2.1). With a total drainage area of 55.8 square miles, the watershed spans highly developed suburban communities and multiple neighborhoods within the City of Philadelphia (Table 2.1). Over half of the Pennypack Creek Watershed lies within Montgomery County.

Table 2.1 Municipalities within Pennypack Creek Watershed

County, Municipality, Neighborhood	**Area within Watershed (sq. mi.)**	**Percentage of Watershed**
Bucks County	**6.60**	**11.83%**
Upper Southampton Twp.	1.92	3.43
Warminster Twp.	4.68	8.39
Montgomery County	**31.70**	**56.81%**
Abington Twp.	7.69	13.77%
Bryn Athyn Borough	1.96	3.51%
Hatboro Borough	1.44	2.58%
Horsham Twp.	5.71	10.22%
Jenkintown Borough	0.00	0.01%
Lower Moreland Twp.	6.24	11.18%
Rockledge Borough	0.22	0.40%
Upper Dublin Twp.	0.53	0.95%
Upper Moreland Twp.	7.91	14.17%
Philadelphia County	**17.52**	**31.40%**
Total Pennypack Creek	**55.8**	**100%**

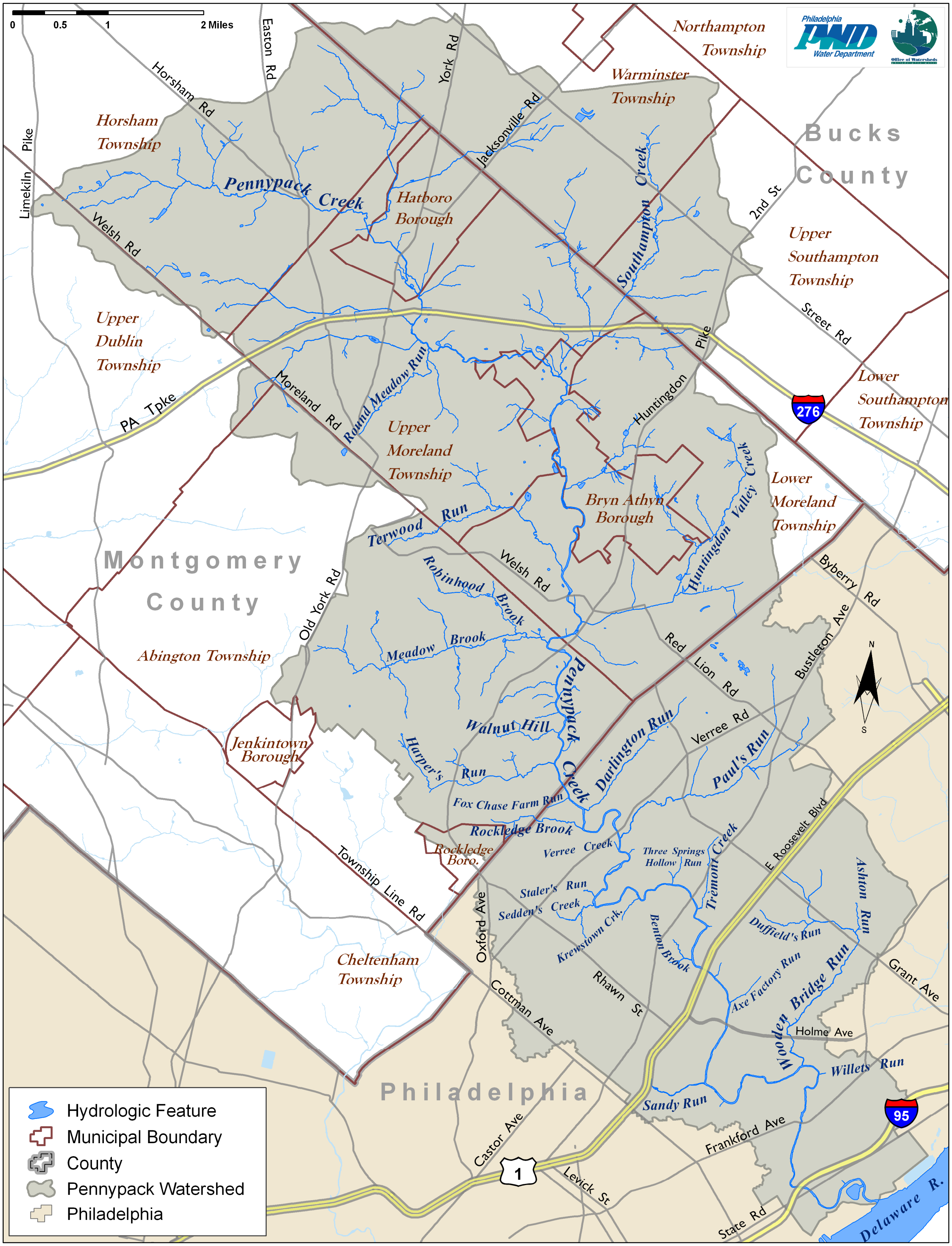


Figure 2.1 Pennypack Creek Watershed

Numerous tributaries flow into the Pennypack Creek (Figures 2.1 and 2.2); the total number of stream miles within the Pennypack Creek Watershed is estimated to be 124.3 miles.

Utilizing orthophotography and topography data from 2004, hydrology of the stream was traced in order to give a detailed account of stream mileage (Table 2.2). Sub-watersheds of Pennypack Creek (Figure 2.2) were delineated using topographical data, PWD storm sewer data, ArcHydro GIS software, and manual digitization by PWD staff as needed.

Table 2.2 Pennypack Creek and Tributary Stream Lengths

Reach Name	Length Miles	Reach Name, Continued	Length Miles
Ashton Run	0.41	Pennypack Creek, unnamed trib. (C)	2.41
Axe Factory Run	0.46	Pennypack Creek, unnamed trib. (D)	0.75
Benton Brook	0.36	Red Rambler Run	0.56
Darlington Run/Ballard Run	1.81	Robinhood Brook	1.86
Darlington Run/Ballard Run, unnamed trib.	0.10	Robinhood Brook, unnamed trib.	0.85
Duffield's Run	0.77	Robinhood Brook, unnamed trib. (B)	1.00
Duffield's Run, unnamed trib.	0.16	Rockledge Brook	1.16
Fox Chase Farm Run	0.26	Rockledge Brook, unnamed trib.	0.22
Harper's Run	2.07	Round Meadow Run	1.51
Harper's Run, unnamed trib.	1.56	Round Meadow Run, unnamed trib.	1.32
Horrock's Creek	0.15	Sandy Run	0.71
Horrock's Creek, unnamed trib.	0.11	Sedden's Creek	0.55
Hower Creek	0.09	Sedden's Creek, unnamed trib.	0.32
Huntingdon Valley Creek	3.48	Slater's Run	0.17
Huntingdon Valley Creek, unnamed trib.	4.89	Southampton Creek	3.53
Krewstown Creek	0.33	Southampton Creek, disconnected trib.	0.92
Meadow Brook	2.66	Southampton Creek, unnamed trib.	7.33
Meadow Brook, unnamed trib.	2.92	Southampton Creek, unnamed trib. (A)	0.63
Meadow Brook, unnamed trib. (A)	0.66	Southampton Creek, unnamed trib. (B)	2.16
Paul's Run	3.14	Tabor Creek	0.20
Paul's Run, unnamed trib.	0.22	Terwood Run	2.78
Paul's Run, unnamed trib. (A)	1.02	Terwood Run, unnamed trib.	1.62
Pennypack Creek (mainstem)	24.35	Three Springs Hollow Run	0.34
Pennypack Creek, disconnected trib.	1.01	Three Springs Hollow Run, unnamed trib.	0.09
Pennypack Creek, unnamed trib.	24.07*	Tremont Creek	0.87
Pennypack Creek, unnamed trib. (A)	1.84	Verree Creek	0.11
Pennypack Creek, unnamed trib.	0.41	Walnut Hill	0.95

(AA)			
Pennypack Creek, unnamed trib. (AB)	1.42	Walnut Hill, unnamed trib.	0.16
Pennypack Creek, unnamed trib. (AC)	1.73	Willet's Run	0.08
Pennypack Creek, unnamed trib. (ACA)	0.51	Wooden Bridge Run	3.03
Pennypack Creek, unnamed trib. (B)	2.56	Wooden Bridge Run, unnamed trib.	0.63

*Total river mile distance of 152 unnamed tributary segments of Pennypack Creek

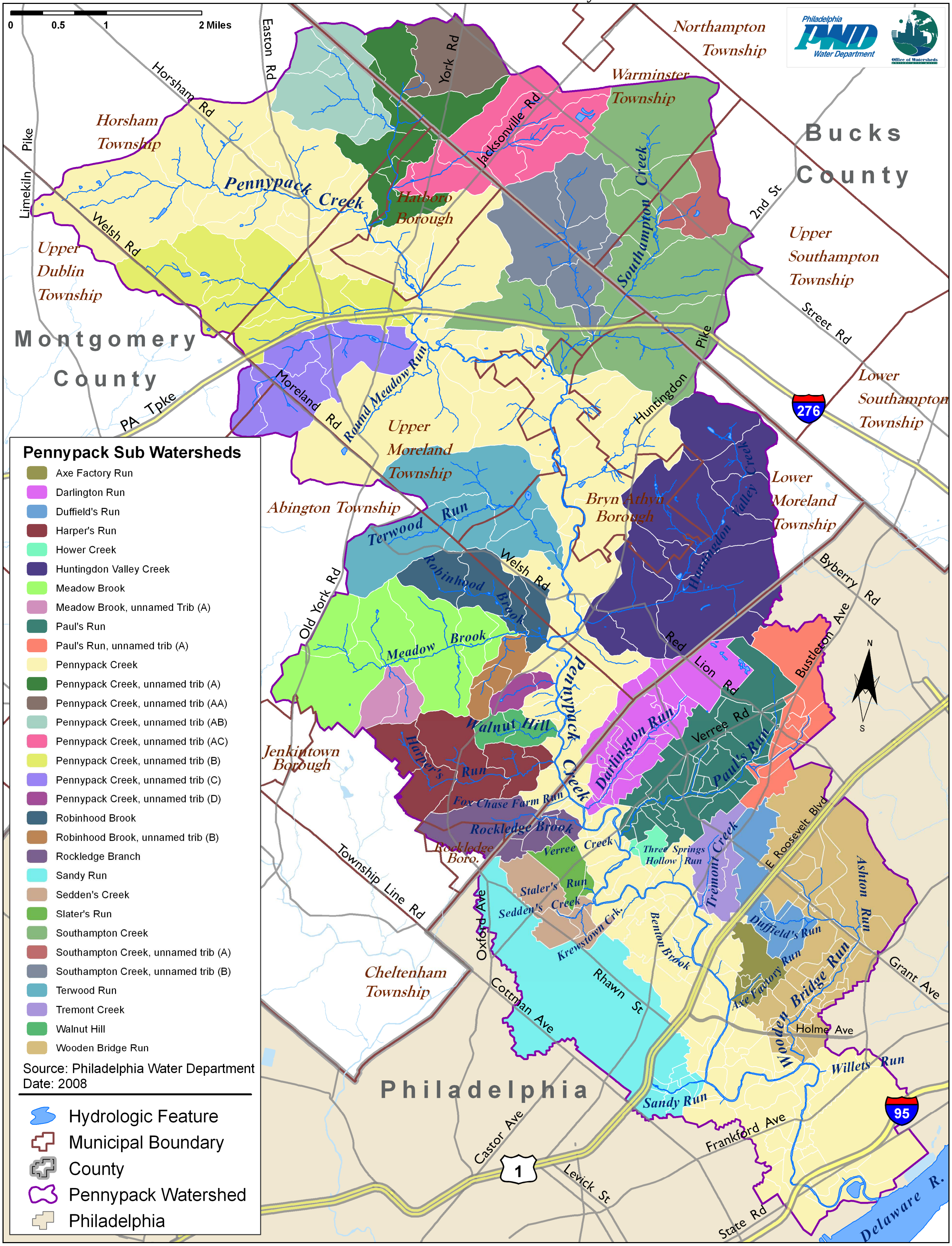


Figure 2.2 Pennypack Creek Sub-Watersheds

2.2 LAND USE IN THE PENNYPACK CREEK WATERSHED

Land use information for the Pennypack Creek Watershed was obtained from the Delaware Valley Regional Planning Commission (DVRPC). Over time, the Pennypack Creek Watershed has experienced continual and extensive urban and suburban land development. Overall, more than half of the Pennypack Creek Watershed is covered by residential development with single-family detached residential (40.54%) 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, Old York/Easton Road Rt. 611, Roosevelt Boulevard Rt. 1, and York Road Rt. 263. SEPTA regional railroad lines R1 Glenside, R2 Warminster, R3 West Trenton, R5 Doylestown, and R8 Fox Chase all have multiple stops within the Pennypack Creek Watershed. Residential, commercial, and industrial development closely follows these major train and vehicle transportation corridors.

A large portion of the riparian corridor of the Pennypack Creek and its tributaries has remained wooded land, mostly protected through long-term preservation efforts of the Fairmount Park Commission and multiple organizations based out of Montgomery County. This network, the Pennypack Greenway, is described in detail in Section 2.3.2.1. Additionally, large tracts of privately owned open space in Montgomery County, such as agricultural land and golf courses, remain undeveloped and are dispersed throughout the watershed, presenting opportunities for future Pennypack Greenway preservation efforts.

Table 2.3 Land Use in the Pennypack Creek Watershed by County

Land Use	Philadelphia County	Montgomery County	Bucks County	Total Pennypack Watershed
Agriculture	0.35%	6.07%	1.66%	**3.75%**
Commercial	5.76%	5.00%	5.50%	**5.30%**
Community Services	4.05%	2.60%	2.42%	**3.04%**
Golf Course	0.00%	2.48%	0.00%	**1.41%**
Manufacturing: Light Industrial	4.19%	2.37%	5.50%	**3.31%**
Military	0.00%	0.66%	5.52%	**1.03%**
Mining	0.00%	0.10%	0.12%	**0.07%**
Parking	5.11%	5.51%	7.40%	**5.61%**
Recreation	2.64%	2.61%	5.83%	**3.00%**
Residential: Mobile Home	0.00%	0.03%	0.00%	**0.02%**
Residential: Multi-Family	25.95%	3.16%	5.55%	**10.60%**
Residential: Row Home	2.71%	0.06%	0.00%	**0.89%**
Residential: Single-Family	17.77%	51.10%	50.31%	**40.54%**
Transportation	5.89%	0.67%	0.91%	**2.34%**
Utility	1.59%	0.32%	0.31%	**0.72%**
Vacant	6.04%	1.80%	3.05%	**3.28%**
Water	1.00%	0.53%	0.04%	**0.62%**
Wooded	16.96%	14.91%	5.88%	**14.48%**
Total	**100.00%**	**100.00%**	**100.00%**	**100.00%**

Source: Delaware Valley Regional Planning Commission, 2000.

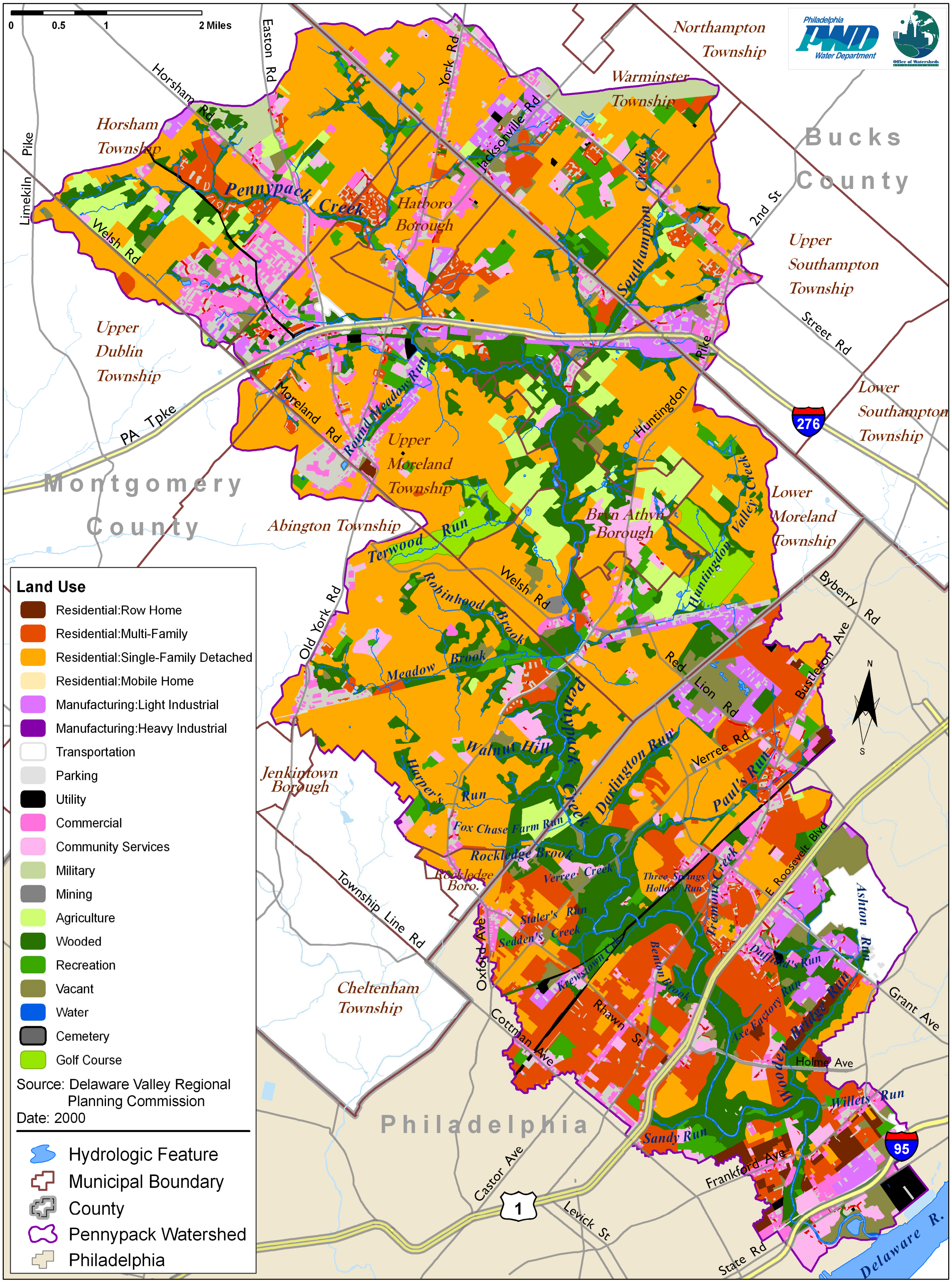


Figure 2.3 Land Use in the Pennypack Creek Watershed

2.3 PENNYPACK WATERSHED OPEN SPACE

The Pennypack Creek Watershed has over 3899 acres of preserved open space, much of which is located along the mainstem of the creek (Table 2.4, Figure 2.4). Multiple parties—including the counties, municipalities, nonprofit groups and others—are working together to realize the completion of the Pennypack Greenway. The Greenway, a strip of permanently protected land along the creek, connects the municipalities of Montgomery County and the City of Philadelphia.

2.3.1 GENERAL CHARACTERISTICS OF OPEN SPACE

Within Montgomery County, the Pennypack Ecological Restoration Trust (PERT) has acquired 720 acres within Montgomery County that are open to the public for hiking, birding, and general enjoyment. Additionally, golf courses including Philmont, Island Green, Huntington Valley, and Meadowbrook Country Clubs total 688 acres of preserved open space.

Within the Philadelphia portion of the Pennypack Creek Watershed, over 1700 acres of open space are protected by the Fairmount Park Commission, known as Pennypack Park. Pennypack Park includes trails, picnic areas, sports fields, birding, and fishing access.

Table 2.4 Estimated Acres of Open Space in the Pennypack Creek Watershed

Municipality	Conservation Land Acres	Golf Course Acres	County/Local Park Acres
Abington Township	16.0	139.1	301.3
Bryn Athyn Borough	223.7	1.3	26.1
Hatboro Borough	-	-	26.1
Horsham Township	70.9	-	99.8
Lower Moreland Township	239.6	342.9	50.3
Philadelphia	-	136.1	1702.6
Rockledge Borough	-	-	4.3
Upper Dublin Township	-	-	5.2
Upper Moreland Township	149.5	205.3	189.6
Total	**669.7**	**824.8**	**2405.2**

2.3.2.1 PENNYPACK GREENWAY

The Pennypack Greenway describes the network of open space that borders the Pennypack Creek from the Delaware River through Philadelphia and into Montgomery County (Figure 2.8). The Pennypack Greenway is composed of a number of individual parks including Pennypack Park, Lorimer Park, Pennypack Preserve, and additional undeveloped yet unpreserved tracts of land. Pennypack Park is approximately 1600 acres of natural and recreational lands owned and maintained by the City of Philadelphia Fairmount Park Commission. Lorimer Park is 250 acres and continues the Greenway from Philadelphia into Montgomery County. Continuing upstream lies the 725 acre Pennypack Preserve, owned and maintained by the Pennypack Ecological Restoration Trust. Lorimer Park and Pennypack Preserve are currently separated by undeveloped, unpreserved land. There are also a number of preserved acres of open space within the watershed in the way of farms, and natural areas in addition to those mentioned that directly border the mainstem.

The Pennypack Greenway Partnership was assembled from representatives of regional organizations between 2005 and 2006 to preserve, expand, and restore natural areas along the Pennypack Creek. The Pennypack Greenway Partnership is committed to linking neighborhoods and communities to the natural resources of Pennypack Creek, improving water resources, enhancing recreational opportunities, and safeguarding the natural and cultural heritage of the watershed. In 2006, the Pennypack Greenway Partnership developed a strategic action plan to prioritize and outline how the group will work with the community, state, and regional organizations to preserve the remaining undeveloped land within the Pennypack Creek Watershed. The Partnership is especially interested in preserving the undeveloped tracts that lie between protected open spaces, ultimately producing a contiguous ribbon of preserved lands along the Pennypack Creek.

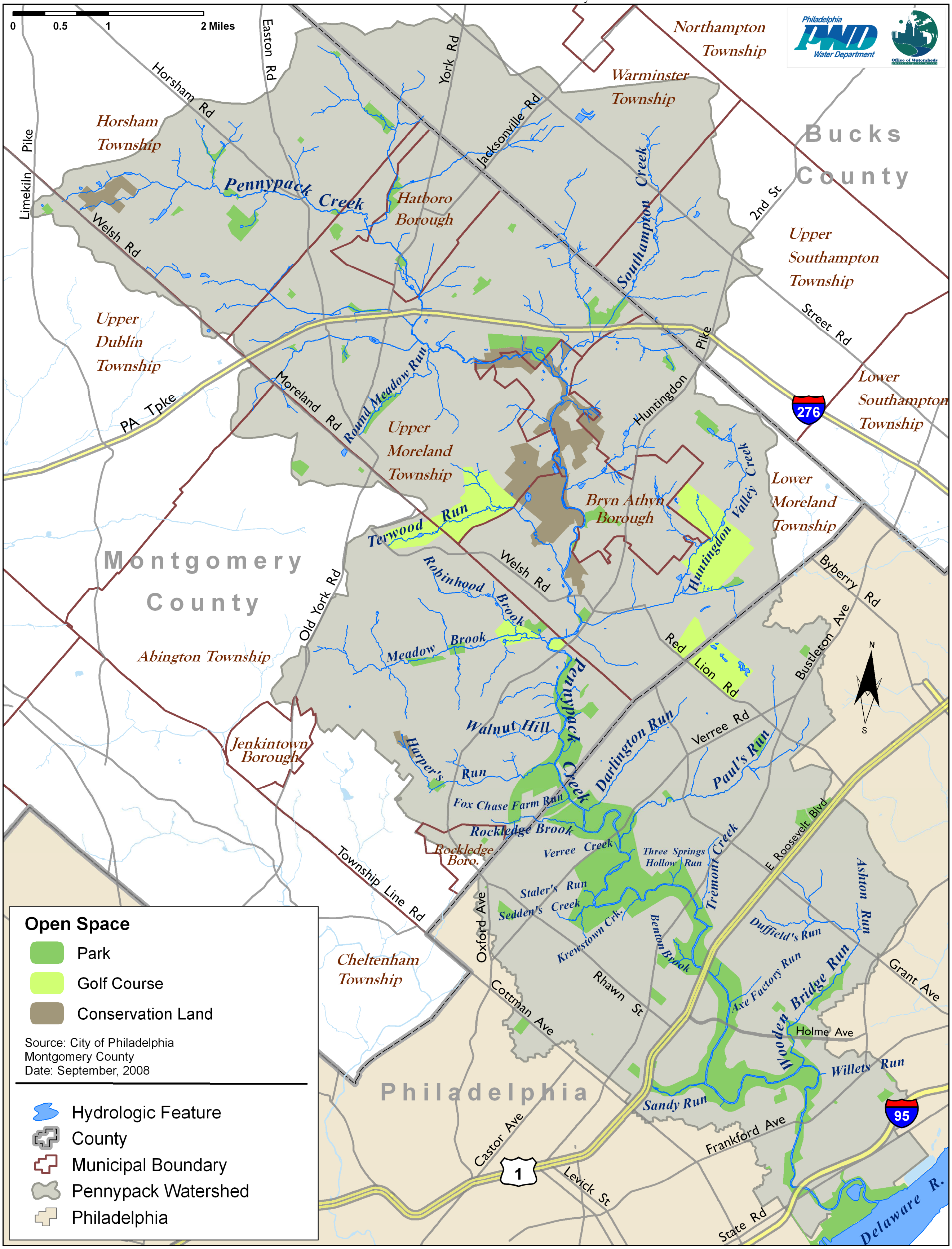


Figure 2.4 Protected Open Space within Pennypack Creek Watershed

2.3.2 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 Pennypack Creek Watershed from 2001-2002, and continued the program in 2004. Initially, the assessments took place within the Philadelphia portion of the Pennypack 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 Pennypack 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 Pennypack 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 Pennypack 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 Pennypack Creek Watershed wetlands assessment found 23 potential wetland creation sites; nine sites within Philadelphia County, 13 sites within Montgomery County, and one site within Bucks County. The estimated size of combined potential wetland creation sites is two acres in Philadelphia County and four acres in Bucks and Montgomery Counties. 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 11 of 31 wetland sites within Philadelphia and 28 of 54 existing wetlands in Montgomery and Bucks Counties (Figure 2.5). The "Southeast Regional Wetland Inventory and Water Quality Improvement Initiative for the Pennypack Creek Watershed" Final Report is available for review at www.phillyriverinfo.org.

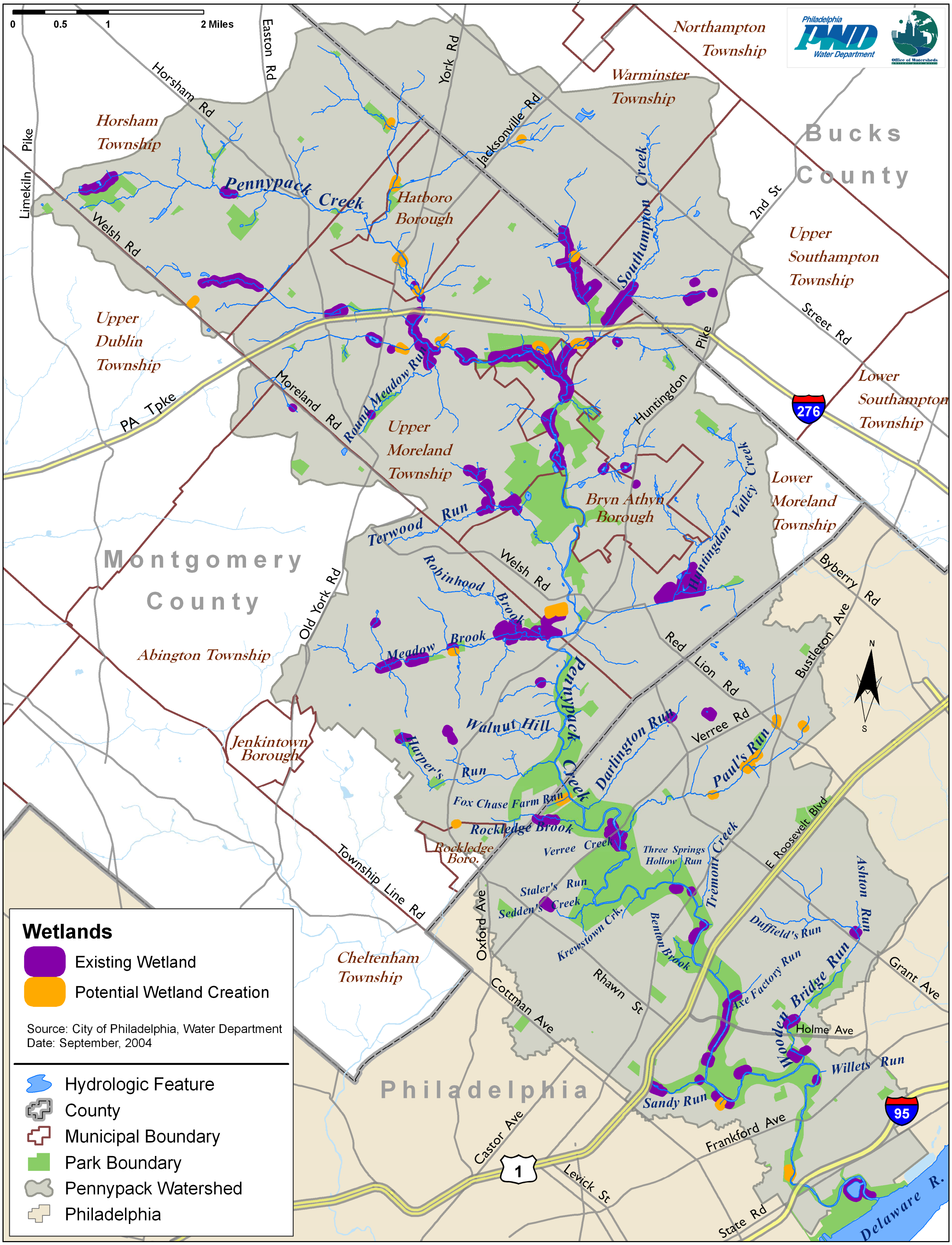


Figure 2.5 Existing and Potential Wetland Creation Sites in Pennypack Creek Watershed

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 Pennypack Creek Watershed are presented in Table 2.5 and Figure 2.6. The location and descriptions of the geology and soils within the Pennypack Creek Watershed are detailed in Figures 2.7 and 2.8, and Table 2.6.

Table 2.5 Generalized descriptions of Physiographic Provinces and Sections within the Pennypack Creek Watershed

Province and Section	Description
Province: Piedmont **Section:** Gettysburg-Newark Lowland	Rolling hills and valleys atop red sedimentary rock; isolated high hills atop diabase, hornfels and conglomerates; dendritic drainage; bedrock composed of sedimentary rock deposited when the area was an inland basin.
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 Lowland	Broad, moderately dissected valleys separated by broad low hills; bedrock is primarily limestone and dolomite; karst topography; dendritic and subsurface drainage.
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.

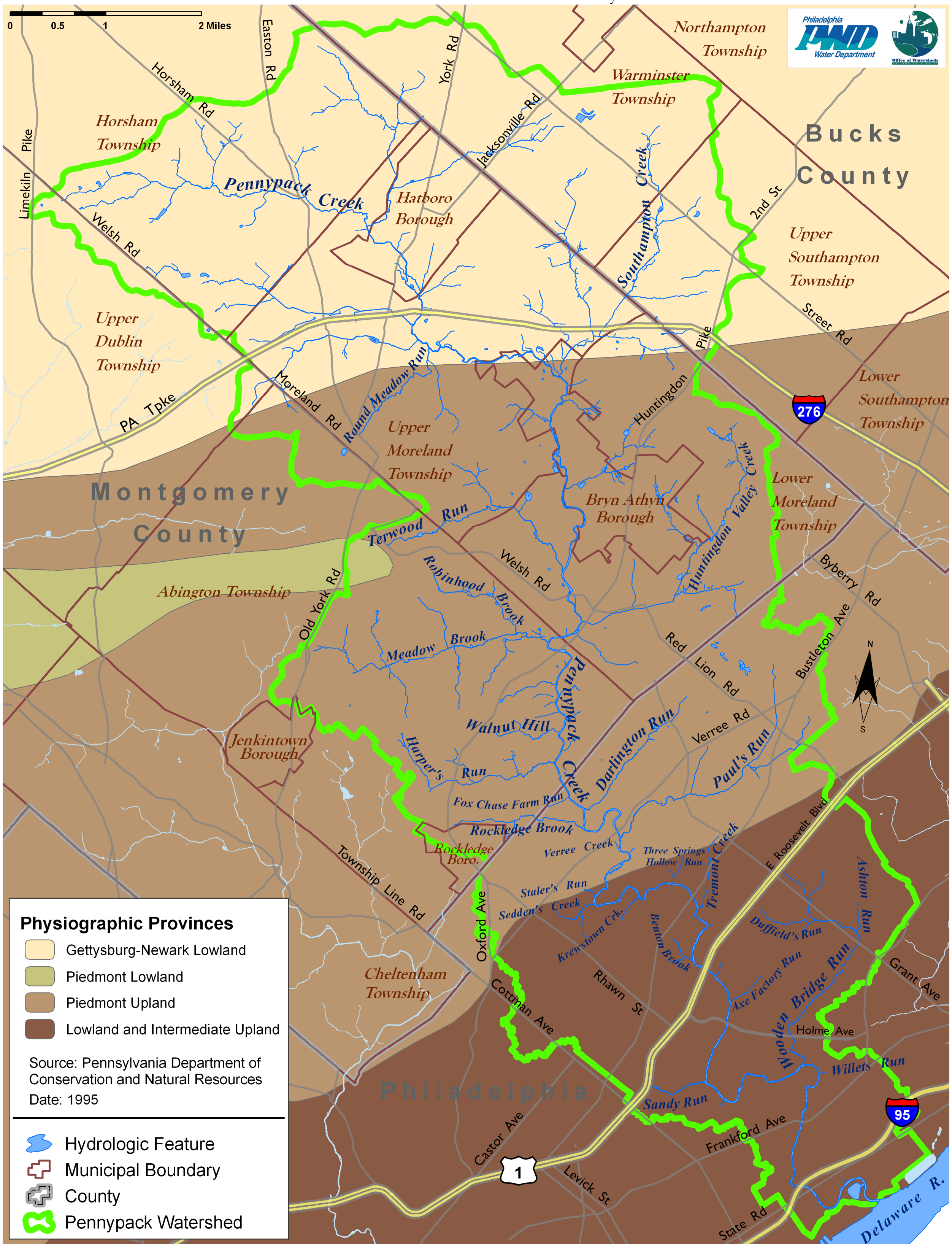


Figure 2.6 Pennypack Creek Watershed Physiographic Provinces

Table 2.6 Generalized descriptions of Geologic Formations within the Pennypack 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.
Lockatong Formation	This formation is composed of dark gray to black argillite with occasional zones of limestone and black shale. This formation is part of a larger band, several miles wide, which runs from the Mont Clare area to the Montgomery/Horsham Township border. Resistant to weathering, these rocks form the prominent ridge that runs through central Montgomery County.
Mafic Gneiss	This formation consists of medium to fine grained, dark colored calcic plagioclase, hyperthene, augite, and quartz. It is highly resistant to weathering, but shows good surface drainage.
Pennsauken Formation	This formation consists of sand and gravel yellow to dark reddish brown, mostly comprised of quartz, quartzite, and chert. It is a deeply weathered floodplain formation.
Stockton Formation	This formation consists of interbedded arkose, arkosic conglomerate, feldspathic sandstone, and red shale and siltstone. It is a primarily coarse sandstone formation, which tends to form ridges resistant to weathering. This rock is a good source of brick, floor tile, and sintered aggregate material. This formation is comprised of light colored sandstone, arkosic sandstone, and conglomerate sandstone. It also includes red to purplish-red sandstone, shale and mudstone. The formation is porous, permitting good surface drainage and good groundwater recharge.
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.

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

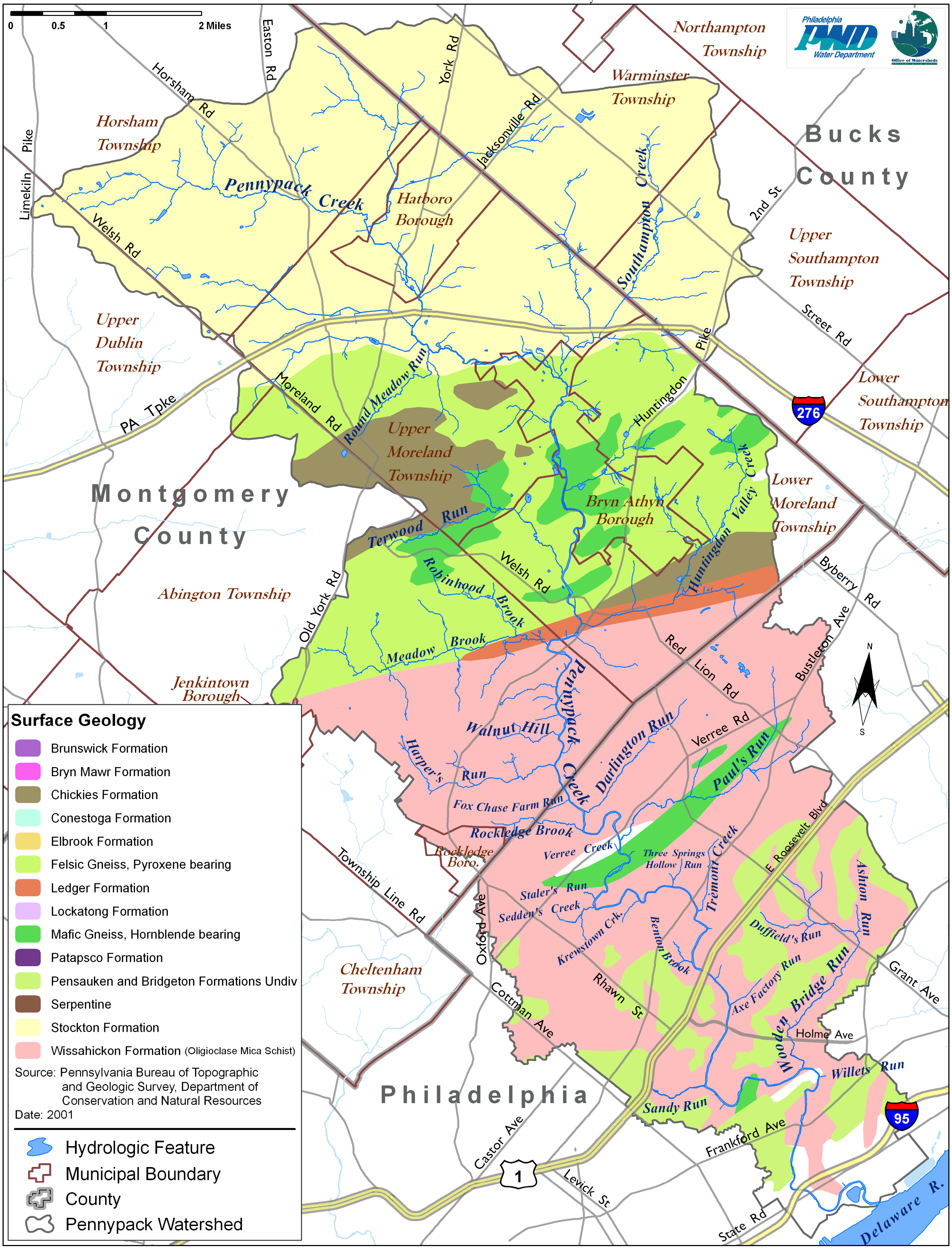


Figure 2.7 Pennypack Creek Watershed Surface Geology

Soils within the Pennypack Creek Watershed are 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 2.7 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 or to accept recharge of treated wastewater or to allow for effective use of septic systems. Most soils in Pennypack Creek Watershed are categorized as hydrologic category B, with some upstream areas in category C (Figure 2.10). This means that most of the study area has soils that have moderate to high rates of infiltration when thoroughly wet, and water movement through these soils is generally rapid. This has implications for the design of stormwater infiltration systems, and also affects the amount of water that needs to be infiltrated in newly developing areas to maintain predevelopment or natural infiltration rates.

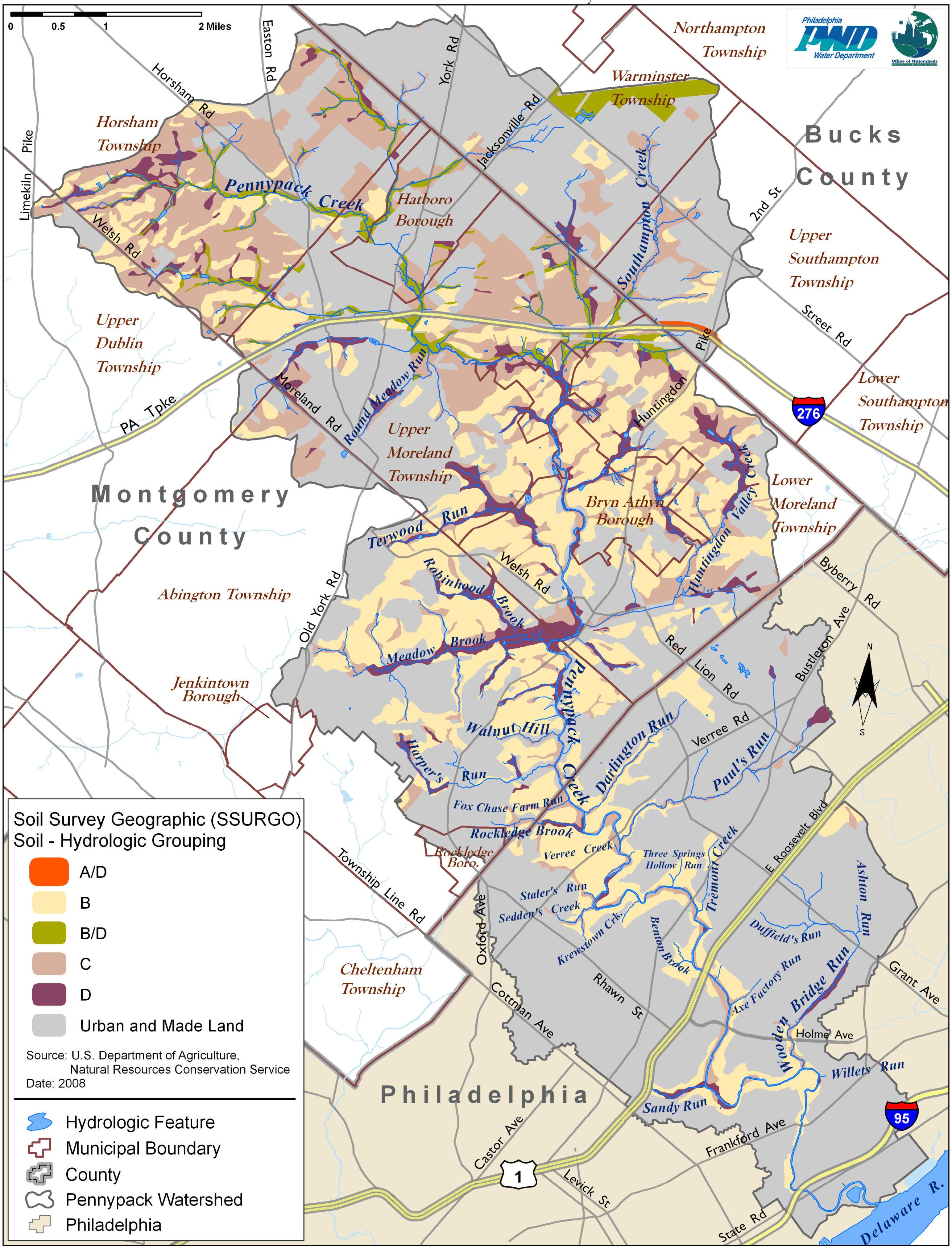


Figure 2.8 Soil Hydrologic Grouping within Pennypack Creek Watershed

2.5 DEMOGRAPHIC INFORMATION

Population density and other demographic information for the Pennypack Creek Watershed taken from the 2000 U.S. Census Survey are listed in Table 2.7. According to the 2000 Census, 227,489 people reside within Pennypack Creek Watershed. The average population density of the watershed is approximately 6 persons per acre (Figure 2.9). 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 1990 vs. 2000 population changes, 2000 race, and 2000 median household income within the Pennypack Creek Watershed are found in Section 2.2 of the Pennypack Creek Watershed River Conservation Plan (RCP) published in December 2005. The RCP examines the municipalities in their entirety, not only the areas within the Pennypack Creek Watershed. The RCP calculated the greatest population change in Bryn Athyn Borough Montgomery County, where the population rose by 20 percent from 1990 to 2000. In Philadelphia during that same time period the population fell by 4.5 percent, continuing a population decline that has lasted for decades.

Table 2.8 Pennypack Creek Demographic Statistics

Municipality	Population	# of Households
Bucks County	**22,595**	**8,739**
Upper Southampton Township	5,182	2,208
Warminster Township	17,412	6,532
Montgomery County	**77,580**	**30,673**
Abington Township	16,769	6,767
Bryn Athyn Borough	1,351	377
Hatboro Borough	7,319	3,015
Horsham Township	14,638	5,739
Lower Moreland Township	9,034	3,335
Rockledge Borough	1,888	779
Upper Dublin Township	1,625	557
Upper Moreland Township	24,956	10,105
Philadelphia County	**127,315**	**52,776**
Total	**227,489**	**92,189**

Source: 2000 U.S. Census

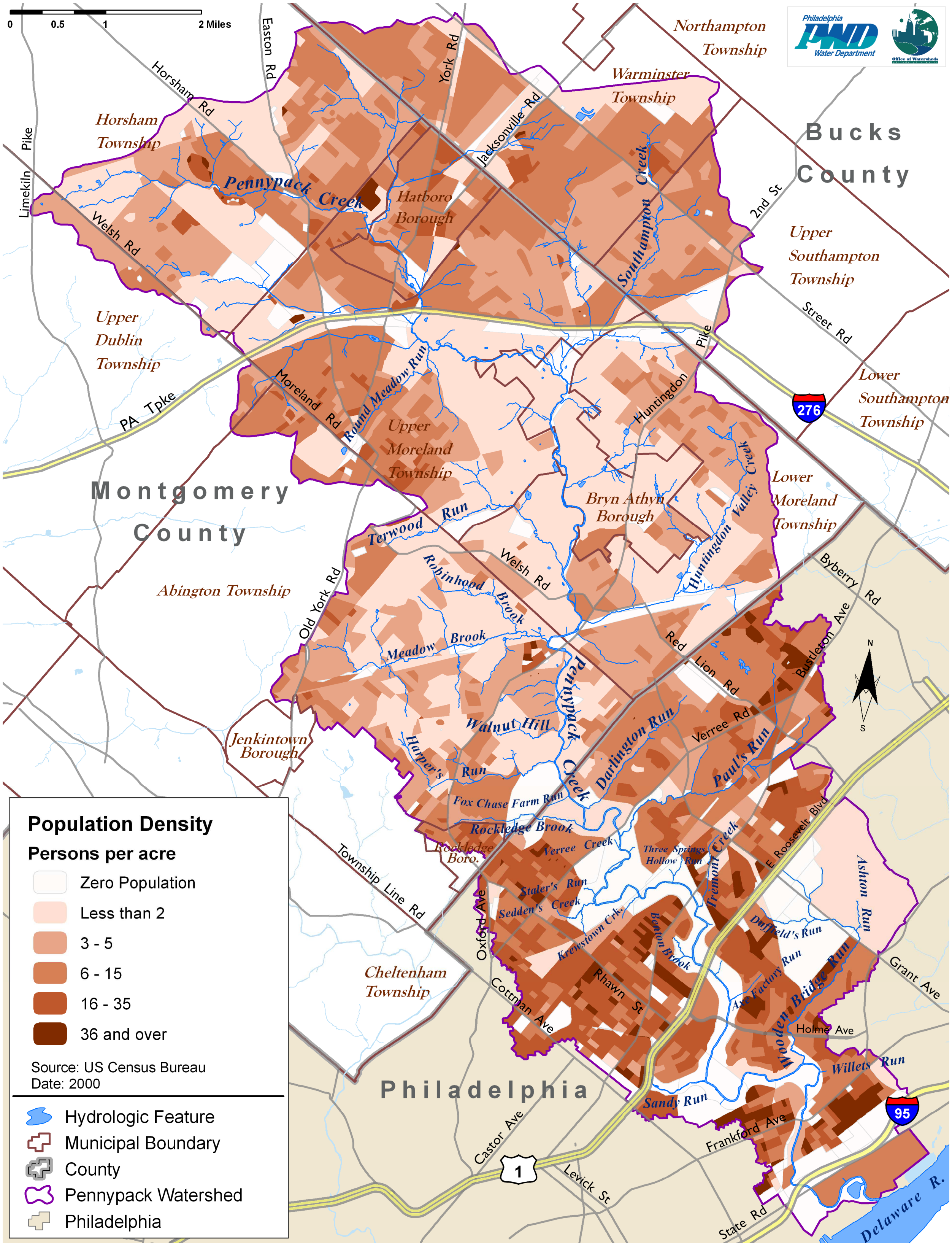


Figure 2.9 Pennypack Creek Watershed Population Density

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 percent impervious cover (Schueler 1995). The Pennypack Creek Watershed has an average of 33% impervious cover overall, placing it solidly in the "Non-Supporting" category of stream health, (Tables 2.9 and 2.10). The City of Philadelphia portion of the watershed has the greatest amount of impervious cover, 41.87%, but according to Table 2.3 also has the greatest percentage of wooded lands in the Pennypack Creek Watershed, which can be attributed to the 1600 acre Pennypack Creek Park. The impacts that overall watershed impervious cover can have on stream health, independent of the area of forested lands, are described below in Table 2.10. In Table 2.10 the adverse changes in critical stream characteristics are listed, along with the levels of imperviousness typically associated with these changes.

Table 2.9 Estimated Impervious Cover in the Pennypack Creek Watershed

Location	Total Area of Watershed Square Miles	Total Impervious Area Square Miles	Percent Impervious
Bucks County	6.6	2.25	34.11%
Montgomery County	31.7	8.83	27.86%
Philadelphia County	17.5	7.34	41.87%
Total Watershed	**55.8**	**18.42**	**33.00%**

Source: PWD internal 2004 planimetrics data

Table 2.10 Impervious Cover as an Indicator of Stream Health (Schueler 1995)

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

Most of the impacts of traditional development on streams and watersheds are directly attributed to the increase of impervious cover, but construction disturbance, non-point source pollution and other changes to the landscape also play an important role (Table 2.10).

Table 2.11 Impacts of Traditional Development on Watershed Resources

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

Source: Schueler 1995

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 published every two years by PADEP.

In the Pennypack Creek Watershed there are approximately 79 miles of streams included in the 303(d) list of impaired streams. The most extensive impairment, 61.8 miles, is due to urban runoff. In the Pennypack Creek Watershed, urban runoff impairs stream segments throughout Bucks, Montgomery, and Philadelphia Counties. A summary of impairments and the lengths of impaired stream segments are listed in Table 2.12. As shown in Figure 2.10, the entire mainstem of the Pennypack Creek within Montgomery County is impaired due to urban runoff. Within Bucks County, the entire length of Southampton Creek is included on the 303(d) list due to residential runoff. In Philadelphia County, the mainstem Pennypack Creek is impaired due to both urban runoff and industrial/municipal point sources.

Table 2.12 Summary of Impairments in the Pennypack Creek Watershed

Impairment	Total Miles
Agriculture	0.4
Industrial/Municipal Point Source	9.5
Residential Runoff	7.3
Urban Runoff	61.8

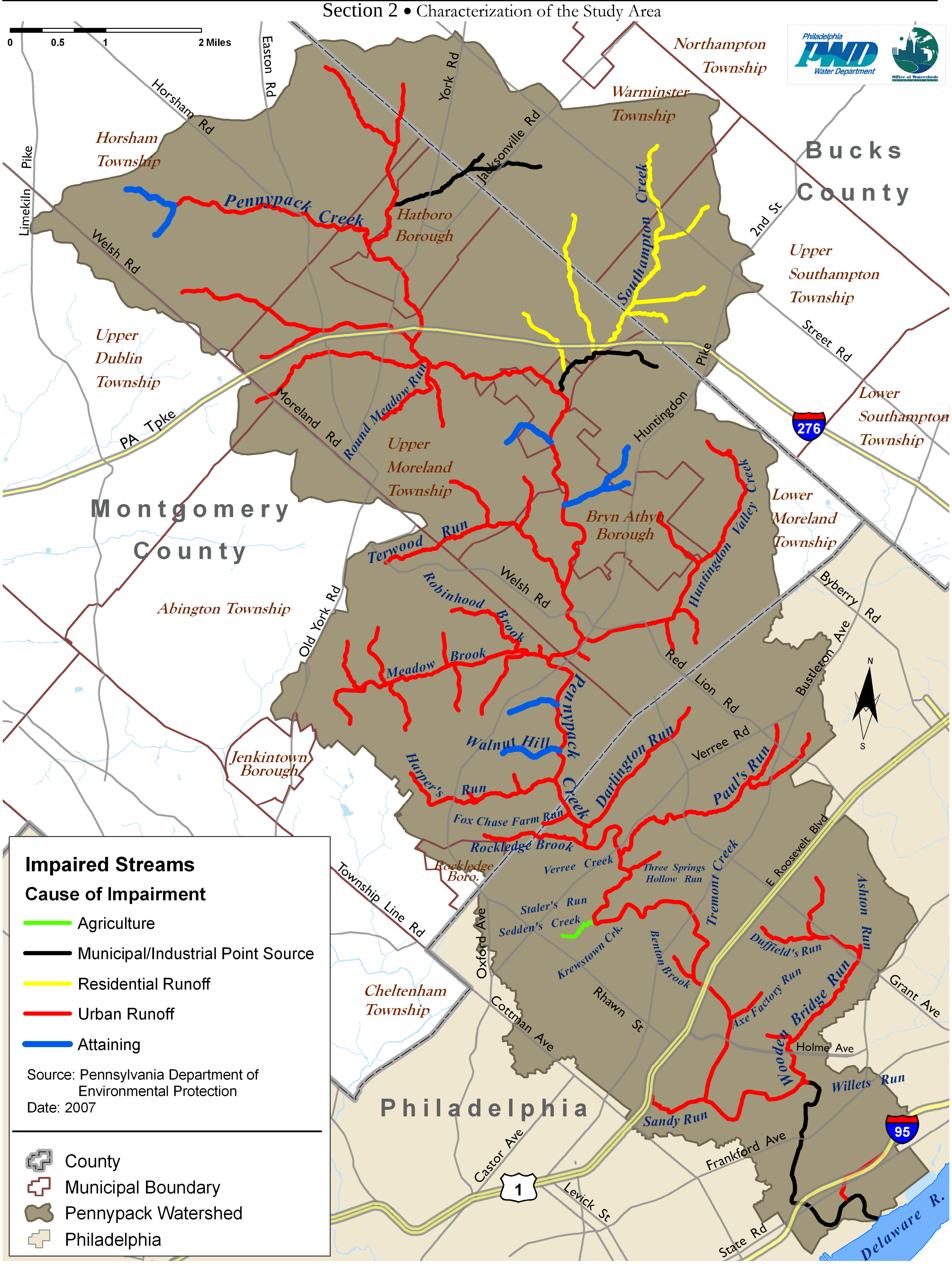


Figure 2.10 Pennypack Creek 303(d) List Stream Impairments

2.7.1 TMDLs IN THE PENNYPACK CREEK WATERSHED

In accordance with the Federal Clean Water Act, TMDL restrictions are imposed on waterways that do not meet water quality standards. A TMDL establishes the maximum amount of a pollutant that a body of water can assimilate, and assigns accountability for the reduction of that pollutant. TMDL compliance involves comprehensive watershed assessment and the development of a remediation strategy through which the impaired waterway may achieve state water quality standards. Section 303(d) of the Clean Water Act and the USEPA's Water Quality Planning and Management Regulations (40 CFR Part 130) provide a framework for watershed planning based on Total Maximum Daily Loads. TMDLs are the sum of individual waste load allocations (point sources) and load allocations (non-point sources) plus a margin of safety. They establish a link between water quality standards and water quality based controls. The objective of TMDLs is to allocate allowable loads among different pollutant sources so that the appropriate control actions can be taken and water quality standards achieved.

Two TMDLs have been established for the Pennypack Creek Watershed and a large portion of the watershed remains on the Pennsylvania State List of Impaired Waters requiring a TMDL.

2.7.1.1 PENNYPACK CREEK TOTAL MAXIMUM DAILY LOAD – 1999

The Pennypack Creek was listed on the PADEP's 1996 303(d) list of impaired waters due to priority organics from industrial point sources and pathogens and organic enrichment/dissolved oxygen (DO) from municipal point sources. The listing was based on a 1989 Aquatic Biology Investigation and Water Quality Assessment conducted by the PADEP. The Summary identified the priority organic pollutant as Trichloroethylene (TCE). The Pennypack TMDL submitted on April 1998 outlines the major contaminants and contributors to the Pennypack Creek including Trichloroethylene (TCE), organic enrichment or dissolved oxygen (DO), and fecal coliform bacteria.

In the TMDL documentation, Fisher & Porter Inc. was identified as the main point source contributor of TCE. The following entities were listed as contributors of fecal coliform, $CBOD_5$ and NH_3:

1. Upper Moreland Hatboro JT Sewer Authority
2. Gloria Dei Apartments
3. Bethayres Apartments
4. Lower Moreland School District
5. Academy of the New Church
6. HPC (aka Meadowbrook Apartments)
7. Holy Redeemer Hospital
8. Tall Trees Apartments

Due to the age of this TMDL, the PA DEP has not made an electronic version of the document available. For more information about this TMDL, please contact the PADEP directly.

2.7.1.2 NUTRIENT AND SEDIMENT TMDLs FOR THE SOUTHAMPTON CREEK WATERSHED – 2008

Nutrient and Sediment TMDLs were completed for the Southampton Creek tributary sub-watershed of the Pennypack Creek Watershed in June, 2008. The Southampton Creek drainage area is just over 6 square miles; the creek is roughly 3.5 mile long stream with six unnamed tributaries located on the border of Montgomery and Bucks County, Pennsylvania. This waterway was listed on the PADEP's 303(d) list of impaired waters for Channelization / Siltation, Urban Runoff / Stormwater Sewer / Nutrients. According to the TMDL documentation, wasteload reductions are needed to eliminate excessive blooms of algae from organic enrichment and to reduce sediment loads in the main stem and tributaries.

The Southampton Creek TMDL defines Waste Load Allocations (WLAs) and End Points for point source dischargers and MS4 municipalities within this watershed for both nutrients and sediments (Tables 2.13, 2.14, 2.15, 2.16, 2.17 and 2.18)

Table 2.13 Sediment WLA for Point Source Dischargers in Southampton Watershed

Permit Number	Name of Discharger	Name of Facility	Receiving Water	Design Flow (MGD)	Sediment WLA (lbs/yr)	Sediment WLA (lbs/day)	Percent Reduction
PA0046868	Lower Moreland Twp Auth	Chapel Hill WWTP	Tributary 02453	0.279 (after expansion)	16,986	47	0%

Table 2.14 Sediment WLAs for MS4 Municipalities in Southampton Watershed

Municipality	Allocated Sediment Load (lbs/yr)	Allocated Sediment Load (lbs/day)
Upper Southampton	349,977	959
Lower Moreland	123,449	338
Upper Moreland	229,252	628
Warminster	367,675	1,007
Bryn Athyn	5,400	15

Table 2.15 Summary of Nutrient TMDL Results

	TMDL (lbs/yr)	TMDL (lbs/day)	MOS (lbs/day)	WLA (lbs/day)	LA (lbs/day)
Total Phosphorus	82	0.22	0.02	0.20	0

Table 2.16 Nutrient WLAs for Point Source Discharger in Southampton Creek Watershed

Permit Number	Name of Discharger	Name of Facility	Design Flow (MGD)	Current TP Permit - Avg Monthly (mg/L)	Allowable TP Effluent Limit (Seasonal Avg) (mg/L)	Allowable TP Seasonal Load for May-Sept [153 days] (lbs/season)	Allocated TP Load (based on Seasonal Flow) (lbs/yr)	Allocated TP Load (based on Seasonal Flow) (lbs/day)
PA0046868	Lower Moreland Twp Auth	Chapel Hill WWTP	0.279 (after expansion)	1.0	0.079	28	67	0.18

Table 2.17 Required Reduction for Point Source Discharger in Southampton Creek Watershed

Name of Discharger	Current TP Permit (mg/L)	Current TP Load (lb/yr)	Current TP Load (lb/day)	Allowable Effluent TP Limit (mg/L)	Allocated TP Load (lb/yr)	Allocated TP Load (lb/day)	Required % Reduction
Lower Moreland Twp Auth	1.00	850	2.33	0.079	67	0.18	92.10%

Table 2.18 Nutrient WLAs for MS4 Municipalities in Southampton Watershed

Source	Allocated TP load (lbs/day)	Allocated TP load (lbs/yr)
Upper Southampton	0.006	2.19
Lower Moreland	0.002	0.73
Upper Moreland	0.004	1.46
Warminster	0.006	2.19
Bryn Athyn	0	0

The TMDL and associated Modeling Report are available online on the EPA Region 3 webpage: http://www.epa.gov/reg3wapd/tmdl/pa_tmdl/SouthamptonCreekNutrient/index.html

2.7.1.3 POTENTIAL FUTURE TMDLS

The Pennsylvania State integrated list of watersheds needing TMDLs lists additional segments of the Pennypack mainstem and tributaries for TMDL development – targeted for 2015 and 2017, though the PADEP has confirmed that an implementation schedule for developing TMDLs for the remaining portion of the watershed has not been developed or committed to.

2.8 FLOODING IN THE PENNYPACK WATERSHED

As previously noted, considerable development and suburbanization within the Pennypack 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 within the floodplain is problematic. The development occurred prior to the enactment of municipal floodplain management ordinances.

The portion of the Pennypack Creek Watershed outside of the City of Philadelphia has experienced floods that have caused property damage and loss of life. During severe weather events, the waterways of the Pennypack Creek Watershed have breached their banks and severely flooded portions of Lower Moreland, Upper Moreland, Hatboro, and Bryn Athyn Townships.

In Upper Moreland Township, thirty-two houses were bought by the State of Pennsylvania, and the residents relocated, after sustaining irreparable damage from Tropical Storm Allison in June 2001. Since 1999, there have been 14 flood-related deaths, including 6 that occurred during Tropical Storm Allison. The property damages and loss of life due to flooding has increased the willingness throughout the watershed to reduce the impacts of flooding and created public and financial support for the Temple University Floodplain Study, described below in Section 2.4.3.

Within Philadelphia County, flooding from the Pennypack Creek frequently damages the trails, grounds, and facilities of Pennypack Creek Park. In 2005, the Fairmount Park Commission and volunteers planted over 500 trees in Pennypack Creek Park in order to strengthen the riparian buffer and increase the ability of the land to infiltrate stormwater and ultimately reduce flood intensity.

2.8.1 TEMPLE UNIVERSITY FLOODPLAIN STUDY

In June 2002, the Temple University Center for Sustainable Communities (CSC) began a comprehensive study of flooding and water quality in the Pennypack Creek Watershed in Bucks and Montgomery Counties. The Philadelphia portion of the watershed was not examined in the study; however PWD assisted and supported the project. For the Pennypack Creek Watershed Study, the CSC received funding from the William Penn Foundation, Federal Emergency Management Agency (FEMA), and municipalities within the watershed. The goal of the CSC Pennypack Creek Watershed Study was to "...assist communities within the watershed in reducing flooding, improving water quality, and better managing future development" (Meenar 2006). The Pennypack Creek Watershed Study has six components: watershed modeling, floodplain mapping and GIS data inventory, water quality studies, stormwater management, open space and corridor activities, and final recommendations. The modeling and mapping components were integrated to produce a series of updated floodplain maps for the Bucks and Montgomery County portions of the Pennypack Creek Watershed.

Floodplains for the 100-year and 500-year storms were developed using the U.S. Army Corps of Engineers HEC-HMS model, field data, and GIS software. The existing FEMA floodplain delineations and the CSC delineations do not differ in all locations, but there are places where the two boundaries diverge by up to 400 feet. The total area of FEMA 100-year floodplains within the Pennypack Creek Watershed is 2.74 square miles; whereas the CSC Study identified 3.4 square miles.

The final CSC floodplain delineations were submitted to FEMA and PADEP for approval to make the CSC floodplains the official floodplains recognized by the Counties and Townships within the Pennypack Creek Watershed, Figure 2.11. FEMA is expected to officially adopt the Temple generated floodplains in the spring of 2009. A detailed report of the modeling and hydrological analyses performed by the CSC to generate floodplain boundaries can be found at http://www.temple.edu/ambler/csc/projects/projects_pennypack.htm .

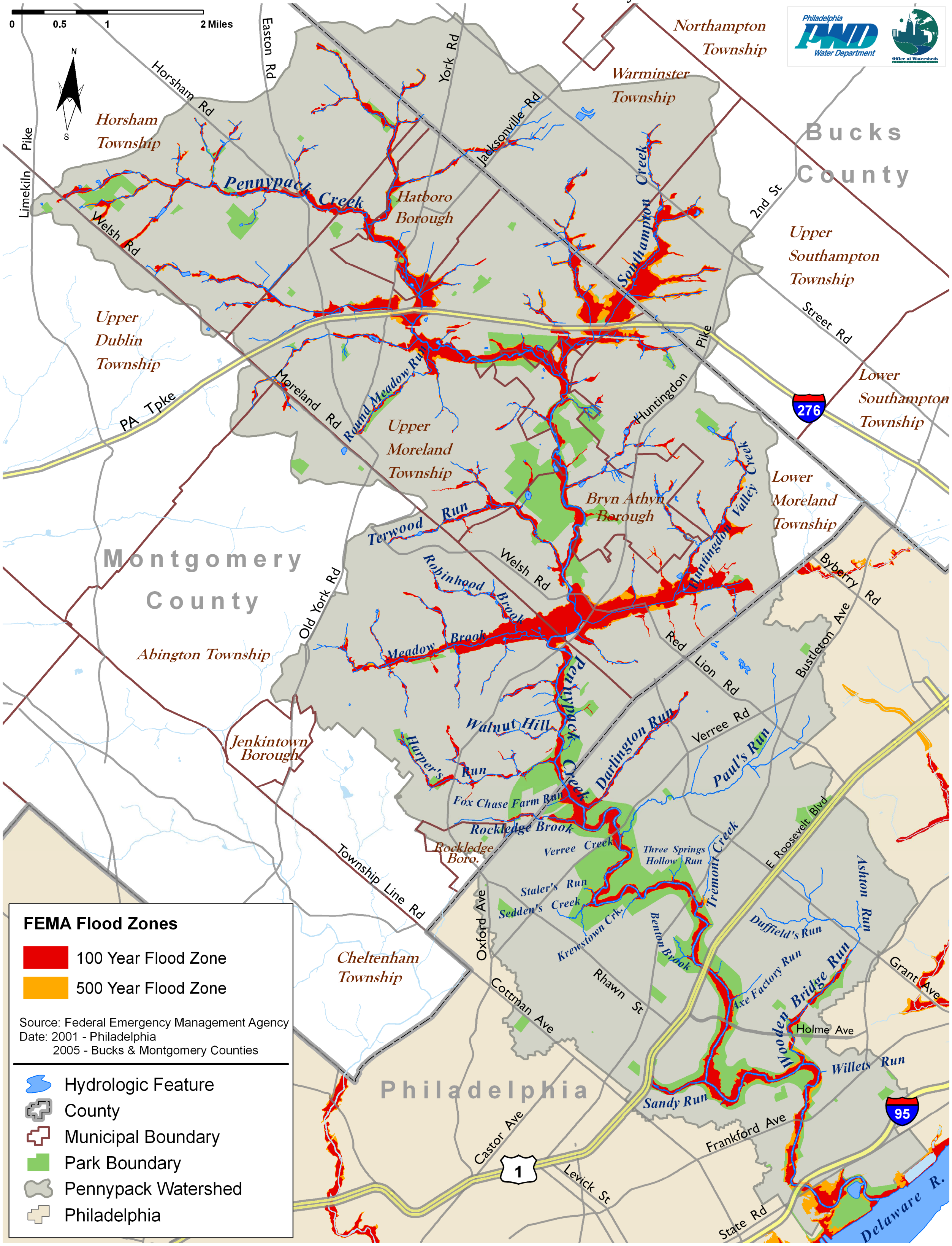


Figure 2.11 Floodplains of the Pennypack Creek Watershed

2.9 FEDERAL MS4 AND NPDES PHASE II STORMWATER REGULATIONS

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

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

These are:

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

Since 2003, all Montgomery County municipalities within the Pennypack 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 following 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 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 that are 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 the fall 2009, PWD in partnership with the Montgomery County Planning Commission (MCPC) will initiate an Act 167 Stormwater Management Plan for the Pennypack Creek Watershed. A Watershed Protection Advisory Committee (WPAC) will be initiated and will provide a forum for municipalities and watershed stakeholders to participate in the planning process. At the conclusion of this planning process, municipalities of the Pennypack Creek Watershed will not only be presented with an updated stormwater ordinance, but also recommendations on BMP retrofits and installation locations specifically identified through this planning process.

2.11 EXISTING MUNICIPAL ORDINANCES

Many municipalities of the Pennypack 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 Pennypack Creek and its tributaries. Ordinances and regulations have been passed in order to help to 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 of 2006, the City of Philadelphia updated stormwater regulations, which complement the existing City-wide stormwater ordinance, §14-1603.1. These updates were largely modeled after the Pennsylvania Act 167 Stormwater Management Plan completed in 2004 for the Darby-Cobbs Watershed portion of Delaware County. The regulations also implement many requirements of the City's NPDES Phase I Stormwater Permit.

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

2.11.1.2 §14-1606: FLOOD PLAIN 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 flood plain 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 flood plain of all surface waters within Philadelphia, including the Pennypack Creek. The 100-year flood plain boundaries are based upon the Flood Insurance Study by the United States Department of Housing and Urban Development, Federal Insurance Administration dated December 1978.

Ordinance §14-1606 stipulates that no fill, new construction, or development is to take place within the 100-year flood plain, 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 flood plain: 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 flood plain, 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 flood plain 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 commonplace throughout the Pennypack 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 Water Topic-Stormwater Management-Announcements. A detailed description of the floodplain ordinances that govern the Bucks and Montgomery County portions of the Pennypack Creek Watershed can be found in Appendix F of the 2006 Pennypack Creek Watershed Study from the Temple University Center for Sustainable Communities.

2.11.2.1 Floodplain Ordinances

In both Bucks and Montgomery Counties, all of the municipalities within the Pennypack 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 Pennypack Creek Watershed can be found in Appendix E of the 2006 Pennypack Creek Watershed Study from the Temple University Center for Sustainable Communities.

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 the groundwater and surface water of the locality.

Official plans contain comprehensive information, including:

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

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

Presently, all of the municipalities in the watershed have adopted an Act 537 Plan; however, some plans are older than others and each vary in the levels of detail (Figure 2.12). Jenkintown and Rockledge Boroughs have the oldest Act 537 Plans, originating over 20 years ago. Horsham, Lower Moreland, Upper Dublin, and Warminster Townships all have Act 537 Plans produced within the past 5 years, making them the most up to date in the Pennypack Creek Watershed.

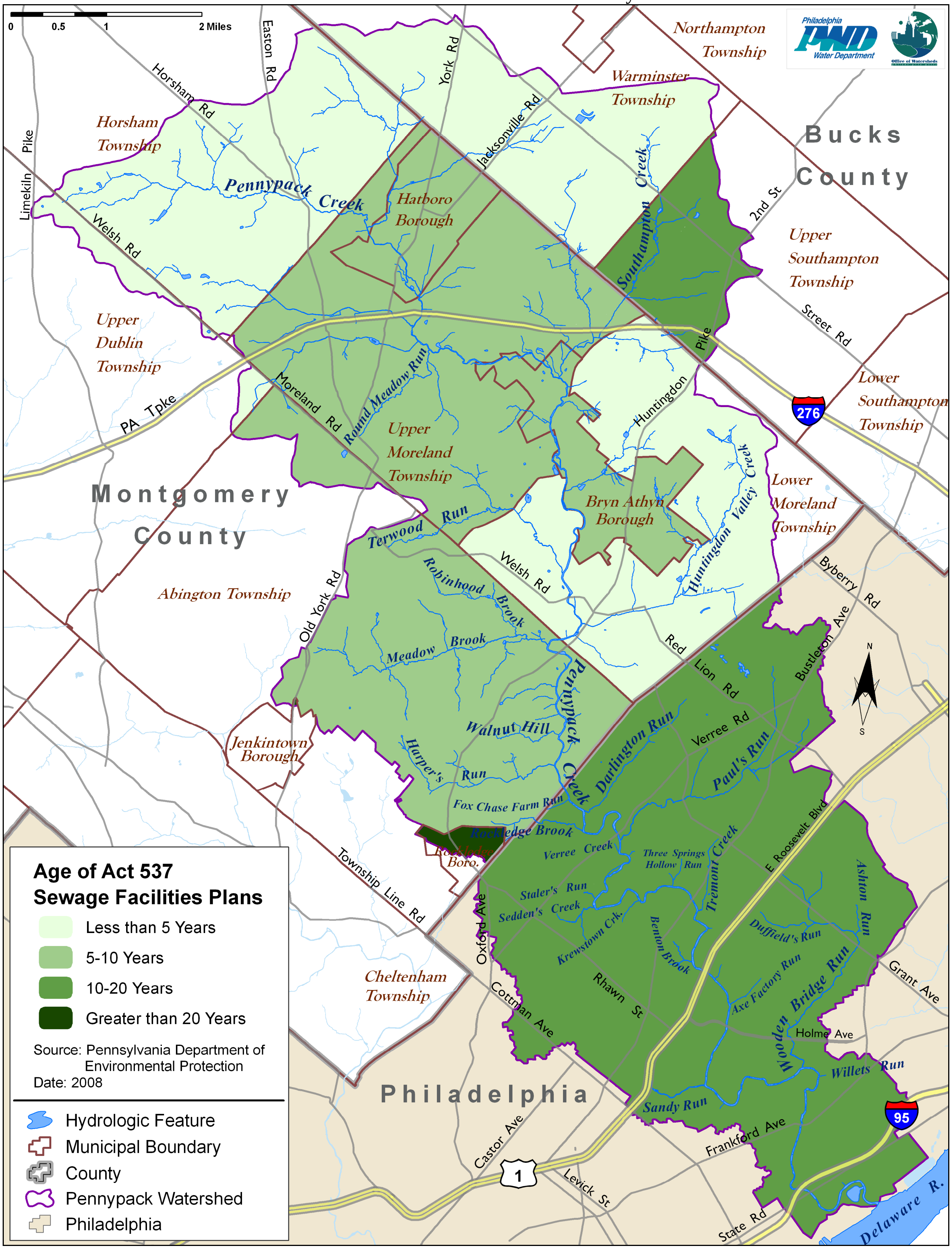


Figure 2.12 Age of Act 537 Municipal Sewage Facilities Plans

3 CHARACTERIZATION OF WATERSHED HYDROLOGY

This section examines the components of the hydrologic cycle for the Pennypack 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 Pennypack Creek itself, the surface drainage area contributing flow to the creek, groundwater shallow enough to communicate with the creek, and manmade piping systems within the topographic watershed boundary. The system inflows and outflows can be split into a number of components. These are shown below as a simple, "input equals output" water balance with the many natural and anthropogenic components of a typical urban water cycle.

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

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

where:

P is the average precipitation recorded at the Philadelphia gages,

OPW is the outside potable water brought in,

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

EDR is the estimated domestic recharge from private septic systems,

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

RO is the surface water runoff component of precipitation,

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

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

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

BF is the median baseflow of streams,

OWD is the discharge of wastewater to outside plants, and

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

3.1.1 PRECIPITATION

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

Precipitation data can be obtained from PWD's network of 24 rain gages throughout the City. 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 Pennypack Creek Watershed, as shown in Figure 3.1. Data from these gages provide precipitation at a high level of spatial and temporal detail within the City of Philadelphia. Monthly and yearly summaries of rain gage data are located in Tables 3.1 and 3.2, respectively.

Table 3.1 Monthly Summary of Philadelphia Rain Gage Data (1990 – 2007)

Month	Rain Gage			Average
	3	4	10	
	(in)	(in)	(in)	(in)
January	3.10	3.14	3.22	3.15
February	2.19	2.27	2.25	2.24
March	4.00	4.13	4.23	4.12
April	3.87	3.81	3.93	3.87
May	3.31	3.40	3.56	3.42
June	4.07	3.92	4.20	4.06
July	4.11	4.36	4.25	4.24
August	3.97	3.52	4.14	3.88
September	4.18	4.07	4.29	4.18
October	3.48	3.44	3.76	3.56
November	3.11	3.03	3.23	3.12
December	3.41	3.65	3.80	3.62

Table 3.2 Yearly Summary of Philadelphia Rain Gage Data (1990 – 2007)

Year	Rain Gage			Average
	3	4	10	
	(in)	(in)	(in)	(in)
1990	41.56	41.41	41.53	41.50
1991	43.58	48.23	46.01	45.94
1992	42.17	46.75	42.89	43.94
1993	44.08	37.44	50.34	43.95
1994	46.11	44.04	46.94	45.70
1995	34.46	35.89	33.88	34.74
1996	53.37	56.38	62.59	57.45
1997	35.07	32.45	37.29	34.93
1998	33.74	34.89	35.66	34.76

1999	45.35	45.20	42.38	44.31
2000	41.57	42.03	45.27	42.96
2001	31.60	32.87	36.01	33.50
2002	39.87	39.84	39.90	39.87
2003	46.07	45.33	46.92	46.11
2004	51.56	49.08	48.07	49.57
2005	42.50	45.91	47.07	45.16
2006	50.52	45.95	52.17	49.55
2007	45.50	44.67	50.23	46.80
Mean	42.70	42.69	44.73	43.37
Max	53.37	56.38	62.59	57.45
Min	31.60	32.45	33.88	32.64
N	18	18	18	18
Std. Dev.	6.11	6.24	7.02	6.46

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		Potential Evaporation (in/month)
	High (°F)	Low (°F)	
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 3.4 (City of Philadelphia Combined Sewer Overflow Program: System Hydraulic Characterization).

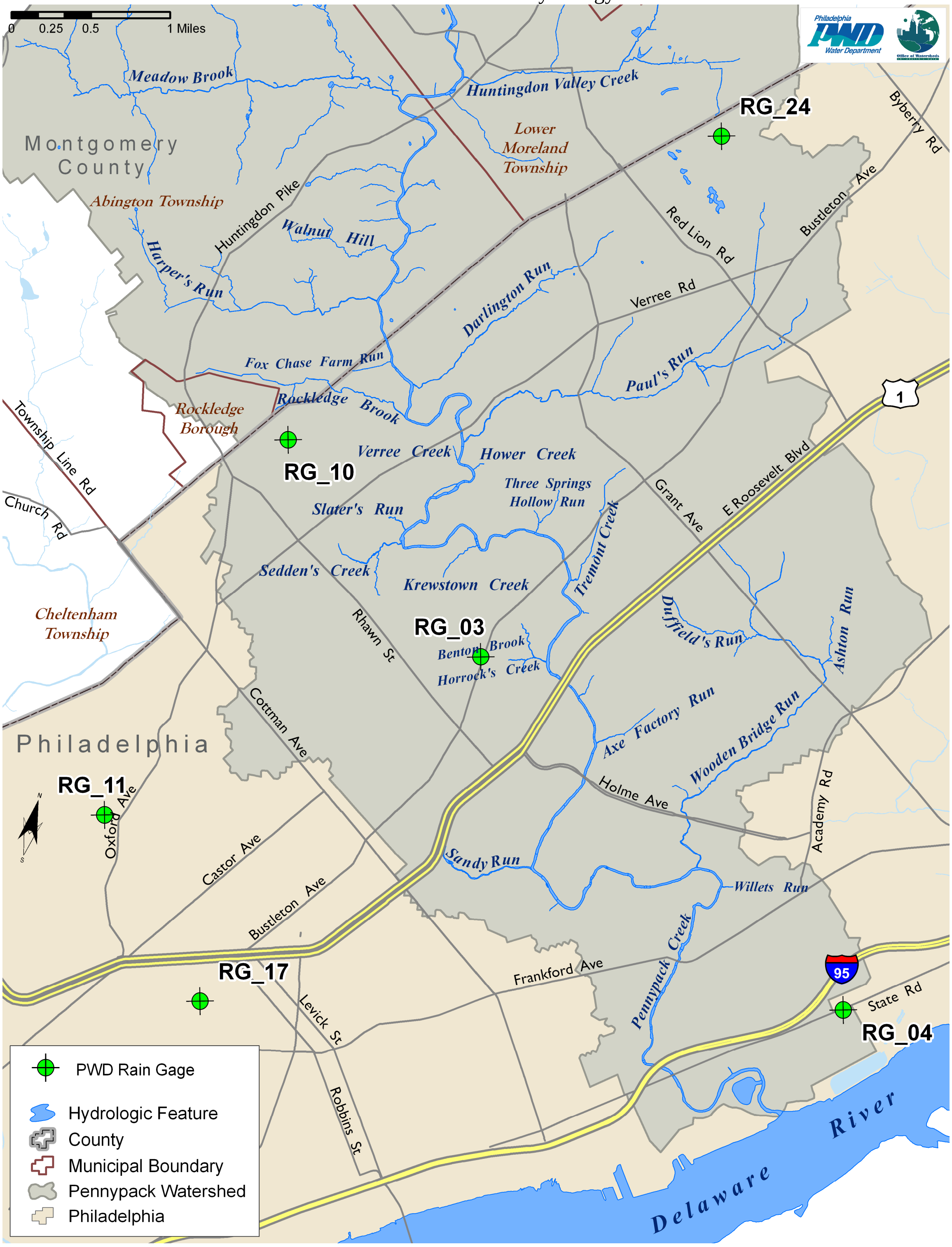


Figure 3.1 City of Philadelphia Rain Gages In and Around Pennypack Creek Watershed

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, Hatboro Authority, and Horsham Township Water Authority).

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 Pennypack Creek Watershed. Baxter Water Treatment Plant, which draws water from the Delaware River, is the sole source of potable water in Philadelphia portion of Pennypack Creek Watershed.

The Hatboro Water Authority operates sixteen groundwater wells outside of the Pennypack Creek Watershed. The groundwater wells operated by the Hatboro Water Authority are listed within Table 3.4.

Table 3.4 Hatboro Water Authority Groundwater Wells (The Center for Sustainable Communities, 2007)

Withdrawal Site	MGD
Hatboro Boro Auth Well #1	0
Hatboro Boro Auth Well #2	0
Hatboro Boro Auth Well #3	0
Hatboro Boro Auth Well #6	0.0761
Hatboro Boro Auth Well #7	0
Hatboro Boro Auth Well #8	0.1448
Hatboro Boro Auth Well #9	0.1206
Hatboro Boro Auth Well #12	0.0492
Hatboro Boro Auth Well #13	0
Hatboro Boro Auth Well #14	0.1051
Hatboro Boro Auth Well #15	0.0357
Hatboro Boro Auth Well #16	0
Hatboro Boro Auth Well #17	0.204
Hatboro Boro Auth Well #18	0
Hatboro Boro Auth Well #20	0.2516
Hatboro Boro Auth Well #21	0.0376
Total	**1.0247**

The Horsham Township Water Authority operates nine wells outside of the Pennypack Creek watershed. The groundwater wells operated by the Horsham Township Water Authority are listed within Table 3.5.

Table 3.5 Horsham Township Water Authority Groundwater Wells (The Center for Sustainable Communities, 2007)

Withdrawal Site	MGD
Horsham TWP Water Authority Well #1	0.0433
Horsham TWP Water Authority Well #2	0.1285
Horsham TWP Water Authority Well #5	0
Horsham TWP Water Authority Well #6	0.0582
Horsham TWP Water Authority Well #9	0.0503
Horsham TWP Water Authority Well #10	0.0573
Horsham TWP Water Authority Well #20	0.2166
Horsham TWP Water Authority Well #22	0.3231
Horsham TWP Water Authority Well #25	0
Total	**0.8773**

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 and or industrial recharge into the groundwater within the Pennypack 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 Pennypack 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 Pennypack Creek Watershed contains one large publicly owned wastewater treatment plant as well as three smaller "package" plants (Figure 3.2). The permitted discharge limits and actual flows are listed below in Table 3.6. The actual discharges were estimated from Discharge Monitoring Reports (DMRs).

Table 3.6 Permitted and Actual Flows Reported in DMRs (MGD)

Parameters	Units	Service Area/ Water User	Period of Record	Limit	Min	Mean	Max	Standard Deviation
Discharge	MGD	ABB Automation Inc.	2/1/2002 to 4/30/2008	N/A	0	0.105	0.108	0.0175
Discharge	MGD	Bryn Athyn	2/1/2006 to 3/31/2008	0.065	0.0360	0.0432	0.0570	0.00509
Discharge	MGD	Chapel Hill	5/1/2006 to 2/29/2008	0.279	0.117	0.144	0.197	0.0191
Discharge	MGD	Meadowbrook	1/1/2006 to 2/29/2008	0.154	0.0730	0.0818	0.0940	0.00521
Discharge	MGD	Upper Moreland Hatboro JSA	1/1/2005 to 12/31/2007	7.173	3.71	5.91	9.50	1.43

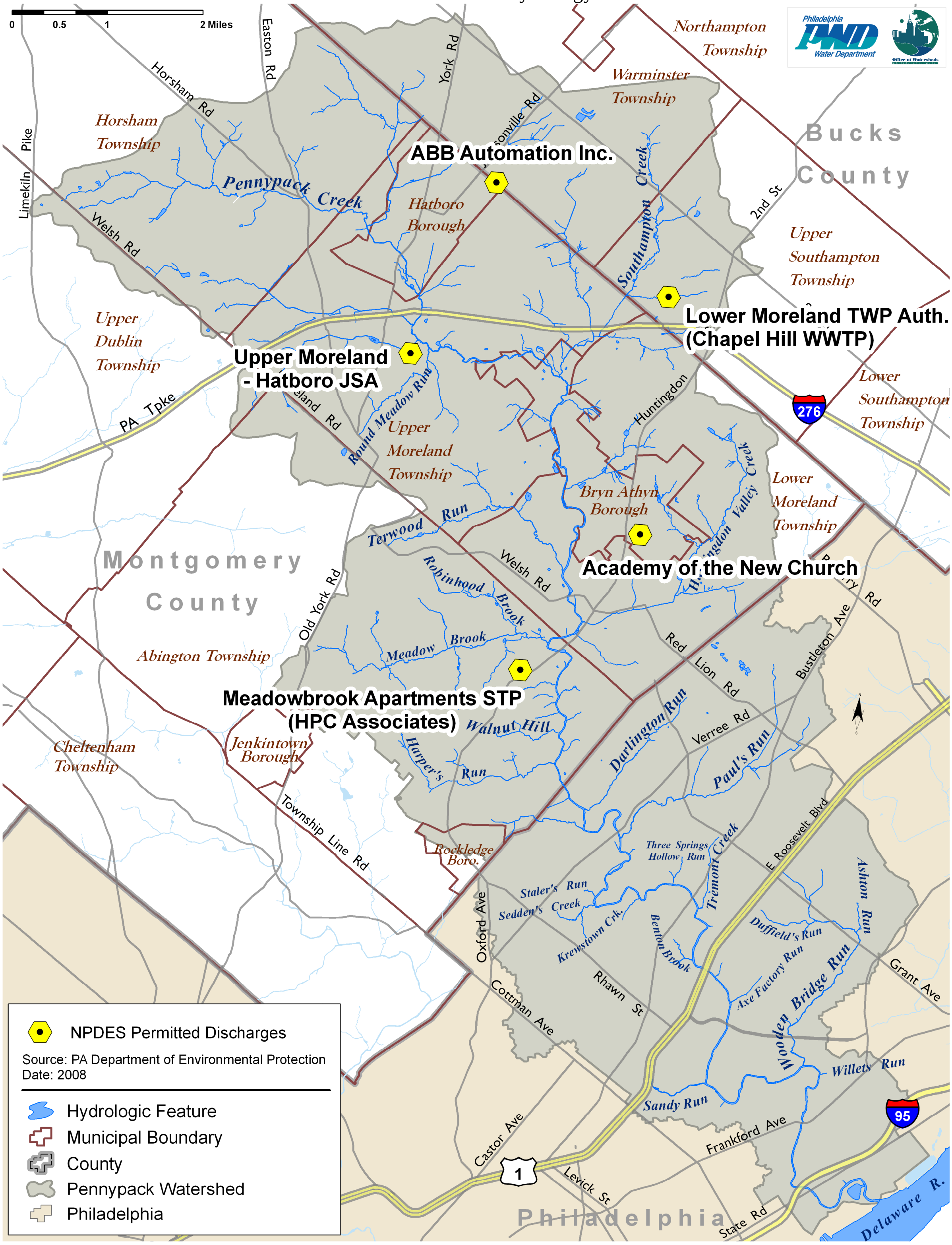


Figure 3.2 Major Municipal Wastewater Treatment Plants Discharging to Pennypack Creek

3.1.6 RUNOFF

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

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

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

> "The duration of surface runoff is calculated from the empirical relation:
>
> $$N=A^{0.2}$$
>
> where N is the number of days after which surface runoff ceases, and A is the drainage area in square miles (Linsley and others, 1982, p. 210).
>
> "The interval 2N* used for hydrograph separations is the odd integer between 3 and 11 nearest to 2N (Pettyjohn and Henning, 1979, p. 31). For example, the drainage area at the streamflow-measurement station French Creek near Phoenixville, Pa. (USGS station number 01472157), is 59.1 mi2. The interval 2N* is equal to 5, which is the nearest odd integer to 2N, where N is equal to 2.26. The N and 2N* values used for the four gages in this analysis were listed in Table 3.5.
>
> "The hydrograph separation begins one interval (2N* days) prior to the start of the date selected for the start of the separation and ends one interval (2N* days) after the end of the selected date to improve accuracy at the beginning and end of the separation. If the selected beginning and (or) ending date coincides with the start and (or) end of the period of record, then the start of the separation coincides with the start of the period of record, and (or) the end of the separation coincides with the end of the period of record.
>
> "The sliding-interval method finds the lowest discharge in one half the interval minus 1 day [0.5(2N*-1) days] before and after the day being considered and assigns it to that day. The method can be visualized as moving a bar 2N* wide upward until it intersects the hydrograph. The discharge at that point is assigned to the median day in the interval. The bar then slides over to the next day, and the process is repeated."

Summary Statistics

During the USGS/PWD cooperative program in the 1970s, the USGS established streamflow gaging stations at four locations in Pennypack Creek Watershed. These locations are presented in Figure 3.1. Table 3.7 contains summary information at each of the gaging stations for their respective periods of record. A historical rating curve is shown in Figure 3.4.

Table 3.7 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)
01467048	Pennypack Cr at Lower Rhawn St Bdg, Philadelphia, PA	6/1/1965 to Present	43	49.8	2.185	5
01467045	Pennypack Cr Below Verree Road, Philadelphia, PA	10/1/1964 to 9/30/1970	6	42.8	2.12	5
01467042	Pennypack Creek at Pine Road, at Philadelphia, PA	8/1/1964 to 10/6/1981	17	37.9	2.069	5

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

The results of the hydrograph decomposition exercise are summarized in Tables 3.8 and 3.9.

Table 3.8 Runoff Statistics For Pennypack Creek Watershed USGS Gages Compared to Other Area Streams.

	Runoff (in/yr)			
	Mean	Max	Min	St.Dev.
01467048 Lower Rhawn	12.71	22.01	6.88	3.93
01467045 Verree Road	7.41	11.45	3.98	2.69
01467042 Pine Road	10.42	19.24	4.00	3.89
01474000 Wissahickon Creek	10.40	22.30	5.10	3.90
01475127 French Creek	7.40	15.40	2.90	3.10
01475550 Cobbs Creek	10.70	15.60	5.20	2.70
01475510 Darby Creek	8.90	15.60	3.60	2.90
01467087 Frankford Creek	11.40	20.30	6.20	3.50

The results of the hydrograph decomposition exercise suggest differences in degree of urbanization for watersheds in southeastern Pennsylvania, the flows in Table 3.8 are expressed as a mean volume divided by drainage area over a one-year time period. Table 3.8 shows stream flow statistics for French Creek as representative of a minimally impaired stream. On a unit-area basis, runoff in Pennypack Creek Watershed is slightly greater than in the Darby watershed, a suburban watershed, and less then both the Cobbs and Frankford systems, two highly urbanized streams 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 3.9). Results in Pennypack Creek Watershed range from 49% to 57%, indicative of a highly urbanized stream.

Table 3.9 Runoff as a Percentage of Annual Total Flow for Pennypack Creek Watershed USGS Gages Compared to Other Area Streams.

	Runoff (% of Annual Total Flow)			
	Mean	Max	Min	St.Dev.
01467048 Lower Rhawn	57%	69%	46%	5%
01467045 Verree Road	52%	59%	46%	5%
01467042 Pine Road	49%	61%	38%	6%
01474000 Wissahickon Creek	61%	76%	51%	6%
01475127 French Creek	36%	47%	25%	5%
01475550 Cobbs Creek	58%	84%	46%	10%
01475510 Darby Creek	38%	46%	25%	6%
01467087 Frankford Creek	62%	74%	51%	6%

The estimated stormwater runoff discharges by outfall within the City of Philadelphia were obtained from the 2006 PWD Stormwater Annual Report. Results are presented in Table 3.10. The period of record represented within Table 3.10 is 1902 to 2005.

Table 3.10 Philadelphia Stormwater Outfall Runoff

Outfall	Area (Acres)	Annual Flow (in/yr)	Outfall	Area (Acres)	Annual Flow (in/yr)	Outfall	Area (Acres)	Annual Flow (in/yr)
P04-A-S	26.6	10.75	P-100-21	20.5	8.49	P-108-16	77.0	9.03
P-082-01	18.7	8.99	P-100-22	6.5	11.16	P-108-17	30.6	6.29
P-083-01	6.0	12.28	P-100-23	13.0	13.23	P-108-18	8.6	8.37
P-083-02	16.5	15.77	P-100-24	15.7	14.37	P-108-19	11.4	7.93
P-083-03	467.0	14.44	P-100-25	9.9	8.52	P-108-20	48.6	7.58
P-083-04	141.6	12.65	P-101-01	9.5	11.59	P-108-21	75.3	8.74
P-090-01	9.7	16.79	P-101-02	55.3	9.12	P-108-22	1.9	4.26
P-090-02	1569.3	11.19	P-103-01	36.7	7.06	P-108-23	15.1	8.05
P-091-01	55.8	10.92	P-103-02	7.8	3.33	P-108-24	97.9	8.34
P-091-02	30.8	9.38	P-103-03	27.6	9.86	P-109-01	120.4	9.26
P-091-03	19.3	7.28	P-104-01	8.2	2.78	P-109-02	11.4	13.20
P-091-04	54.2	8.40	P-104-02	11.9	5.88	P-109-03	6.2	11.64
P-091-05	25.9	6.69	P-104-03	74.9	9.83	P-109-04	62.2	13.25
P-091-06	180.0	11.70	P-104-04	14.9	4.42	P-109-05	38.4	8.65
P-091-07	82.3	9.86	P-104-05	29.8	8.50	P-109-13	213.8	10.03
P-091-08	57.6	8.58	P-104-06	58.0	9.73	P-109-X	5.2	10.11
P-091-09	60.7	8.65	P-104-07	116.5	10.04	P-112-01	21.8	7.90
P-091-10	66.3	8.24	P-104-08	48.3	10.93	P-112-02	30.5	8.15
P-091-11	22.7	9.11	P-104-09	57.6	7.67	P-112-03	114.3	11.10
P-091-12	19.9	9.13	P-104-10	36.6	7.81	P-112-04	42.1	8.06
P-091-13	8.0	7.25	P-105-01	244.1	12.21	P-112-05	12.4	8.09
P-092-01	4.6	11.77	P-105-02	92.8	11.53	P-113-01	49.1	12.35
P-092-02	8.7	9.92	P-105-03	83.3	12.24	P-113-02	2.1	11.99
P-092-03	5.3	10.27	P-105-04	8.5	8.24	P-113-03	16.9	8.58
P-092-04	6.5	8.88	P-105-05	8.5	12.23	P-113-04	282.2	11.11

P-099-01	73.9	9.42
P-099-02	165.6	10.57
P-099-03	135.6	11.64
P-099-04	27.1	9.25
P-099-05	27.8	11.78
P-100-01	26.9	9.26
P-100-02	12.9	15.03
P-100-03	40.8	13.05
P-100-04	49.2	10.44
P-100-05	22.3	12.50
P-100-06	6.4	10.18
P-100-07	11.4	10.80
P-100-08	118.0	12.20
P-100-09	2.5	12.95
P-100-10	5.7	10.18
P-100-11	45.7	13.90
P-100-12	0.4	4.60
P-100-13	13.1	12.14
P-100-14	58.4	10.05
P-100-15	10.1	10.70
P-100-16	56.5	11.20
P-100-17	25.4	10.43
P-100-18	0.3	2.46
P-100-19	9.2	9.06
P-100-20	15.6	12.58
P-105-06	200.9	12.28
P-105-07	21.7	12.80
P-105-08	10.1	12.69
P-105-09	1.3	2.57
P-105-10	4.2	2.69
P-105-11	18.0	14.30
P-105-12	42.5	16.11
P-105-13	15.3	14.79
P-106-01	40.1	10.98
P-106-02	19.5	9.30
P-108-01	18.6	6.41
P-108-02	6.8	4.62
P-108-03	35.4	8.48
P-108-04	12.7	6.41
P-108-05	13.2	7.69
P-108-06	14.5	7.42
P-108-07	46.3	8.89
P-108-08	29.4	7.96
P-108-09	38.0	7.51
P-108-10	21.3	6.82
P-108-11	71.6	7.91
P-108-12	37.4	8.51
P-108-13	40.1	9.90
P-108-14	68.5	7.87
P-108-15	24.9	9.30
P-113-05	0.7	12.83
P-113-06	27.5	9.94
P-113-07	103.3	12.22
P-113-08	142.5	11.13
P-113-12	0.6	6.03
P-113-13	0.7	8.07
P-116-01	35.2	10.39
P-116-02	68.1	11.98

Figure 3.3 provides some idea of trends in unit-area runoff from year to year. Although there is considerable variability between years, flows at the three gages follow the same patterns.

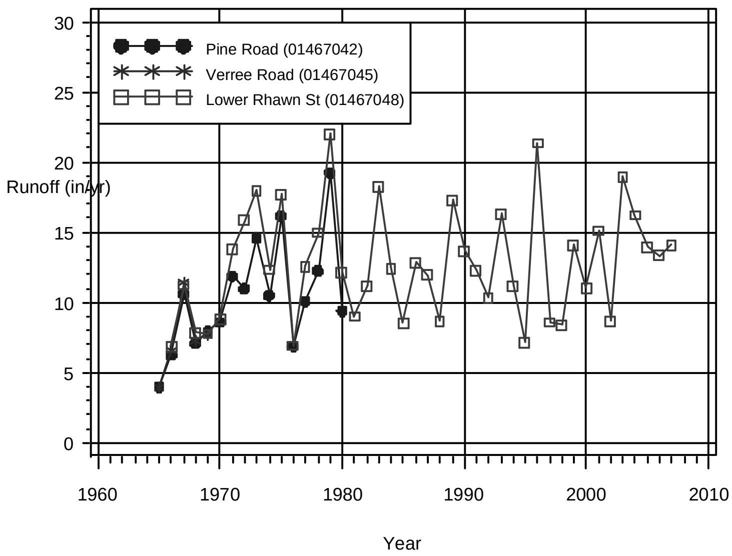


Figure 3.3 Runoff Trends at four USGS Stations in Pennypack Creek Watershed

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 Pennypack Creek watershed. The Aqua-Pennsylvania Water Company has a permit to withdraw water for potable water use but has not utilized this source.

3.1.8 GROUNDWATER WITHDRAWALS

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

A list of groundwater withdrawals was provided by The Center for Sustainable Communities Temple University Ambler College and is shown below. The data that was provided was then broken down into three categories (Industrial Withdrawals, Municipal Withdrawals, and Federal Government Withdrawals) and are shown below in Table 3.12, Table 3.13, and Table 3.14 respectively. A summary table is provided below in table 3.15.

Table 3.11 Industrial Groundwater Withdrawals (The Center for Sustainable Communities, 2007)

Names	Zip code	Days Operated	Hrs Operated	Million Gallon per Year Total	Average MGD
A M L INDUSTRIES INC - HOUSE WELL	19040	250	8	0	0
A M L INDUSTRIES INC - SHOP WELL	19040	250	8	0	0
ABINGTON MEMORIAL HOSPITAL WELL M12	19001	0	0	0	0
ABINGTON MEMORIAL HOSPITAL WELL M-4	19001	0	0	0	0
ABINGTON MEMORIAL HOSPITAL WELL M-5	19001	0	0	0	0
ABINGTON MEMORIAL HOSPITAL WELL M-6	19001	0	0	0	0
AMERICAN WHOLESALE FENCE - WELL	19044	365	12	0	0
ANCHOR PRINTING CO INC-WITHDR WELL	19044	260	0	0	0
AUDIO TECHNOLOGIES - WELL	19044	250	9	0	0
AZTEC MACHINERY CO - WITHDRAW WELL	18974	260	8	0	0
BIO/DATA CORP - WELL	19044	260	8	0	0
BOMPADRE FRANK J & SONS - WELL	19006	250	8	0	0
DAKON INDUSTRIES INC - WELL	19040	300	8	0	0
FISCHER & PORTER CO - WELL #FP1	18974	250	8	12.96	0.03
FISCHER & PORTER CO - WELL #FP2	18974	0	0	0	0
FISCHER & PORTER CO - WELL #FP7	18974	0	0	0	0
FORMS INC - WELL #1	19090	143	24	0	0
GLENSIDE READY-MIX - WELL	19090	195	8	0	0
HAMPTON SCIENTIFIC INC	18966	250	8	0	0
HULL CORP – WELL	19040	260	24	0	0
HUNTING VALLEY COUNTRY CLUB	19006	0	0	0	0
J D M MATERIALS CO - WELL #A	18966	0	0	0.2	5.00E-04
J D M MATERIALS CO - WELL #B	18966	0	0	0.2	5.00E-04
J D M MATERIALS CO - WELL #C	18966	0	0	0.2	5.00E-04
J D M MATERIALS CO - WELL #D	18966	0	0	0.2	5.00E-04

J D M MATERIALS CO - WELL #E	18966	0	0	0.2	5.00E-04
J D M MATERIALS CO - WELL #F	18966	0	0	0.2	5.00E-04
K V INC - WITHDRAW WELL	19006	286	9	0	0
K&S AMBULANCE & RESCUE - WITH WELL	19044	250	8	0	0
MILLER & SON PAVING--WITHDRAW WELL	18974	200	8	0	0
TRANSIT AMERICA - WELL #RO14	19116	0	0	0	0
TRANSIT AMERICA - WELL #RO15	19116	0	0	0	0
TRANSIT AMERICA - WELL #RO16	19116	0	0	0	0
TRANSIT AMERICA - WELL #RO6	19116	0	0	0	0
TRANSIT AMERICA - WELL #RX10	19116	0	0	0	0
TRANSIT AMERICA - WELL #RX11	19116	0	0	0	0
TRANSIT AMERICA - WELL #RX15	19116	0	0	0	0
TRANSIT AMERICA - WELL #RX16	19116	0	0	0	0
TRANSIT AMERICA - WELL #RX3	19116	0	0	0	0
TRANSIT AMERICA - WELL #RX5	19116	0	0	0	0
TRANSIT AMERICA - WELL #RX7	19116	0	0	0	0
TRANSIT AMERICA - WELL #RX8	19116	0	0	0	0
TRIPOINT MACHINE & TOOL - WELL	19006	288	8	0	0
UNICRAFT CO INC - WITHDRAW WELL	19006	240	7	0	0
PHILMONT C C - WELL #1	19006	77	0	0	0
PHILMONT C C - WELL #2	19006	77	0	0	0
PHILMONT C C - WELL #3	19006	77	0	0.4	1.10E-03
PHILMONT C C - WELL #4	19006	0	0	0	0
REFRESHMENT MACHINERY INC	18974	286	8	0	0
SENTINEL PROCESS DYSTEMS-WITH WELL	19040	260	0	0	0
SERVICE TOOL & DIE CO - WITH WELL	19006	255	10	0	0
SPECTRA GRAPHICS - WELL	19090	338	24	0	0
STRAUSS ENGINEERING - OFFICE WELL	19006	250	24	0	0
STRAUSS ENGINEERING CO-PLANT WELL	19006	250	8	0	0
TCS - WELL	19006	230	7	0	0
PARKING PRODUCTS INC - WITHDR WELL	19090	260	0	0	0
PHILA SUB WATER CO-MAPLE GLEN WELL8	19010	0	0	0	0

Table 3.12 Municipal Groundwater Withdrawals (The Center for Sustainable Communities, 2007)

Names	Zip code	Days Operated	Hrs Operated	Million Gallon per Year Total	Average MGD
HATBORO BORO AUTH WELL #1	19040	0	0	0	0
HATBORO BORO AUTH WELL 2	19040	0	0	0	0
HATBORO BORO AUTH WELL#12	19040	365	24	17.95	0.04
HATBORO BORO AUTH WELL#13	19040	0	0	0	0
HATBORO BORO AUTH WELL#14	19040	365	24	38.36	0.1
HATBORO BORO AUTH WELL#15	19040	365	24	13.03	0.03
HATBORO BORO AUTH WELL#16	19040	0	0	0	0
HATBORO BORO AUTH WELL#17	19040	365	24	74.46	0.2

HATBORO BORO AUTH WELL#18	19040	365	24	0	0
HATBORO BORO AUTH WELL#20	19040	365	24	91.84	0.25
HATBORO BORO AUTH WELL#21	19040	365	24	13.8	0.03
HATBORO BORO AUTH WELL#3	19040	0	0	0	0
HATBORO BORO AUTH WELL#6	19040	365	24	27.78	0.07
HATBORO BORO AUTH WELL#7	19040	0	0	0	0
HATBORO BORO AUTH WELL#8	19040	365	24	52.87	0.14
HATBORO BORO AUTH WELL#9	19040	365	24	44.02	0.12
HORSHAM TWP WATER AUTHORITY WELL#1	19044	337	24	15.81	0.04
HORSHAM TWP WATER AUTHORITY WELL#10	19044	364	24	20.92	0.05
HORSHAM TWP WATER AUTHORITY WELL#2	19044	360	24	46.89	0.12
HORSHAM TWP WATER AUTHORITY WELL#20	19044	355	24	79.06	0.21
HORSHAM TWP WATER AUTHORITY WELL#22	19044	232	24	117.93	0.32
HORSHAM TWP WATER AUTHORITY WELL#26	19044	24	24	0	0
HORSHAM TWP WATER AUTHORITY WELL#5	19044	0	0	0	0
HORSHAM TWP WATER AUTHORITY WELL#6	19044	364	24	21.24	0.05
HORSHAM TWP WATER AUTHORITY WELL#9	19044	365	24	18.35	0.05
UPPER SOUTHAMPTON MUN AUTH WELL#10	18966	0	0	0	0
UPPER SOUTHAMPTON MUN AUTH WELL#3	18966	365	24	13.64	0.03
UPPER SOUTHAMPTON MUN AUTH WELL#5	18966	0	0	0	0
UPPER SOUTHAMPTON MUN AUTH WELL#6	18966	353	24	10.33	0.02
UPPER SOUTHAMPTON MUN AUTH WELL#7	18966	365	24	67.48	0.18
WARMINSTER HEIGHTS WATER CO WELL#1	18974	365	24	32.6	0.08
WARMINSTER HEIGHTS WATER CO WELL#2	18974	365	24	32.8	0.08
WARMINSTER TWP MUN AUTH - WELL #1	18974	365	24	37.53	0.1
WARMINSTER TWP MUN AUTH - WELL #12	18974	0	0	0	0
WARMINSTER TWP MUN AUTH - WELL #2	18974	325	24	18.52	0.05
WARMINSTER TWP MUN AUTH - WELL #3	18974	209	24	33.45	0.09
WARMINSTER TWP MUN AUTH - WELL #7	18974	218	0	38.74	0.1
NORTH WALES WATER AUTH WELL#31	19454	357	24	16.17	0.04

Table 3.13 Federal Government Groundwater Withdrawals (The Center for Sustainable Communities, 2007)

Names	Zip code	Days Operated	Hrs Operated	Million Gallon per Year Total	Average MGD
NAVAL AIR DEV CTR W1-CONTAMINATED	18974	0	0	0	0
NAVAL AIR DEV CTR WELL#10	18974	365	24	20.26	0.05
NAVAL AIR DEV CTR WELL#6	18974	0	0	0	0
NAVAL AIR DEV CTR WELL#8	18974	0	0	0	0

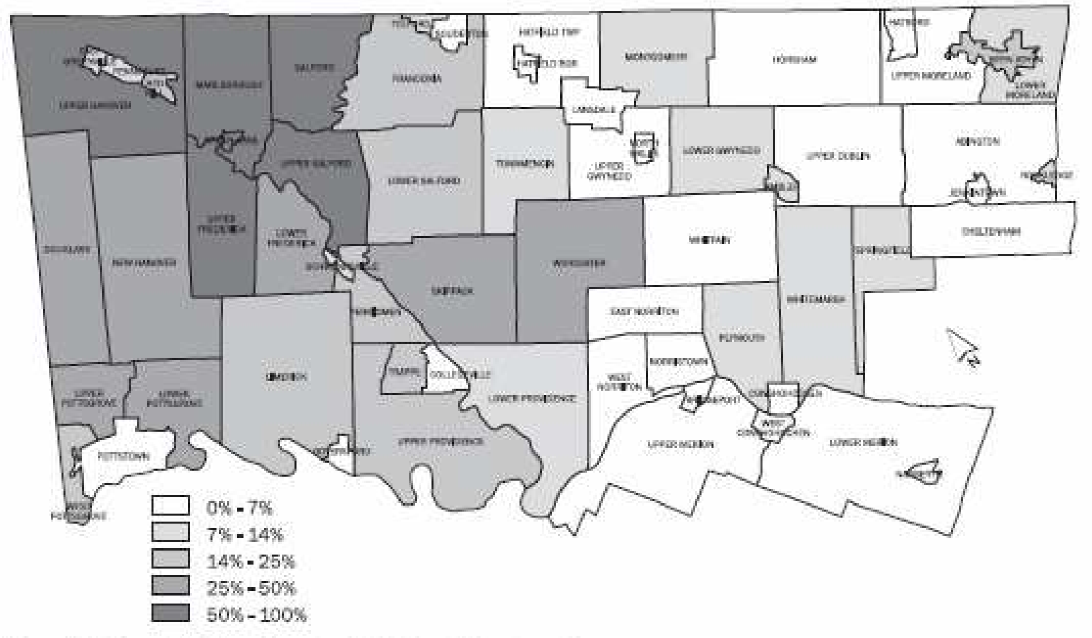
Table 3.14 Summary of Groundwater Withdrawals

Category	Number of Withdrawals	Million Gallons Per Year Total	Average MGD
Industrial	57	14.6	0.0341
Municipalities	38	996	2.59
Federal Government	4	20.3	0.0500
Total	99	1030	2.67

3.1.9 ESTIMATED DOMESTIC WITHDRAWALS

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

According to the 2005 Montgomery County Water Resource Plan, roughly 3,696 Montgomery County residents within the Pennypack Creek Watershed receive their water from private wells. The most concentrated population of private wells users is in the western and central portion of the county. Based on the information provided in Figure 3.4, Table 3.15 was calculated using populations within the Pennypack Creek Watershed from each municipality within Montgomery County. Total daily withdrawals from the groundwater table were calculated to be roughly 185,000 gallons per day.



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

Figure 3.4 Estimated Montgomery County Domestic Groundwater Withdrawals

Table 3.15 Estimated Montgomery County Domestic Groundwater Withdrawals

Municipality	Population*	% of Population Using Wells**	Population Using Wells	Withdrawal*** (Gal/day)
Abington Township	16,769	3.50%	587	29,346
Bryn Athyn Borough	1,351	19.50%	263	13,172
Hatboro Borough	7,319	3.50%	256	12,808
Horsham Township	14,638	3.50%	512	25,617
Lower Moreland Township	9,034	10.50%	949	47,429
Rockledge Borough	1,888	10.50%	198	9,912
Upper Dublin Township	1,625	3.50%	57	2,844
Upper Moreland Township	24,956	3.50%	873	43,673
		Total	**3,696**	**184,800**

*Population from 2000 U.S. Census
** Percentage of Population using wells from Montgomery County Water Resource Plan, 2005
***Estimated water use of 50 gal/person/day

3.1.10 BASEFLOW

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

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

Unit-area baseflow is greater at the upstream gage then at the downstream gage, but it is less than baseflow in French Creek and Darby Creek (Table 3.15). The Darby and Pennypack Creek Watersheds have a similar suburban character. Expressing baseflow as a percentage of total flow, the same pattern is evident (Table 3.16).

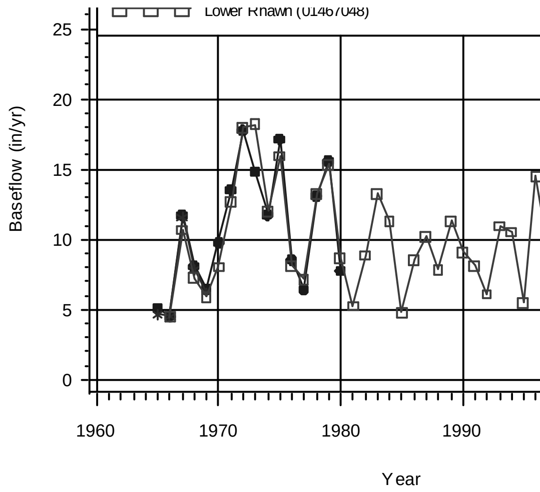
Table 3.16 Baseflow Statistics

	Baseflow (in/yr)			
	Mean	Max	Min	St.Dev.
01467048 Lower Rhawn	9.88	18.21	4.42	3.46
01467045 Verree Road	6.97	11.59	4.56	2.91
01467042 Pine Road	10.79	17.79	4.57	4.28
01474000 Wissahickon Creek	6.90	12.90	2.20	2.70
01475127 French Creek	12.90	20.80	5.80	3.80
01475550 Cobbs Creek	8.10	16.10	1.80	3.60
01475510 Darby Creek D/S	14.50	21.40	7.60	4.00
01467087 Frankford Creek	7.10	13.00	4.50	2.20

Table 3.17 Baseflow Statistics as a Percentage of Total Flow

	Baseflow (% of Annual Total Flow)			
	Mean	Max	Min	St.Dev.
01467048 Lower Rhawn	43%	54%	31%	5%
01467045 Verree Road	48%	54%	41%	5%
01467042 Pine Road	51%	62%	39%	6%
01474000 Wissahickon Creek	39%	49%	24%	6%
01475127 French Creek	64%	75%	53%	5%
01475550 Cobbs Creek	42%	54%	16%	10%
01475510 Darby Creek D/S	62%	75%	54%	6%
01467087 Frankford Creek	38%	49%	26%	6%

Although there was considerable interannual variation and periods of record did not completely overlap, baseflows measured at the three gages generally followed the same patterns (Figure 3.5).



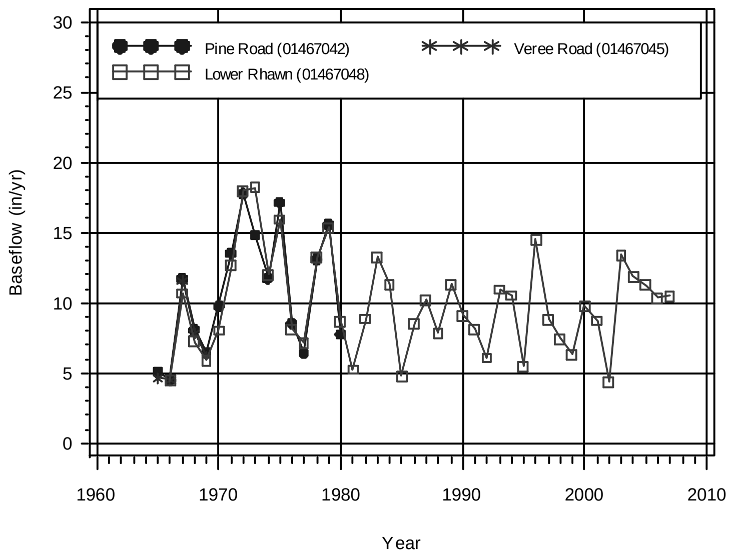


Figure 3.5 Baseflow Trends at Three USGS Gages in Pennypack Creek Watershed (Point Sources Removed)

3.1.11 OUTSIDE WASTEWATER DISCHARGES

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

Wastewater in the City of Philadelphia is exported to PWD's Northeast Water Pollution Control Plant. According to the 2000 U.S. Census, the population of Philadelphia within the Pennypack Creek watershed was 127,315 people. It was estimated that within the Pennypack Creek watershed in Philadelphia a daily flow of 6.4 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 PENNYPACK 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 3.18 Average Annual Streamflow Components

Components of Streamflow	Lower Rhawn St	Verree Road	Pine Road
Drainage Area (sq.mi.)	49.8	42.8	37.9
Runoff (in/yr)	12.7	7.41	10.4
Baseflow (Groundwater) (in/yr)	9.88	6.97	10.8
Municipal Wastewater Effluent (in/yr)	2.62	3.05	3.45

Table 3.19 Average Annual Discharge from Municipal and Industrial Sources

Discharger	Average Discharge (in/yr)
ABB Automation	0.046
Bryn Athyn	0.018
Meadowbrook Apartments	0.0035
Moreland-Hatboro JSA	2.49
Chapel Hill	0.06

3.2.1 ADDITIONAL ANALYSIS OF TOTAL FLOW

Figure 3.6 provides some idea of trends in unit-area total flow from year to year. Although there is considerable variability between years, flows at the three gages follow the same patterns.

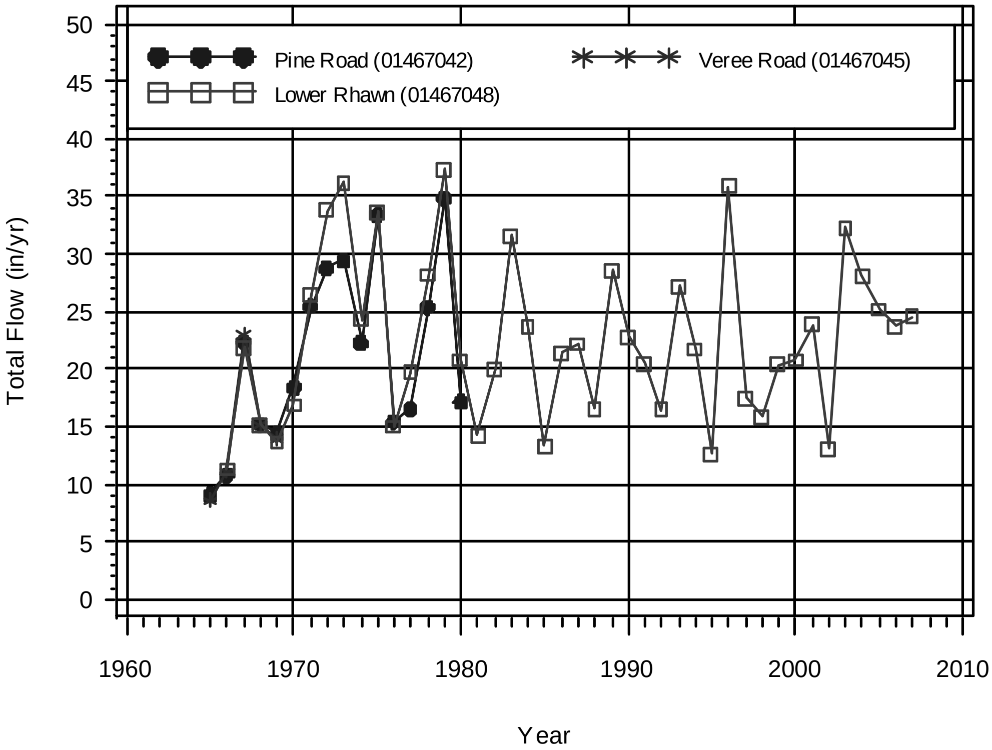


Figure 3.6 Unit Area Total Streamflow Trends at three USGS gages in Pennypack Creek Watershed

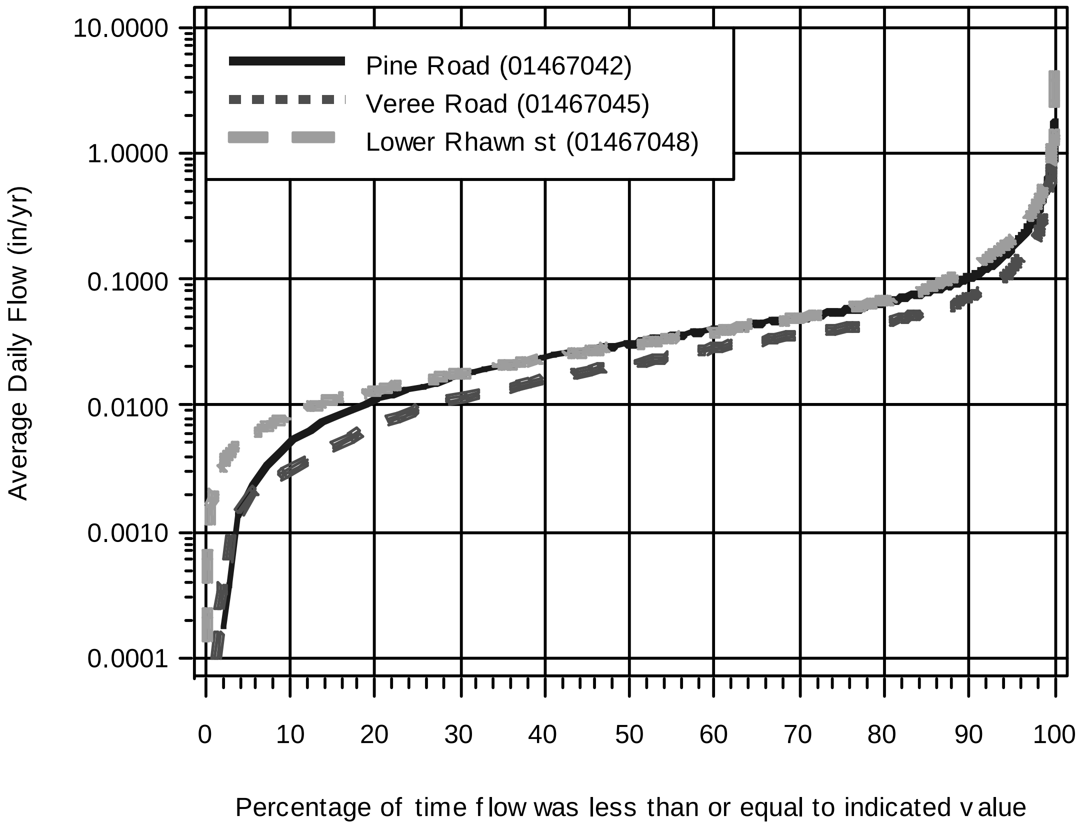


Figure 3.7 Cumulative Distribution of Total Flow with Point Sources Removed

Cumulative Distribution

The cumulative distribution of average daily flow at Lower Rhawn St. in Philadelphia shows the percent of daily flow observations, excluding point sources (horizontal axis) that are equal to or less than a given value (on the vertical axis). For example, average daily flow at Lower Rhawn St. was less than 0.1 in/yr on about 87% of days observed (Figure 3.7). The USGS flow gage with the second highest flow is located at Pine Road in Philadelphia. Although the gage on Pine Road has a smaller drainage area than the gage on Verree Road the flow tends to be higher. It is believed that this is caused by the difference in monitoring data between the two gages. The Pine Road gage only has flow data for a time period of 6 years while the Verree Road gage has a time period of 17 years.

4 WATER QUALITY

4.1 BACKGROUND

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

National water quality criteria include aesthetic qualities that protect the quality of streams. The criteria state:

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

(1) settle to form objectionable deposits;

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

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

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

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

Also, PADEP 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

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

Protected use categories for streams include aquatic life, water supply, recreation, and special protection. The criteria for water quality under each category vary; streams are designated in one of several subcategories. Streams with a designation of WWF (Warm Water Fishes) are able to support fish species, flora, and fauna that are indigenous to a warm-water habitat. Similarly, streams designated CWF (Cold Water Fishes) support life found in and around a cold-water habitat. Streams that are designated TSF (Trout Stocking Fishes) are intermediate quality streams that support stocked trout, as well as other wildlife and plant life that are indigenous to a warmwater 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).

Pennypack Creek is designated a Trout Stocked Fishery (TSF) with water quality appropriate for stocking trout as a recreational "put-and-take" fishery, as well as supporting other life indigenous to a warm water habitat. Based on biological assessments carried out by biologists from PADEP, Pennypack Creek has been identified on Pennsylvania's 2008 Integrated List of waters as an impaired waterbody, with all but a few small tributary segments failing to attain this aquatic life use (Figure 4.1). With some exceptions, assessments that initially identified these impairments occurred in the late 1990s, and 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.*, nutrients, siltation) when other segments ostensibly impaired by similar stressors were not listed as such. Subsequent listings in 2002 and 2004 generally synchronized listings within basins across the region.

Aside from the downstream-most segments of Pennypack Creek Mainstem and Sedden's Run tributary, all stream segments of Pennypack Creek Watershed in the City of Philadelphia are listed as impaired due to urban runoff/storm sewers, with the causes of impairment listed variously as "habitat modification", "water/flow variability", "flow alterations", "siltation", and "cause unknown". Stream segments impaired due to a pollutant and thus requiring a TMDL are described in section 4.1.3, below.

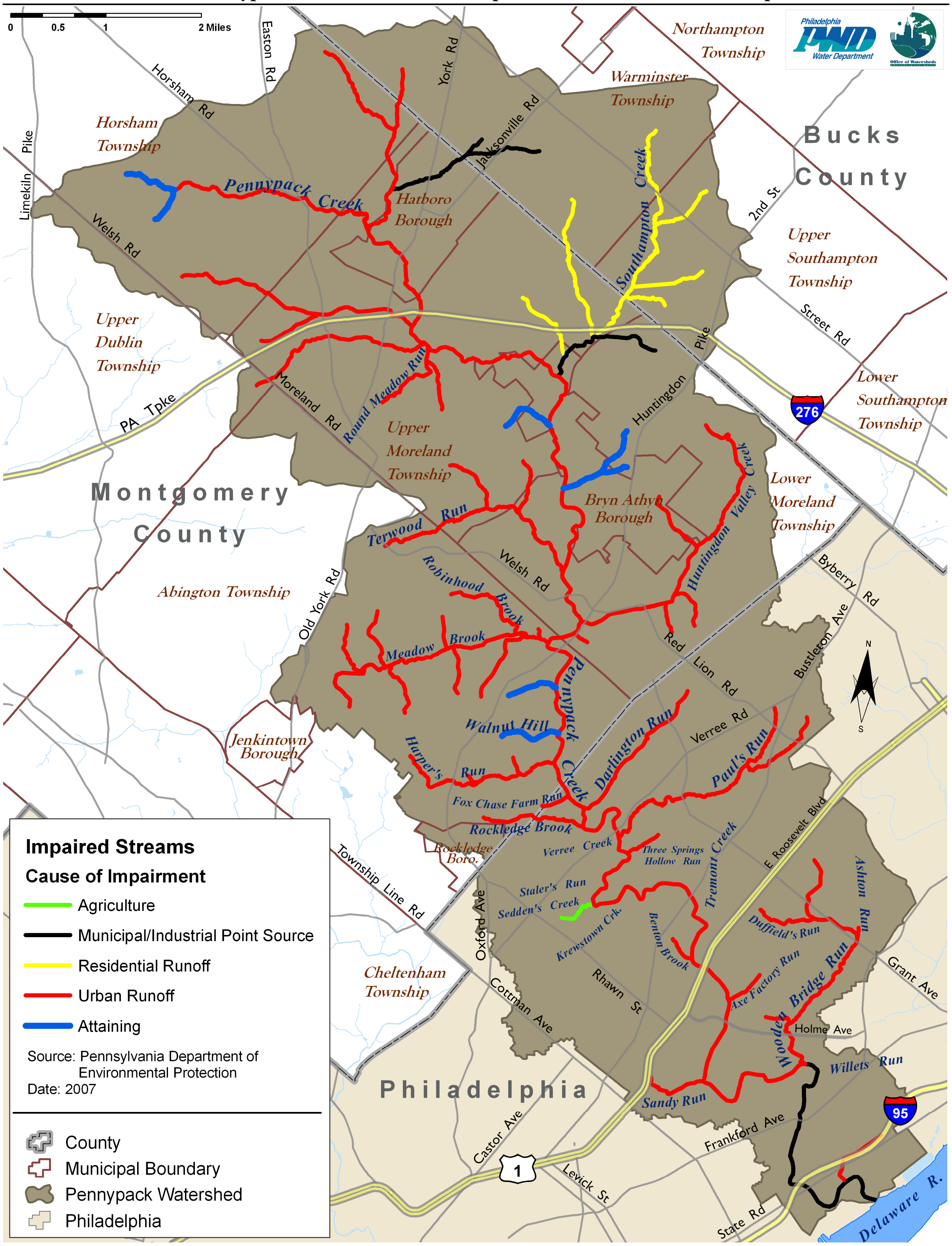


Figure 4.1 Pennypack Creek Watershed Stream Segments Listed as Impaired in Pennsylvania 2008 Integrated List of Waters

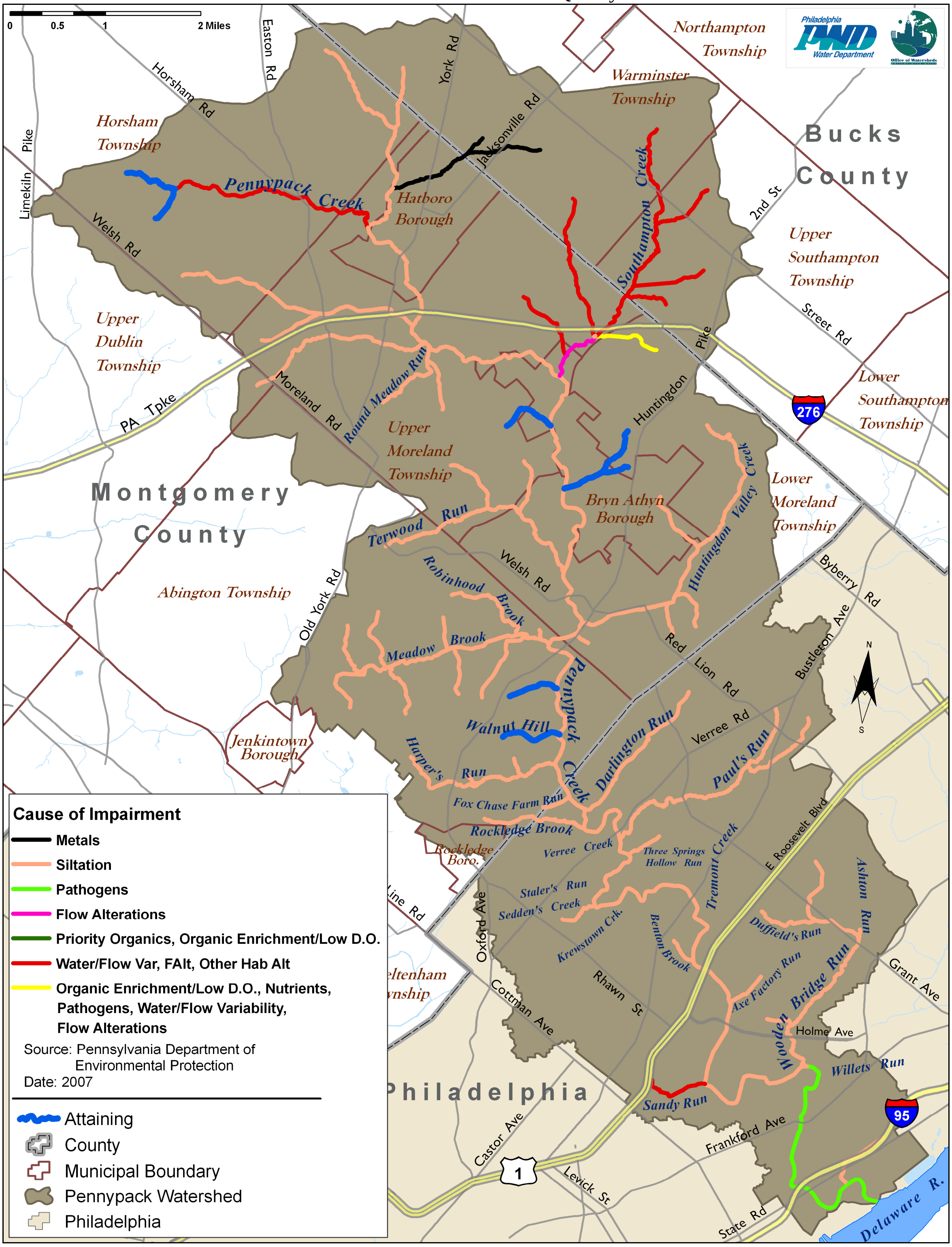


Figure 4.2 Pennypack Creek Segments Impaired due to a Pollutant and Requiring a TMDL

180 stream segments in the Pennypack Creek Watershed have been included on Pennsylvania's 2008 Integrated List of Waters due to siltation impairments (Figure 4.2). These include 31 segments of mainstem Pennypack Creek and 159 tributary segments. Siltation reduces habitat complexity

through filling pools and interstitial spaces between larger substrate particles. Excess sediment can clog an organism's gill surfaces, decreasing its respiratory capacity. This pollutant may also negatively affect visual predators by adversely impacting their ability to acquire prey. Sources of siltation impairments include urban runoff/storm sewers and habitat modification.

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.

4.1.4 PENNYPACK CREEK TOTAL MAXIMUM DAILY LOAD – 1999

The Pennypack Creek was listed on the PADEP's 1996 303(d) list of impaired waters due to priority organics from industrial point sources and pathogens and organic enrichment/dissolved oxygen (DO) from municipal point sources. The listing was based on a 1989 Aquatic Biology Investigation and Water Quality Assessment conducted by the PADEP. The Summary identified the priority organic pollutant as Trichloroethylene (TCE). The Pennypack TMDL submitted on April 1998 outlines the major contaminants and contributors to the Pennypack Creek including Trichloroethylene (TCE), organic enrichment or dissolved oxygen (DO), and fecal coliform.

In the TMDL documentation, Fisher & Porter Inc. was identified as the main point source contributor of TCE. The following entities were listed as contributors of fecal coliform, CBOD5 and NH3:

1. Upper Moreland Hatboro JT Sewer Authority
2. Gloria Dei Apartments
3. Bethayres Apartments
4. Lower Moreland School District
5. Academy of the New Church
6. HPC (aka Meadowbrook Apartments)
7. Holy Redeemer Hospital
8. Tall Trees Apartments

Due to the age of this TMDL, the PA DEP has not made an electronic version of the document available. For more information about this TMDL, please contact the PADEP directly.

4.1.5 NUTRIENT AND SEDIMENT TMDLS FOR THE SOUTHAMPTON CREEK WATERSHED – 2008

Nutrient and Sediment TMDLs were completed for the Southampton Creek tributary sub-watershed of the Pennypack Creek Watershed in June, 2008. The Southampton Creek drainage area is just over 6 square miles; the creek is roughly 3.5 mile long stream with six unnamed tributaries located on the border of Montgomery and Bucks County, Pennsylvania. This waterway was listed on the PADEP's 303(d) list of impaired waters for Channelization / Siltation, Urban Runoff / Stormwater Sewer / Nutrients. According to the TMDL documentation, this tributary experiences excessive blooms of algae from organic enrichment and must reduce sediment loads in the main stem and tributaries.

The Southampton Creek TMDL defines Waste Load Allocations (WLAs) and End Points for point source dischargers and MS4 municipalities within this watershed for both nutrients and sediments (Section 2 Tables 2-13, 2-14, 2-15, 2-16, 2-17 and 2-18)

4.1.6 PWD COMBINED SEWER OVERFLOW LONG TERM CONTROL PLAN (CSO LTCP)

Industrial activity was established along the Delaware River in the vicinity of the mouth of Pennypack Creek relatively early compared to the rest of Northeast Philadelphia, with the Pennypack Creek serving as a source of water power for mills and the King's highway (presently Frankford Avenue) serving as a primary transportation corridor from the farms in this region to the City. Several portions of the City in this area are still served by combined sewer systems, five of which discharge directly to the tidal Pennypack Creek. Philadelphia's CSO Long Term Control

Plan (LTCP) is presently being updated to reflect planned improvements in capture and prevention of combined sewer overflows citywide. Recent technology based improvements in the Pennypack combined sewer system have helped mitigate CSO discharge and bring overall capture of combined sewage to 85%.

4.2 WATER QUALITY CRITERIA AND REFERENCE VALUES

Data collected from discrete wet and dry weather sampling in Pennypack 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). A color coding system was used to indicate problems (red) and potential problems (yellow). Problems were identified if more than 10% of samples exceeded the applied water quality standard or criterion. Potential problems were identified if between 2% and 10% of samples exceeded the standard or criterion.

Table 4.2 Water Quality Standards and Reference Values

Parameter	Criterion	Water Quality Criterion or Reference Value	Source
Alkalinity	Minimum	20 mg/L	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
Chlorophyll *a*	Reference reach frequency distribution approach for Ecoregion IX, subregion 64, 75th percentile	3 µg/L, (Spectrophotometric) ***	EPA 822-B-00-019
Dissolved Cadmium	Aquatic Life Acute Exposure Standard	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	120 µg/L *	PA DEP

	Standard		
	Human Health Standard	7.4 mg/L****	PA DEP
Dissolved Oxygen	Minimum Daily Average (August 1 to February 14)	5 mg/L	PA DEP
	Instantaneous Minimum (August 1 to February 14)	4 mg/L	PA DEP
	Minimum Daily Average (February 15 to July 31)	6 mg/L	PA DEP
	Instantaneous Minimum (February 15 to July 31)	5 mg/L	PA DEP
Fecal Coliform	Maximum (Swimming season)	200 CFU/100mL	PA DEP
Fecal Coliform	Maximum (Non-swimming season)	2000 CFU/100mL	PA DEP
Fluoride	Maximum	2.0 mg/L	PA DEP
Iron	Maximum	1.5 mg/L	PA DEP
Manganese	Maximum	1.0 mg/L	PA DEP
Ammonia Nitrogen (NH_3-N)	Maximum	pH and temperature dependent	PA DEP
$NO_{2\text{-}3}$-N	Nitrates – Human Health Consumption for water + organisms	2.9 mg/L ***	EPA 822-B-00-019
$NO_2 + NO_3$	Maximum (Public Water Supply Intake)	10 mg/L	PA DEP
Periphyton Chl-*a*	Maximum	Ecoregion IX – 20.35 mg/m2	EPA 822-B-00-019
pH	Acceptable Range	6.0 - 9.0	PA DEP
Phenolics	Maximum	0.005 mg/L	PA DEP
TDS	Maximum	750 mg/L	PA DEP
Temperature		Varies w/ season. **	PA DEP
TKN	Maximum	0.675 mg/L ***	EPA 822-B-00-019
TN	Maximum	4.91 mg/L ***	EPA 822-B-00-019
TP	Maximum	140 µg/L ***	EPA 822-B-00-019
TSS	Maximum	25 mg/L	Other US states
Turbidity	Maximum	8.05 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 seasonal median
**** - Agency notes "organoleptic effect criterion is more stringent than the value for priority toxic pollutants."

4.2.1 Review of Existing Data and GIS Consolidation of Historical Monitoring Locations

As part of the data review for the Pennypack 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 Geologic 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 Pennypack Creek Watershed was compiled, more than 100 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 Pennypack Creek Watershed (gage 01467048 at Rhawn St., gage 01467042 at Pine Rd., gage 01467045 at Verree Rd. and gage 01467050 on Wooden Bridge Run). By 1980, 9 additional stations were established in Pennypack Creek and its tributaries (Figure 4.3). Water quality data were transcribed from a hard copy of the aforementioned report in the PWD Bureau of laboratory Services (BLS) library and entered into an Microsoft Access database.

Overall, three stations on mainstem Pennypack Creek and two stations on Wooden Bridge Run were instrumented with water level sensors and rated for discharge, while other stations were used only to collect water quality samples. While only two of the twelve original stations remain operational stream gages today, continuous water quality monitoring has recently been implemented. USGS gage stations 01467048 at Rhawn St. and 01467042 at Pine Rd. have been instrumented with continuous water quality monitoring equipment, with the responsibility for maintenance shared between PWD and USGS personnel.

PWD and USGS conducted water quality sampling from 1971 to 1980 at gages 01467048 (Rhawn St.), 01467042 (Pine Rd.), and gages 01467050 and 01467049 on Wooden Bridge Run (Figure 4.3). Samples were initially collected monthly, but sampling became less frequent as the study progressed. Furthermore, some chemical analytes were not consistently sampled (Table 4.3).

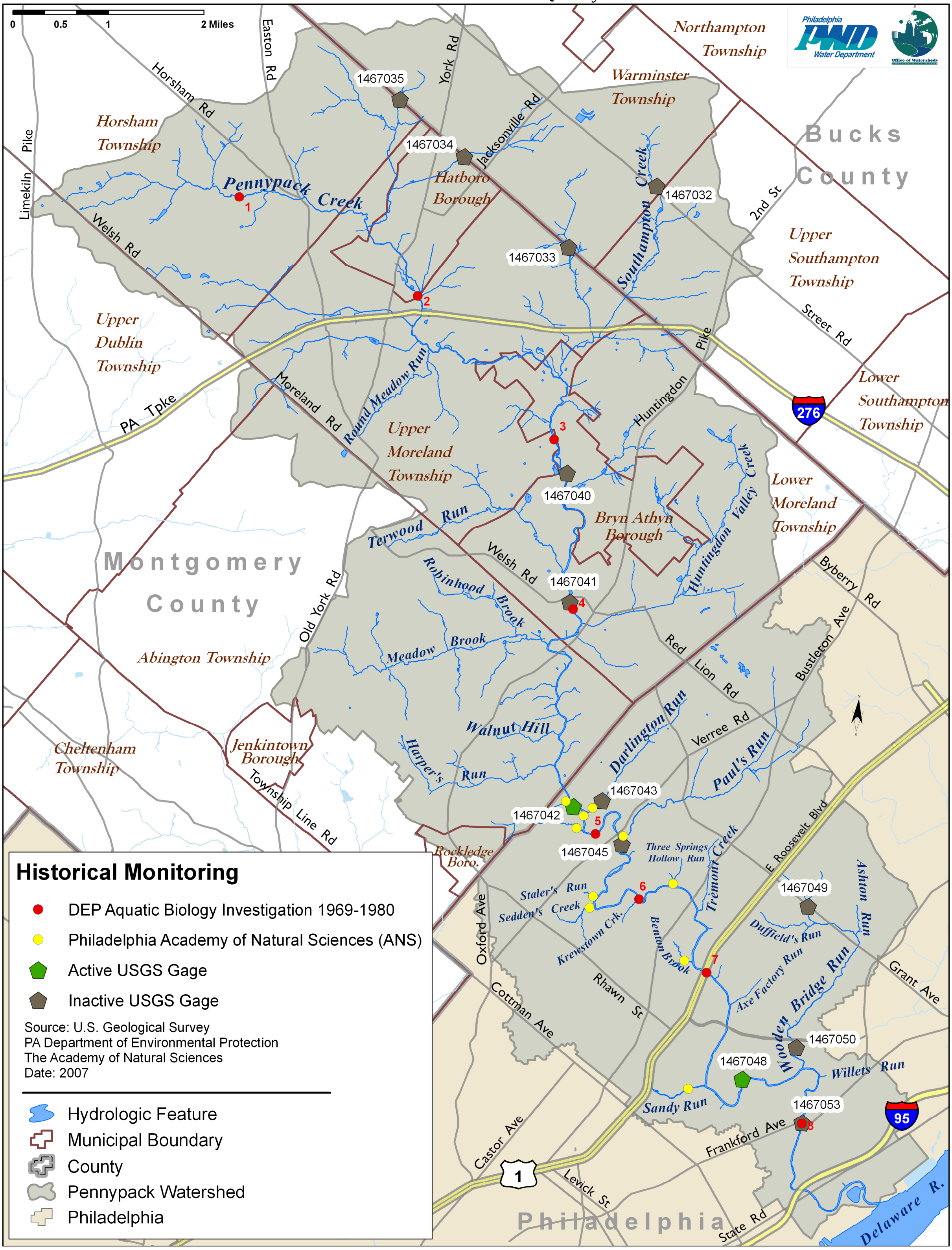


Figure 4.3 Historical Monitoring Locations in Pennypack Creek Watershed

Table 4.3 Number of Samples by Sampling Location for PWD/USGS Historical Water Quality Monitoring program, 1971-1980.

Parameter	Units	1467050	1467049	1467048	1467042	Parameter Total
BOD_5	mg/L	100	17	100	100	317
COD	mg/L	36	*0*	35	36	107
Dissolved Oxygen	mg/L	108	20	109	109	346
Fecal Coliform	mg/L	108	20	109	108	345
Ammonia	mg/L as N	104	19	105	105	333
Nitrite	mg/L	108	20	108	108	344
Nitrate	mg/L	108	20	108	108	344
pH	pH units	*0*	*0*	34	34	68
Orthophosphate	mg/L	108	*0*	108	108	324
Total Phosphorus	mg/L	*0*	20	*0*	*0*	20
Discharge	CFS	105	20	106	106	337
Specific Conductance	µS/cm	106	18	106	*0*	230
Total Dissolved Solids	mg/L	13	20	13	36	82
Temperature	°C	107	20	107	108	342
Total Organic Carbon	mg/L	31	*0*	31	31	93
Total Organic Nitrogen	mg/L	2	*0*	2	2	6
Total Suspended Solids	mg/L	36	*0*	36	36	108
Site total		1180	214	1217	1135	3746

4.2.3 USGS National Water Information System

As described above, USGS established a total of 13 monitoring locations in Pennypack Creek Watershed. The National Water Information System (NWIS) (http://waterdata.usgs.gov/nwis) was queried in spring 2008 to retrieve all streamflow and water quality data from these sites, as listed below 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 primarily unfiltered.

Table 4.4 USGS Gages in Pennypack Creek Watershed, from USGS NWIS System

PWD Site	USGS Gage Number	Site Description	Water Quality
N/A	1467034	Pennypack Creek Tributary at Bonair, PA	N/A
N/A	1467035	Middle Bridge Pennypack Creek Trib at Warminster, PA	N/A
N/A	1467040	Pennypack Creek at Paper Mill, PA	N/A
N/A	1467041	Pennypack Creek at Welsh Road, Philadelphia, PA	N/A
PP970	1467042	Pennypack Creek at Pine Road, at Philadelphia, PA	1967-1973
N/A	1467045	Pennypack Creek below Veree Road at Phila., PA	N/A
PP340	1467048	Pennypack Creek at Lower Rhawn St Bdg, Phila., PA	1967-1973
N/A	1467053	Pennypack Creek at Frankford Ave, at Philadelphia, PA	N/A
N/A	1467032	Southampton Creek at Davisville, PA	N/A
N/A	1467033	Southampton Creek Trib at County Line Rd nr Lacey Park	N/A
N/A	1467049	Wooden Bridge Run at Grant Ave, Philadelphia, PA	1971-1973
PPW010	1467050	Wooden Bridge Run at Philadelphia, PA	1968-1972
N/A	1467043	Stream 'A' at Philadelphia, PA	N/A

Data retrieved from NWIS was found to be completely independent of the data collected under the PWD/USGS sampling program, in that no common records were found between the two datasets. USGS NWIS streamflow data were used as the primary determinant of whether water quality samples collected by other historical monitoring programs were collected in dry weather or wet weather. When there were discrepancies between streamflow observations between two datasets, the USGS NWIS dataset was assumed to be of better quality and used preferentially when making these determinations.

4.2.4 PDH/PADEP Aquatic Biology Investigation of Pennypack Creek Watershed

The Philadelphia region office of the Pennsylvania Department of Health (PDH) and PADEP conducted chemical sampling in Pennypack Creek Watershed on a yearly basis at 8 sites from 1969 to 1976, then in 1978 and 1980 (Figure 4.3, Table 4.5). These data were collected with assistance from the Pennsylvania Fish and Boat Commission and Pennypack Watershed Association in an effort to evaluate yearly trends in water quality, effects of the Hatboro-Upper Moreland Joint Sewer Authority (HUMJSA) sewage treatment plant discharge on water quality and aquatic life, and whether Pennypack Creek was appropriate for trout stocking by PFBC. PWD acquired hard copies of these reports in 2002 from the Pennypack Ecological Restoration Trust (PERT), which were then scanned to create digital copies. Water quality and biological data were manually transcribed and entered into a Microsoft Access database. Despite the fact that wastewater effluent was a major focus of the work, no monitoring stations were selected in close proximity downstream of the HUMJSA facility. In contrast, PWD site PP1680 was located approximately 450m downstream of the HUMJSA facility discharge point (Figure 4.3).

Table 4.5 Number of Samples for PDH/PADEP Water Quality Monitoring Program by Sampling Location, 1969-1980.

PDH/DEP site		**Site 8**	**Site 7**	**Site 6**	**Site 5**	**Site 4**	**Site 3**	**Site 2**	**Site 1**	
PWD site		**PP180**	**PP490**	**PP690**	**PP970**	**PP1250**	**PP1380**	**PP1850**	**PP2020**	**Parameter Total**
Parameter	**Units**									
Alkalinity	mg/L	11	11	11	11	11	11	11	11	88
Dissolved Oxygen	mg/L	10	10	10	10	10	10	10	10	80
Ammonia	mg/L as N	11	11	11	11	11	11	11	10	87
Nitrite	mg/L	11	11	11	11	11	11	11	10	87
Nitrate	mg/L	11	11	11	11	11	11	11	10	87
pH	mol/L H+	11	11	11	11	11	11	11	11	88
Ortho-phosphate	mg/L	11	11	11	11	10	11	11	11	87
Temperature	℃	11	11	11	11	11	11	11	11	88
Site Total		87	87	87	87	86	87	87	84	692

4.2.5 HISTORIC DATA PROCESSING

Historical records from the PWD/USGS Cooperative Study and PDH/PADEP Assessments were combined in a Microsoft Access database and subsequently classified as wet or dry using USGS NWIS discharge data and other components of the dataset associated with wet weather (*e.g.*, decreased conductivity, increased turbidity and TSS). Records without data values and water quality results from filtered samples were removed. The resulting dataset of approximately 9000 records afforded an opportunity to make a meaningful comparison of historical water quality to present-day conditions. Due to chronology of sampling and upgrades to sewage treatment plants, data collected through 1990 were grouped "historical", while data from 2002-2007 were grouped as present day data, though it should be noted that historical data were collected most frequently in the 1970s and present day data were collected primarily in 2002 and 2007 (Figure 4.4, Figure 4.5).

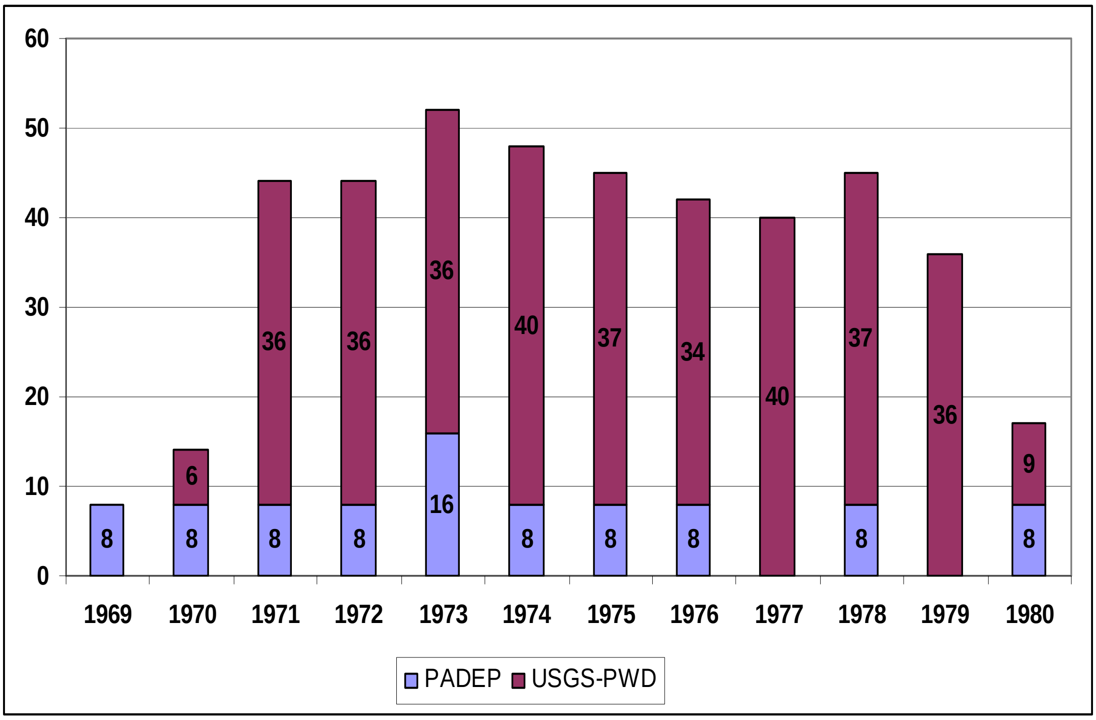


Figure 4.4 Number of Water Chemistry Sampling Events per Monitoring Period, 1969-1980

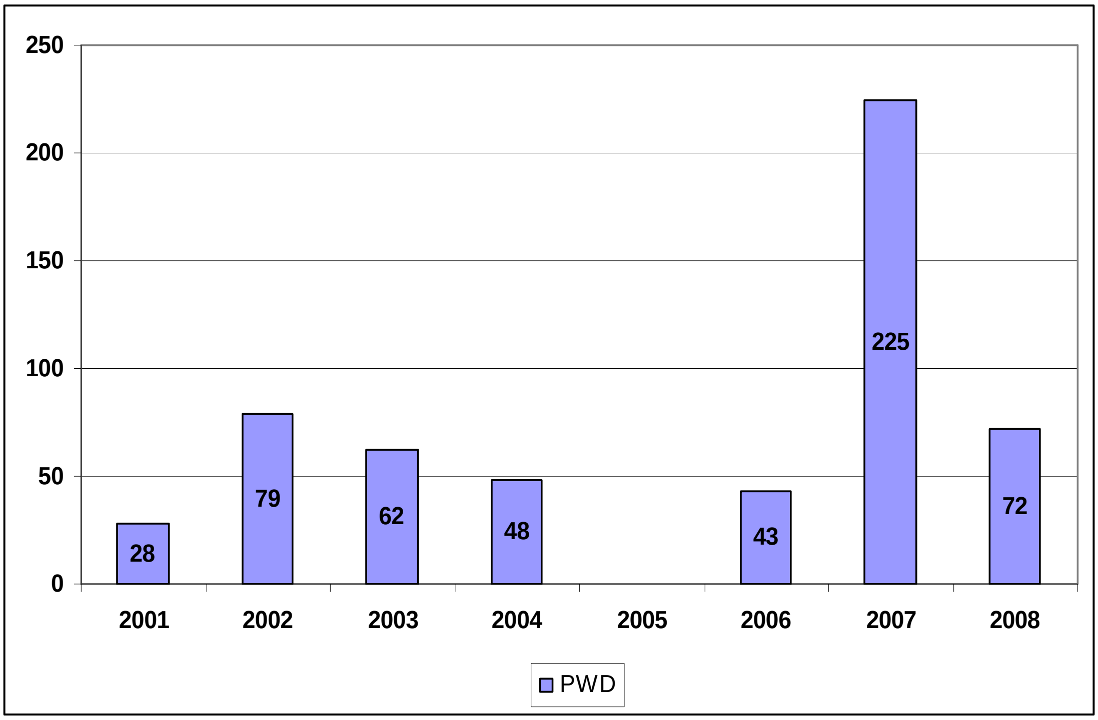


Figure 4.5 Number of Water Chemistry Sampling Events per Monitoring Period, 2001-2008

While some historical monitoring locations were similar to present-day monitoring locations, pairwise site-specific comparisons were generally not possible, due to sites being located too far apart (Figure 4.3) or an insufficient number of samples were collected for the comparisons to be meaningful. Spatial data trends were addressed by grouping sites inside/outside the City of Philadelphia, and effects of wet weather were accounted for by categorizing data as wet or dry.

As discovered in the preliminary data gathering phase, Wooden Bridge Run (USGS gage 01467050) was affected by a severe dry weather sewage problem during the early 1970s. Because these samples might skew the overall dataset within the City of Philadelphia when comparing modern water quality data to historical data, erroneously making it seem as if there had been an improvement in dry weather water quality, Wooden Bridge Run data were analyzed separately from mainstem Pennypack Creek data when assessing trends within the City of Philadelphia and excluded from inside/outside City comparisons.

Likewise, the modern dataset contained a large number of samples collected from Fox Chase Farm Run, a small tributary at the upstream extent of The City of Philadelphia. Fox Chase Farm is a working farm purchased as public land by The City of Philadelphia in 1972. In 2002, PWD and FPC implemented a stream buffer agricultural BMP at this location in order to limit cattle access to the stream and reduce pathogen loading to Pennypack Creek. Water quality samples were collected at various locations along Fox Chase Farm Run over the monitoring period 2003-2006 from a variety of sites upstream of, within, and downstream of the stream buffer. Furthermore, agricultural practices such as application of fertilizers and manure may have skewed the data. For this reason, Fox Chase Farm data were analyzed separately from mainstem Pennypack Creek data when assessing trends within the City of Philadelphia and excluded from City of Philadelphia aggregate data when performing inside/outside City comparisons.

4.2.6 HISTORIC DATA COMPARISON RESULTS

When a sufficient number of samples were available, comparisons were made between modern and historical data, grouped by geographic location (inside or outside the city of Philadelphia) and weather (wet or dry). Significant differences were observed between the modern and historical dataset for nutrients (nitrate, orthophosphate, ammonia, nitrogen, and total phosphorus) (Table 4.6). While statistically significant, most of these differences were minor when one considers that concentrations are so drastically different from natural conditions that effects on the natural communities are probably minimal. For example, present-day dry weather mean PO_4 concentration is approximately 0.5mg/L (Table 4.6). Though considerably lower than historical values, the difference may not be particularly meaningful, as concentrations are much greater than might be expected to limit growth of algal periphyton.

Table 4.6 Comparison Between 2007 Water Quality Data and Historic Water Quality Data

Parameter	Wet/ Dry	Comparison	Test	*U-value	p-value	Historic valid n	Modern valid n	Historic mean	Modern mean
NO3	Dry	Historic data vs. City of Philadelphia 2007 data	Mann Whitney U-test	5325	0.00	127	130	3.52	4.28
NO3[1]	Dry	Historic data vs. Upstream City of Philadelphia 2007 data	T-test	-2.71	0.01	30	117	2.91	4.59
NO3	Wet	Historic data vs. City of Philadelphia 2007 data	Mann Whitney U-test	10216	0.00	188	143	2.24	3.33
NO3	Wet	Historic data vs. Upstream City of Philadelphia 2007 data	Mann Whitney U-test	1425	0.01	28	144	3.46	3.09
PO4	Dry	Historic data vs. City of Philadelphia 2007 data	Mann Whitney U-test	155	0.00	126	130	3.58	0.51
PO4	Dry	Historic data vs. Upstream City of Philadelphia 2007 data	Mann Whitney U-test	883.5	0.00	24	116	2.44	0.57
PO4	Wet	Historic data vs. City of Philadelphia 2007 data	Mann Whitney U-test	1344.5	0.00	200	143	2.63	0.46
PO4	Wet	Historic data vs. Upstream City of Philadelphia 2007	Mann Whitney U-test	967	0.01	21	144	3.39	0.45
TP[1]	Dry	Historic data vs. City of Philadelphia 2007 data	T-test	9.47	0.00	17	103	1.64	0.49
TP	Dry	Historic data vs. Upstream City of Philadelphia 2007	Mann Whitney U-test	12	0.00	6	108	3.34	0.60
TP[1]	Wet	Historic data vs. City of Philadelphia 2007 data	T-test	1.0	0.32	32	103	0.80	0.71
TP	Wet	Historic data vs. Upstream City of Philadelphia 2007	Mann Whitney U-test	137	0.00	8	115	1.66	0.69

[1] Log (x) + 1 transformation used to normalize data
* T-value where T-tests were used

4.2.7 WATER QUALITY SAMPLING 1990-PRESENT

4.2.7.1 PWD BASELINE BIOLOGICAL ASSESSMENT OF PENNYPACK CREEK WATERSHED

PWD conducted a baseline assessment of Pennypack Creek Watershed in 2002. Water quality samples were collected from 14 sites in Pennypack Creek Watershed along with habitat and macroinvertebrate assessments from 20 locations and fish collections from 9 sites. The primary differences between the 2002 and 2007 water quality monitoring programs were as follows:

1.) Water quality samples were collected on a weekly basis without regard for weather or streamflow conditions in 2002, while the 2007 sampling schedule was adjusted to ensure that a sufficient number of grab samples be collected in dry weather (baseflow) conditions.
2.) The 2007 water quality sampling effort was more comprehensive, addressing wet weather and continuous effects.
3.) A small number of sites were moved and/or discontinued from 2002 to 2007.

4.2.7.2 PWD WATER QUALITY SAMPLING OF FOX CHASE FARM TRIBUTARY

Fox Chase Run is a small tributary that runs through Fox Chase Farm, which is owned by the Fairmont Park Commission, before reaching its confluence with the mainstem Pennypack. Prior to May of 2002, the tributary was subject to unrestricted access by cattle using the tributary both to drink and avoid the summer heat. Furthermore, pasture surrounding the creek was mowed very close to the tributary streambanks. Visual assessments suggested that the lack of riparian buffer could increase rates of agricultural runoff. Grab samples and water chemistry probes revealed that temperatures within the tributary were elevated, dissolved oxygen levels were diminished and high concentrations of *E.coli*, fecal coliform, turbidity and nutrients were entering Pennypack Creek from Fox Chase Run during both wet and dry weather. Preliminary assessments also suggested the tributary could not support a taxonomically diverse macroinvertebrate community.

In May of 2002, through the joint efforts of collaborators that included Philadelphia Water Department, Fairmount Park Commission, the School District of Philadelphia, Friends of Fox Chase Farms, Friends of Pennypack Creek and volunteers, agricultural best management practices (BMPs) were implemented on Fox Chase Run to reduce some of its adverse impacts on water quality in Pennypack Creek. Streambank fencing was installed along the length of Fox Chase Run, restricting cattle to a single crossing which allowed them to drink and move between pastures. In addition, a forested riparian buffer (~1.85ac) was established along the length of the tributary as over 400 trees and 735 shrubs were planted on the banks within a 45 ft buffer on either side of Fox Chase Run. The project also included an educational demonstration site for the enhancement of the agricultural curriculum of the nearby Lincoln High School.

From 2001 to 2006, PWD conducted water quality monitoring of the farm's tributary and of the Pennypack Creek (upstream and downstream of the tributary) with the goal of establishing a baseline understanding of water quality impacts from farm runoff and to evaluate water quality improvements resulting from project implementation. Unfortunately, this work was not carried out in accordance with sampling design and quality control oversight robust enough to determine whether the BMP has had a significant impact on water quality in Pennypack Creek. Prior to project implementation, in 2001, the concentration of both fecal coliform and *E. coli* in the Pennypack Creek increased downstream of the tributary as a result of high bacteria concentrations in the tributary. Following project implementation, the tributary demonstrated a diluting affect on the bacteria concentrations in Pennypack Creek, causing a reduction of both fecal coliform and *E. coli* concentrations in the Pennypack downstream of the farm's tributary.

Monitoring at Fox Chase Run represents a unique case among tributary assessments in that an obvious point source within the Fairmount Park/Pennypack Creek system was identified and ameliorated through riparian restoration. The sites chosen for PWD continuous and discrete chemical monitoring are strategically chosen such that they allow potential sources or causes of impairment to be identified through upstream to downstream comparisons of water quality data. Monitoring in Fox Chase Run was conducted over both a pre-implementation [BMP] period and a post-implementation period at Fox Chase Farms; however, these data are not included in the water quality analysis as the sampling protocol, sampling frequency and the parameters analyzed do not match that of the chemical monitoring conducted at PWD monitoring locations. Furthermore, agricultural practices such as the application of fertilizers and manure may have skewed the data and for this reason, the Fox Chase Farm dataset was analyzed separately from mainstem Pennypack Creek data when assessing trends within the City of Philadelphia and excluded from City of Philadelphia aggregate data when performing inside/outside City comparisons.

Fox Chase Farm sampling and subsequent monitoring occurred in 2001, (12 sampling events during 12 consecutive weeks from July to October), 2003 (8 sampling events during 8 consecutive weeks from July through September), and 2004 (monthly from March to December) with samples taken at the tributary's headwaters and confluence with Pennypack Creek as well as upstream and downstream of the confluence. Most of the monitoring done at Fox Chase Farm was timed in order to evaluate water quality conditions during the peak of both recreational activity in the Pennypack Creek and cattle activity in the farm's tributary such that samples were taken during dry weather, 48 hours after a rain event of at least 0.5 inches. As such, the lack of adequate wet weather sampling further precludes comparison with PWD chemical monitoring data.

4.2.7.3 TEMPLE UNIVERSITY AMBLER CAMPUS PENNYPACK CREEK WATERSHED STUDY

Students and faculty from Temple University Ambler Campus have collected water quality data from Pennypack Creek Watershed periodically since 1999, and this partnership is expected to continue as the School's Center for Sustainable Communities is participating in urban stormwater BMP research with Villanova University and the Pennypack Ecological Restoration Trust. A number of small experimental BMPs have been installed and the researchers are collecting water quality and other data to assess performance of these BMPs.

4.2.7.4 PWD 2007 COMPREHENSIVE WATER QUALITY ASSESSMENT OF PENNYPACK CREEK WATERSHED

4.2.7.4.1 SAMPLING BACKGROUND

The Philadelphia Water Department (PWD) has carried out an extensive sampling and monitoring program to characterize conditions in Pennypack 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 Pennypack Creek Watershed, stormwater outfalls, combined sewer overflows and wastewater treatment facilities are classified as point sources and are regulated by NPDES.

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

Pennypack Creek and its tributaries are designated trout stocking fisheries. With the exception of the upstream-most headwaters segments and four small tributaries in Montgomery County, all stream reaches in Pennypack Creek Watershed are classified by PADEP as not meeting all designated uses (Figure 4.2). 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 in Pennypack Creek Watershed.

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

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 Pennypack 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, PA DEP, and USGS. A river mile-based naming convention is followed for sampling and monitoring sites located along waterways in the watershed. The naming convention includes 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 PPW010 is named as follows:

- "PP" an abbreviation of Pennypack Creek.
- "W" an abbreviation of Wooden Bridge Run, a tributary to Pennypack Creek.
- "010" a series of digits to indicate the river mile distance in hundredths of a mile from the confluence of Wooden Bridge Run and Pennypack Creek.

Table 4.7 Summary of Physical and Biological Sampling and Monitoring

Site Name	Stream Name	USGS Gage Number	USGS		PWD		
			USGS Daily Flow	USGS Water Quality	RBP III*	RBP V**	Habitat
PP180	Pennypack Creek				3/2007		3/2007
PPW010	Wooden Bridge Run				3/2007		3/2007
PP340	Pennypack Creek	1467048	1965-present	1967-present	3/2007		3/2007
PP490	Pennypack Creek				3/2007	6/2007	3/2007
PP690	Pennypack Creek				3/2007	6/2007	3/2007
PP860	Pennypack Creek				3/2007		3/2007
PP970	Pennypack Creek	1467042	1964-1974; 2007-present	1967-present	3/2007	6/2007	3/2007
PPHA003	Harpers Run				3/2007		3/2007
PP1060	Pennypack Creek				3/2007	6/2007	3/2007
PP1150	Pennypack Creek				3/2007		3/2007
PPM070	Meadow Brook				3/2007		3/2007
PPHU070	Huntingdon Valley Creek				3/2007		3/2007
PP1250	Pennypack Creek				3/2007		3/2007
PP1380	Pennypack Creek				3/2007		3/2007
PP1500	Pennypack Creek				3/2007		3/2007
PPS030	Southampton Creek				3/2007		3/2007
PP1680	Pennypack Creek				3/2007	6/2007	3/2007
PPHO010	Horsham Branch				3/2007		3/2007
PP1870	Pennypack Creek				3/2007		3/2007
PP2020	Pennypack Creek				3/2007	6/2007	3/2007
PPSR010	Sandy Run				3/2007		3/2007
PPSC010	Seddens Run				3/2007		3/2007
PPPR010	Pauls Run				3/2007		3/2007
PPRB010	Rockledge Brook				3/2007		3/2007
PPDR010	Darlington Run				3/2007		3/2007
PP1850	Pennypack Creek				3/2007		3/2007

* EPA Rapid Bioassessment Protocol III Benthic Macroinvertebrates

** EPA Rapid Bioassessment Protocol V Ichthyofaunal (Fish)

4.3 WATER QUALITY SAMPLING AND MONITORING

4.3.1 BACKGROUND INFORMATION

In order to comply with the State-regulated stormwater permit obligations, water quality sampling was conducted in Pennypack Creek Watershed during 2007 and 2008. Samples were collected at 9 mainstem sites and 4 tributary sites in the watershed (Figure 4.6, 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 attempt to identify historical changes in water quality.

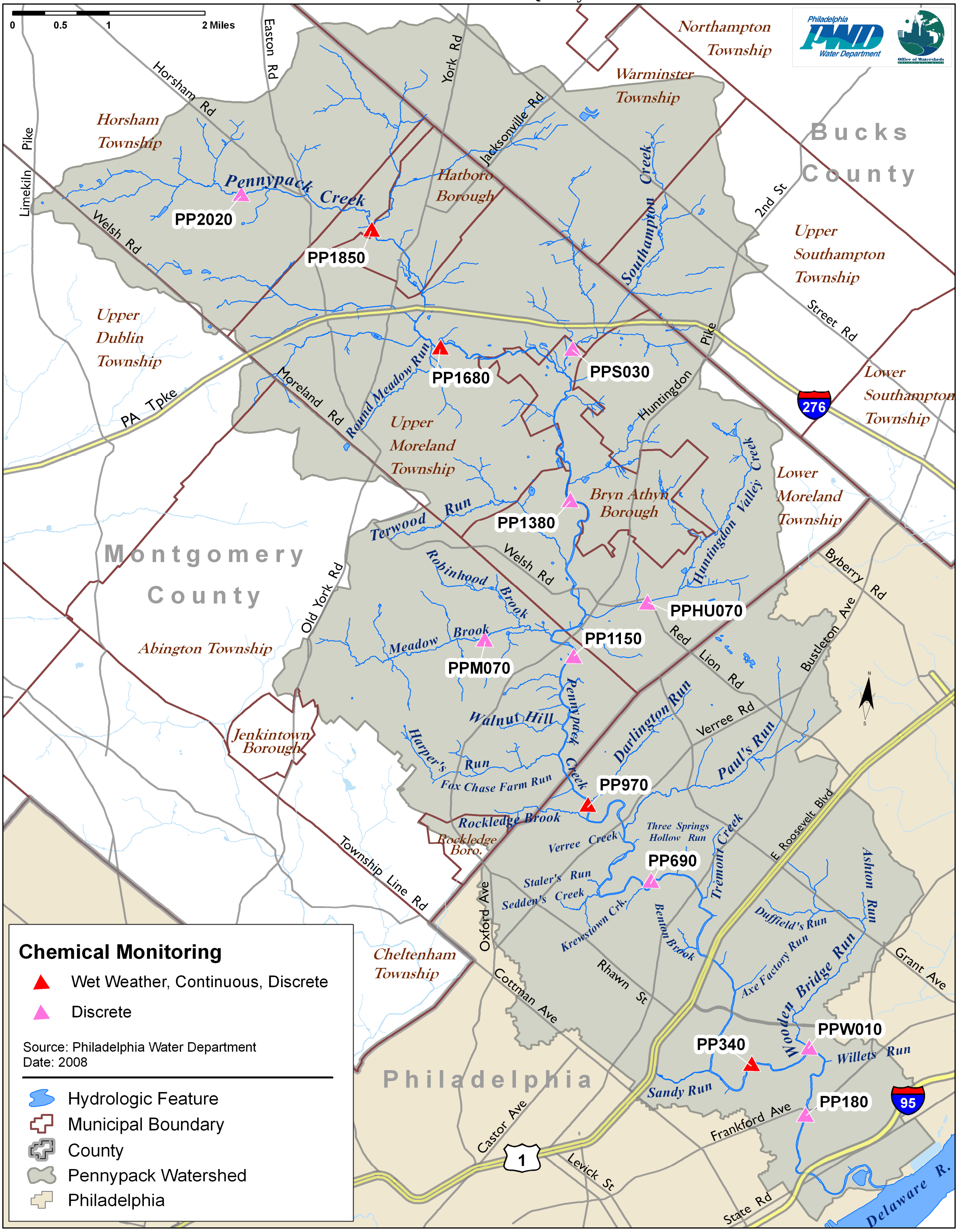


Figure 4.6 Water Quality Sampling Locations in Pennypack Creek Watershed, 2007

Table 4.8 Summary of Water Quality Monitoring Activities at Various Sampling Locations in Pennypack Creek Watershed, 2007

SITE	ASSESSMENT		
	Discrete	Continuous	Wet Weather
PP180	X		
PPW010	X		
PP340	X	X	X
PP490			
PP690	X		
PP860			
PP970	X	X	X
PPHA003			
PP1060			
PP1150	X		
PPM070	X		
PPHU070	X		
PP1250			
PP1380	X		
PP1500			
PPS030	X		
PP1680	X	X	X
PPHO010			
PP1870			
PP2020	X		
PPSR010			
PPSC010			
PPPR010			
PPRB010			
PPDR010			
PP1850	X	X	X

Table 4.9 Water Quality Parameters Sampled in Comprehensive Water Quality Assessment of Pennypack Creek Watershed, 2007

Parameter	Units	Discrete	Wet Weather	Continuous
Alkalinity	mg/L	X	X	
Aluminum	mg/L	X	X	
Dissolved Aluminum	mg/L	X		
Ammonia	mg/L as N	X	X	
Arsenic	mg/L	X	X	
Dissolved Arsenic	mg/L	X		
BOD5	mg/L	X	X	
Cadmium	mg/L	X	X	
Dissolved Cadmium	mg/L	X	X	
Calcium	mg/L	X	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	
Fecal Coliform	CFU/100mL	X	X	
Hardness	mg/L CaCO3	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		
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	
Sodium	mg/L	X		
Suspended Solids	mg/L	X	X	
Total Solids	mg/L	X	X	
Temperature	℃	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 thirteen (n=13) locations within Pennypack Creek Watershed for chemical and microbial analysis (Figure 4.6**)**. 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 8 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 A.

Sampling events were planned to occur at each site at weekly intervals for one month during three separate seasons. Actual sampling dates were as follows: "winter" samples collected 1/17/07, 1/24/07, 1/31/07, and 2/7/07; "spring" samples collected 4/25/07, 5/2/07, 5/9/07, and 5/16/07; "summer" samples collected 8/1/07, 8/8/07, 8/15/07, and 8/22/07. A total of 120 discrete samples, comprising 5420 chemical and microbial analytes, were collected and analyzed during the 2007 assessment of Pennypack Creek Watershed. To add statistical power, additional discrete water quality samples from PWD's wet-weather chemical sampling program were included in analyses when appropriate. Discrete sampling was conducted on a weekly basis and was specifically designed to collect a minimum of 8 samples during dry weather flow conditions. These data are most pertinent to Target A of the Pennypack 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 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 A) were deployed in Pennypack Creek Watershed at four (n=4) sites in order to collect DO, pH, temperature, conductivity, turbidity and depth data (Figure 4.6). Spring 2007 sonde deployments in Pennypack Creek Watershed were delayed due to personnel being allocated toward upgrading water quality monitoring equipment in the PWD/USGS gage network. Five gages throughout the Philadelphia region were fitted with continuous water quality monitoring equipment during this timeframe. In order to ensure that an entire year's worth of data were collected, sondes were re-deployed (at the two non-USGS continuous monitoring stations) through spring 2008.

Sondes continuously monitored conditions and discretized the data in 15 minute increments. The instrument measures parameters using optical, voltage and diffusion-based probes rather than physically collecting samples. This method produces 96 measurements per parameter every 24 hours, but cost and quality control are more challenging compared to discrete sampling. The BLS SOP for continuous sampling (Appendix A) describes the extensive quality control and assurance procedures applied to the data.

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

4.3.4 Wet Weather Event Sampling

Target C of the Pennypack Creek Watershed Management Plan (in draft) addresses water quality in wet weather. Yet characterization of water quality at several widely spatially distributed sites simultaneously over the course of a storm event presents a unique challenge. Automated samplers (Isco, Inc.) were used to collect samples from 4 mainstem sites (PP340, PP970, PP1680, PP1850) during runoff-producing rain events in 2007 and 2008. Successful deployments during wet weather events took place 8/08/07, 10/9/07, 11/05/07 and 5/16/08. 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 4 grab samples at 40 minute intervals and the remaining samples at 1 hr. intervals.

Use of automated samplers allows for a greater range of flexibility in sampling programs, including flow-weighted composite sampling based on a user defined rating curve, but stage discharge rating curves at these sites were poorly defined for larger flows. Though some difficulties were encountered due to a combination of mechanical failure, individual site characteristics, and/or vandalism, the 40 minute and 1 hour intervals were found to be generally satisfactory in collecting representative samples over the course of a storm event.

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 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 Zn and Cu only, as other toxic constituents (*e.g.*, Cd and Cr) were rarely or never measured above reporting limits. Some model input parameters (*i.e.*, Sulfate, DOC, percent humic acids) were not sampled or only a small number of results were available in the Pennypack Creek Watershed dataset. Parameter input values for these parameters were substituted with conservative values from other regional streams.

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

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

Continuous water quality monitoring instruments (YSI Model 6600 and 600XLM Sondes) were deployed at four sites throughout Pennypack Creek Watershed from 2007 to 2008 in order to collect data in 15-minute intervals. A total of 807 days of DO data were collected from these monitoring locations through spring 2008 and are considered herein for the Pennypack 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 Pennypack Creek Watershed. A protocol for evaluating and rejecting data from intervals when probe failure occurred was developed (Appendix B). Intervals during which probe failure occurred are summarized in (Appendix C). Quality of recovered data 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 Pennypack 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 treated municipal sewage and untreated stormwater. Overall, violations of instantaneous minimum DO criteria occurred on 42 days monitored and violations of daily average DO criteria occurred on 18 days monitored (Tables 4.10 and 4.11, respectively). These violations were generally restricted to the warmer months and immediately downstream of wastewater treatment plant discharge at site PP1680, the only site at which violations of DO criteria were observed (both daily average and daily minimum criteria were violated on some days).

WWTP effluent no doubt has a considerable impact on DO levels at PP1680; however, the interaction between BOD and temperature, as well as physical and biological processes cannot be ignored. There is a positive relationship between temperature and metabolism (*i.e.,* metabolism increases with increasing temperature) such that DO suppression caused by metabolic activity is further exacerbated at elevated temperatures. Besides being the only site where DO violations occurred, PP1680 had the greatest number of daily mean and instantaneous maximum temperature violations. Violation of water quality standards for DO and temperature occurred concurrently in many instances and temperature was a factor contributing to DO suppression.

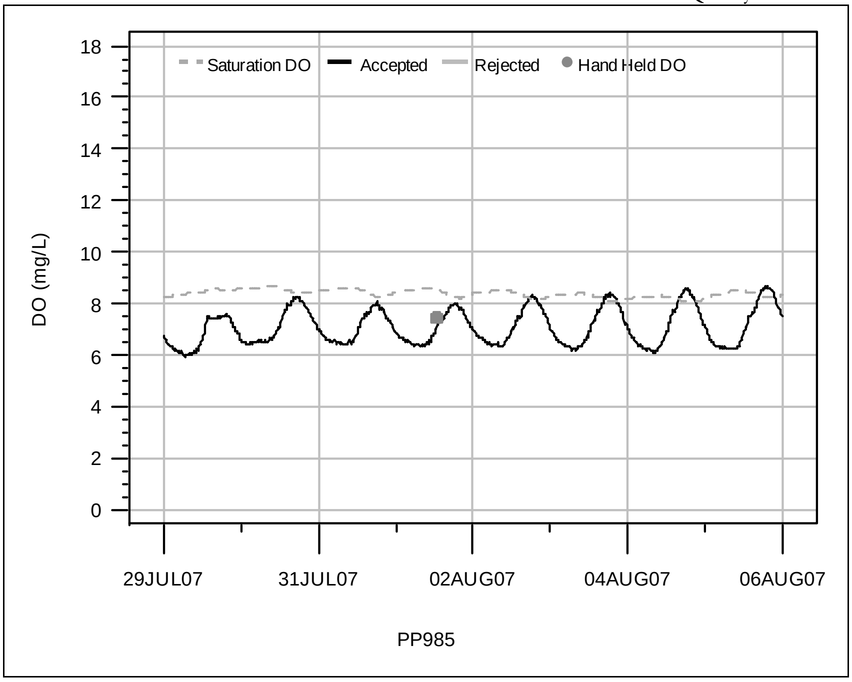


Figure 4.7 Dissolved Oxygen Diel Fluctuations at Site PP985, 7/29/2007-8/06/2007

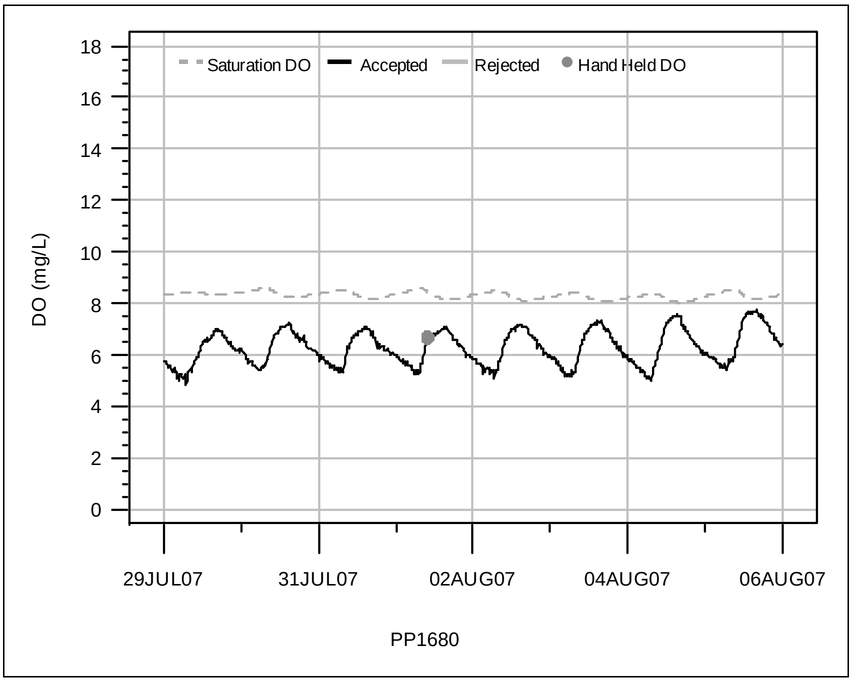


Figure 4.8 Dissolved Oxygen Diel Fluctuations at Site PP1680, 7/29/2007-8/06/2007

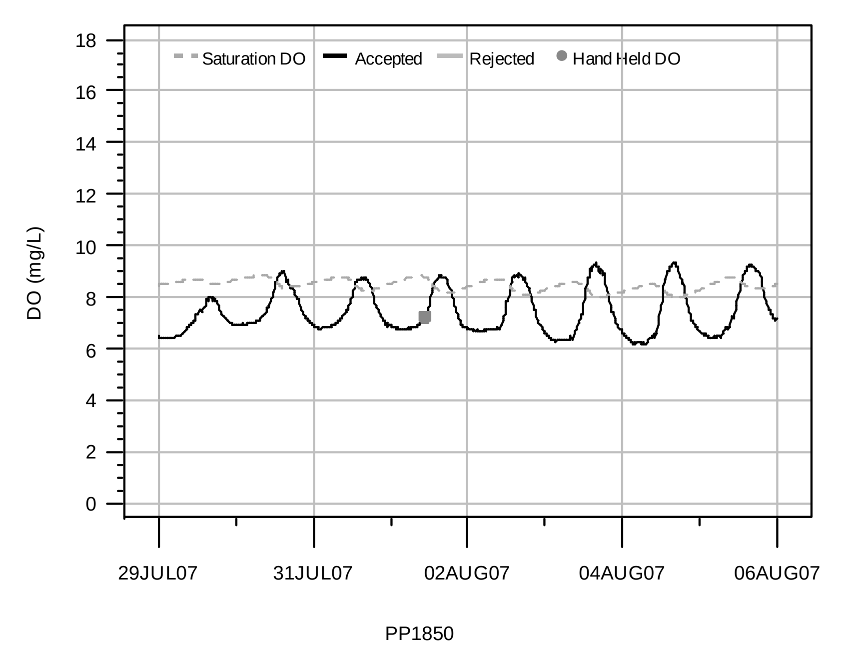


Figure 4.9 Dissolved Oxygen Diel Fluctuations at Site PP1850, 7/29/2007-8/06/2007

Downstream sites in the City of Philadelphia had only moderate DO fluctuation due to biochemical activity, perhaps because of increased tree canopy cover within Pennypack Park (Figure 6.12), increased dilution, or reaeration at dams. Effects of stream metabolism on DO concentration are addressed further in section 4.5 (Stream Metabolism). Weekly plots of continuous dissolved oxygen concentration compared to saturation dissolved oxygen conditions are presented in Appendix D.

Table 4.10 Continuous Water Quality Data Meeting/Exceeding Standard by Site

		PP340			PP985			PP1680			PP1850		
Parameter	Standard	No. Obs	Number Exc.	Percent Exc.	No. Obs	Number Exc.	Percent Exc.	No. Obs	Number Exc.	Percent Exc.	No. Obs	Number Exc.	Percent Exc.
Sonde DO	Minimum (inst)	14668	0	0	18819	0	0	18074	1062	5.88	22567	0	0
Sonde Temperature	Maximum	14756	2306	15.63	18922	2418	12.78	20504	9638	47.01	22597	3301	14.61
Sonde Turbidity	Maximum - Reference	11502	2083	18.11	15685	3164	20.17	20186	2275	11.27	21716	3677	16.93
Sonde pH	Maximum	14652	10	0.07	16407	0	0	20152	0	0	22354	0	0
Sonde pH	Minimum	14652	0	0	16407	0	0	20152	6	0.03	22354	1	0

Table 4.11 Continuous Water Quality Daily Exceedances by Site

		PP340			PP985			PP1680			PP1850		
Parameter	Standard	Days	No. Exceed	% Exceed	Days	No. Exceed	% Exceed	Days	No. Exceed	% Exceed	Days	No. Exceed	% Exceed
Sonde DO Daily Average	Minimum Average	159	0	0	203	0	0	198	18	9.1	247	0	0
Sonde DO Daily Min	Minimum	159	0	0	203	0	0	198	42	21	247	0	0
Sonde pH Daily Max	Maximum	159	1	0.63	177	0	0	222	0	0	246	0	0
Sonde pH Daily Min	Minimum	159	0	0	177	0	0	222	3	1.4	246	1	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 thirty or more days to yield ultimate BOD. The BOD_5 test, in which depletion of DO is measured over a five day period, was applied most consistently to water samples from sites in Pennypack 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 re-aeration due to atmospheric diffusion and instream production of DO by algal photosynthesis.

Pennypack Creek Watershed is affected by municipal wastewater treatment plants and other permitted discharges that introduce BOD to the stream. These discharges were believed to be the most important sources of BOD loading to Pennypack 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= 2mg/L), which is often the case in dry weather samples from streams where point source discharges of BOD are regulated and there are no other major sources of organic enrichment. Overall, 92% of dry weather samples and 61% of wet weather samples had BOD_5 concentration below reporting limits. In 209 dry weather samples, BOD_5 was never detected (*i.e.*, greater than 2mg/L) in the headwaters of Pennypack Creek (site PP2020) or within the City of Philadelphia (*i.e.*, at site PP975 or downstream). Dry weather BOD_5 was only detected at sites PP1850 and PP1680. However, elevated BOD_5 observed at site PP1850 (upstream) suggests that the major wastewater treatment plant discharge immediately upstream of site PP1680 is not the only source of BOD_5 in dry weather.

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 usually greatest downstream of point source discharge at site PP1680.

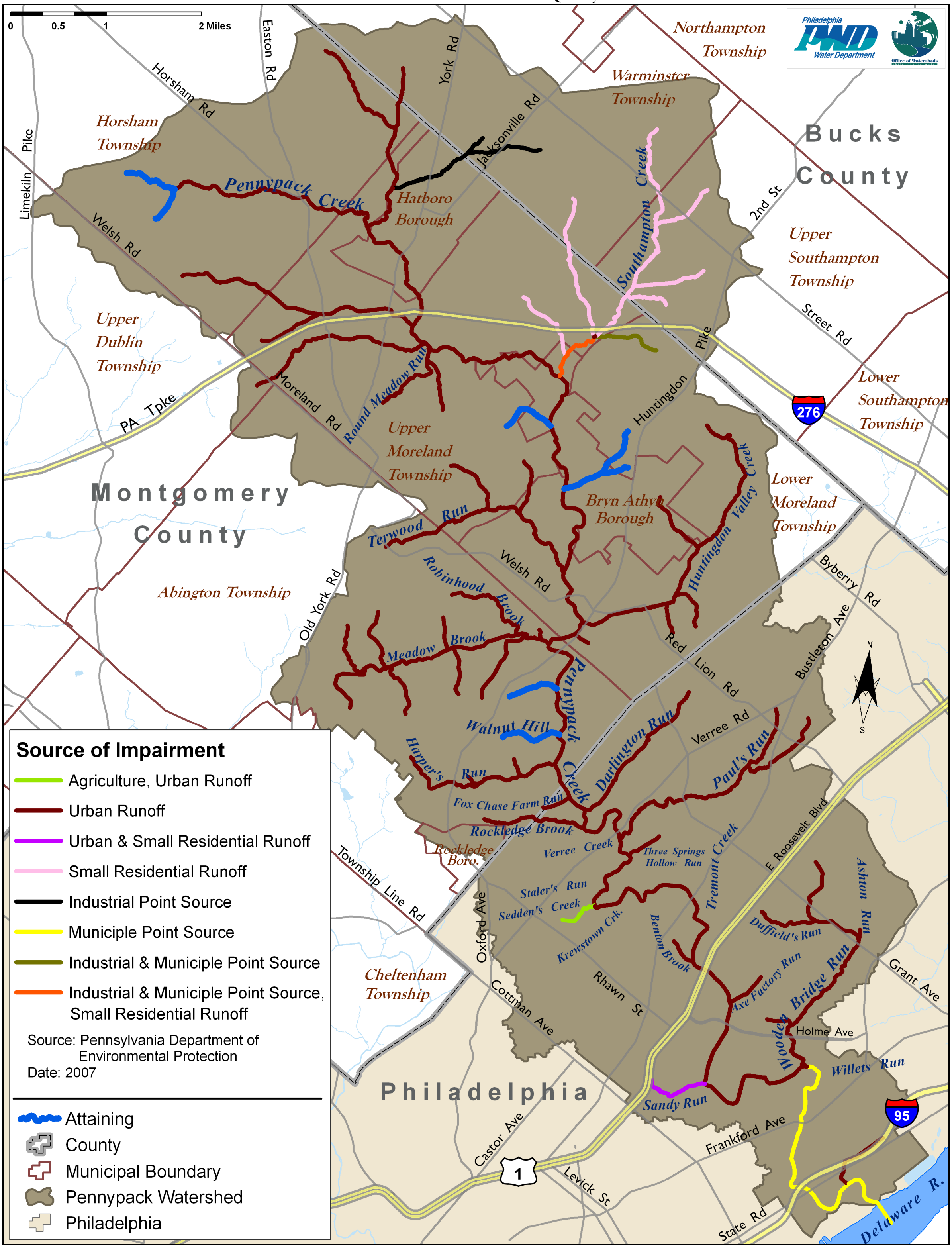


Figure 4.10 Sources of Stream Impairment in Pennypack Creek Watershed

4.4.3 pH

Water quality criteria established by PA DEP regulate pH to a range of 6.0 to 9.0 in Pennsylvania's freshwater streams (25 PA Code § 93). Direct effects of low pH on aquatic ecosystems have been demonstrated in streams affected by acid mine drainage (Butler *et al*., 1973) and by acid rain (Sutcliff and Carrick 1973). Aquatic biota may also be indirectly affected by pH due to its influences on other water quality parameters, such as ammonia. As pH increases, a greater fraction of ammonia N is present as un-ionized NH_3 (gas). For example, ammonia is approximately ten times as toxic at pH 8 as at pH 7. Extreme pH values may also affect solubility and bioavailability of metals (*e.g.*, Cu, Al), which have individually regulated criteria established by PA DEP.

pH fluctuations generally occur most often at highly productive sites with abundant periphytic algae (Figure 4.11), 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 4.12). Moderate diurnal fluctuations in pH were observed at most sites along with DO fluctuations, yet pH violations were very rare, occurring on 4 (maximum) and 1 (minimum) of 804 total days monitored. Algal densities and stream metabolism effects on stream pH are discussed further in section 4.5.2 (Relation of Algal Activity to stream pH).

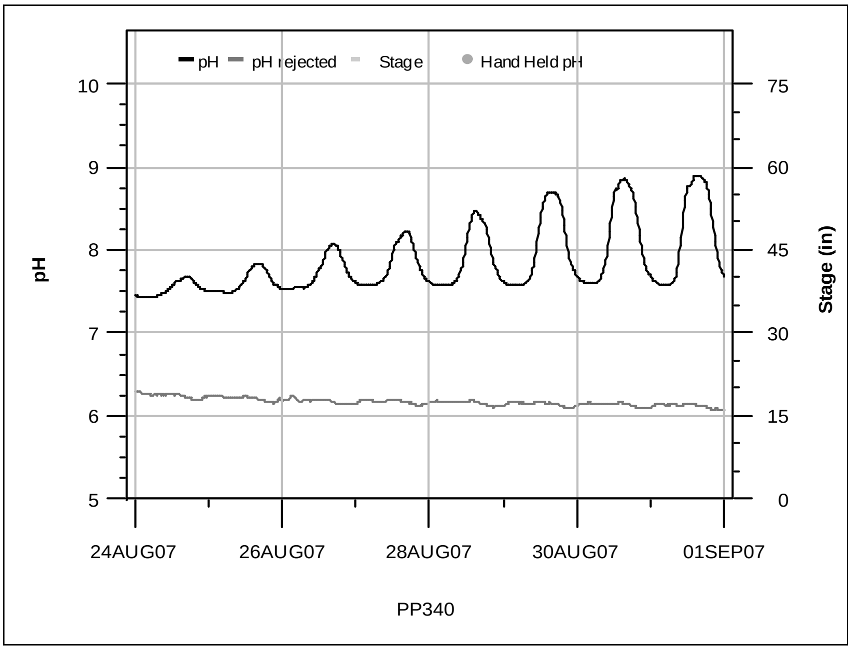


Figure 4.11 pH Fluctuations at Site PP340 8/24/2007-9/1/2007

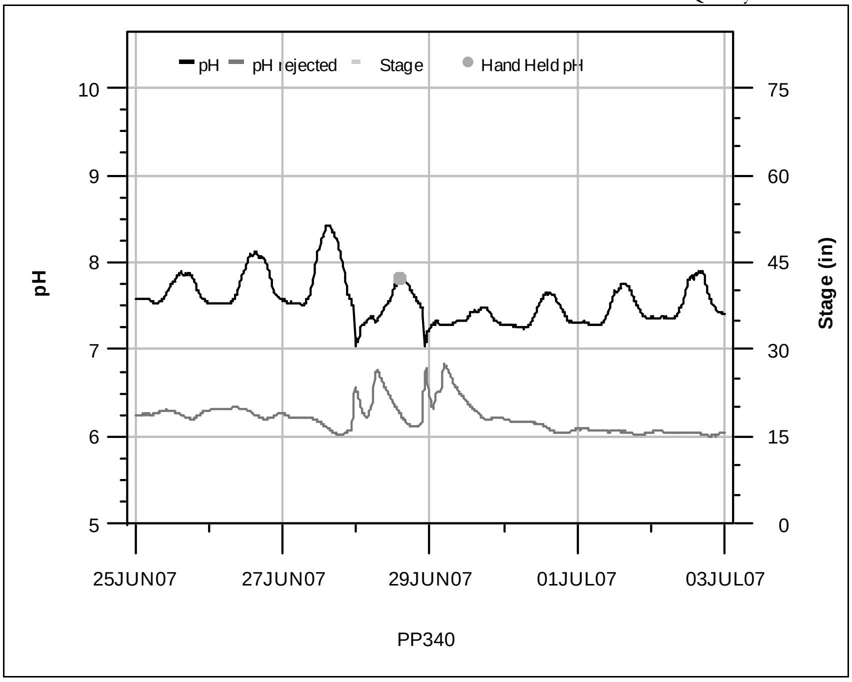


Figure 4.12 Dampening of pH Fluctuations at Site PP340 Following a Wet Weather Event on 6/28/07

Pennypack 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 PCWIMP 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 nuisance algal blooms 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 AND *E. COLI* BACTERIA

4.4.4.1 INTRODUCTION

Fecal coliform and *E. coli* bacteria concentrations are positively correlated with point and non-point contamination of water resources by human and animal waste and are used as indicators of poor water quality. PA DEP has established a maximum limit of 200 colony forming units, or “CFU,” per 100mL sample during the period 1May - 30Sept, the “swimming season” and a less stringent limit of 2000 CFU/100mL for all other times. It should be noted that state criteria are based on the geometric mean of a minimum of five consecutive samples, each sample collected on different days during a 30-day period (25 PA Code § 93.7). As bacterial concentrations can be significantly affected by rain events and otherwise may exhibit high variability, individual samples are not as reliable as replicate or multiple samples taken over a short period.

PWD has expended considerable resources toward documenting concentrations of fecal coliform bacteria and *E. coli* in the Philadelphia regional watersheds. The sheer amount of data collected allows for more comprehensive analysis 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 10% increase in flow and a minimum rainfall of 0.05 inches in a 24 hour period (*e.g.*, assuming a baseflow of 100 CFS, a flow of 110 CFS and at least 0.05 inches of rainfall is considered wet weather).

4.4.4.1.1 DRY WEATHER FECAL COLIFORM BACTERIA (TARGET A)

The geometric mean of 105 fecal coliform bacteria concentration samples collected from Pennypack Watershed, including tributaries, in dry weather during the non-swimming season from 2001-2008 did not exceed 2000 CFU/100mL (Table 4.13). In fact, no individual samples had greater than 2000 CFU/100mL. Conversely, dry weather geometric mean fecal coliform concentration exceeded water quality criteria of 200 CFU/100mL during the swimming season at 11 of 14 sites (Table 4.15). It should be noted that sites which were sampled during wet weather have pre-storm dry weather grab samples and thus more samples in total.

A decrease in dry weather fecal coliform concentrations can be seen in both swimming and non-swimming season when data from 2007-2008 is compared to historical data from 1970-1998 (Table 4.12). 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 ($F_{0.05(2)144,247}$= 233.5, p<0.001 and $F_{0.05(2)198,193}$=115.9, p<0.001, respectively). Post-hoc analysis of (ANOVA) results indicate that significant decreases in fecal coliform concentrations have occurred between the period from 1970-1998 and 2007-2008 during both the swimming (p<0.001) and non-swimming (p<0.001) seasons.

Table 4.12 Historic (1970-1998) Fecal Coliform Concentration (CFU/100mL) Dry Weather Non-swimming Season (1 Oct. - 30 Apr.)

Site	Valid N	Mean	Geo. Mean	Std. Dev.	Median	Minimum	Maximum
PP340	31	494.5	271	738.1	280	35	3200
PP970	33	730.9	410.9	826.7	460	60	3000
PPW010	29	26833.9	1960.1	96367.4	800	40	520000
All Sites	93	8791.8	582.2	54551.9	400	35	520000

Table 4.13 Modern (2001-2008) Fecal Coliform Concentration (CFU/100mL) Dry Weather Non-swimming Season (1 Oct. - 30 Apr.)

Site	Valid N	Mean	Geo. Mean	Std. Dev.	Median	Minimum	Maximum
PP180	8	74.8	33.9	93.4	40	9	280
PP340	10	135	120.9	1657	135	10	510
PP690	8	41.1	24.3	43	15	9	110
PP970	8	100.8	55	144.8	47.5	10	450
PP985	4	122.5	118.6	38.6	105	100	180
PP990	3	116.7	52.5	151.4	50	10	290
PP1150	8	71.9	37.9	79.4	43	9	210
PP1380	8	48.9	32.8	41.4	40	9	120
PP1680	10	164.7	103.1	121.7	149.5	10	320
PP1850	6	147	100	130	100	27	350
PP2020	8	52.8	25.4	79.5	20.5	9	240
PPW010	8	257.1	94.8	287.9	165	9	820
PPM070	8	17	13.7	14.6	10	9	50
PPHU070	8	50	34.3	41.9	33.5	10	120
All Sites	105	105.1	48.3	136.1	50	9	820

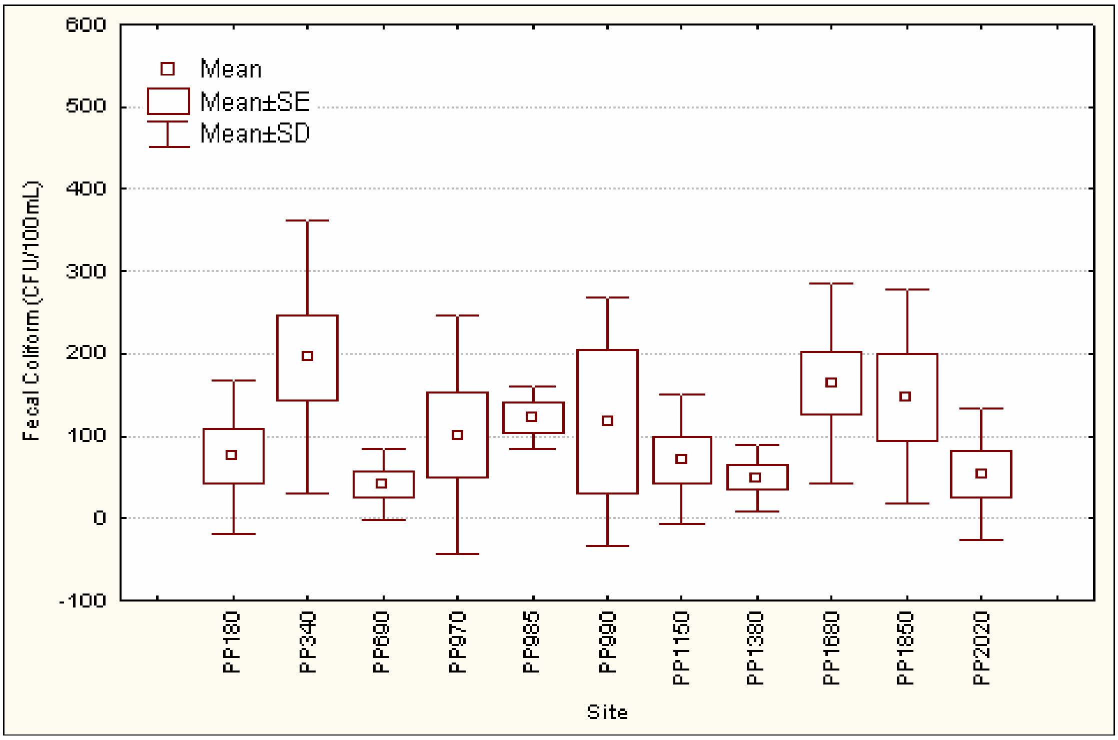


Figure 4.13 Dry Weather Fecal Coliform Concentrations During Non-swimming Season at Mainstem Pennypack Creek Sites

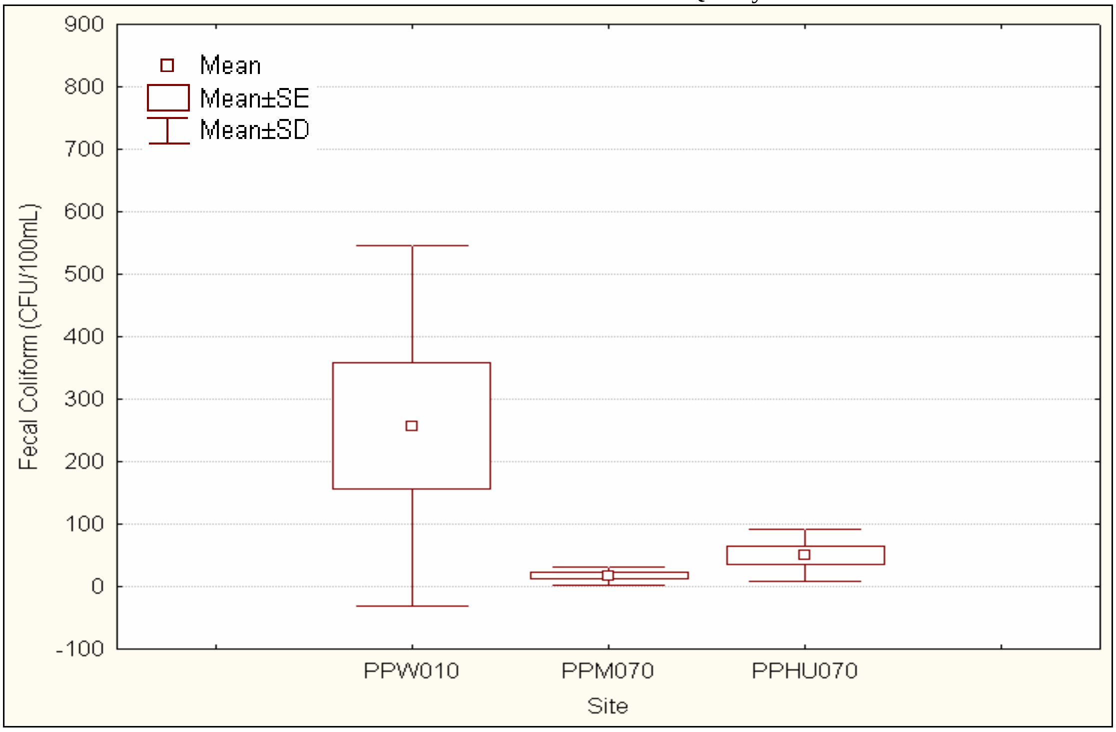


Figure 4.14 Dry Weather Fecal Coliform Concentrations During Non-swimming Season at Pennypack Creek Tributary Sites

Table 4.14 Historic (1970-1998) Fecal Coliform Concentration (CFU/100mL) Dry Weather Swimming Season (1 May - 30 Sept.)

Site	Valid N	Mean	Geo. Mean	Std. Dev.	Median	Minimum	Maximum
PP340	18	1120	900.4	770.4	840	300	2800
PP970	18	2141.7	1530.2	2069.5	1550	400	8400
PPW010	15	119446.7	14292.7	206936.7	11000	700	640000
All Sites	51	36282.6	2448.2	122195.1	1550	300	640000

Table 4.15 Modern (2001-2008) Fecal Coliform Concentration (CFU/100mL) Dry Weather Swimming Season (1 May - 30 Sept.)

Site	Valid N	Mean	Geo. Mean	Std. Dev.	Median	Minimum	Maximum
PP180	9	186.8	149.9	96.1	200	18	340
PP340	11	336.1	262.6	230	240	70	700
PP690	9	125.7	93.9	94.7	100	11	350
PP970	9	1016.8	746.6	7948	800	164	2700
PP985	13	331.3	295.6	166.6	300	100	727
PP990	19	451.6	406.8	264.9	400	190	1400
PP1150	9	330	297.6	145	300	100	540
PP1380	9	157.2	147.3	57.9	150	80	240
PP1680	11	401.8	378.7	145.5	380	210	700
PP1850	7	834.4	575.1	750.6	700	100	2400
PP2020	9	962.1	313.9	2085.3	300	91	6500
PPW010	9	506.9	368.5	335.2	390	36	1036
PPM070	9	409.6	293.5	311.7	300	64	870
PPHU070	9	360.6	301.2	170.8	400	55	550
All Sites	142	446.1	296.6	636	310	11	6500

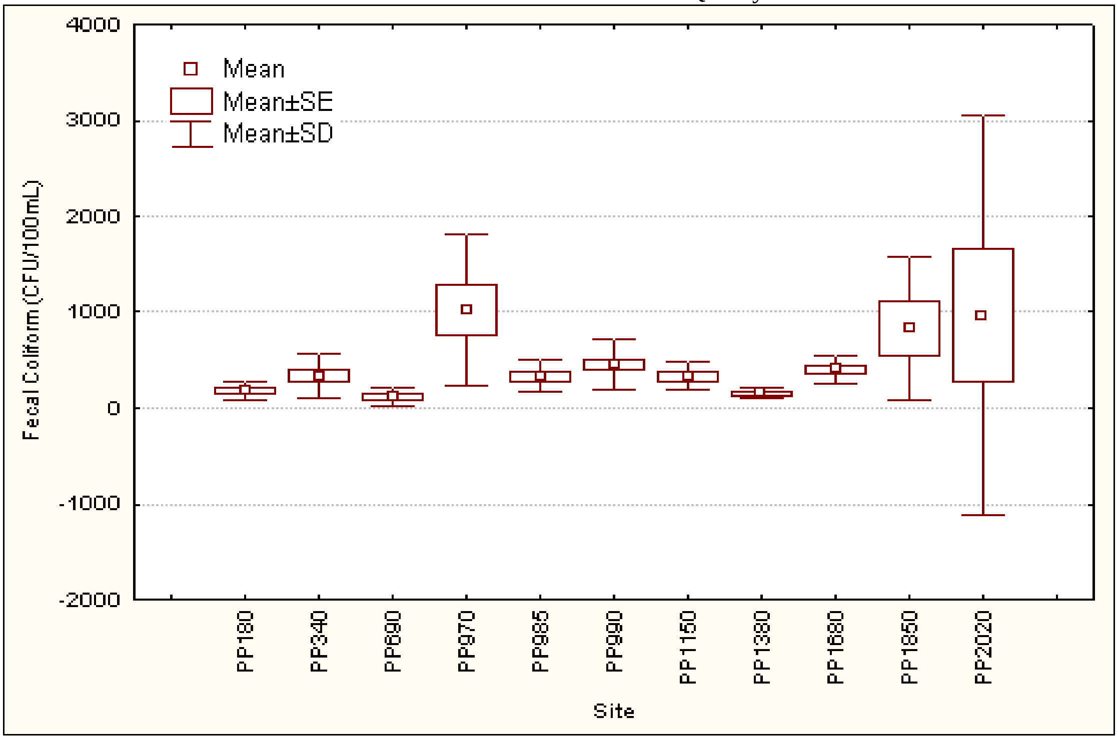


Figure 4.15 Dry Weather Fecal Coliform Concentrations During Swimming Season at Mainstem Pennypack Creek Sites

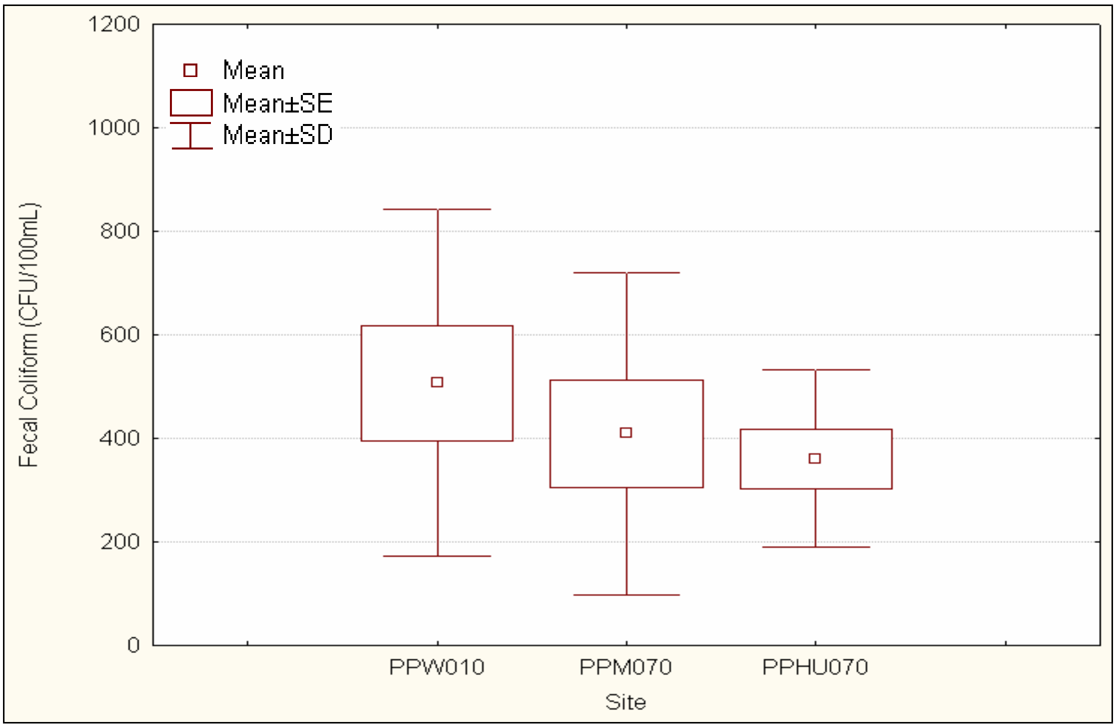


Figure 4.16 Dry Weather Fecal Coliform Concentration During Swimming Season at Pennypack Creek Tributary Sites

Table 4.16 Historic (1970-1998) and 2007-2008 Fecal Coliform Concentrations (CFU/100mL) During Dry Weather (Swimming and Non-swimming Seasons)

Sampling Period	Season	Valid N	Mean	Geometric Mean	Median	Minimum	Maximum	Std. Dev.
2007-2008	Swimming	78	264	385	5500	11	2400	351.7
2007-2008	Non Swimming	55	63.3	28.9	18	9	390	91.9
1970-1998	Swimming	51	36282.6	2448.2	1550	300	640000	122195
1970-1998	Non Swimming	93	8791.8	582.2	400	35	520000	54552

Spatial and temporal variability of fecal coliform concentrations was also compared by performing a two-way analysis of variance (ANOVA). Location (*i.e.*, Montgomery County and Philadelphia County) and season (*i.e.*, swimming vs. non-swimming) served as the categorical predictors and fecal coliform concentration was considered the dependent variable. Collectively, there was no significant difference in mean fecal coliform bacteria concentrations among upstream and downstream sites ($F_{0.05(1),1,139}$=3.50, p>0.05), season ($F_{0.05(1),1,139}$=0.06, p>0.05) or interactions among season and location ($F_{0.05(1),1,139}$=0.05, p>0.05). Comparison of historic data to modern data show large reductions in fecal coliform concentration during both the swimming and non-swimming season (Table 4.16); however there was a more than two-fold increase in fecal coliform concentration at PP340 during swimming season (Table 4.17).

Dry weather fecal coliform concentration in Pennypack Creek during swimming and non-swimming periods was significantly lower than wet weather concentration. 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 (1970-1998) and Modern (2002-2008) Dry Weather Fecal Coliform Concentrations by Site

Site	Season	Valid N	Historic Mean	Valid N	Modern Mean
PP340	S	85	65.76	51	154.17*
PP340	NS	103	57.02	46	91.41
PP970	S	84	96.83*	23	44.98
PP970	NS	103	78.7***	19	18.49
PPW010	S	77	443.61*	23	44.36
PPW010	NS	87	345.14***	18	15.28

*p<0.05 **p<0.001 ***p<0.0001

4.4.4.1.2 WET WEATHER FECAL COLIFORM BACTERIA (TARGET C)

Wet weather fecal coliform concentration of 188 samples collected during the swimming season (*i.e.*, 5/1 - 9/30) and 105 samples collected during the non-swimming season were estimated. Geometric mean fecal coliform concentration of all samples collected in wet weather during the swimming season exceeded the 200 CFU/100mL water quality criterions (Table 4.19, Figure 4.17). All sites, including tributaries (*i.e.*, PPM070 and PPHU070), had geometric mean fecal coliform concentrations between 4 (PPM070) and 34 (PP340) times the state criterion during the swimming season. Student t-tests further support the conclusion that fecal coliform concentrations are considerably high during the swimming season as there was a significant difference between swimming and non-swimming mean fecal coliform concentrations in Pennypack Creek($T_{0.05,(1),287,251}$ = 7.021, p=0.00).

Table 4.18 Historic (1970-1998) Fecal Coliform Concentration (CFU/100mL) Wet Weather, Swimming Season (1 May - 30 Sept.)

Site	Valid N	Mean	Geometric Mean	Std. Dev.	Median	Minimum	Maximum
PP340	34	5259.4	1823.9	8703.6	2000	30	40000
PP970	33	4183.6	1772.6	6865.4	2160	100	30000
PPW010	29	161201.7	17445.3	449496.5	17100	170	2410000
All Sites	96	51997.2	3572.7	254576.7	2400	30	2410000

Table 4.19 Modern (2001-2008) Fecal Coliform Concentration (CFU/100mL) Wet Weather, Swimming Season (1 May - 30 Sept.)

Site	Valid N	Mean	Geometric Mean	Std. Dev.	Median	Minimum	Maximum
PP180	6	8318.2	2582.5	7052.1	7450	9	18000
PP340	30	12468	6836.6	10190.2	12000	100	36000
PP690	6	7429.8	2154.9	10224.2	3600	109	27000
PP970	6	5905	3327	6462.9	3700	430	18000
PP985	31	6961.9	2609.9	14630	2000	310	81000
PP990	15	8135.3	2169.3	16288.2	2300	370	61000
PP1150	6	5760	1035.1	9323.6	500	100	23000
PP1380	6	5631.7	991	9287.7	415	100	23000
PP1680	30	11188.9	6694.5	9020.5	9050	173	31000
PP1850	29	10625.4	5091.5	12503.4	3800	600	42000
PP2020	6	5997.5	1324.3	11316.1	1800	45	29000
PPW010	6	10503	4343.7	11213.8	4950	118	28000
PPM070	6	4614.8	866.4	8139.4	1165	9	21000
PPHU070	6	8433.3	5743.3	7877.2	4300	2000	19000
All Sites	189	9160.1	3580.1	11473.8	4100	9	81000

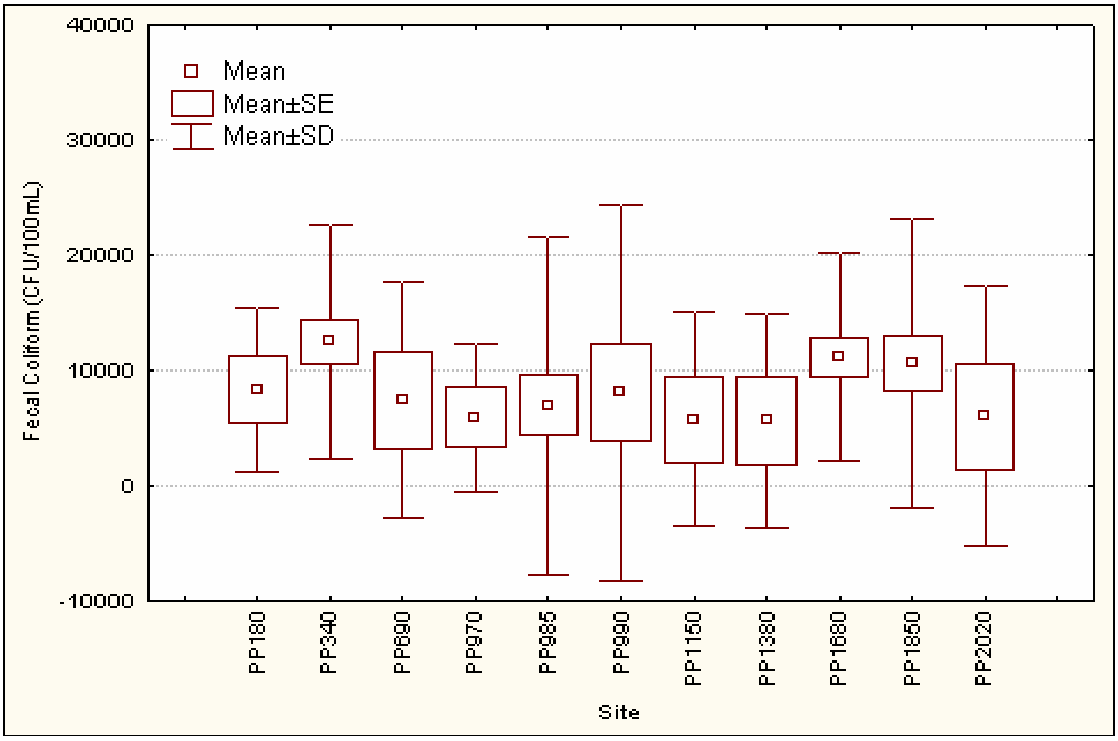


Figure 4.17 Wet Weather Fecal Coliform Concentration During Swimming Season at Mainstem Pennypack Creek Sites

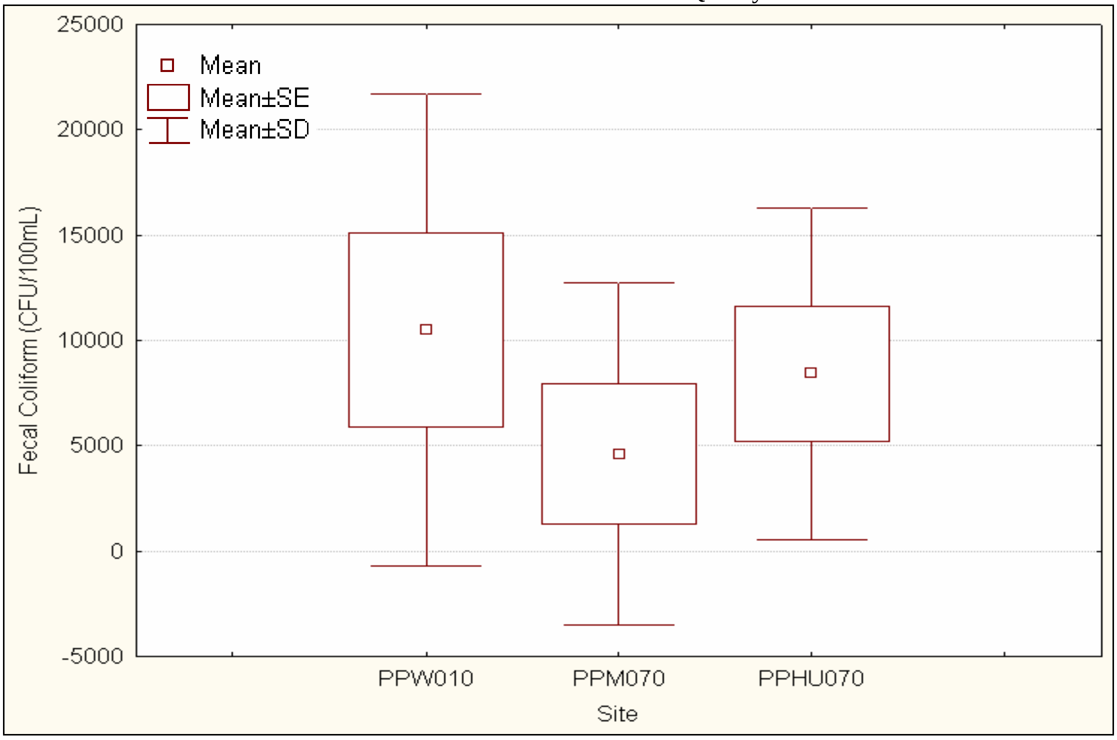


Figure 4.18 Wet Weather Fecal Coliform Concentration During Swimming Season at Pennypack Creek Tributary Sites

Table 4.20 Modern (2001-2008) Fecal Coliform Concentration (CFU/100mL) Wet Weather, Non-swimming Season (1 Oct. - 30 Apr.).

Site	Valid N	Mean	Geometric Mean	Std. Dev.	Median	Minimum	Maximum
PP180	2	39.5	25.1	43.1	39.5	9	70
PP340	25	8882.5	3530.2	11433.5	3100	82	37000
PP690	2	50	30	56.6	50	10	90
PP970	2	49	37.9	43.8	49	18	80
PP985	12	5929.2	2261.6	6923.2	3150	10	20000
PP990	3	686.7	669.8	191.4	630	530	900
PP1150	2	29.5	21.21	29.99	29.5	9	50
PP1380	2	44	35.5	36.8	44	18	70
PP1680	24	15290.4	1780.7	40883.1	1091	36	200000
PP1850	25	38705.4	3359.6	73121.4	1454	190	200000
PP2020	2	14	13.4	5.7	14	10	18
PPW010	1	118	118		118	118	118
PPM070	2	14	13.4	5.7	14	10	18
PPHU070	2	14	13.4	5.7	14	10	18
All Sites	106	15382.1	1218.6	42628.9	1318	9	200000

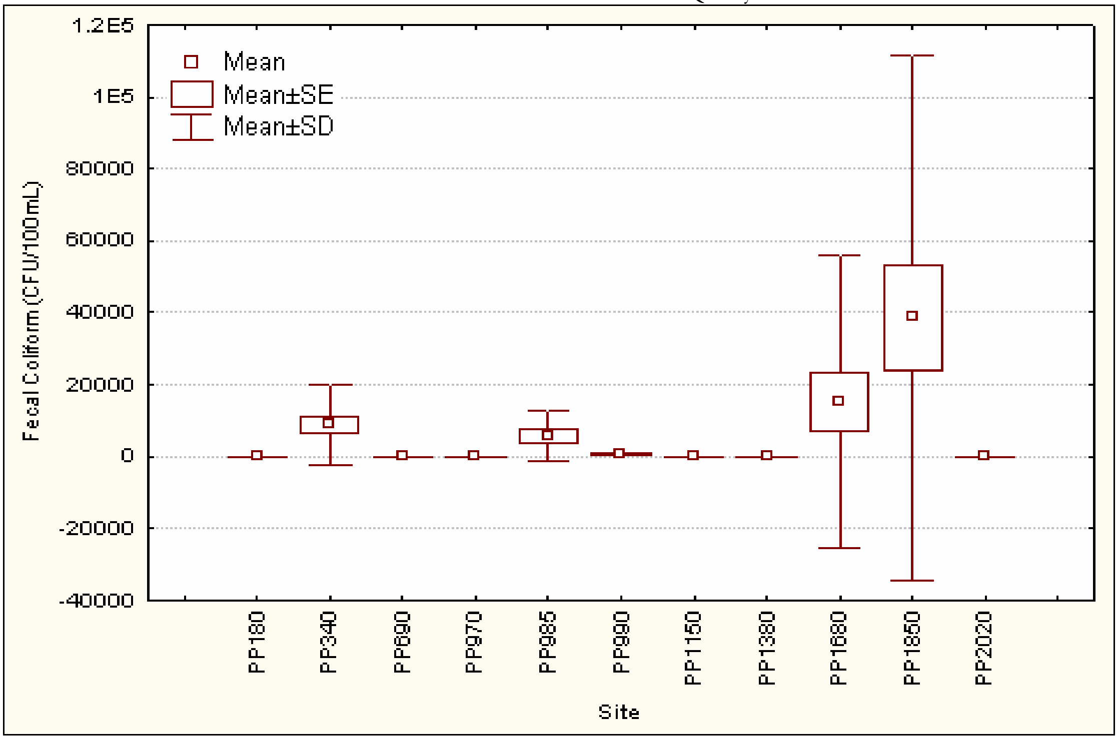


Figure 4.19 Wet Weather Fecal Coliform Concentration During Non-swimming Season at Mainstem Pennypack Creek Sites

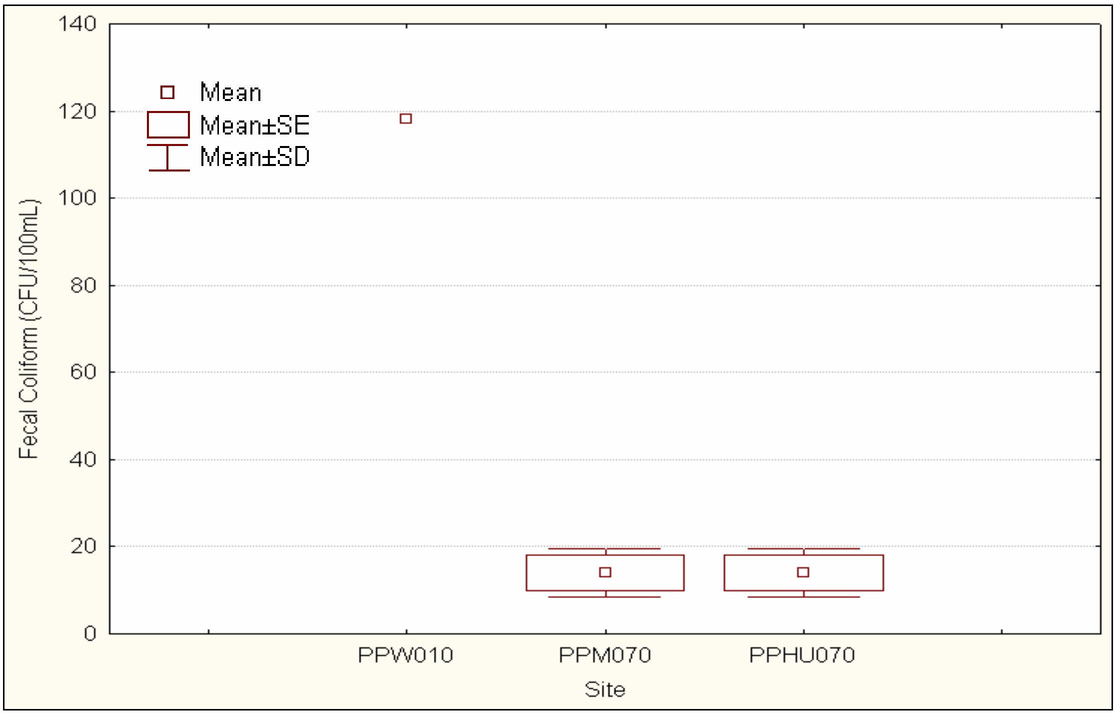


Figure 4.20 Wet Weather Fecal Coliform Concentration During Non-swimming Season at Pennypack Creek Tributary Sites

Similarly, geometric mean fecal coliform concentrations during the non-swimming season exceeded 2,000 CFU/100mL at sites PP340, PP985, PP1680 and PP1850 (Table 4.20). These results reflect the lack of adequate samples taken at other sites on the mainstem and should be considered with discretion. At sites with limited samples (n =1-3), geometric mean fecal coliform concentrations were below the non-swimming season standard; however, the true distributions of fecal coliform concentration at these sites can not be accurately estimated with such limited sampling size.

The highest fecal coliform concentrations were observed in the upstream reaches PP1680 and PP1850 (Figure 4.20). At this time, there is no definitive explanation for the elevated concentrations of fecal coliform in the upstream reaches in wet conditions during the non-swimming period. Regardless, fecal coliform concentrations at all locations with sufficient samples (n>5) were well above the state criterion of 2000 CFU/100mL, and therefore, the problem should be addressed as a watershed-wide issue and not as a targeted study. Future wet weather events collected during the 2009 monitoring season will elucidate the spatial and temporal trends and will be posted as an addendum to the current report. As previously stated, plans to initiate a bacteria source tracking program (BST) will also be informative in distinguishing the origin of pathogens during wet weather events.

Spatial variability (*i.e.*, upstream vs. downstream) of fecal coliform concentration was compared by performing a one-way analysis of variance (ANOVA) on data collected from 2002 through 2008. Results indicate that the mean concentration of fecal coliform during wet weather was not significantly different between upstream and downstream mainstem sites during neither the swimming season ($F_{0.05,(1),89,167} = 2.175$, $p>0.05$) nor the non-swimming season ($F_{0.05,(1),59,151} = 0.0$, $p>0.05$). There was however, a significant difference in fecal coliform concentrations between sites in both the swimming season ($F_{0.05,(13),210} = 7.25$, $p=0.00$) and non-swimming season ($F_{0.05,(13),256} = 2.112$, $p=0.014$). During the non-swimming season, post-hoc tests confirm that sites PP340, PP1680 and PP1850 had significantly higher mean fecal coliform concentrations than PP1150 and PP2020. In addition, site PP1850 had a significantly greater mean fecal coliform concentration than sites: PP180, PP690 and PP1380. There were no statistically significant differences found between the mean fecal coliform concentrations of the three tributary sites assessed (PPW010, PPHU070 and PPM070). Post-hoc tests revealed that sites PP1680 and PP1850 had significantly higher mean fecal coliform concentrations during the swimming season than PP970, PP1150 and PP1380. Furthermore, site PP1680 had a higher mean fecal coliform concentration than PP985, PP990 and PP2020. Tributary site PPHU070 had a significantly higher fecal coliform concentration than PPM070, but not PPW010.

In addition to analysis of the 2007-2008 sampling period, a comparison of historical data collected by USGS and PADEP during 1970-1998 was performed (Table 4.22). However, it must be noted that the sampling program conducted by PWD specifically targeted wet weather events in their entirety. Sampling methods and equipment (*i.e.*, automated samplers) were more conducive to characterize fecal coliform concentrations at all points along the hydrograph and were more suitable to collect periods of peak fecal coliform concentrations.

Table 4.21 Historic (1970-1998) and 2007-2008 Fecal Coliform Concentrations (CFU/100mL) During Wet Weather (Swimming and Non-swimming Seasons)

Sampling Period	Season	Valid N	Mean	Geometric Mean	Median	Minimum	Maximum	Std. Dev.
2007-2008	Swimming	136	8343.2	3604.5	4250	9	42000	9240.5
2007-2008	Non Swimming	90	18066.2	1893.4	1800	9	200000	45778
1970-1998	Swimming	96	51997	3572.7	2400	30	2410000	254576.7
1970-1998	Non Swimming	144	22870	1558.5	1300	30	593000	82847

Student t-tests were used to compare fecal coliform concentrations between the swimming and non-swimming seasons using both the historic and modern datasets. Results show that mean fecal coliform concentrations were significantly higher during the swimming season in both the historic ($T_{0.05(1),98,145}$=2.45, p=0.015) and modern ($T_{0.05(1),189,106}$=4.69,p<0.001) datasets. To further dissect potential temporal trends in mainstem Pennypack Creek, two-way ANOVA was used to compare historic and modern fecal coliform concentrations by season (*i.e.*, swimming versus non-swimming). Results of this analysis indicate that both season ($F_{0.05(1),208,235}$=18.97, p<0.001) and sampling period (*i.e.,* historic and modern) ($F_{0.05(1),171,272}$=11.1, p<0.001) were significant categorical predictors. Tukey HSD pos-hoc test revealed that there was no significant difference between historic non-swimming and modern non-swimming fecal coliform mean concentrations; however, modern swimming mean fecal coliform concentration was significantly greater than that of historic swimming mean concentration (p=0.024).

These results do not specifically imply that fecal coliform loading to Pennypack Creek has been getting worse over time. Considerable reductions were observed at some individual sites over time, and the historic analysis was limited by the number and spatial distribution of sites with historic data. There were only three sites with sufficient data to allow for comparison of historic and modern data. These sites, PPW010, PP340 and PP970 are all within the City of Philadelphia; however, the modern dataset contains sites from both inside and outside of the City. This no doubt introduces the potential for much more variation in the modern data compared to the historic dataset. The higher number of sites in the modern dataset increases the probability that the spatial distribution of sites may introduce autocorrelation effects; furthermore, the lack of a robust distribution of sites in the historic dataset could preclude an accurate estimation of the true mean fecal coliform concentration between 1970 and 1998.

Following the previous analysis, t-tests were used to investigate the relationship between the historic and modern fecal coliform concentrations at the three sites that allowed for valid comparisons (Table 4.22). Site PP340 was the only site in which modern mean fecal coliform concentrations were significantly greater than historic values. Comparatively, PPW010 exhibited the most improvement as fecal coliform concentrations have decreased over time during both seasons.

Table 4.22 Comparison of Historic (1970-1998) and Modern (2002-2008) Wet Weather Mean Fecal Coliform Concentrations by Site

Site	Season	Valid N	Historic Mean	Valid N	Modern Mean
PP340	S	104	117.22	66	309.03***
PP340	NS	119	74.13	65	285.76***
PP970	S	103	125.6	17	89.54
PP970	NS	118	89.33**	16	24.89
PPW010	S	87	714.49*	16	88.89
PPW010	NS	103	378.44*	15	45.19

*p<0.05 **p<0.001 ***p<0.0001

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, thermal preferenda and tolerance values determine, to a large degree, the range of many species' distributions. This effect is especially true of larger vertebrates, such as fish. Thermal water quality criteria for Pennypack Creek Watershed are based on the trout stocking fishery (TSF) designation, and reflect the fact that the watershed is not expected to have appropriate conditions to support self-propagating populations of coldwater fish (*e.g.*, trout species), but can support stocked fish as part of a put-and-take fishery.

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

Stream temperatures in Pennypack Creek Watershed were generally similar across sites with the exception of PP1680 where temperature trends were much different than all other sites. Many violations of daily maximum temperature occurred during the first half of the year, but rarely during late summer at sites PP340, PP985 and PP1850. Daily maximum temperature criteria were exceeded regularly from May through late July 2007 in all sites. Daily mean temperature violations were infrequent at the upstream sites PP1850 and PP1680; however, violations of daily mean temperature occurred regularly at PP985 and PP340 (Appendix D continuous temp plots). This may be partially explained by the fact that upstream sites have narrower channels which increases the probability that the majority of the stream will be shaded by riparian vegetation. In the downstream sites, where the stream channels are wider, streamside riparian vegetation may only be able to shade the portion of the stream closer to the banks, thus the mid-channel portion of the steam receives higher amounts of solar radiation.

Violations of temperature TSF criteria during the summer months usually occurred June through late July. This phenomenon was primarily related to changes in TSF temperature criteria than the actual ambient air temperature. At the beginning of August, the maximum daily temperature criterion increases from 23ºC to 27ºC and then increases again to 30.5 ºC. During the month of August 2007, there were no violations of mean daily temperature and very few instances of max daily temperature violations at all sites. The most severe maximum daily temperature violation occurred at PP1680 on 8/11/07 where max temperature reached 29.03 ºC (standard=27 ºC).

Between August and early November of 2007, all sites except PP1680 had similar temperature regimes, characterized by no violations of daily mean temperature criteria and very few violations of daily maximum criteria. During the month of November 2007, the temporal fluctuation patterns in temperature at these sites were still very similar; however, there was an increased frequency and magnitude of daily maximum temperature violations as well as a few violations of daily mean temperature. Site PP340 was the only site that did not violate daily mean criteria during that month.

Temperature water quality criteria were violated more frequently at site PP1680 compared to the other monitoring sites (Table 4.23). The rate of exceedance was similar with respect to wet and dry weather, at 46.5% for dry weather and 47.5% during wet weather (Table 4.24). From November 2007 through May of 2008, both daily maximum and mean daily temperature criteria were consistently violated at site PP1680. The highest magnitude violations occurred during spring and early winter. In the spring of 2008, maximum daily temperatures reached 22ºC and daily mean temperatures reached as high as 16ºC during first half of April, at which time the maximum temperature criterion is 11ºC. The most severe winter violations occurred from mid-November through early December 2007, as max daily temperatures reached as high as 18ºC and daily mean temperature reached 16ºC compared to the 10ºC standard for that time period. There was also substantial violation of mean daily and daily maximum criteria from mid-October to early November when temperatures as high as 22 ºC were observed, violating the 19 ºC water quality standard for that time period.

Table 4.23 Sonde Temperature Measurements Exceeding Maximum Standards by Site, 2007-2008

Site	No. Obs	Number Exceeded	Percent Exceeded
PP340	14756	2306	15.6
PP985	18922	2418	12.8
PP1680	20504	9638	47.0
PP1850	22597	3301	14.6

Table 4.24 Sonde Temperature Measurements Exceeding Maximum Standards by Site, Categorized as Wet or Dry weather, 2007-2008

Site	DRY			WET		
	No. Obs.	No. Exc.	Percent Exc.	No. Obs.	No. Exc.	Percent Exc.
PP340	8849	1097	12.4	5907	1209	20.47
PP985	10533	948	9.0	8889	1470	17.5
PP1680	10666	4961	46.5	9838	4677	47.5
PP1850	12330	1895	15.4	10267	1406	13.7

As stream temperatures are most strongly related to ambient air temperature (Bartholow 1989), it is recognized that patterns observed in the 2007/2008 dataset are not necessarily representative of other years. Stream temperatures for a given time period exhibit a great deal of inter-annual 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 D Temperature).

Water temperature was, however, consistently higher at site PP1680 than at other sites and potential violations of water quality criteria occurred throughout the year at this site. This observation is probably due to baseflow suppression (*i.e.*, reduced groundwater recharge) causing minimal dilution of municipally treated wastes at this location, but without data from a monitoring site upstream of the point source discharge it is impossible to determine how much of the temperature increase is attributable to the point source.

The temperature anomaly at PP1680 may be explained by other factors such as lack of adequate riparian vegetation upstream of the site, as groundwater input and shading are important thermal regulation mechanisms in smaller order streams such as Pennypack Creek at PP1680. Site PP1680 is directly downstream of the confluence with Round Meadow Run as well as two larger, unnamed tributaries with confluences approximately a half-mile upstream of the site. The upstream tributaries drain subwatersheds with heavy commercial and industrial manufacturing land uses containing a high density of impervious cover. Similarly, Round Meadow Run has commercial and manufacturing land uses, but the primary landuse is single family residential housing (Figure 2.3). The high density of imperviousness and the lack of riparian buffers along most of the length of these three tributaries' streambanks may reduce the flow of groundwater to the stream's hyphorheic zone and also reduce the amount of shading offered by streamside vegetation.

According to 25 PA Code §93.7, "heated wastes" can neither cause stream temperature to exceed the maximum temperature criterion for a given time period, nor can they result in an increase of 2ºF (~1.1ºC) over one hour. Continuous water quality monitoring results suggest that temperatures in Pennypack Creek Watershed frequently exceeded maximum (Table 4.23) and rate-of-change water quality criteria (Appendix D Temperature). However, increases of 2ºF over a one hour period have been observed to be common throughout southeast PA due to natural temperature fluctuations, especially in low gradient streams, reservoirs and ponds.

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

Flow modifications and channel alterations (*i.e.*, incision) have probably reduced the influence of groundwater on baseflow water temperatures in Pennypack Creek Watershed. Dam construction and riparian buffer removal have also probably resulted in enhanced solar heating of stream water; however, temperature did not appreciably increase in a downstream direction within the city of Philadelphia despite numerous dam impoundments. One explanation for this could be the nearly contiguous mature forest canopy buffer along both streambanks in Fairmount Park. Effects of temperature on fish populations are also discussed briefly in section 6.3.2 Fish Habitat Indices.

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 generally sediment transport is related to streamflow and sediment particle size. Stable streams are generally capable of maintaining equilibrium between sediment supply and transport, while unstable streams may be scoured of smaller substrate particles or accumulate fine sediments. The latter effect is particularly damaging to aquatic habitats. PA DEP has identified the cause of impairment in Pennypack Creek to be “siltation” in 21 stream segments. Six of these segments are mainstem Pennypack and 15 segments are tributaries. Most of the segments have “urban runoff/storm sewers” listed as the source of siltation. Three exceptions list habitat modification, municipal and other non-point sources and surface mining as sources.

Water sampling techniques that are adequate to characterize most water quality parameters (*e.g.*, grab samples, automated sampling) are not generally appropriate for evaluating sediment transport in fluvial systems (Edwards and Glysson 1988, Ongley 1996, Ferguson 1986); errors related to sampling technique should preclude computation of sediment transport during severe storm events that mobilize large streambed particles. Traditional TSS analytical methods have been found to underestimate suspended sediment concentrations, especially as the proportion of sand in the sample increases. Due to 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.

TSS and turbidity concentrations were measured from surface water grab samples collected prior to wet weather events and from samples collected by automated samplers (Teledyne Isco Inc.) during wet weather events. TSS concentration was significantly greater in wet weather than in dry weather (Mann-Whitney test $U_{0.05(2)124,305} = 5570$, $p<0.001$).

A total of 607 TSS samples were collected from 4 sites along mainstem Pennypack Creek between 5/02/02 and 5/18/08 (PP340, PP985, PP1680 and PP1850), with 284 during dry weather and 323 during wet weather (Figure 4.21). Over this period, TSS exceeded the 25 mg/L reference value in only 7.04% of the dry weather samples compared to 31.6% of the wet weather samples. TSS concentration in mainstem Pennypack Creek was found to be significantly positively correlated to turbidity ($r_{(508)}=0.92$, $p<0.00$). The minimum and maximum TSS concentrations observed were 1.0 and 606 mg/L, respectively. Minimum and maximum turbidity values observed were 0.412 and 634

NTU, respectively. TSS and turbidity were more closely correlated in mainstem samples than in the tributaries, however, the latter correlation was still significant ($r_{(71)}$=0.836, p<0.00). Due to their relatively smaller drainage areas, tributary sites must experience generally more concentrated local rainfall in order to result in greater flow magnitude. The more ephemeral nature of these events constrained the range of flows in the data set. Minimum and maximum TSS concentrations of samples collected from tributary sites were smaller than those observed in mainstem sites, at 1.0 and 198.5 mg/L, respectively (Figure 4.22). The minimum and maximum turbidity concentrations of samples collected from tributary sites were 0.314 and 29.7 NTU respectively. Strong correlations between TSS and turbidity support the future use of turbidity as an indicator of TSS concentration with the caveat that extrapolation is less reliable outside of the measured range.

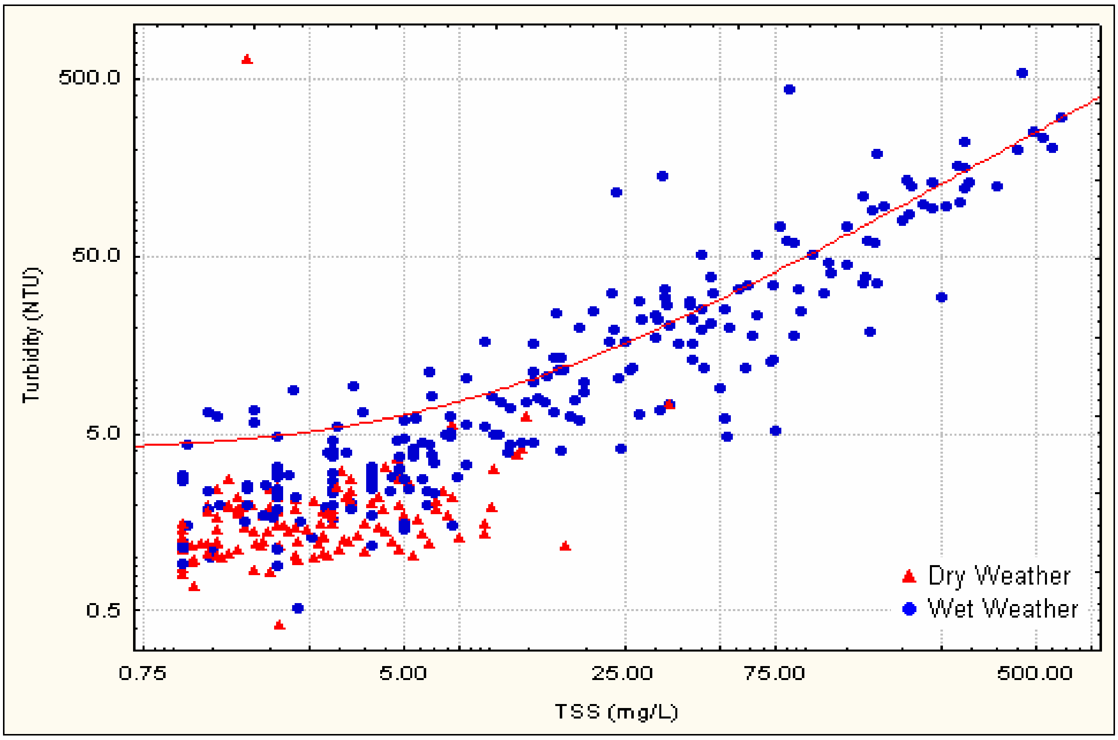


Figure 4.21 Scatterplot of paired TSS and Turbidity Samples Collected from 12 Mainstem Sites in Pennypack Creek Watershed

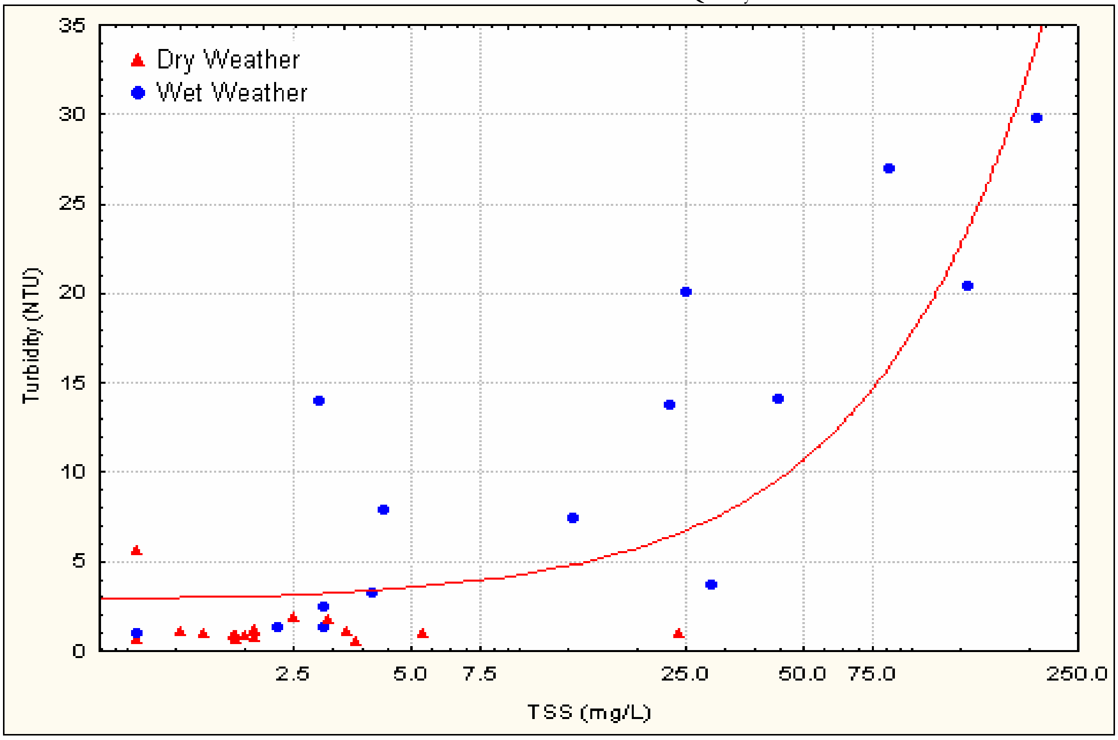


Figure 4.22 Scatterplot of paired TSS and Turbidity Samples Collected from 3 Tributary Sites in Pennypack Creek Watershed

Using the relationship between TSS and turbidity in Pennypack Creek described by the equation: TSS= 0.43518*[Turbidity] + 1.5573 (r^2 = 0.8478; r = 0.9208, p = 00.00), TSS concentration was extrapolated from continuous sonde turbidity data. The extrapolated data was plotted against corresponding streamflow data collected by USGS. Data was collected in 15 minute increments producing a large data set. Only a subset of this data was plotted and reported data are from sites PP340 and PP985 which are both in close proximity to USGS gauges. Log_{10}-transformed TSS and streamflow data were found to be significantly positively correlated at site PP340 ($r_{(9346)}$= 0.842, p<0.00); however, at site PP985 there was not a strong relationship($r_{(6183)}$= 0.249, p<0.00) between TSS and discharge. Maximum TSS concentration, turbidity and discharge recorded at PP340 were 478.9 mg/L, 1097 NTU and 1420 cfs, respectively, and at PP985 the parameter values were, 2289.3 mg/L, 1397.1 NTU and 1354.9 cfs, respectively.

Though a significant correlation exists, it is not always the case that peak TSS and peak streamflow will occur simultaneously. Plots of TSS vs. streamflow often exhibit hysteretic loops (*i.e.*, tracing the samples synchronously, one may find that the data points do not follow a straight line, but rather resemble a clockwise or counterclockwise loop). Hysteretic loops occur because the timing of peak TSS is dependant on its source and antecedent wet weather event conditions. TSS that is predominantly channel supplied will generally peak prior to peak streamflow, creating a clockwise (positive) hysteretic loop. Alternatively, there will be a lag between peak discharge and peak TSS if suspended sediment originates from runoff and streambank erosion (Van Sickle and Breschta 1983, Klein 1984). Graphically, this phenomenon called “negative hysteresis,” would be represented by a counter-clockwise hysteretic loop. Two storms occurring in succession may produce very dissimilar discharge-suspended sediment relationships as the first storm can leave the stream in a variety of potential states, particularly with regard to in-channel sediment availability. Preliminary analyses of TSS-discharge plots indicate that negative hysteresis may be the predominant sediment-discharge relationship in Pennypack Creek.

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.

PA DEP has not established numeric water quality criteria for turbidity, though General Water Quality Criteria (25 PA Code §93.6) specifically prohibit substances attributable to any point or non-point source in concentrations inimical or harmful to aquatic life. Discharge of substances that produce turbidity are also specifically prohibited. As turbidity may vary considerably from stream to stream, the PCWIMP uses a reference value of 8.05 NTU to define excess turbidity, based on an analysis of turbidity data from reference reaches in EPA Region IX, subregion 64 (US EPA 2000).

Turbidity was determined to be a problem in all sites in Pennypack creek Watershed during wet weather based on continuous Sonde data. The worst sites were PP340 and PP985, where turbidity exceeded water quality standards during wet weather 36.86% and 35.21% percent of the time respectively. At sites PP1680 and PP1850, continuous sampling data during wet weather exceeded water quality standards at a considerably lower proportion compared to PP340 and PP985. PP1680 exceeded the turbidity standard in 20.83% of wet weather continuous samples compared to 25.48% exceedance for PP1850. Turbidity measured at the two USGS gauges on Pennypack Creek followed similar trends in exceedance frequency. During dry weather the Rhawn St. gauge (01467048) exceeded the 25 mg/L turbidity reference value in 7.7% of dry weather samples followed by the Pine Rd. gauge (01467042) at 6.23%. In wet weather, the Rhawn St. and Pine Rd. gauges exceeded the standard in 48.02% and 33.56% of the wet weather samples respectively.

Discrete data were similar, as turbidity was determined to be a problem during wet weather and a potential problem during dry weather in the watershed overall. During wet weather, 129 out of 322 total samples were above the reference value. While there were differences in the proportion of samples above the reference value among sites, turbidity was determined to be a problem or a potential problem during both dry and wet weather in all sites with a sufficient number of discrete samples.

4.4.6.3 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. Though some formulations may increase levels of Chloride, PA DEP water quality criteria for Chloride (maximum 250mg/L) are intended to protect water supplies, and aquatic life effects have not been reliably demonstrated at moderate levels typically experienced in streams.

4.4.6.4 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 Pennypack Creek Watershed is naturally moderately hard to hard, so streams usually have greater hardness in dry weather than in wet weather. Domestic drinking water supplies may also be somewhat naturally hard, with pH and sulfate levels that allow municipal water suppliers in Montgomery County to forego addition of corrosion inhibitors. Elevated dissolved metals (*e.g.*, lead and copper) concentrations in municipal wastewater effluents may be primarily due to corrosion in potable water distribution systems.

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 relatively abundant in the soils and surface geology of Pennypack 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 563 of 571 samples collected from Pennypack Creek Watershed. Manganese was slightly less abundant but detectable in 561 of 566 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 ($r^2 = 0.7946$; $r = 0.8914$, $p < 0.001$) during dry weather. Furthermore, blooms of iron fixing bacteria which are indicators for the presence of oxidized Fe, were observed in some areas of the watershed during dry weather.

Mn criteria were never exceeded in 307 samples, but 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 22.1% of the samples collected as opposed to only 7.7% 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 Pennypack 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.

4.4.7 TOXIC METALS

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

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 which is applied to non-toxic parameters. Non-parametric statistical procedures and datasets containing less 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 PA, have adopted dissolved metals criteria (40 CFR 22227-22236). As many metals occur naturally in various rocks, minerals and soils, storm events can expose and entrain soil and sediment particles that naturally contain metals. These inert particles are removed when samples are filtered for dissolved metals analysis (Eaton *et al*., 2005). Total recoverable metals samples are digested and acidified to liberate organically-bound and complexed metals, but this process may also solubilize metals in inorganic and particulate states that are stable and inert under normal stream conditions, overestimating the potential for toxicity.

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

However, Pennypack Creek Watershed is also affected by point sources of toxic metals. Point and non-point sources may differ significantly with respect to the ratio of dissolved vs. total recoverable metal. Dry weather point source inputs tended to have a very high dissolved to total metal ratio that remained consistent over a range of total metals concentration. The predominant factor influencing dry weather dissolved metals concentration was due to dilution effects of stream discharge.

As dissolved metals concentrations in the smaller tributaries to Pennypack Creek Watershed were usually small or undetectable in both dry and wet weather, the potential for heavy metal toxicity in these tributaries is believed to be low, at least for water column organisms. Sediment and pore water conditions may result in greater concentrations or otherwise contribute to increased potential for toxicity to benthic organisms within stream sediment microhabitats, but these effects remain poorly defined and are difficult to measure. For example, (Borgmann and Norwood 1997) found *Hyalella azteca* (Amphipoda:Hyalellidae) demonstrated increased sensitivity to sediment pore water Zn, but no observable increase in toxicity with increases in sediment pore water Cu concentration.

Total recoverable metals results and comparisons to discontinued total metals water quality criteria are included herein as a reference measure of the potential for sediment metal loading and metals loading to the Delaware estuary from Philadelphia's urban stormwater; though it is believed that, for at least some metals, samples more closely reflect natural soil and geologic features than water pollution.

With the exception of Aluminum and hexavalent Chromium, PA water quality criteria are based on hardness (as $CaCO_3$), to reflect inverse relationships between hardness and toxicity that exist for most metals (Figure 4.24). This relationship becomes especially important in streams where stormwater tends to dilute the ionic content of water while increasing concentrations of toxic metals. Point source influenced Philadelphia streams tend to experience decreased conductivity and hardness during storm events.

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

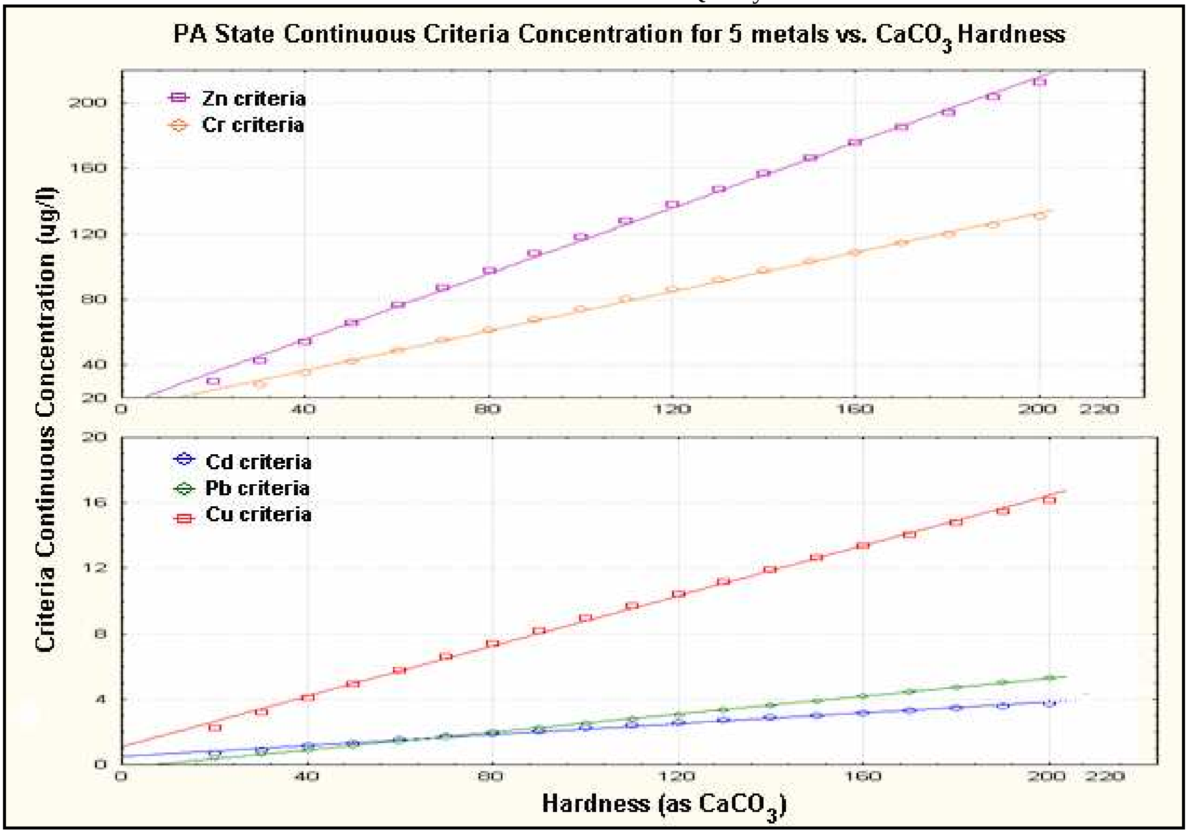


Figure 4.23 PA DEP Hardness-based Criteria Continuous Concentrations for 5 Toxic Metals

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 2007-2008 Pennypack water quality database contains results from numerous sampling programs with varying objectives. Considering only the sites from which a valid number of samples were collected, water column Al concentrations were significantly higher in wet weather than in dry weather ($U_{0.05(2)110,213}$=3317,p<0.001). Examination of paired dissolved and total recoverable Al concentrations from discrete interval grab samples collected from Pennypack 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 4.24). The strong positive correlation between Al and TSS also suggested that Al was usually present in particulate form, such as clay, during storm events (Figure 4.25).

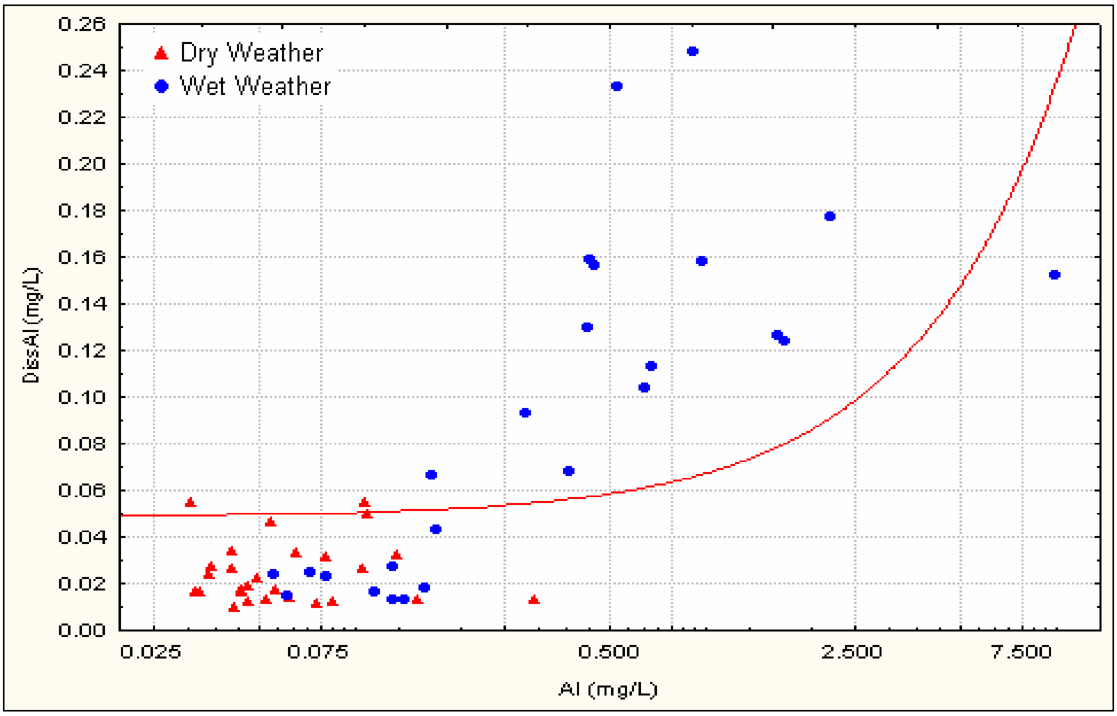


Figure 4.24 Scatterplot of paired Total Recoverable Aluminum and Dissolved Aluminum Samples Collected at 12 Mainstem and 3 Tributary Sites in Pennypack Creek Watershed, 2007

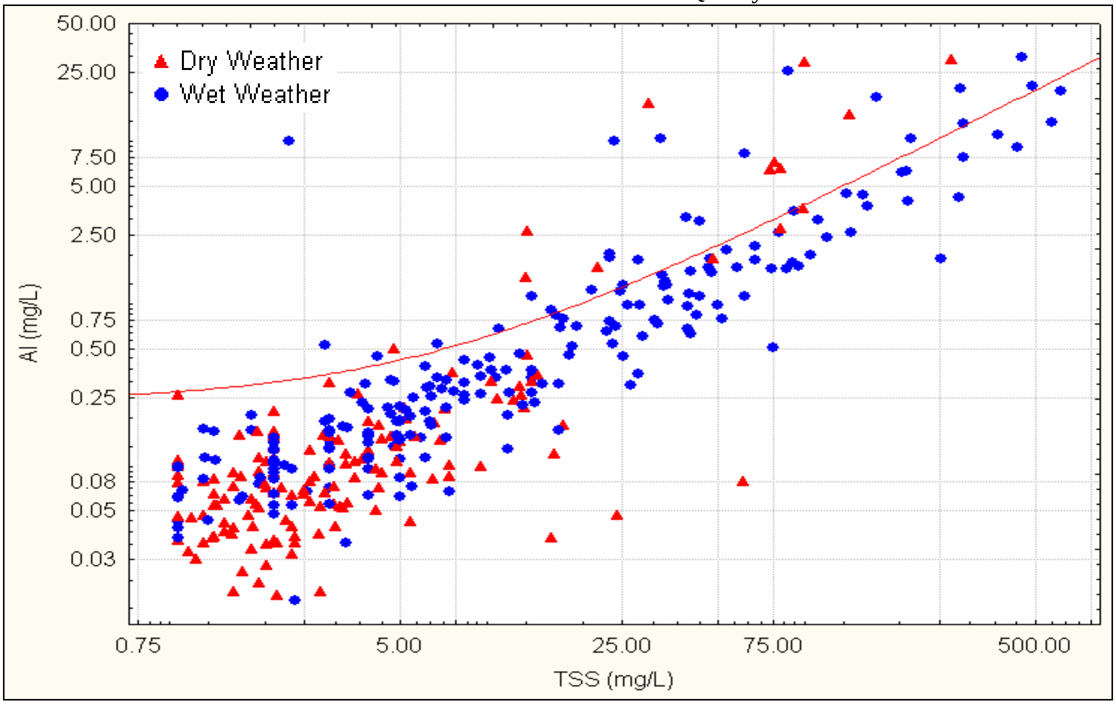


Figure 4.25 Scatterplot of paired TSS and Total Recoverable Aluminum Samples Collected from 12 Mainstem Sites in Pennypack Creek Watershed, 2007

Wet-weather targeted sampling events are more likely to capture greater concentrations of wet weather constituents that correlate with flow than discrete interval samples, especially in flashy urban streams. Tributary sites PPW010, PPHU070 and PPM070 did not have a sufficient number of dry weather samples to compare the effects of wet weather on total or dissolved metals, but it is assumed that dry weather concentrations of total metals are generally much smaller and that only a small fraction of the metal is present as the dissolved fraction. As such, measurements of dissolved Al concentrations in both tributary and mainstem sites were highly correlated to TSS (r=0.536 and 0.7107 respectively) during wet weather as opposed to dry weather. During dry weather, correlations between TSS and Dissolved Al were much lower, with product-moment coefficients of (r= 0.203 and r=0.028) for tributary and mainstem sites respectively.

Al was almost always detected in water samples from Pennypack Creek Watershed (Table 4.25); violations of PADEP water quality criteria were observed in 5.4% and 28.8% of samples collected in dry weather and wet weather, respectively. However, a much greater proportion of wet weather samples were collected from smaller tributaries which are not affected by point source discharge. Wet weather suspended solids loads consist of a mixture of urban/suburban stormwater, eroded upland soils, streambank particles, and in mainstem Pennypack Creek downstream of PP1680, municipal treated waste. It is thus impossible to determine individual Al contributions of these sources.

Al found in natural streams may be predominantly mica and clays, which are inert under normal stream conditions. Dissolved Al had less of a correlation with TSS (r = 0.375) than total recoverable Al (r= 0.5328); however, there was a stronger relationship between Dissolved Al and TSS when only mainstem samples were included in the analysis (r=0.5148). As of September 2005, PWD wet weather sampling procedures have been modified to so that grab samples are taken for dissolved metals analysis while replacing collection bottles. This additional sampling effort is being directed at analyzing these total/dissolved metals relationships for stormwater-impacted tributaries within the city of Philadelphia.

PA water quality criteria for Al are based upon total recoverable fractions rather than dissolved, partially because under experimental conditions, Brook Trout (*Salvelinus fontinalis*) experienced greater mortality with increased total Al concentration despite constant levels of dissolved Al. The form of particulate Al present in this experiment was Aluminum hydroxide, and experimental pH was low. Furthermore, EPA has recognized that total recoverable Al in stream samples may be due to clay particles and documented many high quality waters that exceed water quality standards for total recoverable Al (USEPA 1988, 53FR33178). As Pennypack 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 Pennypack Creek Watershed to Al toxicity.

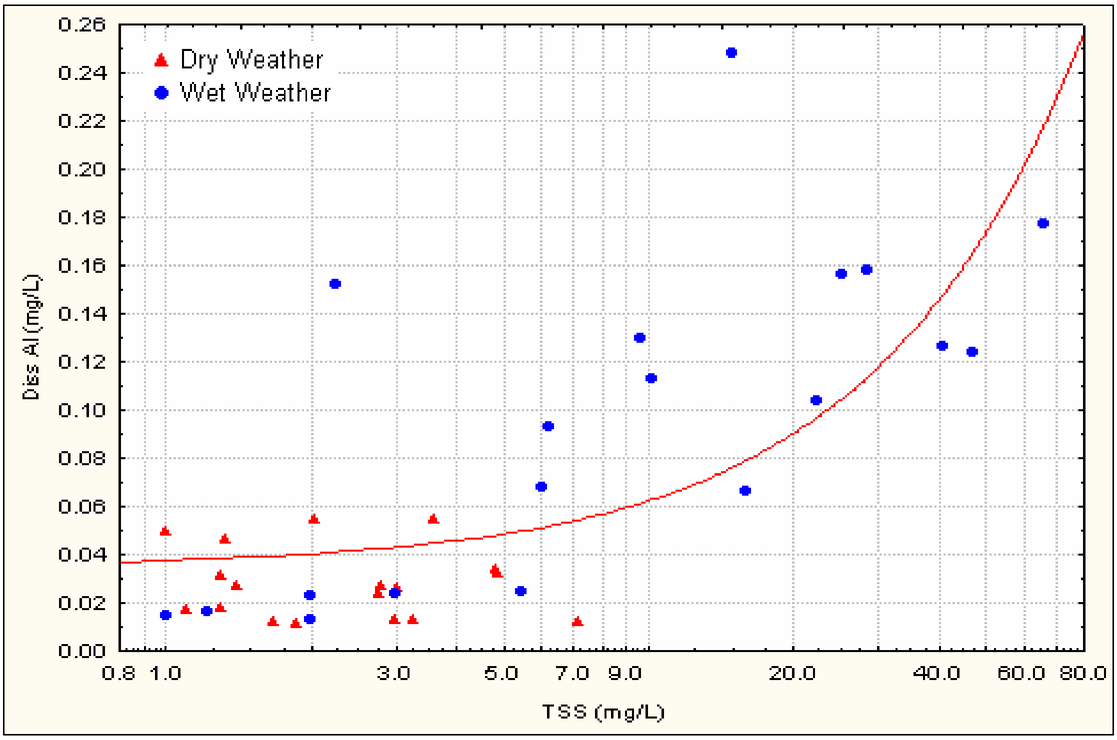


Figure 4.26 Scatterplot of Paired TSS and Dissolved Aluminum Samples Collected from 12 Mainstem Sites in Pennypack Creek Watershed, 2007

Table 4.25 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	214	94.85	268	97.4
Dissolved Aluminum	92	32.6	64	10.9
Total Cadmium	236	0.85	285	4.2
Dissolved Cadmium	165	0.0	120	0.0
Total Chromium	196	10.2	248	25.4
Dissolved Chromium	92	0.0	64	0.0
Total Copper	224	82.1	274	90.9
Dissolved Copper	91	82.4	64	93.8
Total Lead	245	9.8	292	36.3
Total Zinc	245	85.3	292	67.8
Dissolved Zinc	92	100	64	100

4.4.7.2 CADMIUM

Cadmium (Cd) is a heavy metal that is widely but sparsely distributed in the earth's crust. Cd is often associated with Zinc (Zn), but may also be found with other metals such as Copper (Cu) and Lead (Pb). For this reason, smelting and other industrial uses of nonferrous metals may be sources of Cd pollution. Other industrial sources include battery, pigment, and plastics manufacturing. Atmospheric deposition and some types of agricultural fertilizers may also contribute Cd to the environment. Cd has no known biological function, and may be toxic in very small concentrations. In aquatic environments, toxicity is assumed to be due to uptake of dissolved Cd, so PA DEP water quality criteria are based on dissolved concentrations. Cd was rarely detected in 521 water samples, so it is unlikely that Cd toxicity is responsible for observed biological impairment in Pennypack Creek Watershed.

Though concentrations were nearly always below reporting limits, water quality criteria for Cd reflect the fact that this metal may be toxic in very small concentrations. Water quality criteria for Cd are calculated based on hardness, and Cd concentrations less than 1ug/L may be in violation of water quality criteria in very soft water. Dissolved Cd was detected in 12 of 285 wet weather samples (Table 4.25); however, there were no violations of state water quality criteria. Hardness would have to decrease below 34 mg/L in dry weather and below 26.5 mg/L in wet weather in order for the reporting limit to exceed Continuous Criteria Concentration (CCC) and Criteria Maximum Concentration (CMC), respectively. Hardness was never observed to decrease below 103 mg/L in Pennypack Creek Watershed.

4.4.7.3 CHROMIUM

Chromium (Cr) is commonly used in alloys of stainless steel and as Chromate salts in other metallurgical and industrial applications. Of the two predominant naturally occurring forms, only hexavalent Chromium (Cr[VI]) is toxic, while trivalent Cr (Cr[III]) is an essential trace nutrient. Separate water quality standards exist for Cr[III] and Cr[VI]. Toxic Cr[VI] is much more soluble at normal stream pH than Cr[III] (Rai *et al*., 1989), so at the extremes, dry weather dissolved Cr samples probably more closely reflect actual water column concentrations of Cr[VI], while wet weather total recoverable Cr samples will contain a much greater proportion of insoluble, nontoxic Cr[III]. Despite the influence of other water quality constituents on the speciation and bioavailability of Cr, water quality criteria for Cr[VI] are absolute (CCC=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 156 samples (Table 4.25), and there were no violations of water quality criteria

4.4.7.4 COPPER

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

Dissolved concentrations of Cu are usually much smaller than total recoverable concentrations in natural waters, as Cu forms complexes and ligand bonds with other water column constituents (Morel & Hering 1993). Cu can also be present in particulate form or be adsorbed to large particles that are trapped by filtering surface water grab samples. However, point sources such as industrial or municipal wastewater may have a much greater relative proportion of dissolved Cu. The suspected source is corrosion of copper pipes and plumbing materials in the water distribution system(s).

Individual dischargers and groups of dischargers in Southeastern PA have submitted Water Effects Ratio (WER) studies to PADEP in applications for exemptions to specific water quality criteria for Cu. When approved, these exemptions established water effect ratios (WER), or "multipliers" that modified the water quality criterion to account for properties of the effluent and receiving waters that affect toxicity of the pollutant. PWD was unable to compile accurate information regarding existing WERs in order to evaluate results of stream samples for dissolved Cu, specifically the extent to which WERs exempt downstream violations of WQ criteria.

Cu and dissolved Cu were mostly detectable above reporting limits in Pennypack Creek Watershed (Table 4.25). One potential violation of water quality criteria was observed at site PP1680 which is downstream of point source discharge. PWD was unable to determine whether this observation represents a violation of water quality standards because the individual discharger may be subject to less stringent site specific water quality criteria or a WER. Standard field procedures stipulate that water samples should be filtered within 15 minutes for dissolved metals analysis (Eaton *et al.*, 2005), but it was not possible to use this recommended technique for dissolved metals samples collected with automated Isco samplers. Dissolved metals samples are predominantly from the discrete interval (weekly) sampling program.

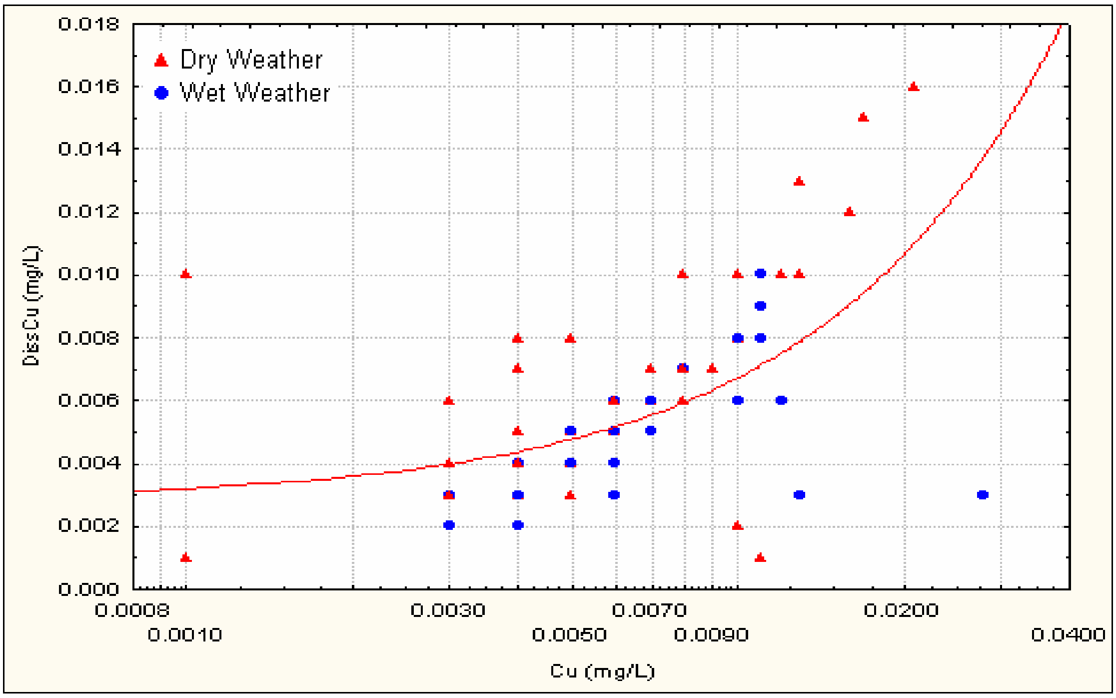


Figure 4.27 Scatterplot of paired Total Recoverable Copper and Dissolved Copper Samples Collected from 12 Mainstem and 3 Tributary Sites in Pennypack Creek Watershed

As Cu adsorbs with a high affinity 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 tipulid larvae, which were collected in 10 of 13 mainstem sites and 9 of 11 tributary 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 Pennypack Creek Watershed sites and reference sites with respect to number and abundance of mayfly and other sensitive taxa may be partially attributable to heavy metal pollution. Sensitive mayfly taxa were very poorly represented in Pennypack Creek Watershed, with only four taxa collected. Sediment metals concentrations and reference site chemistry data are needed before any definitive conclusions can be drawn.

4.4.7.4.1 Biotic Ligand Model Analysis of Dissolved Copper

Cu toxicity was also investigated using the Biotic Ligand Model (BLM) (DiToro *et al.*, 2001) as many water chemistry parameters can affect Cu toxicity. Other ions and organic molecules tend to compete with gill ligand bonding sites for available Cu. Figures 4.29 and 4.30 illustrate the effect of pH and temperature respectively, on Cu bioavailability and toxicity. BLM data were used to address the question of whether Cu toxicity could be affecting the biology of Pennypack Creek

Watershed. EPA is in the process of developing new water quality recommendations for Cu integrating the BLM with appropriate margins of safety for protecting aquatic life, but it is unlikely that these recommendations will be adopted into state water quality criteria due to the relatively large number of samples and parameters that must be analyzed to supply the BLM input data.

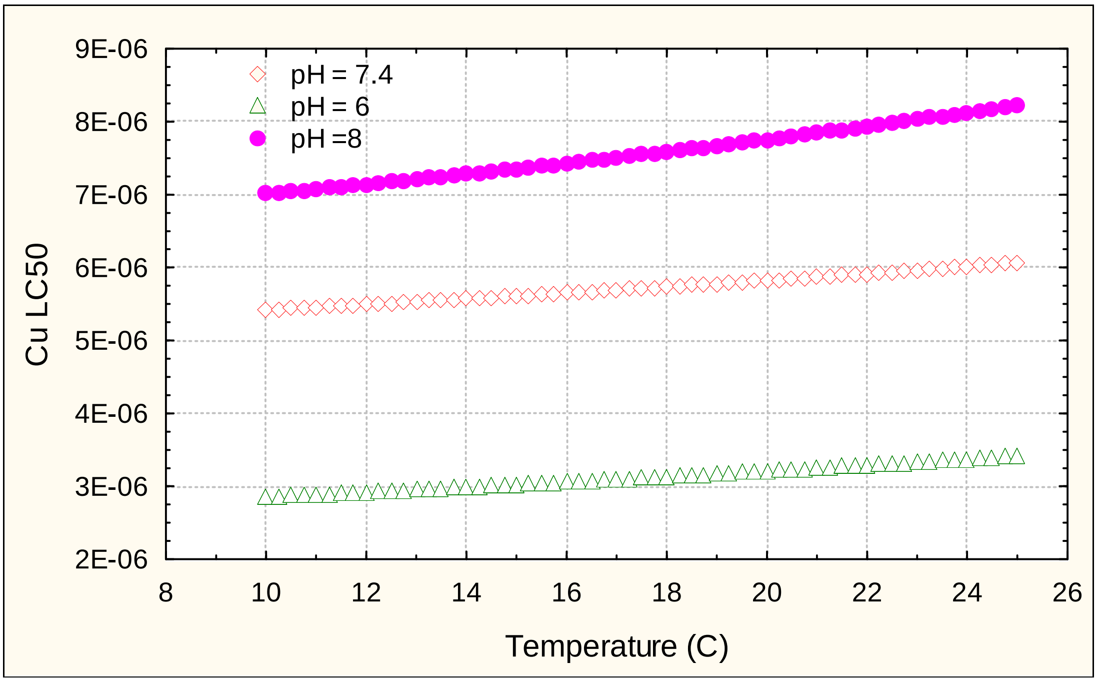


Figure 4.28 Effects of pH and Temperature on Copper Toxicity to Fathead Minnows

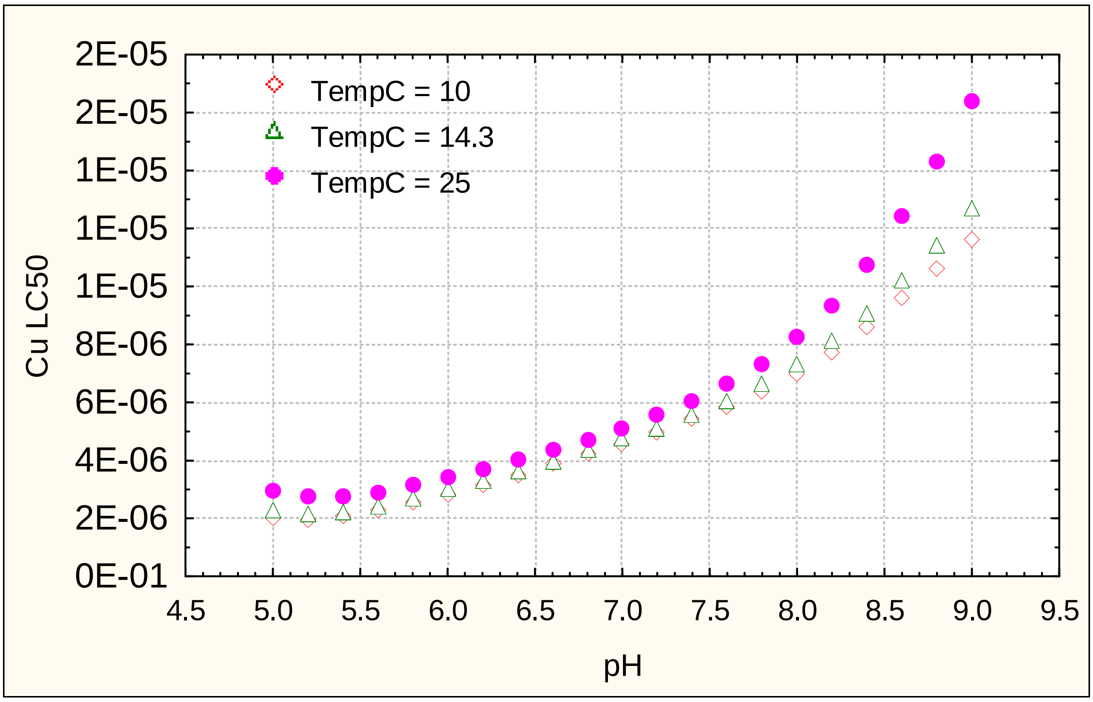


Figure 4.29 Effects of pH and Temperature on Copper Toxicity to Fathead Minnows

The BLM was used to estimate the LC_{50} of dissolved copper to Fathead Minnows (*Pimephales promelas*) and three cladoceran microcrustaceans (*Ceriodaphnia dubia*, *Daphnia magna*, and *Daphnia pulex*). Each model input case consisted of water quality data from a single sample from Pennypack Creek Watershed, though some parameters were estimated due to lack of availability in the 2007 data set. Parameters for which estimates were used included: dissolved organic carbon (DOC), percent of DOC contributed by humic acids, chloride, and sulfate. DOC competes for Cu with gill ligand sites and is positively correlated to the LC_{50} of Cu, therefore a conservative estimate of 2.6 mg/L (wet weather) and 2.4 mg/L (dry weather from PWD data at site PP110 was used). Due to the lack of DOC characterization data, ten percent was used for the relative proportion of DOC made up by humic acids as recommended by the model documentation (DiToro *et al*., 2001). Actual instream DOC content is probably greater in zones where dissolved Cu toxicity is most likely.

Chloride and sulfate model input values for wet weather (5.5 mg/L and 38.7 mg/L, respectively) at sites downstream of PP970 and sites upstream of PP970 (7.85 mg/L and 22 mg/L) were means from historical USGS grab samples at gauges on the Pennypack during non-winter months. Chloride and sulfate model input values for dry weather (28.48 mg/L and 38.7 mg/L, respectively) at sites downstream of PP970 and sites upstream of PP970 (29.56 mg/L and 42.11 mg/L) were calculated by the same means. As with DOC, these values are conservative and probably smaller than the concentrations expected at upstream locations where point source discharges contribute a greater proportion of flow, especially during low flow conditions.

When comparing dissolved Cu concentrations from Pennypack Creek Watershed to predicted LC_{50}, the predicted LC_{50} concentration was reduced by an order of magnitude (margin of safety) and when analytical results were below reporting limits or no dissolved Cu analysis was performed, samples were entered into the model as the method reporting limit (*i.e.*, 0.004mg/L). When individual samples (n=481) were compared to BLM-derived reference values with this margin of safety, some samples exceeded these reference values (Table 4.26). 0, 132, 414, and 294 out of 481 samples had dissolved Cu concentration above the LC_{50} /10 for *P. promelas, D. magna, D. pulex*, and *C. dubia* respectively. Model results indicated that daphnia were quite sensitive, as many samples showed toxicity (with the MOS) for reporting limit samples. Without this margin of safety, 3 samples (*C. dubia)* and 11 samples (*D. pulex*) had dissolved Cu concentrations above model-estimated LC_{50}.

Table 4.26 Exceedance of BLM-derived Dissolved Cu LC_{50}

Species	Exceedances with MOS	Exceedances without MOS
C. dubia	294	3
D. magna	132	0
D. pulex	414	11
P. promelas	0	0

4.4.7.5 LEAD

Lead (Pb) is a toxic heavy metal that was once commonly used in paints (as recently as 1978) and in automotive fuels (until being phased out in the 1980s). Pb is still used industrially in solder and batteries. Some areas have banned the use of lead in shotgun pellets and fishing weights, as chronic toxicity results when these items are ingested by waterfowl. 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 65ug/L, respectively, at 100mg/L $CaCO_3$ hardness) (25 PA Code § 16.24). Dissolved Pb was rarely detected in Pennypack samples from 2007 (Table 4.25). CCC was exceeded only once during wet weather at site PPW010 and CMC was never violated.

4.4.7.6 ZINC

Zinc (Zn) is a common element present in many rocks and in small concentrations in soil. Zn is a micronutrient needed by plants and animals, but when present in greater concentrations in surface water, it is moderately toxic to fish and other aquatic life. Toxicity is most severe during certain sensitive (usually early) life stages. Zn is a component of common alloys such as brass and bronze and is used industrially for solders, galvanized coatings, and in roofing materials. Zn is usually present in surface waters of Pennypack Creek Watershed, and dissolved zinc was always detected (Table 4.23). Dissolved zinc concentrations were significantly positively correlated with total recoverable zinc (r= 0.59), and more strongly so in dry weather (r=0.66) than wet weather (r=0.48). This phenomenon was similar to that observed in Cu and Mn data.

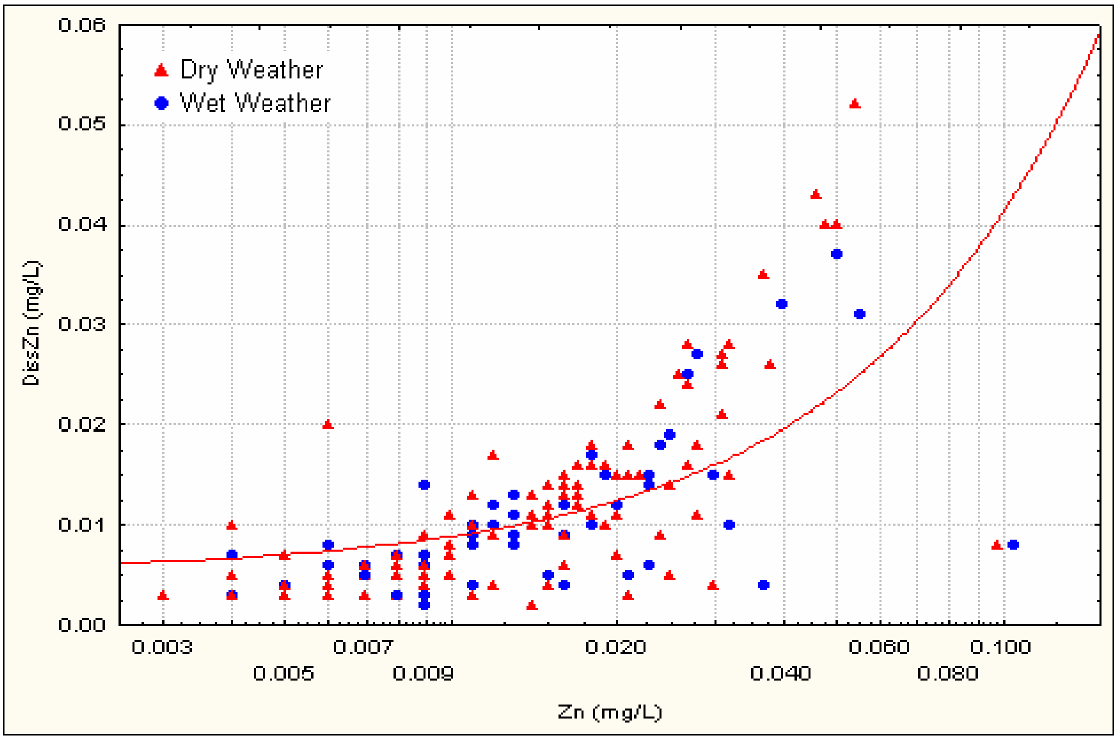


Figure 4.30 Scatterplot of paired Total Recoverable Zinc and Dissolved Zinc Samples Collected from 12 Mainstem and 3 Tributary Sites in Pennypack Creek Watershed, 2007

Discrepancies occurred with both dry and wet weather samples. Bench sheets did not indicate any problems with samples or the instrumentation, and all QC checks were passed. As samples were preserved and stored, the PWD Bureau of Laboratory Services (BLS) was able to re-analyze these samples, obtaining similar results. The analyst visually confirmed the presence of settled solids in sample containers used for total recoverable metal, while sample containers used for dissolved metals were visually clear. A series of subsequent filter blank trials showed filters used to prepare dissolved metals samples may have leached Zn, but the magnitude of the difference in total and dissolved concentrations was much too great to be explained by filter contamination. The source of contamination remains unknown, but airborne zinc particles in dust are another potential source.

The BLM was used to estimate the toxicity of dissolved Zn to Fathead Minnows (*Pimephales promelas*), rainbow trout (*Oncorhynchus mykiss*), and a cladoceran water flea (*Daphnia magna*). Input data were compiled or estimated in the same manner as dissolved copper model input data. An order of magnitude safety factor was applied to the LC_{50} concentrations generated by the model and the resulting concentration was compared with dissolved zinc data collected in 2007 from Pennypack Creek Watershed. With this safety margin, observed dissolved zinc concentrations exceeded the calculated LC_{50} for *O. mykiss* only, in 8 of 481 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. With the exception of the Southampton Creek tributary watershed, where a TMDL for nutrients was being revised at the time of writing, Pennypack Creek Watershed has not been listed by PADEP as impaired due to nutrients. 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 (PO_4^{3-}) have been proposed for various types of water bodies (Dodds and Welch 2000, Dodds and Oakes 2004, USEPA 2000).

Total P concentrations in Pennypack Creek Watershed were evaluated against reference stream data in EPA Ecoregion IX, subregion 64 (75th percentile of observed data=140µg/L) (USEPA 2000). This reference value is considerably greater than the mesotrophic/eutrophic boundary for TP suggested by Dodds *et al*. (1998) (*i.e.*, 75µg/L). While total phosphorus accounts for all forms of P that may be able to be made available through various decomposition scenarios, release from sediments upon desorption under anoxic conditions, and other biochemical pathways, phosphate (PO_4^{3-}) 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 PENNYPACK CREEK WATERSHED 1969-2008

Based on a comparison of 2008 data to historic data (1968 – 1980), a very large decrease in PO_4^{3-} concentration has occurred within Pennypack Creek Watershed over the past 4 decades, both inside and outside the City of Philadelphia. Decreases were evident during both dry and wet weather. In 1968, USGS documented PO_4^{3-} concentrations as high as 11.7mg/L, 11.6 mg/L and 8.79 mg/L at sites PP970, PP340 and PPW010 respectively, but historical data exhibit obvious reductions concomitant with construction and upgrading of municipal waste treatment facilities in the 1970s and 1980s (USGS 2008, PADEP 1969-1982). Mean orthophosphate values over the 1969-1980 time period were much greater than modern data. An example of this trend is exhibited in the comparison of the historic (1969-1980) mean concentration at PP970 (5.59 mg/L) to the contemporary dataset (2001 to 2008) where mean PO_4^{3-} concentration had decreased to 0.436 mg/L. Unfortunately, PO_4^{3-} concentrations downstream of site PP1680 continue to greatly exceed the levels needed to prevent nuisance algae effects. Mainstem sites upstream of site PP1680 generally did not exceed the mesotrophic/eutrophic thresholds defined by both Dodds *et al*. (1998) (75µg/L) and the 75th percentile of data compiled for reference streams in Ecoregion IX subregion 64 (140µg/L) (EPA 2000).

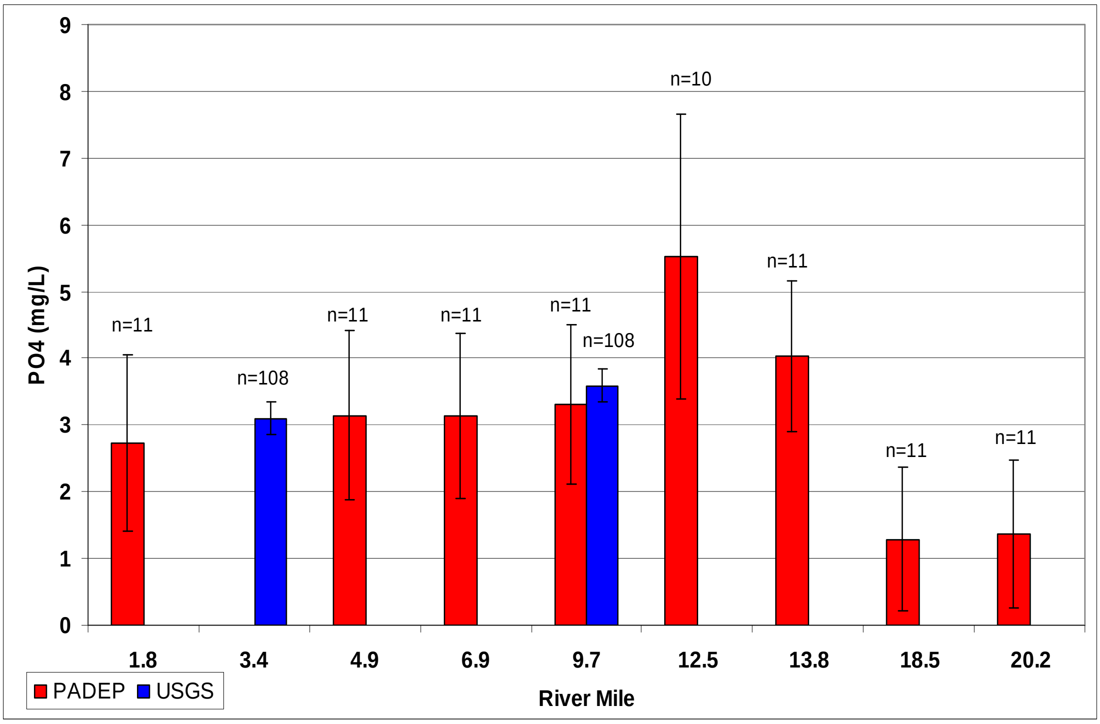


Figure 4.31 Mean PO_4^{3-} Concentration of PADEP and USGS Historic Water Quality Samples by River Mile Distance, 1969-1980

4.4.8.1.3 PHOSPHORUS RESULTS

Readily available dissolved orthophosphate (PO_4^{3-}) concentration was greater than 0.1 mg/L in 181 of 311 total samples collected in dry weather, and in 203 of 325 wet weather samples. Log transformed PO_4^{3-} concentration was significantly negatively correlated with discharge in mainstem sites ($r_{(446)}$= -0.63, p<0.001) (Figure 4.36). The rather strong correlation between discharge and PO_4 concentration suggests a dilution effect during wet weather such that higher discharges result in lower PO4 concentrations.

Overall, mean PO_4^{3-} concentration during dry weather was not significantly greater than mean wet weather PO_4^{3-} concentration. However, when only mainstem sites were analyzed, median dry weather PO_4^{3-} concentration (0.457 mg/L) was significantly greater than median wet weather concentration (0.319 mg/L) ($U_{0.05(2)195,264}$=20082.5, p<0.001), suggesting that PO_4^{3-}originates from continuous point source discharges that are diluted during wet weather events. To further support this conclusion, a Kruskal-Wallis ANOVA procedure was conducted to see if there was a statistically significant difference in mean PO_4^{3-} concentration between sites. Results confirmed that the PO_4^{3-} concentration at site PP1680 was significantly greater than all sites except PP985, PP1150 and PP1380.

Site PP1680 had the greatest mean PO_4^{3-} concentration of all sites sampled in Pennypack Creek Watershed in both wet and dry weather (Figures 4.33 and 4.34, respectively). This observed increase in PO_4^{3-} concentration downstream of the HUMJSA plant suggests that wastewater effluent is the primary source of PO_4^{3-} enrichment in mainstem Pennypack Creek. At sites PP1850 and PP2020, mean PO_4^{3-}concentrations were 0.06 mg/L and 0.08 mg/L respectively during dry weather (Figure 4.32), while mean PO_4^{3-}concentration at site PP1680 was more than 20 times that of the upstream concentrations at 1.64 mg/L. Similarly, the wet weather mean concentrations at PP1850 and PP2020 (0.07 mg/L and 0.09 mg/L respectively) were greatly exceeded by the concentration at PP1680 (0.91

mg/L) (Figure 4.33). Downstream of PP1680, PO_4^{3-} concentrations decrease gradually due to dilution such that the mean concentration at PP180 was 0.34 mg/L during dry weather and 0.38 mg/L during wet weather. Standard deviations at PP1850 and PP2020 were small, suggesting that PO_4^{3-} at these sites originates from constant, low concentration sources. Standard deviations at the sites downstream of PP1850 were greater and varied between sites, especially during dry weather.

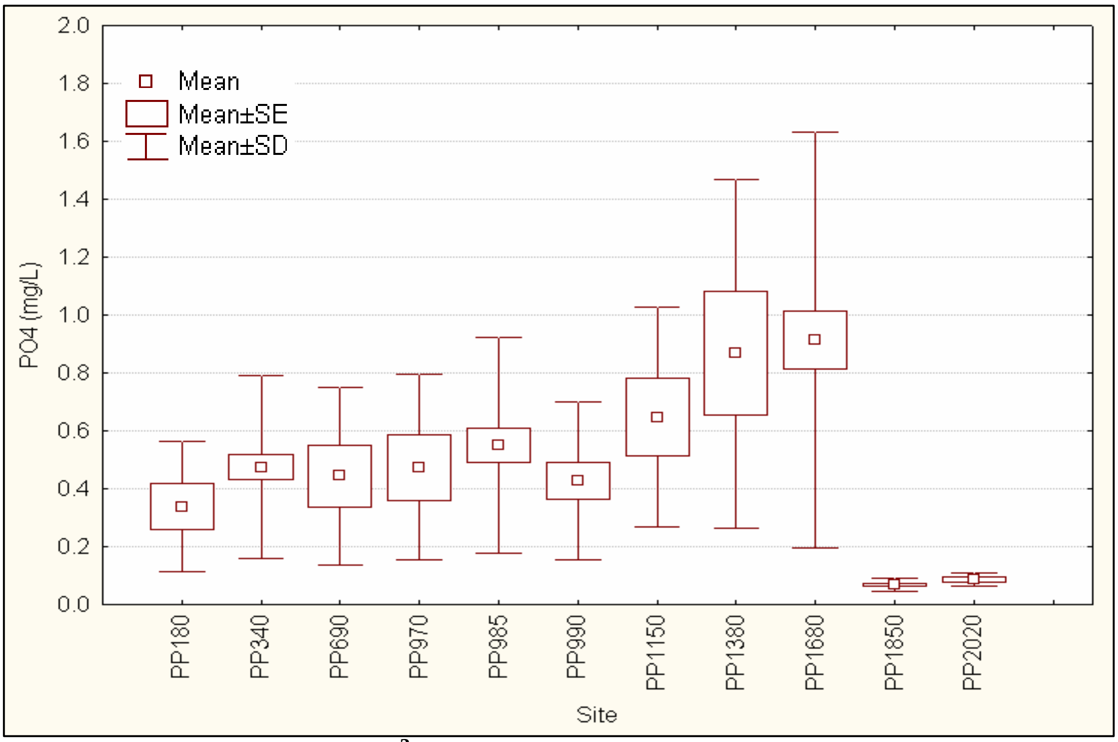


Figure 4.32 Dry Weather PO_4^{3-} Concentrations at 11 Mainstem Pennypack Creek Sites, 2007-2008

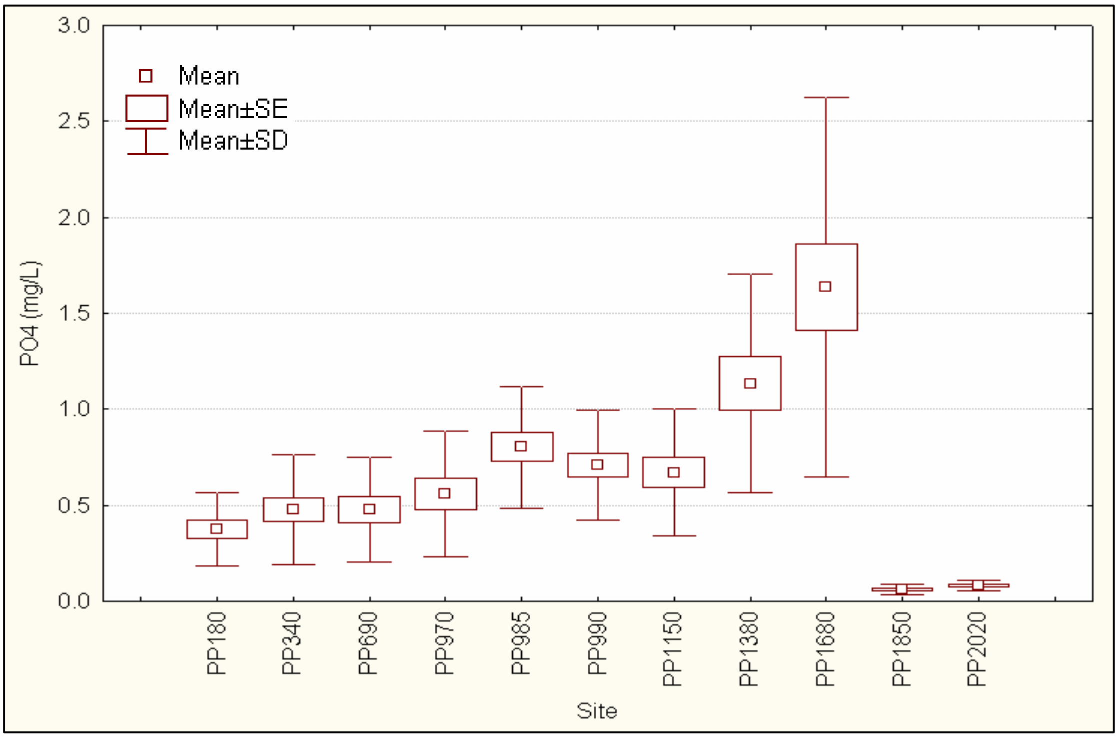


Figure 4.33 Wet Weather PO_4^{3-} Concentrations at 11 Mainstem Pennypack Creek Sites, 2007-2008

PO_4^{3-} concentration was generally much smaller and less variable in tributary sites than at mainstem sites (Figures 33 through 36). Furthermore, there was no significant difference between wet and dry weather PO_4^{3-} concentrations at tributary monitoring locations. A similar analysis conducted with tributary data revealed no significant difference in wet and dry weather concentration (Kruskal-Wallis test $U_{0.05(2)51,23}$=513.5, p>0.05), however it should be noted that the sample size in this analysis was much smaller than that of the mainstem sites analysis. Excluding sites on Fox Chase Run which was sampled very frequently and affected by agriculture, site PPHU070 had the highest PO_4^{3-} concentrations observed in the Pennypack Creek tributaries in both wet (0.08 mg/L) and dry weather (0.09 mg/L). The mean PO_4^{3-} concentration at PPHU070 was slightly higher during dry weather; however the distribution of the sample data was much more variable during dry weather, suggesting periodic, high concentration point source inputs of nutrients.

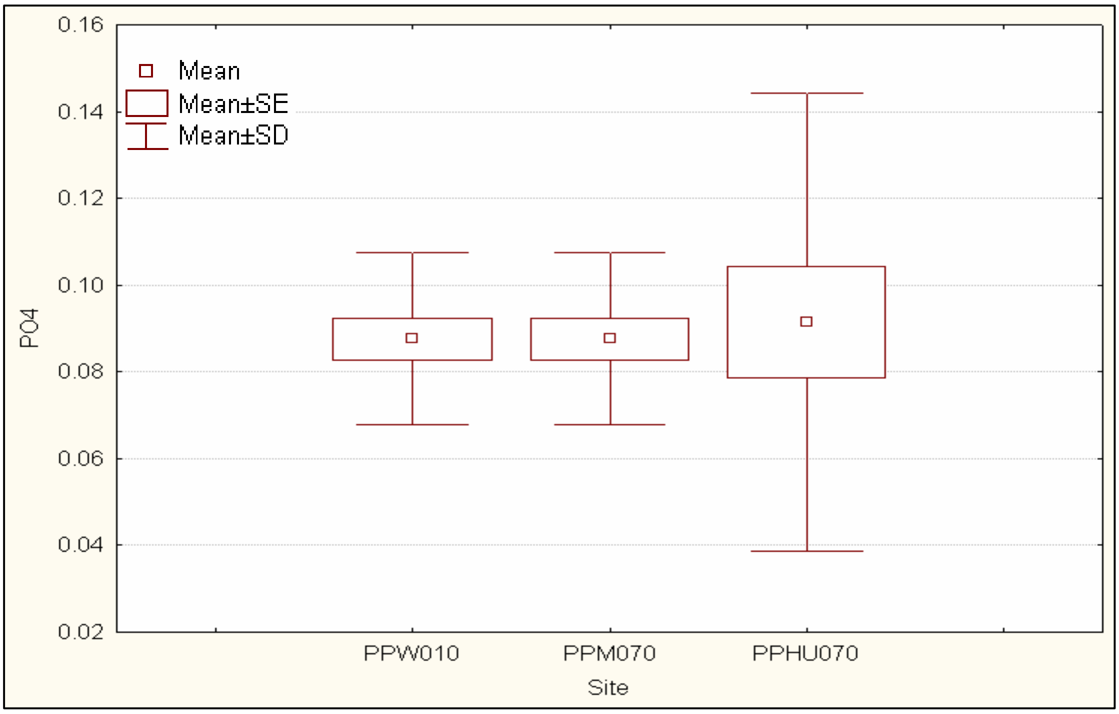


Figure 4.34 Dry Weather PO_4^{3-} Concentrations at 3 Pennypack Creek Tributary Sites, 2007-2008

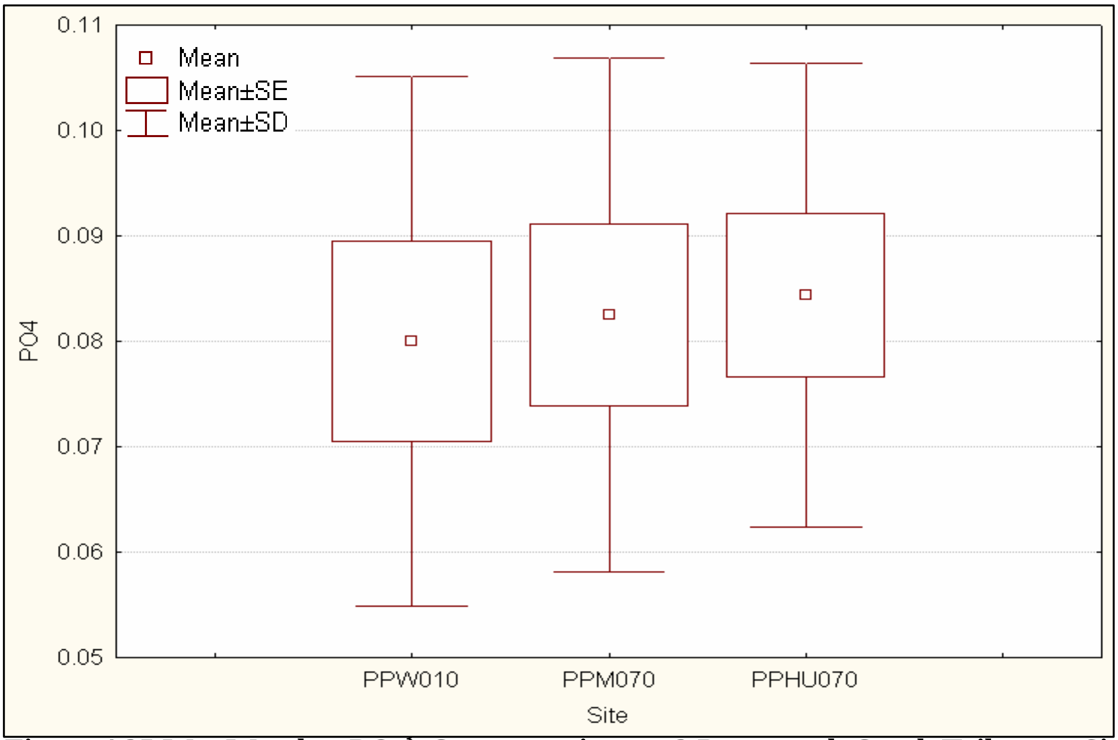


Figure 4.35 Wet Weather PO_4^{3-} Concentrations at 3 Pennypack Creek Tributary Sites, 2007-2008

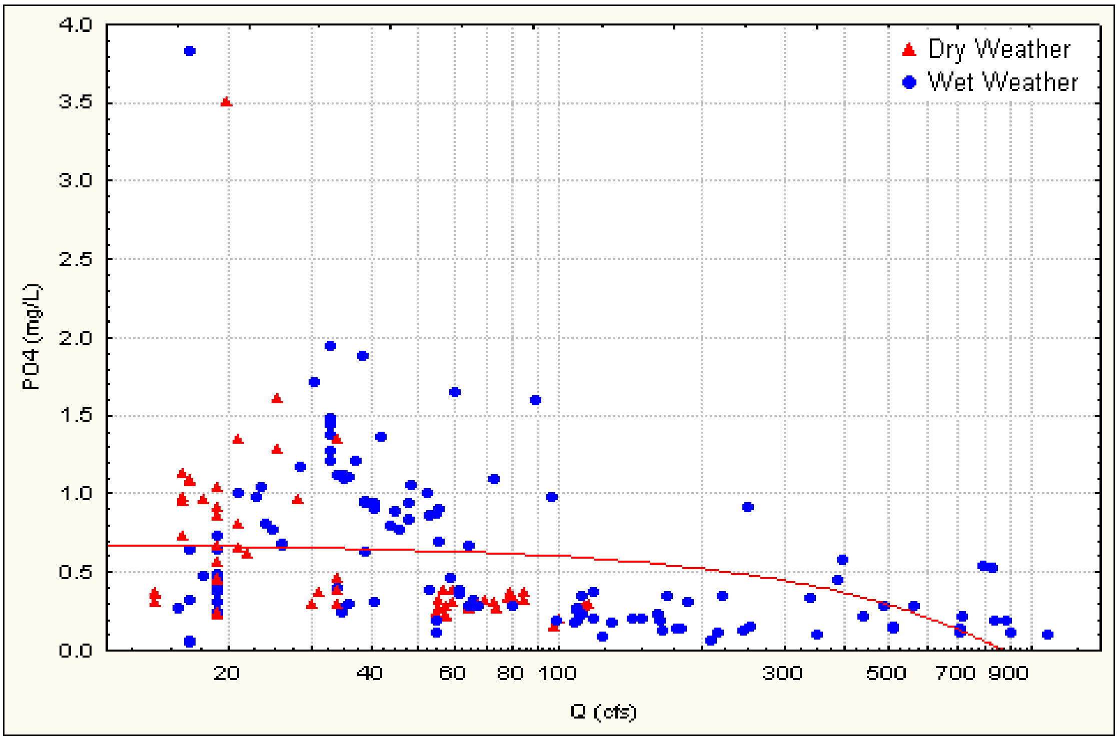


Figure 4.36 Paired Streamflow and PO_4^{3-} Samples Collected from 12 Mainstem and 3 Tributary Sites in Pennypack Creek Watershed, 2007-2008

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, NH_3 is converted to nitrate (NO_3^-) by a pair of bacteria-mediated reactions, together known as the process of nitrification. Nitrification occurs quickly in oxygenated waters with sufficient densities of nitrifying bacteria, effectively reducing NH_3 concentration, although at the expense of increased NO_3^- concentration. PA DEP 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 PENNYPACK CREEK WATERSHED 1969-2008

Ammonia concentrations in Pennypack Creek Watershed have decreased considerably compared to historic conditions, when ammonia toxicity appears to have been a potential water quality problem (Figure 4.37). Historical data collected by PADEP and USGS exhibit obvious reductions concomitant with construction and upgrading of municipal waste treatment facilities (USGS 2008, PADEP 1969-1982). During the data review for the PCWIWMP, PWD reviewed PA Code (Commonwealth of Pennsylvania 2009) and discharge monitoring reports (DMRs) to estimate the relative contribution of ammonia to Pennypack Creek watershed from point sources of treated wastewater. The primary wastewater treatment facility has seasonal numeric instantaneous (not to exceed) and 30-day average permit limits for ammonia. Enhancements to treatment necessary to meet these limits are likely responsible for observed decreases in ammonia concentration, as well as concomitant increases in Nitrate concentration.

While only a limited number of samples were available, trends of decreasing ammonia concentration were also observed in the small Wooden Bridge Run tributary within the City of Philadelphia. Samples collected in the early 1970s showed evidence of episodic inputs of organic pollution, most likely caused by leaks and other faults in the sewer system such as defective laterals, crossed connections and sewer chokes. While there has been some improvement, some present day samples continue to show elevated ammonia concentration, as well as elevated fecal coliform concentration, suggesting that these problems may still exist.

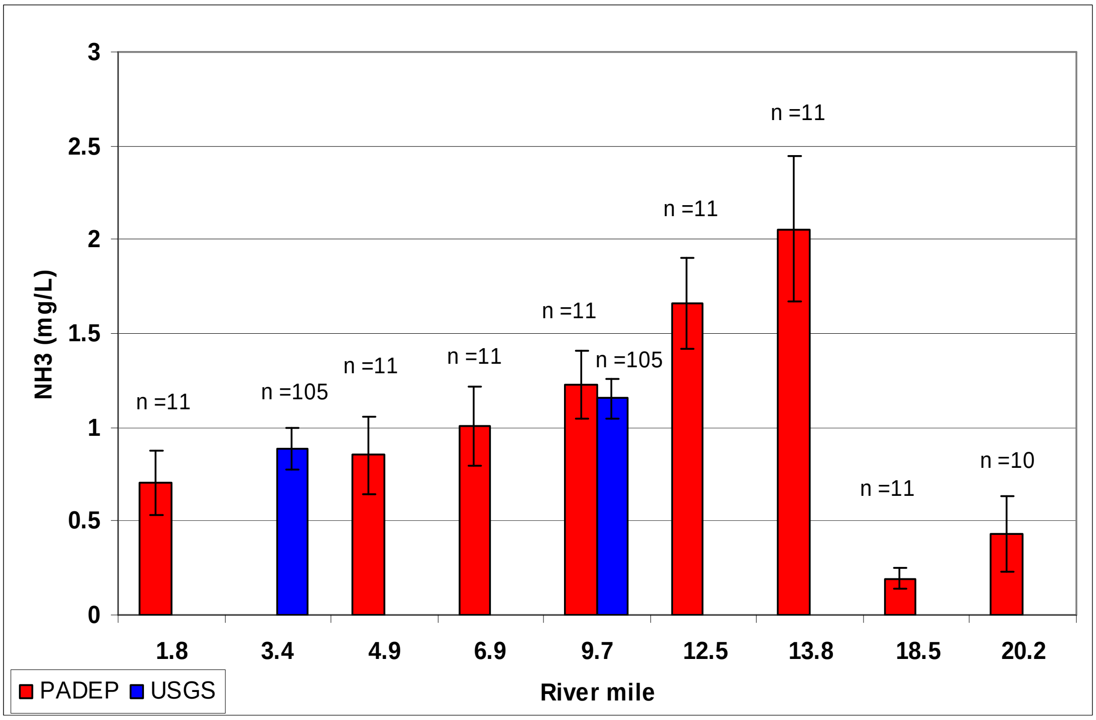


Figure 4.37 Mean NH_3 Concentrations of PADEP and USGS Historic Water Quality Samples by River Mile Distance, 1969-1980.

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. Reporting limits for some sample events were as high as 0.1mg/L. NH_3 concentration exceeded the maximum reporting limits of 0.1 mg/L in 111 of 309 wet weather samples, and only 25 of 137 dry weather samples. Due to the large number of samples with NH_3 concentration below reporting limits, half the reporting limit was substituted for these samples. Once this correction was made, NH_3 concentration was significantly greater in wet weather than in dry weather ($U_{0.05(2)137,309}$=16792, p<0.001) (Figures 4.39 through 4.42). Most samples with elevated NH_3 concentration during wet weather were collected from tributary sites (Figure 4.41).

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 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 Pennypack Creek Watershed in the 2007-2008 sample dataset. However, the NH_3 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, daily maximum pH recorded at each site was subsequently used to calculate toxicity levels and compared to measured NH_3 concentrations. Using the maximum pH values and adjusting for lower temperature, only 3 of 446 total samples had the potential to violate water quality criteria.

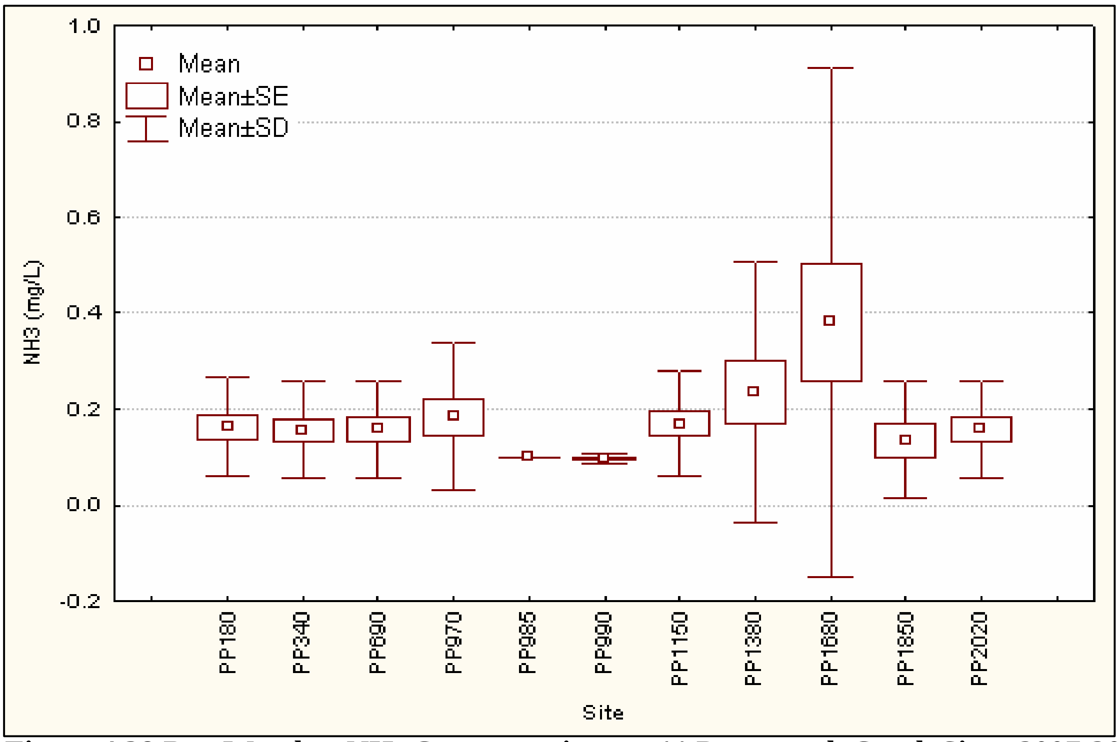


Figure 4.38 Dry Weather NH_3 Concentrations at 11 Pennypack Creek Sites, 2007-2008

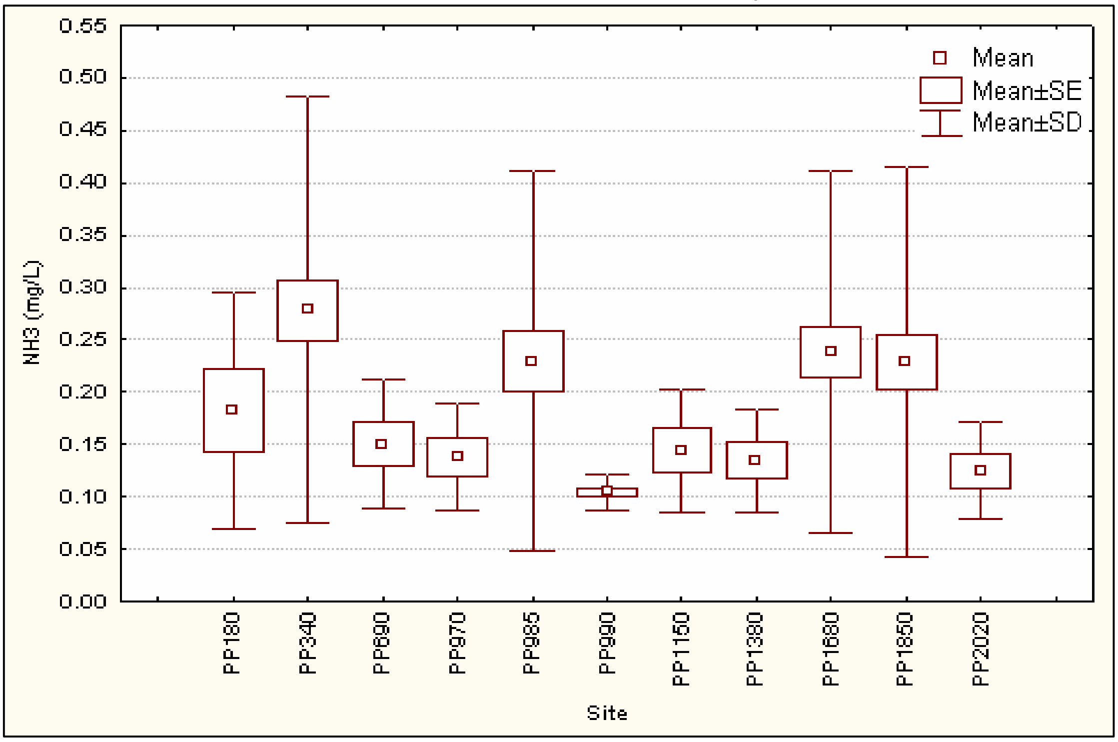


Figure 4.39 Wet Weather NH_3 Concentrations at 11 Pennypack Creek Sites, 2007-2008

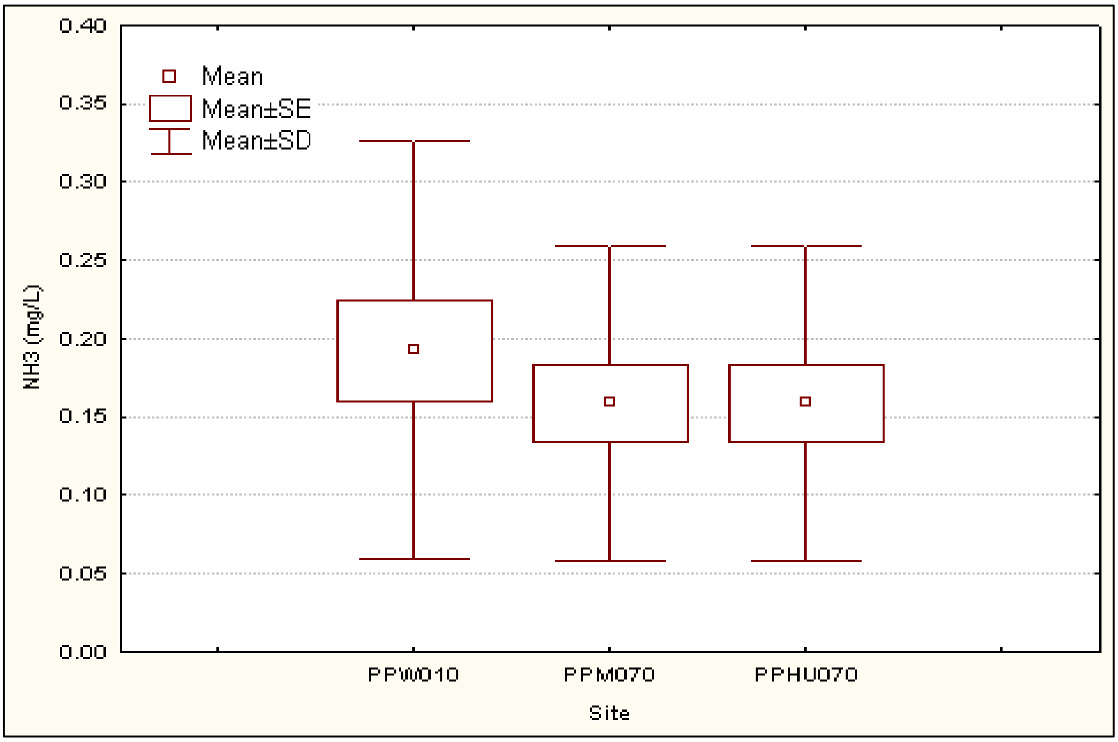


Figure 4.40 Dry Weather NH_3Concentrations at 3 Pennypack Creek Tributary Sites, 2007-2008

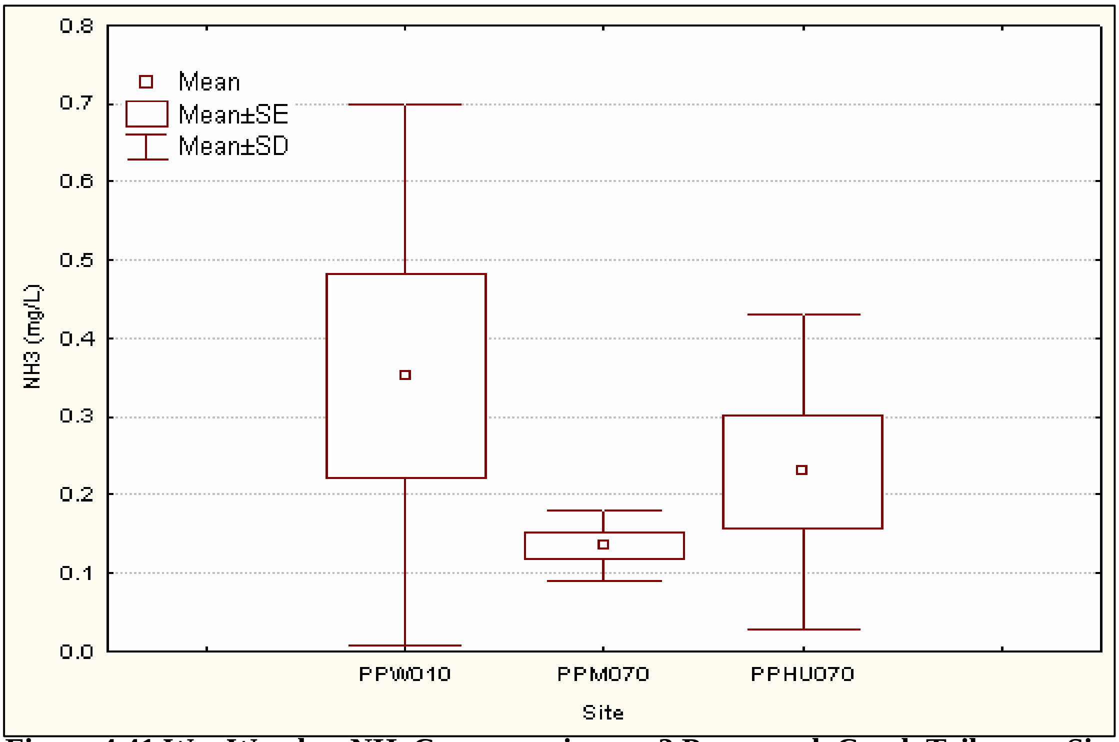


Figure 4.41 Wet Weather NH_3 Concentrations at 3 Pennypack Creek Tributary Sites, 2007-2008

Site PP1680 was the only site at which violations of PA water quality standards for dissolved oxygen were observed in 2007-2008. During some periods when dissolved oxygen stress was observed, diel fluctuations in dissolved oxygen concentration were generally not severe, and the stream did not exceed saturation levels of DO even during the afternoon when algal photosynthesis infuses high levels of DO. This pattern suggested that an additional source of oxygen demand was a major contributing factor to the dissolved oxygen problem at this site. Nitrogenous biological oxygen demand (NBOD) may be a contributing factor in reducing oxygen concentrations in the vicinity of this site.

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

NO_2 concentrations were greater than reporting limits relatively more frequently in dry weather (24 of 131 samples) than in wet weather (47 of 305 samples). Contribution of NO_2 to total inorganic nitrogen was usually small and concentrations of many samples were estimated to be half the detection limit for the purpose of evaluating nutrient ratios. Once this adjustment was made, Mann-Whitney U test analysis showed no significant difference in NO_2 concentration in samples collected during dry weather than in samples collected during wet weather ($U_{0.05(2)131,305}$=19348, p=0.42).

4.4.8.4 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 Pennypack Creek Watershed generally has elevated nitrate levels (median NO_3^- concentration of groundwater samples from monitoring wells in PADEP groundwater monitoring network zone 77 = 3.14mg/L, Reese 1998), while rainwater tends to be more dilute.

Nitrate is a less toxic inorganic form of nitrogen than ammonia and serves as an 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.

PA DEP 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 PENNYPACK CREEK WATERSHED 1969-2008

Improved sewage treatment in Pennypack Creek watershed has been successful in reducing ammonia concentration over the past 4 decades (section Dodds and Welch 2000, Dodds and Oakes 2004, USEPA 2000), but this reduction has come at the expense of an increase in nitrate concentration (Figures 4.43 and 4.44). Ammonia is removed from this wastewater primarily by conversion to nitrate through nitrification in the presence of oxygen. Since nitrate has remained consistently in the range of 3.0 mg/L in dry weather, nitrate concentration has likely never been a limiting nutrient for algal growth. The primary change has been in the degree to which nitrate concentrations are diluted by stormwater. As more nitrate is present during dry weather, the relative dilution is greater overall.

4.4.8.4.3 NITRATE RESULTS

With the exception of Southampton Creek, Pennypack Creek Watershed has not yet been listed as impaired due to nutrient enrichment. For the PCWIMP, NO_2 +NO_3 concentrations were evaluated against reference stream data using a frequency distribution approach recommended by USEPA (2000). Data were compiled for reference reaches in EPA Ecoregion IX, subregion 64 (75th percentile of observed data=2.9mg/L) (US EPA 2000). As mentioned above in section 4.4.8.4.1, groundwater nitrate concentration in Pennypack Creek Watershed is considerably greater than in the reference streams used to compile this data (USEPA 2000). The reference value used for the PCWIMP is also considerably greater than the mesotrophic/eutrophic boundary for Total N suggested by Dodds *et al*. (1998) (*i.e.*, 1.5 mg/L TN).

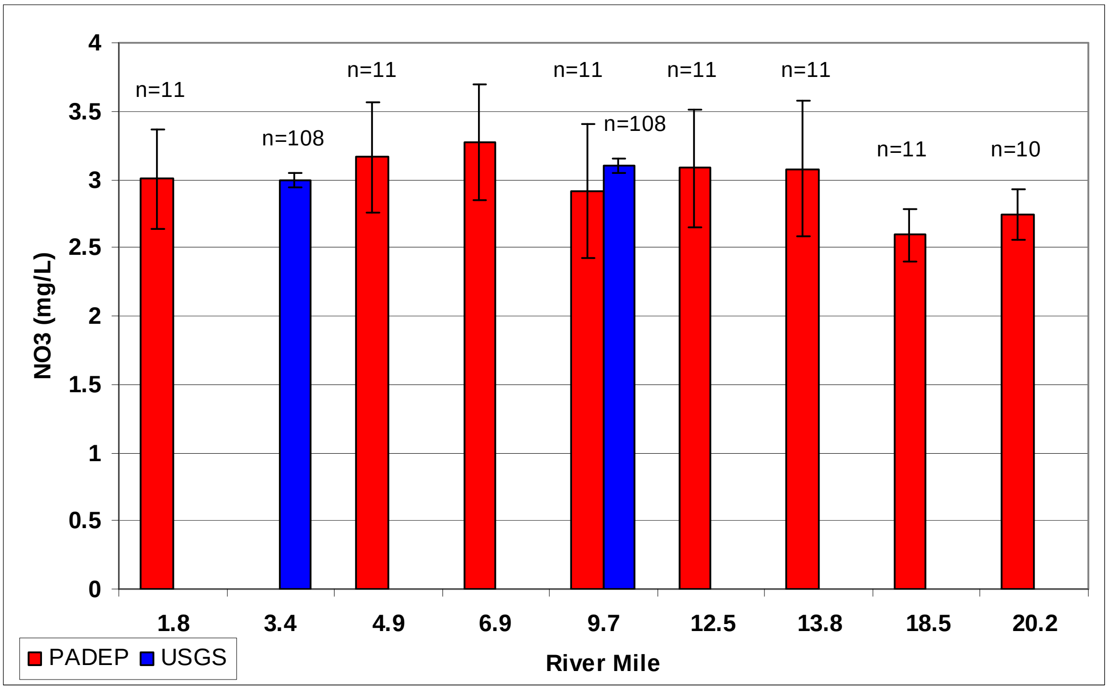


Figure 4.42 Mean NO_3^- Concentrations of PADEP and USGS Historic Water Quality Samples by River Mile Distance, 1969-1980.

The reference value of 2.9mg/L was exceeded in 247 of 450 (54.8%) samples from Pennypack Creek Watershed. Nitrogen enrichment was greatest upstream in dry weather where and when point sources were minimally diluted. On mainstem Pennypack Creek, during both wet and dry weather, mean NO_3^- concentrations were lowest at sites PP1850 and PP2020 which are upstream of the HUMJSA sewage treatment plant, and highest at PP1680, which is directly downstream of this point source. NO_3^- concentration generally decreased as a function of distance downstream from PP1680. This is an indication that the WWTP effluent is a major, if not the primary source of NO_3^- loading to mainstem Pennypack Creek (Figures 4.44, 4.45).

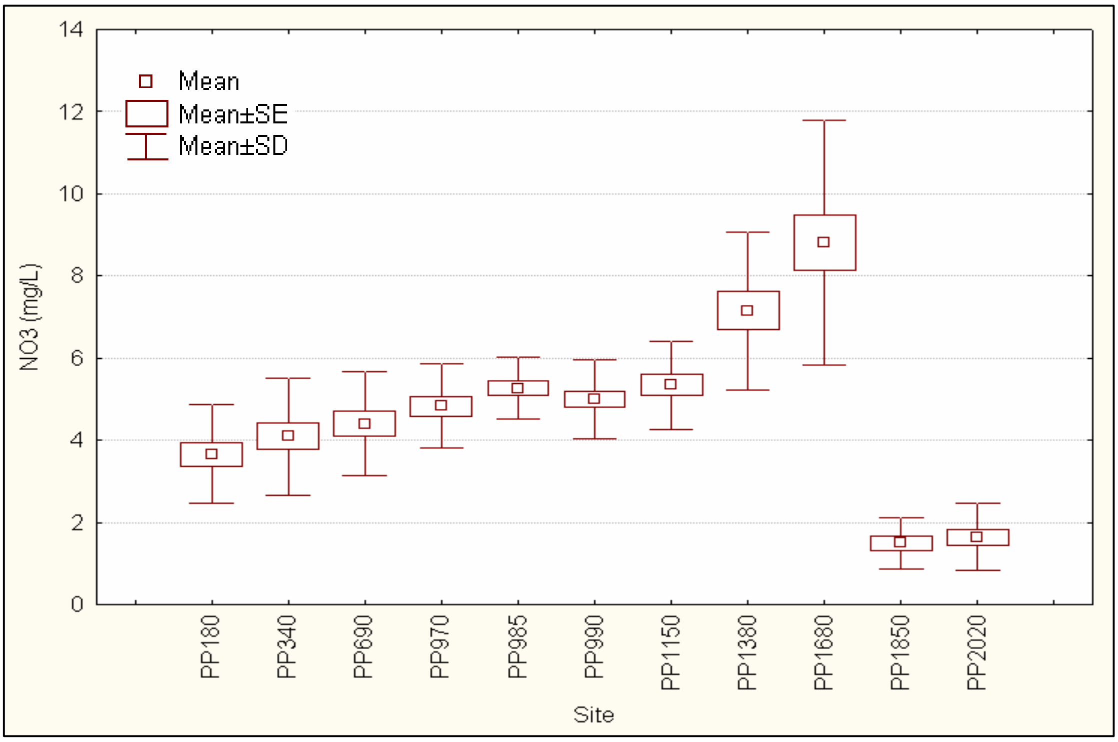


Figure 4.43 Dry Weather NO_3^- Concentrations at 11 Pennypack Creek Sites, 2007-2008

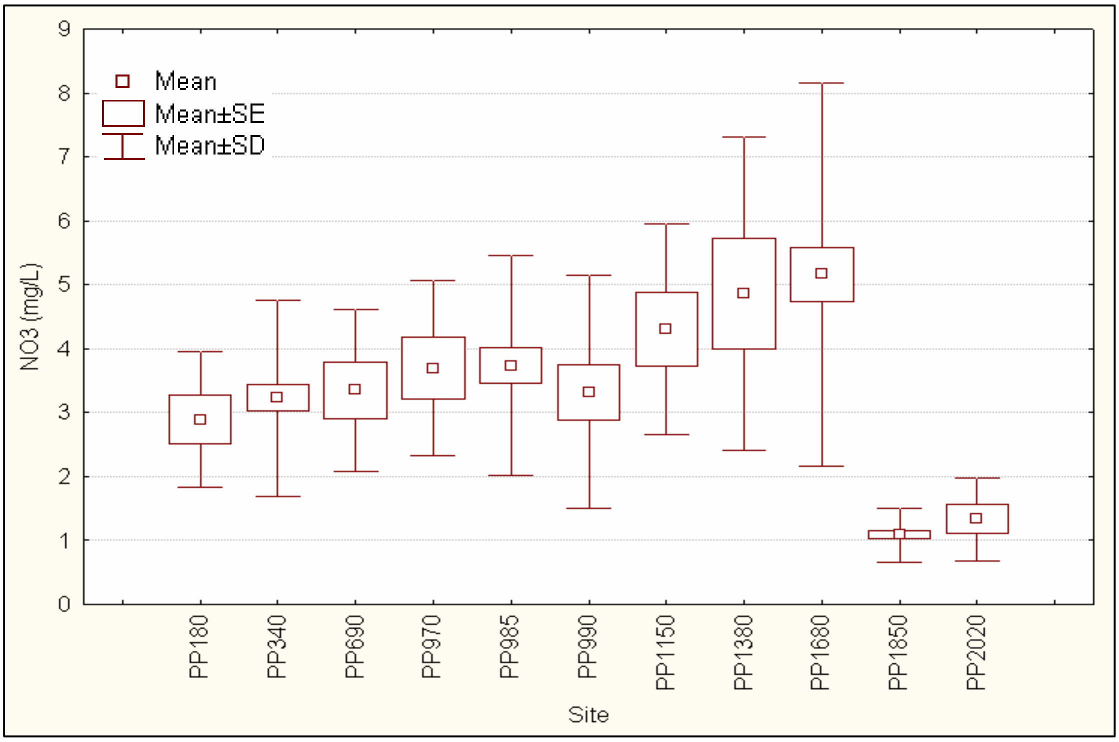


Figure 4.44 Wet Weather NO_3^- Concentrations at 11 Pennypack Creek Sites, 2007-2008

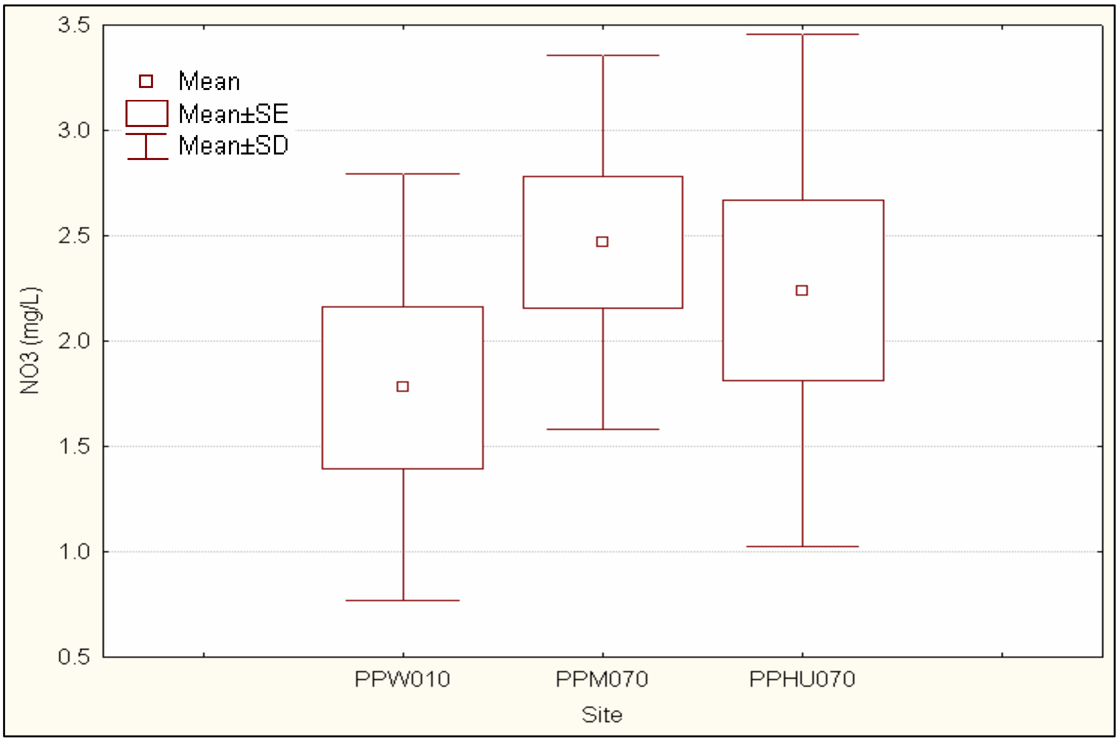


Figure 4.45 Dry Weather NO_3^- Concentrations at 3 Pennypack Creek Tributary Sites, 2007-2008

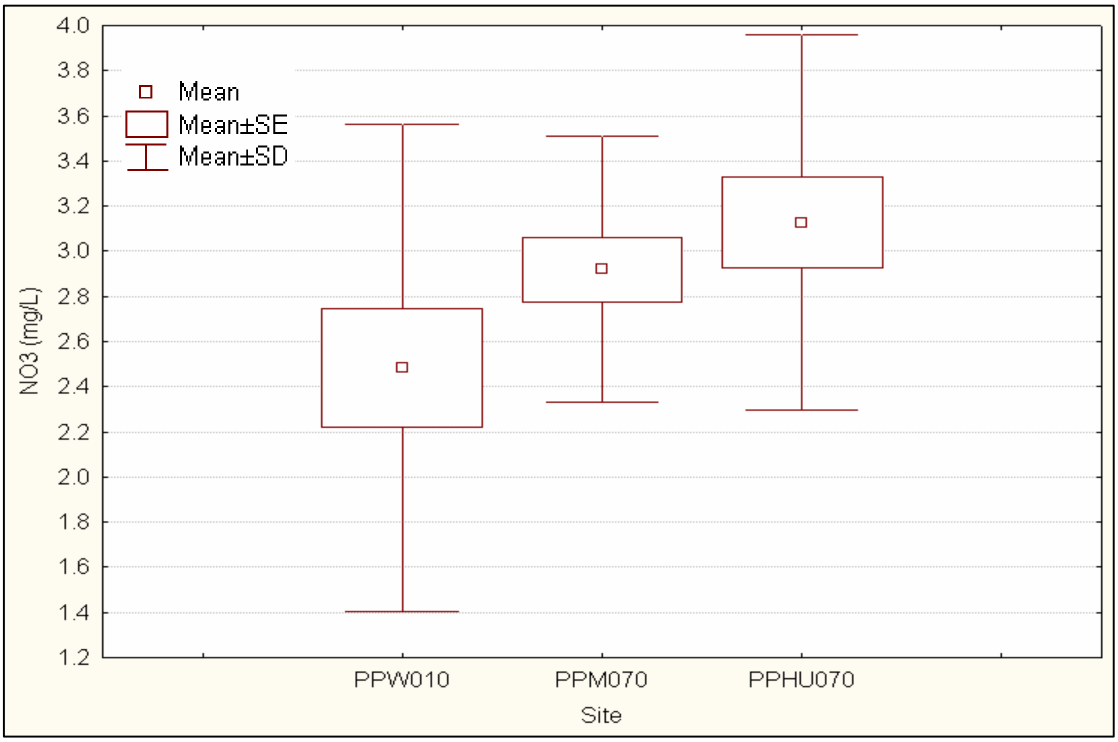


Figure 4.46 Wet Weather NO_3^- Concentrations at 3 Pennypack Creek Tributary Sites, 2007-2008

Among mainstem sites, sites PP1680 had the greatest mean NO_3^- concentration during both wet and dry weather (5.16 mg/L and 8.81 mg/L respectively). The site directly upstream of PP1680, PP1850 had considerably lower mean concentrations in both wet (1.08 mg/L) and dry (1.508 mg/L) weather. Kruskal-Wallis ANOVA was used to determine if any sites were statistically different during both wet and dry weather. Comparing only mainstem sites, the dry weather median NO_3^- concentration at PP1680 was found to be significantly higher ($H_{0.05(10)196}$=126.4., p<0.01) than the dry weather NO_3^- concentrations at: PP180 (p=1.0E-6); PP340 (p=2.5E-5); PP690 (p=3.18E-4); PP970 (p=0.007); PP990 (p=0.01); PP1850 (p=0.00); AND PP2020 (p=0.00). There was no statistically significant difference between the NO_3^- concentrations at PP1680 and sites PP985, PP1150 and PP1380. In wet weather conditions, there were statistically significant differences amongst mainstem sites ($H_{0.05(10)263}$=113.6, p<0.01). Sites: PP340 (p=0.00); PP690 (p=0.028); PP970 (p=0.006); PP985 (p=0.00); PP990 (p= 1.61E-4); PP1150 (p=2.28E-4); PP1380 (p=5.2E-5); and PP1680 (p=0.00) all had significantly greater levels of NO_3^- than the upstream site PP1850. The median NO_3^- concentration at sites PP180 and PP2020 were not statistically different from that of PP1850. There were no significant differences between NO_3^- concentrations at tributary sites (Figure 4.45, 4.47) in wet or dry weather conditions. Mainstem sites had significantly higher concentrations of NO_3^- than tributary sites in both wet ($U_{0.05(2)73,276}$=7643, *p*=0.0015) and dry ($U_{0.05(2)84,164}$=2305.5, *p*<0.01) weather.

Overall, NO_3^- concentrations were typically lower in magnitude during wet weather. Mean dry weather NO_3^- concentration in the Pennypack Creek Watershed was significantly greater than mean wet weather concentration (Mann-Whitney test $U_{0.05(2)248,349}$=31210.5, *p*<0.001). NO_3^- was significantly negatively correlated with discharge at mainstem sites with corresponding gauge data (Log transformed $r_{(97)}$= -0.57, *p*<0.01 (Figure 4.47). This relationship demonstrates dilution of

NO_3^- by stormwater. Nutrient dynamics and relationships to autotrophic community production are addressed in greater detail in section 4.5 - Stream Metabolism.

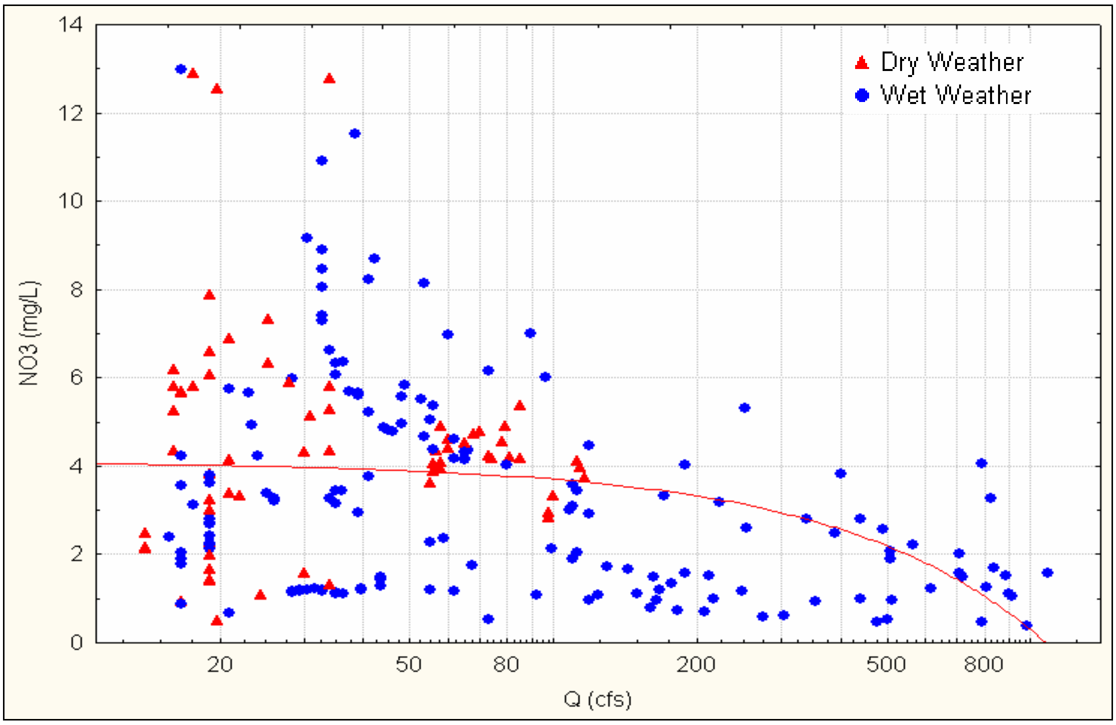


Figure 4.47 Scatterplot of Paired Streamflow and Nitrate Samples Collected from 12 Mainstem Sites in Pennypack Creek Watershed, 2007

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. TKN analysis also does not account for several other N compounds (*e.g.*, azides, nitriles, hydrazone); these compounds are rarely present in significant concentrations in surface waters.

Sampling results suggest the most important source of organic N in Pennypack 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, $r_{(323)}$ =0.436, p<0.001) between paired TKN and Fecal coliform samples (Figure 4.48), 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 ($U_{0.05(2)125,238}$=9670,p<0.001). Log transformed organic N was also significantly positively correlated with fecal coliform bacteria concentration, $r_{(407)}$=0.59, p<0.001 (Figure 4.52), suggesting that fecal material (whether from domestic animals, wildlife or human waste) is a component of the organic N load.

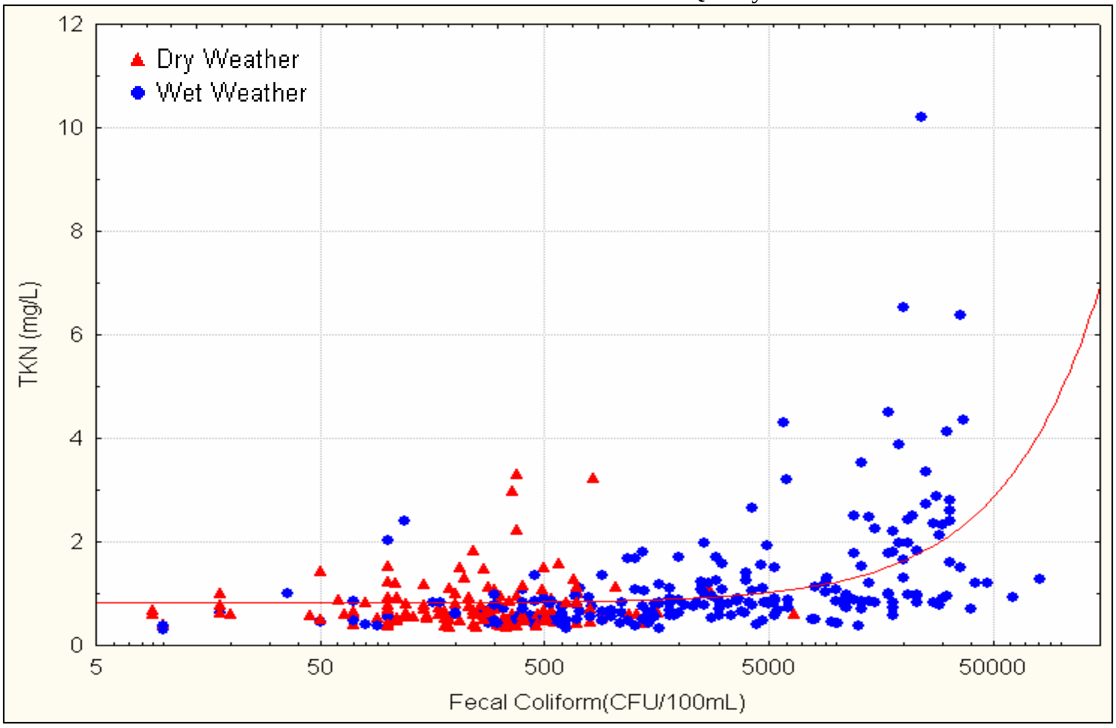


Figure 4.48 Scatterplot of Paired Fecal Coliform and TKN Samples Collected from 12 Mainstem and 3 Tributary Sites in Pennypack Creek Watershed, 2007-2008

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 Pennypack 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. Also supporting this conclusion are observed reductions in the magnitude of 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 Pennypack 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 diurnal fluctuations in dissolved oxygen concentration (Figure 4.50). Algal photosynthesis infuses oxygen during the day (often to the point of supersaturation), while respiration by algae and heterotrophic organisms remove oxygen throughout the night. Diurnal fluctuations are more pronounced in the spring and summer months than the autumn and winter months as colder water has a greater capacity for DO and biological metabolic activity is generally regulated by temperature.

Following storm events, the amplitude of daily DO fluctuations was reduced, more so than could be explained by dilution of BOD_5 alone (mean BOD_5 was slightly greater at sites PP1680 and PP340, and greater in dry weather than in wet weather, while all samples within the City of Philadelphia were below reporting limits). Scouring and flushing effects of high flows reduced periphyton and phytoplankton algal biomass, and oxygen produced through photosynthesis and consumed through respiration was reduced (*i.e.*, amplitude of diel fluctuations was dampened). Peak DO concentrations and range of diurnal fluctuations subsequently returned to pre-flow conditions (Figure 4.50) rather quickly, often in 3 days. This phenomenon was assumed to be due to accrual of algal biomass following scouring events.

Mainstem sites in Pennypack Creek Watershed experienced pronounced diurnal fluctuations in dissolved oxygen (DO) concentration. When biological activity was high, DO concentrations were observed to violate state regulated (seasonally variable) TSF minima of 4.0 and 5.0 mg/L, although violation of these standards was limited to site PP1680. 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 sections 4.4.1, 4.4.2, 4.4.4.8.2, and 4.5.1, diel fluctuations in dissolved oxygen were not always severe (Figure 4.9), and did not always result in afternoon supersaturation during episodes of violation of DO water quality standards. These findings suggest that another source of DO flux, such as biological oxygen demand (BOD), nitrogenous oxygen demand (NBOD), or some other stressor is also a major factor in the DO impairment observed at this site.

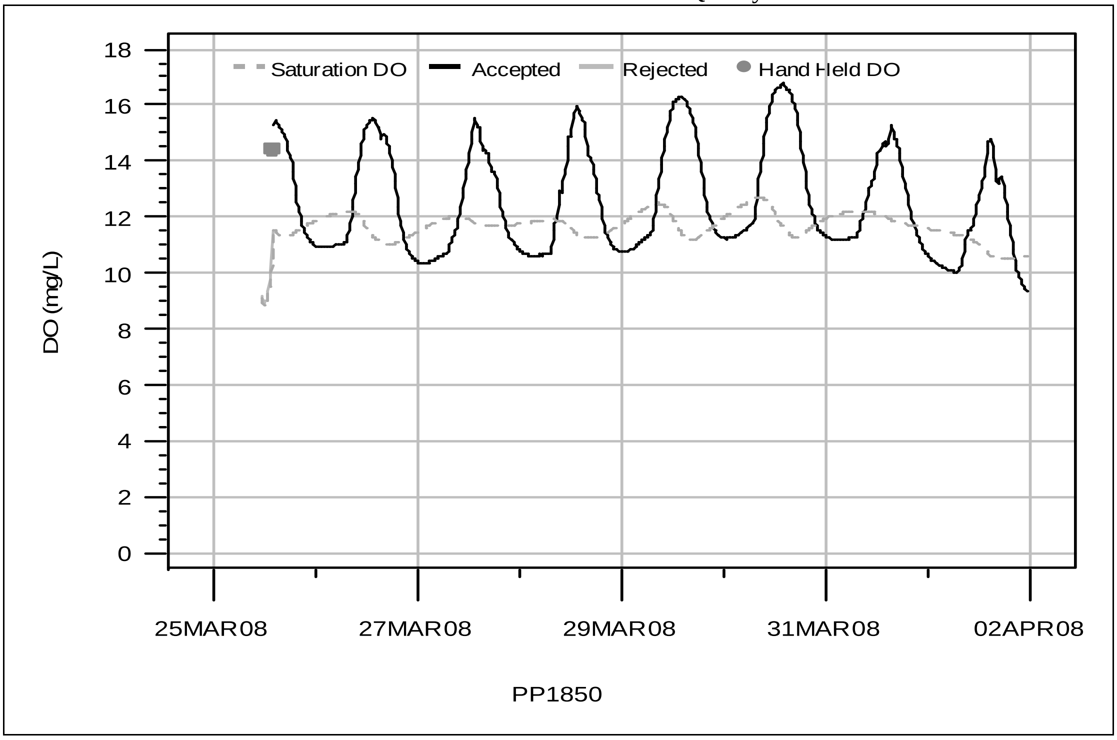


Figure 4.49 Examples of Severe Dissolved Oxygen Fluctuations at Site PP1850

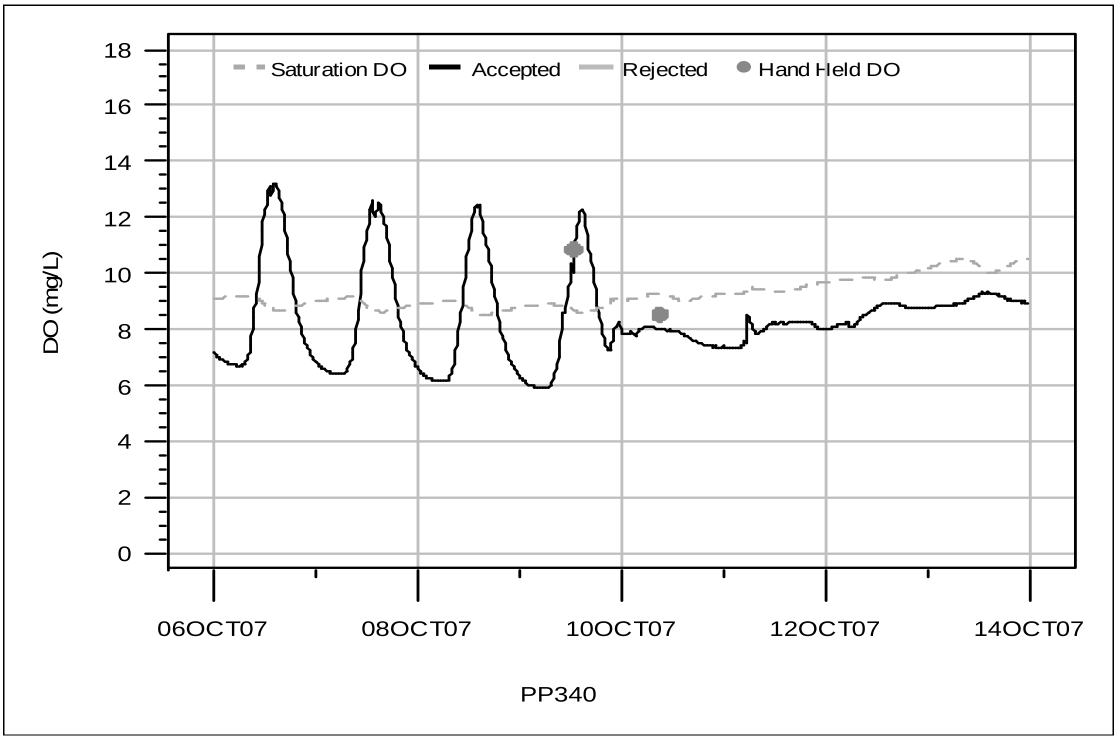


Figure 4.50 Example plot of Continuous Dissolved Oxygen Concentration at site PP340 Showing Changes Due to Rainfall. (Storm Events Occurred 10/9 through 10/11)

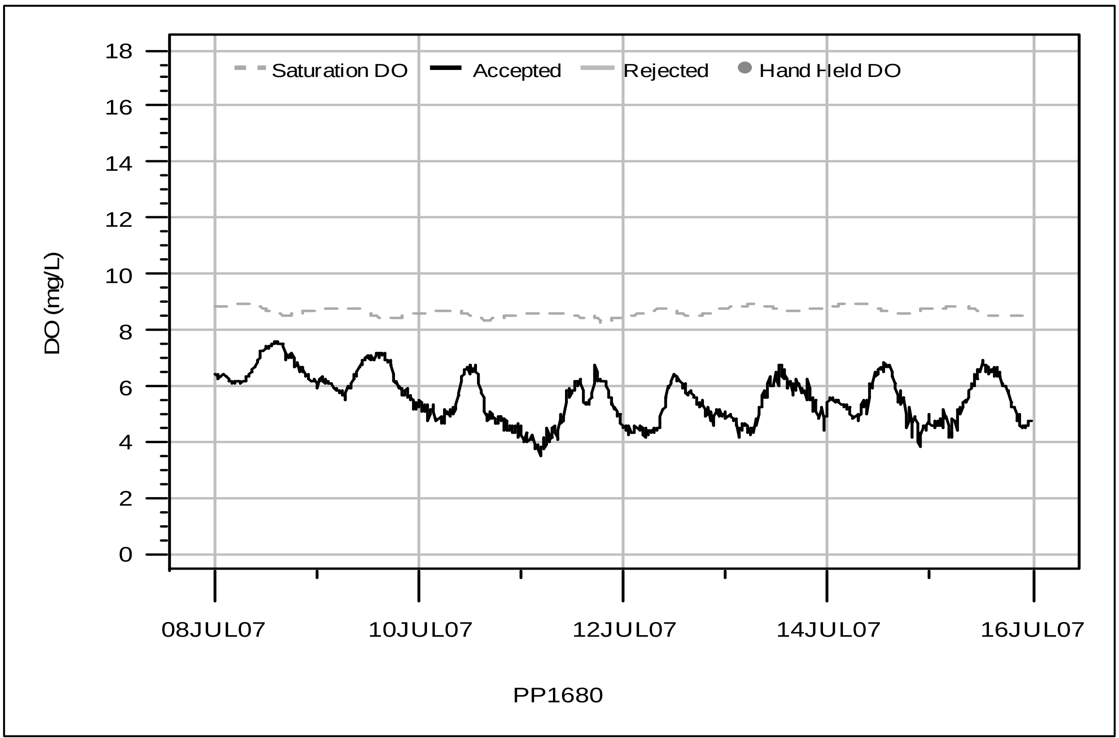


Figure 4.51 Continuous Plot of Dissolved Oxygen Concentration at site PP1680, 7/8/2008-7/16/2008

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. Severe 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 concentrations cause 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 Pennypack Creek Watershed is chiefly determined by this metabolic activity as the watershed is not heavily influenced by anthropogenic inputs, such as acid mine drainage. Comparison of diurnal fluctuations of pH at sites in Pennypack Creek Watershed found that PP340 had a greater variability between daytime and nighttime pH. This finding may be attributed to presence of periphytic algae found at this site; however, greater periphyton biomass was observed at all sites upstream of PP340.

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 with examination of the nutrient-algae relationship requiring both an autecological and community-level approach (Borchardt 1996).

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

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

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

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 700 μg/L and 25 μg/L respectively. The mesotrophic-eutrophic boundary was represented by the upper third of the distribution of values with mean and maximum benthic chl-*a* concentrations of 70 mg/m^2 and 200 mg/m^2, respectively; and TN and TP concentrations of 1500 μg/L and 75 μg/L, respectively. Other recent studies examining specific chl-*a*-nutrient relationships include Dodds *et al*. (1997), Biggs (2000), Francouer (2001), Dodds *et al*. (2002a, b), Kemp and Dodds (2002).

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 Pennypack 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, Pennypack Creek shares other common factors as well, such as land use and presence of point source discharge of treated municipal wastewater. 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 3). The target TP concentration of 205ug/L is perhaps most appropriate as a long term management goal for the watershed.

Table 4.28 Regression Models Applied Towards 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 50, 100 µg/L
Cattaneo 1987	Chl=3.6 $(TP)^{0.61}$	Canadian lakes, r^2=0.31	75, 233
Dodds *et al*., 2002 **N:P Ratio 15:1**	logChl=log(TN) 0.236 + log(TP) 0.443 + 0.155	N. America, New Zealand R^2=0.40	74, 205
Dodds *et al.,* 2002 **N:P Ratio 4:1**	logChl=log(TN) 0.236 + log(TP) 0.443 + 0.156	N. America, New Zealand R^2=0.40	110, 305

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

Algal biomass, estimated as chlorophyll-a, was greater at site PP1680 than at sites further downstream where wider channels and thus increased light availability should promote higher rates of periphyton growth. Of the four sites where periphyton biomass was sampled, PP1680 had the lowest intercellular N:P ratio at 5.4:1, which is slightly skewed from the Redfield mass ratio 7:1. These results suggest that P may not be limiting here and also that there is a greater supply of P at PP1680 than at other sites. Given the propensity of some periphytic algal taxa to store un-needed P, intercellular 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 through which further investigation through intensive chemical sampling can be undertaken.

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 0.3-0.6 µg 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 (25-50 µg PO_4-P/L) as algal mats develop (Horner *et al*., 1983, Bothwell 1989). Nitrogen has been shown to limit benthic algal growth at 55 µg NO_3-N/L (Grimm and Fisher 1986) and 100 µg NO_3-N/L (Lohman *et al*., 1991). In the past, the Redfield ratio (Redfield 1958) of cellular carbon, nitrogen, and phosphorus at 106:16:1 (atomic ratio) has been used to determine nutrient limitation. In benthic algae studies, ambient N:P ratios greater than 20:1 are considered phosphorus limited whereas those less than 10:1 are considered nitrogen limited. Nutrient limitation analysis for Pennypack Creek Watershed was focused on steady state (*i.e.*, dry weather) conditions because these are the conditions under which dissolved oxygen suppression effects are greatest and also when nutrient limitation is most likely to affect periphyton communities.

Combining the above frameworks, many of the samples collected from sites in mainstem Pennypack in dry weather were determined to be limited by phosphorus, but seldom found to be nitrogen limited (*i.e.*, N:P ratio was not between 10:1 and 20:1). 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 even micronutrients such as silica. Ignoring these physical factors, of 62 mainstem samples collected within Philadelphia during dry weather, 41 were considered phosphorus limited and 4 were considered nitrogen limited. Outside of the City of Philadelphia 57 out of 108 mainstem samples were considered phosphorus limited and 6 were nitrogen limited. Using the mesotrophic-eutrophic boundary 75 µg/L for TP and 1500 µg/L for TN (Dodds 1998), all samples collected within the City of Philadelphia were considered eutrophic with respect to both macronutrients. Mean orthophosphate concentration of samples collected in the city of Philadelphia was significantly lower ($t_{0.05(2);97}=-5.86$, $p<0.001$) than samples collected in Montgomery County, as most dry weather orthophosphate (PO4) originated from point sources outside the city. Average DIN (NO_3, NO_2 and NH_3) values were lower within the city as well ($t_{0.05(2);97}=-5.98$, $p<0.001$).

Similar to the mainstem Pennypack monitoring sites, nearly all of the tributary sites within the City of Philadelphia were determined to be phosphorus limited. Sixty out of 63 orthophosphate samples collected in Philadelphia were below the detection limit of 0.1 mg/L, while outside the city, 14 of 14 samples were considered to be orthophosphate limited. Only eleven out of 63 samples were considered eutrophic for phosphorus (as orthophosphate) while 52 samples had a nitrogen concentration above the threshold considered to be eutrophic.

Periphyton intercellular nutrient ratios were slightly skewed from the Redfield ratio toward an overabundance of P (section 5.2.5, Table 5-21), especially at site PP1680, which had the lowest N: P ratio at 5.4:1. These results suggest that P is not limited here and also that there is a greater supply of P at PP1680 than at other sites, which alludes to the continuous nutrient source presented by WWTP effluent. Given the propensity of periphytic algae and other primary producers to store un-needed 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 Pennypack Creek Watershed are dynamic. Macronutrients of greatest concern exhibited different responses to wet weather. NO_3^- concentrations were relatively stable and adequate for abundant algal growth during dry weather and diluted in wet weather (mean NO_3^- concentration 6.00, and 2.85mg/L, respectively). Conversely, other forms of N (*i.e.*, NH_3, NO_2, TKN) generally increased in concentration during wet weather, which is likely due to organic constituents in stormwater runoff and possibly SSO discharges. Nitrate (NO_3^-) and ammonium ions NH_4^+ forms are generally bioavailable, but other forms are not available for algal growth. Log transformed total organic nitrogen concentration (TON; calculated as TKN minus NH_3) showed a significant positive correlation with fecal coliform concentration, suggesting that sewage is a primary source of organic loading to the watershed ($r_{(409)}=0.60$, $p<0.001$)

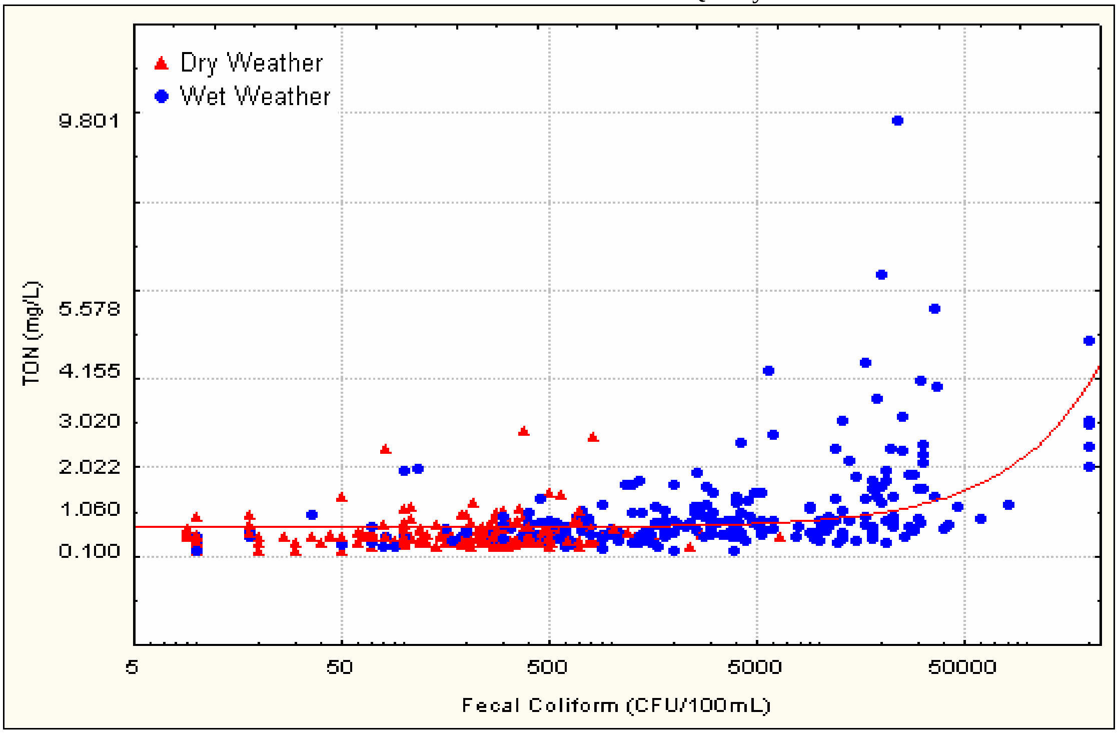


Figure 4.52 Scatterplot of paired Fecal Coliform and TON Samples Collected from 12 Mainstem and 3 Tributary Sites in Pennypack Creek Watershed, 2007-2008

Phosphorus concentrations followed a pattern similar to NO_3^-, with concentrations generally greater in samples collected during dry weather than samples collected in wet weather (Figure 4.32). Increased PO_4^{3-} concentration in dry weather (mean = 0.85mg/L) is indicative of loads originating from point sources which are periodically diluted in wet weather events.

4.6 PROBLEM SUMMARY

4.6.1 RECREATION

Table 4.29 Summary of Fecal Coliform Recreation Criteria Exceedances (Fox Chase Data Excluded)

Season	Site	No. Obs.	No. Exceed	% Exceed
Non Swimming	PP180	10	0	0
	PP340	35	17	48.6
	PP690	10	0	0
	PP970	10	0	0
	PP985	16	8	50
	PP990	6	0	0
	PP1150	15	13	86.7
	PP1380	15	7	46.7
	PP1680	34	9	26.5
	PP1850	31	9	29
	PP2020	10	0	0
	PPW010	9	0	0
	PPM070	10	0	0
	PPHU070	10	0	0
Swimming	PP180	15	9	60
	PP340	40	34	85
	PP690	15	6	40
	PP970	15	14	93
	PP985	44	42	95.5
	PP990	34	33	97
	PP1150	15	13	86.7
	PP1380	15	7	46.7
	PP1680	41	40	97.6
	PP1850	35	34	97.1
	PP2020	15	10	66.7
	PPW010	15	13	86.7
	PPM070	15	10	66.7
	PPHU070	15	13	86.7

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

4.6.2 AQUATIC LIFE

Table 4.30 Summary of Aquatic Life Acute Criteria Exceedances

Parameter	Criteria	Dry			Wet		
		No. Obs.	No. Exceed	% Exceed	No. Obs	No. Exceed	% Exceed
Al	Acute Maximum	242	13	5.37	240	68	***28.33***
DO (continuous observations)	Minimum	41234	710	**1.72**	32894	352	1.07

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

Table 4.31 Aquatic Life Acute Criteria Exceedances by Site

Parameter	Site	Dry				Wet			
		No. Obs.	No. Exceed	% Exceed	PADEP Criterion	No. Obs.	No. Exceed	% Exceed	PADEP Criterion
Al	PP180	16	0	0	A	8	4	*50*	NA
	PP340	18	0	0	A	37	14	*37.8*	NA
	PP690	16	0	0	A	8	1	*12.5*	*ID*[1]
	PP970	16	0	0	A	8	1	*12.5*	*ID*[1]
	PP985	11	0	0	A	25	8	*32*	NA
	PP990	13	0	0	A	11	3	*27.3*	NA
	PP1380	16	0	0	A	8	2	*25*	NA
	PP1680	12	0	0	A	37	17	*45.95*	NA*
	PP1850	13	0	0	A	36	4	*11.1*	*ID*[1,*]
	PP2020	16	0	0	A	8	2	*25*	NA
	PPHU070	16	0	0	A	8	1	*12.5*	*ID*[1]
	PPM070	16	0	0	A	8	1	*12.5*	*ID*[1]
	PPW010	16	0	0	A	7	3	*42.8*	*ID*
DO (continuous samples)	PP1680	9786	710	7.26	A	8288	352	4.25	A

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

NA-not attaining A–attaining ID–insufficient data * not normally distributed [1] fails 10% rule

Table 4.32 and Table 4.33 list parameters that have been identified as problems because they exceed aquatic life chronic criteria. Since these are chronic, thus long term, exposure limits, they are not split into dry weather and wet weather results.

Table 4.32 Summary of Dry Weather Aquatic Life Chronic Criteria Exceedances

Parameter	Criteria	No. Obs.	No. Exceed	% Exceed
Dissolved Cu	Chronic Maximum	98	1	1.02
Dissolved Pb	Chronic Maximum	92	0	0
DO (continuous samples)	Min. Daily Average	807	18	2.2

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

Table 4.33 Summary of Wet Weather Aquatic Life Chronic Criteria Exceedances

Parameter	Criteria	No. Obs	No. Exceed	% Exceed
Dissolved Cu	Chronic Maximum	52	2	3.85
Dissolved Pb	Chronic Maximum	52	1	1.92
DO (continuous samples)	Min. Daily Average	1400	70	5

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

Table 4.34 Summary of Dry Weather Aquatic Life Chronic Criteria Exceedances By Site

Parameter	Criteria	Site	No. Obs.	No. Exceed	% Exceed	PADEP Criterion
Dissolved Cu	Chronic Maximum	PP340	9	0	*0*	*A*
		PP985	2	0	*0*	*ID*
		PP1680	9	1	*11.1*	*ID**
Dissolved Pb	Chronic Maximum	PPW010	7	0	*0*	*A*
DO (continuous samples)	Min. Daily Average	PP1680	151	8	5	

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

NA-not attaining A–attaining ID–insufficient data *not normally distributed [1] fails 10% rule

Table 4.35 Summary of Wet Weather Aquatic Life Chronic Criteria Exceedances By Site

Parameter	Criteria	Site	No. Obs.	No. Exceed	% Exceed	PADEP Criterion
Dissolved Cu	Chronic Maximum	PP340	5	1	20	ID
		PP1680	5	0	0	ID
Dissolved Pb	Chronic Maximum	PPW010	4	1	25	ID
DO (continuous samples)	Min. Daily Average	PP1680	110	13	***12***	

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

NA-not attaining A–attaining ID–insufficient data * not normally distributed [1] fails 10% rule

4.6.3 STREAM TROPHIC STATUS

Table 4.36 Summary of Stream Trophic Criteria Exceedances

Parameter	Criteria	Dry			Wet		
		No. Obs.	No. Exceed	% Exceed	No. Obs	No. Exceed	% Exceed
Chlorophyll-*a*	Maximum	86	40	***47***	10	1	*10*
pH (continuous observations)	Range	40876	10	0.02	32689	7	0.02
Temperature (continuous samples)	Maximum	42378	8901	*21*	34401	9228	*28*
TKN	Maximum	251	73	*29*	278	167	*60*
TP	Maximum	209	125	*60*	230	166	*72*
TSS	Maximum	284	20	*7*	323	102	*31*
Turbidity	Maximum	36096	1971	5.5	32993	9228	*28*

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

Table 4.37 Summary of Stream Trophic Criteria Exceedances by Site

Parameter	Site	Dry			Wet		
		No. Obs.	No. Exceed	% Exceed	No. Obs.	No. Exceed	% Exceed
Turbidity	PP340	6543	255	3.9	4959	1828	36.8
	PP985	8261	550	6.66	7424	2614	35.241
	PP1680	10179	191	1.88	10007	2084	20.83
	PP1850	11113	975	8.77	10603	2702	25.48
pH (continuous observations)	PP340	8769	10	0.11	5883	0	0
	PP1680	10449	0	0	9703	6	0.06
	PP1850	12133	0	0	10221	1	1
Temperature (continuous observations)	PP340	8849	1097	12.4	5907	1209	20.47
	PP985	10533	948	9	8389	1470	17.5
	PP1680	14165	10666	46.51	9398	4677	47.54
	PP1850	12330	1895	15.37	10267	1406	13.69

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

4.6.4 PROBLEM PARAMETER SUMMARY

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

In Table 4.38, the problem and potential problem parameters are listed by category. They are also categorized as either wet or dry weather problems, if applicable. Toxic metals were categorized further to address separate chronic vs. acute criteria.

Table 4.38 Summary of Problem and Potential Problem Parameters

Parameter	Standard	Dry	Wet
Recreation			
Fecal Coliform	Maximum Swimming Season	PP340 PP970 PP985 PP990 PP1150 PP1680 PP1850 PP2020 PPHU070 PPM070 PPW010	PP180 PP340 PP970 PP985 PP990 PP1150 PP1380 PP1680 PP1850 PP2020 PPHU070 PPM070 PPW010
Fecal Coliform	Maximum Non-Swimming Season	---	PP340 PP985 PP1380
Aquatic Life-Acute			
Al	Acute Maximum	---	PP180 PP340 PP985 PP990 PP1380 PP1680 PP1850 PP2020
Continuous Data			
DO	Minimum Daily Average		
DO	Minimum Instantaneous	PP1680	PP1680
Temperature	Maximum	PP340 PP985 PP1680 PP1850	PP340 PP985 PP1680 PP1850
Turbidity			PP340 PP985 PP1680 PP1851
Other Parameters Based on Reference Values			
Fe	Maximum		PP340 PP985 PP990 PP1680

5 BIOLOGICAL CHARACTERIZATION

5.1 SUMMARY OF HISTORICAL AND EXISTING INFORMATION

As described in Section 2, much of the suburban development within the Pennypack 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. Pennypack Creek Watershed has also been increasingly used for disposal of wastewater. While improvements in treatment have somewhat offset the most serious impacts, nutrients from wastewater, 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 had a deleterious effect on natural communities.

The ecological value of wetlands and headwaters 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. Nearly all first and zero order streams (springs, ephemeral streams, and small streams without tributaries) in Pennypack 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 critical to sustaining populations of certain sensitive macroinvertebrates.

As development has progressed, infrastructure needs have grown. While a large portion of the land directly abutting Pennypack Creek Watershed and its major tributaries is 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. Hundreds of dams have also been constructed on Pennypack Creek and its tributaries. Larger dams alter instream habitats and impede passage of native migratory fish, while man-made small landscape and farm ponds disrupt the natural habitat and ecological processes of tributaries to Pennypack Creek, displacing sensitive macroinvertebrates that rely on intact forested small order streams.

5.1.1 PADEP AQUATIC BIOLOGY INVESTIGATIONS OF PENNYPACK CREEK 1969-1980

In 1969, PADEP conducted an aquatic biology investigation of Pennypack Creek in cooperation with, and at the request of the Pennsylvania Fish and Boat Commission. The stated purpose of the investigation was to determine whether water quality in Pennypack Creek was appropriate for stocking trout. The initial investigation involved water chemistry sampling and benthic macroinvertebrate surveys (quantitative Surber samples) at 8 sites along mainstem Pennypack Creek. PADEP summarized results of these studies, along with recommendations that trout not be stocked in Pennypack Creek in April of 1969 and that additional investigations be carried out in order to determine whether improvements water quality and aquatic life would result from additional treatment of municipal wastewater. Additional studies were conducted 1970-1980. These studies are noteworthy as a good source of quantitative biological and water chemistry data for Pennypack Creek, some of which predate the Federal Clean Water Act. Several sites sampled 1969-1980 (Figure 5.1) were located nearby present day USGS gages or PWD sampling sites, allowing a basic evaluation of trends in water quality and biological community health over the past 4 decades.

5.1.2 NLREEP Master Plan

In 1999 and 2000, the Academy of Natural Sciences of Philadelphia (ANS) submitted a 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 5, Pennypack Creek was one of the last watersheds within the City of Philadelphia to be developed (ANS 2000). The Bromley Map of 1894 (Figure 5.2) depicts the relatively limited development along the mouth of the Pennypack, as many of the other watersheds in the City of Philadelphia were more heavily developed by this time. 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 Pennypack Creek.

There is scant historical information about aquatic life in Pennypack 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. He documented relative occurrence of fish species in a variety of habitats, from ponds and intermittent streams to both the non-tidal upper reaches and the tidal reaches of Pennypack Creek near the Delaware confluence. Fowler noted 24 species above the Frankford Ave. Dam, which he considered to be naturally supported by the Creek. Of these, many native species such as brook trout, margined madtom, tadpole madtom, bridle shiner, and fallfish have been extirpated from the watershed. He also noted introduced and sport fishes, such as bluegill, chain pickerel and largemouth bass.

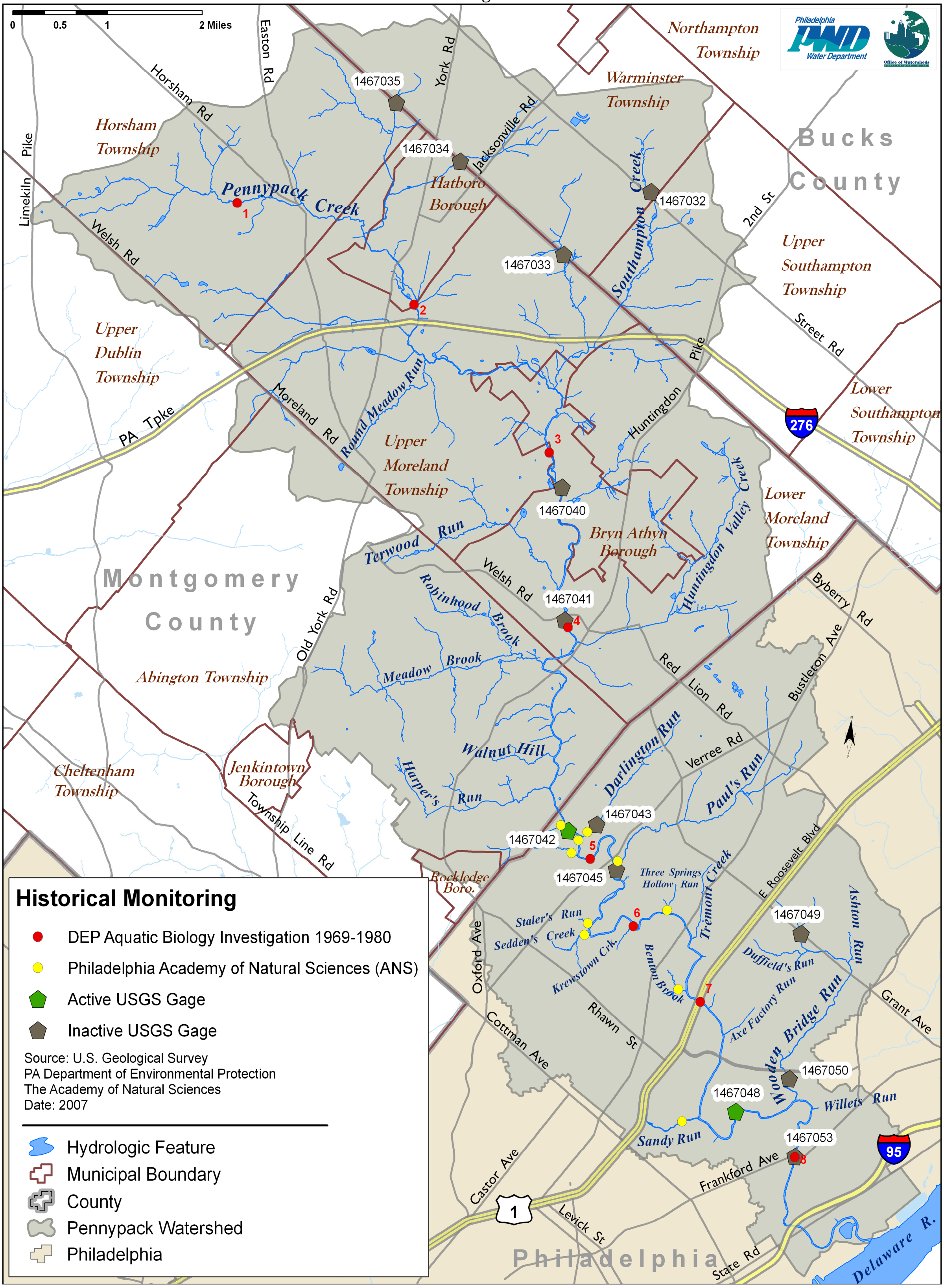


Figure 5.1 Historical Monitoring Activities in Pennypack Creek Watershed, 1969-1999

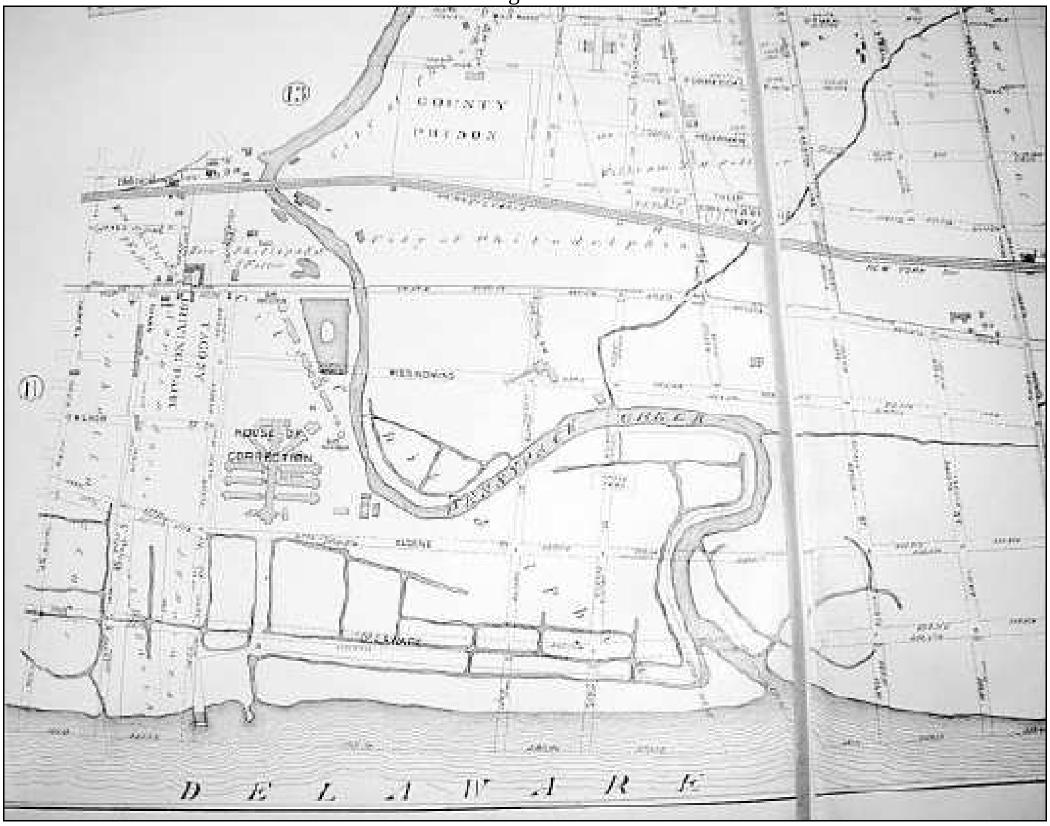


Figure 5.2 Mouth of Pennypack Creek and early Delaware Riverfront Development (Bromley 1894)

ANS (2000) cited the abundance of modern historical fish sampling records as the primary reason for reduced sampling effort in Pennypack Creek as part of the NLREEP assessment program. Seven sites were sampled, and while the qualitative information from this collection effort allowed comparisons to present day conditions, the electrofishing procedures were not thorough enough to account for all species that may have been present. Furthermore, the methods employed were not appropriate for quantitative metrics or estimating biomass.

Conversely, methods used by ANS for macroinvertebrate collection used at 11 sites throughout the watershed (10 tributary and one mainstem site, Figure 5.1) were very thorough and quantitative. Macroinvertebrates were collected from 3 riffles within each site using a fixed area Surber sampler ($1ft^2$) or a portable invertebrate box sampler ($0.5m^2$) for deeper riffles. Quantitative estimates of density (number of indivuduals/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. 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).

5.1.3 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 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 19 locations in Pennypack Creek Watershed in 1999.

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 Pennypack 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. A small number of stream segments in Southampton Creek and several downstream segments in Philadelphia were listed for more serious pollution impairments such as priority organic pollution, pathogens, metals, and low dissolved oxygen. Subsequent sampling resulted in listing of additional segments in 2000 and 2004. 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 2008).

5.1.4 PWD 2002 Baseline Assessment of the Pennypack Creek Watershed (Published 2003)

In 2002, through a joint effort between the Philadelphia Water Department's Bureau of Laboratory Services and Office of Watersheds, EPA Rapid Bioassessment Protocols III and V as well as physical and chemical assessments were used to evaluate the ecological health of Pennypack Creek Watershed. Physical habitat, benthic macroinvertebrates and fish were sampled from 14 and 6 sites of mainstem Pennypack Creek and its tributaries, respectively. Water quality data was collected at 7 mainstem sites and 6 tributary sites (PWD 2003).

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 G), allowing for comparison of macroinvertebrate and fish communities in Pennypack Creek Watershed to regional reference conditions. In comparison to previous work, PWD 2002 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 quantitative, but that study was restricted to Philadelphia only. PWD fish surveys of 2002 were quantitative, unlike earlier studies conducted by PADEP and ANS.

A total of 3,452 benthic macroinvertebrate individuals from 30 taxa were identified during the 2002 Pennypack Creek Baseline Assessment. Subsequent analysis of the benthic macroinvertebrate community structure and relevant biodiversity metrics observed in the Pennypack Creek Watershed indicated severe impairment based on the combination of poor taxa richness, elevated HBI scores, trophic structures dominated by generalist feeders (89.63%) and the lack of sensitive and EPT taxa. Furthermore, in terms of proportional abundance, the benthic assemblages of most communities were dominated by either Chironomidae (55.13%) or net-spinning caddisflies (24.83%) 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 16,869 individuals of 39 species representing 10 families were collected throughout Pennypack Creek Watershed in the 2002 fish assessment. The fish community was dominated by a small number of taxa, as seven species contributed over 80% of the abundance. Similarly, three species made up 80% of total biomass, with white sucker (*Catostomus commersonii*) contributing more than 50% 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 IBI score for Pennypack Creek Watershed was 30 (out of 50), placing it in the "fair" category.

5.1.5 PADEP Integrated List of Waters

In 2004, PADEP began publishing the 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). PADEP published Integrated Lists again in 2006 and 2008, listing additional segments of Pennypack Creek Watershed as Impaired for the Aquatic Life Designated Use (Figure 5.3) and making some changes to the listed sources and causes of impairment. The 2008 Integrated List of waters is thus the most up-to-date report on the listing status of Pennypack Creek Watershed for Federal Clean water Act Reporting Purposes.

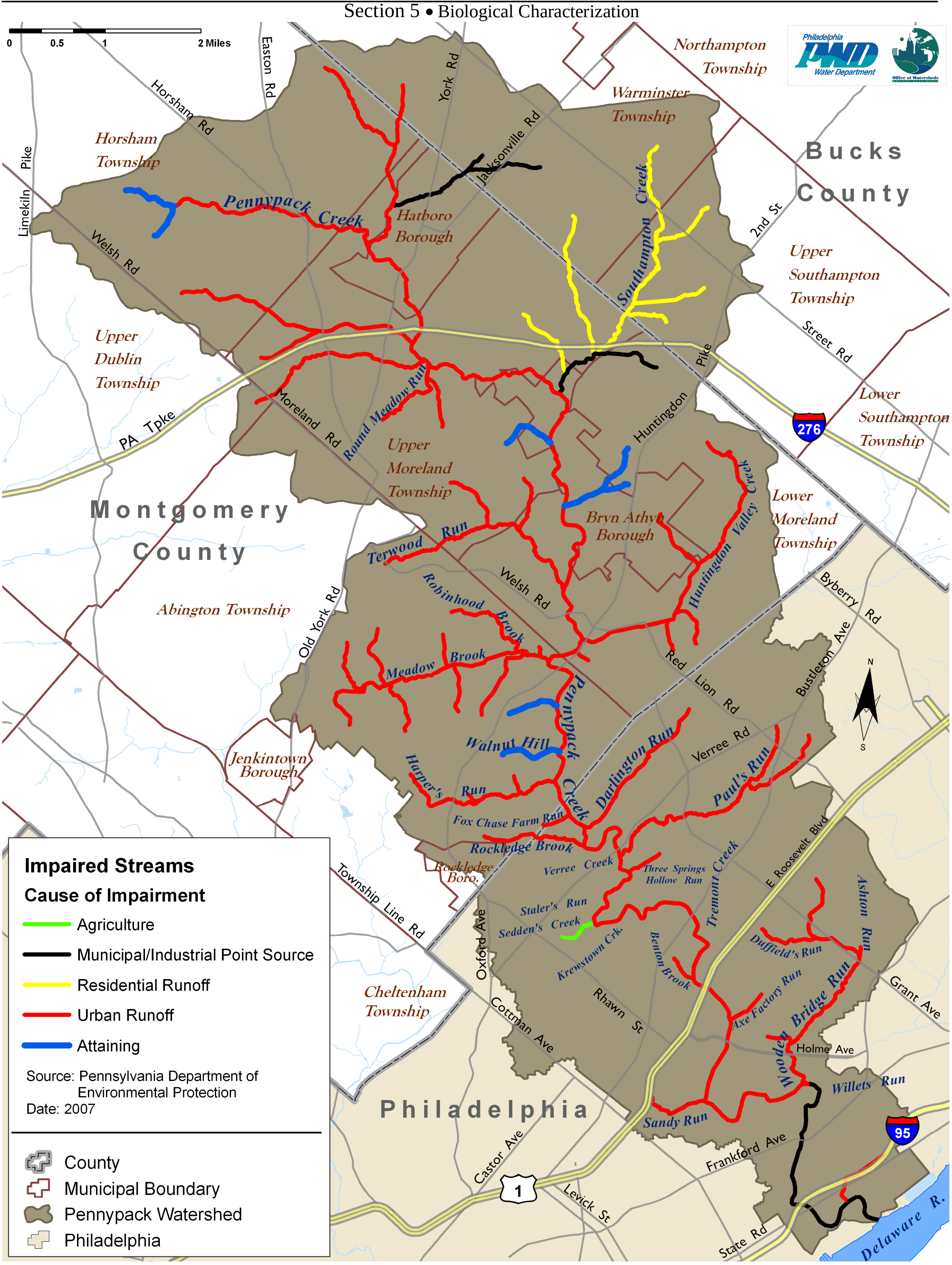


Figure 5.3 Impaired Streams in Pennypack Creek Watershed with Cause of Impairment, 2008

5.1.6 SUMMARY OF HISTORIC BIOLOGICAL INFORMATION

Results of all historical studies have been consistent and clear; impairment was evident in both macroinvertebrate and fish communities, whether measured as taxa richness, ecosystem function, or various numeric criteria used to evaluate aquatic communities (*e.g.*, Hilsenhoff Biotic Index, EPT index, Fish MIwb, etc.). The 2003 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 has improved slightly in Pennypack Creek Watershed over the past 40 years, but the stream generally remains impaired with respect to macroinvertebrate and fish communities. Impairment within the Pennypack Creek Watershed generally follows a pattern seen in urbanized watersheds worldwide.

After water quality improvements were made in the 1970s and 1980s, depauperate benthic macroinvertebrate assemblage and highly skewed fish community present throughout the watershed were determined to be 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.*, storm water or combined sewer outfalls), physical impairments to the habitat structure within the Pennypack 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 Pennypack 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 Pennypack 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.* 5yrs) 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).

Pennypack 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 USEPA. Reference reaches in French Creek Watershed (Chester County, PA) (Appendix H) 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 Watershed Management Plans. 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 (IBI) rather than amending existing Watershed Management Plans and supporting documentation.

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.

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.

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 superb 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 has practical benefits as PADEP water pollution biologists no longer need 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 and 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 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 waterbody to improve or degrade further. The BCG is arranged in tiers of condition, from communities that are equivalent to natural and undisturbed (BCG Tier 1 and 2) to completely disrupted (BCG Tier 6) (Figure 5.4).

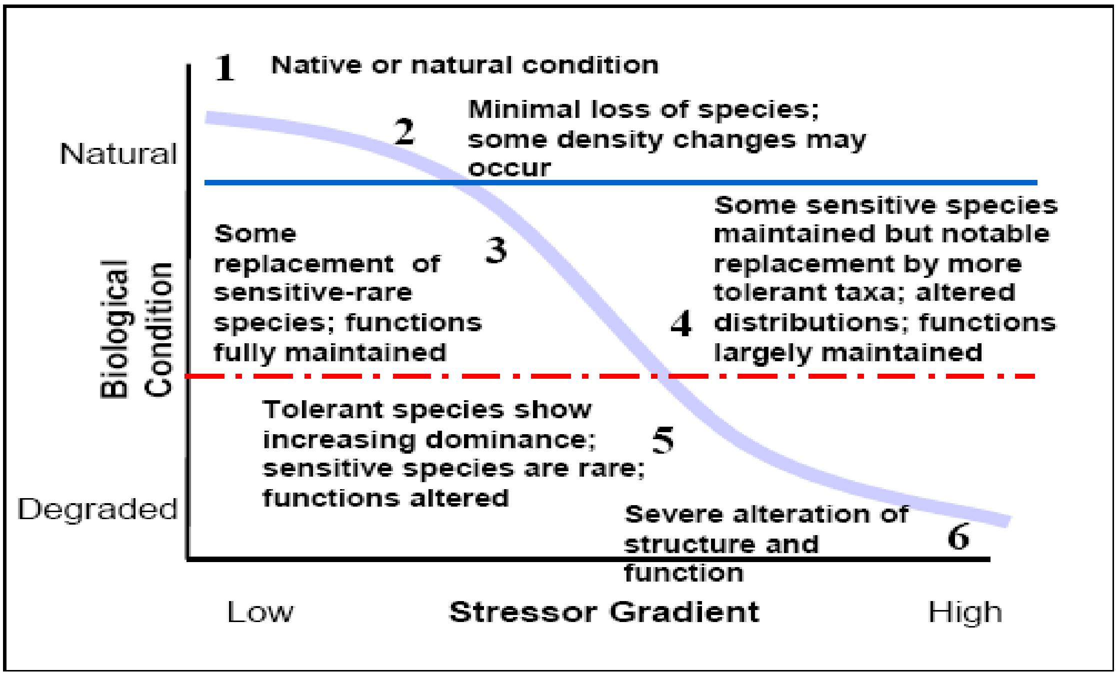


Figure 5.4 The Biological Condition Gradient (as adapted from Davies & Jackson 2006, in PADEP 2007a)

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 ten 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 5.5). 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).

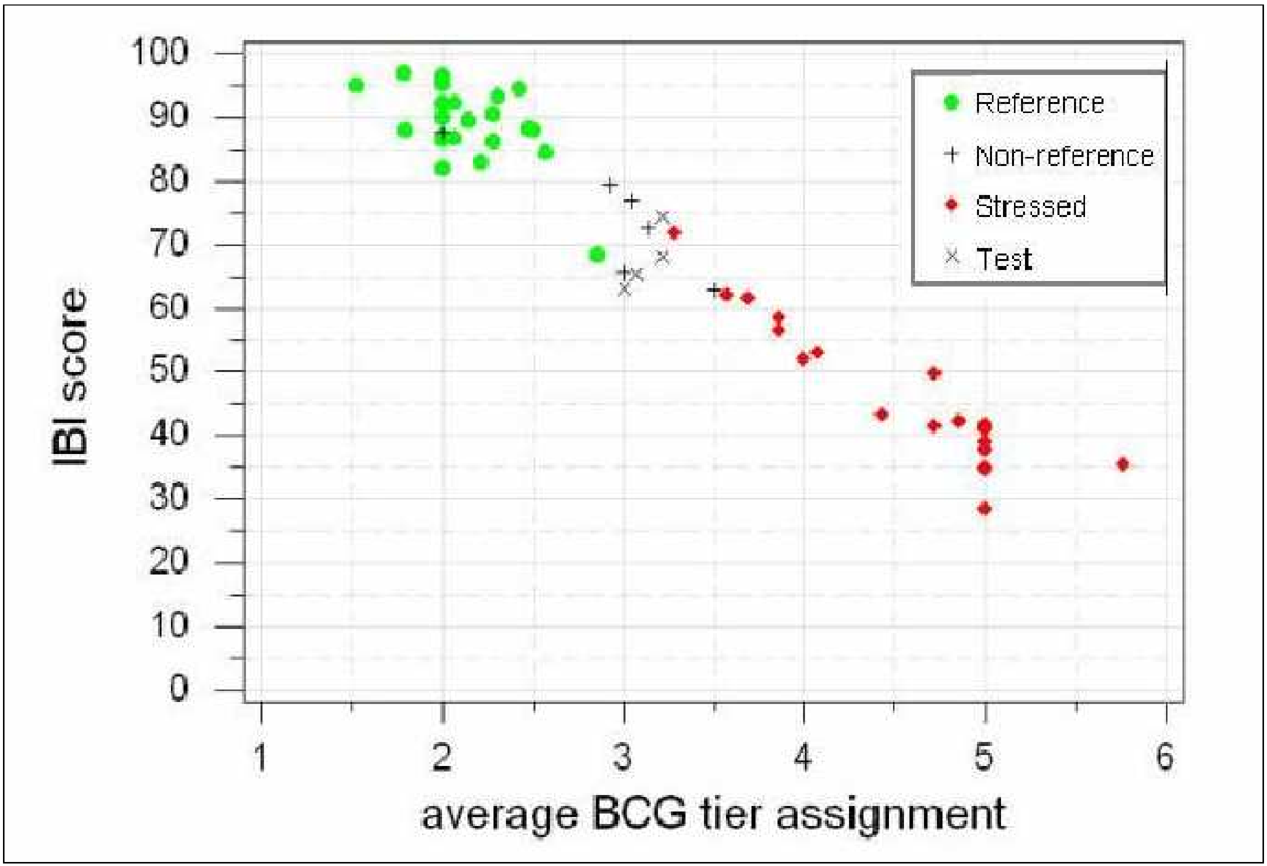


Figure 5.5 Benthic IBI score vs. Biological Condition Gradient Tier Assignment for 53 sites in Pennsylvania (PADEP 2007)

For urbanized watersheds which dominate the landscape of Southeastern Pennsylvania, this could have severe implications on the attainability of Tiered Aquatic Life Use (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 (6 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 Benthic Macroinvertebrate Assessment

5.3.1 Monitoring Locations

From 3/6/07 to 3/28/07, PWD conducted Rapid Bioassessment Protocols (RBP III) at twenty-four (n=24) locations within Pennypack Creek Watershed. Surveys were conducted at 13 mainstem locations and 11 tributary locations. Six of the 19 tributary sites were located within the City of Philadelphia (Figure 5.6).

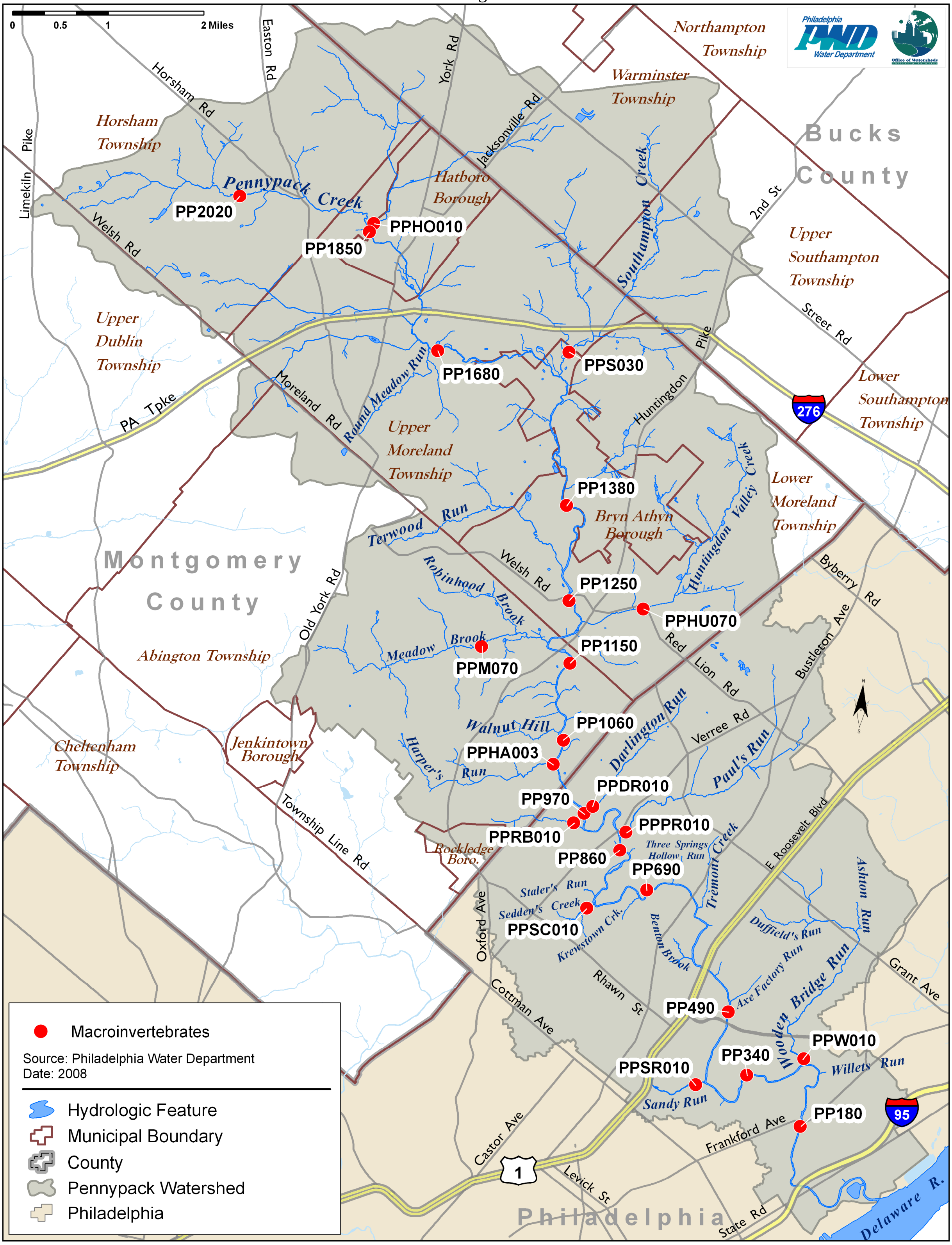


Figure 5.6 Benthic Macroinvertebrate Assessment Sites in Pennypack Creek Watershed, 2007

5.3.2 FIELD STANDARD OPERATING PROCEDURES

Using the PADEP Instream Comprehensive Evaluation 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 10cm as substrate allowed. This procedure was repeated at other riffle locations of variable flow within the 100m 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 $1m^2$ kicknet (500µm); samples are a composite of 6 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 2 to 6 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).

5.3.3 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 4 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 Pennypack Creek Watershed in 2002 and 2007, further complicated by differences in field and laboratory methods. For example, total area sampled was approximately $2m^2$ and $0.5m^2$, respectively. Furthermore, stream sample area represented by each subsample, or “plug” in the PADEP ICE protocols is approximately twice as large as in the PWD RBP III protocol.

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.

5.3.4 DATA ANALYSIS

As described in Sections 5.2.4 and 5.3.3, 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 2002 baseline assessment of Pennypack Creek Watershed for clarity and in order to retain compatibility with previous studies and ongoing Watershed Management Planning initiatives. Analyses based upon the 2002 RBPIII Baseline Assessment metrics and 2007 PADEP ICE assessment metric frameworks are presented in sections 5.3.5.2.1 and 5.3.5.2.2, respectively.

Baseline PWD macroinvertebrate assessments in Pennypack Creek (PWD 2003) were compared to reference sites in French Creek Watershed, Chester County PA. Data for 5 scoring metrics and 3 supplementary metrics (Table 5.3) were used to compare sites and assign total biological quality scores (Table 5.6). 2007 data were compared to these same metrics to facilitate a comparison between these assessments. As PADEP ICE sample processing methods require a sample size of 200±20% individuals compared to the 1999-2006 data collected with minimum 100 individual sample size, PWD investigated actual sample sizes from the 2002 assessment to determine whether randomized subsampling or other normalization procedures should be used to standardize sample sizes and maintain compatibility with pre-established IWMP indicators for Indicator Status Update reports (Table 5.4). It was decided that although some sites sampled in 2002 had fewer than 160 individuals per sample, the average number of individuals was within the specified range 160-240, so no normalization was performed.

Table 5.3 RBP III Macroinvertebrate Community Metrics used in PWD 2002 Baseline Assessment of Pennypack 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	35
EPT Taxa Richness	23
Beck's Index	39
Shannon Diversity Index	2.9
Hilsenhoff Biotic Index	1.78
Percent Intolerant Taxa	92.5

5.3.5 RESULTS

5.3.5.1 WATERSHED OVERVIEW

A total of 4,451 individuals from 34 taxa were identified during the 2007 macroinvertebrate survey of Pennypack Creek Watershed. Some individual subsamples were observed to contain relatively few individuals, and many samples required sorting of more than 10 subsamples, or "plugs", in order to count the required number of invertebrates (Figures 5.6 and 5.7). As the 2007 assessment was the first 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. All 28 subsample "plugs" were counted from the sample collected on the Sedden's Run tributary, returning a total of only 76 individuals.

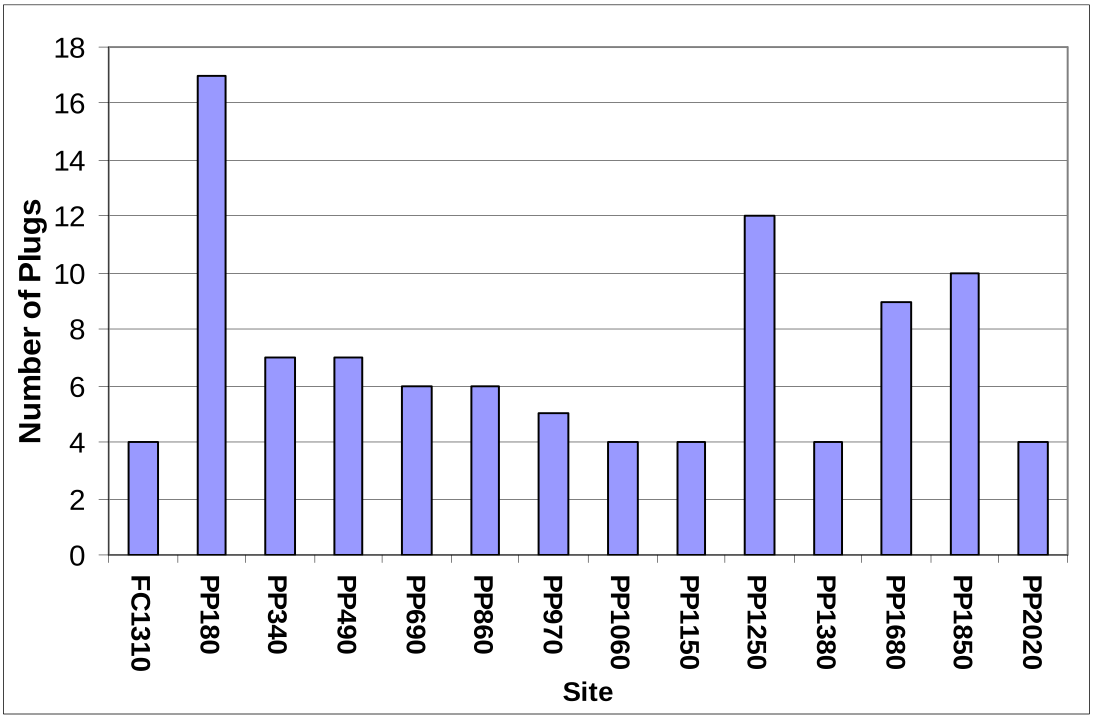


Figure 5.7 Number of Subsamples, or "Plugs" Sorted for 13 Mainstem Pennypack Creek Sites, 2007 and French Creek Reference site, 2005

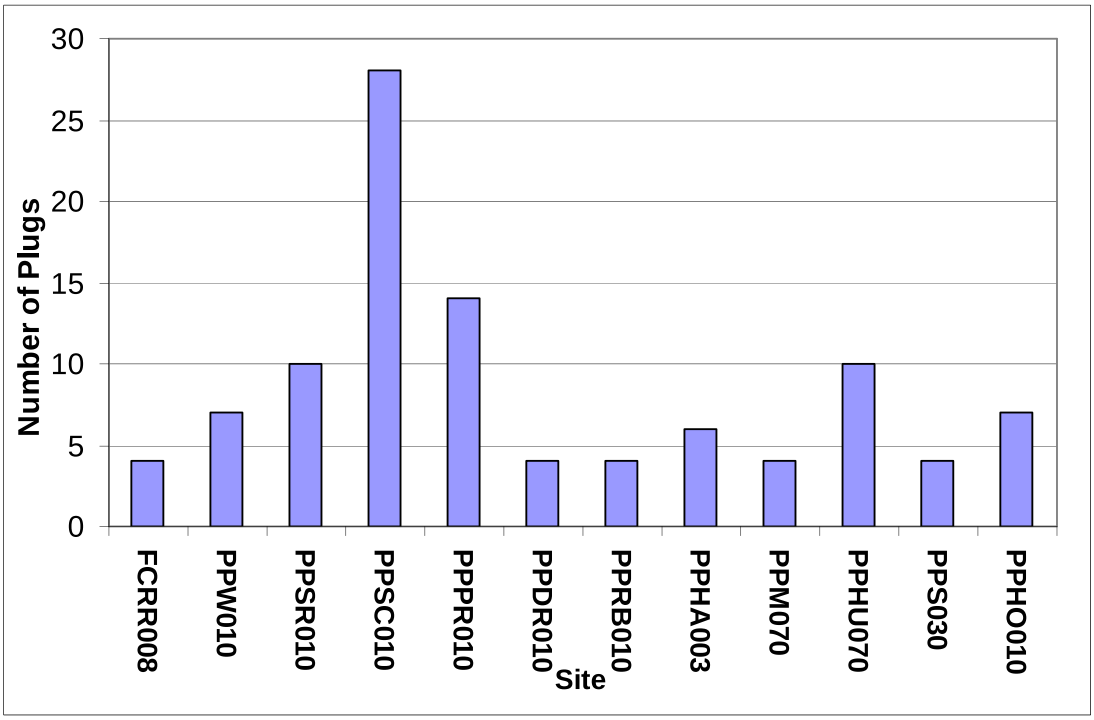


Figure 5.8 Number of Subsamples, or "Plugs" Sorted for 11 Pennypack Creek Tributary Sites, 2007 and French Creek Reference site, 2005

Average taxa richness of sites within Pennypack Creek Watershed was ten (n=10) taxa. Overall, moderately tolerant (86.7%) and generalist feeding taxa (79.75%) dominated the watershed. The average Hilsenhoff Biotic Index (HBI) of all assessment sites was 6.27. Pollution sensitive Ephemeroptera, Plecoptera, and Trichoptera (EPT) taxa were rare throughout the watershed. The most commonly collected EPT taxon was the Fingernet caddisfly (*Chimarra* spp.), which was found at 6 sites. The most common sensitive taxon observed in the macroinvertebrate assessments was the Tipulid *Antocha* spp., which was found at 19 sites (10 mainstem and 9 tributary sites). Modified EPT taxa are Ephemeroptera, Plecoptera, and Trichoptera (EPT) taxa with HBI score of four or less. Pennypack Creek Watershed averaged 0.67 Modified EPT taxa per site. The monitoring location on Harpers Run (site PPHA003) in Lorimer Park, Abington Township had the highest number of Modified EPT taxa collected at any site with 3. A single Modified EPT taxon was observed at sites PP180, PP340, PP860, PP1060, PP1150, PP1380, and PP2020 on mainstem Pennypack Creek.

Chironomidae (non-biting midges) dominated the benthic assemblage of the watershed. The percent contribution of Chironomidae midges ranged from 43.7% to 80% at mainstem sites and 43.4% to 95.2% at tributary sites. Oligochaetes and net-spinning caddisflies (Hydropsychidae) were the most numerically abundant taxa after Chironomidae, with the exception of site PP1680 where oligochaetes were the dominant taxon (44.91%). 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 Pennypack Creek Watershed by midges 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 12.4% of taxa in the watershed and reached a maximum percent contribution of 31% (site PP340). 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 can not 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 (75.02%) and filterers (18.92%). Scrapers (3.91%), omnivores (1.67%), predators (0.26%) and shredders (0.22%) were very rare in the Pennypack Creek Watershed. 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) like 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 5.5). 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 (86.7%) dominated the macroinvertebrates collected in Pennypack Creek Watershed. Sensitive taxa were poorly represented (2.1 %), 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 zero (very sensitive) to ten (very tolerant). The mean HBI score for Pennypack Creek Watershed was 6.27. The dominance of moderately tolerant individuals and general lack of pollution sensitive taxa contributed to elevated HBI. In comparison, mean HBI score of the French Creek reference sites was 3.63, which suggests severe impairment in Pennypack Creek Watershed.

Another metric that employs macroinvertebrates as indicators of biotic integrity is the unique taxa metric. Unique taxa are taxa 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 as 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 (FC1310, FCR008) contained greater numbers of unique taxa (Table 5.5) than Pennypack 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. Unique taxa collected at site PP1680, downstream of wastewater treatment discharge, were moderately tolerant of pollution (mean unique taxa HBI=7). Comparatively, the mean HBI of the unique taxa found in FC1310 and FCR008 were 3.25 and 1.8, respectively.

Table 5.5 Unique taxa of French Creek and Pennypack Creek Watersheds

Site	Site HBI	Order	Family	Genus	Taxon HBI
FC1310	3.19	Trichoptera	Brachycentridae	Brachycentrus	1
FC1310	3.19	Trichoptera	Uenoidae	Neophylax	3
FC1310	3.19	Megaloptera	Corydalidae	Corydalus	4
FC1310	3.19	Diptera	Empididae	Clinocera	5
FCRR008	4.07	Trichoptera	Rhyacophilidae	Rhyacophila	1
FCRR008	4.07	Plecoptera	Peltoperlidae	Tallaperla	1
FCRR008	4.07	Plecoptera	Taeniopterygidae	Oemopteryx	1
FCRR008	4.07	Ephemeroptera	Isonychidae	Isonychia	3
FCRR008	4.07	Diptera	Ephydridae	-----	6
PP1060	5.87	Ephemeroptera	Ameletidae	Ameletus	0
PP1680	7.88	Amphipoda	Crangonyctidae	Crangonyx	6
PP1680	7.88	Hirudinea	-----	-----	8
PP340	5.85	Trichoptera	Hydroptilidae	Hydroptila	6
PPHA003	5.76	Trichoptera	Philopotamidae	Dolophilodes	0
PPHO010	5.89	Gastropoda	Ancylidae	-----	7
PPW010	6.05	Gastropoda	Physidae	-----	8

5.3.5.2 MAINSTEM PENNYPACK CREEK RESULTS

5.3.5.2.1 Mainstem Pennypack Creek Macroinvertebrate Community Metrics Comparison to Regional Reference Condition

A total of 2,365 individual macroinvertebrates were collected from the thirteen mainstem sites (PP180, PP340, PP490, PP690, PP860, PP970, PP1060, PP1150, PP1250, PP1380, PP1680, PP1850 and PP2020) assessed during the 2007 PWD benthic macroinvertebrate survey of Pennypack Creek Watershed (Table 5.6). All mainstem sites except for PP340 had a total Biological Quality score of zero (0) out of a possible 30. PP340 received a score of 4 out of 30 due to its relatively high taxa richness (n=16), which was (72.7%) of the taxa richness in the reference reach FC472 (n=22). Nevertheless, all sites were designated “severely impaired” and were characterized by low taxa richness (n=8 to n=16) (Figures 5.9 and 5.10), low or absent modified EPT taxa, and elevated Hilsenhoff Biotic Index score (5.78 to 7.88) when compared to reference reach standards (Figures 5.11 and 5.12). 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 coarse scale climatic factors.

While spatial trends were not very distinct, benthic macroinvertebrate communities sampled at upstream sites PP2020, PP1850, PP1680, PP1380 and PP1250 did not perform as well as downstream sites in terms of HBI and taxa richness. Upstream sites had average HBI score 6.6 and taxa richness of 10, whereas downstream sites PP1150, PP1060, PP9670, PP860, PP690, PP490, PP340, and PP180 had average HBI 5.94 and taxa richness of 11.88. Overall, Chironomids (43.7% to 80%), which are moderately tolerant of pollution, were the dominant taxon at all mainstem assessment locations. The proportional dominance of Chironomids is evidence of increasingly homogenous community assemblages in Pennypack 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 and 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 2007 EPA RBP Physical Habitat assessment.

Macroinvertebrate assessment data from the 2002 Pennypack Baseline Assessment was compared to 2007 assessment data in order to assess changes in macroinvertebrate community structure. There was a relatively large change in all metrics between the 2002 and 2007 surveys for most sites. Taxa richness was generally greater in the 2007 assessment, as sites PP2020 and PP1250 were the only two sites assessed in 2007 that did not increase in taxa richness. These results suggest an increase in biodiversity; however, there were large increases in percent dominant taxa from 2002 to 2007 which suggest that taxa within Pennypack Creek assemblages are becoming less evenly distributed. It also should be noted that the change to PADEP ICE field and laboratory protocols also may have increased the likelihood that rare taxa would be collected as six different riffle sites were sampled in 2007 rather than two riffle sites in 2002 and the taxonomist generally counted a greater number of "plugs" and macroinvertebrate individuals in the 2007 study.

Excluding sites PP970 and PP180, at which the observed increase in proportion of dominant taxon was relatively minor (3.8% and 0.13% increase, respectively), other sites at which Chironomidae was the dominant taxon in both 2002 and 2007 assessments (PP2020, PP1250, PP1150, PP860 and PP490) saw average increase of 27% in percent dominance by chironomids. Sites PP1680 and PP1060 were unique in that the dominant taxon was not the same in the 2007 assessment as in 2002. Site PP1680 experienced the most extreme change, as the dominant taxon changed from Chironomidae (84.36%) in 2002 to Oligochaeta (44.91%) in 2007. This change in dominant taxon corresponds to a large increase in HBI at the site, from 2002 (6.06) to 2007 (7.88). 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. Site PP1680 is downstream of point source discharge of municipally treated wastewater.

At site PP1060, a similar increase in HBI corresponded to a shift in dominant taxon from 2002. HBI increased by 0.72 from 2002 to 2007 at site PP1060, while the dominant taxon changed from *Hydropsyche* (41.67%) in 2002 to Chironomidae (75.77%) in 2007. 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 on strictly the presence or absence of a taxon (such as total taxa richness) are best considered in light of other measures of community structure.

There were six sites assessed in the 2007 study (PP180, PP490, PP690, PP970, PP1250 and PP2020) that allowed for comparison between both the 2002 baseline assessment and historic PADEP macroinvertebrate assessments (1969-1980). Generally, the HBI for all sites has decreased (improved in quality) when compared to historic PADEP data. The sites with the highest degree of relative improvement were PP490 (ΔHBI=-0.86), PP970 (ΔHBI=-0.81) and PP1250 (ΔHBI=-1.14).

Average historic HBI classified the invertebrate communities at these sites as tolerant, but by 2002, HBI had been reduced such that the sites were now considered as having moderately tolerant communities. Between 2002 and 2007, results show a trend of increasing HBI throughout the watershed, especially in the upstream-most monitoring location PP2020.

Historic PADEP records were also used to evaluate trends in taxa richness. At all 6 sites with corresponding data, assessment taxa richness increased in 2007 when compared to historic PADEP averages. Between 2002 and 2007, taxa richness increased at downstream sites PP180, PP490, PP690 and PP970, but decreased at upstream sites PP1250 and PP2020 (taxa richness decreased by n=5 taxa at both sites) (Figure 5.13). This decrease in taxa richness corresponds to an increase in HBI at these sites (HBI increased by 0.76 and 0.73, respectively) (Figure 5.14). Other sites where increase in HBI was observed did not decrease in taxa richness; however as previously noted, sites with increased HBI had macroinvertebrate assemblages that underwent major changes to community composition compared to previous assessments.

Table 5.6 Macroinvertebrate Community Metric Results from 13 Mainstem Sites in Pennypack Creek Watershed Compared to Regional Reference Condition, 2007

2008 Pennypack Creek Watershed Assessment	Taxa Richness	Modified EPT Taxa	Hilsenhoff Biotic Index (Modified)	Percent Dominant Taxa	Percent Modified Mayflies	Biological Quality (%)	Biological Assesment
PP180[a]	10	1	6.06	74.15 (CHIRONOMIDAE)	0.49	0	Severely Impaired
PP340[a]	16	1	5.85	43.69 (CHIRONOMIDAE)	0	13	Severely Impaired
PP490[a]	10	0	6.03	83.18 (CHIRONOMIDAE)	0	0	Severely Impaired
PP690[a]	12	0	5.93	75.12 (CHIRONOMIDAE)	0	0	Severely Impaired
PP860[a]	12	1	5.95	73.06 (CHIRONOMIDAE)	0	0	Severely Impaired
PP970[a]	12	0	5.94	77.38 (CHIRONOMIDAE)	0	0	Severely Impaired
PP1060[a]	13	1	5.78	75.77 (CHIRONOMIDAE)	0.44	0	Severely Impaired
PP1150[a]	12	1	6.02	58.49 (CHIRONOMIDAE)	0.00	0	Severely Impaired
PP1250[b]	8	0	6.46	80 (CHIRONOMIDAE)	0.00	0	Severely Impaired
PP1380[b]	11	1	6.12	78.43 (CHIRONOMIDAE)	0.00	0	Severely Impaired
PP1680[b]	9	0	7.88	44.91 (OLIGOCHAETA)	0.00	0	Severely Impaired
PP1850[b]	9	0	6.56	62.44 (CHIRONOMIDAE)	0	0	Severely Impaired
PP2020[b]	13	1	6.00	68.25 (CHIRONOMIDAE)	0	0	Severely Impaired
FC472*	22	7	2.51	25 (SERRATELLA)	27.68	********	********
FC1310	26	12	3.19	20.64 (PROSIMULIUM)	30.28	********	********

* Data collected in 2005
[a]FC472 used as reference
[b]FC1310 used as reference

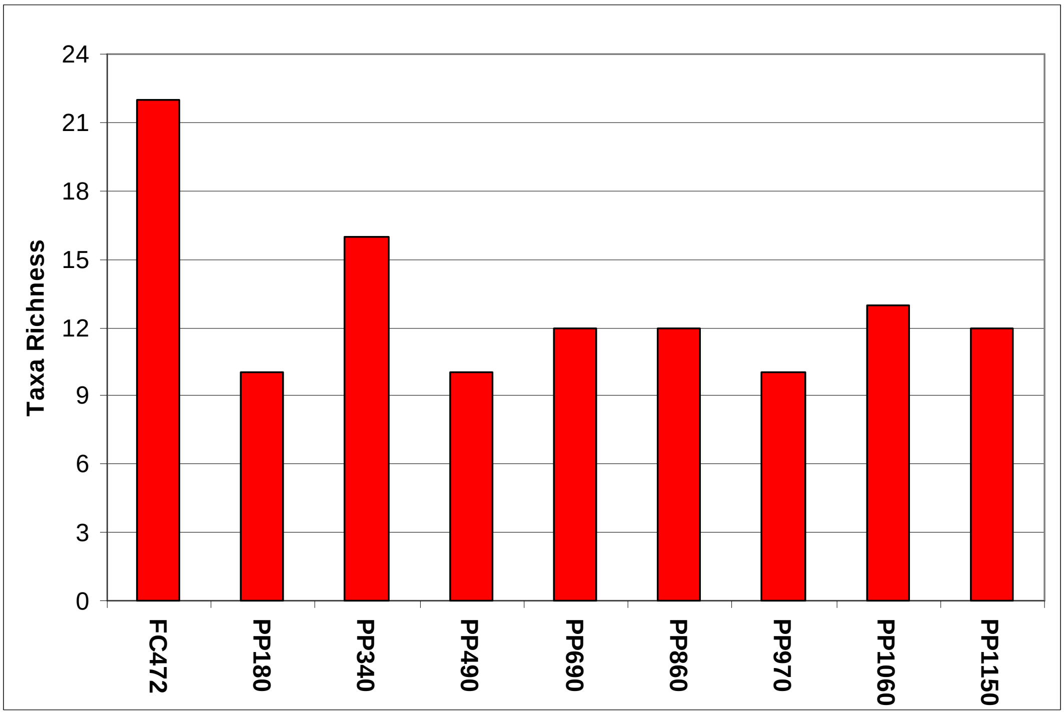


Figure 5.9 Benthic Macroinvertebrate Taxa Richness at 8 (4th Order) Mainstem Sites in Pennypack Creek Watershed and French Creek Reference Site, 2007

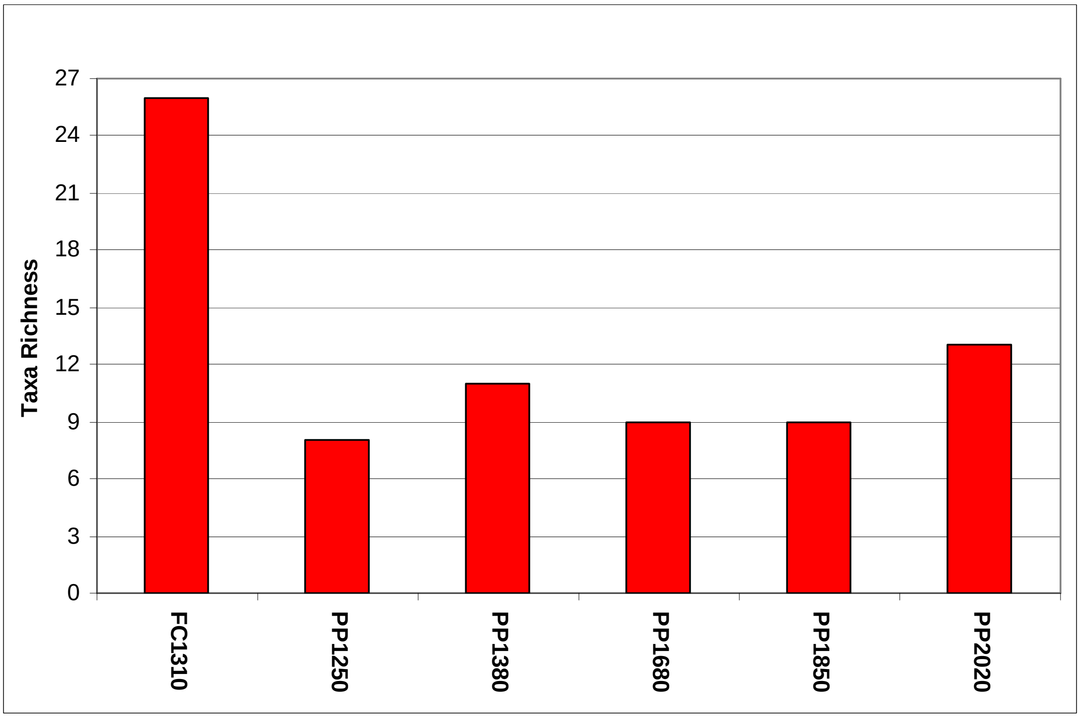


Figure 5.10 Benthic Macroinvertebrate Taxa Richness at 5 (2nd and 3rd Order) Mainstem Sites in Pennypack Creek Watershed and French Creek Reference Site, 2007

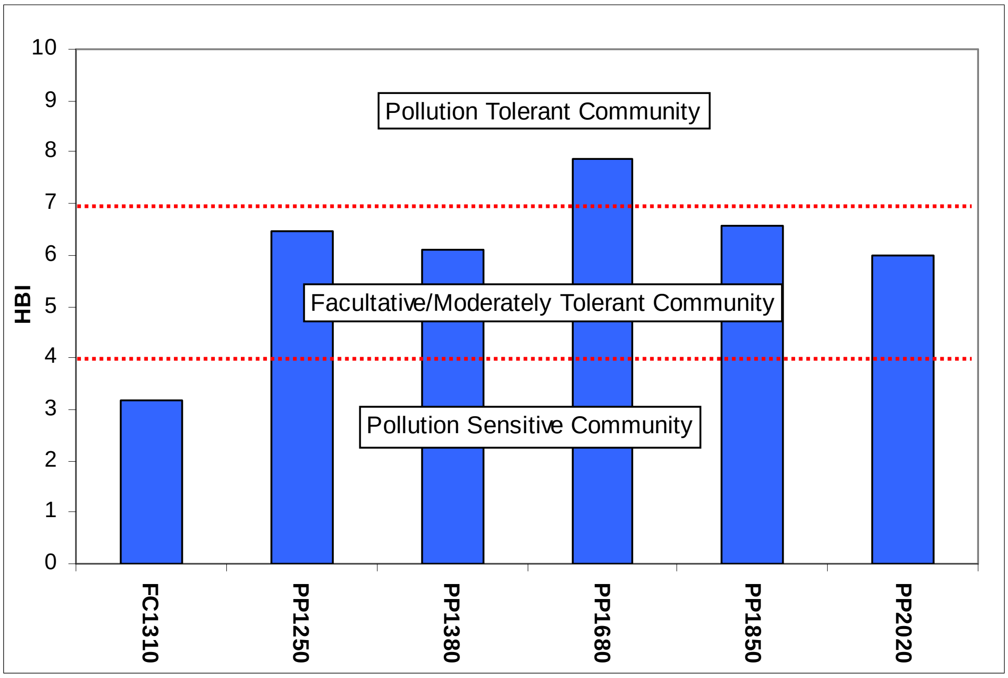


Figure 5.11 Hilsenhoff Biotic Index of Macroinvertebrate Communities at 5 (2nd and 3rd Order) Mainstem Sites in Pennypack Creek Watershed and French Creek Reference Site, 2007

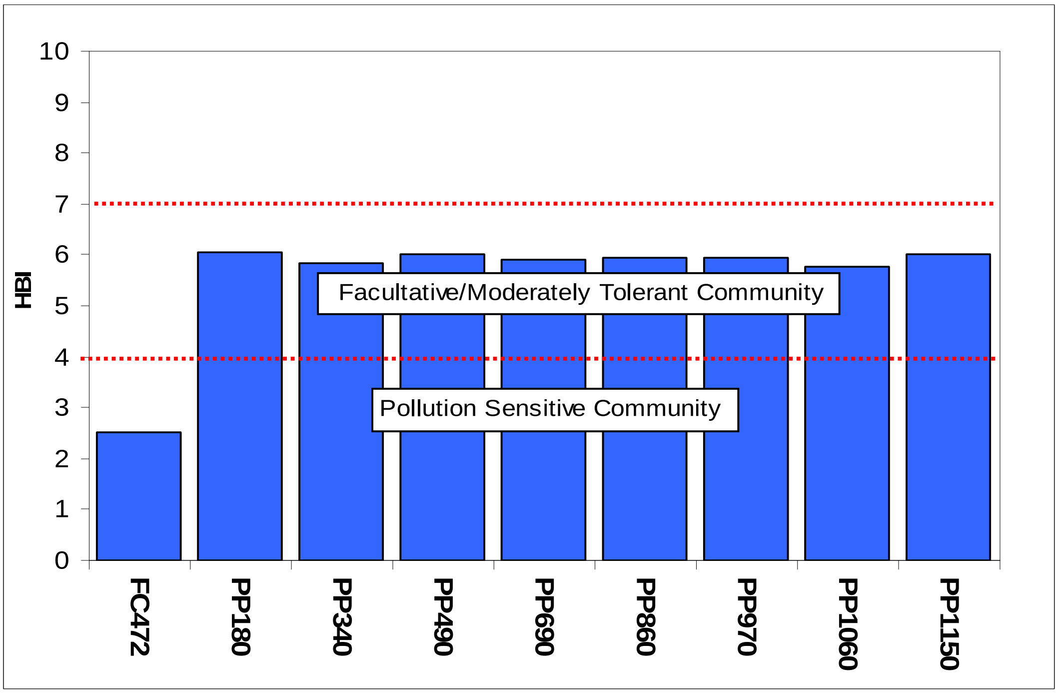


Figure 5.12 Hilsenhoff Biotic Index of Macroinvertebrate Communities at 8 (4th Order) Mainstem Sites in Pennypack Creek Watershed and French Creek Reference Site, 2007

Table 5.7 Macroinvertebrate Community Metric Results from 13 Mainstem Sites in Pennypack Creek Watershed Compared to Regional Reference Condition, 2002 and 2007

Pennypack Creek Watershed Assessment	2002 Taxa Richness	2007 Taxa Richness	2002 Modified EPT Taxa	2007 Modified EPT Taxa	2002 Hilsenhoff Biotic Index (Modified)	2007 Hilsenhoff Biotic Index (Modified)	2002 Percent Dominant Taxa	2007 Percent Dominant Taxa	2002 Percent Modified Mayflies	2007Percent Modified Mayflies
PP180[a]	7	10	0	1	6.20	6.06	74.02 (CHIRONOMIDAE)	74.15 (CHIRONOMIDAE)	0	0.49
PP340[a]	8	16	0	1	5.69	5.85	48.18 (CHIRONOMIDAE)	43.69 (CHIRONOMIDAE)	0	0
PP490[a]	7	10	0	0	5.61	6.00	55.28 (CHIRONOMIDAE)	83.18 (CHIRONOMIDAE)	0	0
PP690[a]	10	12	0	0	5.60	5.93	50.52 (CHIRONOMIDAE)	75.12 (CHIRONOMIDAE)	0	0
PP860[a]	13	12	1	1	5.60	5.95	46.07 (CHIRONOMIDAE)	73.06 (CHIRONOMIDAE)	0	0
PP970[a]	9	12	0	0	5.79	5.94	73.58 (CHIRONOMIDAE)	77.38 (CHIRONOMIDAE)	0	0
PP1060[a]	14	13	2	1	5.06	5.78	41.67 (HYDROPSYCHE)	75.77 (CHIRONOMIDAE)	0	0.44
PP1150[a]	9	12	0	1	5.44	6.02	35.14 (CHIRONOMIDAE)	58.49 (CHIRONOMIDAE)	0	0
PP1250[b]	13	8	0	0	5.70	6.46	67.68 (CHIRONOMIDAE)	80 (CHIRONOMIDAE)	0	0
PP1380[b]	8	11	1	1	5.52	6.12	50.31 (CHIRONOMIDAE)	78.43 (CHIRONOMIDAE)	0	0
PP1680[b]	8	9	0	0	6.03	7.88	84.36 (CHIRONOMIDAE)	44.91 (OLIGOCHAETA)	0	0
PP2020[b]	18	13	1	1	5.27	6.00	22.4 (CHIRONOMIDAE)	68.25 (CHIRONOMIDAE)	0	0
*FC472[+]	28	22	8	7	4.3	2.51	21.31 (BAETIS)	25 (SERRATELLA)	10.66	27.68
*FC1310	27	26	6	12	4.53	3.19	18.31 (HYDROPSYCHE)	20.64 (PROSIMULIUM)	13.37	30.28

*Reference reach used for metric comparison
[a]FC472 used as reference
[b]FC1310 used as reference
[+]2003 and 2005 data respectively

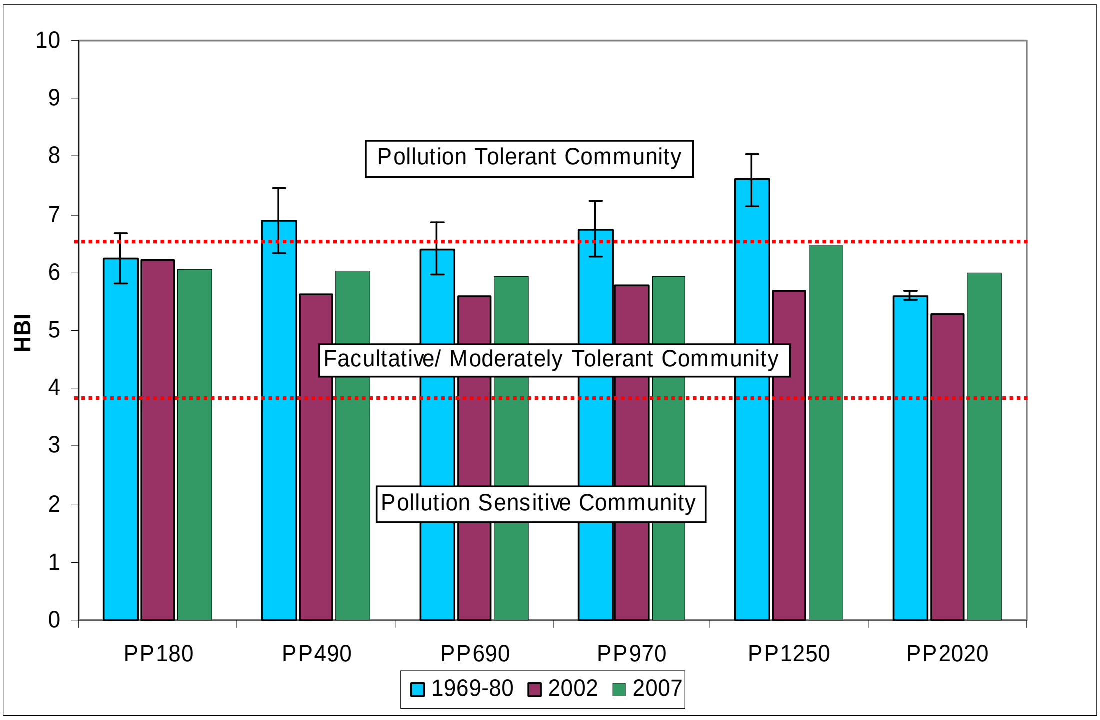


Figure 5.13 HBI Scores at 6 Mainstem Sites in Pennypack Creek Watershed, pooled data 1969-1980, 2002, and 2007

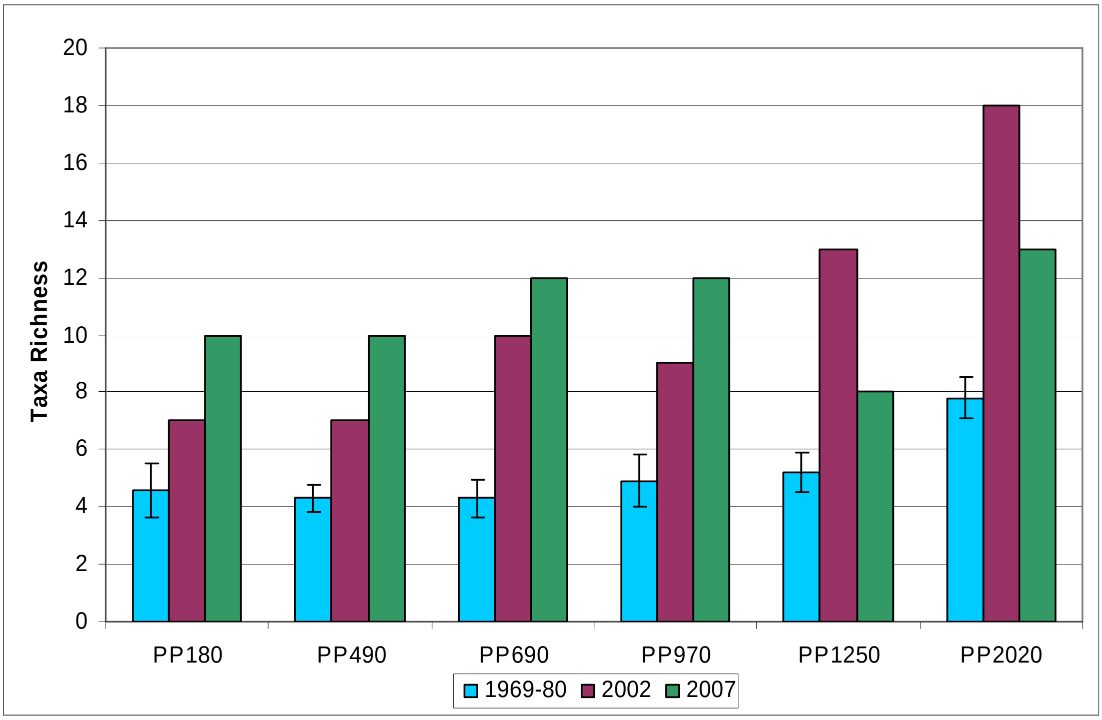


Figure 5.14 Taxa Richness at 6 Mainstem Sites in Pennypack Creek Watershed, Pooled Data 1969-1980, 2002, and 2007

5.3.5.2.2 MAINSTEM PENNYPACK CREEK PADEP IBI RESULTS

When compared to PADEP ICE reference conditions, all mainstem assessment sites in Pennypack Creek Watershed were classified as stressed. No mainstem sites achieved 63% comparability of reference IBI for attaining the WWF designated use. Percent comparability with standard reference IBI scores were poor, ranging from 17-35% (Table 5.8). Furthermore, no site met the PADEP reference value for any individual metric (Figures 5.15 and 5.16). Taxa richness ranged (n=8 to n=13) compared to the reference value of n=35. Sample sites also performed poorly when measured against the Ephemeroptera, Plecoptera, Trichoptera (EPT) taxa richness metric, as the range of values on the mainstem (n=3-6) fell far below the reference value of (n=23).

Of the EPT taxa found on the mainstem, few were classified as sensitive to pollution, a fact which is further illustrated by the low values of Beck's Index (n=0-4) when compared to the reference value of (n=39). Beck's index (also known as the Florida index) is a weighted index of all sensitive macroinvertebrates rather than just the EPT orders. Of the 13 sites assessed, very sensitive taxa (pollution tolerance value ≤2) were present in only 5 sites (PP180, PP340, PP690,PP1060 and PP1150) (Table 5.9). Site PP1060 had the highest Beck's Index score (n=4) mostly due to the presence of *Ameletus* (Ephemeroptera; Ameletidae) which has a pollution tolerance value of n=0. *Ameletus* was unique to PP1060 and was the most sensitive taxon found on the mainstem.

Diversity was also very low among mainstem sites. The Shannon Diversity Index scores for mainstem sites ranged from (H=0.78 to H=1.81) compared to the reference value of (H=2.9). The mainstem site with the highest diversity was PP340 (H=1.81), which also had the highest taxa richness (n=16), EPT taxa richness (n=6) and percent comparability (35%) to reference standards. The average HBI of mainstem sites was 6.2 and HBI values ranged from 5.78-7.88, suggesting aquatic communities on the Pennypack Creek mainstem are exposed to elevated levels of organic pollution. Mainstem scores for the Percent Intolerant Taxa metric (1.9%-24.32%) fell below the PADEP reference standard (92.5%) 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 the mainstem sites as severely impaired, corresponding to BCG Tiers 5 or 6.

Table 5.8 Summary of PADEP IBI Metric Scores for Mainstem Pennypack Creek Watershed Sites, 2007

2008 Pennypack Creek Watershed Assessment	Taxa Richness	EPT Richness	Becks Index	Shannon Diversity Index	Hilsenhoff Biotic Index	Percent Intolerant Taxa	Percent Comparability
PP180	10	5	1	1.02	6.06	1.46	24
PP340	16	6	2	1.81	5.85	4.95	35
PP490	10	4	0	0.78	6.03	1.36	20
PP690	12	3	1	1.02	5.93	2.49	23
PP860	12	5	0	1.13	5.95	2.28	25
PP970	12	5	0	0.98	5.94	0.90	23
PP1060	13	4	4	1.04	5.78	5.28	27
PP1150	12	5	1	1.44	6.02	2.35	29
PP1250	8	4	0	0.75	6.46	0	17
PP1380	11	5	0	0.95	6.12	0.98	23
PP1680	9	4	0	1.36	7.88	7.87	20
PP1850	9	3	0	1.19	6.56	5.85	20
PP2020	13	5	1	1.16	5.99	3.3	25
PADEP Reference	35	23	39	2.9	1.78	92.5	-----

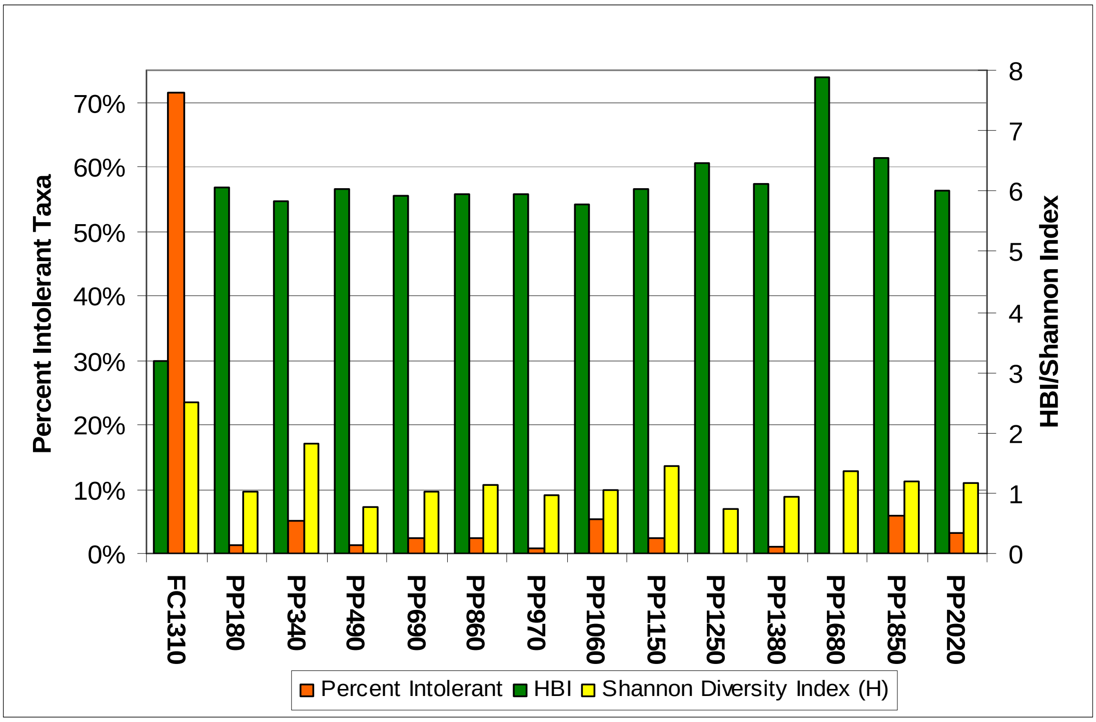


Figure 5.15 PADEP IBI Metrics for 13 Mainstem Sites in Pennypack Creek Watershed and French Creek Reference Site, 2007

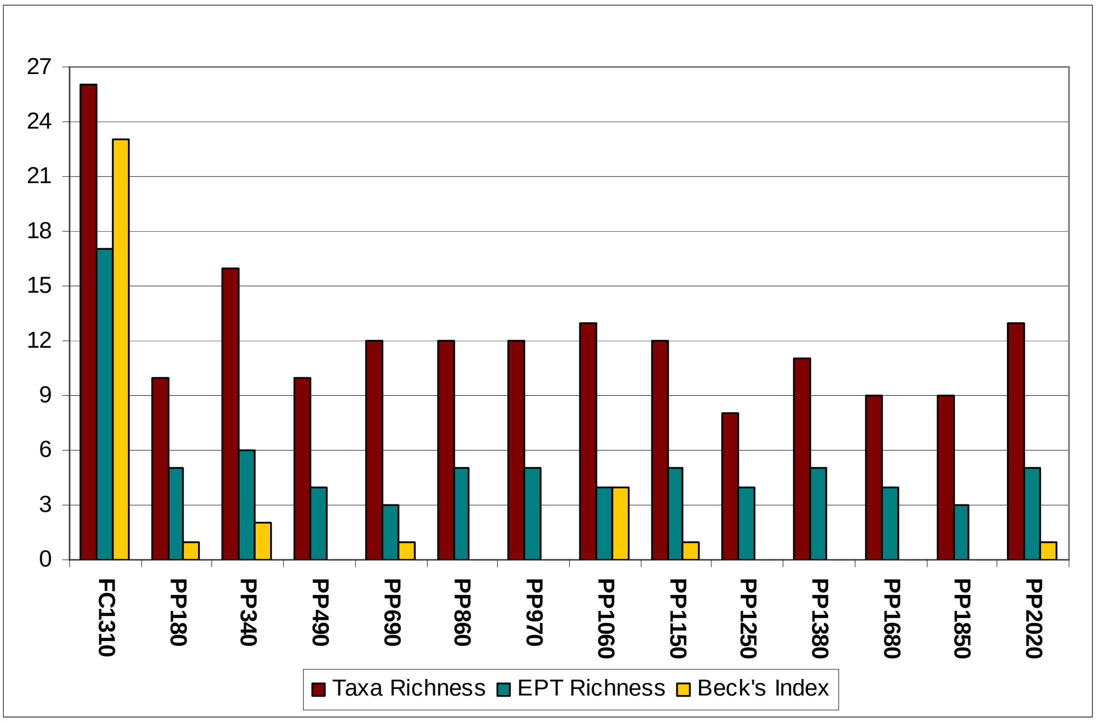


Figure 5.16 PADEP IBI Metrics for Mainstem Sites in Pennypack Creek Watershed and French Creek Reference Site, 2007

5.3.5.2.3 MAINSTEM PENNYPACK CREEK SUPPLEMENTARY RESULTS

In addition to metrics which were used 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 (77.77%) and filterers (15.45%) dominated at all mainstem Pennypack Creek assessment sites (Figures 5.17 and 5.18). Specialized feeders were absent or found in low abundance although there were a few exceptions where specialized feeders were a major component of the trophic structure in a particular site. Scrapers represented 21.6% of taxa at site PP2020 and 10.37% at site PP1250, but on average scrapers only comprised 4.2% of all mainstem taxa. The scrapers in question were not sensitive insect larvae but rather aquatic snails (Physidae) which are more typically found in stagnant water conditions where they can tolerate very low dissolved oxygen. Other functional feeding groups, omnivores (2.4%), predators (0.14%) and shredders (0.034%), were observed in the mainstem macroinvertebrate assessment at much lower proportions. Analysis of trophic structure can serve to indicate potential stressors (*e.g.*, sedimentation/siltation, eutrophication) and identify food resource limitations; however it can not distinguish between the interaction of the two factors.

The proportion of moderately tolerant individuals at all mainstem sites averaged 89.1% (range 49.5% to 97.7%). The site that had the greatest proportion of moderately tolerant taxa was site PP970 with 97.7% dominance, a slight reduction from 2002 (99.37%). Tolerant taxa accounted for (8.72%) of all taxa on the mainstem and the proportion of tolerant taxa at each monitoring site ranged from (0.9%-50.74%) (Figures 5.19 and 5.20). Site PP1680, which is directly downstream of a waste water treatment facility discharge, had the highest proportion of tolerant taxa (50.74%) and was one of two mainstem sites where no intolerant taxa were collected (PP160 and PP1250). There was a slight decrease in the proportion of intolerant taxa from 2002 at site PP1250 (1.2%), however, 2002 was the only year that intolerant taxa were observed at this site since 1969. Intolerant taxa were poorly represented at mainstem sites, as they accounted for only 2.1% of all taxa collected on the mainstem in the 2007 assessment. The highest proportion of intolerant taxa were collected at site PP1060 (5.3%), which is the downstream-most site in Montgomery County and located within Lorimer Park.

Table 5.9 lists the locations where sensitive taxa were collected during the 2007 macroinvertebrate assessment. Sensitive taxa (pollution tolerance values ≤ 3) were collected at every monitoring location on the mainstem except for sites PP1250, PP1680 and PP1850; all mainstem sites within the City of Philadelphia had at least one sensitive taxon (Table 5.9). A possible explanation for the lack of sensitive taxa at the upstream sites could be degradation of water quality, as there were large increases in HBI at these sites between 2002 and 2007 (Table 5.12). Between 2002 and 2007, HBI score increased (0.76), (1.85), and (0.57) for sites PP1250, PP1680 and PP1850, respectively.

Sites PP340 and PP1060 had the most sensitive taxa with n=3. *Antocha* spp. was the most commonly collected sensitive taxon on the mainstem Pennypack Creek (found at 10 sites). The most sensitive taxon, *Ameletus* (Ameletid minnow mayfly), was collected at site PP1060. This taxon was unique to site PP1060 within the watershed; however, it was also collected at the reference site FC1310 during the 2007 assessment. PP1060 is within the forested Lorimer Park, although other land-uses include single-family residential housing and an agricultural area to the north of the site. The presence of *Ameletus* sp. may suggest that PP1060 maintains quality physical habitat even though water quality may be somewhat degraded. It is also possible that *Ameletus* specimens collected at this site drifted to the mainstem from a remnant population in one of the small tributaries within Lorimer Park. The nearby Harpers Run tributary (site PPHA030) had some of the most sensitive taxa collected in the watershed. Ameletid minnow mayflies are strong swimmers and can tolerate relatively high current velocities which may also partially explain their presence at the site.

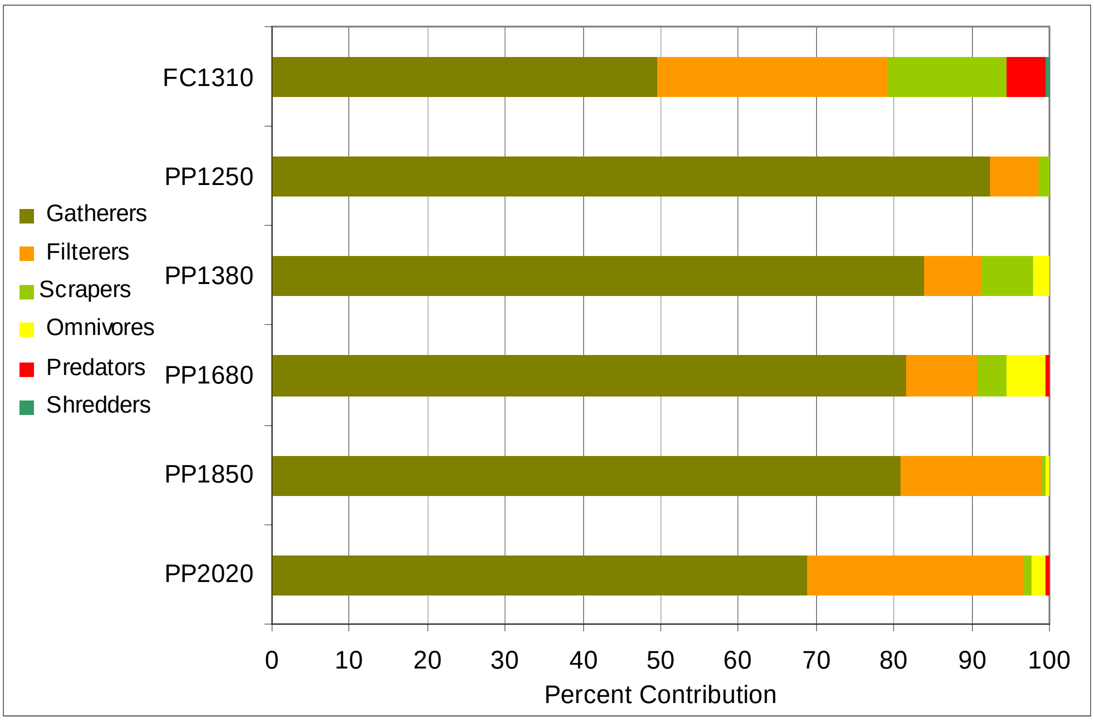


Figure 5.17 Benthic Macroinvertebrate Community Trophic Composition at 5 (2nd and 3rd Order) Mainstem Pennypack Creek Sites and French Creek Reference Site, 2007

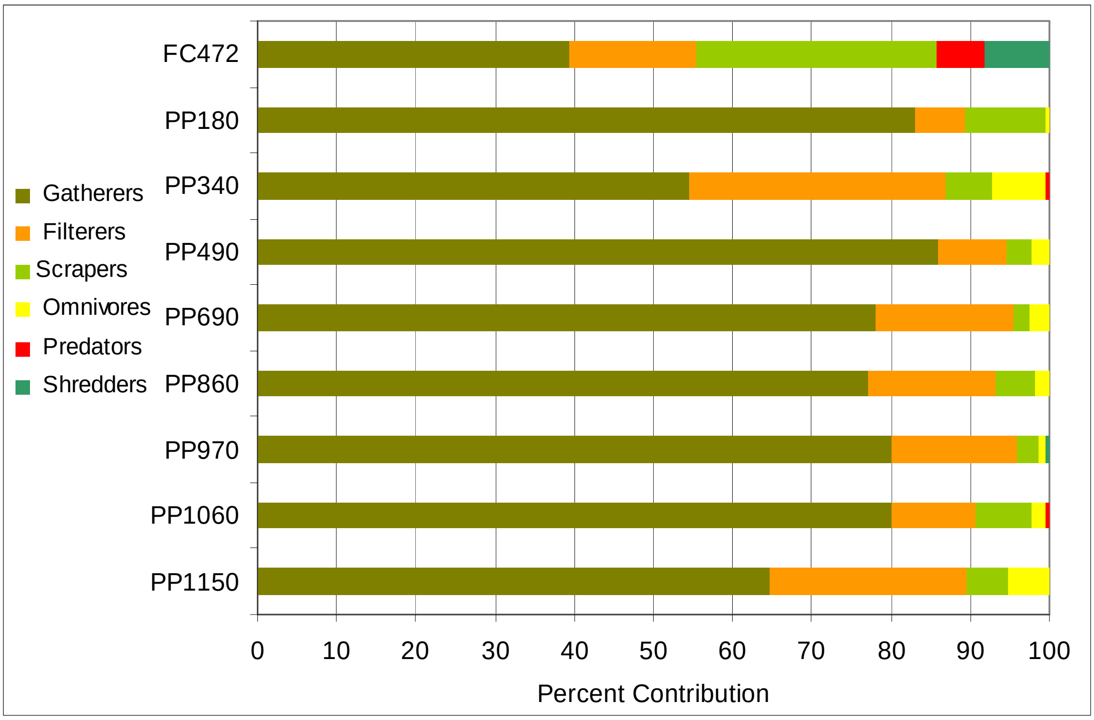


Figure 5.18 Benthic Macroinvertebrate Community Trophic Composition at 8 (4th Order) Mainstem Pennypack Creek Sites and French Creek Reference Site, 2007

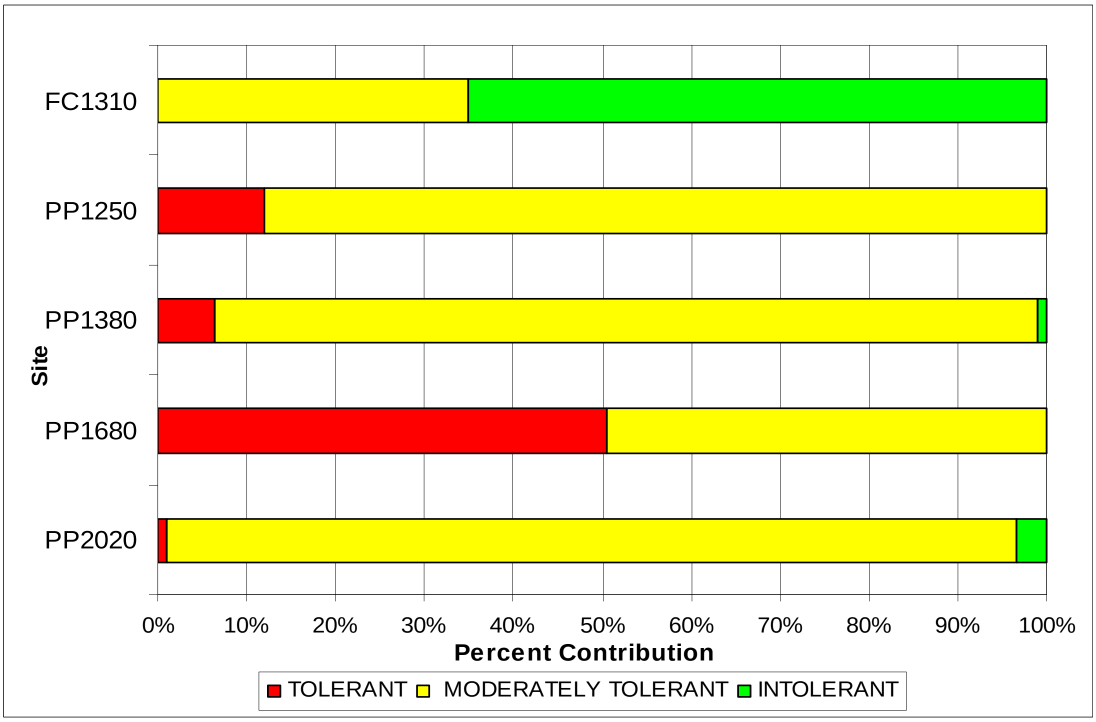


Figure 5.19 Tolerance Designations of Benthic Macroinvertebrate Communities at 5 (2nd and 3rd Order) Mainstem Pennypack Creek Sites and French Creek Reference Site, 2007

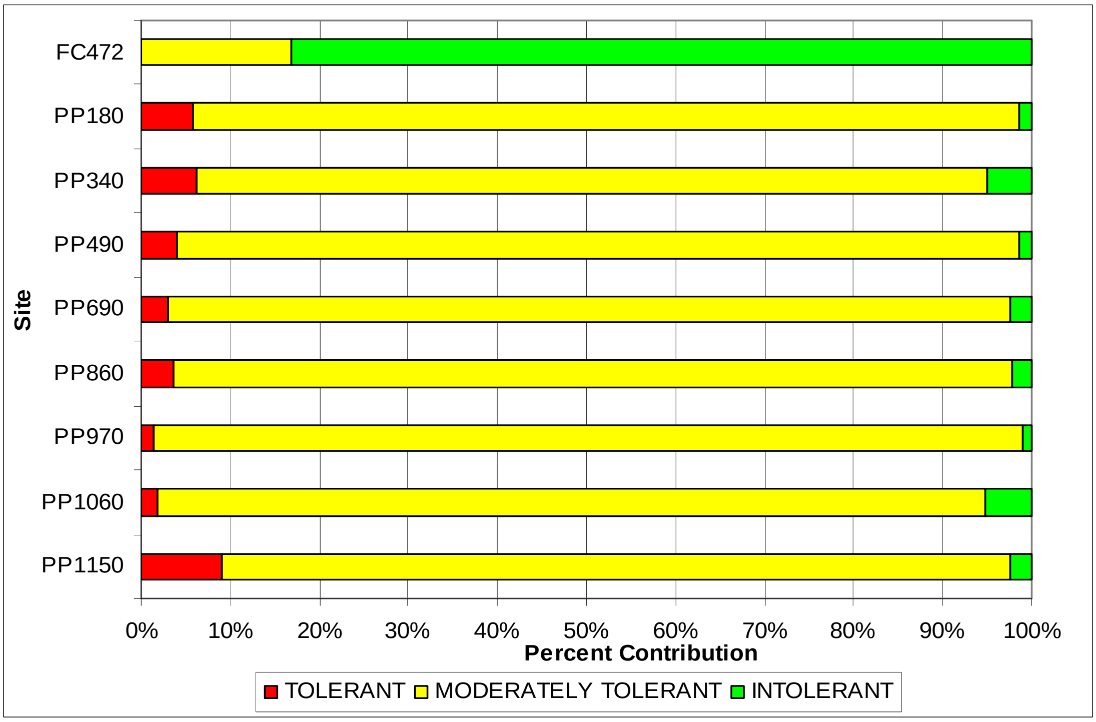


Figure 5.20 Tolerance Designations of Benthic Macroinvertebrate Communities at 8 (4th Order) Mainstem Pennypack Creek Sites and French Creek Reference Site, 2007

Table 5.9 Sensitive Taxa Collected from Mainstem Pennypack Creek

Site	Order	Family	Genus	HBI
PP180	Ephemeroptera	Ephemerellidae	Attenella	2
PP180	Diptera	Tipulidae	Antocha	3
PP340	Coleoptera	Elmidae	Macronychus	2
PP340	Coleoptera	Elmidae	Ancyronyx	2
PP340	Diptera	Tipulidae	Antocha	3
PP490	Diptera	Tipulidae	Antocha	3
PP690	Coleoptera	Elmidae	Ancyronyx	2
PP690	Diptera	Tipulidae	Antocha	3
PP860	Diptera	Tipulidae	Antocha	3
PP970	Diptera	Tipulidae	Antocha	3
PP1060	Ephemeroptera	Ameletidae	Ameletus	0
PP1060	Coleoptera	Elmidae	Macronychus	2
PP1060	Diptera	Tipulidae	Antocha	3
PP1150	Coleoptera	Elmidae	Macronychus	2
PP1150	Diptera	Tipulidae	Antocha	3
PP1380	Diptera	Tipulidae	Antocha	3
PP2020	Diptera	Tipulidae	Antocha	3

Table 5.10 Unique Taxa Collected from Mainstem Pennypack Creek

Site	Site HBI	Order	Family	Genus	Taxon HBI
PP180	6.06	Ephemeroptera	Ephemerellidae	Attenella	2
PP340	5.85	Trichoptera	Hydroptilidae	Hydroptila	6
PP970	5.94	Ephemeroptera	Baetidae	Baetis	6
PP1060	5.87	Ephemeroptera	Ameletidae	Ameletus	0
PP1060	5.87	Diptera	Ceratopogonidae	Ceratopogon	6
PP1680	7.88	Amphipoda	Crangonyctidae	Cragonyx	6
PP1680	7.88	Hirudinea	----	----	8

5.2.5.3 TRIBUTARY ASSESSMENT SITES

5.2.5.3.1 Pennypack Creek Tributary Macroinvertebrate Community Metrics Comparison to Regional Reference Condition

During the 2007 macroinvertebrate survey of Pennypack Creek Watershed, a total of 2,176 individuals from 22 taxa were collected from tributary sites PPW010, PPSR010, PPSC010, PPPR010, PPPRB010, PPDR010, PPHA003, PPM070, PPHU070, PS030, and PPHO010. Taxa richness was poor for tributary sites (n= 5-13) compared to the French Creek reference standard (n=25). Modified EPT taxa richness was also very poor in comparison to reference standards, as tributary sites ranged from (n=0-3) compared to (n=10) for French Creek. No EPT taxa were found at five of the eleven sites assessed (PPSR010, PPW010, PPSC010, PPPR010 and PPS030). The range of HBI values was very high (5.74-9.25) and each site exceeded the FCRR008 reference value of (4.07), which is relatively high for a reference standard.

The monitoring station on Sandy Run (site PPSR010) (HBI=9.25) exceeded the reference standard by the largest margin of all sites assessed in 2007 and was the only tributary site with an HBI score classified as supporting a “pollution tolerant” community. This HBI score was also the highest ever recorded by PWD (n=162 samples) in the last 10 years of collecting macroinvertebrates in urban streams. All other sites were classified as supporting facultative to moderately tolerant communities by HBI scores. Average taxa richness and HBI of tributary sites were 8.18 and 6.35, respectively, compared to 10.19 and 6.25 for mainstem sites. There was relatively strong negative relationship between taxa richness and HBI (r=-0.68).

Benthic assemblages were dominated by Chironomids (43.4%-95.2%) in all assessment sites, except for the aforementioned site PPSR010, which was dominated by Oligochaetes. All tributary assessment sites had metric scores of zero out of a possible 30 and were designated as “severely impaired” when compared to French Creek reference reach standards. No tributary site had a metric score comparable (≥83%) to that of the French Creek reference. Sites were characterized by low taxa richness (n=5 to n=13), poor representation of sensitive and EPT taxa (0%-6.86%) and elevated Hilsenhoff Biotic Index scores (5.74 to 9.25).

RBPIII data from 2002 and 2007 were compared for six tributary sites (PPW010, PPHA003, PPM070, PPHU070, PPS030, and PPHO010). No distinct spatial or temporal trends were observed; however, there were relatively large changes for most of the assessed metrics. Taxa richness increased for three sites (PPW010, PPM070, and PPHO010) by n=1, n=2 and n=3 taxa respectively. Sites PPS030 and PPHU070 decreased in taxa richness by n=2 and n=3 taxa respectively, while no change in taxa richness was observed for site PPHA003. HBI values increased (0.07-0.45) at all sites except PPHU070. PPHU070 decreased in HBI by (0.26) suggesting a slight decrease in the net pollution tolerance of the community; however, it can be argued that the 2002 community is no longer established as the proportional dominance by Chironomidae increased by a large margin (+20.94%) and taxa richness decreased by n=3 taxa. The percent dominant taxa metric increased for each site where Chironomidae was established as dominant in 2002, as Chironomidae increased in proportional abundance at all sites (+0.5%-20.94%) except for PPHA030, where the proportional dominance of Chironomidae decreased by a considerable margin (17.14%). Site PPM070 exhibited a dramatic shift in its benthic community assemblage as: the dominant taxa shifted from Hydropsyche (48.5%) in 2002 to Chironomidae (55.66%) in 2007; taxa richness increased from n=8 to n=10; and HBI increased by 0.45.

Table 5.11 Macroinvertebrate Community Metric Results from 11 Tributary Sites in Pennypack Creek Watershed Compared to Regional Reference Condition, 2007

2007 Pennypack Creek Watershed Assessment	Taxa Richness	Modified EPT Taxa	Hilsenhoff Biotic Index (Modified)	Percent Dominant Taxa	Percent Modified Mayflies	Biological Quality (%)	Biological Assessment
PPSR010	5	0	9.25	80.88 (Oligochaeta)	0	0	Severely Impaired
PPW010	8	0	6.05	76.92 (Chironomidae)	0	0	Severely Impaired
PPSC010	9	0	6.54	53.95 (CHIRONOMIDAE)	0	0	Severely Impaired
PPPR010	8	0	6.33	57.43 (CHIRONOMIDAE)	0	0	Severely Impaired
PPRB010	8	1	5.87	76.89 (CHIRONOMIDAE)	0	0	Severely Impaired
PPDR010	6	1	5.99	95.22 (CHIRONOMIDAE)	0	0	Severely Impaired
PPHA003	13	3	5.76	43.41 (CHIRONOMIDAE)	0	0	Severely Impaired
PPM070	10	2	5.74	55.66 (CHIRONOMIDAE)	0	0	Severely Impaired
PPHU070	12	1	6.39	59.13 (CHIRONOMIDAE)	0	0	Severely Impaired
PPS030	5	0	6.06	92.38 (CHIRONOMIDAE)	0	0	Severely Impaired
PPHO010	13	1	5.90	72.55 (CHIRONOMIDAE)	0	0	Severely Impaired
*FCRR008	25	10	4.07	24.78 (CHIRONOMIDAE)	28.32	********	*******

*Reference site used for metric comparison

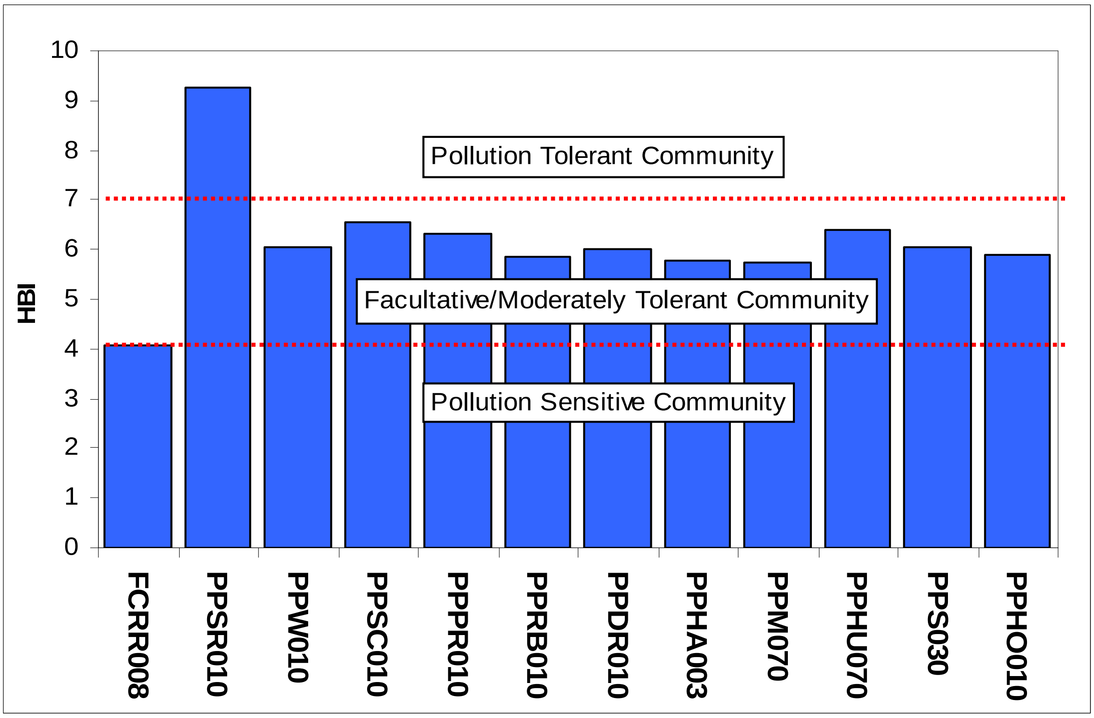


Figure 5.21 Hilsenhoff Biotic Index of Benthic Macroinvertebrate Communities at 11 Tributary Sites in Pennypack Creek Watershed and Reference Site, 2007

Table 5.12 Macroinvertebrate Community Metric Results from 6 Tributary Sites in Pennypack Creek Watershed Compared to Regional Reference Condition, 2002 and 2007

Pennypack Creek Watershed Assessment	2002 Taxa Richness	2007 Taxa Richness	2002 Modified EPT Taxa	2007 Modified EPT Taxa	2002 Hilsenhoff Biotic Index (Modified)	2007 Hilsenhoff Biotic Index (Modified)	2002 Percent Dominant Taxa	2007 Percent Dominant Taxa	2002 Percent Modified Mayflies	2007 Percent Modified Mayflies
PPW010	7	8	1	0	5.9	6.05	72.87 (CHIRONOMIDAE)	76.92 (CHIRONOMIDAE)	0	0
PPHA003	13	13	2	3	5.69	5.76	60.55 (CHIRONOMIDAE)	43.41 (CHIRONOMIDAE)	0	0
PPM070	8	10	1	2	5.29	5.74	48.55 (HYDROPSYCHE)	55.66 (CHIRONOMIDAE)	0	0
PPHU070	15	12	1	1	6.65	6.39	38.19 (CHIRONOMIDAE)	59.13 (CHIRONOMIDAE)	0	0
PPS030	7	5	0	0	5.9	6.06	84.44 (CHIRONOMIDAE)	92.38 (CHIRONOMIDAE)	0	0
PPHO010	10	13	1	1	5.65	5.9	58.06 (CHIRONOMIDAE)	72.55 (CHIRONOMIDAE)	0	0
*FCRR008	16+	25	4+	10	3.23+	4.07	30.35+ (PROSIMULIUM)	24.78 (CHIRONOMIDAE)	9.34+	28.32

*Reference site used for metric comparison
+Data collected in 2005

5.2.5.3.2 PENNYPACK Creek TRIBUTARY PADEP IBI METRICS

All Pennypack Creek tributary sites in the 2007 assessment were classified as stressed according to PADEP IBI metrics, as no sites met the requirement of 63% comparability (TSF and WWF streams) to reference conditions. Observed comparability for tributary assessment sites ranged from (8%-32%) (Table 13). Poor comparability can be attributed to the fact that all sites scored well below reference standards for all six PADEP metrics. For the sake of comparison, the French Creek reference (FCR008) scored 68% comparability to reference conditions. Taxa richness ranged from n=5 taxa to n=13 taxa at Pennypack Creek tributary sites compared to the reference value of n=35 taxa. Sites PPHA030 and PPHO010 had the highest taxa richness (n=13 taxa) followed by site PPHU070 (n=12 taxa). Sites PPS030 and PPSR010 had the lowest taxa richness with n=5 taxa, a mere 14.3% of the PADEP reference criteria (Figure 5.22). EPT taxa richness scores were equally poor, ranging from n=2 taxa to n=8 taxa compared to the reference value of n=23 taxa (Figure 5.22). The lack of EPT taxa within the Pennypack Creek tributary network is quite possibly attributed to frequent and persistent disturbance associated with stormwater runoff and supporting infrastructure as many tributary sites are within highly developed sub-catchments that support residential, commercial, agricultural, municipal and recreational land uses. The lack of very sensitive taxa within the tributary network is also exhibited by Beck's Index, which is a weighted average of highly sensitive taxa (tolerance values ≤ 2). Only two sites (PPHA030 and PPM070) had very sensitive taxa, and as such were the only sites with Beck's Index score >0 (BI=6 and 3, respectively) (Table 5.13).

No tributary site approached the level of biodiversity set by the PADEP reference standard. Shannon Diversity Index values of samples collected from tributary sites were very low, ranging from H=0.37-1.49 compared with the PADEP IBI standard H=2.9. Three sites exhibited relatively high levels of diversity (PPHA030, PPHU070 and PPSC010) with SDI values of 1.49, 1.45 and 1.44 respectively. Conversely, sites PPSR010, PPS030 and PPDR010 had comparably low levels of diversity with SDI scores of 0.58, 0.37, and 0.25 respectively (Figure 5.22).

The HBI metric, which is an index directed at detection of disturbance due to organic pollution, reached very high levels within many of the tributary assessment sites. The mean HBI of tributary sites was 6.35 compared to a mean of 6.19 for mainstem Pennypack Creek (Figure 5.22). The difference may be attributed to site PPSR010 (HBI=9.25), which had the highest HBI score in the watershed. Sites PPM070 and PPHA030 fared considerably better with HBI scores of 5.74 and 5.76 respectively. The detrimental effects of urbanization on water and instream habitat quality are also reflected in the low proportion of intolerant taxa (proportion of sensitive taxa/all taxa) collected from tributary sites. The relative proportion of intolerant taxa at each site ranged from 0%-6.86% compared to the PADEP standard of 92.5%. Sites PPSR010 and PPS030 lacked intolerant taxa completely. In general, site PPHA003 was found to be the least degraded site, having the best metric scores of all the tributary sites in taxa richness, EPT taxa richness, Beck's Index, and Shannon Diversity Index metrics, as well as the greatest overall comparability to IBI reference conditions (32%) (Table 5.13).

Table 5.13 Pennypack Tributary PADEP IBI Macroinvertebrate Metrics

2008 Pennypack Creek Watershed Assessment	Taxa Richness	EPT Taxa Richness	Becks Index	Shannon Diversity Index	Hilsenhoff Biotic Index	Percent Intolerant Taxa	Percent Comparability
PPSR010	5	2	0	0.58	9.25	0	8
PPW010	8	3	0	0.94	6.05	1.8	20
PPSC010	9	3	0	1.443	6.54	2.63	22
PPPR010	8	3	0	1.29	6.33	2.48	21
PPRB010	8	5	0	0.892	5.87	2.67	21
PPDR010	6	4	0	0.25	5.99	0.95	14
PPHA030	13	8	6	1.49	5.76	5.37	32
PPM070	10	6	3	1.32	5.74	3.77	29
PPHU070	12	5	0	1.45	6.39	1.44	26
PPS030	5	3	0	0.37	6.06	0	14
PPHO010	13	4	0	1.13	5.89	6.86	24
FCRR008	25	18	22	2.62	4.06	46.46	68
PADEP Reference	35	23	39	2.9	1.78	92.5	-----

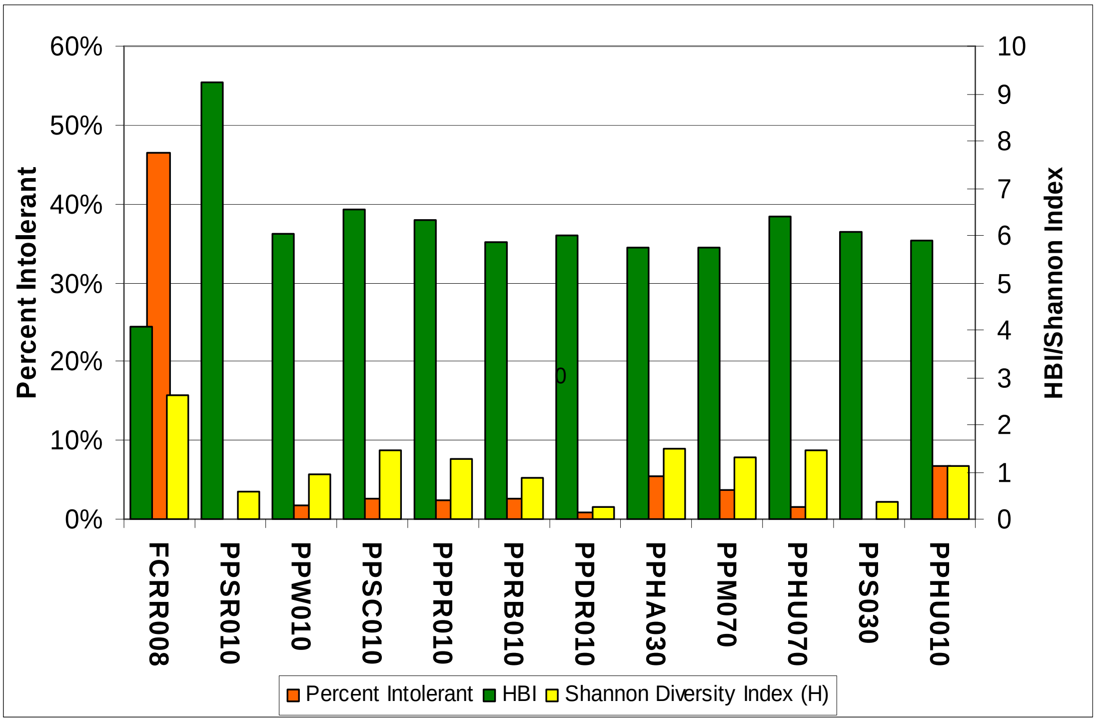


Figure 5.22 PADEP IBI Metric Scores of 11 Tributary Sites in Pennypack Creek Watershed and French Creek Reference Site, 2007

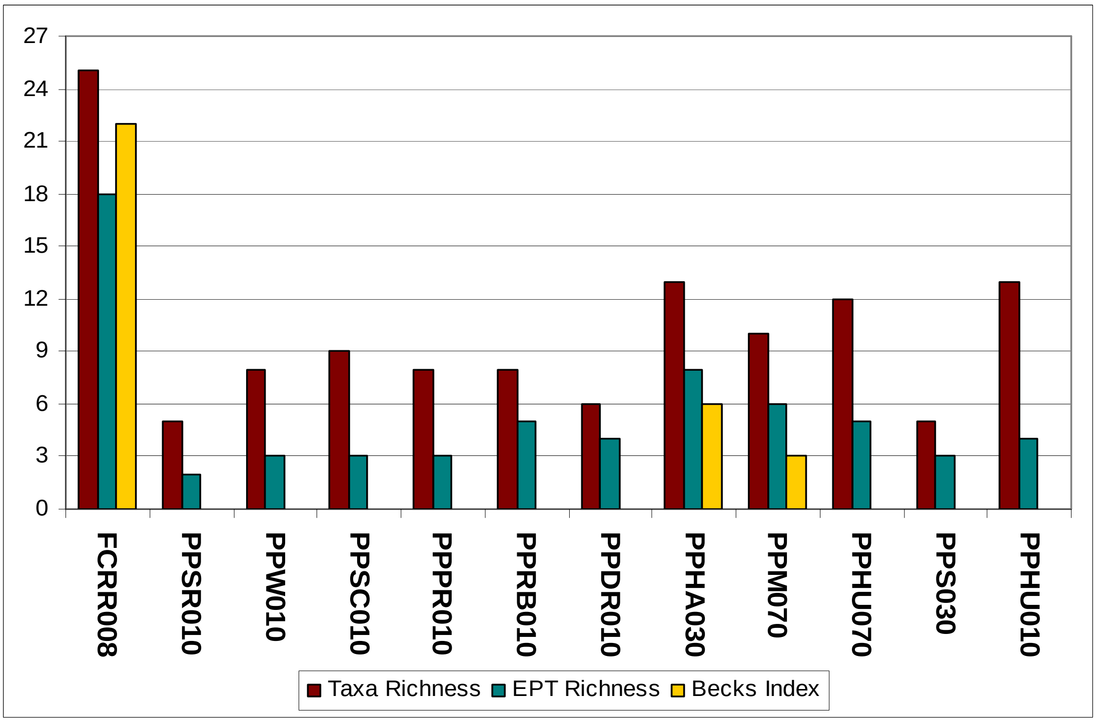


Figure 5.23 PADEP IBI Metric Scores of 11 Tributary Sites in Pennypack Creek Watershed and French Creek Reference Site, 2007

5.2.5.3.3 PENNYPACK CREEK TRIBUTARY SUPPLEMENTARY RESULTS

Generalist feeders (60.85% to 96.17%) and moderately tolerant individuals (18.63% to 98.56%) dominated the benthic assemblage at all tributary sites (Figures 5.24 and 5.25). Intolerant taxa were absent or found in very low abundance in the tributary assessment, composing only 1.66% of all taxa collected in tributary sites. Specialized feeders were also absent or found in low abundance. The trophic composition of the 11 tributary sites was heavily skewed towards generalist feeders, which composed 81.98% of all taxa collected in the assessment. Filterers were the next highest trophic class as they represented 15.51% of all taxa collected from tributary sites. Other functional feeding groups were not as abundant nor were they distributed evenly between sites. The scraper group contributed 1.62% of taxa collected in tributaries and representative taxa were found in all sites except for PPDR010, PPPR010, and PPRB010. Omnivores were the next most numerically abundant at 0.58% and were found in all sites except for PPDR010, PPHA003, PPHU010 and PPM070 (Figure 5.24).

Predators and shredders were highly underrepresented in the Pennypack tributaries, indicating simplification of food web structure and loss of ecosystem functions (Figure 5.24). In natural streams, shredders are usually more dominant in smaller, lower order streams where the concentration of allochthonous organic matter (*e.g.*, leaves) is much higher than larger order streams. Many of the most intolerant EPT taxa are shredders, and their absence from Pennypack Creek tributaries provides evidence of historical degradation in habitat and water quality.

Generally, mainstem Pennypack Creek sites had better metric scores (taxa richness, HBI) and greater numbers of sensitive taxa than tributary sites. There were 5 sensitive taxa from 10 sites on the mainstem, whereas the tributaries had 4 sensitive taxa from 9 sites. *Antoch*a spp. (Diptera: Tipulidae), the most commonly observed sensitive taxon in both the 2007 mainstem and tributary assessments, was observed at 9 tributary monitoring sites.

Sites PPHA003, PPHO010 and PPHU070, in particular, had slightly higher taxa richness than all other tributary assessment sites (n= 13, n=13 and n=12 respectively) as well as greater numbers of EPT and sensitive taxa. Site PPHA030, the most downstream tributary monitoring site in Montgomery County, had both the most sensitive taxa (2 individuals with a sensitivity of 0) and the highest number sensitive taxa (n=4). Two very sensitive EPT taxa, both with tolerance values of zero, *Glossosoma* (Trichoptera: Glossosomatidae) and *Dolophilodes* (Trichoptera: Philopotamidae), were collected at PPHA003. Another EPT taxon, the Nemourid stone fly *Amphinemura* (Plecoptera: Nemouridae), was unique to PPHA003 within the Pennypack Creek Watershed. This site is located at the confluence of Pennypack Creek and Harper's Run within Lorimer Park. Its location in this forested parkland setting may explain its relatively good habitat quality in comparison to other tributary sites.

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

The presence of unique taxa at a site offers another tool for use in assessing habitat quality at stream monitoring locations based on macroinvertebrates. Their importance comes in the fact that their niche requirements can shed light on the environmental conditions present in their respective sites. As was the case in the mainstem assessment, sites with better compatibility to the French Creek reference reach and higher PADEP IBI scores standards had unique taxa that, on average, were less tolerant of pollution than less comparable sites. For example, site PPHA003, which was 32% compatible with PADEP IBI reference metrics had 3 unique taxa with a mean HBI of 3.0 compared to PPSR010, which was 8% comparable and contained one unique taxon with a HBI of 6.

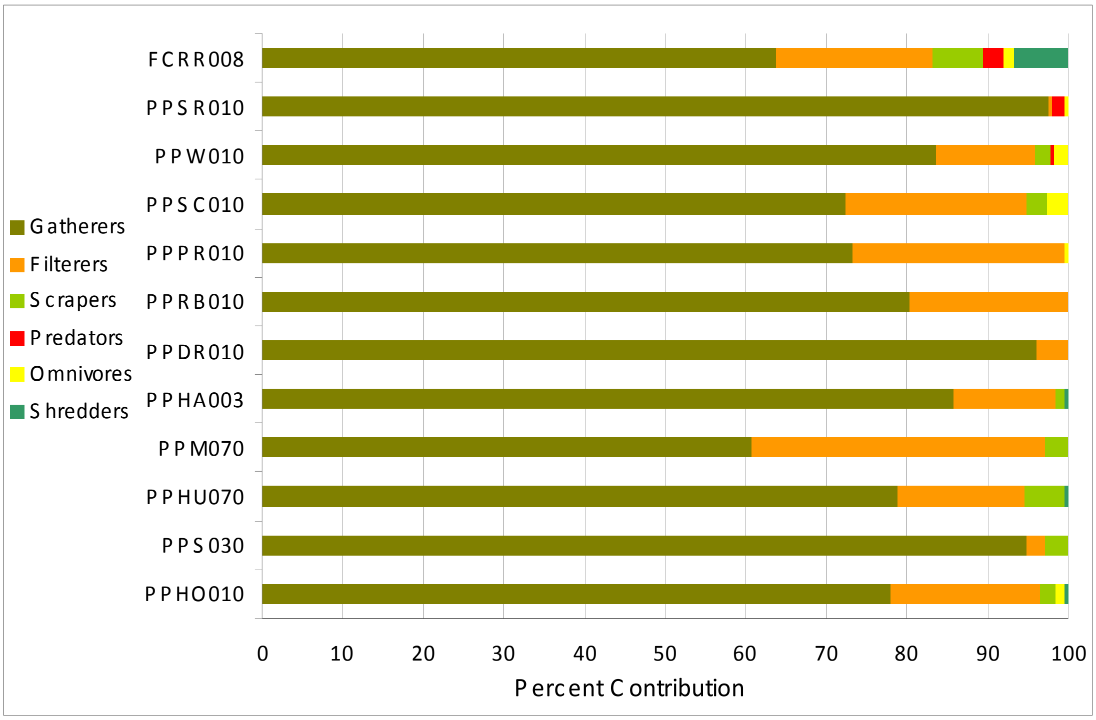


Figure 5.24 Benthic Macroinvertebrate Community Trophic Composition of 11 Tributary Sites in Pennypack Creek Watershed and Reference Site, 2007

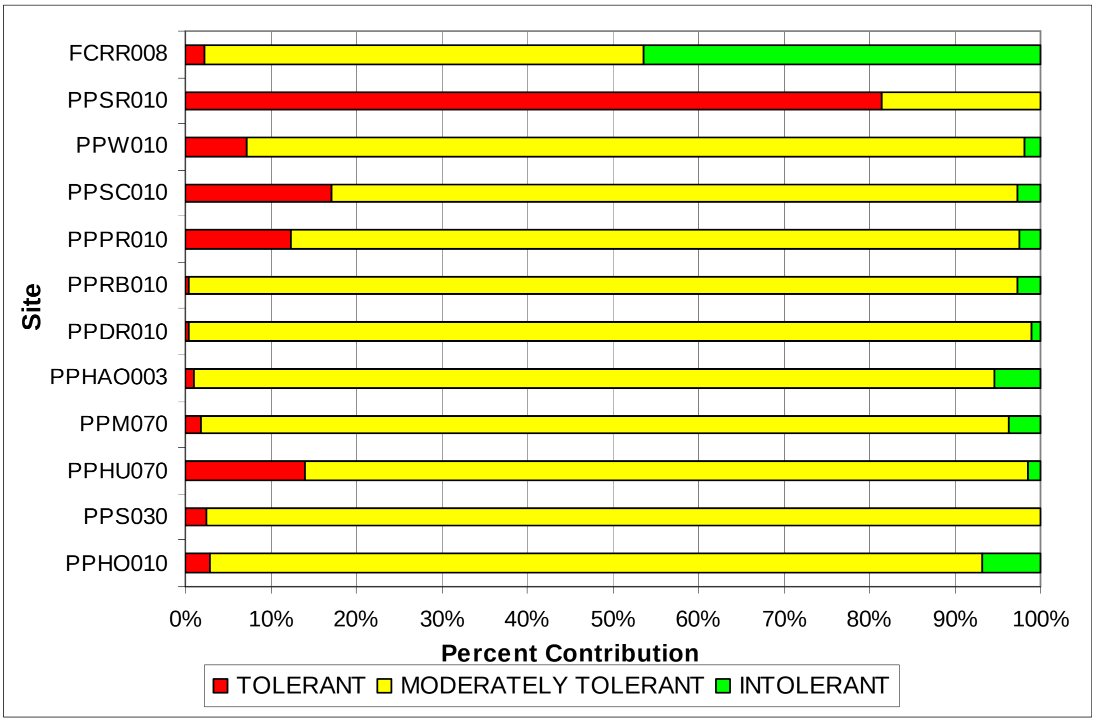


Figure 5.25 Tolerance Designations of Benthic Macroinvertebrate Communities at 11 Tributary Sites in Pennypack Creek Watershed and Reference Site, 2007

Table 5.14 Sensitive Taxa Collected from Pennypack Creek Tributaries

Site	Order	Family	Genus	HBI
PPW010	Diptera	Tipulidae	Antocha	3
PPSC010	Diptera	Tipulidae	Antocha	3
PPPR010	Diptera	Tipulidae	Antocha	3
PPRB010	Diptera	Tipulidae	Antocha	3
PPDR010	Diptera	Tipulidae	Antocha	3
PPHA003	Trichoptera	Glossosomatidae	Glossosoma	0
PPHA003	Trichoptera	Philopotamidae	Dolophilodes	0
PPHA003	Diptera	Tipulidae	Antocha	3
PPHA003	Plecoptera	Nemouridae	Amphinemura	3
PPM070	Trichoptera	Glossosomatidae	Glossosoma	0
PPM070	Diptera	Tipulidae	Antocha	3
PPHU070	Diptera	Tipulidae	Antocha	3
PPHO010	Diptera	Tipulidae	Antocha	3

Table 5.15 Unique Taxa Collected from Pennypack Creek Tributaries

Site	Site HBI	Order	Family	Genus	Taxon HBI
PPSR010	6.33	Diptera	Ceratopogonidae	----	6
PPW010	6.05	Trichoptera	Hydroptilidae	Leucotrichia	6
PPW010	6.05	Gastropoda	Physidae	----	8
PPHA003	5.76	Trichoptera	Philopotamidae	Dolophilodes	0
PPHA003	5.76	Isopoda	Asellidae	Caecidotea	6
PPHA003	5.76	Plecoptera	Nemouridae	Amphinemura	3
PPHU070	6.39	Coleoptera	Elmidae	Optioservus	4
PPHO010	5.9	Gastropoda	Ancylidae	----	7

5.4 ICHTHYOFAUNAL ASSESSMENT

5.4.1 MONITORING LOCATIONS

Between 6/4/07 and 6/19/07, PWD biologists conducted fish assessments at 6 (n=6) locations on mainstem Pennypack Creek (Figure 5.26). Data from these assessments were used to compile biotic integrity metrics as well as to estimate fish biomass which was used in correlational analyses in conjunction with habitat suitability models (Section 6.3.2)

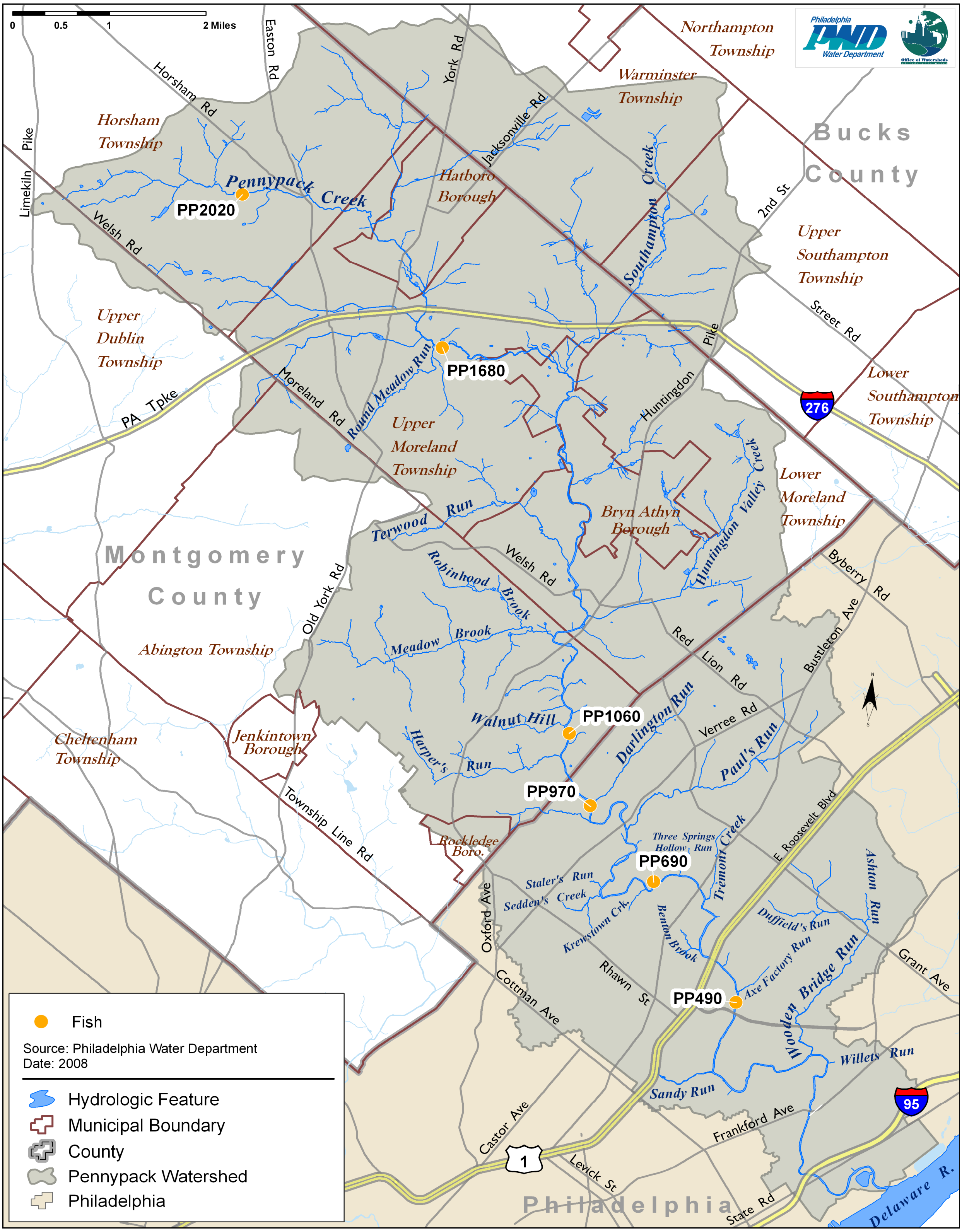


Figure 5.26 Fish Monitoring Sites in Pennypack Creek Watershed, 2007

5.4.2 FIELD STANDARD OPERATING PROCEDURES

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

5.4.3 DATA ANALYSES

5.4.3.1 FISH IBI METRICS

The health of fish communities in Pennypack 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 5.16 and 5.17 describe the various indices and scoring criteria used for the IBI metrics in Pennypack Creek Watershed. Additional metrics used in the analysis are displayed in Table 5.18.

Table 5.16 Metrics Used to Evaluate the Index of Biological Integrity (IBI) at Representative Sites *

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

* Metrics used are based on modifications as described in Barbour *et al*., 1999.
[a] Metric based on USGS NAWQA study (2002).

Table 5.17 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 5.18 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

5.4.3.2 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:

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

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

5.4.3.4 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).

5.4.3.5 MODIFIED INDEX OF WELL-BEING (MIWB)

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

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

where;

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

5.4.4 RESULTS

5.4.4.1 WATERSHED OVERVIEW

During the 2007 Pennypack watershed fish assessment, PWD surveyed 7 sites and collected a total of 5,451 fish representing 36 species in 11 families (Tables 5.19 and 5.20). Satinfin shiner (*Cyprinella analostana)* and blacknose dace (*Rhinichthys atratulus),* two taxa tolerant of poor stream conditions, were most abundant and comprised 28.7% of all fish collected. Other common species included white sucker (*Catostomus commersonii*), redbreast sunfish (*Lepomis auritus*), green sunfish (*Lepomis cyanellus*), and American eel (*Anguilla rostrata*). Of 36 species collected in the watershed, the six aforementioned species composed 67.3% of the entire fish assemblage.

Similarly, three species made up 72.0% of the total fish biomass, with white sucker contributing 47.4% of the biomass.

Though fewer sites were sampled in 2007, most fish species collected in 2002 were also collected from at least one location in 2007. Overall fish diversity in Pennypack watershed decreased slightly from 39 species in 2002 to 36 species in 2007, however fish diversity decreased at most individual sites and major changes in fish community composition were also observed. There was also a marked decrease in overall fish abundance, biomass and density at both the watershed level and at 5 of 6 individual sampling sites (Figures 5.27 through 5.30). Site PP2020 was the only site at which increases in fish abundance, biomass, and density were observed. The relationship between productivity and stream health is not straightforward; changes in productivity need to be evaluated alongside other measures of fish community health, such as trophic relationships and tolerance, as well as the trophic state and overall health of the stream system. Decreased overall fish abundance along with increased proportions of tolerant and non-specialized feeding forms suggests that the shift in the composition of the Pennypack Creek fish community is likely due to increased habitat degradation and diminished water quality.

In addition to the trend of decreased overall fish abundance, there was a shift in dominance, with swallowtail shiner most abundant overall in 2002 (n=2690) and satinfin shiner (n=657) most abundant overall in 2007. The importance of this shift should be noted, as swallowtail shiner is considered to be only moderately tolerant of pollution, while satinfin shiner is considered pollution tolerant. There was a sharp decrease (119.4%) in overall swallowtail shiner proportional abundance from 2002 to 2007. Four of the six most common fish species (satinfin shiner, white sucker, redbreast sunfish, and blacknose dace) from the 2002 assessment were among the six most commonly collected species in the 2007 assessment; however, the abundance of two of the six most common species collected in 2002 (swallowtail shiner and spottail shiner) were noticeably reduced and replaced by the nonnative, pollution-tolerant green sunfish and the native, pollution-tolerant American eel (Figure 5.31). There were substantially more trout collected in 2007 (n=85) than in 2002 (n=10), even though fewer sites were surveyed in 2007. Since all trout in Pennypack Creek are stocked, the increased number of trout is mostly likely attributable to stocking activities and not an indicator of improved stream conditions.

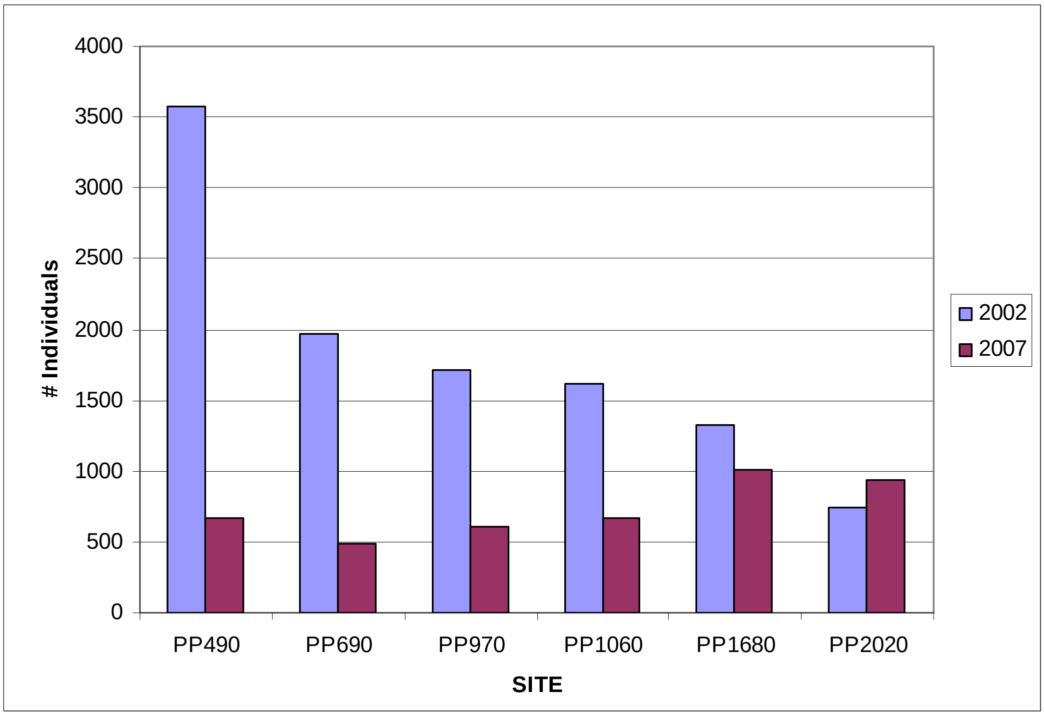


Figure 5.27 Total Fish Abundance of 6 Mainstem Pennypack Creek Sites, 2007

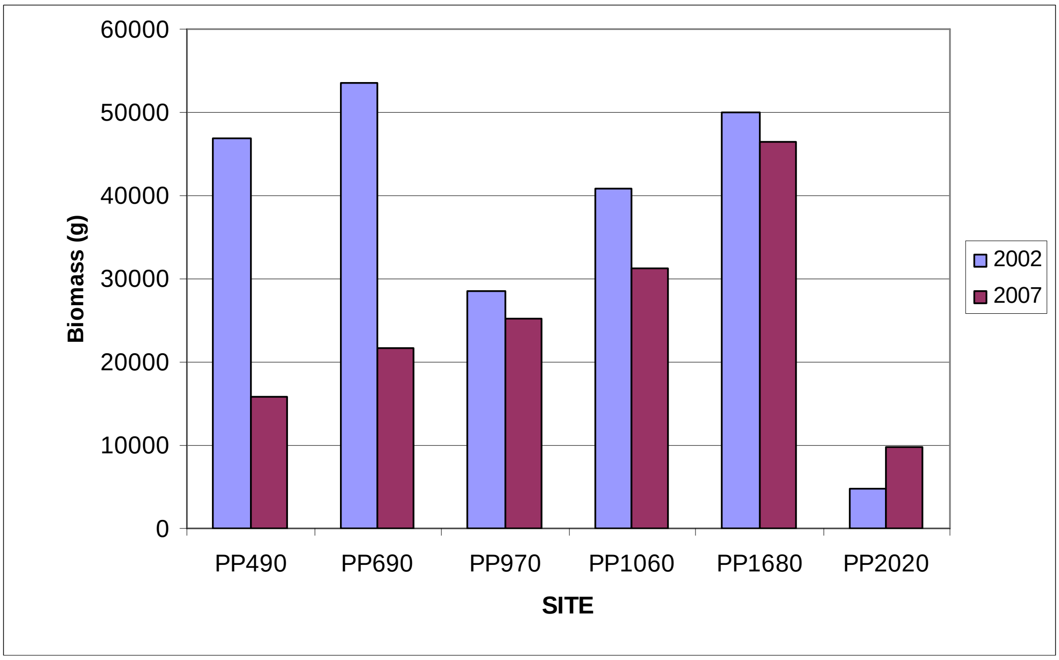


Figure 5.28 Total Fish Biomass of 6 Mainstem Pennypack Creek Sites, 2007

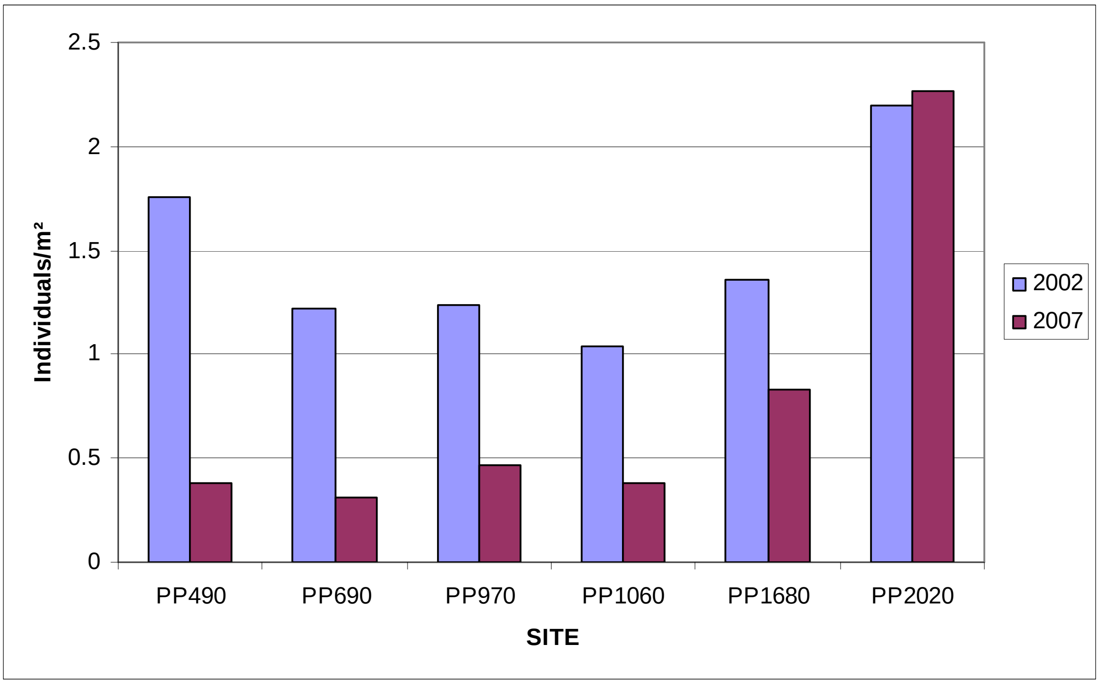


Figure 5.29 Fish Density (Abundance per Unit Area) of 6 Mainstem Pennypack Creek Sites, 2007

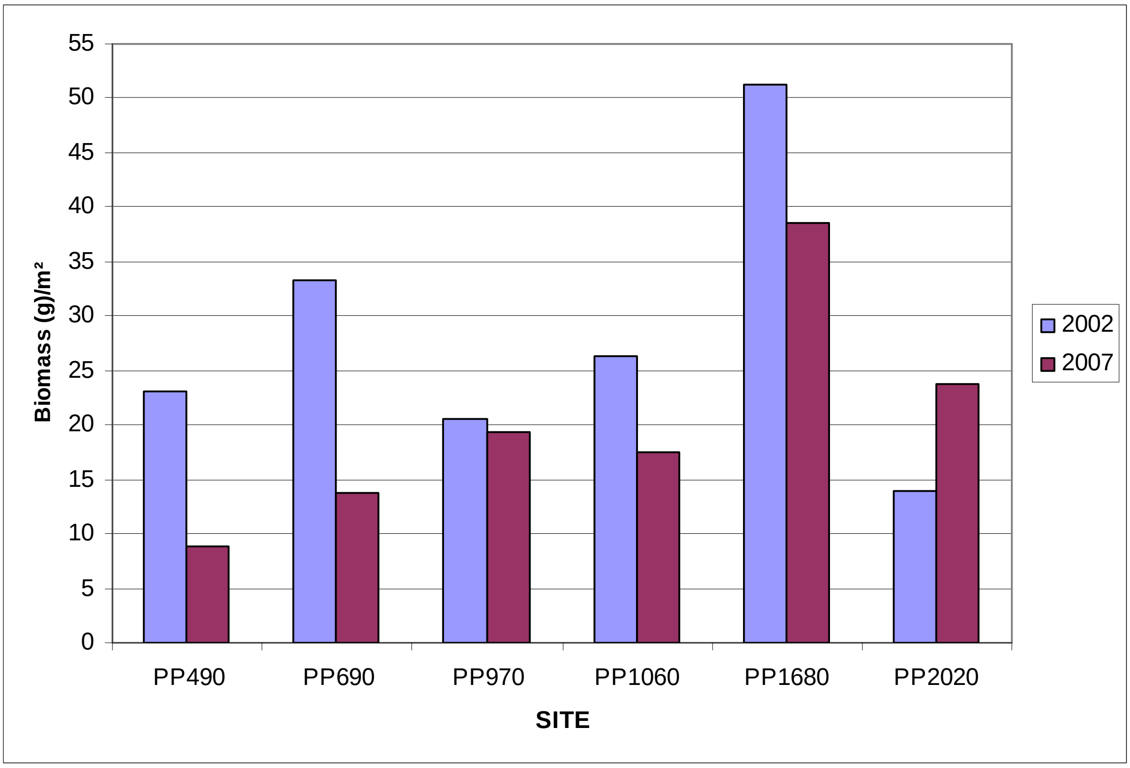


Figure 5.30 Fish Density (Biomass per Unit Area) of 6 Mainstem Pennypack Creek Sites, 2007

Table 5.19 Fish Abundance and Biomass of 6 Mainstem Pennypack Creek Sites, 2002 and 2007

Pennypack Creek Watershed Fish Assessment	2002 Abundance	2007 Abundance	2002 Density (individuals/m²)	2007 Density (individuals/m²)	2002 Biomass (g)	2007 Biomass (g)	2002 Biomass/m²	2007 Biomass/m²
PP490	3,571	646	1.76	0.36	46,854.40	11,225.50	23.06	6.27
PP690	1,964	476	1.22	0.3	53,554.40	19,089.10	33.32	12.17
PP970	1,717	594	1.23	0.45	28,645	22,341	20.60	17.11
PP1060	1,622	647	1.04	0.36	40,861.30	26,770.70	26.30	15.02
PP1680	1,323	1,004	1.36	0.56	50,042.50	46,377.90	51.34	26.03
PP2020	747	934	2.2	2.27	4,750	9,824.20	13.99	23.83

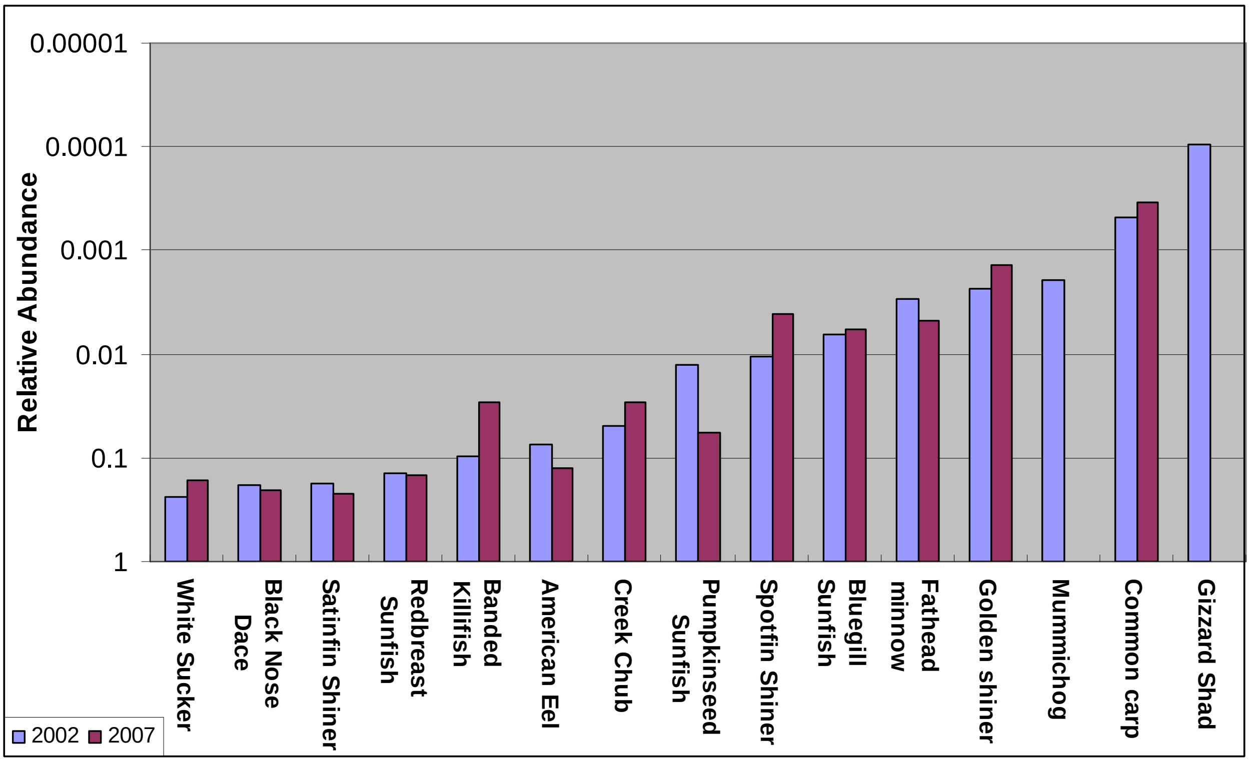


Figure 5.31 Relative Abundance of Tolerant Fish Species Collected in Pennypack Creek Watershed, 2002 and 2007

American eel, blacknose dace, white sucker, redbreast sunfish, green sunfish, pumpkinseed sunfish (*Lepomis gibbosus*), satinfin shiner, spottail shiner (*Notropis hudsonius*), swallowtail shiner (*N. procne*), and tessellated darter (*Etheostoma olmstedi*) were found at all non-tidal sites in the watershed while comely shiner (*N. amoenus*), golden shiner (*N. crysoleucas*), and common carp (*Cyprinus carpio*) were each only found at only one site on the non-tidal Pennypack Creek.

Of particular concern was the absence of longnose dace (*Rhinichthys cataractae*) from all but two sampling locations found within Philadelphia's Fairmount Park System. Failure to collect any longnose dace in the upstream sites, despite presence of suitable habitat in some areas, is a strong indication that poor water quality is negatively impacting the fish assemblage. The presence of stocked brown trout (*Salmo trutta*) and rainbow trout (*Oncorhynchus mykiss*) was spatially documented in the lower, middle, and upper portions of the watershed as far upstream as site PP1680 at Davisville Road, Upper Moreland Township, Montgomery County (river mile 16.8). Trout abundance was greatest in the lower watershed and decreased in an upstream direction.

Four species collected by PWD in a 2002 survey were absent in the 2007 fish assessment; creek chubsucker (*Erimyzon oblongus*), margined madtom (*Noturus insignis*), black crappie (*Pomoxis nigromaculatus*), and fallfish (*Semotilus corporalis*). Notably, creek chubsucker was the only native pollution intolerant species collected in Pennypack watershed, and its absence five years later implies increased degradation of habitat and water quality. Only one species, western mosquitofish (*Gambusia affinis*), was collected in 2007 but not in 2002. This non-native species is tolerant of low dissolved oxygen conditions and is occasionally stocked in man made ponds and fountains as a mosquito control measure, which may explain the circumstances of the species' introduction to Pennypack Creek.

Margined madtom individuals collected in 2002 are believed to have been stocked as part of a reintroduction project. The absence of margined madtoms in 2007 indicates that the reintroduction effort has failed to establish a reproducing population. While the details of this reintroduction effort are poorly documented, this failure suggests Pennypack Creek Watershed may have insufficient water quality, habitat quality, or both to support margined madtoms. It is worthwhile to note that longnose dace (*R. cataractae*), a species with similar habitat requirements, has also apparently suffered a decline over the same time period in Pennypack Creek Watershed. Hydrologic and Fluvial Geomorphic analyses conducted in 2007 documented severe diminution of baseflow, and extreme destabilization and overwidening of stream channels throughout the watershed. The combination of these factors may strongly decrease habitat suitability for species such as longnose dace and margined madtoms that rely on well oxygenated, swiftly flowing riffles with adequate baseflow depth.

Since trout do not reproduce in Pennypack Creek and their populations are maintained solely by the state stocking program, we excluded trout when calculating metrics which are intended to be measures of stream health (*i.e.*, Index of Biotic Integrity, number of individuals with deformities, lesions and tumors, percent white sucker, diversity indices, and Modified Index of well being). Nevertheless, stocked trout are a component of the fish community at many sites, and trout have thus been included in most "raw" descriptions of fish assessment results (*i.e.*, biomass, Catch per unit effort, density, standing crop) for completeness and fish IBI metrics were calculated both with and without trout to explore the influence of including trout in the IBI analysis. Figures have been prepared both with and without stocked trout.

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 Pennypack Creek was 30 (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. The only site for which a different IBI score condition category would have been calculated by including stocked trout in the analysis was site PP970 (IBI including trout =30 or “fair”, IBI excluding trout =28, or “poor”) (Figures 5.32 and 5.33).

Spatial trends showed that sites in the downstream sections of the watershed received a “good” to "fair" IBI score, while the middle and upper watershed scored “poor”, signifying unhealthy stream conditions (Figures 5.32 and 5.33). Only two of the six stations received an IBI score above “poor”, with both being in Philadelphia’s Fairmount Park System. Scores for the Modified Index of Well-Being, which is an index that takes into account measures of diversity and abundance, were well below reference site values at all monitoring sites and did not show obvious spatial trends. Overall, monitoring stations in the downstream portion of the watershed had higher biological integrity, and thus environmental quality, than upstream stations.

Table 5.20 List of Fish Species Collected from 6 Mainstem Pennypack Creek Watershed Sites, 2007

Common Name	Scientific Name	PP490	PP690	PP970	PP1060	PP1680	PP2020	Totals
American Eel	*Anguilla rostrata*	93	118	35	75	30	13	364
Banded Killifish	*Fundulus diaphanus*	7	6	4	0	33	36	86
Blacknose Dace	*Rhinichthys atratulus*	30	18	168	50	44	290	600
Bluegill Sunfish	*Lepomis macrochirus*	1	3	3	6	4	0	17
Brown Bullhead	*Ameiurus nebulosus*	0	1	0	0	5	0	6
Brown Trout	*Salmo trutta*	17	8	6	16	0	0	47
Comely Shiner	*Notropis amoenus*	24	0	0	0	0	0	24
Common Carp	*Cyprinus carpio*	0	0	0	0	1	0	1
Common Shiner	*Luxilus cornutus*	1	0	71	89	0	0	161
Creek Chub	*Semotilus atromaculatus*	2	0	2	0	9	72	85
Fathead Minnow	*Pimephales promelas*	0	1	3	3	0	7	14
Golden Shiner	*Notemigonus crysoleucas*	0	0	0	0	4	0	4
Green Sunfish	*Lepomis cyanellus*	13	42	3	49	79	234	420
Hybrid Sunfish	*Lepomis hybrid*	0	0	0	2	4	1	7
Largemouth Bass	*Micropterus salmoides*	0	1	0	0	1	0	2
Longnose Dace	*Rhinichthys cataractae*	7	4	0	0	0	0	11
Pumpkinseed Sunfish	*Lepomis gibbosus*	8	14	2	45	90	11	170
Rainbow Trout	*Oncorhynchus mykiss*	11	6	10	9	2	0	38
Redbreast Sunfish	*Lepomis auritus*	104	133	19	99	30	49	434
Rock Bass	*Ambloplites rupestris*	8	7	2	4	0	0	21
Satinfin Shiner	*Cyprinella analostana*	86	23	76	47	399	26	657
Smallmouth Bass	*Micropterus dolomieui*	5	7	5	8	0	0	25
Spotfin Shiner	*Cyprinella spiloptera*	7	3	0	2	0	0	12
Spottail Shiner	*Notropis hudsonius*	77	7	34	28	51	13	210
Swallowtail Shiner	*Notropis procne*	153	38	68	46	27	6	338
Tessellated Darter	*Etheostoma olmstedi*	3	20	8	10	2	99	142

White Sucker	*Catostomus commersonii*	15	27	91	82	185	77	477
Western Mosquitofish	*Gambusia affinis*	1	0	0	2	0	0	3
Yellow Bullhead Catfish	*Ameiurus natalis*	1	3	0	0	6	0	10
	TOTAL	**674**	**490**	**610**	**672**	**1006**	**934**	**4386**

Trophic composition metrics evaluate quality of the energy base and foraging dynamics of a fish assemblage. However, interpreting results of biological indexing methods that evaluate certain attributes of a fish community, such as the relative abundance of top predators, or proportion of intolerant species, can be difficult in a watershed that is heavily stocked with trout. It is important to consider stocked fish when examining the trophic composition of the fish community. While an increase in top predators in an urban stream usually would be viewed as a positive development, top predators are never expected to be overwhelmingly dominant in balanced ecosystems. Data from some Philadelphia area sites surveyed by PWD suggest that at high predator densities, abundance and diversity of forage fish may be reduced.

As applied to urban streams, the trophic composition of a fish assemblage is an effective means of evaluating the shift towards more generalized foraging that typically occurs with increased degradation of the physicochemical habitat (Barbour *et al*., 1999). For example, generalist feeders (51.2%) dominated the Pennypack watershed fish assemblage, with 37.5% insectivores and 11.3% top carnivores (or 9.6% top carnivores if stocked trout are excluded) (Figure 5.34). 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 all sites except the upstream-most station illustrates this point. Trophic composition was fair to poor when compared to reference sites, which have more insectivores than generalists. Though community composition varied between sites, the fish assemblage in Pennypack watershed was heavily skewed towards a pollution tolerant, generalist feeding community. Overall trophic composition shifted over a five year period from an insectivore dominated community in 2002, to a community dominated by generalists in 2007. This observation suggests deterioration in stream quality.

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, no intolerant taxa (excluding stocked trout) were collected from Pennypack Creek Watershed in 2007, suggesting high levels of chemical and physical disturbance (Figure 5.35). More specifically, creek chubsucker was the only native pollution intolerant species collected in Pennypack watershed in 2002, and its absence five years later implies increased stream degradation. The percentage of fishes tolerant of poor stream quality increased from 55.1% in 2002 to 64.8% in 2007, again adding to the evidence that conditions in Pennypack Creek are degrading. In general, tolerant fish were found to dominate the uppermost stations, whereas the downstream stations had more moderately tolerant individuals.

Another general metric used to assess stream health, the percentage of fish with deformities, lesions, tumors, or anomalies (DELTA), revealed that the middle portion of the watershed was slightly more heavily impacted than the downstream and upstream portions (Figure 5.36). With a range from 0.46-8.15 the incidence of DELTA in Pennypack Creek Watershed was not as severe as in other watersheds surveyed by the PWD, and some sites were similar to reference conditions. While the greatest increase in DELTAs over background conditions coincided with the site that was found to be most affected by point source discharges of municipal treated wastewater, at 8.15% this level was poor, but not as severe as that observed at other impaired sites in PWD fish surveys. One possible confounding factor is the fact that tolerant fish have become much more dominant throughout the watershed and these tolerant species may be less likely to express DELTAs.

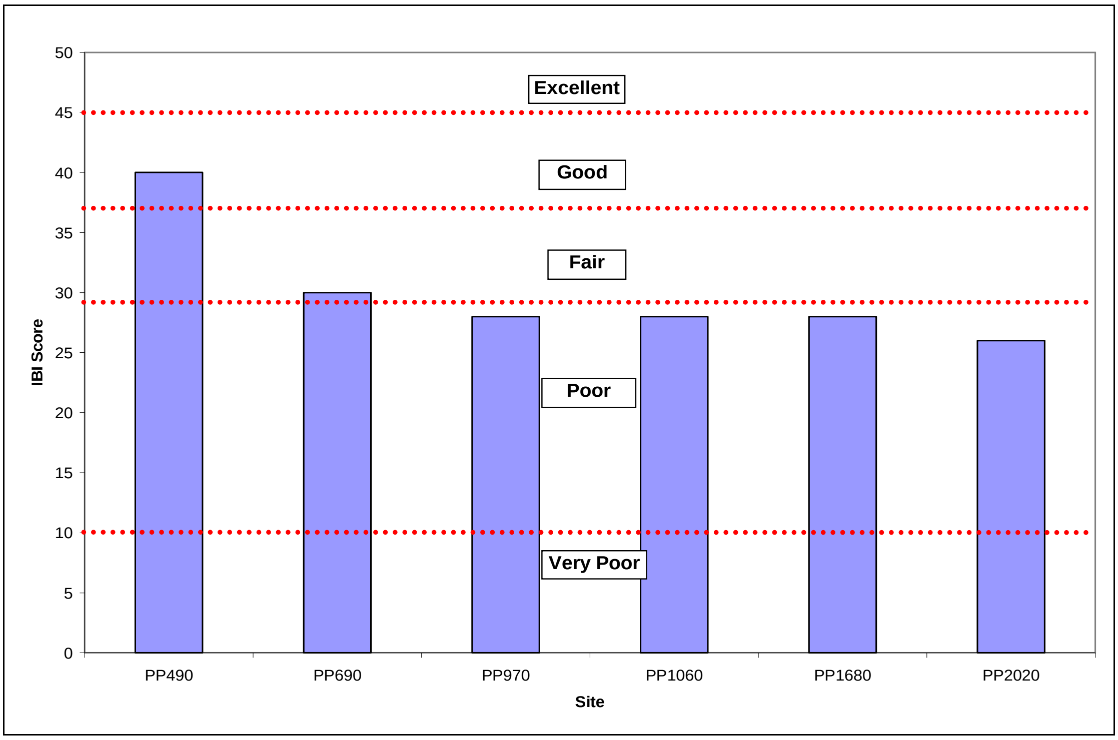


Figure 5.32 Fish Index of Biotic Integrity (IBI) of 6 Pennypack Creek Watershed Sites Pennypack Creek Watershed (Excludes Trout), 2007

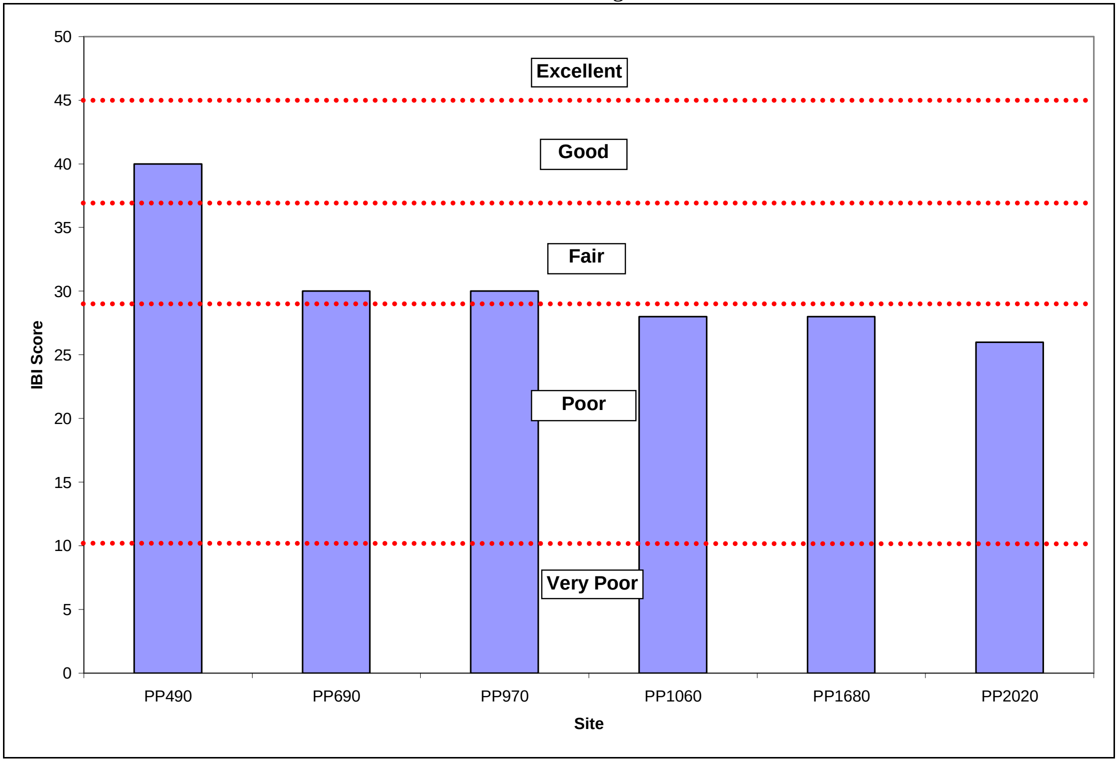


Figure 5.33 Fish Index of Biotic Integrity of 6 Pennypack Creek Watershed Sites (Includes Trout), 2007

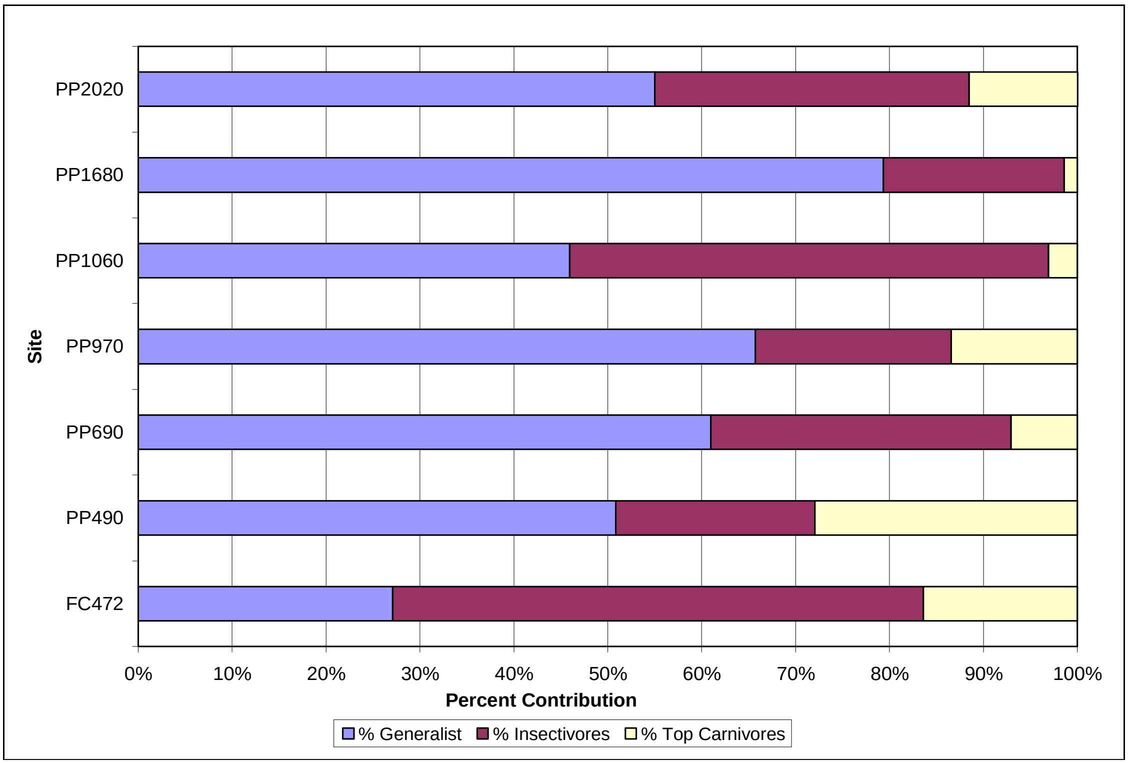


Figure 5.34 Fish Community Trophic Composition of 6 Pennypack Creek Watershed Sites (Includes Trout), 2007

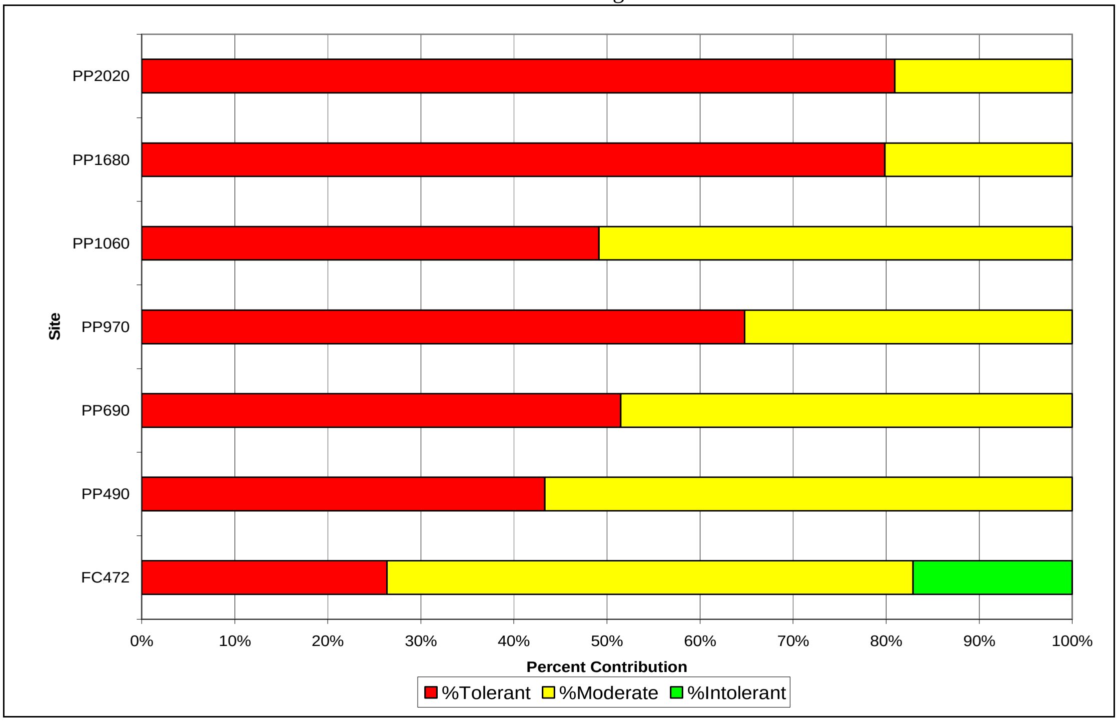


Figure 5.35 Fish Community Tolerance Designations of 6 Pennypack Creek Watershed Sites (Excludes Trout), 2007

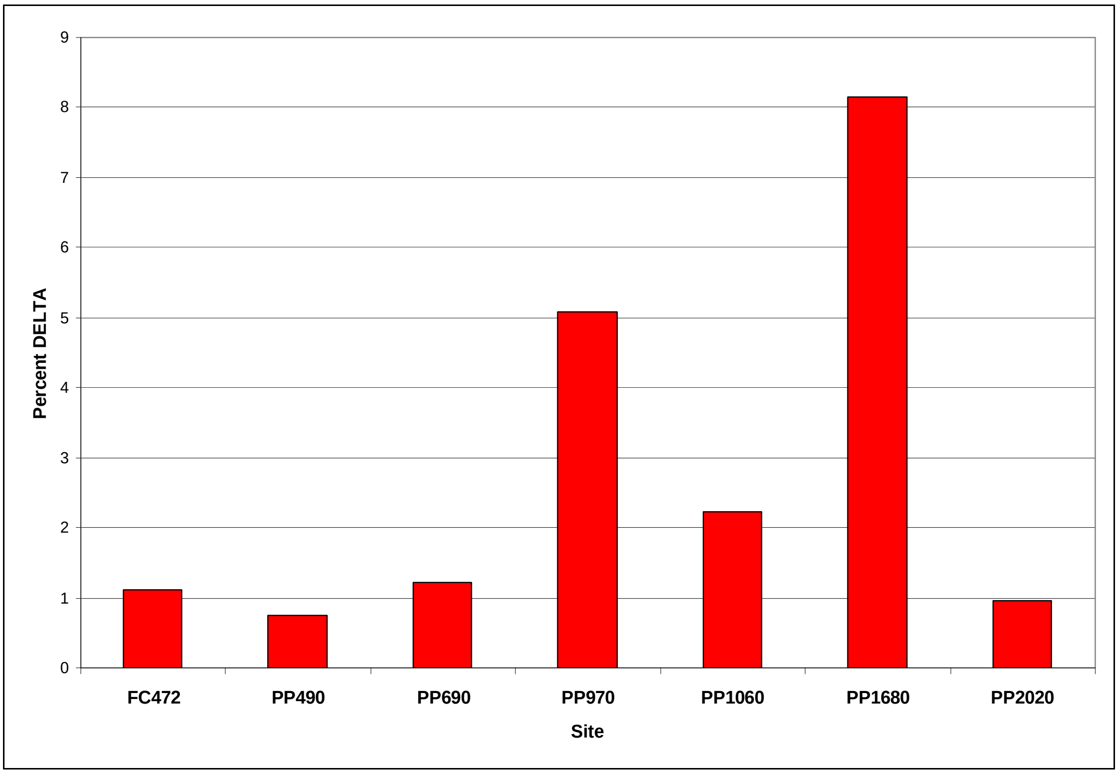


Figure 5.36 Percentage of Fish with Disease, Tumors, Fin Damage, or Anomalies (DELTA) at 6 Mainstem Pennypack Creek Sites, 2007

5.4.4.2 Individual Site Results

5.4.4.2.1 PP490

A total of 674 fishes represented by 19 species yielded a biomass of 15.8 kg during 82 minutes of electrofishing. This site had the highest fish diversity (*i.e.*, species richness) in the watershed, but relatively low abundance (*i.e.*, number of fish) given the size of the stream. A five-fold decrease (81%) in overall fish abundance was observed at PP490 from 2002 (n = 3,572) to 2007 (n = 674), with nearly 3,000 fewer fish collected. The species with the largest decline in numbers include swallowtail shiner (87% decrease), spottail shiner (89% decrease), satinfin shiner (84% decrease), and white sucker (96% decrease). Total biomass and standing crop showed similar diminishing trends. Based on a stream surface area of 1790 m^2, a density of 0.38 fish per m^2 and a standing crop of 8.8 grams per m^2 were calculated. These values signified the lowest standing crop and second lowest density in the watershed. Similarly, this site had the second smallest catch per unit effort (CPUE) at 8.14 fish per minute of electrofishing.

Six species collected in 2002 (Eastern silvery minnow, fallfish, mummichog, largemouth bass, and golden shiner) were not present in 2007, while three species collected in 2007 (yellow bullhead, western mosquitofish, and brown trout) were not collected in the 2002 survey. Swallowtail shiner, a moderately tolerant insectivore, was most abundant; whereas white sucker, a pollution tolerant generalist, dominated total biomass at this site. Trophic composition was well-balanced, with the lowest percentage of generalist feeders and highest percentage of insectivores in the Pennypack Creek. Site PP490 was one of only two sites at which more insectivores were collected than generalist feeders.

Despite the low abundance and biomass, PP490 received the highest Index of Biotic Integrity (IBI) score in the watershed (40 out of 50), representing a "good" quality fish assemblage and therefore, good environmental health. Since the IBI utilizes multiple biological metrics, several other characteristics of the fish community account for the good score: highest species diversity; the presence of two benthic insectivorous species; seven water column species; low percentage of white suckers; low percentage of generalist feeders; high percentage of top carnivores; low percentage of individuals with disease or anomalies; and low percentage of dominant species. The Modified Index of Well-Being (11.94) was the best among all sites in Pennypack watershed and corroborated with the IBI designation. In summary, although PP490 scored low for fish abundance metrics, the high values for diversity, trophic structure, fish condition, and community composition metrics elevated the overall IBI score.

5.4.4.2.2 PP690

In 1568 m^2 of stream surface area, a total of 490 individuals of 17 species were collected during 75 minutes of electrofishing. This site had the lowest abundance (n=490), density (0.31 fish/m^2), and CPUE (6.5 fish/minute) in the watershed. This represents a four-fold decrease (75%) in total fish abundance at PP690 from 2002 (n=1965) to 2007 (n=490). The species with the largest decline in numbers include swallowtail shiner (92% decrease), spottail shiner (94% decrease), satinfin shiner (92% decrease), and white sucker (92% decrease). These decreases correspond to a major shift in the dominant fish species (*i.e.*, assemblage percent contribution) from 2002 to 2007. Spottail shiner, satinfin shiner, and white sucker were the three dominant species in 2002; however, redbreast sunfish, green sunfish, and American eel dominated in 2007. This significant reduction in insectivores and increase in generalist feeders suggests stream quality degradation during the 5 year period. Generalized foraging typically occurs with increased deprivation of the physicochemical habitat (Barbour *et al*., 1999). White sucker contributed most to overall biomass (37%), followed by American eel (25%), and redbreast sunfish (16%).

PP690 had the highest percentage of top carnivores (30%) in the watershed, due to increased density of American eels and stocked trout, with 49% generalist feeders and 21 % insectivores. Two benthic insectivorous as well as five water column species were collected. This site had more pollution tolerant (50%) than moderately tolerant fishes (47%), and stocked trout accounted for the only intolerant species (3%) at this site.

The IBI score of 30 (out of 50) was the second highest in the watershed and typical of a fish assemblage with "fair" biotic integrity. Nonetheless, the 2002 IBI score from this site was higher (38 out of 50) than in 2007 and, consequently, decreased from “good” to “fair” biotic integrity. The biologic characteristics responsible for the decline are related to the significant change in trophic structure from insectivores to generalist feeders.

5.4.4.2.3 PP970

PP970 contained the second lowest number of individuals (*i.e.*, abundance) in the watershed with 610 fishes of 14 species, resulting in a density of 0.47 fish/m^2 and catch per unit effort of 8.79 fishes/minute electrofishing. Again, there was a decline (64%) in total fish abundance from 2002 (n=1717) to 2007 (n=610), mostly from a decrease in the cyprinid (minnow) family representation. Blacknose dace and white sucker, two taxa extremely tolerant of poor stream conditions, were most abundant and contributed 42.4% of all fish collected. Other common species included satinfin shiner, common shiner, and spottail shiner. Similarly, two species made up 72.4% of the total fish biomass, with white sucker contributing 63.6% of the biomass.

Margined madtoms were not collected within Pennypack Creek Watershed in 2007, and the two individuals collected in 2002 were likely stocked as part of a larger reintroduction project in this vicinity. The absence of margined madtoms by 2007 suggests insufficient water quality and/or habitat to support a reproducing population. Of similar concern was the absence of longnose dace (*R. cataractae*) at this sampling location, when this species was found at two downstream sites. Longnose dace were not collected upstream of site PP690 in the 2007 fish survey, despite presence of suitable habitat in some areas. The disappearance of this riffle specialist species is a strong indication that poor water quality, habitat degradation, or both factors are negatively impacting the fish assemblage.

Spatially in the watershed, this site represents the start of a decline in diversity, number of benthic insectivorous species, and water column species; and an increase in percent white suckers and percentage of individual fishes with deformities, eroded fins, lesions, and other anomalies (DELTA). There was an unbalanced trophic structure with a lower percentage of insectivores (31.2%) than generalist feeders (59.3%); however, these results were similar to the 2002 survey. Tolerance designations were 63.1% tolerant; 34.3% moderately tolerant; and 2.6 % intolerant (includes trout); again, similar to the results from 2002. As a result, this site received an IBI score which bordered between “fair” to “poor” biotic integrity. When stocked trout were included in the index calculation, the IBI score was “fair” (30 out of 50); but when trout were excluded, the site was categorized “poor” (28 out of 50). Similarly, the Modified Index of Well-Being (10.7) and Shannon Diversity Index (2.2) values support the IBI classification.

5.4.4.2.4 PP1060

A total of 672 fishes representing 14 species were collected in 1781 m^2 of stream surface area in 75 minutes of electrofishing. This site had a total biomass of 31.2 kg (second greatest in watershed), standing crop of 17.5 g/m^2, and catch per unit effort of 8.9 fish/minute (second highest). The declining trend (59%) in total fish abundance from the 2002 survey (n=1625) to 2007 (n=672) continued at PP1060. Not only did the overall abundance decrease, but also the proportional community composition; most notably, the 88% decrease in swallowtail shiner and 79% decrease in spottail shiner abundance. As these moderately tolerant insectivorous cyprinids declined, there was a corresponding increase in proportion of more pollution tolerant, generalist feeding centrarchid sunfishes, particularly the non-native, transient green sunfish. It should be noted that there was also an increase in stocked brown and rainbow trout collected at this site, which may exert top-down predation pressures on various minnows.

Ultimately, the result was a change in a fish community more balanced between insectivores (48%) and generalist feeders (42%) in 2002, to an uneven community dominated by generalist feeders (63%) in the 2007 survey. This was the highest percentage of generalist feeders in the entire Pennypack 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 number of white suckers in the watershed, which is symptomatic of degraded stream conditions. Of the 14 species found here, five species composed 59% of all individuals collected and 86% of the total biomass. With negative scores for abundance, diversity, and trophic structure, this monitoring location received an IBI score of 28 out of 50 and displayed the disposition of a "poor" quality fish assemblage.

5.4.4.2.5 PP1680

This site was characterized by several negative biological aspects which suggest a high level of stream disturbance. PP1680 had the greatest percentage of white suckers (18%) in the 2007 survey of Pennypack Creek Watershed, indicating degradation as this species shows increased distribution or abundance despite the historical disturbances and white suckers generally shift from incidental to dominant in disturbed sites (Barbour *et al*., 1999). Furthermore, this site had the greatest percentage of individual fishes with deformities, eroded fins, lesions, and other anomalies (DELTA), with 8% 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). This is symptomatic of an impacted assemblage downstream of point source pollution or in areas where toxic chemicals are concentrated (Barbour *et al*., 1999). Site PP1680 was located in the downstream vicinity of a point source discharge of treated municipal waste.

Whereas this location had the greatest fish abundance (n=1006), biomass (46.5 kg), and standing crop (38.5 g/m^2), five (out of 16) species comprised 80% of all individuals collected and 85% of total fish biomass at this location. Furthermore, nearly 80% of all fishes collected at this site were tolerant of pollution. Only one benthic insectivorous species, four water column species, and zero pollution intolerant species were found in 1205 m^2 of stream surface area. Catch per unit effort (8.8 fish/minute) was close to average, while density (0.2 fish/ m^2) was well above average among sites sampled in Pennypack Creek Watershed during 2007. The trophic structure was relatively well balanced with 50.9% insectivores, 45.8% generalist feeders, and 3.3% top carnivores.

Modified Index of Well-Being (10.56) and Shannon Diversity Index (2.01) scores were second-worst in the watershed. With the highest prevalence of DELTA, highest percentage of white suckers, highest percentage of dominant species, and high percentage of fish tolerant of pollution, this site received a "poor" IBI score of 28 out of 50. This IBI score represented a fish community reflective of poor environmental quality.

5.4.4.2.6 PP2020

The fish assemblage at PP2020 contained only eleven species, which was the fewest number of species collected at any individual site in Pennypack Creek Watershed. Blacknose dace, green sunfish and white sucker, species which are characterized as pollution tolerant, constituted 64% of all fish collected at this location. American eel, white sucker, redbreast sunfish, and green sunfish composed nearly 80% of total fish biomass. Also, this site was devoid of pollution intolerant taxa and only contained one benthic insectivorous species. Of particular concern was the absence of creek chubsucker (*Erimyzon oblongus*), a native pollution intolerant species, which was collected in the 2002 fish survey but not in 2007. Species richness typically decreases with increased degradation. With 79% generalist feeders and only 1.4% top carnivores, site PP2020 had the most highly skewed trophic structure by abundance in the Pennypack watershed. There was also an increase in the percentage of generalist feeders (and subsequent decrease in insectivores) from 2002 to 2007. In addition, this site had the greatest percentage of pollution tolerant fishes in the watershed.

Site PP2020 was the only survey location that had an increase in fish abundance from 2002 (n=747) to 2007 (n=934), which explains why PP2020 had the greatest fish density (2.3 fish/ m^2) and catch per unit effort (11.6 fish/minute). The Modified Index of Well-Being (10.1) and Shannon Diversity Index (1.9) were worst in the watershed. This site received the worst IBI score (26 out of 50) in the watershed, which signifies “poor” biotic integrity. Low species richness and trophic composition metrics combined with poor tolerance and condition metrics yielded a fish assemblage reflective of severely degraded stream quality.

5.5 PERIPHYTON

5.5.1 INTRODUCTION

PWD’s 2007-2008 periphyton monitoring activities in Pennypack Creek Watershed were enhanced by a partnership with the Academy of Natural Sciences of Philadelphia (ANS). The Phycology section of the Patrick Center for Environmental Research provided taxonomic expertise, identifying and enumerating diatoms and soft algae collected at each site. ANS was also responsible for determining intercellular 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.

5.5.2 MONITORING LOCATIONS

Periphyton communities were sampled from sites PP340, PP970, PP1680 and PP2020, chiefly to assess the role of periphyton in regulating stream metabolism (Section 4.5). Surveys were conducted at mainstem locations only, and 2 sites were located within Philadelphia County (PP340 and PP970) (Figure 5.37). 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. Continuous water quality monitoring equipment at Site PP1680 was installed on the upstream side of Davisville Rd. Bridge, a location that was unsuitable for sampling periphyton due to very dense canopy cover upstream of the bridge and local scouring at the bridge itself and immediately downstream. The periphyton sampling location thus had to be relocated downstream of Davisville Rd. to find the suitable combination of canopy cover, substrate and depth. Periphyton was sampled from all sites in spring of 2007 and 2008.

5.5.3 METHODS

5.5.3.1 FIELD STANDARD OPERATING PROCEDURES

Periphyton was collected from natural substrate particles in shallow (~20cm) 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 several 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.

Three replicate samples were collected at each site. Depending on the size of the substrate particles collected, 1 to 3 particles were used for each replicate sample at each site. Each member of the three person sampling team was assigned a different replicate letter, “A”, “B”, or “C”, and sample containers were pre-labeled with site and replicate information. Periphyton was removed from the upper surface of each substrate particle using firm bristle toothbrushes that had one half the brush length trimmed away. 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 (Pennypack Creek stream water was previously characterized as having very low phytoplankton density, with water column chlorophyll-*a* <5ug/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 5.38). All substrate particle foil molds for each replicate were stored in pre-labeled Ziploc bags.

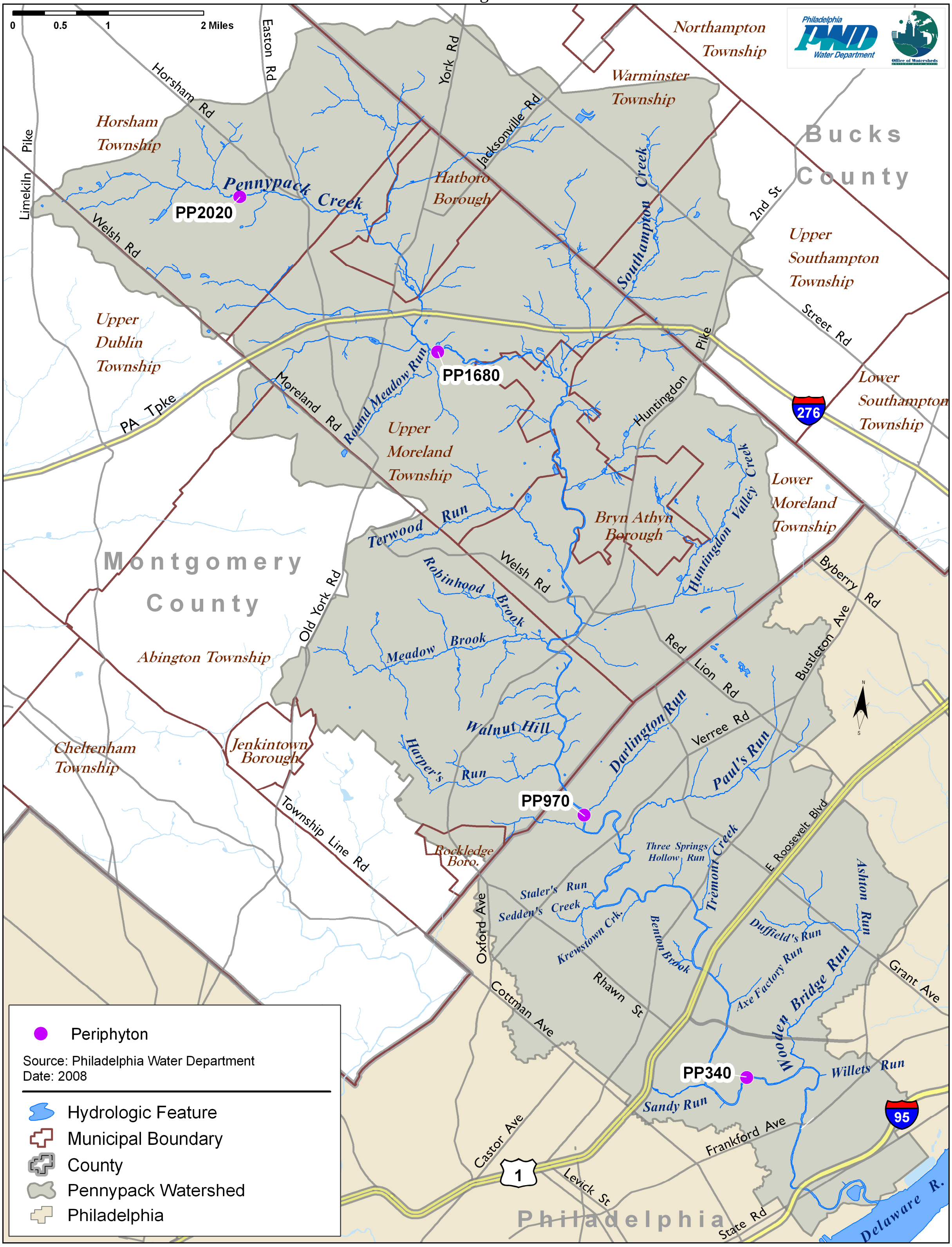


Figure 5.37 Periphyton Monitoring Locations in Pennypack Creek Watershed, 2007

Figure 5.38 Cutting Foil to Algal Periphyton Sampling Surface Area

5.5.3.2 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 Scion Image version 4.0.3.2. Differences in color between the foil and background were used to select and count the number of foil pixels, which was converted to square meters based on a calibration to the scanned image. For replicates in which more than one substrate particle was scraped to obtain the periphyton sample, the total surface area of all substrate particles sampled for each replicate was calculated by summing the individual areas of each particle used for the sample.

5.5.3.3 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 1L for ease of filtration and to simplify volumetric calculation of algal density.

5.5.3.4 CHLOROPHYLL-A FLUOROMETRIC ASSAY

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

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

5.5.3.5 PERIPHYTON INTERCELLULAR NUTRIENT CONCENTRATION ASSAY
Intercellular nutrient concentration assays were performed by the Biogeochemistry Section of the Patrick Center for Environmental Research. 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.

5.5.3.6 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.

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

5.5.3.8 RESULTS
Periphytic algae grew to nuisance densities within many of the Pennypack Creek assessment sites, causing 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 possible exception of site PP1680, which is also affected by point source discharge of municipal treated wastewater (sections 4.5.1 and 4.5.2). pH fluctuations were also observed, but again, the magnitude of fluctuations was not severe enough as to cause violations of water quality standards. While water quality standards may not have been violated, dense algal growths may be partially responsible for the biological impairment that was observed throughout the watershed (sections 5.2.5 and 5.3.5). In some locations, nearly every stable substrate particle (approximately the size of a small boulder, or 10in/256mm) in sufficient depth of flow was covered with brown algae or filamentous green algae, while smaller particles generally appeared scoured and cleaner (Figure 5.41).

Mean periphyton chlorophyll-*a* density ranged from 78.21 mg/m^2 at site PP340 to 164.39 mg/m^2 at site PP1680 (Figure 5.39). ANOVA showed that chl-*a* concentrations were significantly different between sites ($F_{0.05(2);3\ 14}=5.49$, $p<0.05$). Results of Tukey's post-hoc test revealed mean chlorophyll-*a* at site PP1680 was significantly greater ($p=0.017$) than that of the other 3 sites. At each monitoring site, mean periphyton chlorophyll-*a* exceeded the EPA Ecoregion IX water quality reference value of 20.35 mg/m^2 (USEPA 2000), and three of 4 sites 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).

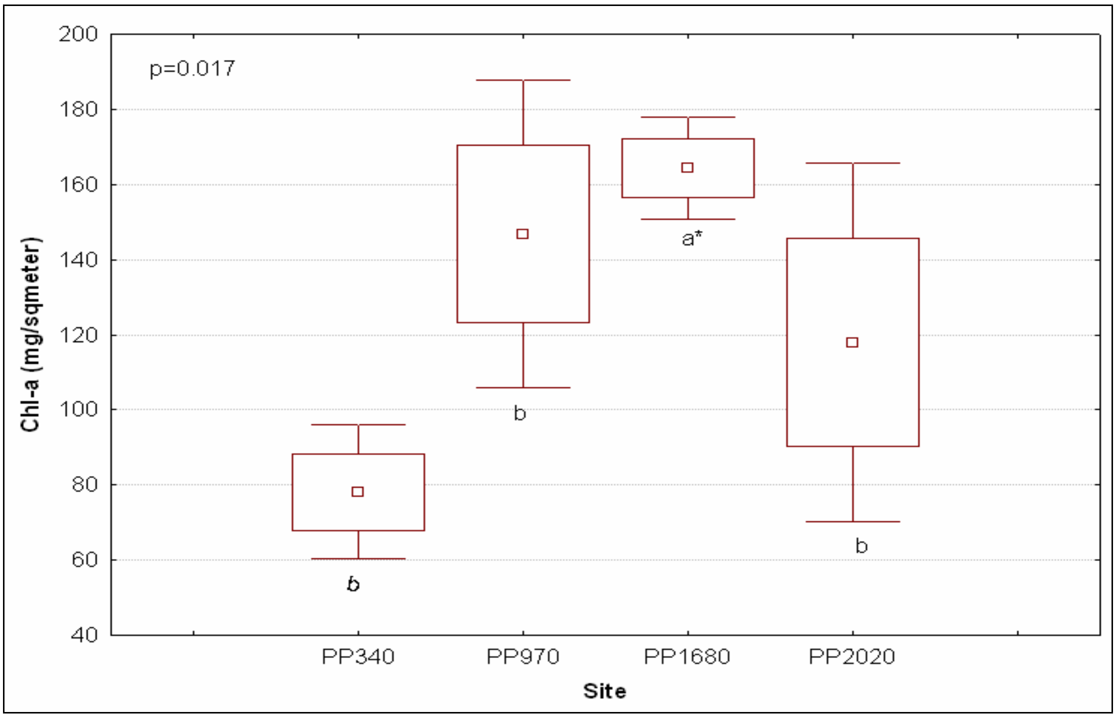


Figure 5.39 Mean Periphyton Biomass Estimates (Chl-*a*) at Four Sites in Pennypack Creek Watershed, 2007

Periphyton biomass accrued in high densities (as chlorophyll-*a*) throughout the watershed, including site PP2020, the upstream-most sampling site. In natural systems, periphyton biomass generally is greatest in mid-order streams, such as the downstream-most reaches of Pennypack Creek, because these reaches are wider and less shaded than narrower upstream reaches. The presence of dense algal growths at site PP2020 demonstrated that Pennypack Creek is not a well-shaded forested natural stream system with low productivity and that point sources of nutrients are not necessary for nuisance buildup of algal periphyton. 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. The upstream sites PP1680 and PP2020 both lacked a riparian buffer on one bank and PP970 lacked a buffer on both banks. More light is available at PP970 compared to the upstream sites due to the greater stream width and lack of riparian buffer; however, as periphyton biomass at PP970 did not exceed that of the upstream sites, it is likely that light is not the most important factor governing periphyton distribution and abundance in the Pennypack 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.

Another explanation for increased levels of periphyton chlorophyll-*a* in the upstream reaches could be that these reaches are eutrophic. The Redfield ratio 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 was first described by the American oceanographer Alfred Redfield in the 1930s and 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. In the Pennypack Creek analysis, the mass ratio (41:7:1) was used as this method was more compatible with observed periphyton nutrient data (i.e mass C / unit area). Analysis of C:N:P mass ratios from Pennypack Creek periphyton samples revealed that N:P nutrient ratios were slightly less than the Redfield Ratio (7:1) at 3 of 4 sites, suggesting that there may be an overabundance of phosphorus at these sites (Figure 5.39), but the degree to which observed C:N:P ratios diverged from the Redfield ratio was not as extreme as other nutrient enriched sites sampled by PWD (*i.e.*, Wissahickon Creek).

Table 5.21 Mean C, N, P, and Chl-*a* Concentrations of Periphyton Samples from 4 Mainstem Pennypack Creek Sites, 2007 and 2008

PWD Site	River Mile	C (g/m^2)	N (g/m^2)	P (g/m^2)	C:N:P	Chl-a (mg/m^2)
PP340	3.4	43.52224	6.307511	1.091767	42:6:1	78.21141
PP970	9.7	166.63	24.29136	4.299169	39:6:1	146.7439
PP1680	16.8	185.2109	27.96642	5.173761	36:5:1	164.394
PP2020	20.2	202.2526	27.74959	3.834832	53:7:1	117.9593
Redfield Ratio	---	---	---	---	41:7:1	---

Excessive amounts of P may stimulate growth of certain taxa that can take advantage of greater amounts of P as well as taxa that uptake increased amounts of phosphorus to be stored internally in a process known as "luxury consumption". Orthophosphate (the form of phosphorus that is immediately available to producers) concentrations were observed to decrease as a function of increasing distance downstream of PP1680 (Figures 4.33 and 4.34). Site PP1680 is located downstream of a point source of wastewater effluent. Nutrient enrichment from treatment plant effluent could no doubt stimulate increases in periphyton primary production, especially during dry weather when nutrient concentrations are likely to be highest. Mean concentrations of both orthophosphate (PO4) and nitrate (NO3) were found to be significantly higher at PP1680 compared to the remaining three periphyton sampling sites in both wet and dry weather (Section 4.4.8). Furthermore, the N:P ratio at PP1680 was the lowest observed (5.4:1) among the four sites assessed for periphyton biomass, suggesting that phosphorus is not a limiting nutrient at PP1680, but rather, it is available for luxury uptake. While nutrient levels were elevated, direct evidence for a causal relationship between DO impairment at PP1680 and nutrient enrichment was weak.

As described in Section 5.5.2, the continuous monitoring station at Site PP1680 was very well shaded and may not have provided the most optimal light conditions for periphyton growth. Instead, the site chosen for periphyton sampling was comparable to other downstream sites. Nutrient enrichment by PO4, which is most often limited in the Eastern United States, could explain the overabundance of periphyton biomass at the site, while the relatively shady conditions at the continuous monitoring location may explain why diel DO fluctuations observed at PP1680 were not the most severe in the watershed (Appendix C, figures C-58 through C-96).

There was a proportionally greater amount of C within the tissues of periphyton collected at site PP2020. This site lies within the headwaters of Pennypack Creek. Net energy production in headwater streams is usually derived from the input and subsequent processing of allochthonous (outside of system) inputs such as leaf litter and coarse woody debris, which is one possible explanation for the carbon-skewed C:N:P ration at the site. Another potential explanation could be that the periphyton scum layer at site PP2020 had a greater proportion of bacteria or fungi decomposers that may have contributed to the differences observed.

Pennate diatoms were found to be ubiquitous at all sites and the dominant form of periphyton in Pennypack Creek Watershed overall (Tables 5.22 and 5.23). Also observed at many sites were very extensive mats of branched filamentous green macroalgae (Figure 5.41), with filaments as long as 1m attached to stable substrate particles. Aquatic mosses were also locally abundant at some sites. Furthermore, algal mats and dense accumulations of macroalgae were observed at site PP2020 as well as in some tributary streams (Figure 5.22), suggesting that algae may reach nuisance densities even where nutrient concentrations are generally much smaller than in the wastewater effluent-influenced main channel. Algal mats and odors also may detract from the aesthetic value of Pennypack 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 (Figures 4.7-4.9 Section 4.4.1.1).

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). The four assemblages were dominated by *Navicula* spp. and *Nitzschia* spp. (Table 5.22). 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 and less sunlight is available for cells near the lower surfaces of the mat and these lower cells die and decompose), or entrainment of gas bubbles in the algal-detrital matrix.

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 Pennypack Creek Watershed have been fully characterized through extensive sampling, using periphyton communities to infer an ecological condition was given a lower priority. Periphyton community assemblage data is presented here for the sake of inter-site comparison; however comparison of diatom community assemblages among sites does have biomonitoring implications. Taxa richness was highest at site PP2020 (n=36 taxa) and the lowest taxa richness was in the downstream site PP340. Trends in diatom taxonomic analysis were similar between monitoring sites. *Navicula* (Table 5.22**)** was the dominant genus at all Pennypack diatom assessment sites except for PP1680, where the dominant genus was *Nitzschia* spp. Taxa within the *Navicula* genus, *Navicula subminuscula*, *Navicula lanceolata* and *Navicula minima,* were the dominant species at sites PP340, PP970 and PP2020 respectively; whereas *Nitzschia inconspicua* Grunow was the dominant species at site PP1680 (Table 5.22).

Table 5.22 Diatom Community Taxonomic Results

Metric	PP340	PP970	PP1680	PP2020
Number of Individuals	627	618	609	631
Taxa Richness	22	35	25	36
Shannon H'	1.89	2.63	2.39	2.48
Simpson D	0.22	0.11	0.11	0.16
% Dominance (species)	37.48 *Navicula subminuscula* Manguin	21.68 *Navicula lanceolata*	17.08 *Nitzschia inconspicua* Grunow	35.34 *Navicula minima* Grunow
% Dominance (genus)	73.05 *Navicula* spp.	52.91 *Navicula* spp.	32.51 *Nitzschia* spp.	44.85 *Navicula* spp.

The dominance of the naviculoid species and *Nitzschia* spp. have implications for biomonitoring because these species all are categorized as tolerant of organic pollution (*i.e.*, orthophosphate, nitrate) and can thus serve as indicators of organic pollution. In a study conducted by ANSP (Potapova *et al*., 2004), 155 diatom samples were collected across a gradient that spanned 118 sites within the Northern Piedmont Ecoregion (Figure 5.40). Parametric and non-parametric regression analyses were used to measure the response (abundance) of diatom species along a gradient of increasing total phosphorus (TP) concentration (µg/L) and a positive relationship was found between abundance and (TP) for all four dominant species.

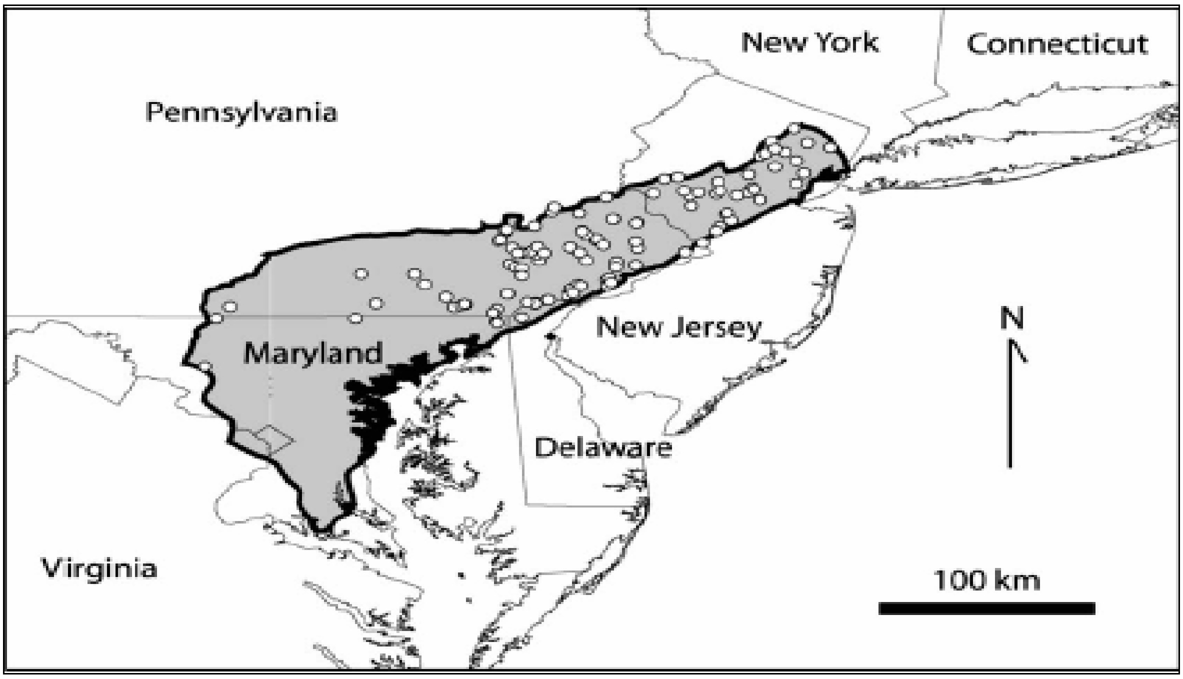


Figure 5.40 Sampling Locations in Northern Piedmont (copied from Potapova et. al, 2004)

Two commonly used diatom taxonomic indices were compared for each of the dominant species in samples collected from Pennypack Creek Watershed (Table 5.23). Trophic Diatom Index (TDI), commonly used in the UK, is based on the premise that phosphorus is most likely to limit net primary production in streams and different taxa will have preferred optima for filterable organic phosphorus which is often used as an indicator of eutrophication (Kelly *et al.*, 1995). Saprobic index is another commonly used diatom indicator index and is based on an organism's ability to mineralize organic material. Essentially, organisms with higher tolerance to organic pollution harbor the kinetic pathways needed to mineralize the array of organic constituents often found in eutrophic waterbodies.

All diatom species listed in Table 5.23 were the proportionally dominant taxa during respective samplings (5/10/2007 and 5/28/2008). Values for TDI were the same at each site and although this metric does not discriminate well the differences between diatom assessment sites, it does offer valuable information. The listed TDI sensitivity value (5) is the highest value in the TDI sensitivity scale, such that these taxa are classified to be the most pollution-tolerant taxa relative to all other diatom taxa. There was considerable variation in the Saprobic Index metric among both sampling dates and sites. Sites PP340 and PP970 had the most pollution-tolerant diatom taxon, *Navicula* s*ubminuscula*, which was the dominant species in both diatom collections at PP340. The least sensitive dominant taxon, *Amphora pediculus*, was found in the second diatom collection at PP2020.

While taxonomic periphyton data for the Pennypack 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 very valuable resource with respect to the amount of additional background information available for the site, especially when compared to the locations which may be used in regional studies, many of which 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).

Table 5.23 Diatom Indicator Indices

Species	Site	Trophic Diatom Index[a]	Optimal filterable P (mg/L)	Saprobic Index[b]	Tolerance Level	pH tolerance	pH optima
Navicula subminuscula	PP340*	5	0.35-1.0	3.4	heavy to very heavy organic pollution	Alkaliphilous (4)	mainly occurring at pH > 7
Navicula lanceolata	PP970	5	0.35-1.0	2.3	moderate to heavy organic pollution	Alkaliphilous (4)	mainly occurring at pH > 7
Navicula subminuscula	PP970	5	0.35-1.1	3.4	heavy to very heavy organic pollution	Alkaliphilous (4)	mainly occurring at pH > 7
Nitzschia inconspicua	PP1680	5	0.35-1.0	2.2	moderate to heavy organic pollution	Alkaliphilous (4)	mainly occurring at pH > 7
Navicula gregaria	PP1680	5	0.35-1.1	2.5	moderate to heavy organic pollution	Alkaliphilous (4)	mainly occurring at pH > 7
Navicula minima	PP2020	5	0.35-1.0	2.6	heavy organic pollution	Alkaliphilous (4)	mainly occurring at pH > 7
Amphora pediculus	PP2020	5	0.35-1.1	2.1	moderate to heavy organic pollution	Alkaliphilous (4)	mainly occurring at pH > 7

[a] Index values from Kelly et. al, 2001
[b] Index values from Rott et. al, 1997
[*] Same species for both diatom taxonomic assessments

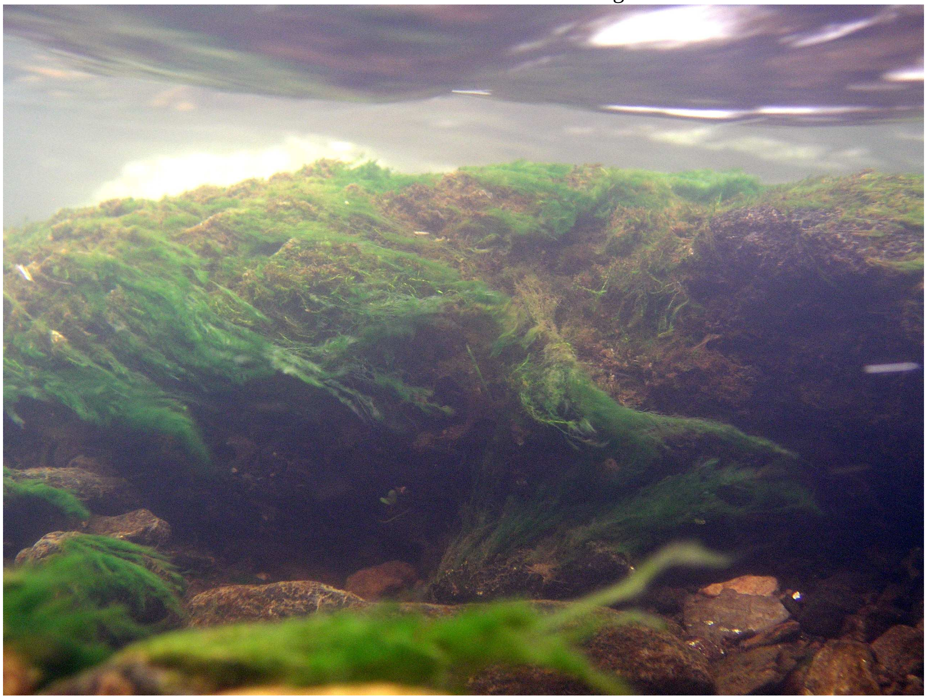


Figure 5.41 Underwater Photograph of Filamentous Green Algae Attached to Cobble Substrate, Pennypack Creek Watershed, 2007

5.6 SUMMARY OF BIOLOGY BY SITE

5.6.1 MAINSTEM PENNYPACK CREEK

5.6.1.1 PP180

Site PP180, located approximately 100m downstream from the Frankford Avenue Bridge, was the downstream-most PWD monitoring site assessed in the Pennypack Watershed and the only tidal site assessed in Pennypack Creek. PWD has, however, conducted qualitative fish sampling via boat and tote barge electroshocking in tidal reaches of Pennypack Creek further downstream in order to document the presence and relative size of spawning runs of native anadromous fish, as well as evaluate the success of fish passage improvement projects. While the results have been disappointing thus far, finding only a meager amount of river herrings, Pennypack creek is relatively one of the better Philadelphia tributaries in terms of relative abundance of native semi-migratory fish such as White perch (*Morone americana*) and the desirable, recreationally-sought Striped bass (*M. saxatilis*).

Land use in the vicinity of site PP180 is varied and includes multi-family residential properties, forested parkland (Pennypack Park), and community services. Results of the 2007 modified EPA RBP Physical Habitat assessment decreased to (67%) from the 2002 Pennypack baseline assessment score of (85%), putting PP180 in the “partially supporting” habitat class. The 18% decrease was the most severe decrease in habitat score on mainstem Pennypack Creek over the 5 year assessment cycle. Metric scores decreased for every RBP variable except for right bank riparian vegetation. The sediment deposition variable, which has direct implications for fish and macroinvertebrate fitness and habitat quality, decreased by 5.8 points-from 12.3 in 2002 to 6.5 in 2007. One possible source of this sediment is the breached Rhawn St. Dam, located upstream of site PP340.

In terms of comparability to PADEP IBI reference standards, PP180 was 24% comparable, which ranked 5th among mainstem sites. Despite its partially supporting classification and the loss of habitat quality, biotic metrics at PP180 fared moderately well amongst mainstem assessment sites and some metrics improved between 2002 and 2007. PP180 was host to two sensitive taxa (mean HBI=2.5), including *Attenella* sp. (Ephemeroptera: Ephemerellidae), that were unique to PP180 among mainstem assessment sites. Site PP180 was one of only two mainstem sites where modified mayflies (Ephemeroptera with HBI ≤ 4) were observed. HBI decreased from 6.2 in 2002 to 6.06 in 2007 (-0.14) and there was a decrease of 0.19 from the 1969-1980 mean HBI (6.25). A HBI range between 4 and 7 supports a facultative to moderately tolerant assemblage, and as such, PP180 supported an assemblage that was 92.7% moderately tolerant.

The macroinvertebrate community assemblage at PP180 was not very diverse (H=1.01) and was dominated by chironomid larvae (74.15%), a slight increase from 2002 where chironomids comprised 74.02% of the assemblage. The feeding structure was dominated by generalist gatherers (82.9%), and specialized feeders like scrapers (10.24%), filterers (6.34%) and omnivores were present in low abundances. Taxa richness increased by n=3 taxa from 2002, but the taxa richness at PP180 was within the lower end of the range (n= 8-16) of taxa richness scores in the mainstem. EPT taxa richness was n=5 which was the second highest total on the mainstem (a total of six sites had 5 EPT taxa).

5.6.1.2 PP340

Site PP340 is located approximately 200m downstream from Rhawn Street Bridge within a relatively wide segment of Fairmount Park. Much of the adjoining land is classified as parkland, but parking lots, recreational trails and mown turf are also present, limiting the overall habitat score at this site. Site PP340 is also the nearest site downstream from the Rhawn St. dam, which was breached in the early 1990s. When this dam breached, water surface elevations dropped approximately 6 feet, exposing a very large expanse of accumulated sand which has gradually been eroding away and moving downstream. Sand has been deposited extensively along the right bank floodplain of Pennypack Creek immediately upstream of site PP340. EPA RBP Physical Habitat scores were low at site PP340 (63%), but there was a slight improvement from the 2002 score (57%). The non-supporting designation is due mostly to poor riparian vegetation quality, narrow riparian zone, and inadequate pool substrate and pool variability. For macroinvertebrate habitat assessments, samples were taken from riffle segments; thus, macroinvertebrate metric scores do not reflect the poor quality of pool habitat in PP340. In spite of poor EPA RBP habitat scores, PP340 was 35% comparable to PADEP ICE reference standards, which was the highest among both mainstem and tributary sites.

In terms of physical habitat quality, this site was deemed as non-supporting, yet biologic assessment results suggest that PP340 is one of the most suitable sites on mainstem Pennypack Creek. A total of n=3 sensitive taxa with a mean HBI of 2.33 were found at PP340. There was one unique species, the micro caddisfly (Trichoptera: Hydroptilidae: Hydroptila), observed in PP340 (HBI=6) and it was unique to both Pennypack Creek and French Creek watersheds. Hydroptila is primarily a scraper and is often used as an indicator species because they are found in high abundances in eutrophic streams where there are excessive growths of epilithic periphyton. Hydroptila cases were observed to be very abundant, covering nearly all rocks in some locations. The small, finely woven cases of this species are attached very securely to rock substrates, so it is expected that the ICE protocol tends to underestimate Hydroptila abundance due to the fact that rocks are not manually scrubbed with this protocol.

There was a slight increase in HBI from 2002 (5.69) to 2007 (5.85). However, site PP340 still maintained the second lowest HBI score on the mainstem Pennypack Creek. Taxa richness increased considerably from 2002 (n=7) to 2007 (n=16), and PP340 had both the largest increase in taxa richness (+9) and highest overall taxa richness among all monitoring sites in Pennypack Creek Watershed. EPT taxa richness (n=6) was the highest among mainstem sites. Site PP340 also had the most diverse community assemblage in Pennypack Creek Watershed (H=1.81). This is no doubt due to the low proportional dominance of Chironomidae (43.7%), as this site had the lowest score for the Percent Dominant Taxon metric among all mainstem sites. Theoretically, reduced proportional dominance of generalist taxa such as chironomids could allow other more specialized species to increase in numbers.

Periphyton biomass assessment was also conducted at site PP340. Estimates of total periphyton biomass were based on the concentration of chlorophyll-*a* (mg/m^2), and with a chlorophyll-*a* concentration of 78.21 mg/m^2, site PP340 had the lowest observed periphyton biomass of 4 mainstem sites assessed. Nevertheless, the estimated periphyton biomass at PP340 still exceeded the EPA Ecoregion IX water quality reference value of 20.35 mg/m^2. This result is surprising because higher biomass estimates are expected in larger, higher order stream reaches that are wider, less turbulent and less shaded than mid-order and headwater streams.

Diatom samples were also collected and analyzed to determine the relative abundance of diatom species by site. Such an analysis has implications for biomonitoring as diatoms have a significant role as indicator species. Both diatom taxa richness (n=22) and diversity (H=1.89) were the lowest in PP340. The dominant diatom genus at PP340, *Navicula,* was the dominant genus in 3 of the 4 diatom assessment sites and comprised 73.05% of diatom relative abundance. The dominant species in both diatom assessments, *N. subminiscula* (37.48%), is a species indicative of moderately to heavily polluted waters.

5.6.1.3 PP490

Site PP490 is located approximately 500m upstream from Holme Avenue Bridge. Land use patterns consist of forested parkland, multi-family residential properties, and community services. Physical habitat conditions in this site have improved since the 2002 Baseline Assessment and represented the second highest improvement on the mainstem. In the 2002 EPA RBP Physical Habitat assessment, PP490 was classified as non-supporting, with a score of (67%) . The 2007 habitat assessment score (80%) improved to a “supporting” classification due mostly to improvements in the sediment deposition (+3.4%), embeddedness (+7%), and bank stability variables—the first two of which are critically important to fish and macroinvertebrate habitat quality and food availability.

Benthic macroinvertebrate metrics at site PP490 fell into the lower end of the ranges of scores for the mainstem Pennypack. One sensitive taxon, the cranefly genus *Antocha* (HBI=3), was collected at site PP490. Between 2002 and 2007, HBI increased (+0.43) from 5.65 to 6.03; however, there was a (-0.86) decrease in HBI from the historic 1969-1980 mean HBI (6.89) to 2007. The increase in HBI from 2002-2007 was coupled with an increase in the relative abundance of the dominant taxon. In 2002, Chironomidae composed 55.28% of the relative abundance at PP490, but in 2007 Chironomidae relative abundance increased to 83.18%, representing the second highest increase (+27.9%) among mainstem Pennypack sites. The proportional dominance of chironomids partially explains low macroinvertebrate diversity (H=0.77) at this site, which was the second lowest on the mainstem. The macroinvertebrate community assemblage at site PP490 was dominated by generalist, collector-gatherer (85.9%) and moderately tolerant (94.5%) taxa. There were relatively few specialized feeders such as filterers (8.6%) or scrapers (3.2%) and even fewer sensitive or intolerant taxa (1.4%) as EPT taxa richness (n=4) was the second lowest on the mainstem (a total of four sites had n=4 EPT taxa). Taxa richness increased from n=7 in 2002 to n=10 in 2007, but there was an even larger increase (+5.7) between the 1969-1980 mean taxa richness (n=4.3) and the 2007 taxa richness.

The Fish IBI score for PP490 (40) was the highest among assessment sites and fell within the integrity class of "good". Good sites are representative of conditions that are similar to those found in pristine streams with the exception that these sites have decreased species richness, especially with regard to intolerant taxa. Similar to macroinvertebrate metrics, results of fish biodiversity analysis were also skewed towards generalists and tolerant taxa, but more concerning was the decrease in total fish abundance compared to the 2002 fish assessment. Total fish abundance at site PP490 decreased by 81%, with n=3,572 individuals in 2002 and only n=674 individuals in 2007 (n=646 without stocked trout). *Catostomus commersonii* (White sucker), a pollution-tolerant generalist feeder, accounted for a large portion of the biomass in the 2002 assessment but decreased in abundance by 93% between the 2002 (n=381) and 2007(n=27) fish assessments. Swallowtail shiner (*Notropis procne)*, a moderately tolerant insectivore, was the most abundant species in 2002 (n=1195), but was replaced as the dominant species by the Redbreast sunfish (*Lepomis auritus*) (n=133) in the 2007 assessment. Biomass per unit area at this site was the lowest within the watershed at 6.27 g/ m^2. Taxa richness (n=19) and diversity (H=2.19) at PP490 were the highest and second highest, respectively, among fish assessment sites; however, all taxa within the assemblage were either tolerant (43.3%) or moderately tolerant (56.7%) of pollution, as there were no sensitive taxa collected in the 2007 assessment (excluding stocked trout). The feeding structure was dominated by insectivores (54.15%), a trend that was uncommon among assessment sites, as all other sites were dominated by generalist feeders. Generalist feeders comprised 24.96% of the feeding structure followed by top carnivores at 19.88%.

5.6.1.4 PP690

Site PP690 is located approximately 100m downstream from Krewstown Road Bridge. Predominant surrounding land use consists of forested parkland (Pennypack Park), with single and multi-family residential properties nearby. In terms of physical habitat quality, PP690 was classified as "supporting" with an EPA RBP Habitat Assessment score of 86%, which is an improvement of +2% from the 2002 assessment score. There were sizable losses for the riffle frequency and sinuosity variables; however these losses were bolstered by gains in the sediment deposition (+2.5%) and embeddedness (+3.4%) variables, which are critical for maintaining quality benthic habitat.

Biological metrics for site PP690 followed similar trends as other mainstem sites in terms of the distribution of functional feeding groups (78.1% generalist) and the dominance of moderately tolerant taxa (94.5%). Two sensitive taxa with a mean HBI of 2.5 were collected at site PP690 as well as n=3 EPT taxa. There was an increase in both taxa richness (+2) and HBI (+0.3) between 2002 and 2007. Compared to means of historic PADEP data (1969-1980), taxa richness increased by n=7.7 and HBI decreased by a magnitude of 0.51. Comparability to PADEP ICE standards was 23%. Dominance of Chironomidae increased dramatically from 50.52% in 2002 to 75.12% in 2007, an increase of 24.6%.This large increase may have adversely impacted diversity as the Shannon Diversity Index score (H=1.02) was closer to the lower range of mainstem observations of diversity (H={0.75-1.81}).

Fish abundance and biodiversity metrics were considerably worse in the 2007 assessment compared to 2002 metrics. The fish assemblage was comprised of 50% tolerant species and 50% moderately tolerant species excluding intolerant stocked trout species (3%). Overall fish abundance decreased by 75%, with n=1,965 individuals collected in 2002 and a mere n=490 observed in 2007. Between the 2002 and 2007 assessments, there was a trend of decreased abundance of insectivores and increased abundance of generalists such as Green sunfish, Redbreast sunfish, and American eel. This trend may be related to decreased macroinvertebrate diversity, which would have adverse impacts on the availability of food resources for obligate insectivore species. Fish IBI scores decreased from fair (38) in 2002 to poor (30) in 2007 due to the loss of specialist insectivore species and increases in generalist and tolerant species.

5.6.1.5 PP860

Site PP860 is located approximately 250m downstream from Verree Road Bridge. The local land use pattern is primarily forested parkland with single-family residential properties nearby. Habitat quality was within the "supporting" class (84%), and some improvement from the 2002 EPA RBP Physical Habitat Assessment score (74%) was observed. Scores for the sediment deposition and embeddedness variables were 12.5 and 12, respectively, suggesting suboptimal benthic habitat for macroinvertebrates.

The benthic macroinvertebrate assemblage was dominated by chironomid larvae (73 %) and other generalist gatherers, which together composed 77.2% of the trophic feeding structure. The proportional dominance of Chironomidae increased by 37% from 2002 to 2007, which was the largest margin observed in the watershed. The proportion of moderately tolerant taxa (94.06%) was also the highest in the watershed. There was only one sensitive taxon (tolerance=3) collected at the site; however, EPT taxa richness was n=5. Between the 2002 and 2007 assessments, taxa richness decreased from n=13 to n=12 and HBI increased from 5.6 to 5.95 respectively. Both diversity (H=1.13) and percent comparison to PA DEP reference standards (25%) were within the central range of values observed at mainstem sites.

5.6.1.6 PP970

Site PP970 is the upstream-most assessment site in Philadelphia County. The site is located approximately 250m downstream from Pine Road Bridge. Predominant surrounding land use patterns consist of forested parklands and a farm (Fox Chase Farm) upstream of the assessment site. Between 2002 and 2007, EPA RBP Physical Habitat quality assessments scores improved (+24%) from 60% to 84%, making site PP970 the site with the highest margin of improvement on the mainstem Pennypack Creek. The sediment deposition variable received a marginal score (7), but embeddedness fared much better at 11.5 which is suboptimal but capable of supporting some interstitial habitability and flow.

Biological metrics were very similar to site PP860, as generalist gatherers (80.6%) and scrapers (15.8%) were a large proportion of the trophic feeding structure. Most taxa observed were moderately tolerant (97.7%) or tolerant (1.4%) of pollution as only 0.9% of taxa were intolerant. There was one sensitive taxon, *Antocha* spp. (Cranefly) (HBI=3), and a single individual specimen of *Baetis* sp. (Small Minnow Mayfly) (tolerance=6), which was unique among mainstem sites in Pennypack Creek Watershed but found in tributaries in the middle sections of the watershed. Proportional dominance of Chironomids (73.58%) decreased slightly between 2002 and 2007 (-3.8). Macroinvertebrate diversity was marginal as the Shannon-Weaver Diversity Index (H=0.98) was the 3rd lowest among mainstem sites. Between 2002 and 2007, taxa richness increased from n=9 to n=12 taxa and when compared to historic PADEP mean taxa richness, there was an increase of (n=7.1) taxa. HBI increased slightly (+0.15) between the 2002 and 2007 assessments; however HBI decreased by a considerable margin (-0.81) when comparing the PADEP historic mean (6.75) to the 2007 HBI score (5.94). Scores for biotic metrics were not as high as would be expected from the "supporting" habitat quality designation as percent comparison to PA DEP IBI reference standards was only 23%.

Periphyton biomass and diatom taxonomic assessments and analysis were also conducted at site PP970. Results show that periphyton biomass, in terms of chlorophyll-*a*, was the second greatest in the watershed at 146.74 g/m². The diatom assemblage at site PP970 was the most diverse (H=2.63) and had the greatest taxa richness (n=35). The assemblage was dominated by taxa in the genus *Navicula* (52.91%), with the dominant species being *N. lanceolata* (21.68%). *Navicula* is commonly found in most periphyton samples containing diatoms and *N. lanceolata* is a common, widespread species in waters of moderate conductivity such as Pennypack Creek. This species, along with other naviculoids, is often an indicator of organic pollution. Similarly, the high levels of chlorophyll-*a* at site PP970 could be an indicator of eutrophic conditions.

Fish IBI scores were generally low, both with intolerant trout species included in the analysis (IBI=30) and without (IBI=28). Fish abundance at site PP970 was the second lowest in the watershed. Overall abundance decreased by 64% from the 2002 assessment, with n=1,717 in 2002 to n=614 in 2007. The pollution tolerant species *Rhinichthys atratulus* (Blacknose dace) and *Catostomus commersonii* (White sucker) were the most abundant species, and together accounted for 42.4% percent of fish abundance. Besides the presence of *R. atratulus*, there was a general lack of other cyprinid species like *R. cataractae* (Longnose dace), which partially explains the decline in abundance. One potential cause of the decline in fish abundance and the presence of less tolerant species is poor water quality, as site PP970 had the 2nd highest percentage of fish with disease, eroded fins, lesions and other physical abnormalities (DELTA=5.2%).

5.6.1.7 PP1060

Site PP1060 is located approximately 350m upstream from Moredon Road Bridge and located within Lorimer Park in Abington Township, PA. The predominant land uses consist primarily of forested parkland with an agricultural area north of the assessment site. There are also single-family residential properties located nearby. Physical habitat was classified as "supporting" and the EPA RBP Physical Habitat Assessment score (85%) was the third highest on the mainstem. Sediment deposition (9) and embeddedness (11) were marginal, but this site, like many others in the watershed, suffered from poor bank stability and riparian condition.

The benthic macroinvertebrate community at site PP1060 was not very diverse (H=1.04), but taxa richness (n=13) was the 2nd highest on the mainstem (tied with site PP2020). The macroinvertebrate assemblage was dominated by generalist gatherers (80.2%) followed by filterers (10.6%) and scrapers (7.05%).The majority of taxa (92.9%) were moderately tolerant of pollution, although there were more intolerant taxa (5.2%) than tolerant taxa (1.8%). HBI increased +0.72 from 5.06 in 2002 to 5.78 in 2007, which corresponds with a very large shift in dominant taxa from 41.67% Hydropsychidae (net-spinning caddisflies) in 2002 to 75.77% Chironomidae in the 2007 assessment.

Site PP1060 is located upstream of Harpers Run (site PPHA003), but downstream of other small forested tributaries in Lorimer Park and may thus benefit from “drift” sensitive organisms that live within these tributaries. There were n=2 unique taxa collected at site PP1060, *Ceratopogon* sp. (Biting Midge) and *Ameletus* spp. (Ameletid Minnow Mayfly), and n=3 sensitive species. *Ameletus* spp., which was unique to site PP1060 among all sites in Pennypack Creek Watershed, is also a very sensitive taxon (HBI=0). Sites PP1060 and PP340 had the most sensitive species (tie, n=3) of all mainstem sites. Overall, site PP1060 was 27% comparable with PA DEP IBI standards, which ranked 2nd among mainstem sites.

As with the macroinvertebrate assemblage, the fish community at site PP1060 underwent significant changes between 2002 and 2007. There was a 59% decrease in abundance from the 2002 assessment (n=1,625) to the 2007 assessment (n=672), with dramatic losses to the cyprinid population offset by increases in pollution tolerant generalists such as green sunfish. Though abundance was very low, biomass (31.2kg) was the 2nd highest in the watershed.

The cyprinids swallowtail shiner (*Notropis procne*) and spottail shiner (*N. hudsonius*), declined in abundance by 88% and 79% respectively. There was a decreasing trend in insectivore abundance; in 2002, insectivores comprised 48% of the relative abundance but only 20.1% in 2007. This was complemented by an increasing trend in generalist abundance, from 42% in 2002 to 63% in 2007, which was the greatest proportion of generalist feeding taxa in the watershed. Due to low diversity, abundance and a skewed trophic structure, site PP1060 received a fish IBI score of 28 out of a possible 50, which classifies it as “poor”.

5.6.1.8 PP1150

Site PP1150 is located approximately 200m downstream of the Old Huntingdon Pike Bridge in Lorimer Park, Abington Township. Forested regions buffer this location but additional land uses within the sub-basin include agricultural lands, and single- and multi-family residential properties. The EPA RBP Physical Habitat Assessment score (92%) was the 2nd highest in the watershed and improved by (+9%) since the 2002 assessment. This was one of two mainstem sites with habitat quality classified as “comparable to reference”.

Diversity at site PP1150 (H=1.44) was relatively high and ranked 2nd among mainstem sites. The trophic structure was more balanced than most sites as gatherers (64.7%) were represented in lower proportions than the mainstem average followed by filterers at 25%. Chironomids were the dominant taxon (58.5%) and although their proportional dominance increased (+23.4%) from 2002, they were represented in lower proportions than many other mainstem sites where chironomids were the dominant taxa. Taxa richness (n=13) and HBI (6.02) increased by +3 and +0.58 respectively between 2002 and 2007. A large proportion of taxa were moderately tolerant (88.7%) and tolerant taxa (8.9%) exceeded the number of intolerant taxa (3.4%). Percent comparability to PA DEP IBI standards was 29%, ranking 2nd among mainstem assessment sites. The high comparability can be explained by the relatively diverse macroinvertebrate assemblage, high EPT richness (n=5) and low proportional dominance of chironomids.

5.6.1.9 PP1250

Site PP1250 is located approximately 100m downstream from the Old Welsh Road Bridge in Upper Moreland. Predominant land use patterns consist of forested areas, multi-family residential properties, commercial land and public services. Single-family residential properties and a large cemetery are located upstream of the site. This site was classified as "partially supporting", with an EPA RBP Physical Habitat Assessment score of 66%, which is a decrease (-3%) from the 2002 PWD assessment. Scores for embeddedness (10) and sediment deposition (6.5) were marginal.

Macroinvertebrate biotic metric scores at site PP1250 were among the worst on the mainstem. This site was one of two mainstem assessment sites where no intolerant taxa were collected; consequently, the macroinvertebrate assemblage was composed of (88.1%) moderately tolerant and (11.9%) tolerant taxa. The benthic assemblage was dominated by Chironomidae, which were 80% of the taxa collected, an increase of +12.3% from 2002. Gatherers dominated the trophic structure (92.4%) followed by filterers (6.2%) and scrapers (1.4%).

Taxa richness decreased by n=5 taxa between the 2002 (n=13) and 2007 (n=8) assessments but increased by n=2.8 taxa compared to the historic PA DEP 1969-1980 mean taxa richness. Similarly, there was a negative trend in HBI, as the 2007 value (6.5) was a +0.8 increase from 2002 (5.7). This score was a major improvement from the PA DEP historic mean HBI of 7.8. The combination of low taxa richness and the dominance of gatherers and chironomids produced the least diverse assemblage (H=0.75) on the mainstem as well as the least comparable (17%) to PA DEP IBI standards.

5.6.1.10 PP1380

Site PP1380 is located within the Pennypack Ecological Restoration Trust in the Borough of Bryn Athyn. The land use pattern is predominantly forested and agricultural with some single-family residential properties. Habitat quality was categorized as "supporting" with a habitat assessment score of 78%, a slight improvement from 2002 (76%). Both sediment deposition (9) and embeddedness were marginal (9.5).

Biotic metrics were marginal for site PP1380. There was an increase in taxa richness between 2002 (n=8) and 2007 (n=11), though a large increase (+28.12%) in the proportional dominance of Chironomidae (78.43%) made site PP1380 among the least diverse assessment sites on the mainstem (H=0.98). There was one sensitive taxon observed (0.98% of assemblage), but moderately tolerant taxa (92.7%) and tolerant taxa (6.4%) dominated the assemblage. Like many of the other Pennypack Creek assessment sites, the trophic structure at site PP1380 was dominated by generalist gatherers (83.8%), followed by filterers (7.35%), scrapers (6.9%) and omnivores (1.96%). Water quality may have degraded since the previous assessment as HBI increased from 5.52 in 2002 to 6.12 in 2007. Overall, comparability to PA DEP IBI reference standards was 23%, far below the 63% threshold for attaining designated aquatic life uses.

5.6.1.11 PP1680

Site PP1680 is located 100m upstream from Davisville Road Bridge in Upper Moreland Township and approximately 600m downstream of the HUMJSA wastewater treatment facility. Land use patterns consist of a forested buffer zone, manufacturing, public utility, and agricultural uses, as well as a cemetery and single-family residential properties. This site was classified as "supporting" with an EPA RBP Physical Habitat Assessment score of (81%), which is an improvement of +3% from 2002. Both sediment deposition (9.5) and embeddedness (9) were marginal.

Despite the "supporting" habitat quality designation, biotic metrics were poor at this assessment site and were characterized by large shifts in the tolerance level of the macroinvertebrate community assemblage. Site PP1680 was one of two mainstem sites where no sensitive taxa were observed, a probable result of decreased water quality as evidenced by a severe increase in HBI (+1.85) between 2002 (HBI=6.03) and 2007 (HBI=7.88). Furthermore, site PP1680 was the only site where tolerant taxa (50.4%) outnumbered moderately tolerant taxa (49.5%). The large increase in HBI coincides with a shift in the dominant taxon, from (84.36%) Chironomidae in 2002, to (44.9%) Oligochaeta in 2007. Implicit in this shift in proportional dominance is a large shift in the macroinvertebrate community tolerance of pollution, as chironomids have a tolerance value of 6 compared to oligochaetes which have a tolerance value of 10. Site PP1680 was the only site in Pennypack Creek Watershed where PADEP dissolved oxygen water quality criteria were violated in the 2007 assessment (21% of days measured). Dissolved oxygen impairment appeared to be related to treatment plant effluent oxygen demand in addition to fluctuations due to stream metabolism.

Surprisingly, diversity (H=1.36) was ranked the 3rd highest on the mainstem, despite low taxa richness (n=9) and the dominance of generalist gatherers (81.5%). One explanation could be the low proportional dominance of oligochaetes which allows other tolerant and moderately tolerant species to utilize the remaining available habitat and food resources. There were two unique species observed at site PP1680, Hirudinea (common leech) and the scud *Cragonyx* sp. (Amphipoda: Crangonyctidae), with tolerance values of 8 and 6 respectively. Overall, site PP1680 was only 20% comparable to PA DEP IBI reference standards.

The periphyton biomass assessment and diatom taxonomic analyses yielded results that clearly distinguished site PP1680 from other assessments sites. Periphyton biomass, estimated as chlorophyll-*a* concentration (164.4g/m^2), was significantly higher (p=0.017) at site PP1680 compared to all other periphyton biomass assessment sites (as noted in Section 5.5.2, the periphyton monitoring station was located approximately 200m downstream of Davisville Rd., or 300m downstream of site PP1680). The high level of primary production is probably the result of eutrophic conditions caused by discharges of nutrient-rich effluent from the waste water treatment plant upstream of site PP1680 as concentrations of the nutrients PO_4^{3-} and NO_3^- were significantly higher at site PP1680 compared to the other periphyton assessment sites (sections 4.4.8.1.3 and 4.4.8.4.1, respectively).

5.6.1.12 PP1850

Site PP1850 is located approximately 800m downstream from Blair Mill Road Bridge crossover between the border of Upper Moreland Township and Hatboro Borough. The surrounding land use is primarily multi-family residential. EPA RBP Physical Habitat Assessment scores were poor at this site (61%) and were the worst on mainstem Pennypack Creek. Low scores were given to both left and right bank stability as well as left and right bank riparian width.

Macroinvertebrate biodiversity metric scores at site PP1850 were among the poorest on the mainstem Pennypack. Taxa richness (n=9) and HBI (6.56) were the second lowest and second highest respectively among mainstem assessment sites. There were no sensitive or unique taxa and EPT taxa richness (n=3) was the lowest on the mainstem Pennypack Creek. The macroinvertebrate assemblage was dominated by pollution tolerant chironomid larvae (62.44%); however, diversity (H=1.19) ranked as the fourth highest among mainstem assessment sites. Trophic composition was the most unbalanced in the watershed, dominated by generalist gatherers (81%) and followed by filterers (18%). Specialized feeders such as scrapers (0.5%) and predators (0.5%) were severely underrepresented.

5.6.1.13 PP2020

Site PP2020 is the upstream-most 2007 assessment site in the Pennypack Creek Watershed. The site is located at Avenue B and Sawmill Road in Horsham Township. Predominant surrounding land use patterns consist of single- and multi-family residential, forested regions, and an agricultural area nearby. The EPA RBP Physical Habitat Assessment score at site PP2020 (98%) was highest in the watershed, an increase of +9% from the 2002 assessment.

Most macroinvertebrate metrics were ranked among the highest in the watershed at site PP2020, likely a product of habitat quality at the site, which is classified as “comparable to reference.” Taxa richness (n=13) was the second highest in the watershed, but decreased by (n=5) taxa from the 2002 assessment. There were n=5 EPT taxa, which was also the second highest total among mainstem assessment sites. One sensitive taxon was collected at the site, with a tolerance value of 3. HBI increased by +0.73 between 2002 (5.27) and 2007 (6.0), but the 2007 score was still within the “moderately tolerant” range. As such, 95.8% of the taxa at site PP2020 were moderately tolerant, followed by 0.94% tolerant taxa and 3.3% intolerant taxa.

The macroinvertebrate community trophic structure was dominated by generalist gatherers (68.9%) and filterers (27.8%) but specialized feeders were generally underrepresented, as omnivores (1.9%), scrapers (0.9%) and predators (0.47%) were present in low proportions. The dominant taxon, Chironomidae, decreased in proportional abundance between 2002 (68.25%) and 2007 (22.4%)—a relative decrease of (-48.85%)—which was the largest magnitude change in the mainstem assessment. Site PP2020 scored 25% comparable to the PA DEP IBI reference standards, ranking 3rd among mainstem assessment sites.

Periphyton chlorophyll-*a* (117.96 g/m²) at site PP2020 was the third greatest in the watershed behind site PP1680 and site PP970. The presence of relatively high periphyton biomass at site PP2020 indicates that wastewater effluent is not the only source of nutrient enrichment in the Pennypack Creek Watershed and that excessive growth of algae can occur even at relatively well shaded upstream sites with mean PO4 concentration <0.1mg/L. In natural systems, periphyton biomass would be expected to be higher in downstream reaches, but there was no clear spatial trend in algal biomass observed from the limited number of sites sampled in Pennypack Creek Watershed in 2007 and 2008. Diatom taxa richness (n=36) and diversity (H=2.48) were ranked 1st and 2nd, respectively, among the four assessment sites. The diatom assemblage was dominated by the genus *Navicula* spp. (48.85%), with the dominant species, *N. minima* composing (35.34%) of the assemblage.

Despite optimal physical habitat conditions, fish biodiversity and community metrics at site PP2020 were worst among mainstem Pennypack Creek sites; however, site PP2020 was the only assessment site where fish abundance and biomass increased from the 2002 assessment. The fish assemblage was dominated by pollution-tolerant taxa (64%) and generalist feeders (79%). Metric scores for taxa richness (n=11), diversity (H=1.9) and IBI (26 of 50), were the worst among the 6 fish assessment sites. While fish metric scores were generally poor, it should be noted that fish community diversity should be expected to decrease in an upstream direction as stream segments become shallower and narrower and direct comparisons between mainstem sites of greatly varying drainage area should be avoided. The combination of a severely skewed trophic structure and poor biodiversity metrics may be an indicator of degraded water quality considering the optimal physical habitat quality at the site.

5.6.2 PENNYPACK CREEK TRIBUTARIES

5.6.2.1 PPW010

Site PPW010 is located on Wooden Bridge Run, approximately 100m upstream from the confluence with Pennypack Creek. Land use patterns consist of forested parkland and multi-family residential properties. Overall, physical habitat quality decreased between the 2002 (62%) and 2007 (54.5%) assessments and was limited by poor pool variability, loss of bank stability and the lack of deep-rooted bank vegetation on both the right and left banks. Despite marginal riparian and bank conditions, scores for the sediment deposition and embeddedness variables were not limiting to aquatic habitat quality.

Biotic metrics were marginal and characteristic of an urbanized and degraded stream ecosystem. Taxa richness (n=8) was poor compared to both the French Creek reference reach (n=25) and PA DEP IBI standards (n=29). There were n=3 EPT taxa collected, however none were sensitive or intolerant taxa. The vast majority of taxa collected were either tolerant (7.2%) or moderately tolerant (91%) of pollution as only 1.8% of taxa were intolerant. The HBI score of 6.05 reflects the dominance of moderately tolerant and tolerant taxa. One sensitive taxon (*Antocha* sp., with a tolerance of 3) was collected at the site; however, the two unique taxa observed, Physidae (Bladder or lunged snail) and *Leucotrichia* sp. (Trichoptera: Hydroptilidae), are both tolerant of pollution with tolerance values of 8 and 6 respectively. Lunged snails, as the name implies, are able to breathe air and are usually found in slower, stagnant water. The macroinvertebrate community trophic distribution was dominated by generalist gatherer taxa (83.7%) and filterers (12.2%) with scant representation of taxa from other trophic levels such as scrapers (1.8%, the aforementioned snails), omnivores (1.8%) and predators (0.45%). Chironomidae was the most abundant taxon, composing 76.9% of the relative abundance at site PPW010 and increasing in proportional dominance from the 2002 assessment (72.87%). Low taxa richness, diversity (H=0.94), and the lack of sensitive taxa combined to reduce site PPW010 to 20% comparability to PA IBI DEP standards.

5.6.2.2 PPSR010

Site PPSR010 is located on Sandy Run, approximately 100m upstream from the confluence with mainstem Pennypack Creek. While land use directly around the site is predominantly forested (Pennypack Park), Sandy Run is almost completely channelized in a large storm sewer draining over 2.4 square miles of the most densely developed portions of the Pennypack Creek Watershed. Like other historic creeks draining large areas of the City, Sandy Run is extremely “flashy” due to the efficiency of the stormwater collection system in routing flows from impervious surfaces to storm sewers. Sandy Run is also affected by hundreds of public street and private stormwater inlets, each of which is a potential source of pollution, including sanitary waste in dry weather. PWD expended a tremendous amount of effort sampling and tracking down chronic sources of pollution in the Sandy Run subwatershed, eventually installing several sanitary flow diversion valves that route pollution-laden dry weather flow to the Northeast Water Pollution Control Plant. Despite these measures, severe impairment is still indicated by the results of physical and macroinvertebrate assessments conducted in 2007.

The EPA RBP Physical Habitat Assessment score at site PPSR010 (40%) was the 2nd lowest score observed in the entire Pennypack Creek Watershed and indicative of the adverse impacts associated with an urbanized, "flashy" hydrologic regime. Scores for the pool variability, pool substrate, bank stability and bank vegetative protection variables were poor and reflect the amplification of erosional and depositional processes often observed in tributaries that receive stormwater from densely developed areas. Physical habitat quality was deemed "non-supporting", which is in agreement with the poor scores observed for macroinvertebrate community metrics.

The benthic macroinvertebrate community at site PPS010 indicated severe chronic dry weather sewage pollution, being dominated by oligochaetes (80.88%). Comparability to PADEP IBI Standards (8%) was worst in the Pennypack Creek Watershed and characterized site PPSR010 as a Tier 6 stream reach according to the Biological Conditions Gradient model; thus, site PPSR010 exhibits severe alteration of ecological structure and function. The HBI score of 9.25 was the worst HBI score ever observed by PWD in ten years of sampling impaired urban streams. Taxa richness was extremely low (n=5) and ranked last (tied with PPS030) among both tributary and mainstem assessment sites in Pennypack Creek Watershed. The trophic assemblage at site PPSR010 was dominated by generalist feeders (97.5%) and was the most skewed distribution observed in both tributary and mainstem assessments. One unique taxon, a pollution-tolerant dipteran in the family Ceratopogonidae (Biting Midges), was observed. Biting midges inhabit the fine sediments associated with pools and the margins of low velocity stream channels (*i.e.*, over-widened urban streams at baseflow) and some species are often associated with algal mats or scums (Vonshell, 2002).

5.6.2.3 PPSC010

Site PPSC010 is located on Sedden's Creek approximately 100m upstream of the Pennypack Creek confluence. The primary land use is forest (Pennypack Park), however, near the headwaters of Sedden's Creek there are small pockets of commercial, recreational, single and multi-family residential land uses which contribute to the Sedden's Creek subwatershed. Habitat quality was classified as "non-supporting" given the low EPA RBP Physical Habitat assessment score (61%).

The macroinvertebrate sample from Sedden's Creek was very sparse. Even though all 28 subsamples, or "plugs" were counted from the composite sample, only n=76 individual macroinvertebrates were found. This total sample abundance was fewer than the minimum number of individuals for PADEP ICE protocols (*i.e.*, 160 individuals) and the fewest number of individuals collected at any assessment site in the watershed. Taxa richness and EPT richness were n=9 and n=3 respectively. Only one sensitive taxon, *Antocha* spp., was collected, as no EPT taxa had a tolerance value less than 5. Macroinvertebrate community diversity was relatively high (H=1.44) and ranked third among tributary assessment sites. Chironomidae had the highest proportional abundance within the assemblage at 53.95%, which was the second lowest score for the percent dominant taxon metric among tributary sites. This partially explains the high diversity at the site given the low taxa richness. The distribution of trophic classed was skewed towards generalist gatherers (72.37%) and filterers (22.37%), with scrapers (2.63%) and omnivores (2.63%) composing a minimal proportion of the assemblage.

The macroinvertebrate community was also dominated by tolerant (17.1%) and moderately tolerant taxa (80.3%), with proportionally few intolerant taxa (2.6%). The dominance of pollution-tolerant taxa is reflected in the HBI at the site (6.54), which is conducive to a facultative and moderately tolerant macroinvertebrate community. Overall, site PPSC010 was 22% comparable to PA DEP reference standards, ranking 5th among the 11 tributary sites assessed.

5.6.2.4 PPPR010

Site PPPR010 is located on Paul's Run, approximately 100m upstream from its confluence with Pennypack Creek. The primary land use at the site is forested (Pennypack Park) but there are parcels of nearby single and multi-family residential uses. On the banks of Paul's Run and at its headwater reaches, there are a variety of land uses which include commercial, recreational and light industrial manufacturing. Physical habitat quality was deemed "non-supporting", with an EPA RBP Physical Habitat Assessment score of 58.6%. Low scores were due in part to poor scores for left bank stability (1.5) and vegetative protection (2). Scores for the sediment deposition (11.5) and embeddedness (9.5) were marginal.

The macroinvertebrate assemblage was characterized by low taxa richness (n=8), EPT richness (n=3) and a low proportion of sensitive taxa (n=1). The only sensitive taxon collected, *Antocha* sp., was the most commonly collected sensitive taxon and was collected in 9 of 11 tributary assessment sites. Chironomid larvae were (57.4%) of the proportional abundance, which was a relatively low proportion compared to most tributary sites (4th lowest of 11 sites). The low proportional abundance of chironomids allowed for increased diversity (H=1.29) at the site given the low taxa richness. The Shannon-Weaver Diversity score ranked 5th among tributary assessment sites, but fared poorly when compared to both the French Creek reference reach (H=2.62) and the PA DEP standard (H=2.9).

The trophic distribution was composed almost entirely of generalist gatherers (73.3%) and filterers (26.2%), with only 0.5% omnivores. Similarly, tolerant (12.4%) and moderately tolerant taxa (85.15%) dominated the assemblage as only 2.5% of the macroinvertebrate community were sensitive taxa. The dominance of non-sensitive taxa, elevated HBI score (6.33) and skewed trophic and tolerance distributions combined to make site PPPR010 only 21% comparable to PA DEP IBI reference standards.

5.6.2.5 PPRB010

Site PPRB010 is located on Rockledge Brook, approximately 100m upstream of its confluence with Pennypack Creek. The primary land use at the site is forested (Pennypack Park) but there is a large parcel of vacant land abutting the site as well as upstream of the Pennypack Creek confluence. Along the banks and floodplains of Rockledge Brook, there are multiple land uses that include single-family residential, agricultural (Fox Chase Farm) and lands designated for community services. The physical habitat quality at site PPRB010 was designated as "partially-supporting" with an EPA RBP Physical Habitat assessment score (65.3%) that ranked 4th among tributary assessment sites. The habitat assessment score was limited by marginal scores for both right and left bank stability. Sediment deposition (9) and embeddedness (11) were marginal and sub-optimal respectively.

Despite the low taxa richness at site PPRB010 (n=8), more than half (62.5%) of the taxa collected were EPT taxa (n=5); however, none of the EPT taxa were sensitive to pollution. Only one sensitive taxon, *Antocha* sp., was collected at the site. The vast majority of the assemblage was moderately tolerant (97%), with few sensitive taxa (2.6%) and even fewer tolerant taxa (0.4%). The lack of tolerant taxa produced a relatively low HBI (5.87), which was the 3rd lowest among tributary assessment sites. The trophic distribution was dominated by generalist gatherers (80.4%) and the only other class observed was filterers (19.6%). The lack of trophic diversity combined with the high proportional dominance of chironomids (76.9%) resulted in low assemblage diversity (H=0.89). Overall, site PPRB010 was 21% comparable to PA DEP ICE standards, which ranked 5th (tied with site PPPR010) among tributary assessment sites.

5.6.2.6 PPDR010

Site PPDR010 is the upstream-most tributary assessment site within the City of Philadelphia and is located on Darlington Run approximately 100m upstream of the Pennypack Creek confluence. The primary land use at the site is forested (Pennypack Creek); however, immediately upstream there is an approximately 0.5 mile segment in which the land use along the banks of Darlington Run is completely utilized as a single- family residential land use. The remainder of the tributary is forested, but receives drainage from single and multi-family land uses. The EPA RBP Physical Habitat Assessment score of (65.9%) ranked third among tributary assessment sites, but was limited by marginal bank stability with a score of (5) for both the right and left banks. Sediment deposition (10) and embeddedness (11) were marginal and sub-optimal, respectively.

Taxa richness at site PPDR010 was among the lowest of all tributary assessments (n=6); however of those taxa collected, n=4 were EPT taxa. Diversity (H=0.25) was very poor due to the proportional abundance of chironomids (95.2%) and low taxa richness. In addition, the trophic distribution was heavily skewed towards generalist gatherers (96.2%) with limited representation by filterers (3.8%). Moderately tolerant taxa dominated the assemblage (98.5%) as both intolerant (0.96%) and tolerant (0.5%) taxa were underrepresented. The proportional dominance of both chironomids and moderately tolerant taxa reached levels observed at no other sites throughout the entire Pennypack Creek Watershed assessment. The HBI at the site was 5.99 due mostly to the high number of taxa with tolerance values in the facultative to moderately tolerant range. Overall, site PPDR010 was only 14% comparable to PA DEP ICE reference standards, due mostly to the extremes (*i.e.*, 2nd highest proportion of gatherers, highest proportion of moderately tolerant taxa and chironomids and lowest diversity) observed in community diversity metrics.

5.6.2.7 PPHA003

Site PPHA003 is located on Harpers Run approximately 300m upstream of its confluence with mainstem Pennypack Creek. This site is the downstream-most assessment site in Montgomery County and is located within Lorimer Park in Abington Township. The predominant surrounding land use consists of forested parkland, but single-family residential housing abuts a considerable portion of the banks of Harper's Run. Physical habitat quality (74%) was classified as "partially-supporting", which is a reduction from the 2002 assessment in which EPA RBP Physical Habitat score was 80% and habitat quality was classified as "supporting." The decrease in the habitat score is partially explained by marginal scores for variables relating to substrate, pool variability and flow regime. Scores for sediment deposition (17.5) and embeddedness (16) were the highest scores observed throughout the entire watershed and were comparable to French Creek reference reach conditions. The Southeastern Montgomery County Chapter of Trout Unlimited has installed 16 log deflectors in Harpers Run in order to improve stream habitat conditions, with plans for 8 additional deflectors to be installed in 2009.

Scores for many biotic metrics at site PPHA030 were among the best observed in the Pennypack Creek tributary assessment. Taxa richness (n=13) and EPT taxa richness (n=8) were the highest observed totals among tributary sites sampled in 2007, and taxa richness remained unchanged between the 2002 and 2007 assessments; however, HBI increased slightly by a margin of (+0.07) between the 2002 (5.69) and 2007 (5.76) assessments. Despite the slight increase, HBI at site PPHA003 was the second lowest among tributary assessment sites.

Macroinvertebrate community diversity ranked 1st among tributary assessment sites (H=1.49), due in part to the low proportional dominance of chironomids (43.4%), a proportional decrease of (-17.14%) from the 2002 assessment. The macroinvertebrate community was dominated by generalist gatherers (85.9%), followed by filterers (12.7%), scrapers (0.9%) and shredders (0.5%). Facultative to moderately tolerant taxa dominated the assemblage and accounted for 93.65% of the proportional abundance, followed by 5.4% intolerant taxa and less than 1% pollution-tolerant taxa. Site PPHA003 had both the highest number of sensitive (n=4) and unique taxa (n=3), with one taxon, *Dolophilodes* spp. (Trichoptera: Philopotamidae), being unique to site PPHA003 among both the Pennypack Creek Watershed and the French Creek reference reaches. Fingernet caddisflies (Philopotamidae) such as *Dolophilodes* and *Chimarra* require interstitial spaces on the undersides of rocks. These caddisflies are much more sensitive to the effects of urbanization than the Hydropsychidae and are thus good indicators of stream health. Otherwise widely distributed and common, philopotamids are among the first taxa to disappear as streams become urbanized and sediment fills in these interstitial spaces.

Site PPHA003 was 32% comparable with PA DEP IBI reference standards, ranking 1st among tributary sites and 2nd within the watershed. The "partially-supporting" habitat quality designation was not supported by macroinvertebrate metric scores for site PPHA003. High scores for sediment deposition and embeddedness may have had a compensatory effect on net habitat quality. Even though other habitat parameters were marginal, the lack of embedded substrate could have provided for an increased supply and connectivity of interstitial spaces between substrate particles. Interstitial spaces between bed substrate particles that are free of fine sediment allow benthic macroinvertebrates increased movement between bed substrate particles—which aids in predator and disturbance (*i.e.*, drift-producing current velocities) avoidance, foraging success, and dissolved oxygen circulation between the stream bed and hyporheic zones.

5.6.2.8 PPM070

Site PPM070 is located on Meadow Brook Run between the Valley Road and Mill Road Bridges about 700m upstream of the Pennypack confluence. Land use in the vicinity of the site includes agriculture, forested land, recreational, and single-family residential. Physical habitat quality (74.6%) was the best among 2007 tributary assessment sites; however habitat quality decreased slightly from the 2002 assessment, in which site PPM070 received a score of 78%. Scores for both sediment deposition (13) and embeddedness (12.5) were suboptimal, yet ranked among the highest observed scores for these variables in the 2007 tributary habitat assessment. Site PPM070 was one of two sites, along with site PPHA003, which were classified as "partially supporting", the highest classification observed among tributary assessment sites.

The macroinvertebrate assemblage at site PPM070 was dominated by generalist feeders (60.85%) and moderately tolerant taxa (94.34%), which was a trend observed throughout the 2007 tributary assessment. Filterers reached the highest proportional abundance (36.3%) observed throughout the entire 2007 watershed assessment. The dominant taxa were chironomids (55.66%), which represents a considerable shift from the 2002 survey in which the dominant taxon was Hydropsychidae (45.55%). Chironomids are more tolerant of organic pollution (tolerance value of 6) than hydropsychids, which may explain why HBI increased from 5.29 in 2002 to 5.74 in 2007. Despite the increase in HBI, site PPM070 had the lowest HBI score among tributary assessment sites, making it the most "sensitive" tributary assemblage in the Pennypack Creek Watershed although only 3.77% of the assemblage was actually intolerant of pollution. Taxa richness increased from n=8 in 2002 to n=10 in the 2007 assessment and of those taxa collected, n=6 were

EPT taxa. Increased taxa richness, combined with a relatively low proportional dominance of chironomids, produced an assemblage that was the 4th most diverse (H=1.32) among tributary assessment sites. Site PPM070 was 29% comparable to PA DEP IBI reference standards, which ranked 2nd among tributary assessment sites.

5.6.2.9 PPHU070

Site PPHU070 is located on Huntingdon Valley Creek, 50m downstream from Red Lion Road Bridge and approximately 1km upstream of the mainstem Pennypack Creek confluence. Predominant land use patterns include commercial and community services, as well as an agricultural area upstream. Single-family residential properties and a recreational area make up the majority of the remaining land use at this assessment site. Physical habitat quality was classified as "non-supporting", with an EPA RBP Physical Habitat assessment score of 36%, a slight improvement from the 2002 score (33%). Scores for the sediment deposition (7) and embeddedness (8) variables were marginal. Bank stability and riparian condition variables received poor or marginal scores for both banks, but of special concern were the right and left bank riparian vegetation widths which received scores of 1 and 0.5 respectively. Bank and riparian conditions reflecting such poor quality can threaten the integrity of aquatic habitat due to diminished buffering (*i.e.*, catchment-borne contaminants) and erosion-control capacity.

Despite the non-supporting habitat quality classification, many of the biotic metrics evaluated at site PPHU070 were among the highest ranking metric scores observed in Pennypack Creek tributary assessment sites. Taxa richness (n=12) and EPT richness (n=5) ranked 2nd and 3rd, respectively, among tributary sites. The dominant taxon was Chironomidae (59.13%), which represented an increase in relative proportional abundance of (+20.94%) from the 2002 assessment. Benthic macroinvertebrate community diversity (H=1.45) was 2nd highest observed among tributaries. The relatively high diversity at site PPHU070 is a result of both high taxa richness and the comparatively low proportional dominance of chironomid larvae.

Trophic diversity at site PPHU070 was limited, as the majority of taxa collected were generalist gatherers (78.85%). Filterers (15.86%), scrapers (4.8%) and shredders (0.5%) composed the remainder of the assemblage. Only one sensitive taxon, *Antocha* sp., was collected at the site, and intolerant taxa (tolerance value $\leq$4) made up only 1.4% of the assemblage. One unique taxon (among tributary assessment sites), the scraper *Optioservus* sp. (Coleoptera: Elmidae), was collected at site PPHU070. Most taxa collected were moderately tolerant (84.6%) and tolerant (14%) of organic pollution as evidenced by the elevated HBI score at the site (6.39). HBI scores in this range reflect facultative to moderately tolerant taxa; however, because of high taxa richness and diversity, site PPHU070 was 29% percent comparable to PADEP IBI reference standards. This site was somewhat unique among tributary assessment sites as it had below average habitat quality, yet still maintained a diverse, although tolerant assemblage.

5.6.2.10 PPS030

Site PPS030 is located on Southampton Creek, approximately 500m upstream from its confluence with Pennypack Creek. Land use patterns in the vicinity of the monitoring site consist of forested land, cemetery, commercial/services, as well as agricultural and manufacturing areas. A small wastewater treatment plant discharges into the upstream portion of the creek, which has potential adverse implications for water quality and stream metabolic processes due to the input of nutrients from WWTP effluent. The EPA RBP Physical Habitat assessment score (44%) classified site PPS030 as "non-supporting". In the 20002 assessment, site PPS030 was classified as "partially-supporting" with a score of (66%). The difference in habitat quality scores between 2002 and 2007 represented the largest margin of degradation (-22%) observed throughout the entire watershed. Both the sediment deposition and embeddedness habitat quality variables were very poor with scores of 5.

Taxa richness (n=5) was the lowest observed throughout the entire watershed (tied with PPSR010). Three EPT taxa were collected; however none were sensitive or intolerant. In fact, no sensitive or intolerant species were collected at the site, as the majority of taxa (97.6) were moderately tolerant. Overall, diversity at site PPS030 (H=0.37) was the 2nd worst in the tributary assessment as well the entire watershed. Chironomid larvae dominated the proportional abundance of the assemblage (92.38%), providing further evidence of degradation, as chironomids were only 88.44% of the proportional abundance in 2002. Generalist gatherers such as chironomids and oligochaetes (tolerance value of 10) comprised 94.76% of the trophic diversity at site PPS030 followed by hydropsychid filterers (2.38%), and one scraper taxon *Stenelmis* spp. (Coleoptera: Elmidae), which represented 2.86% of the trophic assemblage. Site PPS030 was only 14% comparable to PA DEP IBI reference standards, ranking 2nd worst (along with site PPDR010) in the watershed.

Proliferation of sediment deposition and embeddedness provide a competitive advantage opportunity for chironomids. As interstitial spaces under rocks become filled, even moderately tolerant invertebrates such as net-spinning caddisflies are displaced, leaving only the exposed upper surfaces of stream rocks and accumulated sediment for invertebrates to occupy. Chironomid larvae construct silken tube cases on these rocks and feed upon detritus and periphyton near the anterior opening.

5.6.2.11 PPHO010

Site PPHO010 is located on an unnamed tributary to Pennypack Creek, which PWD has historically referred to as the Horsham Branch. The monitoring site is approximately 100m upstream from its confluence with Pennypack Creek in Horsham Township. Land use patterns consist of a forested buffer zone, single- and multi-family residential properties, and a recreational area. The EPA RBP Physical Habitat assessment score of 54% classified the site as "non-supporting" compared to the 2002 habitat assessment, in which site PPHO010 was classified as "partially supporting"(74%). The disparity between the 2002 and 2007 habitat assessments represented the second largest margin of habitat degradation (-19) in the watershed. Sediment deposition (10) and embeddedness (10.5) were both marginal.

In spite of the non-supporting habitat quality classification, site PPHO010 was found to maintain a relatively rich (n=13) and diverse (H=1.13) assemblage. Taxa richness ranked first (along with site PPHA003) among tributary sites and second in the watershed behind site PP340 (n=16). The assemblage was dominated by chironomids (72.55%), which is an increase in relative proportional abundance from the 2002, whereas chironomids were only (58.06%) of the assemblage.

There was one sensitive taxon (*Antocha* spp.) collected at site PPHO010, as well as a host of intolerant taxa (6.89%), which was the highest proportion of intolerant taxa observed among tributary assessment sites. Moderately tolerant taxa dominated the assemblage (90.2%); however site PPHU010 was one of few sites where tolerant taxa (2.9%) were outnumbered by intolerant taxa. Trophic diversity was heavily skewed towards generalist gatherers (78%) and filterers (18.5%), with scrapers (2%), omnivores (1%) and shredders (0.5%) being severely underrepresented. Overall, site PPHU010 was 24% comparable with PA DEP IBI reference standards.

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. Traditional stormwater management practices, such as the stormwater detention basins that were constructed since the 1970s, can “shave peaks” but usually do not provide for 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.

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 the 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.

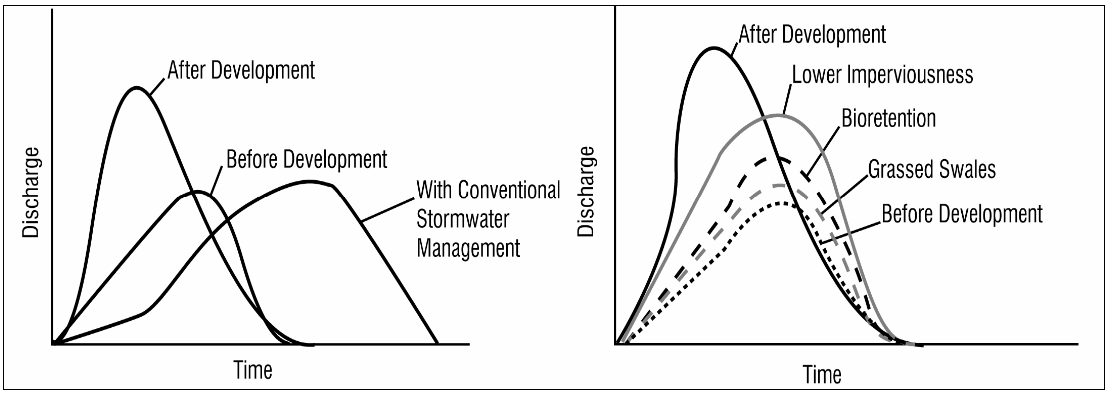


Figure 6.1 Comparison of Volume and Duration of Stormwater Runoff Before and After Land Development, and Reductions in Runoff from BMPs.
Source: Prince George’s County Department of Environmental Resources *et al.*, undated.

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 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. Several dam removal and fish passage enhancement projects have been completed in Pennypack Creek Watershed, and these projects are described in greater detail in Section 6.5.2.3

A large number of manmade ponds have been created for landscaping features in residential developments and golf courses in Pennypack Creek Watershed (Figure 6.2). While nearly all tributaries to Pennypack Creek Watershed in the upper and lower reaches originate in storm sewers or springs, the majority of first order tributaries in the central portion of Pennypack Creek Watershed originate in small manmade ponds. These ponds were created by damming streams, and depending on the configuration of the outlet structure(s) may have very limited floodwater storage capacity. Riparian zones of these ponds are typically open and surrounded by mown turf, often creating areas where resident Canada geese congregate. Due to lack of shading and longer residence times, these ponds often have increased water temperatures. Many first order and intermittent streams have been filled or lost their ecological function to residential development and pond construction.

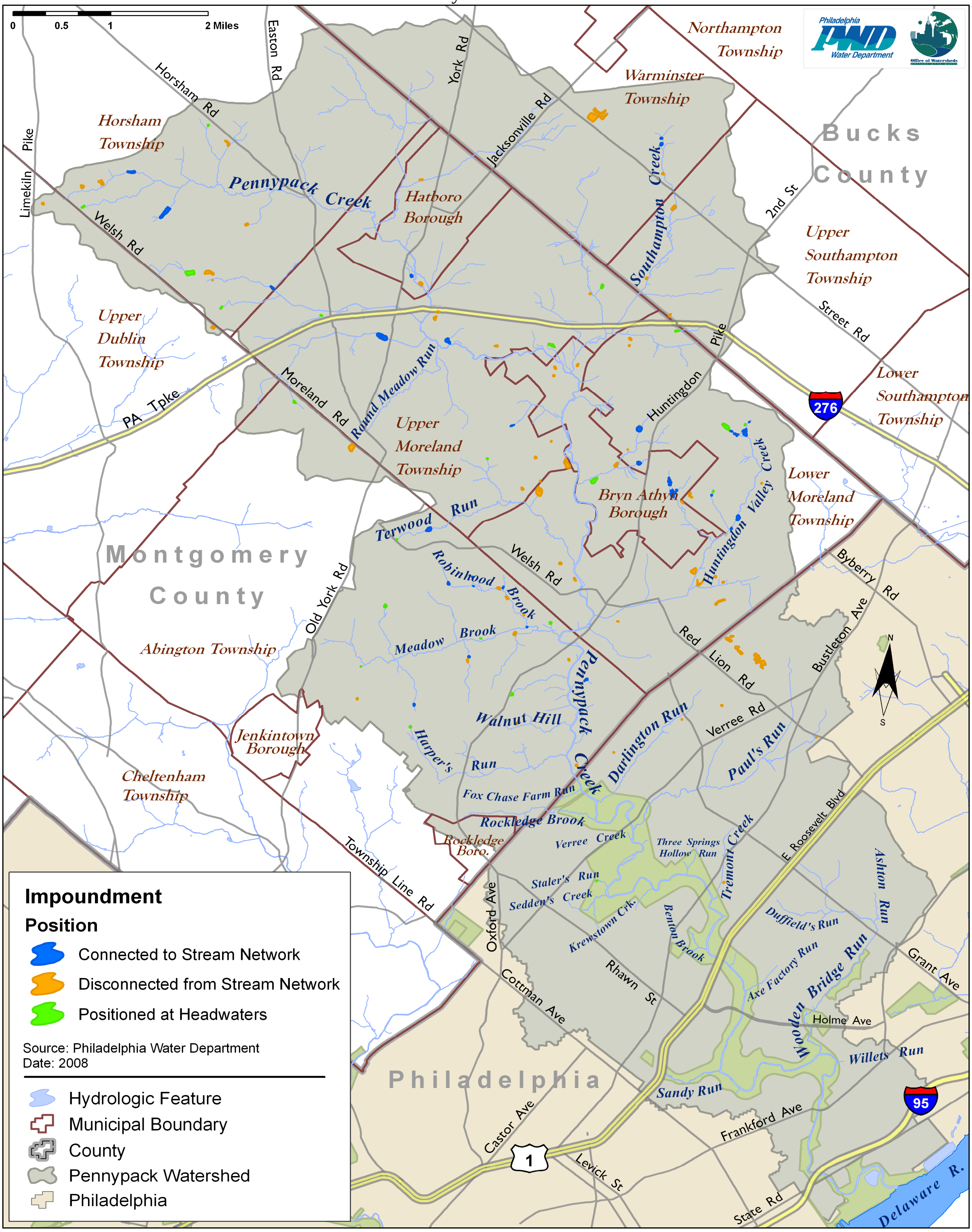


Figure 6.2 Manmade Ponds and Impoundments in the Pennypack Creek Watershed

6.1.1 PADEP 2008 Integrated List of Waters

According to the 2008 PA Integrated List of Waters (PADEP 2008), Pennypack Creek Watershed is listed by PADEP as being impaired due to flow alteration and siltation caused by urban runoff from storm sewers and small residential properties. 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.

Table 6.1 Habitat Related Impairments in Pennypack Creek Watershed Inside Philadelphia County from 2008 PA Integrated List

Stream Name	River Miles Affected	Source	Cause
Pennypack Mainstem	3.07	Municipal point source*	Pathogens
Pennypack Mainstem	3.07	Industrial and municipal point source	Priority organics, organic enrichment/low D.O.
Pennypack Mainstem	6.73	Urban runoff/storm sewers	Siltation
Wooden Bridge Run	3.14	Urban runoff/storm sewers	Siltation
Unnamed Tributary	0.442	Agriculture, urban runoff/storm sewers	Siltation
Unnamed Tributary	8.72	Urban runoff/storm sewers	Siltation

***Potable water supply impairment**

Table 6.2 Habitat Related Impairments in Pennypack Creek Watershed Within Montgomery and Bucks Counties from 2008 PA Integrated List

Stream Name	River Miles Affected	Source	Cause
Pennypack Mainstem	2.52	Urban runoff/storm sewers	Water/flow variability, flow alterations, other habitat alterations
Pennypack Mainstem	9.6	Urban runoff/storm sewers	Siltation
Southampton	0.66	Municipal point source/small residential runoff	Flow alterations
Southampton	2.76	Small residential runoff	Water/flow variability, flow alterations, other habitat alterations
Southampton	0.02	Urban runoff/storm sewers	Siltation
Huntingdon Valley Creek	3.42	Urban runoff/storm sewers	Siltation
Meadow Brook	2.45	Urban runoff/storm sewers	Siltation
Robinhood Brook	1.42	Urban runoff/storm sewers	Siltation
Rockledge Brook*	1.15	Urban runoff/storm sewers	Siltation
Round Meadow Run	0.98	Urban runoff/storm sewers	Siltation
Sandy Run	0.7	Urban runoff/storm sewers/small residential runoff	Water/flow variability, flow alterations, other habitat alterations
Terwood Run	2.52	Urban runoff/storm sewers	Siltation
Unnamed Tributary	1.949	Industrial Point source	Priority organics, metals
Unnamed Tributary	0.715	Municipal point source/small residential runoff	Organic enrichment/low DO, nutrients, pathogens, water/flow variability, flow alterations
Unnamed Tributary	4.496	Small residential runoff	Water/flow variability, flow alterations, other habitat alterations
Unnamed Tributary	18.455	Urban runoff/storm sewers	Siltation

*Rockledge Brook spans Montgomery and Philadelphia Counties

Habitat conditions in Pennypack 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.

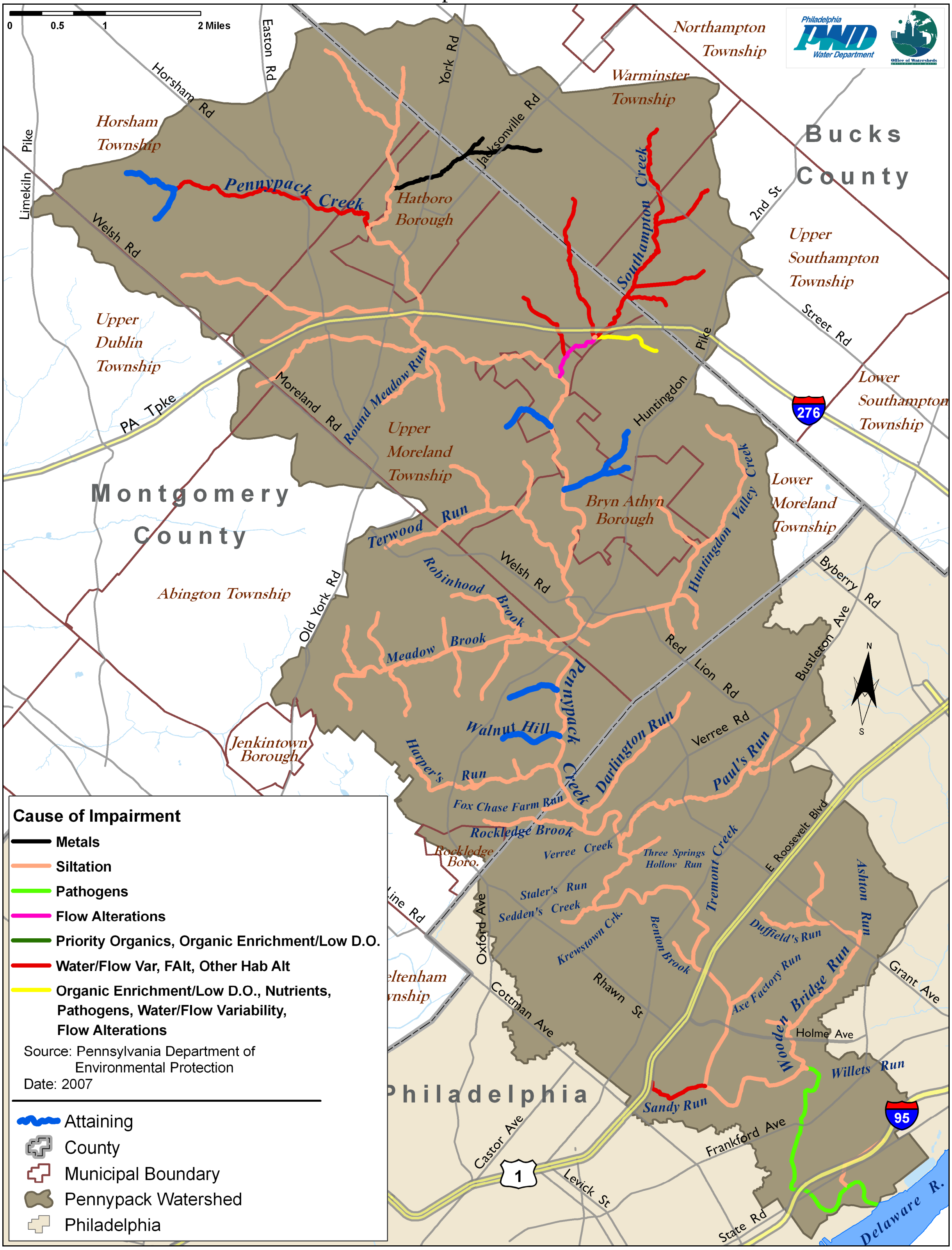


Figure 6.3 Causes of Stream Impairment in Pennypack Creek Watershed According to PA 2008 Integrated List of Waters

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 Pennypack Creek. Mainstem Pennypack Creek itself was not assessed as the researchers determined:

> "...since the majority of the drainage area of the mainstem (95%) was outside the park, restoration activities within the park would have little impact on the overall ecological health of Pennypack Creek" (ANS 2000).

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) which allowed for comparison of the relative condition of all reaches within the Fairmount Park system.

According to ANS,

> "Of a total of 77 reaches in Pennypack Park, all but one were rated as impaired (49.5%) or moderately impaired (49.5%). None of the stream reaches were classified as slightly or non-impaired. One reach, on a tributary in Fox Chase Farm (Fox Chase Run), was categorized as severely impaired."(ANS 2000)

Table 6.3 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 -Pennypack Creek Park
Severely Impaired	0 to 75	11 (3%)	1 (1%)
Impaired	76 to 150	164 (38%)	38 (49.5%)
Moderately Impaired	151 to 225	248 (58%)	38 (49.5%)
Slightly or Non-impaired	226 to 300	3 (1%)	0 (0%)
Totals	0 to 300	426 (100%)	77 (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. Both Pennypack Creek Park and Wissahickon Creek Park had a total of 5 assessment sites compared to 4 for Cobbs Creek Park and 2 for the Fairmount East-West, Poquessing and Tacony 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 PENNYPACK CREEK WATERSHED 2002-2003

In 2002, the Philadelphia Water Department conducted EPA Rapid Bioassessment Protocols, including physical habitat assessments (Barbour *et al*., 1999) at 20 sites within Pennypack Creek Watershed and its tributaries (PWD 2003). Methods and locations were similar to the 2007 sampling effort (Section 5.1.4, Table 5.4) with the exception of sites identified as having changed. The PWD Baseline assessment documented numerous 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 PENNYPACK 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 Pennypack Creek Watershed in 2003 (completed 2005). Other funding and in-kind services to conduct this plan have been provided by the Philadelphia Water Department, Fairmount Park Commission, Friends of Fox Chase Farm, Friends of Pennypack Park, Montgomery County Planning Commission, and Pennypack Ecological Restoration Trust.

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. Stronger regulations and ordinances were recommended as part of the restoration implementation tools. One of the strongest recommendations was a push for more stringent stormwater management controls, which are presently being addressed by a watershed – wide Act 167 plan and revised stormwater regulations in the City of Philadelphia.

As described in Section 2.10, 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 over 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 1-year, 24-hour storm, a depth of 2.6 inches over the DCIA.

In November 2008, PWD and Montgomery County Planning Commission will jointly lead the development of an Act 167 Stormwater Management Plan for the Pennypack Creek Watershed. At the completion of this process a model stormwater ordinance will be produced and provided to the municipalities within the Pennypack Creek Watershed for approval and adoption.

6.2.4 TEMPLE UNIVERSITY PENNYPACK CREEK FLOODPLAIN STUDY

As described in Section 2.8.1 the Temple University Ambler Campus Center for Sustainable Communities revised Federal Emergency Management Agency (FEMA) Flood Insurance Rate Maps (FIRM) for the Montgomery County portion of Pennypack Creek Watershed (Temple University 2006). The pre-existing maps were based on coarse-scale, pre-1970 hydrology that did not account for the effects of contemporary land-use and infrastructure. The new study incorporated more accurate topographical data and modern hydrologic modeling techniques. The hydrologic modeling effort included identification of culverts, bridges and other obstructions that could affect floodwaters. A stormwater facility survey was conducted and opportunities for improvements to stormwater management were also described. This study was funded by FEMA, The William Penn Foundation, and contributions from the participating municipalities.

6.2.5 FAIRMOUNT PARK COMMISSION DAM ENGINEERING STUDIES

Fairmount Park Commission conducted engineering studies of Rhawn St. Dam in Pennypack Creek Watershed and Livezy Dam (Wissahickon Creek Watershed) (STV Inc. 1999) as well as a more recent study of Roosevelt Boulevard and Verree Rd. Dams in Pennypack Creek Watershed (URS Corp. 2007). In both studies, the consulting engineer was asked to research and describe dam conditions, propose dam management alternatives, and evaluate options for dam removal, modification, or reconstruction, depending on project goals. Dam Removal and fish passage improvement projects are described in greater detail in Section 6.5.2.3.

6.3 PHYSICAL HABITAT CHARACTERIZATION 2007-2008

6.3.1 EPA RAPID BIOASSESSMENT PROTOCOL HABITAT ASSESSMENT (RBP)

6.3.1.1 FIELD STANDARD OPERATING PROCEDURES

Immediately following benthic macroinvertebrate sampling procedures, habitat assessments were completed at 23 sites (Figure 6.) based on a modification of the Environmental Protection Agency's Rapid Bioassessment Protocols for Use in Wadeable Streams and Rivers (Barbour *et al.,* 1999). Reference sites in French Creek, Chester County PA were assessed and used to normalize assessment of Pennypack Creek Watershed to the "best attainable" regional condition. Note that while macroinvertebrate sampling followed new field and laboratory protocols provided by PADEP, the EPA RBP Habitat assessment was not changed from the 2002 assessment.

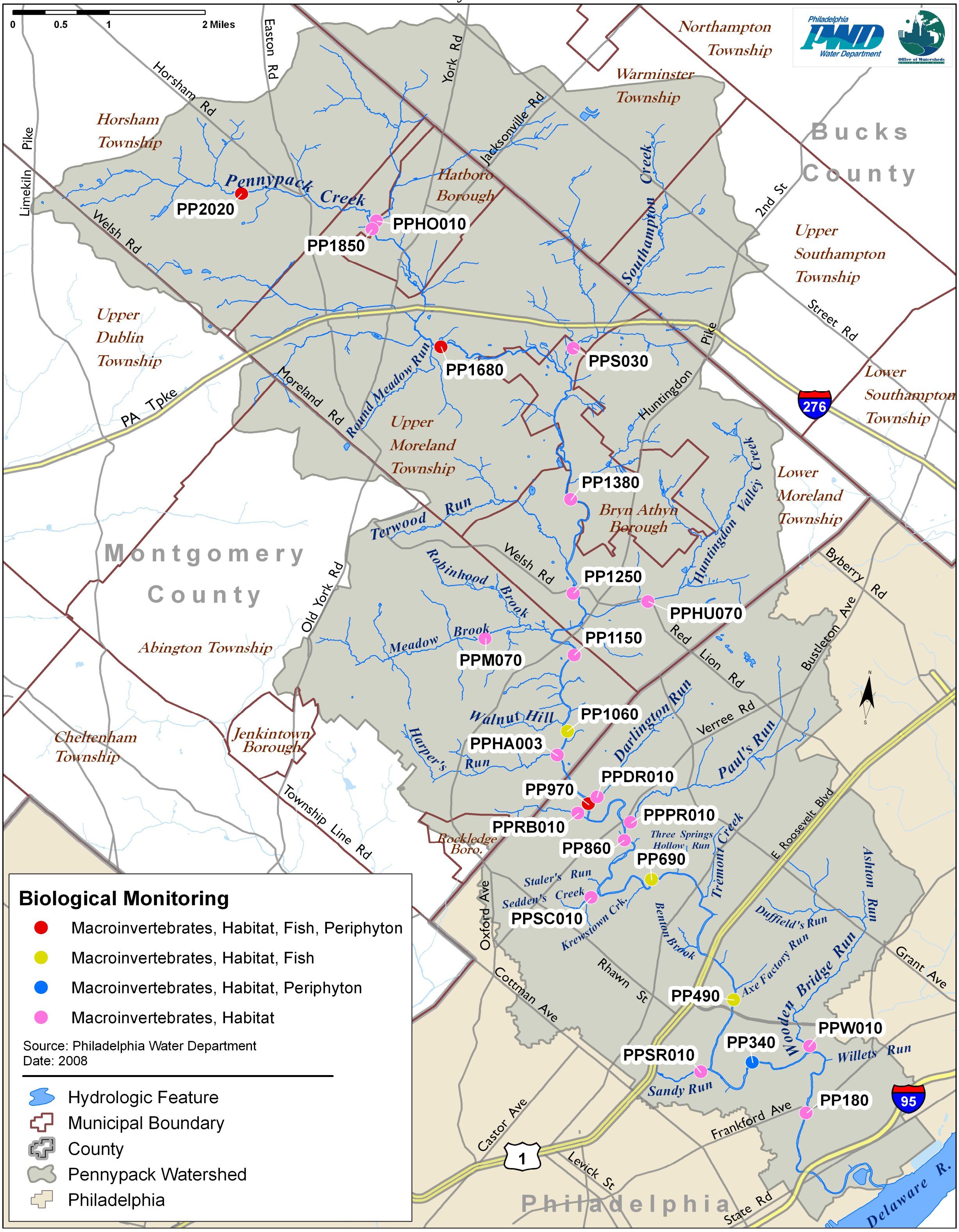


Figure 6.4 EPA RBP Physical Monitoring Sites in Pennypack Creek Watershed, 2007

6.3.1.2 DATA ANALYSIS

Habitat parameters were separated into three principal categories: (1) primary, (2) secondary, and (3) tertiary parameters. Primary parameters are those that characterize the stream "microscale" habitat and have greatest direct influence on the structure of indigenous communities. Secondary parameters measure "macroscale" habitat such as channel morphology characteristics. Tertiary parameters evaluate riparian and bank structure and comprise three categories: (1) bank vegetative protection, (2) grazing or other disruptive pressure, and (3) riparian vegetative zone width. Table 6.4 lists the various parameters addressed during habitat assessments.

Table 6.4 EPA Rapid Bioassessment Protocol Habitat Assessment Parameters

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

*Right and left banks are assessed separately.
Source: (Barbour *et al*., 1999)

6.3.1.3 RESULTS

There was a general trend of improvement in mainstem Pennypack Creek EPA RBP Habitat assessment scores longitudinally from downstream to upstream within the City of Philadelphia (Figure 6.5). North of the Roosevelt Boulevard (Rte. 1), park lands are generally wider and protect a greater riparian corridor around the stream. Mainstem sites located within relatively wide parcels of parks and protected lands (*i.e.*, Fairmount Park, Lorimer Park, Pennypack Ecological Restoration Trust) generally had greater scores than sites located on privately owned property or where protected lands adjacent to the creek were narrow or encroached upon by land development. For example, site PP1150, which was located at the northern extent of Lorimer Park in Lower Moreland Township, received the second-highest EPA Habitat assessment score in the watershed (92), while site PP1250, just one mile north, had a much lower score (66).

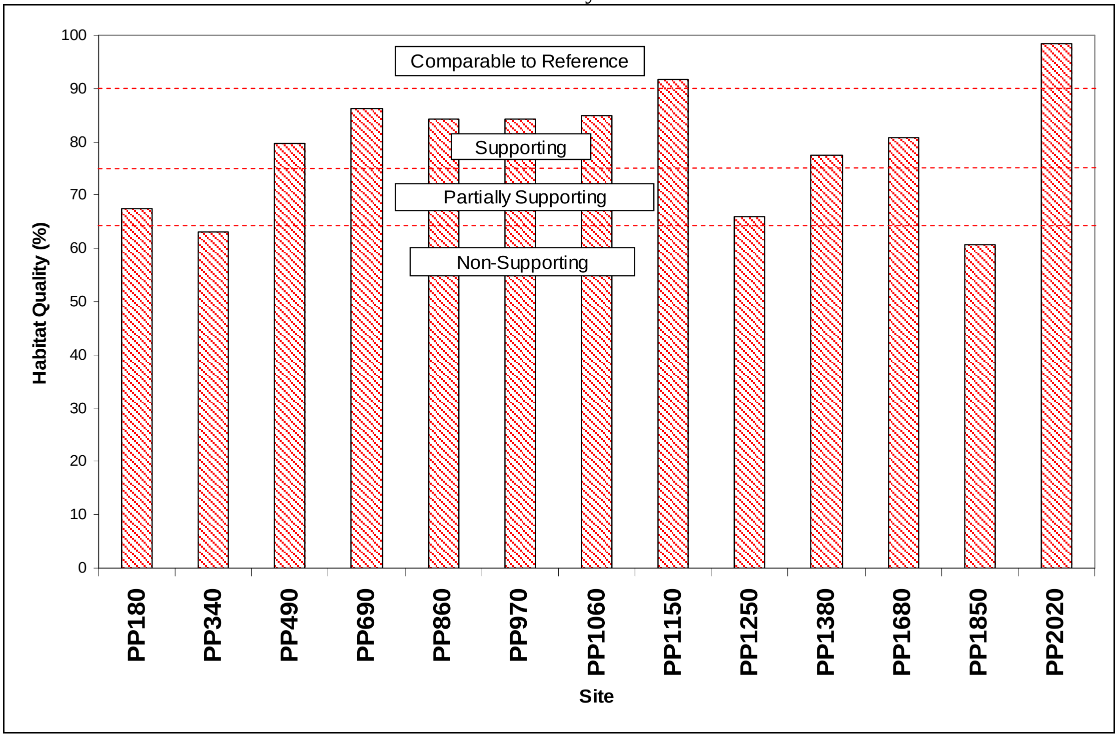


Figure 6.5 EPA RBP Total Habitat Quality Score for 13 Mainstem Sites in Pennypack Creek Watershed, 2007

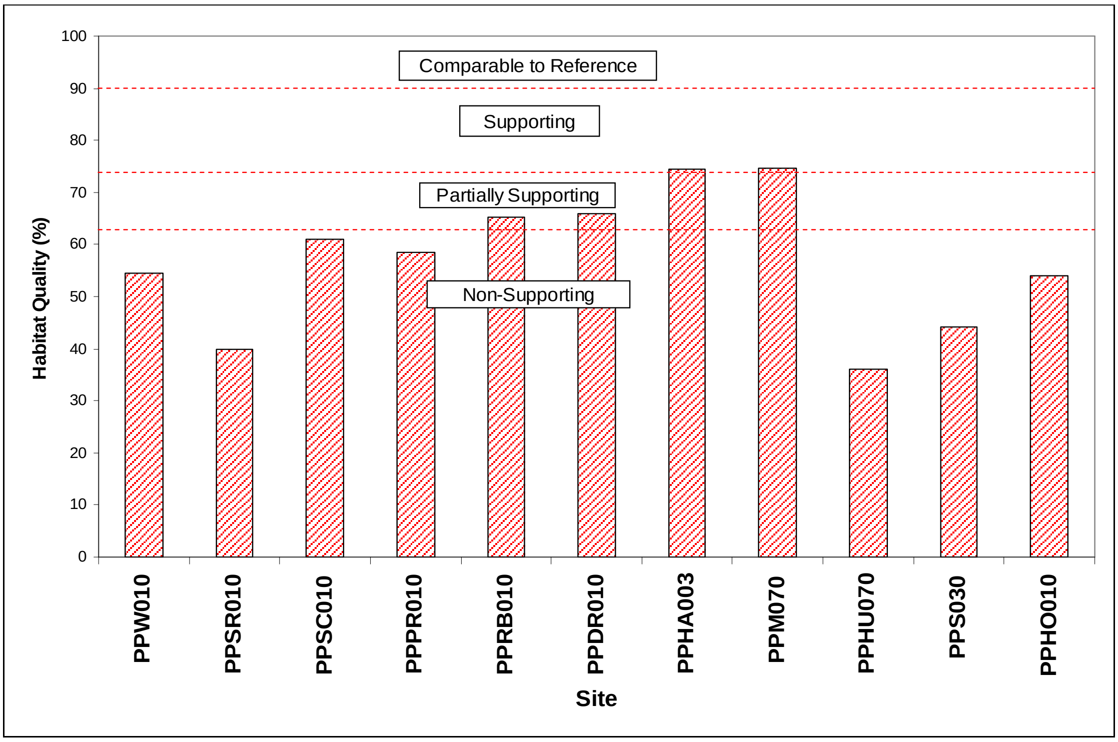


Figure 6.6 EPA RBP Habitat Score for 10 Tributary Sites in Pennypack Creek Watershed, 2007

6.3.1.4 COMPARISON TO HISTORICAL RESULTS

18 of 23 monitoring locations assessed in 2007 were also surveyed in 2002 using the same methods, enabling a coarse comparison to historic data. However, 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. However, temporal changes in site scores for certain parameters might be more attributable to measurement bias between assessment periods. For example, if scores for a parameter that should be expected to remain somewhat stable receive consistently different scores in monitoring events spaced 5 years apart, it is likely these differences 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.

Such was the case with "Channel Sinuosity", which is a numerical ratio of channel planform length. While streams naturally meander within valleys over time, sinuosity is relatively stable over short (*ca.* 5 yr.) timeframes, excluding rapid channelization construction projects. Habitat scores for this parameter were consistently greater in the 2002 assessment, but this difference probably does not mean that the stream channels themselves have been straightened. Differences in scores between 2002 and 2007 are likely due to the difficulty in estimating this property over the large range of channel sizes assessed. Furthermore, the range of scores within the "Suboptimal" to "Marginal" condition categories are not well-differentiated, leaving room for interpretation. Scores range from 6-15, yet a single description is used: "The bends in the stream increase the stream length 1 to 2 times longer than if it was in a straight line."

Likewise, many scores for "Frequency of Riffles (or bends)" decreased from 2002 to 2007, often resulting in a change to the site's condition category assessment for this habitat parameter which is not expected to vary considerably over a 5 yr. time span. Temporal differences are likely due to the difficulty of estimating distances and applying descriptional information to a large range of stream sizes, or a measurement bias between assessment periods. Further evidence for the lattermost factor is the fact that the score for this parameter at reference site FC1310 decreased 33% from 2002 to 2007. It should also be noted that the "Frequency of Riffles" habitat parameter was originally intended to be used only on high gradient streams (Barbour *et al.,* 1999) and may be inappropriate for use within low gradient mainstem sites where riffles are further apart due to reduced channel slope.

Habitat scores of six tributary sites assessed were generally lower in 2007 than in 2002 (Figure 6.8). Huntingdon Valley Creek (PPHU070) flows east to west within an industrial/rail corridor and was assessed as having 36% comparability to reference conditions, worst in the watershed. Mainstem site scores tended to improve from 2002 to 2007 (Figure 6.7). However, changes to habitat parameters at individual sites are not generally predictable, especially at the very local scale (*e.g.*, bank stability, vegetative protection) and these parameters exhibited a great degree of variability from year to year and between sites. Given the observed differences in scores from 2002 to 2007 for parameters that should be relatively stable, and differences in reference site scores from 2002 to 2007, these habitat data should probably be used only to compare sites to each other within a given assessment year. Habitat conditions may be deteriorating overall, but the EPA RBP dataset is not conclusive proof that this is the case.

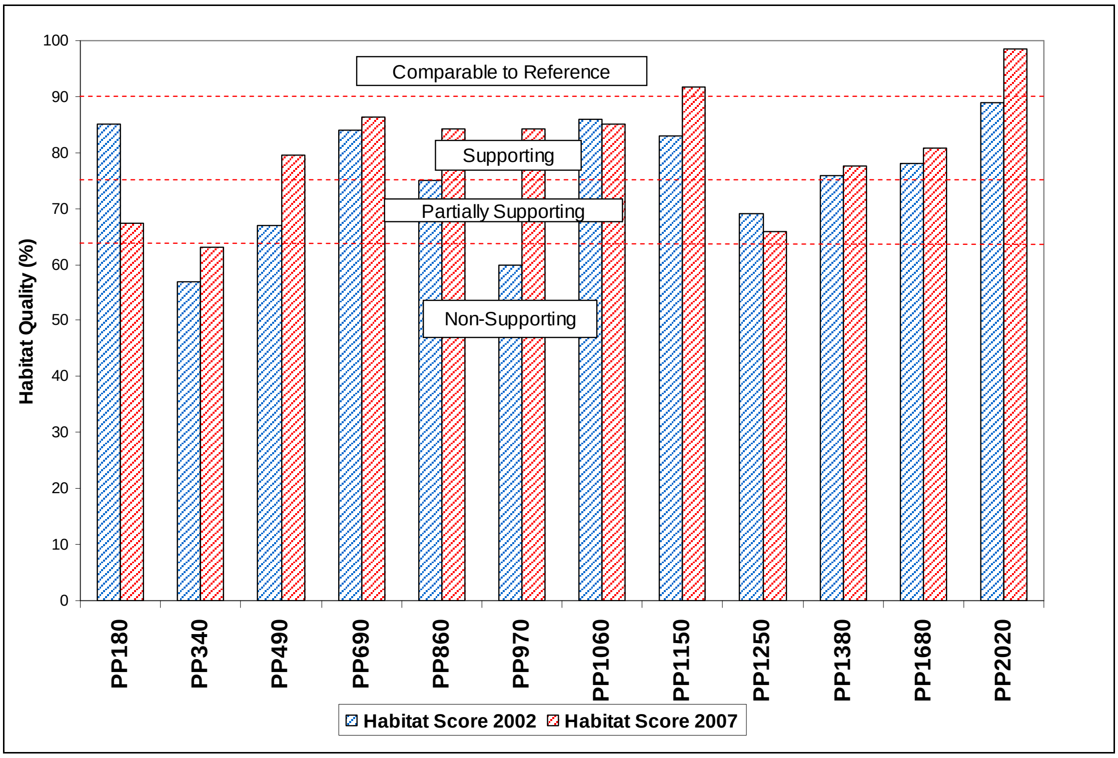


Figure 6.7 EPA RBP Habitat Score of 13 Mainstem Sites in Pennypack Creek Watershed, 2002 and 2007

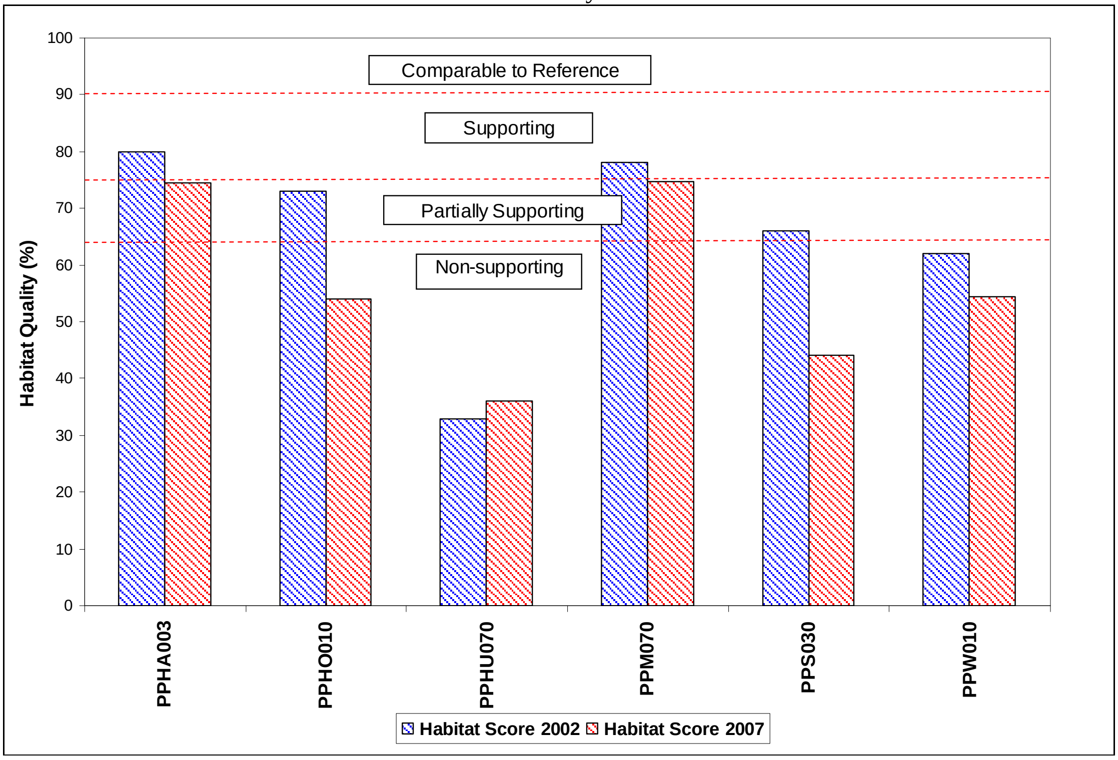


Figure 6.8 EPA RBP Habitat Score of 6 Tributary Sites in Pennypack Creek Watershed, 2002 and 2007

6.3.1.5 PRINCIPAL COMPONENTS ANALYSIS (PCA) OF EPA HABITAT DATA

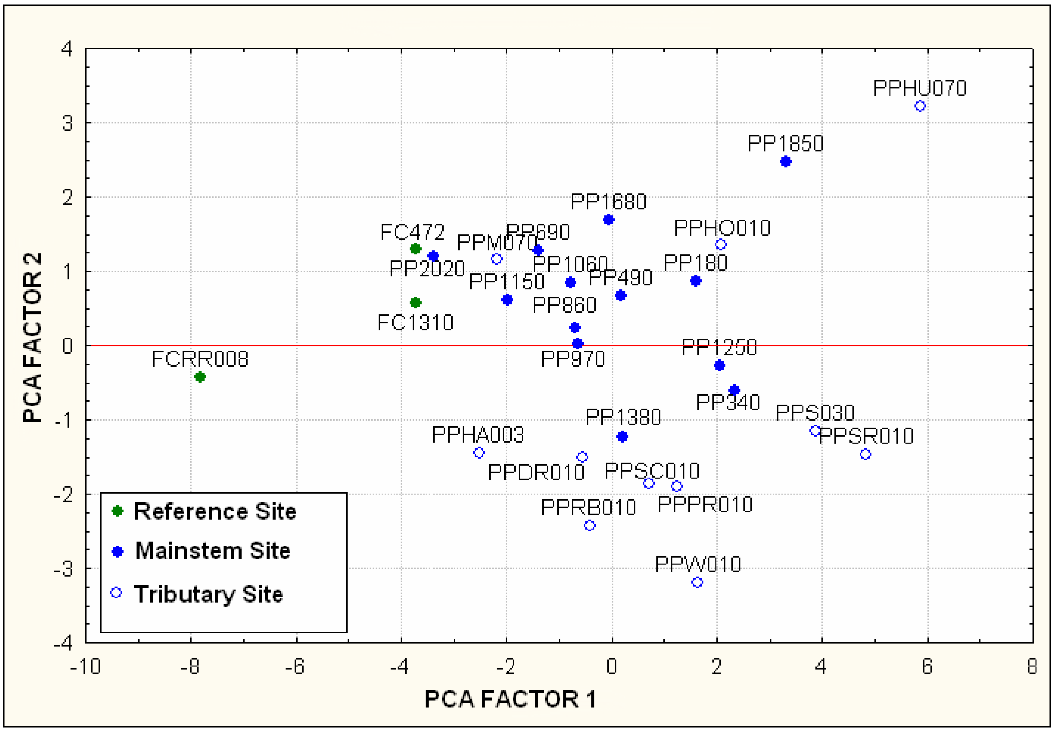


Figure 6.9 PCA Ordination Plot of Habitat Scores for Mainstem, Tributary and Reference Stream Conditions

Principal Components Analysis (PCA) in Statistica (Statsoft 1998) was used to reduce the number of variables needed to explain the variation between scores for 13 different habitat attributes among Pennypack Creek Watershed and Reference sites assessed with EPA habitat assessment procedures. The first factor extracted accounted for 54% of the variance in the data matrix. Habitat attributes with strongly negative loading values for factor one included embeddedness, epifaunal substrate, and pool substrate (Appendix K). The second factor extracted accounted for 15.2% of the variance, for a cumulative total of 69.2% variance explained. The only habitat attributes with a strong loading score for axis two were riparian vegetation and channel flow status (Appendix K).

Overall, the placement of sites along axis 1 correlated closely with total habitat scores and relative comparability to the reference sites (Figure 6.9), while PCA axis 2 appeared to isolate mainstem and tributary sites. There was extensive internal correlation between variables within the data set. In fact, of 120 possible pairwise comparisons between EPA habitat variables, 90 (75%) were significantly positively correlated. When riparian vegetation was excluded, 76 of 90 (86%) possible pairings were significantly correlated. There were no examples of widespread correlations among other habitat variables that would be expected to be independent and randomly distributed, such as drainage area, water quality variables, or other physical habitat data. This unusual finding suggests either that sites are overwhelmingly uniform with regard to various independent measures of impairment considered in the EPA Habitat assessment procedure or perhaps a subjective bias in the assessments.

6.3.2 FISH HABITAT SUITABILITY INDICES (HSI)

6.3.2.1 MODEL HISTORY AND ASSUMPTIONS

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

Numerous assumptions are inherent with use and interpretation of the models. First and foremost is the assumption that habitat features alone are responsible for determining abundance or biomass of the species of interest at the study site. Because fish assessments were conducted in June, conditions that were modeled may not reflect actual conditions during (and up to) sampling. The decision to use continuous data from the entire growing season in model input reflects the philosophy that these models are being applied to evaluate habitat at the site in general, not necessarily to evaluate only those conditions present during the actual fish surveys. For instance, many stream segments were cooler during the fish assessment than in late August. Fish may move from one site to another to find suitable conditions, so comparison of model output to observed fish biomass and abundance data involves a level of uncertainty.

Clearly, no species exists in a vacuum; aside from habitat variables, other ecological and environmental interactions can strongly influence biological communities. HSI models assume that users will exercise professional judgment, consult with regional experts when necessary, and consider the possible effects of other factors (*e.g.*, competition, predation, toxic substances and other anthropogenic factors) when interpreting model output.

6.3.2.2 Model Inputs

Most types of data required by HSI models were available for all sites within Pennypack Creek Watershed. However, a number of habitat parameters were not directly measured in a fashion best suited for use with HSI models and required additional interpretation or normalization. Few water quality parameters were measured with equal sampling effort across all sites; some parameters were measured with continuous monitoring instruments at some sites and grab samples or hand-held meters at other sites; furthermore, some variables were not directly measured at some sites. To facilitate HSI analysis at these sites, conservative values were substituted based on sampling conducted at nearby sites and reference sites in neighboring watersheds.

Turbidity data were excluded from the analyses entirely because all HSI models were developed using Jackson Turbidity Units (JTU), which cannot be converted to/from modern Nephelometric Turbidity Unit (NTU) data. Any other significant modifications to the variables or the modeling approach are explained in the documentation of model results for Individual Species under Section 6.3.2.6. A list of all HSI input variables for the nine HSI models applied to Pennypack Creek Watershed appears in Appendix M.

6.3.2.3 Suitability Index Expressions

HSI models use three major types of Suitability Index (SI) expressions or mathematical relationships to compute the suitability of a given habitat variable; they are (in increasing order of complexity): 1) categorized relationships, 2) linear equations (or more commonly, series of linear equations bounded by inflection points), and 3) suitability curves. Categorized relationships are used for a limited number of HSI variables in which the relationship between the habitat feature and suitability for the species of interest is fairly simple. Substrate size categorization is one example; many HSI models use dominant substrate type categories (*e.g.*, silt, sand, gravel, cobble, boulder, bedrock). Other SI variables that may be defined by simple categorization are temperature, dissolved oxygen, and pH. In some cases, the categorization was based on another statistic, such as the mode of stream depths within pools or variability of water quality measurements (Figure 6.9). Categorized data were processed directly within Microsoft Excel spreadsheet HSI models.

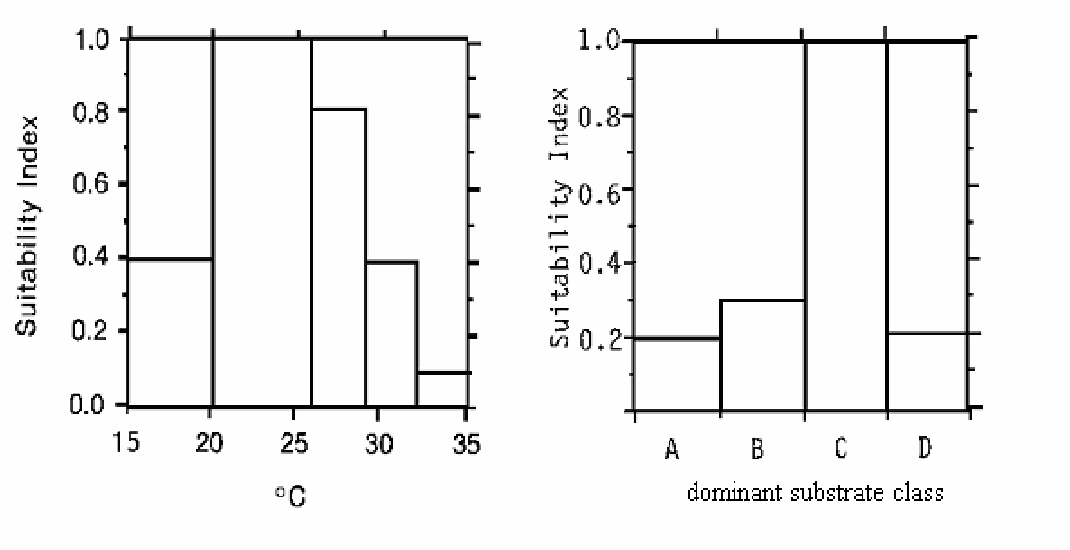


Figure 6.10 Categorized Expressions in HSI Models

Many SI variables are defined by a series of linear relationships bounded by inflection points (*i.e.*, a collection of linear relationships that roughly approximate a curve). Many of these relationships include a range of unsuitable (SI=0) values, a range of ideal (SI =1.0) values, or both. Although all types of SI variables were, in some cases, defined by series of linear relationships (Figure 6.10), these expressions were less likely to be employed as models increased in complexity. As models become more complex, there is a corresponding increased focus on development of SI curves. SI variables defined by linear relationships were processed using linear equations and Boolean commands directly in Excel spreadsheet models.

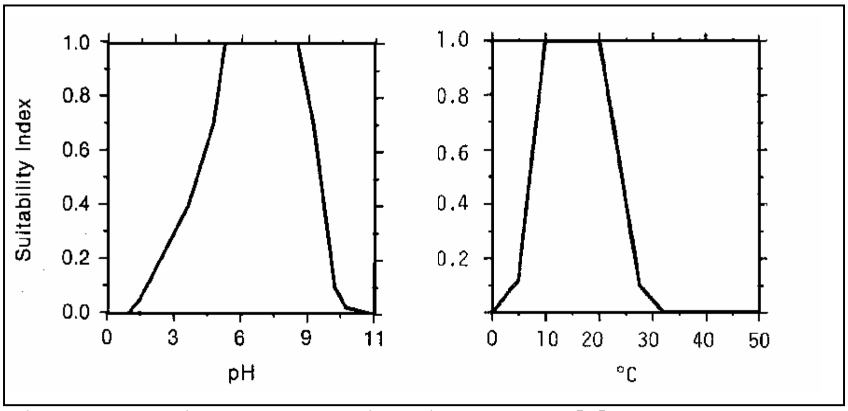


Figure 6.11 Linear Expressions in HSI Models

SI curve relationships are considered the most precise and continuous of SI relationships, and therefore, appear more frequently in more complex HSI models. For example, curves allow models to accurately represent the non-linear, sub-asymptotic change in SI expected as a habitat variable approaches complete unsuitability or ideal suitability (SI score 0 or 1 respectively). Two general SI curve shapes were common, modified parabolae and "s-curves", though there was considerable variation in actual curve shape between different SI variables (Figure 6.11). As curve equations were not provided with HSI model documentation, lookup tables were generated by scanning curves with data extraction software (Data Thief). Subsequent data processing was handled in Excel.

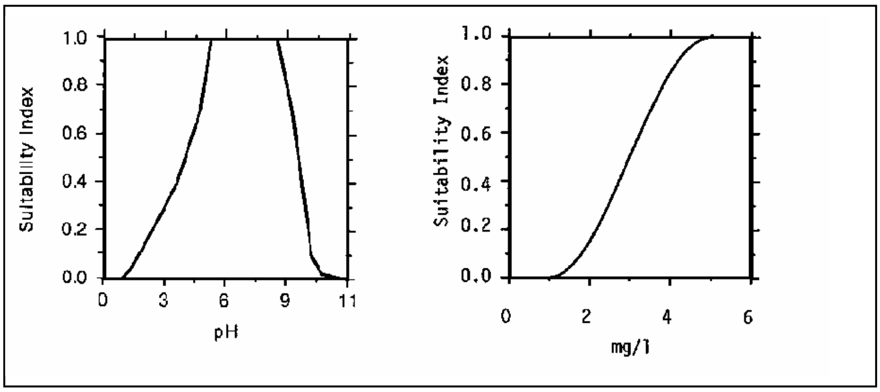


Figure 6.12 Curve Relationships in HSI Models

6.3.2.4 HSI MODEL SELECTION

HSI models for eight species were selected for Pennypack Watershed. Models were chosen to reflect the range of habitat types and attributes needed to support healthy, naturally-reproducing native fish communities and provide recreational angling opportunities in the watershed (Table 7-2). Two centrarchid fish, redbreast sunfish (*Lepomis auritus*) and smallmouth bass (*Micropterus dolomieu*), were included in the analysis. These species are tolerant of warmer water temperatures and require extensive slow, relatively deep water (*i.e.*, pool) habitats with appropriate cover or structure to achieve maximum biomass.

While black basses (*M. dolomieu* and its congener *M. salmoides*) are not native to Southeast Pennsylvania, they occupy the top carnivore niche and are among the most sought-after freshwater game fish in water bodies where they occur. Moreover, the only other large bodied piscivores known to occur naturally in Pennypack Creek Watershed are American eels, native catadromous fish for which no HSI has been developed. Salmonid HSI models were used for Brown trout (*Salmo trutta*) and Rainbow trout (*Oncorhynchus mykiss*). While these coldwater fish generally cannot establish and maintain reproducing populations in warmwater streams, PFBC actively stocks both Rainbow and Brown trout in Pennypack Creek Watershed (see Section 5.1 for more information).

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

6.3.2.5 HSI Model Evaluation

HSI model output for each site was compared to EPA RBP habitat data results. With the exception of fallfish, brown trout and rainbow trout HSI data, HSI model output was compared to observed fish abundance and biomass with correlation analyses. As fish known to associate primarily with pool habitats generally grow to larger sizes, a successful model should perhaps correlate with biomass per unit volume. Conversely, models that aim to predict habitat suitability for small minnows that inhabit riffles might be expected to have a stronger relationship with fish abundance per unit surface area. Several habitat models likely require modification in order to be useful in guiding or evaluating stream habitat improvement activities.

Overall, HSI model results were mixed. HSI correlated well with observed abundance and biomass data for some species but did not correlate well at all with other species (Table 6.5), which is expected given that there was very little effort made to standardize the input variables or model assumptions to the Pennypack Creek Watershed. While time constraints precluded the modification of models to better suit Pennypack Creek Watershed, it is hoped that such modifications will increase the usefulness of these models in the future. Simple correlations between habitat and fish abundance/biomass data are included in individual model results when appropriate, and PWD is currently exploring other statistical tools to study fish and macroinvertebrate habitat relationships.

Table 6.5 Summary of Correlation between HSI Model Score and Fish Abundance and Biomass Metrics at 6 sites in Pennypack Creek Watershed, 2007

Species	HSI:abundance	HSI:abundance per unit area	HSI:biomass per unit area	HSI:biomass per unit volume
Blacknose dace	-0.70	0.02	-0.94	-0.92
Brown trout	0.32	0.41	0.42	0.53
Common shiner	0.51	0.51	0.49	0.45
Creek chub	-0.94	-0.96	-0.95	-0.95
Longnose dace	0.28	0.33	0.40	0.44
Redbreast sunfish	-0.36	-0.28	-0.39	-0.26
Rainbow trout	0.16	0.25	0.41	0.41
Smallmouth bass	0.74	0.75	0.70	0.64

6.3.2.6 HSI Model Results for Individual Species

6.3.2.6.1 Smallmouth Bass HSI Model

Most sites in Pennypack Creek Watershed received HSI scores above 0.60, indicating suitable habitat for smallmouth bass. Site PP1680 had the lowest score (HSI=0.0) and was limited by dissolved oxygen concentration (SI=0.0) and substrate (SI=0.3), which are variables in the Reproduction Component of the HSI. Smallmouth bass were collected only in the middle and downstream sites below the Philadelphia-Montgomery County boundary. However, smallmouth bass abundance and biomass are generally expected to decrease in an upstream direction, as this species requires deeper, calmer water than is typically found in streams with small drainage areas.

Fewer smallmouth bass were collected from Pennypack Creek Watershed than would be expected from the high HSI scores, however, the HSI model was still good predictor of small mouth bass presence (r= 0.74). Despite the optimal habitat conditions predicted by the model, small mouth bass composed only 0.5% of fish individuals collected the 2007 assessment. It is possible that factors other than habitat influence their abundance. Stocked Rainbow and Brown trout seek out low velocity resting cover in the same habitats favored by Smallmouth bass and may compete for larger food items, such as small fish and crayfish. Another possibility is that certain variables have more influence than they carry in the model. For example, at many sites, all 15 variables received high scores with the exception of water fluctuation. However, water fluctuation had little effect on the final HSI scores. The exaggerated rise and fall of the water level characteristic of an urban stream, as well as the increased velocities present in a channelized stream, may have a greater effect than the water fluctuations and flood velocities typical of natural streams. It is unlikely that habitat impairment due to frequent water level fluctuations and effects of erosion and sedimentation will be ameliorated in the near future without significant investments in streambank restoration and basin-wide implementation of stormwater BMPs.

HSI scores correlated most closely with percentage of pools (r = -0.93) and temperature type (r= -0.95). Restoration and stabilization techniques that create, expand, or improve pool habitats probably will result in increased habitat suitability for smallmouth bass. For example, re-meandering of the stream channel and installation of flow diverters such as rock vanes and J-hooks should improve macrohabitat heterogeneity and enhance habitat for smallmouth bass and forage fish. Furthermore, stream restoration activities that increase the amount of instream and overhanging bank cover should improve habitat for smallmouth bass. These fish strongly associate with cover, such as accumulations of brush and fallen trees. Managing the amount, types, and distribution of available brush and downed tree cover can be very difficult in a multi-use setting such as Fairmount Park. Many park users do not understand the value of this type of habitat and consider it a nuisance because improperly disposed trash becomes snagged on tree branches and brush during storm events. Besides being aesthetically unpleasing, large accumulations of brush and logs may also threaten infrastructure; thus, there is a trade-off between maintaining optimal habitat for smallmouth bass, which benefits anglers, and protecting the function of drainage and sewerage infrastructure.

6.3.2.6.2 Redbreast Sunfish HSI Model

As a generalist species, redbreast sunfish (Lepomis auritus) are adaptable to a range of habitat attributes and may feed opportunistically upon a variety of prey types. In the 2007 fish assessment, redbreast sunfish was among the most commonly observed species (relative abundance 9.9%). Most suitability index (SI) variable expressions in this species' HSI include a large range of highly suitable values (or large area "under the curve"). Correlation analysis of HSI scores and abundance yielded an r value of -0.36, thus the HSI was not a predictor of redbreast sunfish presence. Correlation analysis between HSI scores and biomass/surface area and biomass/volume (-0.39 and -0.26 respectively) similarly showed a negative relationship. The negative relationship between abundance and HSI is due mostly to the HSI:abundance ratio at site PP690, which had the highest abundance and the lowest HSI score.

The HSI score for site PP690 was limited by the percent sand and gravel variable. This variable had a large effect on the HSI model for PP690 because redbreast sunfish require a mixture of sand and gravel substrate to successfully spawn. While site PP690 may have been deficient in sand and gravel substrates relative to other sites, sunfish that inhabit the site may spawn elsewhere or group their nests rather close together when spawning. HSI models are intended to be used to evaluate the suitability of a site for all life stages of the species in question, but scores for habitat attributes associated with spawning may not address seasonal or temporal factors that influence behavior and ultimately distribution.

6.3.2.6.3 Longnose Dace

Longnose dace HSI scores were generally low (0.018-0.448) and suggested habitat conditions are not conducive to supporting stable populations. The correlation between HSI and abundance was not strong (r=0.281), however the relative abundance of longnose dace in the 2007 assessment (0.3%) supports model predictions of poor habitat suitability for longnose dace. The HSI model had slightly stronger correlations with longnose dace biomass per unit surface area and volume (r^2= 0.398 and r^2= 0.444 respectively). Longnose dace have a particularly strong association with riffles and might be expected to be more highly correlated to the biomass per unit surface area metric, if riffles were of sufficient depth and velocity. However, streams in Pennypack Creek Watershed are generally overwidened with severely diminished baseflow. Restriction of longnose dace to downstream sites may reflect the fact that adequate baseflow is not present upstream, and riffles only become suitable in the downstream-most reaches where the cumulative discharge is greater.

Abundance and biomass of longnose dace were correlated to riffle attributes such as percent riffles and riffle depth. In the two sites that longnose dace were collected, the SI scores for these variables were ≥0.6; however, the SI scores for these variables were suitable at each site. Though some upstream sites (*e.g.*, PP970 and PP2020) had favorable physical riffle conditions in the model, the max riffle depth metric chosen probably does not address the overall extensive lack of depth in riffles at some sites. Site PP2020 was generally so shallow that it was difficult to find riffles deep enough to allow the Acoustic Doppler Velocimeter (ADV) to accurately gauge riffle velocity, which could explain the low velocity measurements at the site. At every site except for PP970 and PP690, riffle velocity was a limiting variable and given the species association with riffles, this no doubt had a significant effect on HSI predictions of habitat suitability. Overall, HSI was limited by the spring/summer max temperature (PP690), riffle velocity (PP1680 and PP2020) and percent cover (PP490 and PP970) habitat variables.

6.3.2.6.4 BLACKNOSE DACE HSI MODEL

The blacknose dace is classified as a "tolerant" fish. In fact, along with white suckers, American eels, and Fundulus *spp*. (Mummichogs and banded killifish), blacknose dace is one of the most common fish in degraded streams in southeast PA. Blacknose dace appears to be an "upstream" species, as abundance and relative biomass generally increase in an upstream direction. The stream width and gradient factors in the HSI model probably address this aspect of the species' ecology. Blacknose dace is a stocky fish, moderate in body form and somewhat rounded (dorsoventrally flattened) in comparison to vertically compressed minnows. Hydrodynamics may contribute adaptability to a variety of flow conditions and, in part, explain its abundance at degraded sites that are periodically exposed to intense scouring flows. Over-widening of channels and coarsening of stream substrate are typical of streams that are exposed to extremes in hydrology. Blacknose dace appear resilient to these factors, while other minnow species may not be as well adapted for these effects.

Pennypack Creek watershed data from 2007 were partially consistent with historic patterns, as the greatest number of blacknose dace (n=290) were collected at site PP2020, the upstream-most assessment site. However, site PP970, located in the mid-reaches of mainstem Pennypack Creek had the second highest abundance (n=168). This finding agreed strongly with fish surveys conducted in other nearby watersheds such as Poquessing, Tookany/Tacony-Frankford, and Darby Cobbs Creeks, where blacknose dace were not only abundant at the upstream-most site, but generally formed part of the fish community at intermediate sites as well. Blacknose dace was the second most common species observed in the 2007 fish assessment with relative abundance of 13.7%, slightly less than satinfin shiner which composed 15% of fish abundance.

Despite having high relative abundance and distribution throughout each monitoring site, HSI scores were very low for blacknose dace (HSI= 0-0.3). HSI and abundance had a strong negative correlation (r^2= -0.698) due mostly to the influence of site PP2020 which had the highest abundance yet had an HSI score of 0. Correlations were also very strong between the HSI:biomass/surface area and HSI:biomass/volume analysis (r^2= -0.941 and -0.922 respectively). The strong negative correlations between HSI:biomass/surface area and HSI:biomass/volume are a result of low HSI scores and relatively high blacknose dace biomass, thus the model was not a good predictor of blacknose dace presence.

The low HSI at PP2020 was due to the riffle velocity variable of the reproduction component, as blacknose dace embryo development is retarded by slow currents that do not deliver optimal levels of DO to developing embryos. During sampling, water surface elevations were very low at PP2020 due to diminished baseflow. In these conditions it can be difficult to find riffles deep enough to allow the Acoustic Doppler Velocimeter (ADV) to accurately gauge riffle velocity, which could explain the low velocity measurements at the site. All other sites were limited by the stream margin substrate variable from the fry component of the blacknose dace species HSI.

6.3.2.6.6 CREEK CHUB HSI MODEL

The creek chub, like the blacknose dace, is generally an upstream species that seeks out pool habitats in smaller, typically 2nd order streams and tributaries. Though downstream sites (HSI=0.61-.69) have HSI scores higher than the upstream-most site PP2020 (HSI=0.39), the highest number of creek chubs were in the two upstream sites (n=9 and n=72 for PP1680 and PP2020 respectively). Of all the other sites, creek chubs were only collected in PP490 and PP970 (n=2 for both sites). The HSI for PP2020 was limited by the spring riffle velocity and riffle substrate variables in the reproduction component of the species HSI. These riffle characteristics are important to creek chubs because they spawn in gravel and cobble substrates within riffles. As with the Blacknose Dace HSI model at PP2020 during sampling, water surface elevations were very low at PP2020 resulting in poor riffle quality. Correlation between HSI and abundance (r= -0.93) were negative due to the low HSI and the high abundance at PP2020. As with blacknose dace, correlations between HSI and both biomass per unit surface area and biomass per volume had strong negative relationships (r = -0.953 for both) because fewer individuals were collected in sites with high HSI scores.

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

6.3.2.6.7 COMMON SHINER HSI MODEL

The HSI scores for common shiner were limited by the Reproduction Component (C_R=0) for all sites and the Water Quality Component for all but two sites. The Reproduction Component was limited by the spawning temperature variable at all sites except PP2020 and the riffle velocity variable at sites PP1680 and PP2020. The Water Quality Component was limited by pH in both PP1680 and PP2020. As is the case with many of the other HSI models that were applied to the Pennypack Creek dataset, observed values of some physiochemical variables observed in the Pennypack exceed the ranges set by species-specific suitability indices. These indices were derived from observations of fish presence in natural, more pristine streams with ideal instream conditions and were not designed to address the altered physical and chemical environments present in most urban watersheds. An urban stream may thus support conditions amenable to fish productivity; however, many physiochemical parameters in urban streams will often exceed the ranges set by suitability indices due to the impacts of development and urbanization. An example is the “urban heat island effect”, a phenomenon in which temperatures are usually higher in urban areas and cities when compared to adjacent suburbs and rural areas. This temperature difference is due in part to the density of heat-absorbing surfaces like tar-covered roofs, asphalt and concrete as well as tall buildings which circulate warm air via convection.

The pool class variable of the Food/Cover Component was limiting at all sites except PP1680 and PP2020. The common shiner prefers pools of intermediate size and depth, but at the sites where pool class was limiting, the pools were generally large and deep. To attain non-zero values of habitat suitability, the reproduction component was excluded from the model and with limiting factors removed, HSI scores increased; however, these results were poor indicators of common shiner presence as the correlation between HSI and abundance was not very strong (r = 0. 51).

Common shiners represented only 1.9% of the relative abundance in the 2007 fish assessment and were only present in 3 of the six assessment sites. Product-moment coefficients between HSI score and common shiner abundance and biomass were not high enough to suggest any conclusive relationships between these factors. The lack of common shiners in PP690 no doubt decreased the magnitude of the positive correlation between HSI and abundance, which is ultimately an indicator of the predictive ability of the model.

6.3.2.6.8 Brown trout HSI Model

Brown trout (*Salmo trutta*) do not naturally reproduce in Pennypack watershed; however, they are stocked throughout the fishing season by PFBC. Some brown trout are assumed to survive through the winter based on anecdotal angler reports and the collection during fish assessments of adult brown trout greater in size than the stocked fish cohort, or "year-class". Though the HSI model for brown trout includes variables for all life stages, only variables that influence the adult stage were considered. The model can be run using a simple limiting theory or a compensatory limiting factor theory; however because many variables for both the Adult and Other Components were limiting, the compensatory model could not be used as values ≤0.3 can not be compensated.

The simple limiting theory assumes that each variable independently affects habitat suitability and therefore the habitat is limited by the lowest variable score. Run in this fashion, the HSI score for all sites was 0 due to limitation by minimum average dissolved oxygen and maximum summer temperature. HSI was also limited by elevated nitrate levels at all sites except PP2020 (SI= 0.25, Appendix M Table.M2). Non-zero HSI scores were only obtained after removing these two variables, however this would not reflect the true suitability of brown rout to instream conditions on the Pennypack, thus the resulting HSI ranged from 0.0 - 0.0275 (Appendix M Table.M2). These low HSI scores, which suggest poor habitat suitability for adult brown trout, are supported by the paucity of adult brown trout in fish surveys. In the 2007 assessment, brown trout only accounted for 1.07% of all fish collected.

While water temperatures recorded in Pennypack watershed (21.37-23.25 °C) might be expected to be detrimental to "wild" trout, stocked trout are bred for rapid growth and acclimated to greater temperatures in hatcheries. Therefore, negative effect of high temperatures may be more limited than one would expect from model documentation or literature studies based on exposing wild fish to experimental temperatures in a laboratory setting. Thermal impacts are, however, inexorably linked to dissolved oxygen concentration. Increased temperature combined with high biological oxygen demand due to eutrophic conditions may severely limit dissolved oxygen. This may be the case at site PP1680, which is downstream of a wastewater treatment facility and had the most severe dissolved oxygen limitation (3.34 mg/L). Furthermore, a 10 year study of urbanization in Valley Creek, a nearby wild reproducing brown trout stream, showed decreases in trout abundance related to water temperature (Steffy and Kilham 2006).

6.3.2.6.9 Rainbow trout HSI Model

Like brown trout, rainbow trout do not naturally reproduce in Pennypack watershed; however, they are stocked throughout the fishing season by PFBC. As with brown trout, a minimal number of rainbow trout are assumed to survive through the winter based on anecdotal angler reports and collection during fish assessments of adult Rainbow trout greater in size than the stocked fish cohort, or "year-class". Only the adult component of the HSI model was calculated for the Pennypack CCR, and HSI scores were moderately high in all sites (HSI= 0.805-0.881) except for sites PP490 and PP2020 (HSI=0.154 and 0.276 respectively) due to minimum dissolved oxygen limitation (Appendix M Table M.6). The non-compensatory solution was used to derive HSI scores; however, the minimum DO variable was removed in order to obtain a non-zero HSI score at all sites. To some extent, the HSI model accurately predicted rainbow trout presence, as HSI results generally agreed with observed abundance data; however, due to the low HSI score at PP490 which had the highest abundance of rainbow trout, the correlation between HSI and abundance was very low ($r = 0.158$). Despite the influence of site PP490 and taking into consideration that rainbow trout only accounted for 0.8% of relative abundance, the model did well at discriminating rainbow trout presence among sites.

6.3.2.7 HABITAT SUITABILITY SCORE CALCULATOR

The Habitat Suitability Score (HSS) Calculator was created by EPA's Ecosystem Research Division (ERD). A web based form implementing the model is hosted on the Canaan Valley Institute website as a tool to help land owners predict the response of select fish species to stream management options. The model was created using fish and habitat data from sites in the US EPA Environmental Monitoring and Assessment Program for Streams of the Mid-Atlantic Region (EMAP), 1993-1998 (n=337). The relationship between habitat variables and the presence or absence of fish species were developed using multiple logistic regression analysis. The model was tested using goodness of fit statistics which were based on "leave one out cross validation" (each sample was sequentially left out and the model was run to predict presence/absence). Goodness-of-fit statistics for all species yielded a p-value < 0.001. Models were also tested against an independent data set collected by the West Virginia Department of Natural Resources 2001-2 (n=115).

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

HSS proved to be a good predictor of the presence of small mouth bass, blacknose dace and creek chub, but a poor predictor for longnose dace. HSS scores for blacknose dace were moderately suitable (HSS=0.44-0.66) and correlation analysis between HSS and abundance shows ($r^2=0.875$) that the model was a good predictor of blacknose dace presence. HSS scores for creek chub were also moderately suitable (HSS=0.42-0.86) and although creek chub were absent at two sites (PP690 and PP1060) there was a strong relationship between HSS and abundance ($r^2 = 0.89$). Small mouth bass HSS scores (HSS= 0.04-0.63) had a wider range across sites than did the HSS models for the other three species. The model still served as a good predictor of the patchy distribution of small mouth bass across assessment sites given the high correlation between HSS and abundance ($r^2 = 0.705$). HSS scores for longnose dace were by far the lowest among the four species (HSS= 0.02-0.08). Correlation analysis showed a weak association between HSS and abundance ($r^2 = 0.37$) even though longnose dace abundance was among the lowest of the four species evaluated with the HSS model.

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/absence of forested riparian buffers throughout Southeast PA. The project was completed in two phases of grant funding, an initial study of tree canopy in the Perkiomen, Neshaminy, Valley, and Chester Creek Watersheds, and a second, more detailed inventory of the remaining watersheds in the 5 county region, including the Darby-Cobbs, French, Namaan, Pennypack, Pickering, Poquessing, Ridley-Crum, Tookany/Tacony-Frankford, and Pennypack Creeks, as well as the Lower Schuylkill and Delaware Rivers (Heritage Conservancy 2002). Over 1200 miles of stream were mapped using digital orthophotography and helicopter flyover video analysis.

Of 75.8 linear miles assessed in Pennypack Creek, approximately 32% of the riparian land was found to be lacking a forested buffer on one or both banks (a forested buffer was defined as at least 50 ft. wide and at least 50% canopy closure) (Heritage Conservancy 2002).

The Heritage Conservancy study was conducted with an incomplete watershed hydrology data set, 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 80 miles of hydrologic features in Pennypack Creek Watershed, there may be errors related to the exact extent that was assessed. Approximately 25% of mainstem and 15% of tributary river miles within the City of Philadelphia were considered to have complete tree canopy coverage (Figure 6.12). These results generally mirrored the land use analysis, with most riparian buffer problems located at transportation corridors. Some riparian park lands are managed as mown lawn or fields.

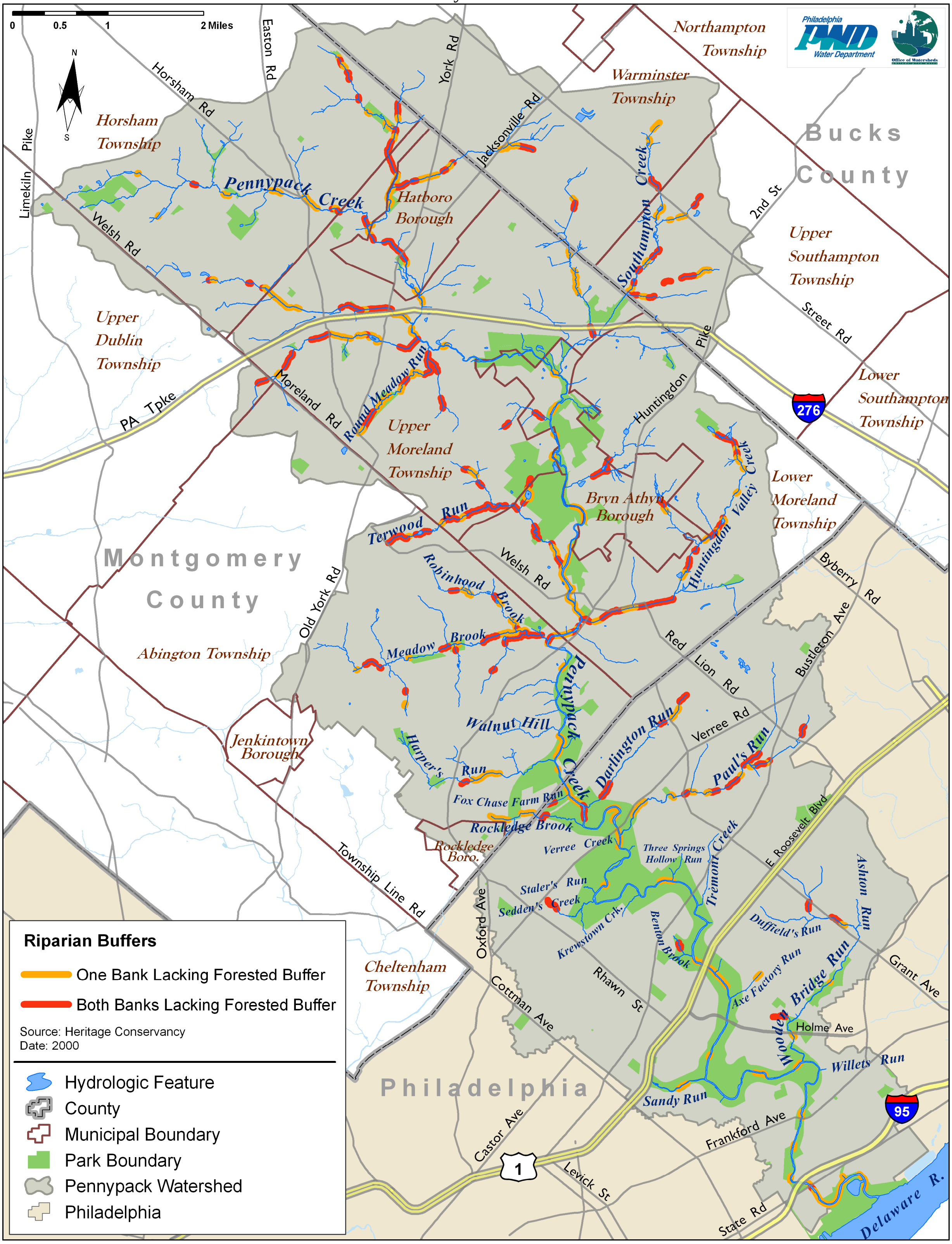


Figure 6.13 Pennypack Creek Watershed Stream Segments Lacking a Forested Riparian Buffer on one or Both Banks (Redrawn from Heritage Conservancy 2001)

6.5 DOCUMENTATION OF INFRASTRUCTURE IMPACTS IN FLOODPLAINS OF PENNYPACK CREEK WATERSHED

6.5.1 INTRODUCTION

As an extension of the fluvial geomorphological (FGM) investigation of stream channels within Pennypack Creek Watershed during 2006, 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 2007, 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 of features overall and the spatial distribution of these features, infrastructure maps (figures 6.13 through 6.15 and 6.18 through 6.21) 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 THE CITY OF PHILADELPHIA

6.5.2.1 STORMWATER OUTFALLS

Pennypack Creek Watershed was developed in distinct stages of differing land use patterns, but generally before 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 (though mostly served by a separate sewer system, there are 5 combined sewer overflows in the tidal portion downstream of Frankford Ave). However, due to the acquisition of Pennypack Creek parklands and steep slopes characteristic of the Pennypack Valley, stormwater outfalls in the City of Philadelphia portion of the watershed tend to be located at the present-day terminus of and along tributaries rather than along the mainstem. While mainstem Pennypack Creek was not found to be severely affected by localized erosion at stormwater outfalls, geomorphic instability caused by stormwater outfalls was determined to be a serious problem in tributaries. 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.

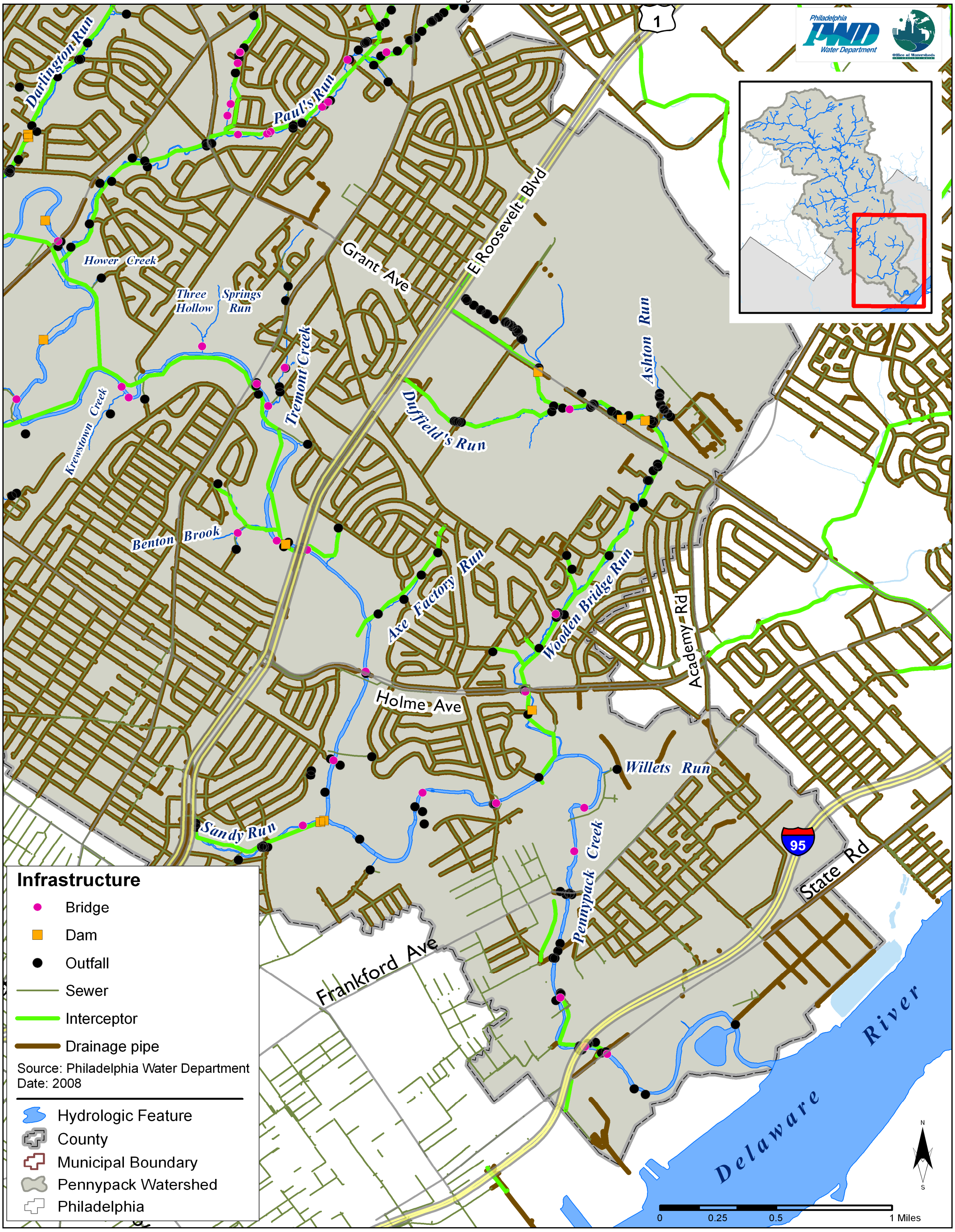


Figure 6.14 Infrastructure Locations in Pennypack Creek within the City of Philadelphia, 2007

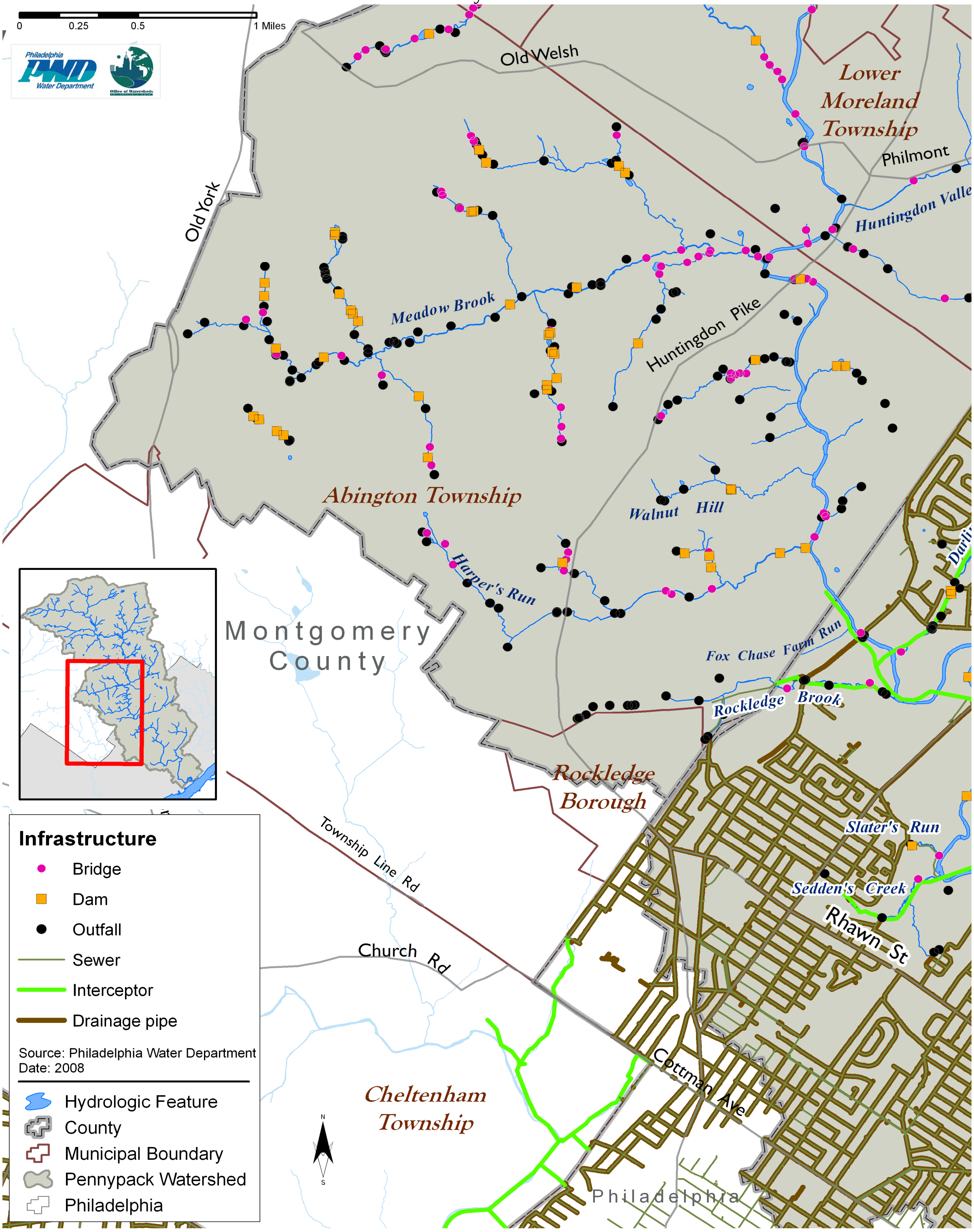


Figure 6.15 Infrastructure Locations in Pennypack Creek within the City of Philadelphia and Montgomery County, 2007

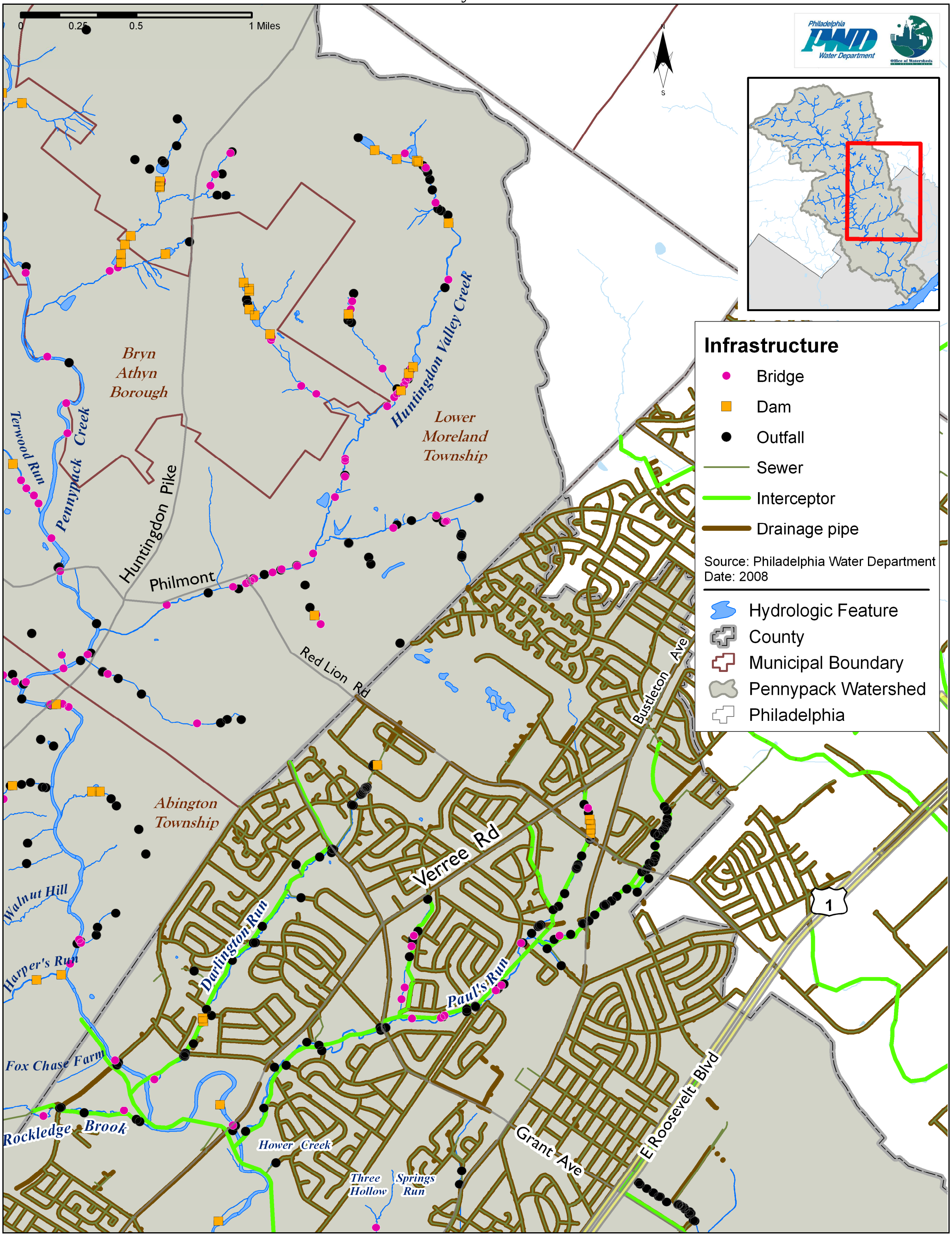


Figure 6.16 Infrastructure Locations in Pennypack Creek within the City of Philadelphia and Montgomery County, 2007

6.5.2.2 CULVERTS, BRIDGES, AND CHANNELIZATION

As the Pennypack valley is protected by the City of Philadelphia's Fairmount Park system, the number and severity of infrastructure impacts along mainstem Pennypack Creek in the City is generally reduced compared to an urban stream where riparian buffers are minimal. Riparian Buffers are reduced in the vicinity of the Delaware River (south of Frankford Ave.) and Bustleton Avenue (Figure 6.13). In general, transportation corridors linking Northeast Philadelphia to Center City run east to west and there are numerous bridges crossing Pennypack Creek that may contribute to instability by constraining the stream or serving as locations where stormwater drains directly to mainstem Pennypack Creek rather than its tributaries. Recreational trail infrastructure and streambank armoring to protect trails, outer meanders, and bridges from stream erosion within the park have resulted in a large amount of channelization (Figure 6.17).

Tributaries in the city of Philadelphia are more severely affected by infrastructure than the mainstem, and numerous stormwater outfalls are situated along the banks of most major Pennypack Creek tributaries in Philadelphia (Figures 6.13 through 6.15). Aside from stormwater outfalls, there are some tributaries that have been prominently culverted and encapsulated within the stormwater collection system (*e.g.*, Sandy Run). Small dams are also numerous along tributaries. Some dams appeared to have been constructed to protect infrastructure, while the majority of dams' original function was unclear.

Figure 6.17 Recreational Trails in Pennypack Creek Park, 2007

6.5.2.3 DAMS, DAM REMOVAL AND FISH PASSAGE ENHANCEMENT PROJECTS

The Pennypack Valley within Philadelphia was once home to many mills and associated mill dams and races (Figure 6.18). Of these, only 2 large dams remain, at Roosevelt Blvd. and Verree Rd. (Appendix N, Figures N.1 and N.2, respectively). In a report to the Fairmount Park Commission (2000), ANS recommended removal or modification of these dams to allow fish passage, restore the stream to a more stable freely flowing state, and eliminate upstream impoundments of stagnant water. A separate dam alternatives analysis commissioned by FPC and prepared by URS Corp in 2006 addressed the options for addressing fish passage, public safety, and liability at these two dams. While the FPC removed partial obstructions due to breached dams in 2006, FPC did not support removal of the remaining dams at the time this report was prepared.

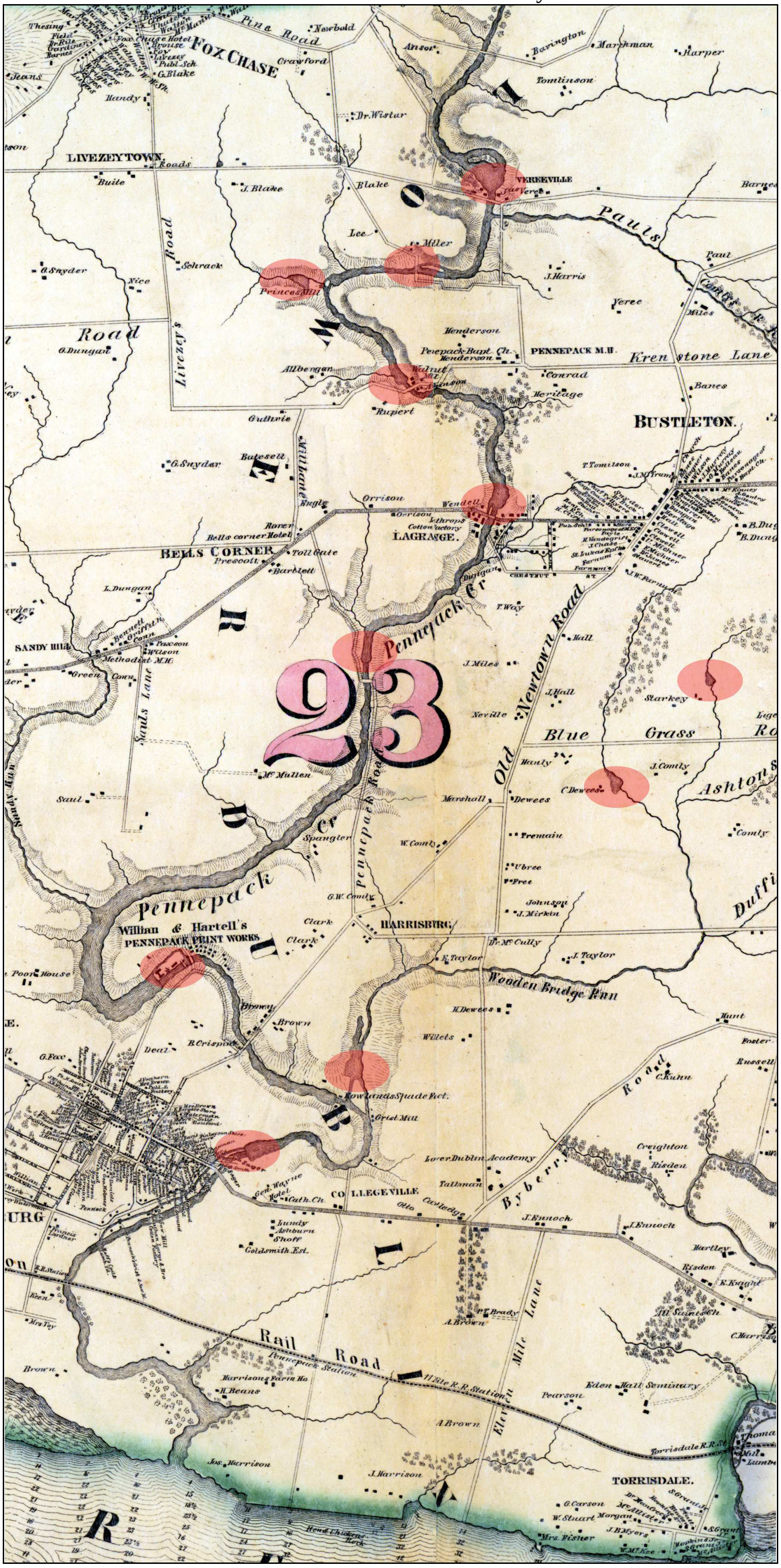


Figure 6.18 1860 Smedley Map, Historic Mills and Dam Locations Highlighted

6.5.2.3.1 DAM REMOVAL PROJECTS

A partnership between Southeastern Montgomery County Trout Unlimited (SEMCTU), FPC, NOAA, American Rivers, Pennsylvania Fish and Boat Commission (PFBC) and PWD restored fish passage at three locations on the Lower Pennypack Creek. These sites include Frankford Avenue Dam, a PWD sanitary sewer line, and Rhawn Street Dam. Frankford Ave. and Rhawn St. Dams were previously breached by hurricanes, but leaving debris that still remained obstruction to fish passage. Dam remnants and debris were removed and stream restoration and stabilization were performed at these sites to stabilize the stream and provide for fish passage (Appendix O, Figures O.1 through O.10).

Led by SMCTU, many of the same stakeholders were responsible for implementing the removal of two upstream dams in Montgomery County – Spring Dam in Bethayres (2005) as well as the Old Huntingdon Pike Dam, in Abington Township in 2007(Appendix O, figures O.5 and O.6). With several obstructions removed over the course of the last few years, Pennypack Creek Watershed is a model for dam removal projects coordinated over a diverse group of stakeholders within Southeastern Pennsylvania.

6.5.2.3.2 PWD SANITARY LINE NATURAL ROCK RAMP FISHWAY

After Frankford and Rhawn St. Dam remnants were removed in 2006, the downstream-most obstruction to anadromous fish passage in Pennypack Creek Watershed was a PWD sanitary sewer line approximately 1200ft upstream of the former Frankford Ave. Dam. Because this was an active sewer line that would be very expensive to relocate, a rock ramp fishway was constructed in 2007 to raise the water surface elevation and provide fish passage at this site (Appendix O, figures O.9 and O.10).

PWD has completed phase one of the physical monitoring activities planned for the rock ramp, by installing a stream gage and recording stream stage to correlate to the nearby Rhawn St. USGS gage station. A detailed post-construction survey of the rock ramp is underway in order to support a finite element 2-Dimensional hydraulic model of the rock ramp (River2D). Preliminary work has shown that a much greater spatial resolution of survey points is required to accurately model the effects of the individual boulders and “slots” in the rock arches, so a second survey is planned for fall 2009. PWD hopes to eventually estimate velocity vectors within the rock ramp at varying river flow conditions and compare physical conditions to fish swimming behavior.

PWD has also conducted rapid, non-quantitative fish surveys in the tidal Pennypack Creek by boat and tote barge electrofishing, beginning in 2006. While a small number of anadromous and semi-migratory fish species have been collected, there is thus far no evidence of a spawning run of Hickory shad having been established in Pennypack Creek. It is possible that Hickory shad fry stocked in Pennypack Creek have failed to “imprint” on Pennypack Creek and have joined Delaware River Runs, though thus far no otolith-tagged fish released in Pennypack Creek have been collected from either the Delaware River or major tributaries where collection and subsequent tag verification is performed by PFBC. It is also possible that Hickory shad fry are not surviving to maturity in order to return and spawn in Pennypack Creek. Hickory shad are stocked at a much earlier phase of development than American shad and thus may be more susceptible to mortality, whether due to predation, lack of appropriate food, poor water quality, or physical habitat factors.

6.5.3 INFRASTRUCTURE IN MONTGOMERY AND BUCKS COUNTIES

6.5.3.1 STORMWATER OUTFALLS

Because information regarding stormwater management facilities outside Philadelphia was not readily available, the destabilizing effect of stormwater outfalls was assumed to be related to the relationship between outfall size and size of the receiving stream. This relationship ignores differences in slope and substrate composition that may be important in determining which outfalls have the greatest likelihood of causing stream stability problems. More than 600 stormwater outfalls greater than 8” in diameter were inventoried throughout the basin in Montgomery County and 118 in Bucks County (Figures 6.18 through 6.21). The relationship between the number and size of stormwater outfalls and potential impacts on stream stability appeared somewhat similar to that observed in Philadelphia, with many tributary streams destabilized and susceptible to instream erosion.

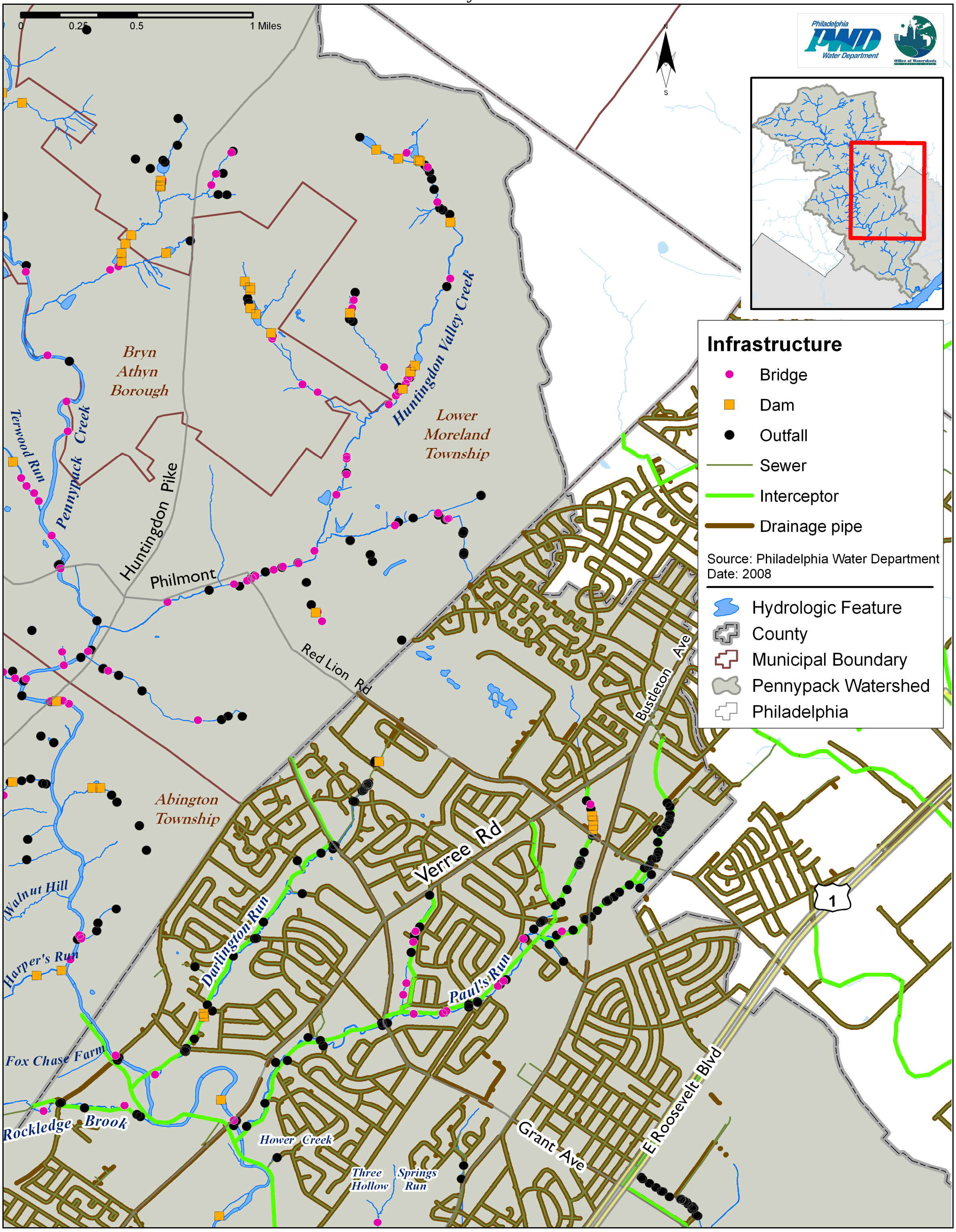


Figure 6.19 Infrastructure Locations in Pennypack Creek within the City of Philadelphia and Montgomery County, 2007

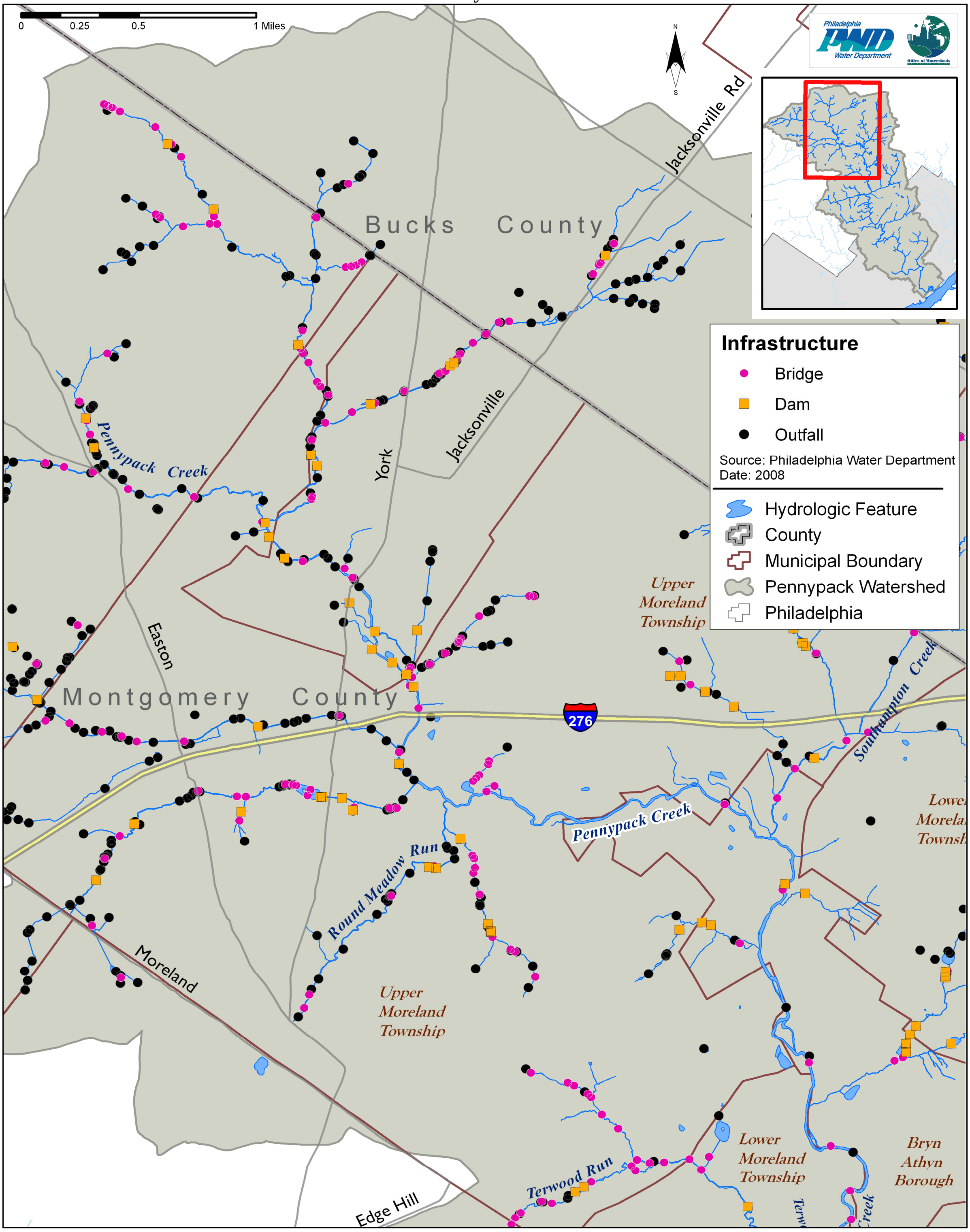


Figure 6.20 Infrastructure Locations in Pennypack Creek within Montgomery County, 2007

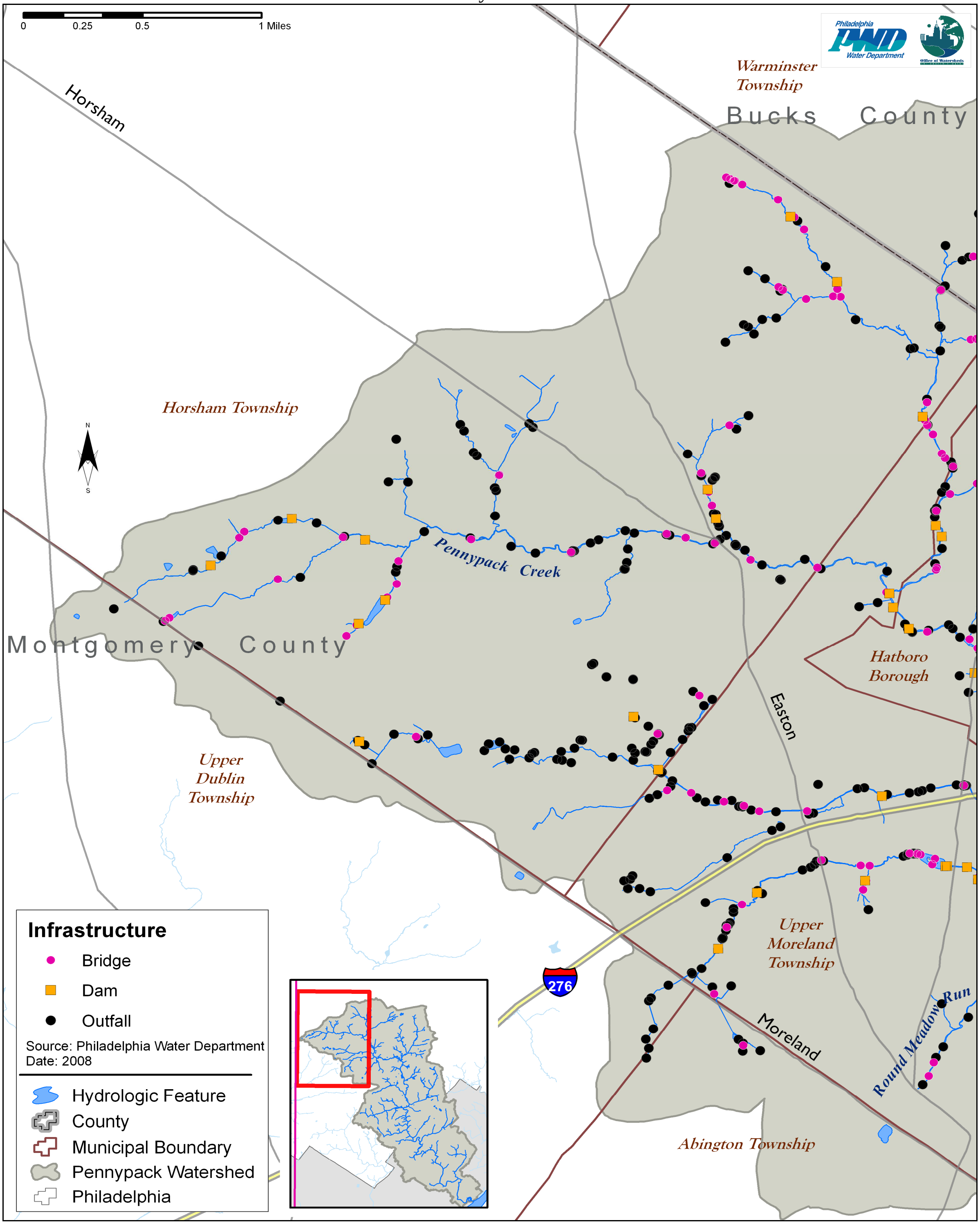


Figure 6.21 Infrastructure Locations in Pennypack Creek within Montgomery County, 2007

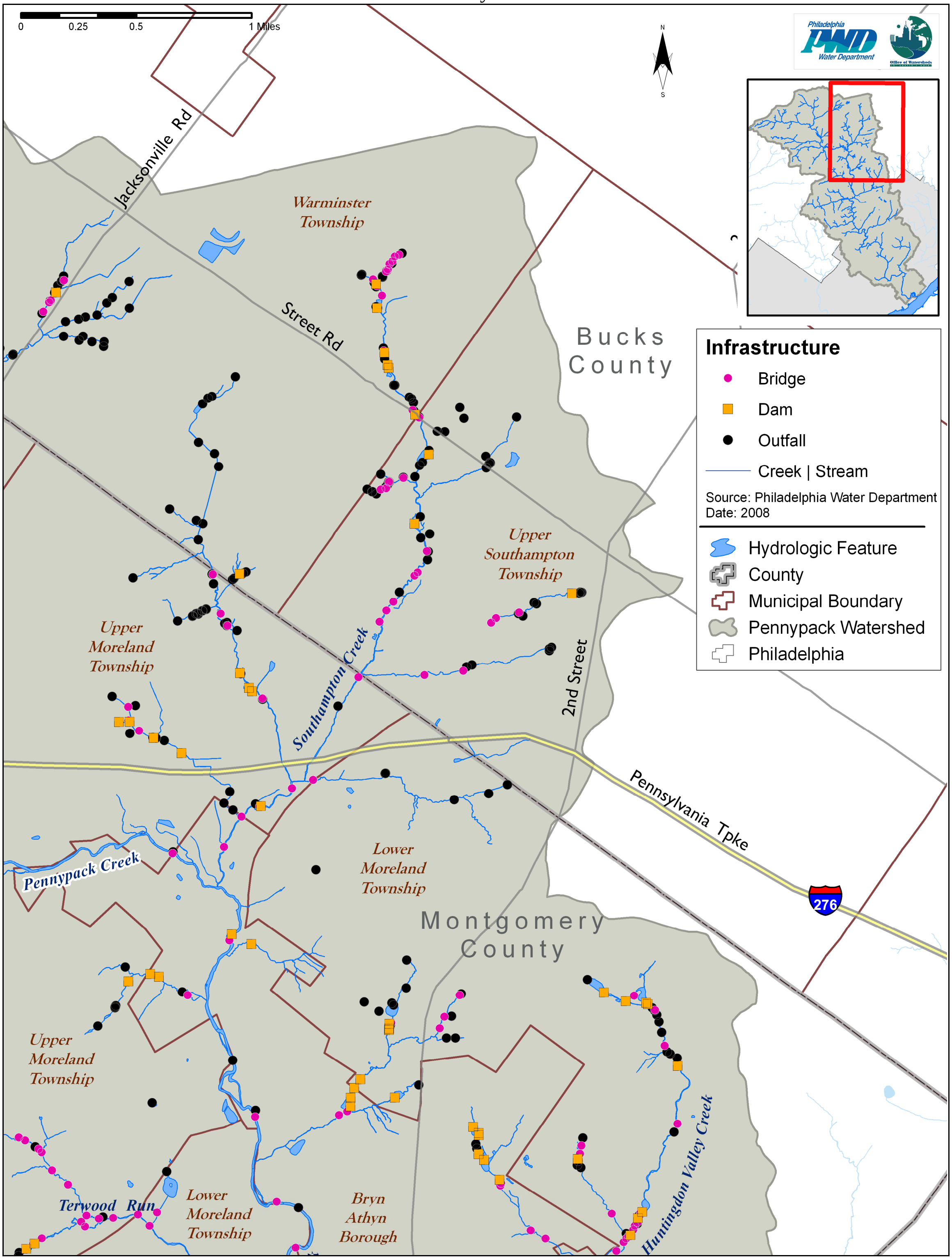


Figure 6.22 Infrastructure Locations in Pennypack Creek within Montgomery County and Bucks County, 2007

6.5.3.2 CULVERTS, BRIDGES, AND CHANNELIZATION

The infrastructure assessment in Montgomery County enumerated 289 bridges, 263 instances of channelization, and 293 culverts and encapsulated stream segments (Figures 6.19-6.22), while 35 bridges, 45 instances of channelization, and 30 culverts and encapsulated stream segments were inventoried in Bucks County (Figures 6.21). Bridges were much more numerous in Montgomery County than Philadelphia County, which can probably be attributed to physical factors (stream segments are generally smaller overall, much of the riparian land is privately owned rather than preserved as parkland, and gentler slopes facilitated development in closer proximity to stream channels).

6.5.3.3 DAMS

Numerous small dams were found along Pennypack Creek and its tributaries in Montgomery and Bucks Counties (n = 129 and 11, respectively) (Figures 6.19 through 6.22). Though most of these dams are small, some are large relative to the streams they obstruct. These dams are all run-of river dams which are not regulated to have flood storage capacity. Dams interrupt natural movement of fish and other aquatic life, while dam impoundments can increase water temperatures, eliminate natural pool-riffle-run bedforms, and cause increased deposition of sediment.

6.5.3.4 PONDS AND IMPOUNDMENTS

A large number of ponds and impoundments have been created in Pennypack Creek Watershed, primarily in Montgomery County portions of the watershed (Table 6.6, Figure 6.2). These ponds were typically created by damming up a small spring or stream, and constructing berm(s) to raise water surface elevation. Small manmade 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 research suggests that this heating effect may not directly impact receiving streams when ambient air temperatures are high.

Table 6.6 Man-Made Ponds in Pennypack Creek Watershed within Philadelphia, Bucks, and Montgomery Counties

County	Total Number of Ponds	Connected	Disconnected	Headwaters	Total Pond Area (acres)
Philadelphia	12	0	11	1	6.46
Bucks	8	2	6	0	8.14
Montgomery	107	35	51	21	62.81

6.6 PROBLEM SUMMARY

Pennypack Creek is an urbanized stream system that has been adversely affected by development and land use practices over the past century. Impervious cover is estimated at 28% of the watershed in total and 26% within the City of Philadelphia. Impervious cover, especially directly connected impervious cover, decreases groundwater recharge and the percent of annual streamflow represented by baseflow. Streams in the watershed are "flashy"– increases in streamflow and erosive forces occur quickly during storm events. Both maximum discharge and total runoff volume are increased compared to an undeveloped watershed.

Changes in hydrology have resulted in de-stabilization of much of the watershed. Urbanization promotes a cumulative, self-reinforcing pattern of streambank erosion. As stream channels become physically larger and further disconnected from their historic floodplains, more stormwater forces are restricted to the stream channel, where compromised, heavily eroded banks are least suited to dissipate them. These overwidened stream segments deficient in baseflow make very poor habitats for all but the most tolerant generalist species. Signs of habitat impairment were present in the watershed's biological communities; Pennypack Creek Watershed is nearly devoid of sensitive macroinvertebrates and fish taxa, while unstable stream banks have been extensively colonized by invasive species, especially Japanese knotweed (*Polygonum cuspidatum*).

Other habitat effects include widespread sedimentation in runs and pools as well as along channel and lateral bars. Many historic first order tributaries and wetlands within the watershed have been filled in and/or piped into storm sewers. Erosion has exposed, threatened, and in some cases, destroyed valuable infrastructure and private property. Unfortunately, traditional solutions for addressing erosion and flooding problems may increase instability overall, exacerbating problems they are intended to solve. Philadelphia's 2006 stormwater ordinance and the Pennypack Creek Watershed Integrated management Plan (PCWIWMP, 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.

7 EXISTING POLLUTANT LOADS, FACILITIES, AND MANAGEMENT PRACTICES

7.1 BASEFLOW LOADS

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

Estimates of concentrations and loads due to groundwater inflow to the creek were based on groundwater monitoring data available from PADEP (1998). Data from one monitoring point (DEP Groundwater Basin #77) in the vicinity of Pennypack Creek are shown in Table 7.1. Estimated pollutant loads were calculated as the product of mean annual baseflow (see Characterization of Hydrology section) and mean groundwater concentrations (Table 7.2).

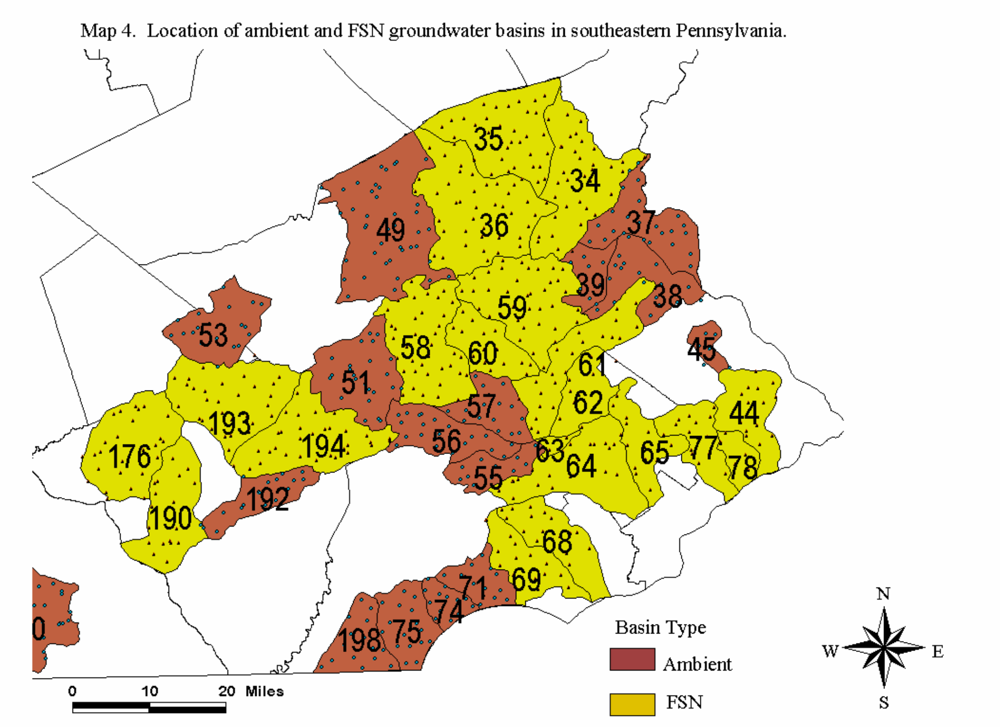


Figure 7.1 PADEP Groundwater Quality Monitoring Stations

Table 7.1 Summary of PADEP Groundwater Quality Monitoring Data

DEP Groundwater Basin	Monitoring Points	Samples	NH3 (mg/L as N)	NO2 (mg/L as N)	NO3 (mg/L as N)	TN* (mg/L as N)	TP (mg/L)	Cu (µg/L)	Total Fe (µg/L)	Pb (µg/L)	Zn (µg/L)
77	13	167	0.03	0.006	3.41	3.45	0.040	52	115	4	16

Notes: *Total Nitrogen (TN) is approximated as the sum of ammonia, nitrite, and nitrate.

Table 7.2 Estimated Loads due to Natural Baseflow

Parameter	Concentration	Concentration Units	Baseflow Load (lb/yr)			
			Philadelphia	Montgomery County	Bucks	Watershed
NH_3	0.03	mg/L as N	685	1,199	257	2,141
NO_2	0.006	mg/L as N	137	240	51	428
NO_3	3.41	mg/L as N	77,867	136,268	29,200	243,335
TN	3.446	mg/L as N	78,689	137,706	29,508	245,904
TP	0.04	mg/L	913	1,598	343	2,854
Cu	52	µg/L	1,187	2,078	445	3,711
Total Fe	115	µg/L	2,626	4,596	985	8,206
Pb	4	µg/L	91	160	34	285
Zn	16	µg/L	365	639	137	1,142

7.2 POINT SOURCES

The Pennypack Creek Watershed contains one large publicly owned wastewater treatment plant as well as three smaller "package" plants. Table 7.3 lists mean concentrations reported on discharge monitoring reports for each plant. Estimates of pollutants loads were obtained by multiplying representative discharges and flows at each plant and expressing results as mass per year. A summary by pollutants is provided in Table 7.4.

Table 7.3 Pollutant Load Estimates from Wastewater Treatment Plants

Service Area	Parameter	Load	Units	Mean Conc.	Unit	Period of Record
ABB Automation Inc.	Tetrachloroethylene	0.0681	lb/yr	0.000316	mg/L	Feb 2002 - April 2008
ABB Automation Inc.	Trichloroethylene	0.103	lb/yr	0.000378	mg/L	
Bryn Athyn	$CBOD_5$	404	lb/yr	3.09	mg/L	Feb 2006 - March 2008
Bryn Athyn	Ammonia	145	lb/yr	0.995	mg/L	
Bryn Athyn	CL	37.7	lb/yr	0.282	mg/L	
Bryn Athyn	TSS	725	lb/yr	5.68	mg/L	
Bryn Athyn	Copper	17.2	lb/yr	0.107	mg/L	
Bryn Athyn	Fecal Coliform	1.32E+12	Col/yr	27.8	Col/100mL	
Chapel Hill WWTP	$CBOD_5$	1807	lb/yr	4.14	mg/L	May 2006 - Feb 2008
Chapel Hill	Ammonia	531	lb/yr	0.602	mg/L	

WWTP						
Chapel Hill WWTP	Fecal Coliform	2.96E+12	col/yr	16.3	Col/100mL	
Chapel Hill WWTP	TSS	2,615	lb/yr	6.05	mg/L	
Chapel Hill WWTP	Copper	11.0	lb/yr	0.0260	mg/L	
Meadowbrook Apartments	$CBOD_5$	128	lb/yr	4.09	mg/L	Jan 2006 - Feb 2008
Meadowbrook Apartments	TSS	349	lb/yr	9.30	mg/L	
Meadowbrook Apartments	Ammonia	74.1	lb/yr	3.89	mg/L	
Meadowbrook Apartments	Fecal Coliform	3.2E+11	col/yr	21.9	Col/100mL	
Meadowbrook Apartments	CL	7.01	lb/yr	0.278	mg/L	
Upper Moreland Hatboro JSA	TSS	113110	lb/yr	6.28	mg/L	Jan 2005 - Dec 2007
Upper Moreland Hatboro JSA	Ammonia	3,994	lb/yr	0.222	mg/L	
Upper Moreland Hatboro JSA	Zinc	1,342	lb/yr	0.0745	mg/L	
Upper Moreland Hatboro JSA	$CBOD_5$	684,939	lb/yr	38.1	mg/L	
Upper Moreland Hatboro JSA	Copper	55,995	lb/yr	3.11	mg/L	
Upper Moreland Hatboro JSA	Fecal Coliform	2.20413E+11	col/yr	0.0183	Col/100mL	
Upper Moreland Hatboro JSA	Lead	631	lb/yr	0.035	mg/L	

Table 7.4 Summary of Yearly Wastewater Treatment Plant Loading

Parameter	Loading	Units
Tetrachloroethylene	0.0681	lb/yr
Trichloroethylene	0.103	lb/yr
CBOD	687277	lb/yr
Ammonia	4744	lb/yr
CL	44.7	lb/yr
TSS	116799	lb/yr
Copper	56024	lb/yr
Fecal Coliform	4.83E+12	Col/yr
Lead	631	lb/yr
Zinc	1342	lb/yr

Tables 7.5 through 7.10 contain detailed results of discharge monitoring report analyses by EPA

Table 7.5 Point Source TSS Concentrations

Parameter	Units	Service Area / Water User	Period of Record	Source	Limit	Count	Min	Mean	Max	Standard Deviation
TSS	mg/L	Bryn Athyn	Feb 2006 - March 2008	EPA	10	22	4	5.68	10	2.01
TSS	mg/L	Chapel Hill WWTP	May 2006 - Feb 2008	EPA	10	21	3	6.05	14	2.94
TSS	mg/L	Meadowbrook	Jan 2006 - Feb 2008	EPA	30	23	2	9.30	37	8.77
TSS	mg/L	Upper Moreland Hatboro JSA	Jan 2005 - Dec 2007	EPA	30	36	2	6.28	10	2.05

Table 7.6 Point Source $CBOD_5$ Concentrations

Period	Parameter	Units	Service Area / Water Users	Period of Record	Source	Limit	Count	Min	Mean	Max	Standard Deviation
5/1 to 10/31	$CBOD_5$	mg/L	Bryn Athyn	Feb 2006 - March 2008	EPA	10	8	2	3.13	8	2.03
1/1 to 4/30 and 11/1 to 12/31	$CBOD_5$	mg/L	Bryn Athyn	Feb 2006 - March 2008	EPA	20	14	2	3.07	5	0.997
5/1 to 10/31	$CBOD_5$	mg/L	Chapel Hill WWTP	May 2006 - Feb 2008	EPA	10	11	2	4.73	7	1.56
1/1 to 4/30 and 11/1 to 12/31	$CBOD_5$	mg/L	Chapel Hill WWTP	May 2006 - Feb 2008	EPA	20	10	2	3.50	6	1.27
1/1 to 12/31	$CBOD_5$	mg/L	Meadowbrook	Jan 2006 - Feb 2008	EPA	25	23	2	4.09	11	2.07
1/1 to 12/31	$CBOD_5$	mg/L	Upper Moreland Hatboro JSA	Jan 2005 - Dec 2007	EPA	25	36	1.5	2.75	15	2.19

Table 7.7 Point Source Fecal Coliform Concentrations

Parameters	Units	Service Area / Water User	Period of Record	Source	Limit	Count	Min	Mean	Max	Standard Deviation
Fecal Coliform	# Col /100mL	Bryn Athyn	Feb 2006 - March 2008	EPA	200	22	10	27.82	179	44.07
Fecal Coliform	# Col /100mL	Chapel Hill WWTP	May 2006 - Feb 2008	EPA	200	21	10	16.29	38	7.58
Fecal Coliform	# Col /100mL	Meadowbrook	Jan 2006 - Feb 2008	EPA	200	23	9	21.87	77	19.84
Fecal Coliform	# Col /100mL	Upper Moreland Hatboro JSA	Jan 2005 - Dec 2007	EPA	200	36	10	38.11	99	23.33

Table 7.8 Point Source Ammonia Concentrations

Period	Parameters	Units	Service Area / Water User	Period of Record	Source	Limit	Count	Min	Mean	Max	Standard Deviation
5/1 to 10/31	Ammonia	mg/L	Bryn Athyn	Feb 2006 - March 2008	EPA	3	8	0.2	1.2	3	1.2
1/1 to 4/30 and 11/1 to 12/31	Ammonia	mg/L	Bryn Athyn	Feb 2006 - March 2008	EPA	9	14	0.2	0.90	2.1	0.77
5/1 to 10/31	Ammonia	mg/L	Chapel Hill WWTP	May 2006 - Feb 2008	EPA	3	11	0.1	0.22	0.4	0.084
1/1 to 4/30 and 11/1 to 12/31	Ammonia	mg/L	Chapel Hill WWTP	May 2006 - Feb 2008	EPA	9	10	0.1	1.0	4	1.2
1/1 to 12/31	Ammonia	mg/L	Meadowbrook	Jan 2006 - Feb 2008	EPA	20	23	0.5	3.9	16.1	4.9
1/1 to 12/31	Ammonia	mg/L	Upper Moreland Hatboro JSA	Jan 2005 - Dec 2007	EPA	6	36	0.1	0.22	0.54	0.11

Table 7.9 Point Source Copper Concentrations

Parameters	Unit	Service Area / Water Users	Period of Record	Source	Limit	Count	Min	Mean	Max	Standard Deviation
Copper	mg/L	Bryn Athyn	Feb 2006 - March 2008	EPA	N/A	22	0.016	0.11	0.34	0.11
Copper	mg/L	Chapel Hill WWTP	May 2006 - Feb 2008	EPA	N/A	21	0.0056	0.026	0.063	0.016
Copper	mg/L	Upper Moreland Hatboro JSA	Jan 2005 - Dec 2007	EPA	N/A	36	0.028	0.035	0.047	0.010

Table 7.10 Point Source Lead Concentrations

Parameter	Units	Service Area / Water User	Period of Record	Source	Limit	Count	Min	Mean	Max	Standard Deviation
Lead	mg/L	Upper Moreland Hatboro JSA	Jan 2005 - Dec 2007	EPA	N/A	36	0.0050	0.011	0.050	0.0097

7.3 STORMWATER RUNOFF

Event Mean Concentrations

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

For the parameters TSS, BOD5, COD, TP (total phosphorus), TN (total nitrogen), total Cu, total Zn, total Fe and fecal coliform, a simple substitution method was used for values that fell below the detection limit. Half the detection limit was substituted for these values. For sites and events where total nitrogen was not reported, other reported nitrogen species were summed to determine TN. The possible combinations, in order of preference, are: (nitrite + nitrate) + TKN, (nitrite + nitrate) + ammonia + organic nitrogen, nitrite + nitrate + TKN, and nitrite + nitrate + ammonia + organic. All species were expressed as nitrogen equivalents.

In the NSQD, more than 15% of EMC estimates were below the detection limit for two parameters (total lead and cadmium) (Table 7.11). EPA (2006) recommends using a simple substitution method when less than 15% of samples are below detection. However, when more then 15% of samples are reported as below the detection limit, a more detailed statistical analysis is recommended. This rule of thumb often is applied to individual water quality samples, and in this study it is assumed to apply to flow weighted EMC estimates based on several samples.

Table 7.11 Station-Storms with Below-Detection Values in NSQD

Pollutant	Total No. of Observations	No. of Observations Below Detection Limit	% Below Detection Limit
TSS	3462	42	1.21
BOD5	3096	109	3.52
COD	2750	44	1.60
TP	3269	99	3.03
Cu	2713	334	12.3
Zn	2991	87	2.91
Fe	48	0	0.00
Fecal Coliform	1611	57	3.54
TN	558	37	6.63
Pb	2852	562	19.7
Cd	2392	1346	56.3

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

In Figures 7.2 through 7.4, results are shown for regression of natural log of total lead versus standard normal statistic. The results suggest that the lognormal model may not be an ideal fit for the above-detection values. However, the MR method should still reduce bias compared to a simple substitution method. Similar results were found for total cadmium.

<u>Regression Results</u>
ln Total Lead = 2.860 + 1.307 X
ln Total Cadmium = -1.755 + 1.932 X
where X = standard normal statistic corresponding to plotting position

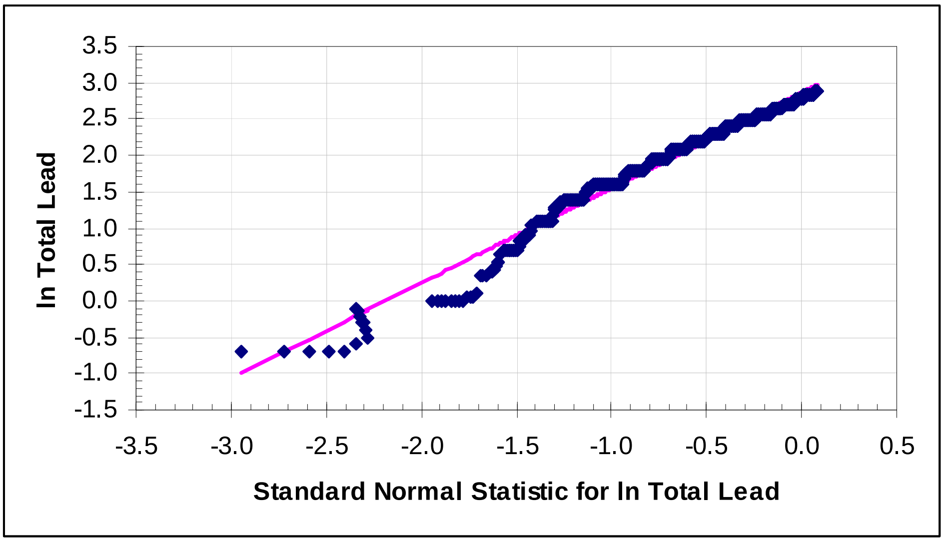


Figure 7.2 Linear Regression Results for Total Lead

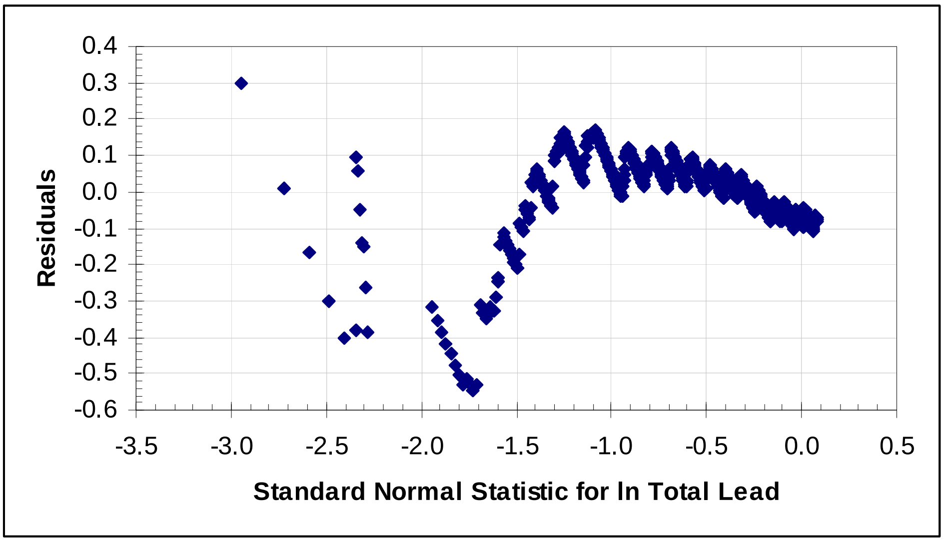


Figure 7.3 Linear Regression Residual Plot for Total Lead

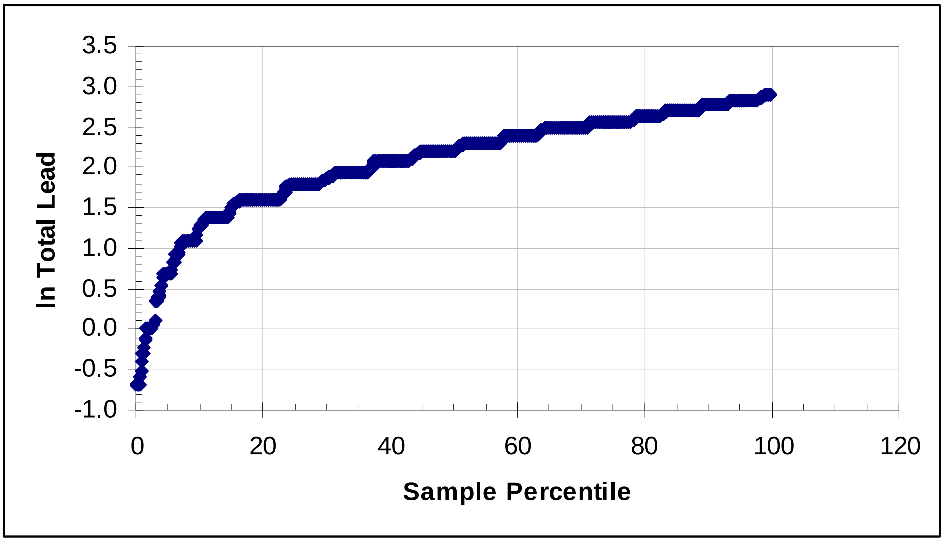


Figure 7.4 Normal Probability Plot for Total Lead

Land uses in the NSQD were grouped into three broader categories. Lands that were coded as residential, institutional, commercial, and industrial were combined into a single group. Urban open spaces were assigned to a group, and freeways were assigned to a group. Pooled EMCs represented all urban land uses were also calculated for comparison to earlier studies. Table 7.12 summarizes the EMCs chosen for the study. Because EMCs are lognormally distributed, median values were used for stormwater load estimates.

Table 7.12 Event Mean Concentrations based on NSQD

Parameter	Units	Land Use	Mean	Median	CV	n
TSS	(mg/L)	R/C/I	125	61	1.63	2176
TSS	(mg/L)	Transportation	172	99	2.60	134
TSS	(mg/L)	Urban Open	186	85	1.91	48
TSS	(mg/L)	Pooled	132	64	1.74	2600
BOD5	(mg/L)	R/C/I	20	9.25	7.93	1909
BOD5	(mg/L)	Transportation	15	8	1.26	22
BOD5	(mg/L)	Urban Open	7	4.75	1.24	40
BOD5	(mg/L)	Pooled	19	9	7.71	2190
COD	(mg/L)	R/C/I	88	59	1.07	1681
COD	(mg/L)	Transportation	139	100	1.07	67
COD	(mg/L)	Urban Open	26	20	0.99	45
COD	(mg/L)	Pooled	87	57	1.12	2023
TP	(mg/L)	R/C/I	0.44	0.29	1.34	2027
TP	(mg/L)	Transportation	0.43	0.25	1.77	128
TP	(mg/L)	Urban Open	0.37	0.20	1.32	48
TP	(mg/L)	Pooled	0.43	0.28	1.35	2447
Total Cu	(µg/L)	R/C/I	32	15.7	2.40	1764
Total Cu	(µg/L)	Transportation	48	33.4	0.96	97
Total Cu	((µg/L)	Urban Open	11	8	1.15	51
Total Cu	(µg/L)	Pooled	31	15	2.30	2103
Total Zn	(µg/L)	R/C/I	268	125	3.41	1838
Total Zn	(µg/L)	Transportation	272	194	1.03	93
Total Zn	(µg/L)	Urban Open	89	45	1.66	49
Total Zn	(µg/L)	Pooled	253	120	3.32	2221
Total Fe	(µg/L)	R/C/I	3293	1575	1.80	14
Total Fe	(µg/L)	Transportation	5097	4000	1.09	27
Total Fe	(µg/L)	Urban Open				
Total Fe	(µg/L)	Pooled	4481	2300	1.27	41
Fecal Coliform	(/100mL)	R/C/I	52653	6700	4.47	1035
Fecal Coliform	(/100mL)	Transportation	7530	1700	1.95	49
Fecal Coliform	(/100mL)	Urban Open	29854	3400	2.52	33
Fecal Coliform	(/100mL)	Pooled	47990	5700	4.50	1274
TN	(mg/L)	R/C/I	2.90	1.88	2.03	277
TN	(mg/L)	Transportation				
TN	(mg/L)	Urban Open	1.70	1.56	0.68	6
TN	(mg/L)	Pooled	2.75	1.82	1.96	339
Total Pb	(µg/L)	R/C/I	45.3	20.0	1.74	1429
Total Pb	(µg/L)	Transportation	48.8	25.0	1.45	107
Total Pb	(µg/L)	Urban Open	37.7	8.0	2.24	31
Total Pb	(µg/L)	Pooled	38.5	16.0	1.86	2111
Cd	(µg/L)	R/C/I	4.14	1.00	380	692
Cd	(µg/L)	transportation	1.43	1.00	90.0	68.0
Cd	(µg/L)	urban open	2.29	2.00	76.8	10.0

Cd	(µg/L)	pooled	1.84	0.370	534	1863

Load Calculations:

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

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

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

For the purposes of this weighted-EMC estimation, Pooled EMCs were applied to all impervious areas.

Pollutant loads due to stormwater runoff were estimated using an event mean concentration (EMC) approach. EMCs are defined as the total mass load of chemical parameter yielded from a site during a storm divided by the total runoff water volume discharged from the site during the storm.

An average annual runoff volume was estimated for each subshed using a computer model as described in the Characterization of Hydrology section.

A Pollutant load is calculated for each water quality parameter.

Load = EMC x runoff

Where:

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

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

Table 7.13 Philadelphia Runoff Load Summary

Parameter	Total Stormwater Load	
	(lb/yr)	(lb/ac/yr)
BOD5	214,790	28.1
TSS	1,017,919	133
COD	834,881	109
TP	4,837	0.633
Cu	207	0.0271
Zn	2,409	0.315
Fe	42,958	5.62
TN	37,411	4.89
Fecal *	4.84E+14	6.33E+10
Pb	947	0.124
Cd	6.91	0.000904

* Fecal Coliform in units of #/yr and #/acre/yr

The loads within Table 7.15 were calculated by using the drainage area and runoff calculated at USGS gage 01467042.

Table 7.14 Bucks and Montgomery Runoff Load Summary

Parameter	Pooled Stormwater Loads	
	(lb/yr)	(lb/ac/yr)
BOD5	235,345	9.70
TSS	1,115,332	46.0
COD	914,777	37.7
TP	5,300	0.219
Total Cu	227	0.00937
Total Zn	2,640	0.109
Total Fe	47,069	1.94
Fecal*	5.30E+16	2.19E+12
TN	40,991	1.69
Pb	1,038	0.0428
Cd	8	0.000312

* Fecal Coliform in units of #/yr and #/acre/yr

7.4 ILLICIT DISCHARGES

Illicit discharges of wastewater into water bodies include dry weather sanitary sewer discharges, wet weather sanitary sewer overflows, and improper connection of sanitary sewer laterals from homes to storm sewer. Discharges directly from sanitary sewers were not quantified for this study. Loads from improper connections were estimated based on information submitted by PWD to PADEP covering illicit connection detection and abatement through March, 2008. PWD is required to submit a quarterly report under its NPDES Phase I stormwater permit. Within Table 7.16 the total number of connections that were tested are shown as well as the total number of improper connections that have been found. The improper connection rate is the ratio of improper connections to total connections that were tested.The results (Table 7.16) suggest that improper connection rate in the Pennypack Creek Watershed is similar to the city as a whole and is approximately 45,844 households.

Table 7.15 PWD Illicit Connection Detection

Watershed	Outfalls	Connections Tested	Improper Connections	Improper Connection Rate
Tacony-Frankford	T-088-01	2828	130	4.60%
Manayunk Canal	S-051-06, S-058-01, S-059-01 through S-059-11	2444	59	2.41%
Wissahickon (Monoshone)	W-060-04, W-060-08, W-060-09, W-060-10, W-060-11, W-068-04, W-068-05	2739	92	3.36%
Wissahickon	W-060-01	611	16	2.62%
Pennypack	P-091-02 and P-105-06	53	2	3.77%
City-Wide		33561	945	2.82%

For planning purposes, loads from improper connections were estimated using the following assumptions:

- households in the Philadelphia portion of Pennypack Creek Watershed (2000 U.S. Census):
- households with improper lateral connections: 4% (45,844)
- average of 2.5 people per household
- 50 gallons per person per day discharged to storm sewer
- Sanitary sewage pollutant concentrations as shown in Table 7.17

Table 7.16 Sanitary Sewer Pollutant Concentrations and Illicit Discharge Loads (Philadelphia)

Parameter	Sanitary Concentration	Concentration Units	Source	Estimated Load	Load Units
BOD_5	211.00	mg/L	PWD dry weather combined sewer sampling	1,950,851	lb/yr
TSS	187.00	mg/L	PWD dry weather combined sewer sampling	1,728,953	lb/yr
COD	446.75	mg/L	PWD dry weather combined sewer sampling	4,130,534	lb/yr
TN	23.31	mg/L	PWD dry weather combined sewer sampling	215,518	lb/yr
TP	3.37	mg/L	PWD dry weather combined sewer sampling	31,112	lb/yr
Cu	0.12	mg/L	PWD dry weather combined sewer sampling	1,114	lb/yr
Pb	0.02	mg/L	PWD dry weather combined sewer sampling	215	lb/yr
Zn	0.26	mg/L	PWD dry weather combined sewer sampling	2,427	lb/yr
Fe	300	µg/L	Metcalf and Eddy, 1979	2,773.7	lb/yr
Fecal Coliform	6.35E+06	/100 mL	PWD dry weather combined sewer sampling	2.66E+17	/yr

Table 7.17 Estimated Illicit Discharge Loads (Montgomery County)

Parameter	Sanitary Concentration	Concentration Units	Source	Estimated Load	Load Units
BOD_5	211.00	mg/L	PWD dry weather combined sewer sampling	964,270	lb/yr
TSS	187.00	mg/L	PWD dry weather combined sewer sampling	854,590	lb/yr
COD	446.75	mg/L	PWD dry weather combined sewer sampling	2,041,648	lb/yr
TN	23.31	mg/L	PWD dry weather combined sewer sampling	106,527	lb/yr
TP	3.37	mg/L	PWD dry weather combined sewer sampling	15,378	lb/yr
Cu	0.12	mg/L	PWD dry weather combined sewer sampling	551	lb/yr
Pb	0.02	mg/L	PWD dry weather combined sewer sampling	106	lb/yr
Zn	0.26	mg/L	PWD dry weather combined sewer sampling	1,200	lb/yr
Fe	300	µg/L	Metcalf and Eddy, 1979	1,371.0	lb/yr
Fecal Coliform	6.35E+06	/100 mL	PWD dry weather combined sewer sampling	1.32E+17	/yr

Table 7.18 Estimated Illicit Discharge Loads (Bucks County)

Parameter	Sanitary Concentration	Concentration Units	Source	Estimated Load	Load Units
BOD_5	211.00	mg/L	PWD dry weather combined sewer sampling	768,276	lb/yr
TSS	187.00	mg/L	PWD dry weather combined sewer sampling	680,889	lb/yr
COD	446.75	mg/L	PWD dry weather combined sewer sampling	1,626,669	lb/yr
TN	23.31	mg/L	PWD dry weather combined sewer sampling	84,874	lb/yr
TP	3.37	mg/L	PWD dry weather combined sewer sampling	12,252	lb/yr
Cu	0.12	mg/L	PWD dry weather combined sewer sampling	439	lb/yr
Pb	0.02	mg/L	PWD dry weather combined sewer sampling	85	lb/yr
Zn	0.26	mg/L	PWD dry weather combined sewer sampling	956	lb/yr
Fe	300	µg/L	Metcalf and Eddy, 1979	1,092.3	lb/yr
Fecal Coliform	6.35E+06	/100 mL	PWD dry weather combined sewer sampling	1.05E+17	/yr

7.5 ON-LOT DISPOSAL (SEPTIC TANKS)

No information could be found on septic tank recharge into the groundwater within the Pennypack Creek Watershed; if any recharge is occurring it is likely to be insignificant compared with other water quality load components.

7.6 STREAM CHANNEL EROSION

A study on stream channel erosion was completed for the tributary of Southhampton Creek but was not completed for the main stream of Pennypack Creek.