PENNYPACK CREEK STREAM ASSESSMENT REPORT
LOWER PENNYPACK WATERSHED

Philadelphia Water Department

Office of Watersheds 2013

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EXECUTIVE SUMMARY

The purpose of the Pennypack Creek Watershed Stream Assessment Report was to provide the Philadelphia Water Department (PWD), local watershed partnership groups, and other interested parties with an analysis and summary of the existing physical conditions within the subwatersheds of Pennypack Creek Watershed inclusive of both stream networks and riparian corridors. Specifically, the goals of this assessment were to provide:

- a characterization and documentation of existing conditions
- a reference point for evaluating changes over time
- a tool for prioritizing stream and habitat restoration sites
- insight into appropriate restoration strategies
- a land use planning and redevelopment tool
- an aid in determining the effects of urbanization

With the insight gained from this assessment, it will be possible to strategically plan and coordinate restoration activities throughout the watershed as well as within individual subwatersheds. The ultimate goals of these restoration efforts will include: improving water quality, managing or replanting riparian vegetation, enhancing in-stream habitat, providing increased fish passage and finally, facilitating stream bank stabilization.

The Pennypack Creek Watershed Stream Assessment consisted of an evaluation of approximately 124 miles of stream channel within the 55.8 square mile watershed. The assessment involved walking the entire length of main stem Pennypack Creek and 13 of its tributaries**,** to record specific information about the channel, surrounding habitat, and infrastructure located in or near the creeks. A suite of field surveys and desktop analyses to summarize watershed, stream, and riparian conditions in the Pennypack Creek Watershed was conducted. Existing GIS resources were used to identify the land use, geology, and soil types present within each subwatershed. Field surveys were focused on the characterization of channel morphology and in-stream hydraulics through the use of surveyed cross section data and substrate particle size distribution. The Unified Stream Assessment Method (USAM) was applied to quantitatively rate the overall stream and riparian condition of each reach.

For the purposes of this report, PWD focused its analysis on the 17.5 square mile portion of the Pennypack Creek Watershed located within the political boundaries of the City of Philadelphia. This area included 27.3 miles of stream, which included 5 major tributaries (Darlington Run (aka Ballard Brook), Paul's Run, Sedden's Creek, Sandyford Run, Wooden Bridge Run), and the main stem of Pennypack Creek.

The Lower Pennypack study area is 42% impervious, and is dominated by Residential (50%), Recreation/Parkland (15%), and Commercial/Industrial (13%). The infrastructure trackdown identified and assessed all observed bridges, culverts, channelized segments, dams, manholes, outfalls, and pipes/sewers within the stream corridor. The Lower Pennypack Creek infrastructure assessment recorded 802 infrastructure elements, of which 74 (9%) were identified as priority infrastructure in poor condition. Evaluation of each subwatershed's and the total Lower Pennypack Creek Watershed infrastructure is included in the Watershed Assessment and Summary sections of this report.

On average, the Lower Pennypack Watershed stream corridor was rated in the 'Sub-Optimal' category (98/160). The average Stream Condition score was 'Sub-Optimal' (49/80) and the Riparian Buffer/Floodplain score was also 'Sub-Optimal' (48/80). The average Main Stem Stream Condition score was 'Optimal' (61/80) and the Riparian Buffer/Floodplain score was 'Sub-Optimal' (54/80). The average Tributary Stream Condition score was 'Marginal' (38/80) and the Riparian Buffer/Floodplain score was 'Sub-Optimal' (43/80). In comparison to the tributary reaches, the main stem reaches tended to rate higher than the Tributary reaches due to Fairmount Park and the riparian buffer that is present and provides the stream with stability and improves habitat and quality of the ecosystem as a whole. The Pennypack Creek Main Stem scored higher than the tributaries in several categories of the USAM assessment such as in-stream habitat, vegetative protection, and bank erosion. Scores for floodplain connection and floodplain habitat were much higher than the tributary scores and a correlation can be made between these scores and the scores for the other categories. This exemplifies the significant impact that a large, healthy riparian buffer or lack thereof can have on the stream corridor's overall condition.

1 INTRODUCTION

1.1 PROJECT PURPOSE

The purpose of the Pennypack Creek Watershed Stream Assessment Report was to provide the Philadelphia Water Department (PWD), local watershed partnership groups, and other interested parties with an analysis and summary of the existing physical conditions within the subwatersheds of the Pennypack Creek Watershed inclusive of both stream networks and riparian corridors. Specifically, the goals of this assessment were to provide:

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1.1.1 REPORT STRUCTURE

Each watershed section has been written to be a standalone document. The methodologies described in the beginning of the report apply to all the data collection and processing techniques mentioned in each of the watershed assessments.

1.2 PROJECT DESCRIPTION

The Pennypack Creek Watershed Stream Assessment consisted of an evaluation of approximately 124 miles of stream channel within the 55.8 square mile watershed by members of the Philadelphia Water Department's Office of Watersheds (PWDOOW) in 2005, with a resurvey of Sandyford Run[1] in spring 2010. The assessment involved walking the entire length of main stem Pennypack Creek and 13 of its tributaries **(**Figure 1-1**),** to record specific information about the channel, surrounding habitat, and infrastructure located in or near the creeks.

[1] The stream examined in this study is referred to in some literature as Sandyford Run and in other sources as Sandy Run. In this report, the names will be used interchangeably, with an emphasis on Sandyford Run to avoid confusion with streams in other Philadelphia watersheds that are also called Sandy Run.

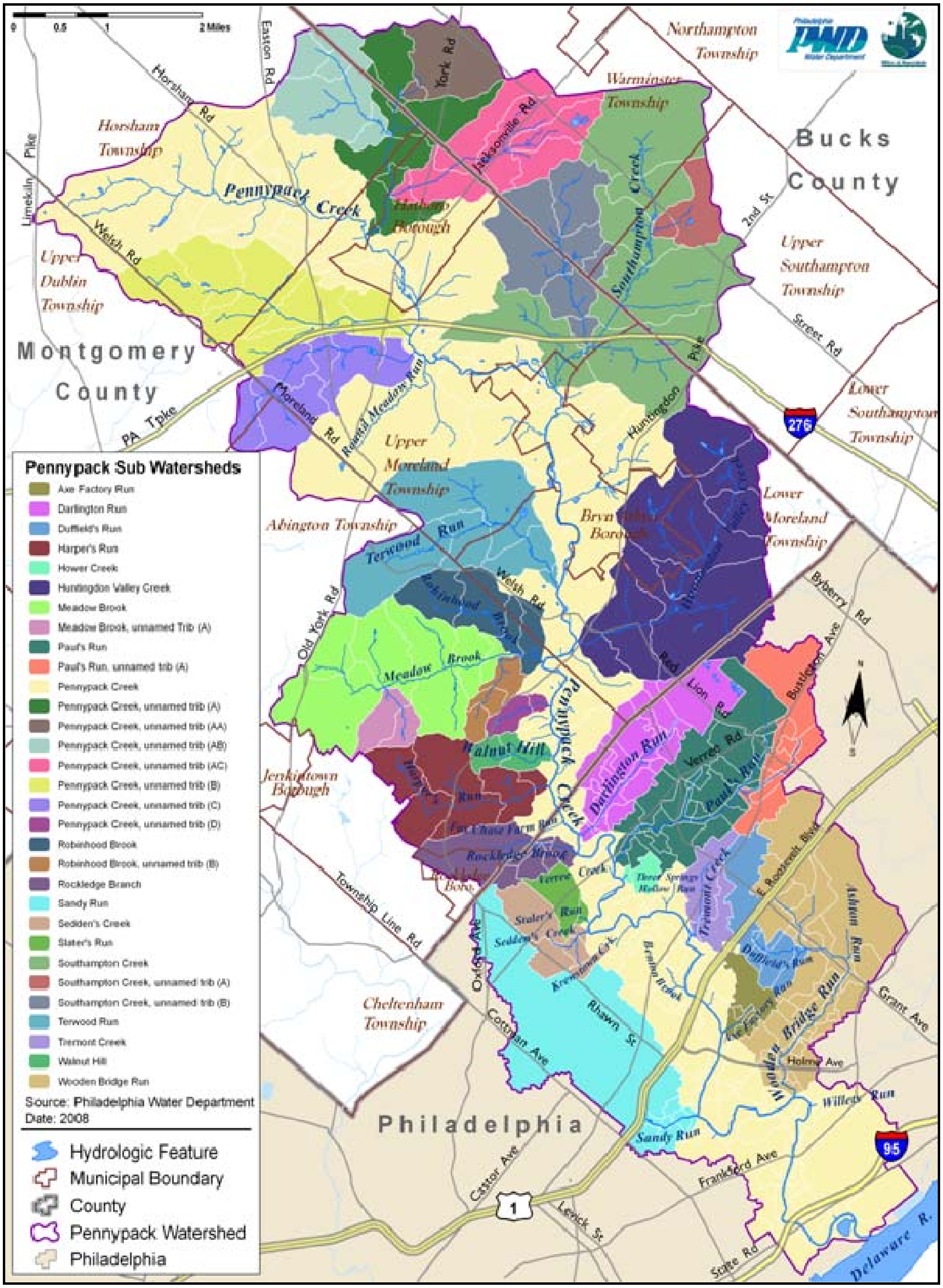


Figure 1-1: Pennypack Creek Watershed

Source: Philadelphia Water Department. 2009. Pennypack Creek Watershed Comprehensive Characterization Report.

PWD completed a suite of field surveys and desktop analyses to summarize existing stream and riparian conditions in the Pennypack Creek Watershed. Field surveys were focused on the characterization of channel morphology and in-stream hydraulics through the use of surveyed cross section data and substrate particle size distribution. The physical processes that determine channel morphology, in-stream hydraulics, channel slope and sediment load are dependent on the physical conditions within the respective sub-catchments that drain into the Pennypack Creek stream network. Factors that influence these conditions include valley slope, land use and local geology as well as the potential impacts of infrastructure. Thus, to thoroughly characterize in-stream conditions, it was necessary to examine the physical conditions within respective subwatershed stream corridors as well (Figure 1-2).

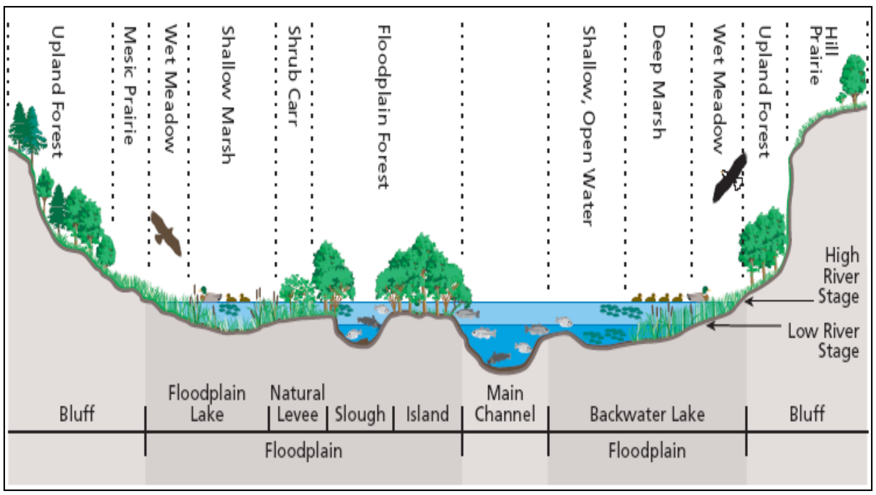


Figure 1-2: Generalized Cross Section of a Stream Corridor

*adapted from Sparks, Richard E. Bioscience, vol. 45, p. 170, March 1995.

Conceptually, stream corridors are extended watershed cross sections consisting of three main components, which are the stream channel, floodplain and an upland transitional zone or terrace. The stream channel lies at the lowest elevation of this system and conveys water at least part of the year. The floodplain exists on one or both sides of the channel and is inundated by floodwaters at an interval determined by the regional hydrologic regime. The transitional upland portion of the river corridor exists on one or both sides of the floodplain and serves as the transition between the floodplain and the surrounding landscape (FISRWG 1998). These three components are dynamically linked through the transport and storage of water, nutrients and sediment, such that alterations to one component will over time influence another component. An example of this process is evident in the change in hydraulic, hydrologic, and sediment regimes of watersheds that undergo urbanization or have changes in land use.

Land cover is intrinsically linked to a watershed's hydrologic regime through the conversion of precipitation to runoff. As a watershed is converted from a natural, forested land cover to a more impervious and urbanized land cover, runoff increases and concomitantly increases the volume of water transported or stored by the stream channel and floodplain (Figure 1-3).

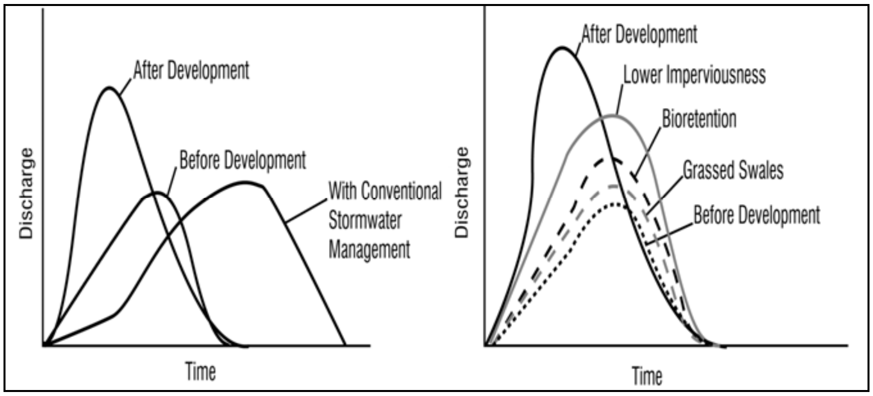


Figure 1-3: Comparison of Volume and Duration of Stormwater Runoff Before and After Land Development, and Reductions in Runoff from BMPs

*Source: Prince George's County Department of Environmental Resources et. al. (undated)

1.3 WATERSHED DESCRIPTION

The Pennypack Creek Watershed encompasses 55.8 square miles of drainage area in Southeastern Pennsylvania. With headwaters originating in Montgomery County, the creek travels about 25 miles until it reaches the Delaware River in Philadelphia. About 30% of the Pennypack is within the city of Philadelphia and over half of the watershed is outside city limits. About 57% is in Montgomery County and about 12% is in Bucks County. The Pennypack drains eleven municipalities and runs through a variety of highly developed urban and suburban communities (Table 1-1). Numerous tributaries converge into the main stem Pennypack Creek, with the entire stream network comprising approximately 124 miles (Table 1-2).

Table 1-1: Municipalities with Contributing Drainage Area to the 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%**

Source: Philadelphia Water Department. 2009. Pennypack Creek Watershed Comprehensive Characterization Report.

Table 1-2: Stream Lengths for Pennypack Creek Main Stem and Tributaries

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

Source: Philadelphia Water Department. 2009. Pennypack Creek Watershed Comprehensive Characterization Report.

1.4 LAND USE

Land use information for the Pennypack Creek Watershed (Figure 1-4) was obtained from the Delaware Valley Regional Planning Commission (DVRPC) 2000 land use data. Until the 20th century, most of the upper basin was dominated by agriculture, while the lower part of the basin saw an abundance of private and commercial mills throughout the 17th to 19th centuries. Though it was one of the last watersheds in Philadelphia to be developed, the Pennypack Creek Watershed has experienced continual and extensive urban and suburban development over time. Today, the watershed is characterized by a mixture of various land uses. A majority (about 52%) of the area of the Pennypack's land area is residential, with single family homes comprising the predominant land use at 40.54% and with 10.6% of the total area being multi-family homes (Table 1-3). The development in the Pennypack (residential, commercial, and industrial) closely follows the major arterial train and motor vehicle corridors that transect the watershed.

Nearly 15% of the Pennypack is wooded area and has been maintained as such by the long-term preservation efforts of the Fairmount Park Commission (now the Philadelphia Department of Parks and Recreation) and other organizations. It is particularly notable that a large portion of the riparian corridor of the Pennypack Main Stem and its tributaries has remained forested, making up the Pennypack Greenway. Large tracts of privately owned, undeveloped open space throughout the watershed present opportunities for future preservation efforts in this basin.

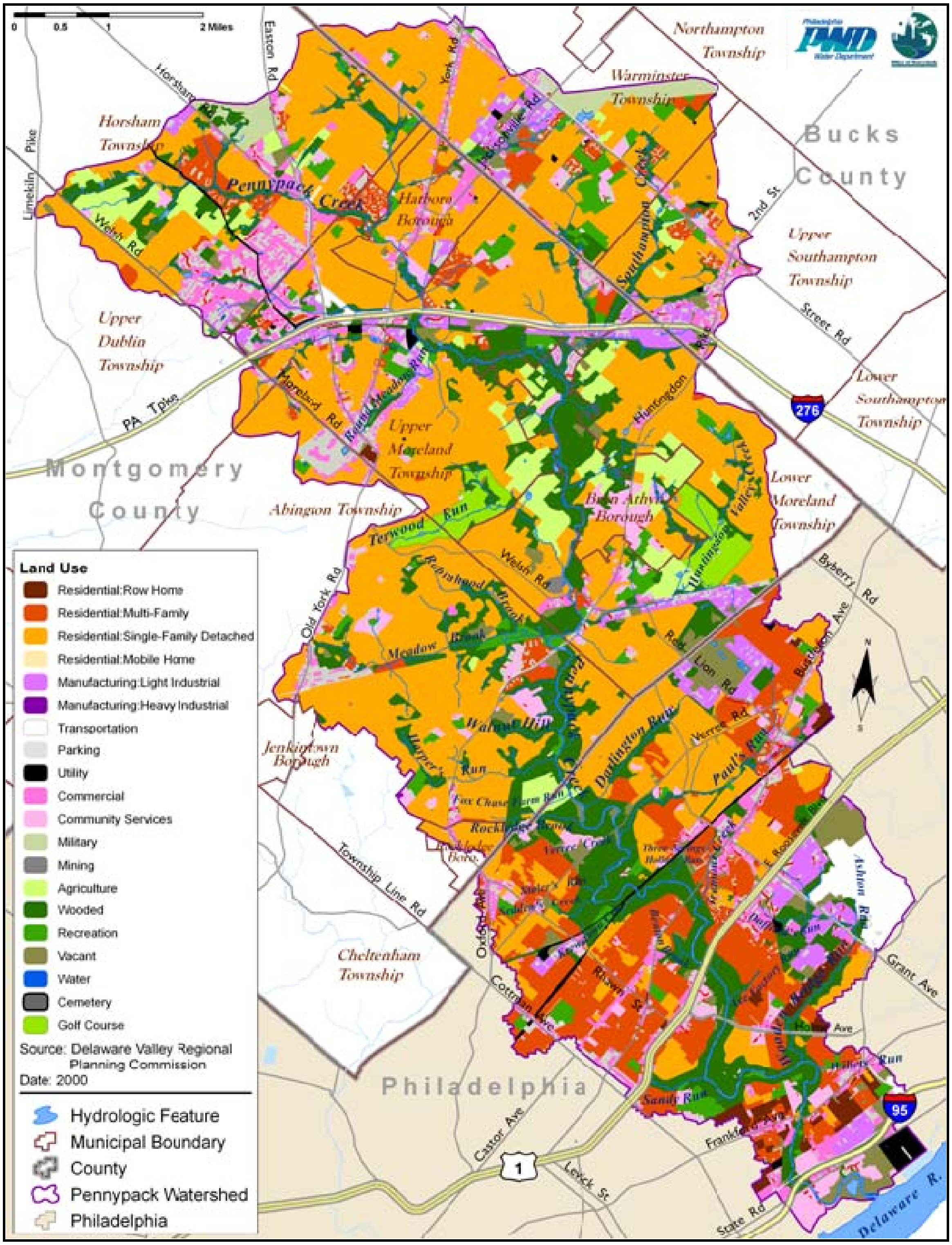


Figure 1-4: Pennypack Creek Watershed Land Use

Source: Philadelphia Water Department. 2009. Pennypack Creek Watershed Comprehensive Characterization Report.

Table 1-3: Land Use within the Pennypack Watershed

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.

1.5 GEOLOGY AND SOILS

1.5.1 PENNYPACK CREEK GEOLOGY

Geology and soils play a significant role in the hydrology, water quality, and ecology of a watershed. The northern portion of the Pennypack Creek Watershed is located within the Gettysburg-Newark Lowlands, underlain by various clastic sedimentary rocks. The middle portion of the watershed is within the Piedmont Upland physiographic region, with a small area of the Piedmont Lowlands intruding into the basin, which is underlain by a variety of sedimentary, metamorphic and igneous rocks (Philadelphia Water Department, Fairmount Park Commission, Montgomery County Planning Commission and Pennsylvania Department of Conservation and Natural Resources, 2005). The southern portion of the watershed is located in the Lowland and Intermediate Upland of the Atlantic Coastal Plain, underlain by various metamorphic rocks. As one moves from north to south in the watershed through each of the physiographic regions, changes in the underlying geology are reflected in corresponding changes in topography, surface geology, and soils. The bedrock and surface geology are described in detail in the tables that follow and shown in their spatial context in Figure 1-5, and Figure 1-6. A description of the geologic formations present throughout the Pennypack Creek Watershed is presented in Table 1-4.

Table 1-4: Generalized Descriptions of Geologic Formations 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.

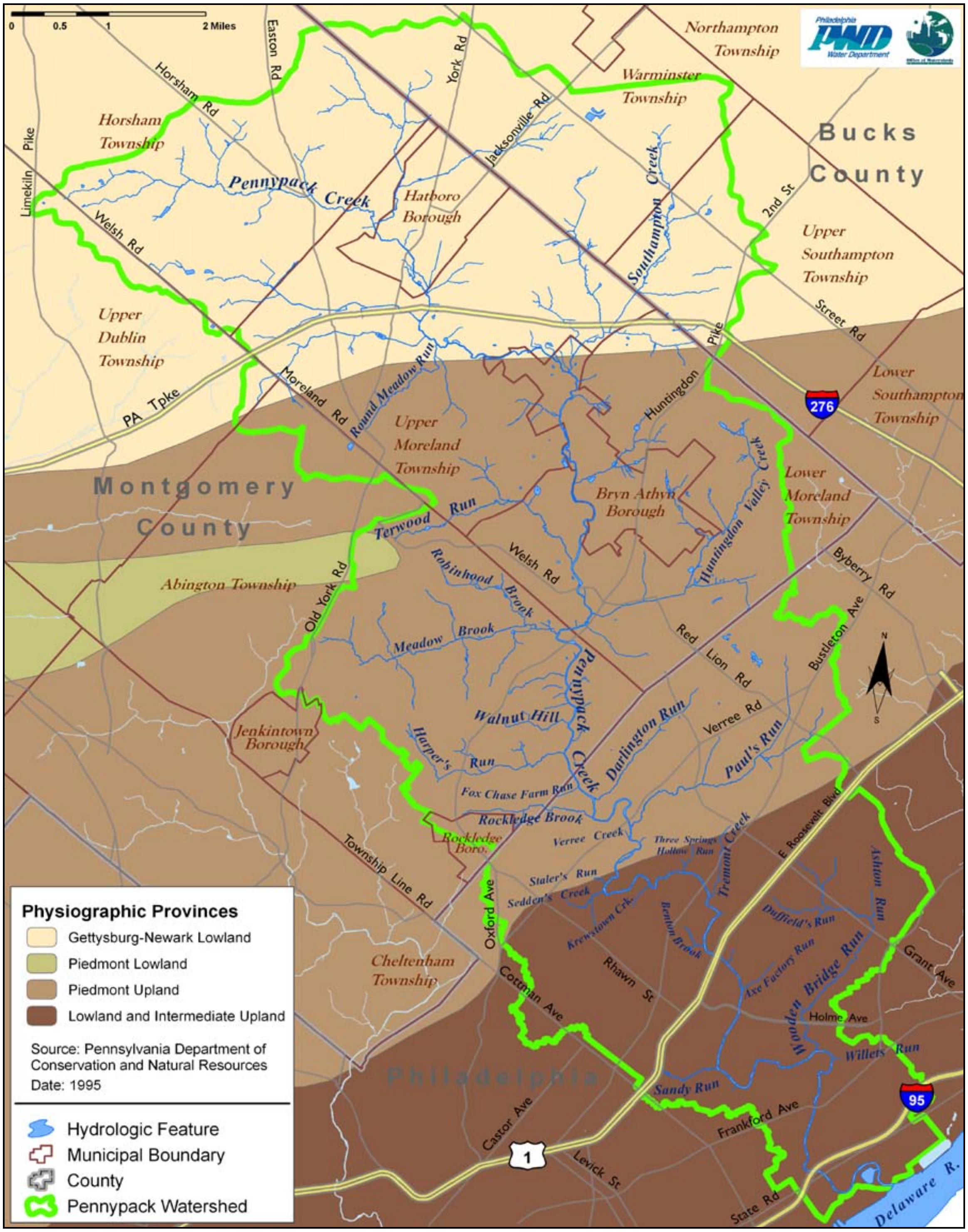


Figure 1-5: Pennypack Creek Watershed Physiographic Provinces

Source: Philadelphia Water Department. 2009. Pennypack Creek Watershed Comprehensive Characterization Report.

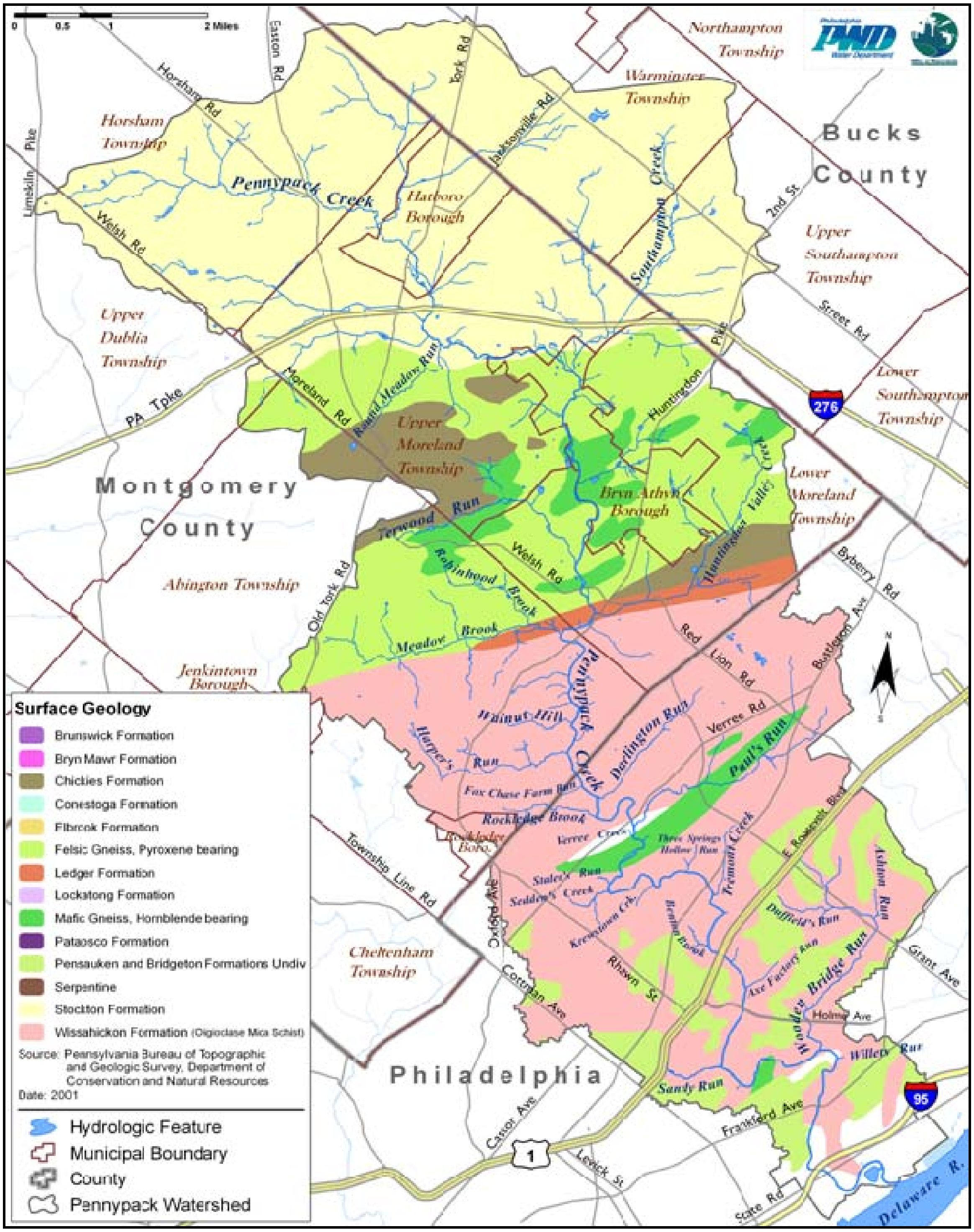


Figure 1-6: Pennypack Creek Watershed Geology

Source: Philadelphia Water Department. 2009. Pennypack Creek Watershed Comprehensive Characterization Report.

Table 1-5: Pennypack Creek Watershed Geology Description

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

1.5.2 PENNYPACK CREEK WATERSHED SOILS

Soils in the United States have been assigned to Hydrologic Soil Groups (HSG). The assigned groups are listed in Natural Resources Conservation Service (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. 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. The average infiltration rates for these soil groups are shown in Table 1-6.

Figure 1-7 shows the hydrologic soil groups in the study area. The map indicates that aside from the vast urban land cover; most of the watershed contains soil in the hydrologic category B, with some upstream areas shown as category C and areas immediately adjacent to stream channels classified as D. This indicates that much of the soils in the Pennypack have moderate to high infiltration rates when saturated (and therefore moderate to low runoff potential) and that water movement through these soils is 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 developed areas to maintain predevelopment or natural infiltration rates.

Table 1-6: NRCS Soil Group Characteristics

Hydrologic Soil Group	Average Infiltration Rates (in/hr)
A	1.00 - 8.3
B	0.50 -1.00
C	0.17 - 0.27
D	0.02 - 0.10

Source: United States Department of Agriculture, Natural Resources Conservation Service. 2006. Field Indicators of Hydric Soils in the United States, Version 6.0

Soils in hydrologic group A have low runoff potential. These soils have a high rate of infiltration when thoroughly wet. The depth to any restrictive layer is greater than 100 centimeters (40 inches) and to a permanent water table is deeper than 150 centimeters (5 feet).

Soils that have a moderate rate of infiltration when thoroughly wet are in hydrologic group B. Water movement through these soils is moderately rapid. The depth to any restrictive layer is greater than 50 centimeters (20 inches) and to a permanent water table is deeper than 60 centimeters (2 feet).

Hydrologic group C soils have a slow rate of infiltration when thoroughly wet. Water movement through these soils is moderate or moderately slow; they generally have a restrictive layer that impedes the downward movement of water. The depth to the restrictive layer is greater than 50 centimeters (20 inches) and to a permanent water table is deeper than 60 centimeters (2 feet).

Soils in hydrologic group D have a high runoff potential. These soils have a very slow infiltration rate when thoroughly wet. Water movement through the soil is slow or very slow. A restrictive layer of nearly impervious material may be within 50 centimeters (20 inches) of the soil surface and the depth to the permanent water table is shallower than 60 centimeters (2 feet). Dual Hydrologic Soil Groups (A/D, B/D, and C/D) are given for certain wet soils that could be adequately drained. The first letter applies to the drained and the second to the undrained condition. Soils are assigned to dual groups if the depth to a permanent water table is the sole criteria for assigning a soil to hydrologic group D.

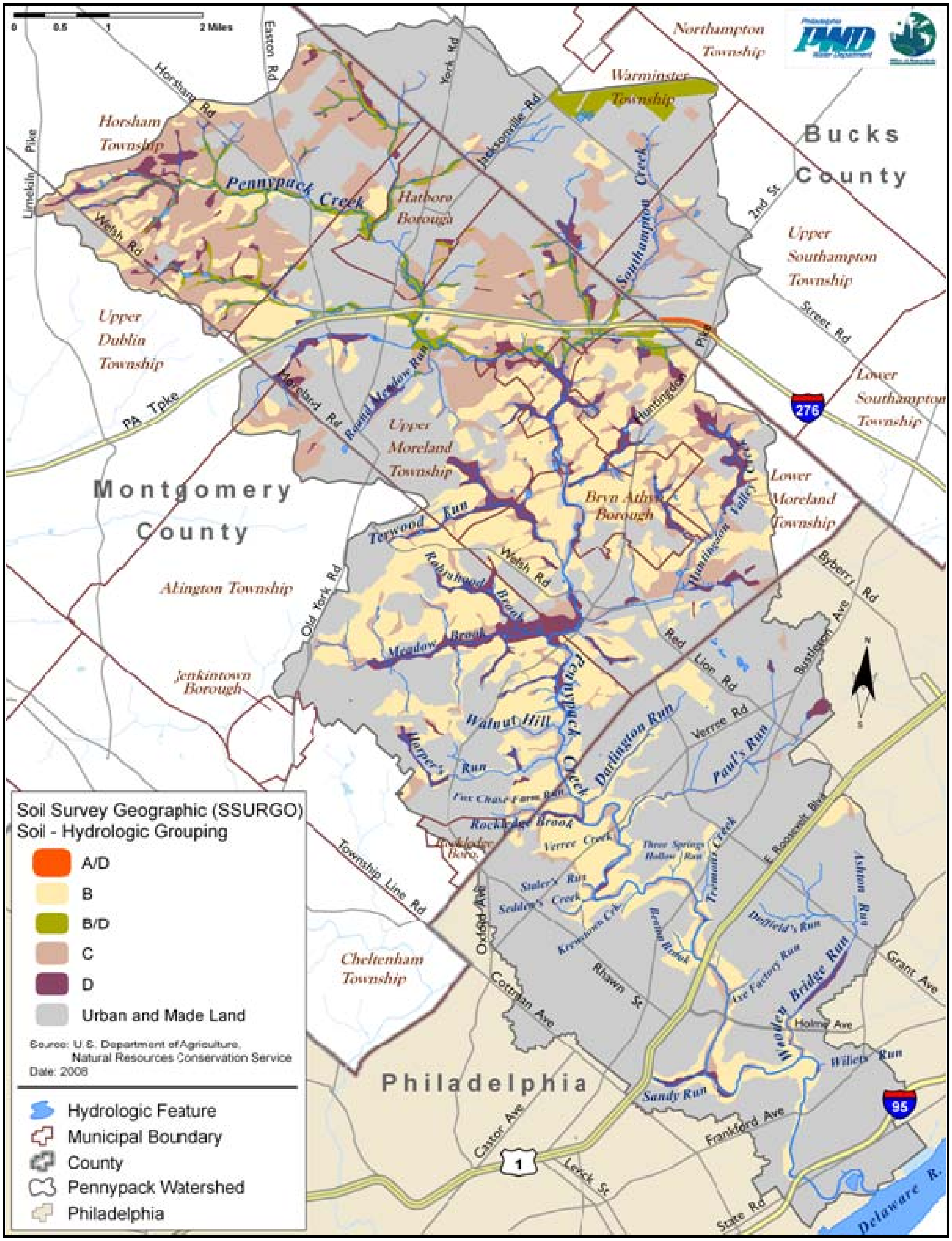


Figure 1-7: Pennypack Creek Watershed (NRCS) Soil Types

Source: Philadelphia Water Department. 2009. Pennypack Creek Watershed Comprehensive Characterization Report.

2 METHODS

2.1 METHODS OVERVIEW

The individual stream networks assessed in this study were divided into one or several representative reaches, depending on the size and complexity of the stream network. One representative stream channel cross section, including local slope, was measured per reach. Measured field data was compiled to determine stream channel types for each reach and to help evaluate channel stability. Qualitative habitat data was compiled and used to determine habitat types adjacent to the stream channel. In addition, a full infrastructure assessment was conducted to survey all manholes, pipes, outfalls, culverts, channels, and bridges that were within the stream corridor. Both quantatative and qualitative datasets were evaluated for correlations between the natural and urbanized watersheds.

This data aided in the calculation of a reach-scale ranking metric which allowed for comparison between reaches and watersheds. Besides being used to make comparisons between reaches, the ranking scheme could also be used to prioritize restoration efforts and provide recommendations for each watershed.

2.2 CROSS SECTION LOCATION

Cross section locations were chosen according to multiple channel stability and geometry parameters that were representative of the entire reach. The appropriate location of a cross section in a channel exhibiting riffle/pool sequences is at the crossover reach (Rosgen, 1996). A crossover reach is a straight riffle section of channel between two meander bends. This riffle is used since it is a hydraulic control. Cross sections were placed in this location when the following criteria were satisfied:

+ Presence of bankfull indicators, or active floodplain
+ Representative of reach
+ No debris or obstructions such as rock, logs, outfalls, or in-stream structures

Debris or obstructions such as rocks, logs, outfalls, or in-stream structures were avoided because they would influence bankfull indicators and yield a false bankfull width. In some cases, reaches were so strongly influenced, degraded and/or altered such that there were no crossover reaches or riffle sections. Criteria used to determine the cross section location in these situations consisted of:

+ Representative of reach
+ Presence of best bankfull indicators
+ Least amount of debris, obstructions, and alterations
+ Safe wading water levels

Cross section locations (Figure 2-3) were demarcated on the downstream right and downstream left banks with two foot long, 1/2 inch – 5/8 inch diameter rebar that was installed flush with the ground, when possible. At some sites where substrate consisted of large rocks, or tree roots or at sites where concrete debris was encountered, rebar could not be installed flush with the ground. After ensuring that the rebar could not be pulled out of the ground, the length of exposed rebar was noted on the data sheet. One inch yellow survey caps imprinted with the letters "PWD" were placed on each rebar as well as red flagging. Flagging was placed on the rebar itself as well as the tree branch closest to the rebar to ensure that the rebar could be easily located upon subsequent field visits. Cross section locations were captured using GPS (Xplore technologies model iX140C2 tablet PC with GPS module).

2.3 REACH SELECTION

The reaches within each watershed were defined after all of the cross sections had been established. The distance between two cross sections was then split in half and the distance upstream and downstream of a single cross section was combined to form one single reach (Figure 2-1). There was minimal geomorphic significance for the reach delineation. Reach lengths averaged 2,800 feet with average cross section spacing of 2,300 feet. Collecting channel cross section data at this increment ensured that all possible Rosgen channel types would be measured and that hydraulic and hydrologic models would be more reliable. The longest reach assessed was 11,837 feet (PPMS90) and the shortest was 1,190 feet (PPWB12). Refer to Appendix C for reach maps.

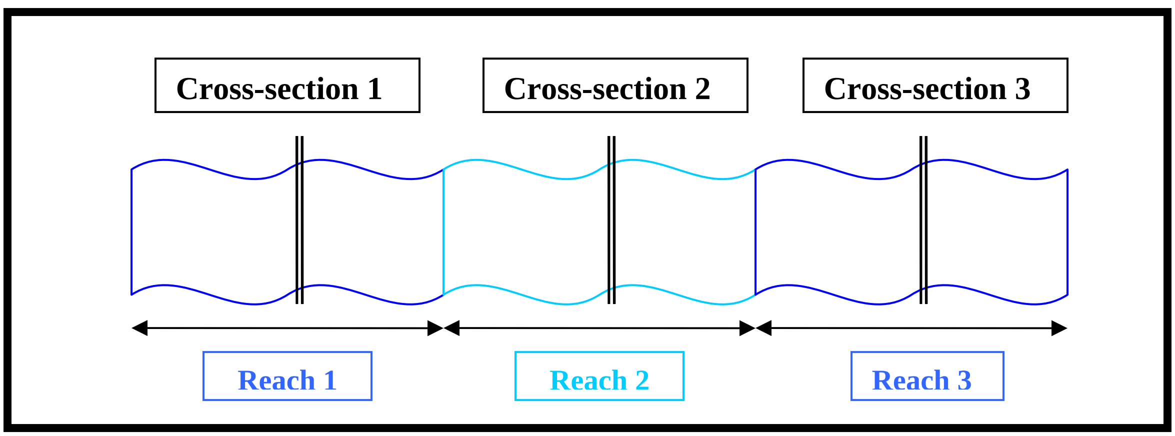


Figure 2-1: Diagram of Reach Delineation Procedure

2.4 STREAM SURVEY

The stream survey consisted of a PWD field crew performing field reconnaissance of the Pennypack Creek Watershed under protocols established by the Unified Stream Assessment Method (USAM) (Center for Watershed Protection, 2004). The USAM is a tool used to quickly and systematically evaluate the physical conditions within stream corridors in urbanized streams and subwatersheds. These conditions include habitat quality, riparian condition, floodplain function as well as the potential for manmade structures and other anthropogenic factors to adversely impact stream corridor quality. The USAM consists of nine components, with eight impact assessments and one reach assessment. Impact assessments are performed in specific areas within a reach that have been identified as potential problems such as severe erosion, impacted or reduced stream buffers, areas with accumulations of trash and debris and also areas that have been altered due to infrastructure such as storm water outfalls, stream crossings, channel modifications and roads.

Reach assessments were performed to get an overall picture of stream corridor conditions over defined survey reaches and to compare reach quality across the subwatershed. The Overall Stream Condition (Figure 2-2) form was used to characterize the average conditions present within a reach, such as bank stability and vegetative protection, in-stream and riparian habitat availability, and flood plain connectivity. Using this form, sites were given a standardized metric score (0-160) which allowed for comparison of total scores and individual component scores between surveyed reaches.

The field reconnaissance included walking the entire length of stream, choosing and marking cross section locations, while also making general observations of the surrounding watershed. All initial field observations and cross section locations were noted on datasheets and large scale field maps, respectively. Field data was later transferred to Mecklenburg sheets in order to calculate stream channel morphology and hydraulic parameters. The field reconnaissance was completed throughout the year of 2005.

2.5 MEASURED STREAM SURVEY AND CROSS SECTION PARAMETERS

Based on results of the stream assessment/field reconnaissance and following additional planning and base map preparation, the measured reach portion of the stream survey was completed. Measured reach stream surveys consisted of collecting data for channel morphology, disturbance, stability, and habitat parameters. Data for this analysis was based on results of stream surveys and field reconnaissance which were used to prepared watershed-scale base maps. Specific channel and habitat parameters included:

Channel Habitat
+ Riparian Width
+ Riparian Composition
+ Canopy Cover
+ Bed Materials
+ Sediment Supply
+ Sinuosity
+ Woody Debris
+ Substrate Attachment Sites

Channel Morphology
+ Stream Bed Materials
+ Sinuosity
+ Water Surface Slope
+ Bankfull Width
+ Floodprone Area Width
+ Entrenchment Ratio
+ Bankfull Cross-sectional Area
+ Rosgen Stream Classification Type

Channel Disturbance
+ Anthropogenic Channels
+ Culverts
+ Utilities (Manholes and Sewers)
+ Fish Blockages
+ Road, Railroad, Mass Transit Crossings

The measured reach stream survey also consisted of surveying channel cross sections at each location previously chosen during the field reconnaissance. Appendix A contains a summary of the results of the surveyed cross sections and local longitudinal profiles. Digital photographs were taken at every cross section location as a means of verification for field identified parameters. The photos consisted of an upstream view, a downstream view, and a view from left bank to right bank and/or right bank to left bank (Appendix A). Cross section locations are shown in Figure 2-3.

OVERALL STREAM CONDITION				
	Optimal	**Suboptimal**	**Marginal**	**Poor**
IN-STREAM HABITAT *(May modify criteria based on appropriate habitat regime)*	Greater than 70% of substrate favorable for epifaunal colonization and fish cover; mix of snags, submerged logs, undercut banks, cobble or other stable habitat and at stage to allow full colonization potential (i.e., logs/snags that are not new fall and not transient).	40-70% mix of stable habitat; well-suited for full colonization potential; adequate habitat for maintenance of populations; presence of additional substrate in the form of newfall, but not yet prepared for colonization (may rate at high end of scale).	20-40% mix of stable habitat; habitat availability less than desirable; substrate frequently disturbed or removed.	Less than 20% stable habitat; lack of habitat is obvious; substrate unstable or lacking.
	20 19 18 17 16	15 14 13 12 11	10 9 8 7 6	5 4 3 2 1 0
VEGETATIVE PROTECTION *(score each bank, determine sides by facing downstream)*	More than 90% of the streambank surfaces and immediate riparian zone covered by native vegetation, including trees, understory shrubs, or nonwoody macrophytes; vegetative disruption through grazing or mowing minimal or not evident; almost all plants allowed to grow naturally.	70-90% of the streambank surfaces covered by native vegetation, but one class of plants is not well-represented; disruption evident but not affecting full plant growth potential to any great extent; more than one-half of the potential plant stubble height remaining.	50-70% of the streambank surfaces covered by vegetation; disruption obvious; patches of bare soil or closely cropped vegetation common; less than one-half of the potential plant stubble height remaining.	Less than 50% of the streambank surfaces covered by vegetation; disruption of streambank vegetation is very high; vegetation has been removed to 5 centimeters or less in average stubble height.
	Left Bank 10 9	8 7 6	5 4 3	2 1 0
	Right Bank 10 9	8 7 6	5 4 3	2 1 0
BANK EROSION (facing downstream)	Banks stable; evidence of erosion or bank failure absent or minimal; little potential for future problems. <5% of bank affected.	Grade and width stable; isolated areas of bank failure/erosion; likely caused by a pipe outfall, local scour, impaired riparian vegetation or adjacent use.	Past downcutting evident, active stream widening, banks actively eroding at a moderate rate; no threat to property or infrastructure	Active downcutting; tall banks on both sides of the stream eroding at a fast rate; erosion contributing significant amount of sediment to stream; obvious threat to property or infrastructure.
	Left Bank 10 9	8 7 6	5 4 3	2 1 0
	Right Bank 10 9	8 7 6	5 4 3	2 1 0
FLOODPLAIN CONNECTION	High flows (greater than bankfull) able to enter floodplain. Stream not deeply entrenched.	High flows (greater than bankfull) able to enter floodplain. Stream not deeply entrenched.	High flows (greater than bankfull) **not** able to enter floodplain. Stream deeply entrenched.	High flows (greater than bankfull) **not** able to enter floodplain. Stream deeply entrenched.
	20 19 18 17 16	15 14 13 12 11	10 9 8 7 6	5 4 3 2 1 0
OVERALL BUFFER AND FLOODPLAIN CONDITION				
	Optimal	**Suboptimal**	**Marginal**	**Poor**
VEGETATED BUFFER WIDTH	Width of buffer zone >50 feet; human activities (i.e., parking lots, roadbeds, clear-cuts, lawns, crops) have not impacted zone.	Width of buffer zone 25-50 feet; human activities have impacted zone only minimally.	Width of buffer zone 10-25 feet; human activities have impacted zone a great deal.	Width of buffer zone <10 feet: little or no riparian vegetation due to human activities.
	Left Bank 10 9	8 7 6	5 4 3	2 1 0
	Right Bank 10 9	8 7 6	5 4 3	2 1 0
FLOODPLAIN VEGETATION	Predominant floodplain vegetation type is mature forest	Predominant floodplain vegetation type is young forest	Predominant floodplain vegetation type is shrub or old field	Predominant floodplain vegetation type is turf or crop land
	20 19 18 17 16	15 14 13 12 11	10 9 8 7 6	5 4 3 2 1 0
FLOODPLAIN HABITAT	Even mix of wetland and non-wetland habitats, evidence of standing/ponded water	Even mix of wetland and non-wetland habitats, no evidence of standing/ponded water	Either all wetland or all non-wetland habitat, evidence of standing/ponded water	Either all wetland or all non-wetland habitat, no evidence of standing/ponded water
	20 19 18 17 16	15 14 13 12 11	10 9 8 7 6	5 4 3 2 1 0
FLOODPLAIN ENCROACH-MENT	No evidence of floodplain encroachment in the form of fill material, land development, or manmade structures	Minor floodplain encroachment in the form of fill material, land development, or manmade structures, but not effecting floodplain function	Moderate floodplain encroachment in the form of filling, land development, or manmade structures, some effect on floodplain function	Significant floodplain encroachment (i.e. fill material, land development, or man-made structures). Significant effect on floodplain function
	20 19 18 17 16	15 14 13 12 11	10 9 8 7 6	5 4 3 2 1 0

Sub Total In-stream: _____ **/80** + Buffer/Floodplain: _____ **/80** = **Total** Survey Reach _____ **/160**

Figure 2-2: Overall Stream Condition Field Sheet

Source: Kitchell, Anne and Schueler, Tom. 2005. Unified Stream Assessment: A User's Manual. Urban Subwatershed Manual No. 10, Version 2.0. Center for Watershed Protection.

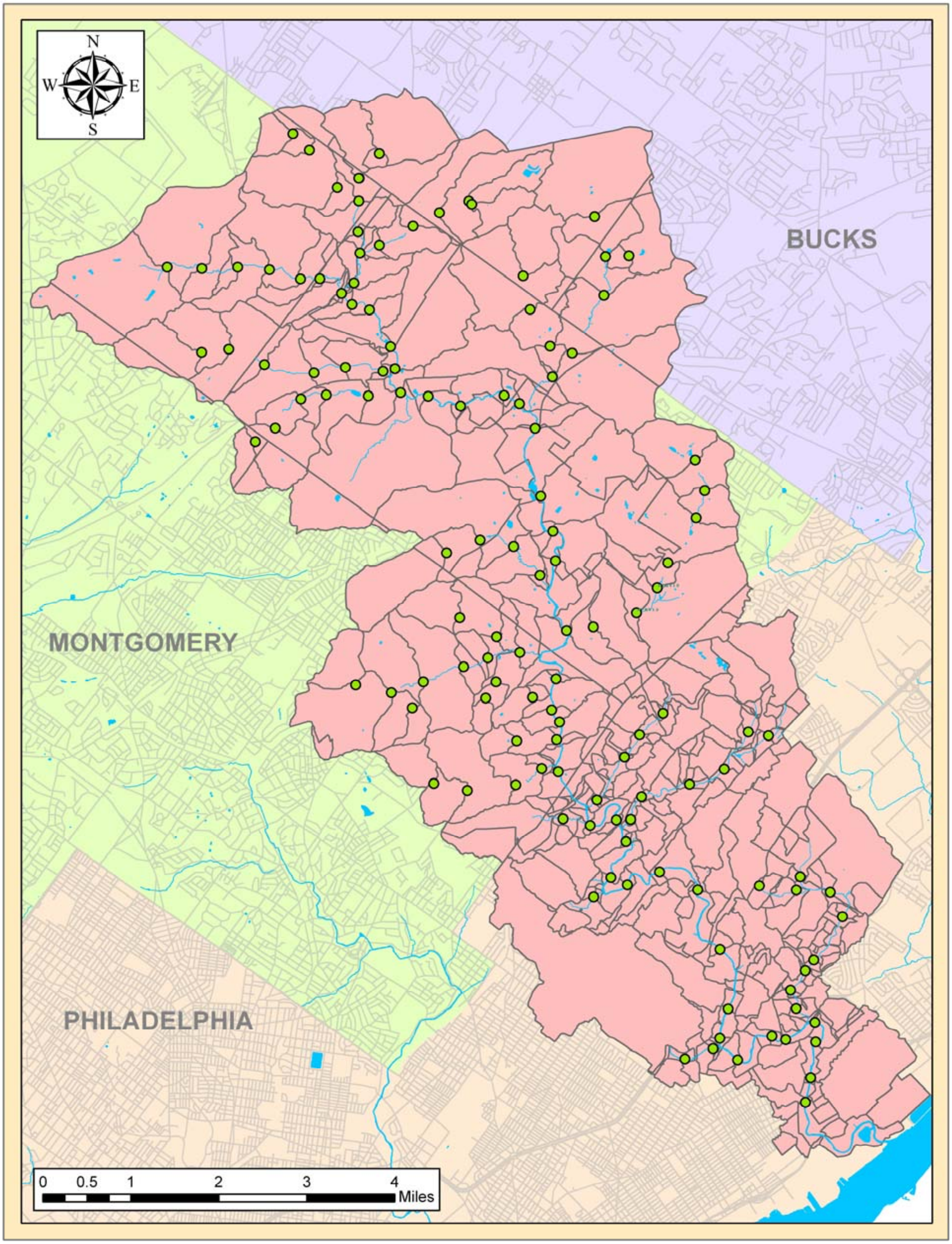


Figure 2-3: Pennypack Creek Watershed Cross Section Locations

2.6 CROSS SECTION SURVEY PROTOCOL

Each stream cross section was measured by extending a 100 feet measuring tape across the channel. Where possible, a measuring tape was extended a minimum of twice the bankfull width for each cross section and a maximum of the entire valley width according to the estimated flood prone width. A total station (Topcon GTS-235) was used to record readings from the downstream left bank across the channel to the end of the measuring tape on the downstream right bank. Rod readings were taken at all significant channel features, or changes in channel features, such as the thalweg, bed materials, vegetation, slope, and flow lines including field identified bankfull. From the survey data, field data, and topographic base map, the following items were calculated:

+ Bankfull Area
+ Width to Depth Ratio
+ Entrenchment ratio
+ Shear Stress
+ Velocity
+ Water Surface/Channel slope
+ Sinuosity
+ Median particle size (D_{50})
+ Bankfull Discharge

2.6.1 EXTENDED CROSS SECTION PROCEDURE

PWD-surveyed cross sections were positioned at the center of the stream corridor and cross sections were then extended manually beyond the flood prone width to the valley wall, where the flood prone width was defined as the width flooded at a stage equal to twice the bankfull channel depth. Extended cross sections allowed for the estimation of entrenchment ratio (Equation 1). Lines were drawn from the last surveyed point on each side of the cross section perpendicular to 2-foot topographic contour line coverage (City of Philadelphia, Mayor’s Office of Information Services, 2004). The extended cross sections were then plotted in Microsoft Excel and corrected if any obvious elevation discontinuities existed between the two data sets (Figure 2-4). Upstream cross sections are assumed to be representative of the stream channel geometry until the next downstream surveyed cross section.

Equation 1

$$\text{Entrenchment Ratio} = \frac{\text{Flood Prone Width}}{\text{Bankfull Width}}$$

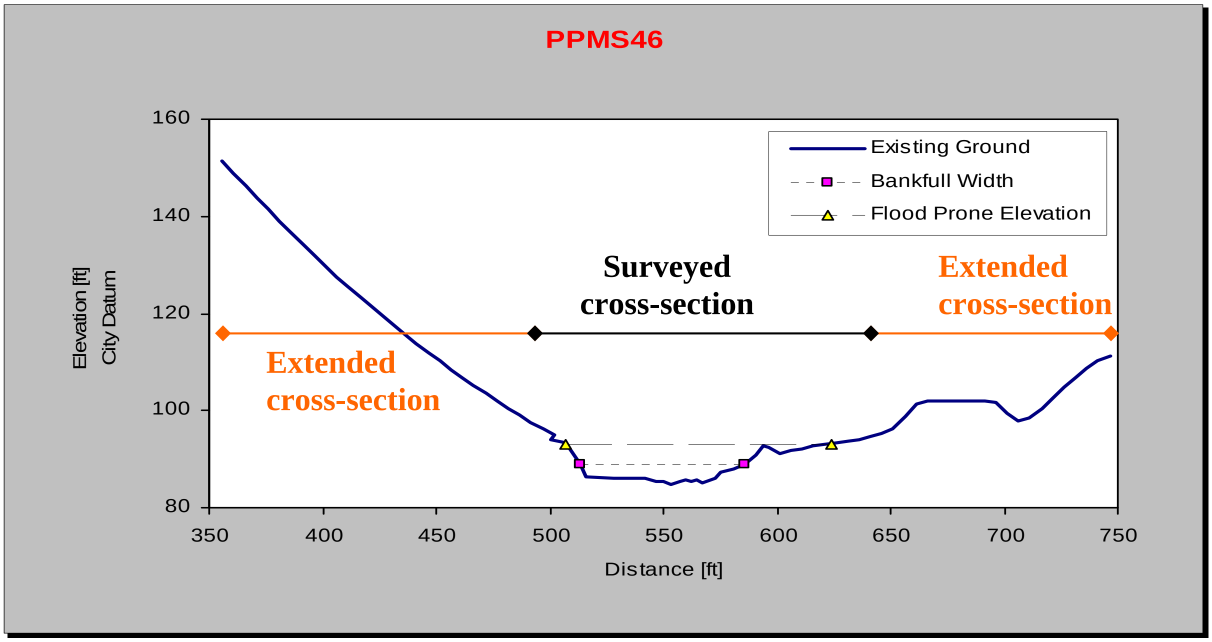


Figure 2-4: Sample Extended Cross Section surveyed on Pennypack Creek

2.7 LONGITUDINAL PROFILE SURVEY PROCEDURE

To estimate the local water surface slope at each cross section, the difference between the water surface elevation at the thalweg at the cross section immediately upstream and the water surface elevation at the thalweg at the cross section immediately downstream was divided by the stream distance measured between those two points as shown in Equation 2.

Equation 2

$Slope_{PR04}$ = (Water Surface Elevation at $Thalweg_{PR06}$ – Water Surface Elevation at $Thalweg_{PR02}$)/ Creek $Distance_{PR06\text{->}PR02}$

In instances where there was no cross section present either upstream or downstream from the reach of interest, Equation 3 was utilized.

Equation 3

$Slope_{B10}$ = (Water Surface Elevation at $Thalweg_{B10}$ – Water Surface Elevation at $Thalweg_{B8}$)/Creek $Distance_{B10\text{->}B8}$

In instances where there was no cross section present both upstream and downstream from the reach of interest, an alternate procedure was implemented. A short channel profile was completed at these cross section locations, extending through the reach from the nearest upstream and downstream rifle. A 300 feet measuring tape was extended, upstream to downstream, in the channel thalweg. When there were no channel or line-of-sight obstructions, the profile was extended the full length of the measuring tape to 300 feet, or to the next riffle. Rod readings were taken at the top of riffles within the thalweg, except at degraded reaches where no riffles were present. These profile measurements were used as an estimate of bankfull slope and also for the calculation of a local slope for each cross section (Appendix A).

2.8 BANKFULL ELEVATION AND DISCHARGE CALIBRATION

In an ideal channel, bankfull elevation is at the top of the bank and is the point where the stream begins to overflow onto the floodplain. The bankfull discharge, defined by Manning's Equation (Equation 4), has the ability to transport sediment, alter a channel's morphology and eventually change the planform of the channel. The bankfull stage has been defined in many ways, but the commonly accepted definition provided here (Dunne and Leopold, 1978) was used for this study:

"The bankfull stage corresponds to the discharge at which channel maintenance is the most effective, that is, the discharge at which moving sediment, forming or removing bars, forming or changing bends and meanders, and generally doing work that results in the average morphologic characteristics of channels."

Equation 4

$$Q = \frac{1.49}{n} * R_h^{2/3} * S^{1/2} * A$$

where:
R_h = hydraulic radius (cross sectional area (A)/ wetted perimeter)
S= slope
n= Manning's Roughness coefficient

2.8.1 CALIBRATION OF BANKFULL DISCHARGE

PWD personnel identified bankfull elevations in the field at varied locations as part of the Pennypack Creek Watershed FGM study. As a result of channel disequilibrium, bankfull indicators were not easily identified. Depositional features were the primary indicator used in the final determination of bankfull elevation. Bankfull discharge was estimated by solving Manning's equation (Equation 4) for discharge given the estimated bankfull elevation and measurements of the local channel geometry, slope, and roughness. Channel roughness, represented by Manning's "n," was approximated using the results of the Limerinos equation (Equation 5).

Equation 5

$$n = \frac{1.49 * R_h^{2/3} * (S/100)^{1/2}}{F * u_*}$$

where:
F^1= Friction factor
u_*= shear velocity

[1]where:

Equation 6

$F= 2.83 + 5.7*\log(d/D_{84})$
d= mean depth
D_{84} = measured particle size where 84% of the particles are this size or smaller

2.9 PEBBLE COUNT PROCEDURE

Pebble counts were conducted at every other cross section within a reach using the Wolman Pebble Count procedure (Wolman, 1954). Intermediate axis lengths were then entered into Mecklenburg sheets to plot particle size frequency distributions used to extract D_{50} and D_{84} parameters for use in channel hydraulic calculations. For cross sections without pebble counts, the pebble count was interpolated based on pebble counts actually performed upstream, downstream, or both.

2.10 INFRASTRUCTURE TRACKDOWN

The infrastructure trackdown was conducted by walking the entire length of the stream and taking note of the infrastructure encountered along the way. Data was collected on outfalls, bridges, manholes, culverts, pipes, dams, channels, and other miscellaneous infrastructure elements. The amount and type of information collected for each point of infrastructure varied depending on type. Basic information included the date in which the data was collected, the names of crew members, and the weather conditions.

For each infrastructure point identified and mapped, photos were taken and documented, along with important notes which included the GPS point number, approximate dimensions, location, and any other miscellaneous characteristics. Photographs of each infrastructure point can be found in Appendix B. Maps with the location of Lower Pennypack Creek Watershed infrastructure locations can be found in Appendix C. The naming convention used to describe infrastructure elements used the following format: PP to denote "Pennypack"; a three letter descriptor indicting the type of infrastructure element being described (i.e. "out" for outfall, "bri" for bridge' or "cha" for a channelized segment); and a unique numerical identifier. For example, outfall 844 (Paul's Run) would be called "PPout844."

2.10.1 OUTFALLS

An outfall was defined as the end of a pipe which releases either stormwater, combined sewage, or an encapsulated creek into the waterway (Figure 2-5). Data was collected on outfalls larger than 12 inches. The data collected for each outfall included the pipe dimensions (diameter, height and width), the presence of an apron, the construction material (i.e. metal, concrete, terra cotta, etc.), structural condition (i.e. good, fair, or poor), presence of, and quality of dry weather flow, bank location (right or left), and submergence depth. The outfall area was determined based on the dimensions and is used for assessment and comparison in the infrastructure sections later in this report.

Figure 2-5: Example of an outfall point assessed in infrastructure trackdown

2.10.2 BRIDGES

A bridge was defined as a structure that spanned a stream over which a road or walkway passes (Figure 2-6). Bridges mapped in this report are shown as one point at the center of the bridge along the creek. The data collected for each bridge included the approximate height, width and length along the stream of the bridge opening, the construction material (i.e. metal, concrete, wood, stone, etc.), and structural condition (i.e. good, fair, or poor).

Figure 2-6: Examples of bridges assessed in infrastructure trackdown

2.10.3 MANHOLES

A manhole was defined as the covered opening that allows access to an existing utility (Figure 2-7). Data was collected for manholes either located within the creek or in close proximity to the stream banks. The data collected for each manhole included the approximate diameter of the manhole, the construction material (i.e. concrete or terra cotta), the height of the portion of manhole exposed above the ground or water surface, structural condition (good, fair, or poor), bank location (left or right) and the presence and description of any odor.

Figure 2-7: Examples of manholes assessed in infrastructure trackdown.

2.10.4 CULVERTS

A culvert was defined as a conduit which carried the stream under a roadway, sidewalk, building, or miscellaneous structure (Figure 2-8). Culverts were mapped by taking GPS coordinates at the start and end of the culvert with photos taken at each point. The data collected for each culvert included the approximate dimensions, construction material (e.g. stone, concrete, brick, etc.), structural condition (i.e. good, fair, or poor), presence and quality of dry weather flow, and bank location (left or right). For comparison between reaches, the percentage of culverted stream length was calculated for each reach. This was determined by dividing the culverted stream length by the total stream length.

Figure 2-8: Examples of culverts assessed in infrastructure trackdown.

2.10.5 DAMS

A dam was defined as an obstruction that impounded stream flow (Figure 2-9). Data was only collected for manmade dams and did not include natural debris jams caused by coarse woody debris (CWD). The data collected for each dam included the approximate dimensions, construction material, structural condition (good, fair, or poor) and bank location (left, right, or across the creek).

Figure 2-9: Examples of dams assessed in infrastructure trackdown.

2.10.6 CHANNELS

A channel was defined as a straightening and reinforcement of stream bed and/or banks with manmade materials such as concrete (Figure 2-10). Channels were located on one or both banks, as well as on the bottom of the stream bed. Each channel was mapped by taking GPS coordinates at the start and end of the channel with photos taken at each point. The data collected for each channel included approximate dimensions, structural condition (good, fair, or poor), the portion of stream that was channelized (i.e. left bank, right bank or bottom), and construction material (stone or concrete). For comparison between reaches, the percentage of channelization was calculated by adding the total length of stream with one side (left bank, right bank, or the bottom) channelized, the total length channelized on two sides multiplied by two, and the total length channelized on all three sides multiplied by three, and dividing the sum by the total stream length multiplied by three.

Figure 2-10: Examples of channels assessed in infrastructure trackdown.

2.10.7 PIPES

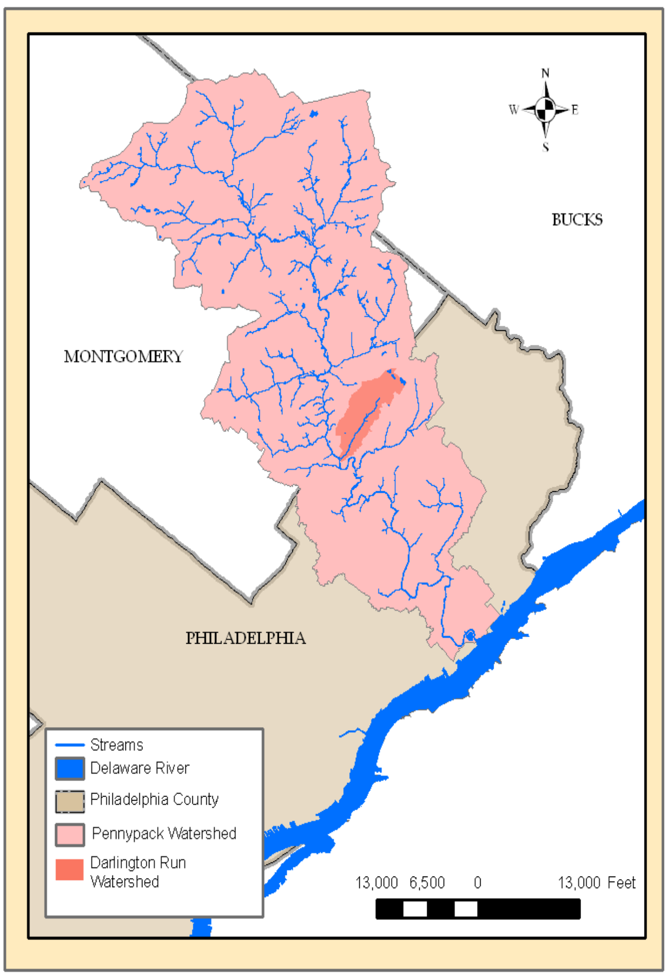
A pipe was defined as a conduit for carrying a utility across the stream (Figure 2-11). The data collected for each pipe included the approximate diameter, construction material (i.e. concrete, metal, terra cotta, etc.), the length and height above the water or ground surface of the exposed portion, structural condition (i.e. good, fair, or poor), presence and quality of dry weather flow, bank location (i.e. left, right or across the creek), and submergence depth.

Figure 2-11: Example of a pipe assessed in infrastructure trackdown.

3 WATERSHED ASSESSMENTS

The Pennypack Creek Watershed assessment consisted of collecting data from the entire watershed. To develop a report that would most effectively illustrate the stream corridor conditions and provide a tool for prioritizing reaches for rehabilitation, the following sections of the report focus on the watershed elements within the city boundary, an area which is referred to as the Lower Pennypack Creek Watershed. Each subwatershed as well as the main stem from the Philadelphia city boundary to the mouth of Pennypack Creek are presented individually and summarized for comparison. The Lower Pennypack Creek Watershed is 17.5 square miles, 10.7 square miles are attributed to the tributaries. The Lower Pennypack Creek includes 27.3 miles of stream, 13.6 miles attributed to the tributaries and 13.7 miles to the main stem.

3.1 DARLINGTON RUN WATERSHED AND REACH CHARACTERISTICS



Darlington Run is a tributary to the main stem of Pennypack Creek. It is the most upstream tributary of Pennypack Creek located completely within the City of Philadelphia. Through research of historic maps it was found that Darlington Run was historically referred to as Ballard Brook. It should be taken into account that future references to this stream could identify this tributary as Ballard Brook.

The stream originates from a PWD stormwater outfall approximately 390 feet southwest of Geiger Road. Darlington Run is a first-order tributary that flows for 9,555 feet to its confluence with Pennypack Creek. There was a small tributary to Darlington Run that started at a small wetland area behind the homes on Kingfield Road near the intersection with Burbank Road. This tributary runs for approximately 1,500 feet before its confluence with Darlington Run. After this confluence the stream flows for approximately 2,900 feet to the Pennypack Creek Main Stem. For reach maps refer to Appendix C.

The dominant substrate varies from medium gravel to medium cobble through the different segments of Darlington Run. The valley floor and stream channel have both been substantially impacted by past and current land use.

The Darlington Run Watershed is 885 acres. A narrow part of the watershed area, about 126 acres, to the northwest is beyond the city's boundary in Montgomery County, but is included in the study of Darlington Run. The majority of the drainage area is residential-single family detached (58%), wooded (28%), and manufacturing (10%).

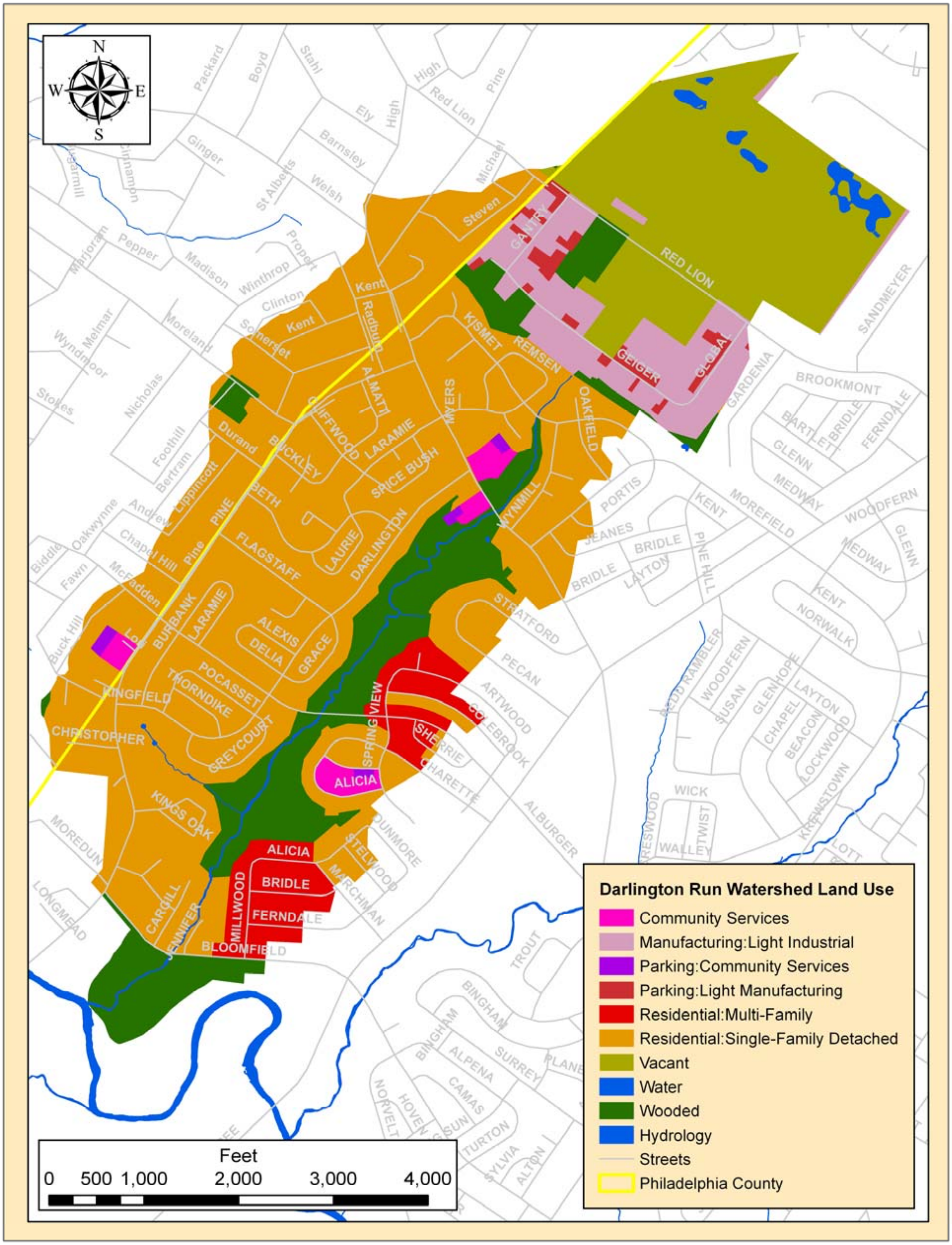


Figure 3-1: Darlington Run Watershed Land Use

3.1.1 GEOLOGY

Darlington Run Watershed is completely underlain by the Wissahickon Formation. The Wissahickon Formation consists of mica schist, gneiss, and quartzite. The schists are softer rocks and are highly weathered at the surface. This formation is composed mostly of metamorphosed sedimentary rock, but it also includes rock of igneous origin.

3.1.2 SOILS

According to the National Resource and Conservation Service Soil Survey, the majority of the soils in the Darlington Run Watershed are classified as Urban Land (Figure 3-3). Urban soils consist of material that has been disturbed by human activity during urbanization. Urban soils have been produced by mixing, filling and contamination of the native soils in both urban and suburban areas.

The rest of the watershed consists of mostly hydrologic group B soils. These soils have a moderate rate of infiltration when the soils are wet (0.50-1.00 in/hr). Water movement through these soils is considered moderately rapid. There is also a small section of C soils located in the area surrounding the stream. Group C soils have a slow rate of infiltration when saturated (0.017-0.27 in/hr). Water movement through these soils is moderate or moderately slow.

Table 3-1: Distribution of NRCS Soil Types in Darlington Run Watershed

Group	Area (ft^2)	Percent of Total Area
B	12,633,405	32.78%
C	1,245,010	3.23%
Urban Land	24,667,371	63.99%
Total Area	38,545,786	100%

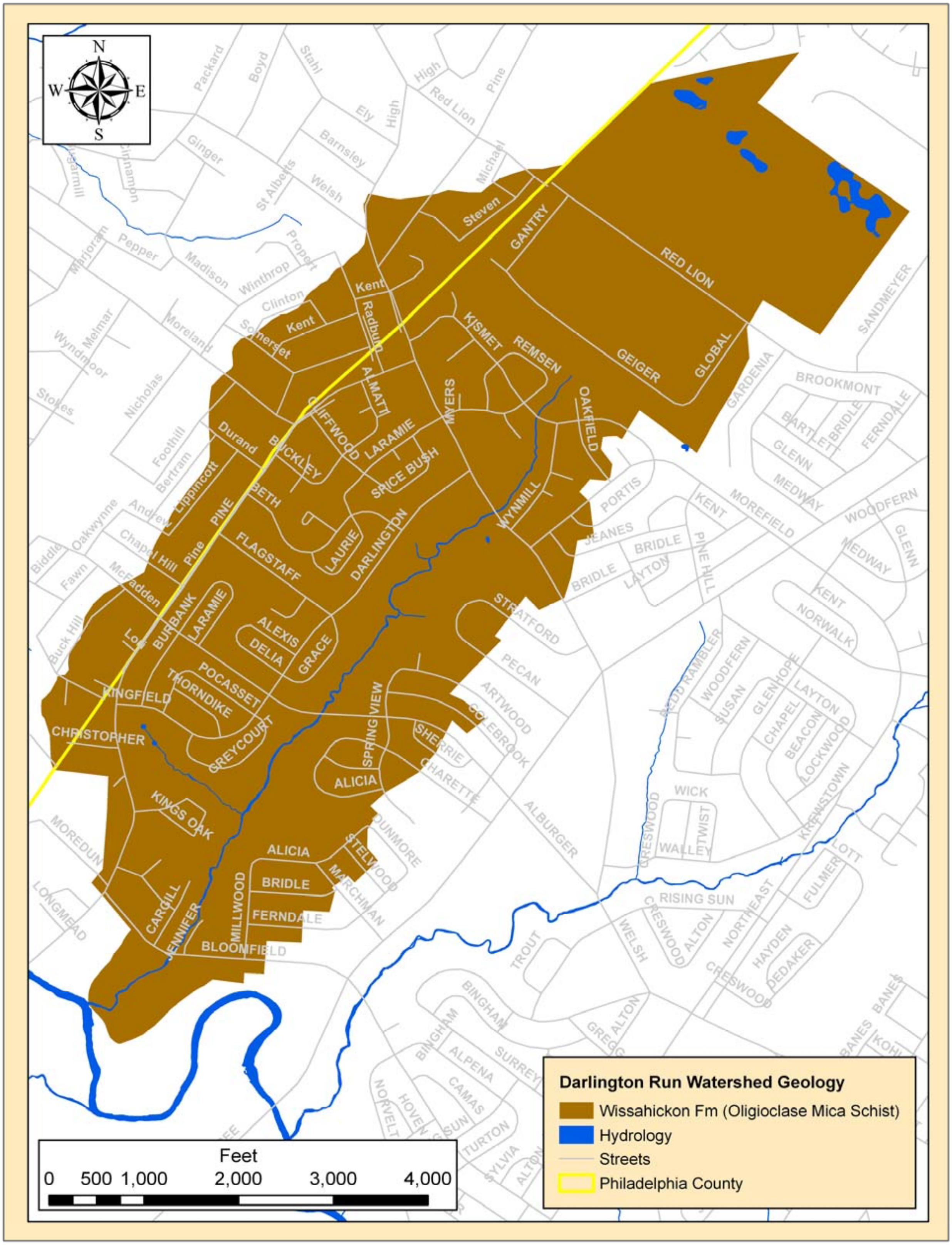


Figure 3-2: Geology of Darlington Run Watershed

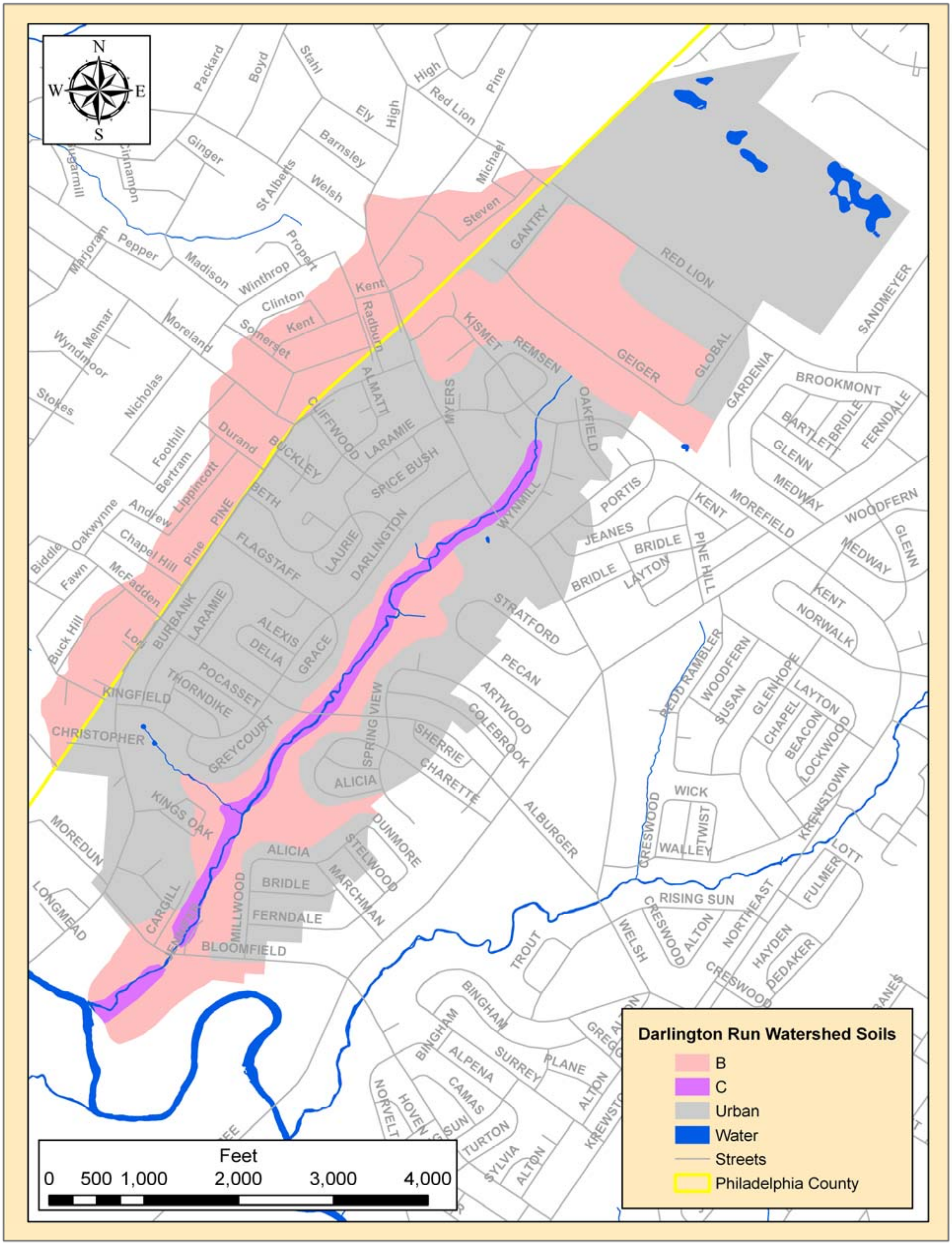


Figure 3-3: Distribution of NRCS Soil Types in Darlington Run Watershed

3.1.3 INFRASTRUCTURE TRACKDOWN SUMMARY

Darlington Run is characterized by a large amount of infrastructure. There is a total of 64 pieces of infrastructure along the 9,555 feet stretch of Darlington Run. Most of Darlington Run flows through a wooded landscape between neighborhoods and it is because of those neighborhoods that surround the stream corridor that there are so many infrastructure elements on the stream. The majority of the infrastructure found in the Darlington Run stream corridor was implemented for the drainage of the surrounding neighborhoods or the stabilization of the stream banks. This is illustrated by the substantial amount of infrastructure pieces in the upstream reaches and there only being one piece of infrastructure (Fairmount Park trail footbridge, PPbri346) downstream of the Bloomfield Road culvert where the stream enters Fairmount Park. From there to the confluence the stream is surrounded by substantial riparian buffer on both sides.

Of the four reaches only PPDR04 has less than 15 pieces of infrastructure. The most upstream section, PPDR02, has the most infrastructure with 29 elements. PPDR02 has a substantial amount of outfalls, 18, and outfall area, 146 square feet. This is the consequence of the homes on Remsen Road and Oakfield Lane being in the direct vicinity of the stream and the industrial area north of the stream around Geiger Road. Nine of these outfalls are privately owned outfalls located in the upstream portion of the section. The largest outfall in the subshed is PPout722, which is the end of an 8 feet by 8 feet reinforced concrete PWD stormwater gravity main at the headwaters of the stream. Reach PPDR08 has the largest amount of channelized length among the Darlington Run reaches, with 703 feet of total channel length and about 9% channelized.

Northwest of Geiger Road, a small segment of open channel stream flow was found. Four pieces of infrastructure were found in this area. It was determined that this small segment was the result of drainage from a pair of commercial facilities on Geiger Road as well as some groundwater seepage. The flow in this area entered back into PWD's stormwater network via a pair of inlets and contributed to the flow from the 8 feet by 8 feet outfall at the headwaters of Darlington Run.

There is a PWD sanitary line that runs parallel to the stream for the entire length. This pipe is 12 inches at the upstream most part of the stream and 24 inches at the junction with the 36 inch Pennypack Interceptor.

Darlington Run has two dams on the stream in reach PPDR08. These dams are considered low-head dams. They are 2 feet and 3 feet high and have a negative effect for extended stream lengths beyond the immediate location of the dam. One of the dams, PPdam144, was found in poor condition and identified as priority infrastructure.

There are three total priority infrastructure elements in the Darlington Run Watershed. The two priority cases, other than PPdam144, are PPcul312 and PPout737. Culvert PPcul312 displays a particularly detrimental consequence to the tributary to Darlington Run. A debris jam at this culvert had caused the stream to erode the banks in the area and flow around the culvert. Urbanization of a watershed has had a dramatic effect on the waterways in the area and the infrastructure in Darlington Run illustrates the urban nature of the drainage area around the stream corridor.

Table 3-2: Darlington Run Infrastructure Point Summary

Section ID	Bridge Count	Channel Count	Culvert Count	Dam Count	Manhole Count	Other Count	Outfall Count	PipeSewer Count	Infra Points Count	Total Combined Outfall Area (ft^2)	Priority Infra Points Count
PPDR02	0	3	3	1	3	1	18	0	29	145.6	2
PPDR04	0	0	0	0	1	0	2	0	3	3.1	0
PPDR06	0	5	2	0	3	1	4	1	16	29.8	0
PPDR08	1	4	1	2	0	0	8	0	16	34.0	1
Total	**1**	**12**	**6**	**3**	**7**	**2**	**32**	**1**	**64**	**212.6**	**3**

Table 3-3: Darlington Run Infrastructure Linear Summary

Section ID	Total Segment Length (ft)	Culvert Length (ft)	% Culverted	Channel Length, one side	Channel Length, two sides	Channel Length, three sides	Total Channel Length	Total Segment Length, 3 sides	% Channelized
PPDR02	2624	109	4.2	259	0	0	259	7872	3.3
PPDR04	2348	0	0.0	0	0	0	0	7044	0.0
PPDR06	2608	52	2.0	0	0	21	63	7824	0.8
PPDR08	2524	101	4.0	607	0	32	703	7572	9.3
Total	**10104**	**262**	**2.6**	**866**	**0**	**53**	**1025**	**30312**	**3.4**

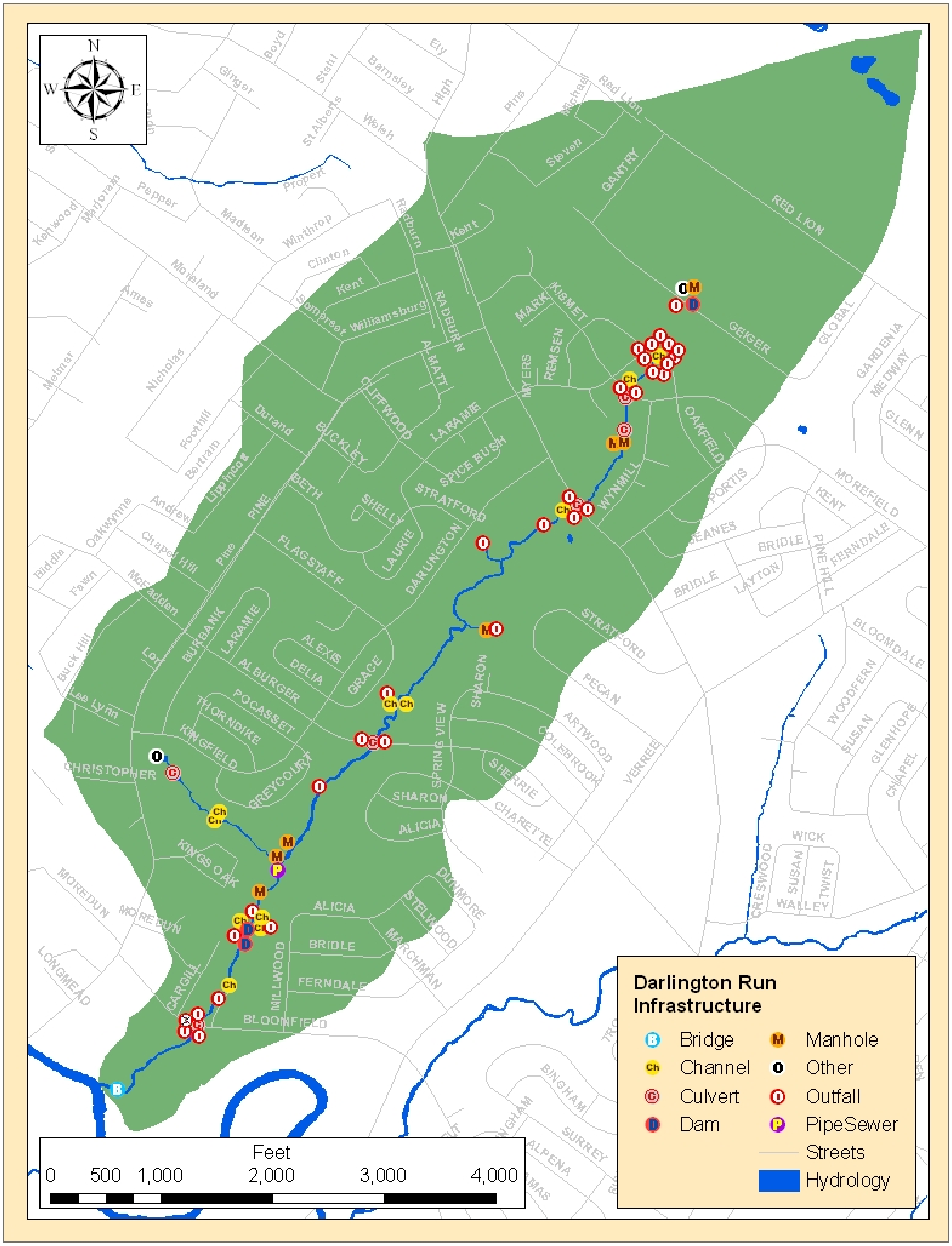


Figure 3-4: Darlington Run Watershed Infrastructure

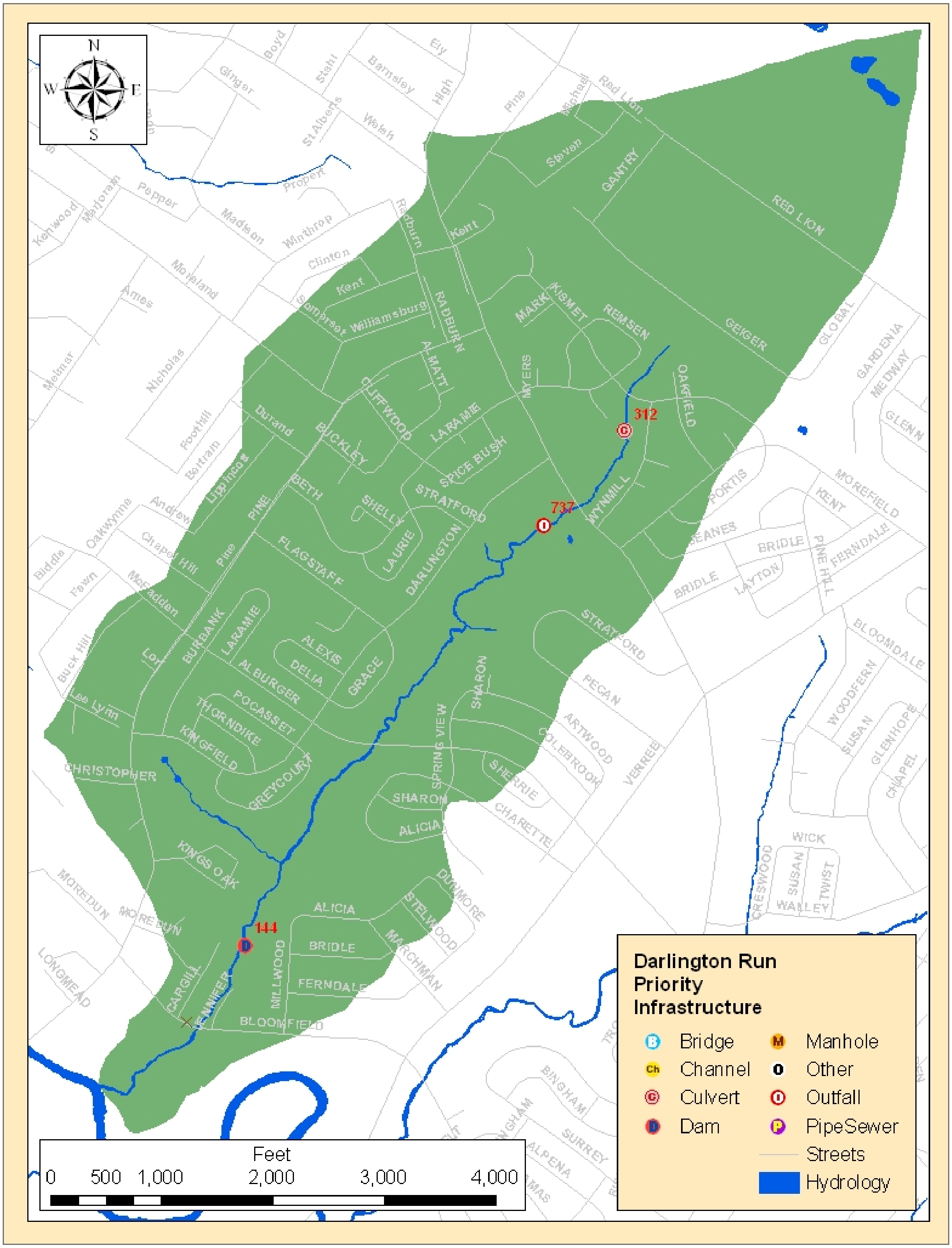


Figure 3-5: Darlington Run Watershed Priority Infrastructure

3.1.4 UNIFIED STREAM ASSESSMENT RESULTS FOR THE DARLINGTON RUN WATERSHED

The Darlington Run Watershed was the upstream-most tributary in the Lower Pennypack Creek Basin and was located entirely within the City of Philadelphia. Only the lower portion of Darlington Run downstream of Bloomfield Avenue was located within Fairmount Park, which likely impacted the ecological and morphological characteristics of the upstream segments that drained highly residential areas.

The Center for Watershed Protection's (CWP) Unified Stream Assessment Methodology (USAM) was used to score and rate the in-stream, riparian buffer and floodplain conditions of the stream corridor to allow for comparison to other reaches and watersheds within the Lower Pennypack Creek basin. The all reaches parameter is the mean of the scores of all tributary reaches in the Lower Pennypack Creek study.

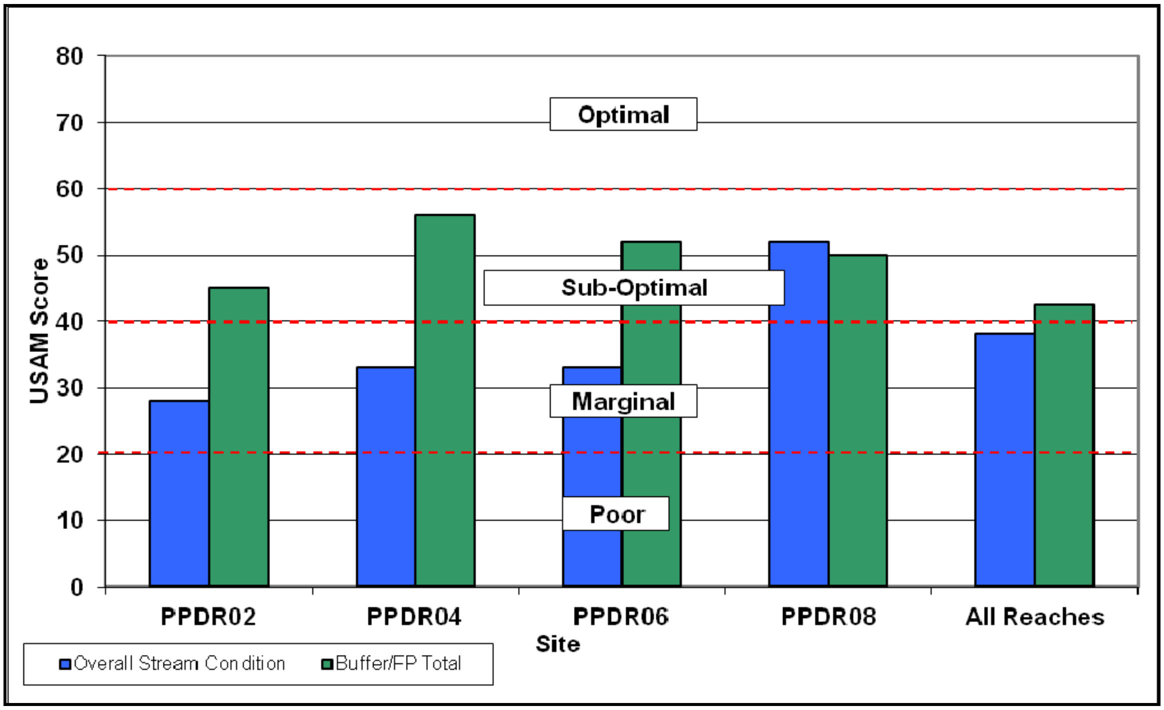


Figure 3-6: Results for Darlington Run USAM Components

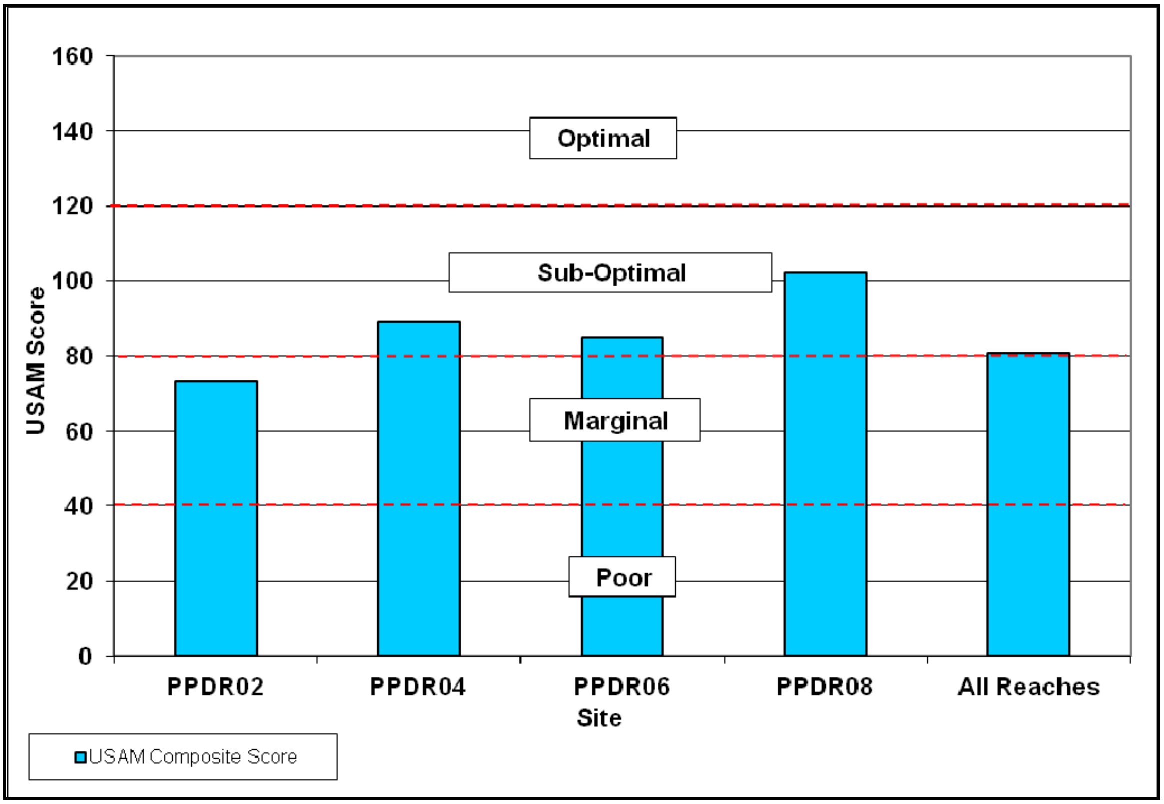


Figure 3-7: Darlington Run USAM Results

3.1.4.1 PPDR02

Reach PPDR02 originated from an outfall, PPout722, located approximately 200 feet from the intersection of Remsen Street and Laramie Road. In total, the reach was 2,358 feet in length and ended approximately 575 feet downstream of PPcul313 which conveys Darlington Run beneath Welsh Road. Reach PPDR02 had drainage area of 0.42 mi^2 and was classified as a Rosgen type F4 stream channel characterized by a low entrenchment ratio (1.2), moderate width to depth ratio (12.1), and a mild slope (1.2%). The substrate particle size distribution was dominated by gravel (70%) and small cobble (17%). The D50 of the reach was 19.8 millimeters which corresponds to coarse gravel. The composite USAM score for PPDR02 (75/160) was rated as "marginal" and was the lowest score among the four Darlington Run reaches (Table 3-4).

3.1.4.2 PPDR04

Reach PPDR04 was 2,053 feet in length which included two small tributaries that originated from outfalls. The upstream tributary was 527 feet in length and originated at PPout738. The downstream tributary was 571 feet in length and originated at PPout739. PPDR04 had drainage area of 0.74 mi^2 and was classified as a Rosgen type F4 stream channel. PPDR04 was similar to PPDR02 in that the stream channel was a deeply incised (entrenchment ratio =1.1), however the width to depth ratio (23.8) in PPDR04 was much higher. The substrate particle size distribution was dominated by gravel and cobble-sized particles with a D_{50} of 30.3 millimeters which corresponds to coarse gravel. The composite USAM score for PPDR04 was 89/160 and rated at the lower end of the "suboptimal" range of scores (Table 3-4).

3.1.4.3 PPDR06

Reach PPDR06 was 2,608 feet in length which included a tributary that came to a confluence with the main stem of Darlington Run on the downstream right bank. The reach was classified as a Rosgen F4 stream channel. It was characterized by a highly entrenched channel (entrenchment ratio = 1.1), a moderate width to depth ratio (16.6) and a mild slope (1.07%). The substrate particle size distribution was dominated by gravel (48%) and cobble-sized (30%) particles with a D_{50} (31 millimeters) corresponding to coarse gravel. PPDR06 had a USAM rating of "suboptimal" although the score for PPDR06 (85/120) was very close to the threshold between "marginal" and "suboptimal".

3.1.4.4 PPDR08

Reach PPDR08 was 2,524 feet in length and had a drainage area of 1.24 mi^2. The portion of the reach upstream of Bloomfield Avenue was highly residential whereas the portion downstream of Bloomfield Avenue was completely within the Fairmount Park boundary. The upstream portion was highly impacted by infrastructure which included PPdam143, PPdam144 and PPcul316, which conveyed the stream beneath Bloomfield Avenue. The cross-section for reach PPDR08 was located in the downstream portion of the reach, which was less impacted by infrastructure. PPDR08 was classified as a Rosgen type C4 channel, which differed substantially from the three upstream reaches. PPDR08 had both a higher width to depth ratio (26.6) and entrenchment ratio (2.2) than the other reaches. The substrate particle size distribution was dominated by gravel-size particles (70%) and the D_{50} of the reach was 18.3 millimeters which corresponds to coarse gravel. The small D_{50} for the reach and the paucity of cobble-size particles may be a product of the two dams in the upstream portion of PPDR08, which likely trapped many of the coarser particles within the impoundments upstream of the dams. Cobble-size particles were only 10% of the particle size distribution in the reach compared to 17% in both PPDR02 and PPDR04, and 30% in PPDR06. The composite USAM score for PPDR08 was 100/180 which was considerably higher than the average score for all of the Lower Pennypack Creek tributary reaches (81/160).

3.1.5 SUMMARY OF UNIFIED STREAM ASSESSMENT RESULTS

The mean score for the *Overall Buffer and Floodplain Condition* component of the USAM was (50.8/80) and was rated as "suboptimal" (Table 3-4). This score was considerably higher than the average condition observed throughout the Lower Pennypack Creek subwatersheds (42.7/80). The mean score for the *Overall Stream Condition* component was (36.5/80) which was slightly lower than the average condition observed in all of the Lower Pennypack Creek tributaries (38.3/80) although both were rated as "marginal". The mean composite USAM score (87.3/120) for all of the Darlington Run reaches was rated a "suboptimal". It was the second highest among the tributaries in the Lower Pennypack Creek Watershed after Wooden Bridge Run which had an average composite USAM score of (90.4/100).

Table 3-4: USAM Results for Darlington Run

Reach ID	Sub-watershed	Overall Stream Condition	Overall Buffer/FP Condition	USAM Score
PPDR02	Darlington Run	28	47	75
PPDR04	Darlington Run	33	56	89
PPDR06	Darlington Run	33	52	85
PPDR08	Darlington Run	52	48	100
Mean		**36.5**	**50.8**	**87.3**
All Reaches		**38.3**	**42.7**	**81.0**

3.1.5.1 SUMMARY OF OVERALL STREAM CONDITION SCORES IN THE DARLINGTON RUN WATERSHED

Overall Stream Condition scores for the Darlington Run reaches were generally very low and with the exception of PPDR08 (52/80), all reaches were rated within the "marginal" range of scores. The score for the *Floodplain Connection* parameter in reach PPDR08 attributed considerably to the high score observed in this reach. Of the four parameters assessed, only the *In-stream Habitat* and *Bank Erosion* parameters were observed to be higher on average in Darlington Run than the average of all the tributary reaches assessed in this study.

Table 3-5: Overall Stream Condition Scoring for Darlington Run

OVERALL STREAM CONDITION								
Reach ID	Sub-watershed	In-Stream Habitat	Vegetative Protection		Bank Erosion		Floodplain Connection	Overall Stream Condition
			Left	Right	Left	Right		
PPDR02	Darlington Run	10	3	3	5	5	2	28
PPDR04	Darlington Run	14	6	2	7	3	1	33
PPDR06	Darlington Run	12	5	3	5	7	1	33
PPDR08	Darlington Run	14	5	7	5	9	12	52
Mean		**12.5**	**4.8**	**3.8**	**5.5**	**6.0**	**4.0**	**36.5**
All Reaches		**11.1**	**6.3**	**6.1**	**5.0**	**5.8**	**4.0**	**38.3**

3.1.5.1.1 IN-STREAM HABITAT

Scores for the *In-stream Habitat* parameter were rated as "suboptimal" for all reaches in Darlington Run with the exception of PPDR02 which was rated as "marginal" with a score of 10/20. The mean score (12.5/20) for the Darlington Run Watershed was higher than the All Reaches average (11.1/20) although both scores were rated as "suboptimal".

In-stream habitat in PPDR02 was characterized by low mean depth and small cobble and gravel substrate embedded with fine-grain sediment although the stream. These characteristics were attributed to the severely overwidened and entrenched channel in PPDR02. Bank erosion and overwidening supplied ample amounts of coarse woody-debris (CWD) to the channel; however, most of the (CWD) was not accessible at baseflow. Reaches PPDR04 and PPDR06 were also deeply entrenched and had low baseflow depths however there was a higher proportion of larger, more stable substrate particle available for colonization in these reaches.

3.1.5.1.2 VEGETATIVE PROTECTION

Scores for the *Vegetative Protection* parameter were very low throughout the watershed. The highest score was observed for on the downstream right bank of PPDR08 (7/10). The mean scores for the left (4.8/10) and right (3.8/10) banks of Darlington Run were rated as "marginal" and both were considerably lower than the respective All Reaches average (Table 3-5). Both banks in PPDR02 (3/10) and the downstream right banks in PPDR04 (2/10) and PPDR06 (3/10) were rated as "poor" for this parameter. The score for the downstream right bank in the PPDR04 was the lowest score observed among all of the tributary reaches assessed. Scores classified as "poor" for this parameter are characterized by high levels of disturbance to the vegetative communities on the stream bank such that vegetation covers less than 50% of the streambank surface. The low scores for these parameters reflect the level of disturbance that vegetative communities are exposed to as a result severe bank erosion associated with stormwater runoff.

3.1.5.1.3 BANK EROSION

There was a high degree of variability among the scores for the *Bank Erosion* parameter as scores ranged from "poor" to "suboptimal". The mean scores for the left (5.5/10) and right (6/10) banks of Darlington Run were slightly higher than the All Reaches averages for the left and right banks. The lowest score was observed on the downstream right bank of PPDR04 (3/10). The downstream right bank in PPDR04 formed the outer bend of a large meander which subjected the bank to higher velocity and shear stress than the downstream left bank. The highest score was observed on the downstream right bank of PPDR08 (9/10) where minimal evidence of bank erosion was observed due to presence of dense vegetation along the downstream right bank. A variety of tree, shrub and forbs species covered over 75% of the downstream right bank surface area providing enhanced bank stability and cohesion of bank sediments.

3.1.5.1.4 FLOODPLAIN CONNECTION

The *Floodplain Connection* parameter is a measure of the frequency in which high flows (i.e. greater than or equal to bankfull stage) are able to enter onto a stream channel’s floodplain. The degree of floodplain connection was determined by the entrenchment ratio observed in each cross section in the reach. With the exception of PPDR08, Darlington Run was a deeply entrenched system characterized by highly incised and overwidened Rosgen type F stream channels. In the upper reaches, flows well in excess of bankfull discharge are entirely contained within the channel which ultimately exacerbates the channel incision and lateral migration process over time. Scores for each of the upper reaches were rated as "poor". The highest score was observed in PPDR08

(12/20), which was the third highest score for this parameter after reaches PPSR03a and PPWB10 (both 20/20).

3.1.5.2 Summary of Overall Buffer and Floodplain Condition Scores in the Darlington Run Watershed

The scores for *Overall Buffer and Floodplain Condition* were rated as "suboptimal" for all of the reaches in Darlington Run. The highest score was observed in PPDR04 which was the least impacted by adjacent residential development and the presence of infrastructure. The mean score of 50.8/80 was considerably higher than the All Reaches average of 42.7/80. The watershed mean scores for all parameters except *Floodplain Habitat* were higher than the respective All Reaches averages (Table 3-6). Of special significance were the scores for the *Vegetated Buffer Width* parameter on downstream left and downstream right bank of PPDR04 which were the highest scores (both 20/20) of all the tributary reaches assessed.

Table 3-6: Overall Buffer and Floodplain Condition Scoring for Darlington Run

OVERALL BUFFER AND FLOODPLAIN CONDITION							
Reach ID	Sub-watershed	Vegatated Buffer Width		Floodplain Vegetation	Floodplain Habitat	Floodplain Encroachment	Buffer/FP Total
		Left	Right				
PPDR02	Darlington Run	7	7	15	2	14	45
PPDR04	Darlington Run	10	10	15	1	20	56
PPDR06	Darlington Run	10	10	14	1	17	52
PPDR08	Darlington Run	8	8	12	12	10	50
Mean		**8.8**	**8.8**	**14.0**	**4.0**	**15.3**	**50.8**
All Reaches		**8.0**	**7.5**	**12.7**	**4.3**	**11.1**	**42.7**

3.1.5.2.1 Vegetated Buffer Width

Scores for the *Vegetated Buffer Width* parameter were high throughout the watershed and ranged from "suboptimal" to "optimal". The average scores for the left and right banks were both 8.8/10 and each was higher than the respective All Reaches average (Table 3-6). PPDR04 and PPDR06 had scores of 10/10 for both the left and right banks. The lowest scores were observed in PPDR02 (7/10 for both bank) where residential development and stormwater conveyance infrastructure limited the expanse of the buffer near the headwaters of Darlington Run (PPout722). Downstream of Kismet Road, the riparian buffer gradually increased in width. PPDR08 was similar to PPDR02 in that the upstream portion of the reach had a more confined riparian buffer than the downstream portion. The riparian buffer in the upstream portion of PPDR08 was confined by residential development on Cargill Lane (downstream right) and Jennifer Terrace (downstream left) but downstream of Bloomfield Avenue, Darlington Run entered Fairmount Park where the riparian buffer was extensive.

3.1.5.2.2 FLOODPLAIN VEGETATION

The quality and abundance of floodplain vegetation was similar throughout Darlington Run. All reaches were rated as "suboptimal" with vegetation characterized by young secondary forests however shrubs and forbs were also abundant. The scores for PPDR02 and PPDR04 were the highest in the watershed due to the presence of large, mature trees on their respective floodplains. The mean watershed score was 14/20 which was higher than the All Reaches average of 12.7/20 (Table 3-6).

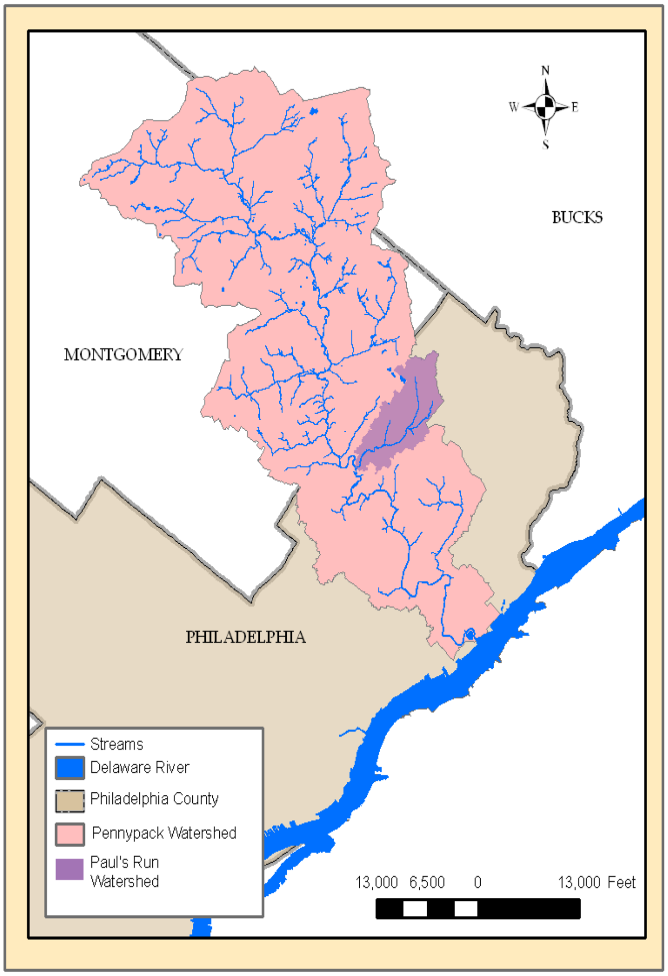
3.1.6 FLOODPLAIN HABITAT

Scores for the *Floodplain Habitat* parameter were generally low throughout the watershed. The mean watershed score of 4/20 was rated as "poor". In the three upstream reaches the floodplain was not observed to support the hydrologic need to maintain habitat features such as wetlands or vernal pools due to the lack of frequent overbank flooding. The highest score was observed in PPDR08 (12/20). In PPDR08, the stream channel is not severely entrenched which allows for more frequent overbank flooding and periodic inundation of the floodplain.

3.1.6.1.1 FLOODPLAIN ENCROACHMENT

The *Floodplain Encroachment* parameter measures the extent to which residential, commercial and industrial development or infrastructure impacts floodplain function in a reach. The most severe impacts usually are observed where development or infrastructure is located on the floodplain or abuts a stream channel. Scores in Darlington Run were highly variable and ranged from "marginal" to "optimal". The mean score of 15.3/20 was rated as "optimal" which was considerably higher than the All Reaches average score of 11.1/20. PPDR04 was almost completely absent of floodplain infrastructure and development with the exception of two outfalls (PPout738 and PPout739) and PPman237 however none of these infrastructure elements had impacts on floodplain function. The other reaches were located in dense residential areas where residential development, culverts and bridges had some degree of impact to floodplain function on small segments of each reach.

3.2 PAUL'S RUN WATERSHED AND REACH CHARACTERISTICS



Paul's Run is a tributary to the main stem of Pennypack Creek located completely within the Northeast section of the City of Philadelphia. The stream originates at a commercial site northeast of Sandmeyer Lane and flows behind the homes on Jeanes Street before entering a PWD stormwater culvert (PPcul038) that conveys the stream approximately 1,600 feet southeast past Verree Road before continuing as an open channel from there. Paul's Run is a first order tributary for approximately 6,500 feet and becomes a second order tributary at the confluence with Paul's Run Tributary A. Tributary A begins at the three feet diameter outfall PPout772, near the intersection of Northeast Boulevard and Serota Drive. Tributary A meets Paul's Run just south of Norwalk Road. After the confluence with Tributary A, Paul's Run flows for approximately 10,100 feet until its mouth on the Pennypack Creek. About 4,000 feet downstream of the Tributary A confluence is the confluence of a 3,000 feet unnamed tributary to Paul's Run. For reach maps refer to Appendix C. The dominant substrate of Paul's Run varies from coarse sand to very coarse gravel at different sections along the tributary. The valley floor and channel have been substantially impacted by past and current land use.

The Paul's Run Watershed is 1,675 acres. The Paul's Run landscape is highly developed. Major land uses of Paul's Run include residential: single-family detached (35%), residential: multi-family (28%), wooded (10%), and vacant (7%). These urban land uses have had detrimental impacts on the stream. The impacts of the urbanization of the watershed are illustrated by the amount and density of infrastructure along the stream. There is a substantial amount of outfalls, bridges, culverts, and channels on Paul's Run and its tributaries. Paul's Run is impaired physically, chemically, and biologically as a direct consequence of the development of its watershed.

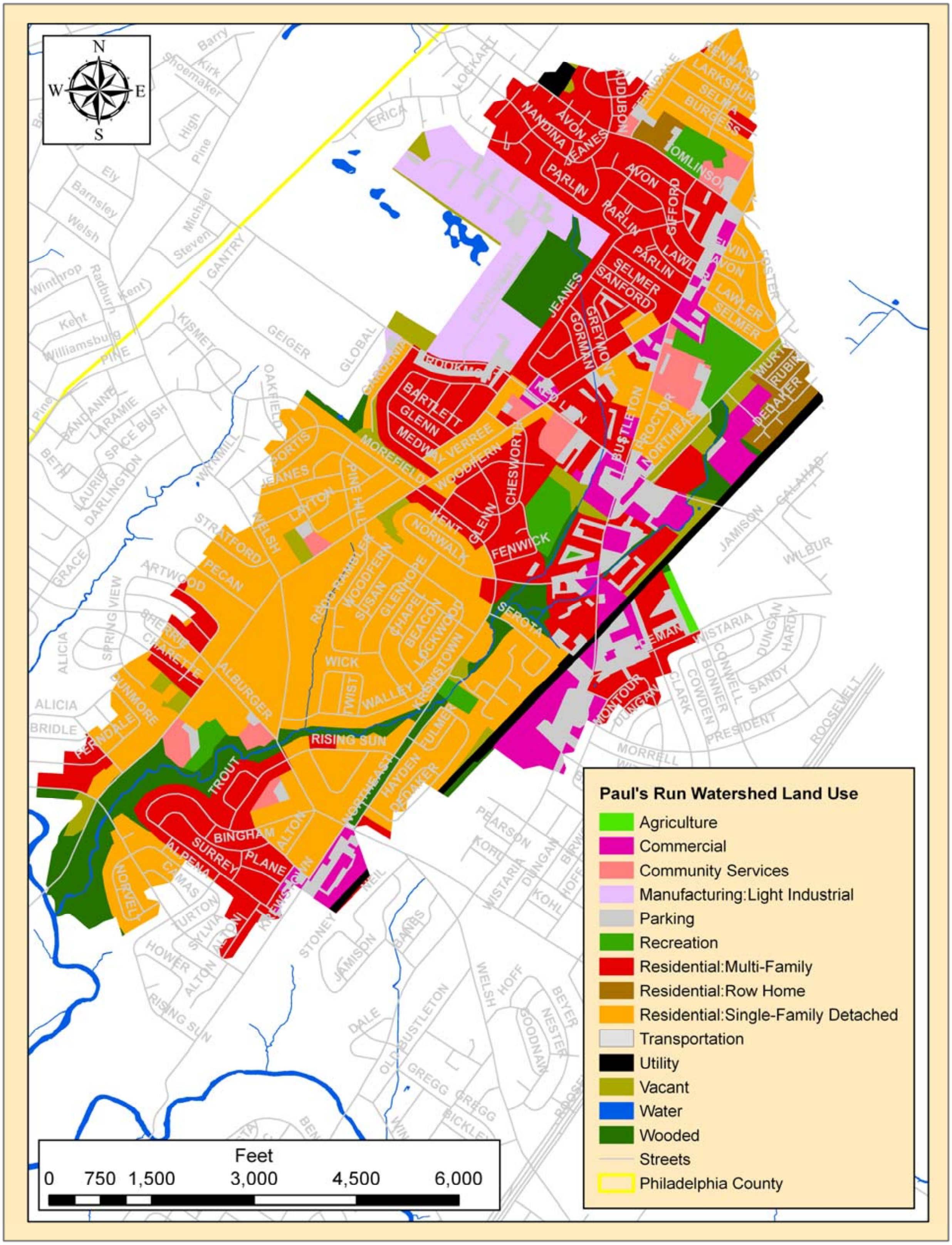


Figure 3-8: Paul's Run Watershed Land Use

3.2.1 GEOLOGY

The geology in the Paul's Run Watershed consists of oligioclase-mica schist, some hornblende gneiss, and granite gneiss and granite. Paul's Run is mostly underlain by the Wissahickon Formation, which exists in over 83% of the watershed (Figure 3-9). This formation is composed of mica schist, gneiss, and quartzite. The schists are softer rock that is highly weathered at the surface. The formation mostly consists of metamorphosed sedimentary rocks, but there is also rock of igneous origin.

Over 16% of the watershed is underlain by mafic gneiss, hornblende bearing formation. This formation is composed of medium grained, dark colored, calcic plagioclase, hyperthene, augite, and quartz. Rocks included in the formation are of sedimentary origin. This formation is very resistant to weathering, but has good surface drainage.

The geology of the watershed near the confluence with the Pennypack Creek Main Stem is granite gneiss and granite. Granite gneiss is a holocrystalline shale rock consisting of quartz, potash feldspar, acid plagioclase, and mica. This formation was formed by metamorphism and consists of rocks of sedimentary and igneous origin. This formation yields small quantities of water due to the small cracks, joints, and openings within the rock. This formation was present in less than 1% of the watershed. These rocks are resistant to weathering, but show good surface drainage.

3.2.2 SOILS

According to the National Resource and Conservation Service Soil Survey, over 90% of the soils in the Paul's Run Watershed are classified as Urban Land (Figure 3-10). Urban soils consist of material that has been disturbed by human activity during development of the watershed. Urban soils have been produced by mixing, filling and contamination of the native soils in both urban and suburban areas.

The rest of the watershed consists of hydrologic groups B, C, and D soils. Group B soils have a moderate rate of infiltration when the soils are wet (0.50-1.00 in/hr). Water movement through these soils is considered moderately rapid. There is section of C soils located in the area surrounding the stream. Group C soils have a slow rate of infiltration when saturated (0.017-0.27 in/hr). Water movement through these soils is moderate or moderately slow. Two areas at the headwaters of both the main stem of Paul's Run and Paul's Run's Tributary A belong in category D for soils. These soils have a very slow infiltration rate when saturated (0.02-0.10 in/hr) resulting in a high runoff potential.

Table 3-7: Distribution of NRCSS Soil Types in Paul's Run

Group	Area (ft^2)	Percent of Total Area
B	2,366,398	3.24%
C	2,434,283	3.34%
D	1,045,785	1.43%
Urban Land	67,138,432	91.99%
Total Area	72,984,898	100%

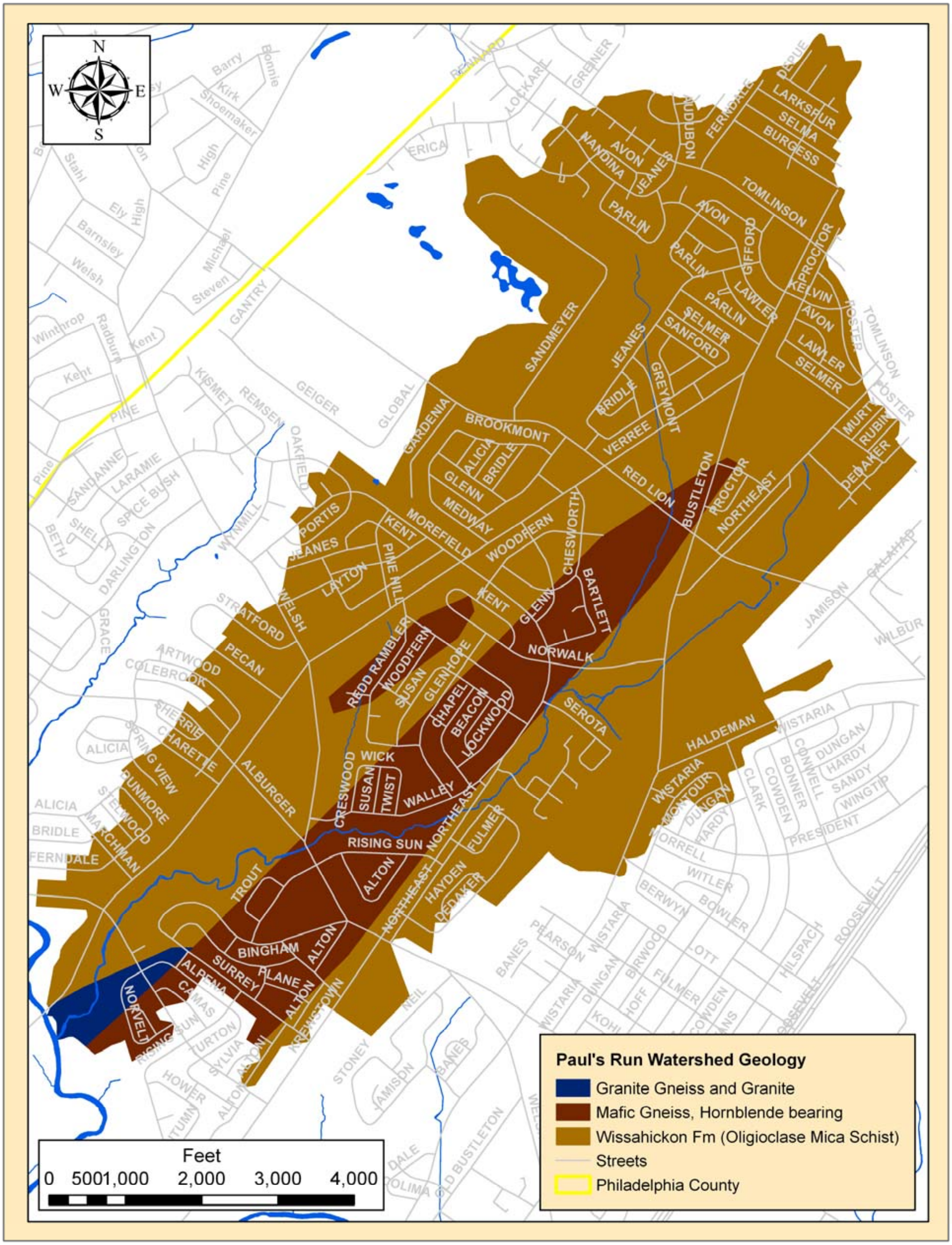


Figure 3-9: Geology of Paul's Run Watershed

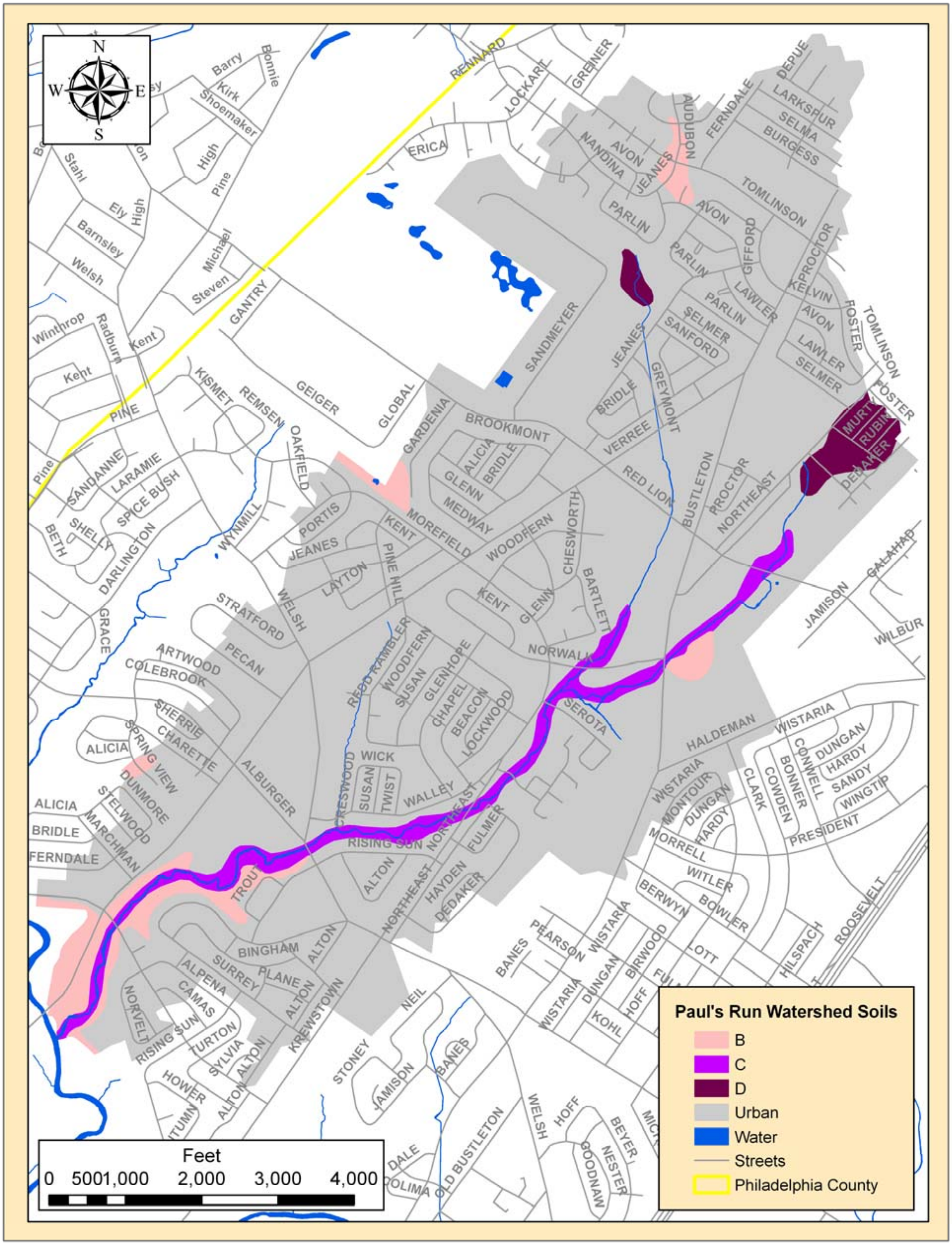


Figure 3-10: Distribution of NRCS Soil Types in Paul's Run Watershed

3.2.3 INFRASTRUCTURE TRACKDOWN SUMMARY

Paul's Run is a very heavily urbanized and developed subwatershed of Pennypack Creek. The infrastructure along the stream corridor gives an accurate portrayal of the impacts this development of the land has had on the stream. During the survey of Paul's Run 234 infrastructure elements were found. Of all of the reaches in the Paul's Run Watershed only PPPR10 has less than ten and three of the other reaches have about 60 a piece. The three reaches with the most infrastructure elements are PPPR06 (66), PPPR02 (64), and PPPRA02 (59). The majority of the infrastructure points are attributed to outfalls and channels. That indicates the substantial emphasis on stormwater conveyance from the drainage area and the effects that the high flows are having on the stream.

The Paul's Run infrastructure illustrates the requirement to convey water from the drainage area and downstream while also conveying people and vehicles over the stream. It can be inferred from the residential land use that there is a lot of impervious surface area that would produce a lot of runoff that must be prevented from flooding the neighborhoods. That can also be inferred from the amount of outfalls along the stream. Paul's Run had 80 outfalls found during the infrastructure survey. Two reaches with several outfalls were PPPR02 (25) and PPPRA02 (29). The total combined outfall area to Paul's Run is 378 square feet, which further illustrates the significant stormwater runoff contribution to the stream.

Another telling part of the infrastructure study for Paul's Run is the amount of channelization. For the entire stream there were a total of 107 channelized portions recorded for 10.2% channelization. Reach PPPR06 had the highest amount (44) and percentage (17.8%) of channelization. These amounts of channel infrastructure are representative of the impervious surfaces in the drainage area and the residential land uses surrounding the stream and the resulting high flows impacting the stream and also creating a desire to prevent the movement of the stream, leading to attempts to stabilize eroding streambanks along Paul's Run.

To convey water under roads and trails there are 16 bridges and 17 culverts. There are 7 bridges in PPPR02 and 6 in PPPR06; these are the most among the watershed's reaches. Culverts are more evenly distributed throughout the watershed reaches, at least in amount. When we consider percent culverted, reach PPPR02 stands out clearly as the most culverted stream section. PPPR02 was 33.5% culverted and included one 2,000 feet culvert that stretches from behind the homes on Jeanes Street and underneath Greymont St to its outlet about 300 feet past Verree Road.

The Paul's Run Interceptor is a waste water gravity main that runs parallel to Paul's Run. The sanitary pipe is 15 inches in diameter near the top of the watershed and is 30 inches where it meets the Pennypack Creek Interceptor. The Paul's Run Interceptor was observed via PWD's wastewater database and despite several locations where it crossed the stream, there were no exposed pipes found during the infrastructure survey.

There was a substantial amount of priority infrastructure points found along Paul's Run. In all, 25 infrastructure elements were identified as being in poor condition. The reach with the highest amount of priority infrastructure was PPPR06 with 17. Of those, 15 were stone or concrete channels that were found either fallen, crumbling, or functioning poorly. No other reach had more than four pieces of priority infrastructure. The infrastructure of Paul’s Run portrays a heavily impacted urban stream representative of the surrounding drainage area and its land uses.

Table 3-8: Paul's Run Infrastructure Point Summary

Section ID	Bridge Count	Channel Count	Culvert Count	Dam Count	Manhole Count	Outfall Count	Infra Points Count	Total Combined Outfall Area (ft^2)	Priority Infra Points Count
PPPR02	7	20	5	3	4	25	64	104.0	4
PPPR04	2	11	3	0	0	7	23	12.9	0
PPPR06	6	44	3	0	1	12	66	75.7	17
PPPR08	0	8	1	0	1	5	15	50.5	1
PPPR10	0	3	1	0	1	2	7	12.9	0
PPPRA02	1	21	4	0	4	29	59	121.8	3
Total	**16**	**107**	**17**	**3**	**11**	**80**	**234**	**377.72**	**25**

Table 3-9: Paul's Run Infrastructure Linear Summary

Section ID	Total Segment Length (ft)	Culvert Length (ft)	% Culverted	Channel Length, one side	Channel Length, two sides	Channel Length, Three sides	Total Channel Length	Total Segment Length, 3 sides	% Channelized
PPPR02	6522	2184	33.5	943	11	401	2168	19566	11.1
PPPR04	2700	185	6.9	637	43	31	816	8100	10.1
PPPR06	6198	310	5.0	861	802	281	3308	18594	17.8
PPPR08	2743	80	2.9	33	52	48	281	8229	3.4
PPPR10	1743	18	1.0	15	5	40	145	5229	2.8
PPPRA02	6188	314	5.1	424	317	80	1298	18564	7.0
Total	**26094**	**3091**	**11.8**	**2913**	**1230**	**881**	**8016**	**78282**	**10.2**

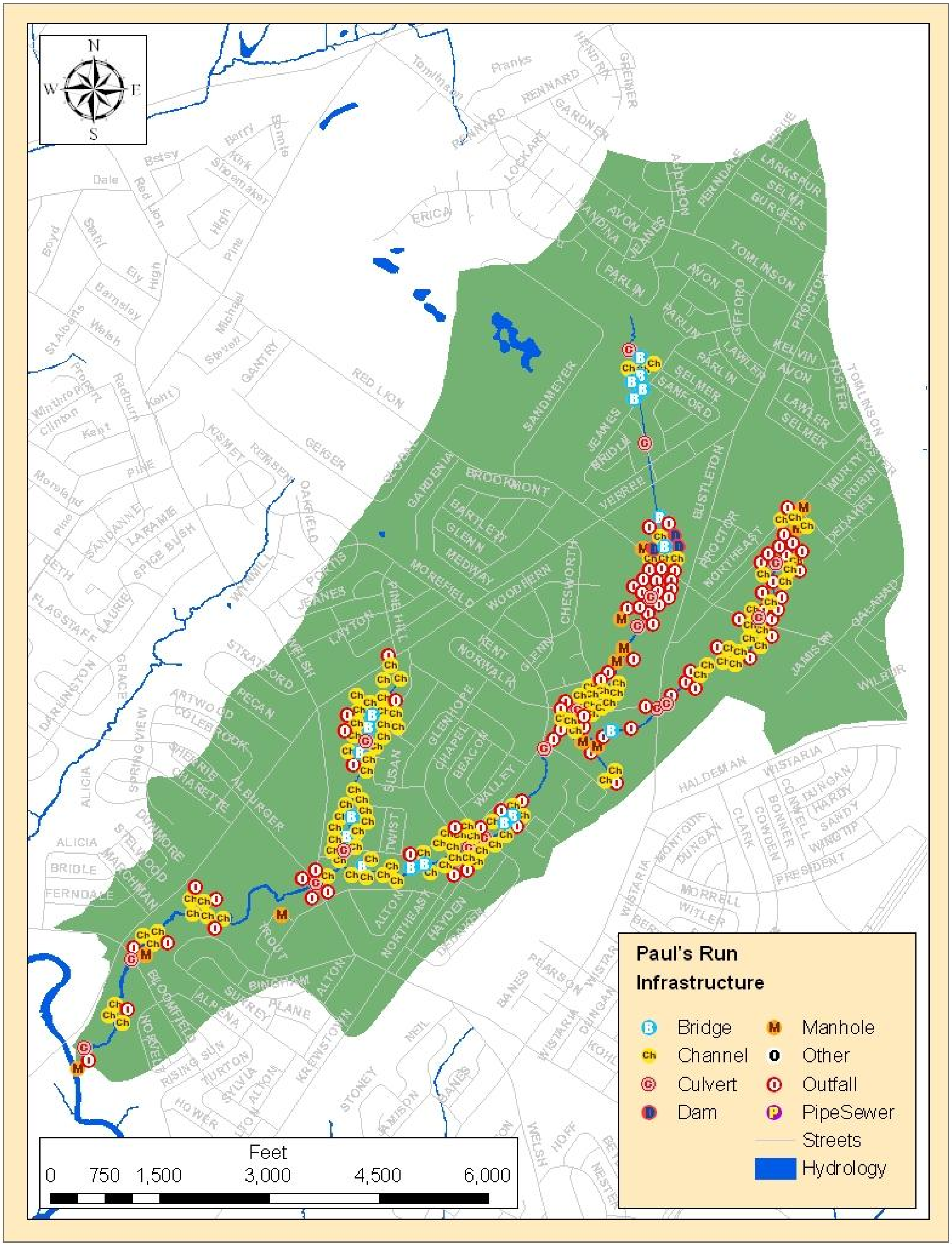


Figure 3-11: Paul's Run Watershed Infrastructure

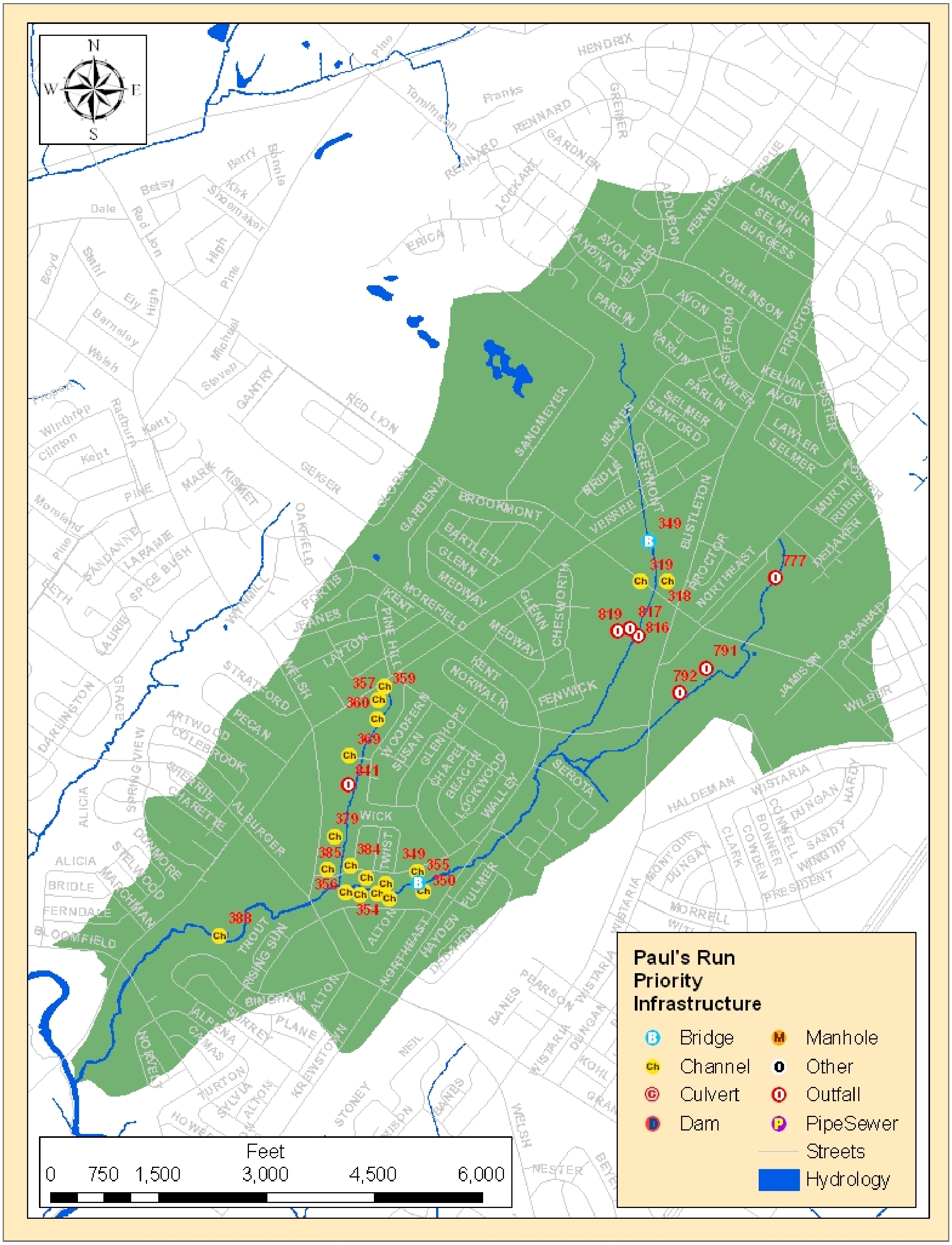


Figure 3-12: Paul's Run Watershed Priority Infrastructure

3.2.4 UNIFIED STREAM ASSESSMENT RESULTS FOR PAUL'S RUN WATERSHED

Paul's Run Watershed was a highly urbanized watershed characterized by residential land-use and a very narrow stream corridor. Wooded land-use composed only 10% of the watershed with the most extensive coverage located in the lower portion of the watershed near the confluence of Paul's Run and Pennypack Creek. The Center for Watershed Protection's (CWP) Unified Stream Assessment Methodology (USAM) was used to score and rate the in-stream, riparian buffer and floodplain conditions of the stream corridor to allow for comparison to other reaches and watersheds within the Lower Pennypack Creek basin. The all reaches parameter is the mean of the scores of all tributary reaches in the Lower Pennypack Creek study.

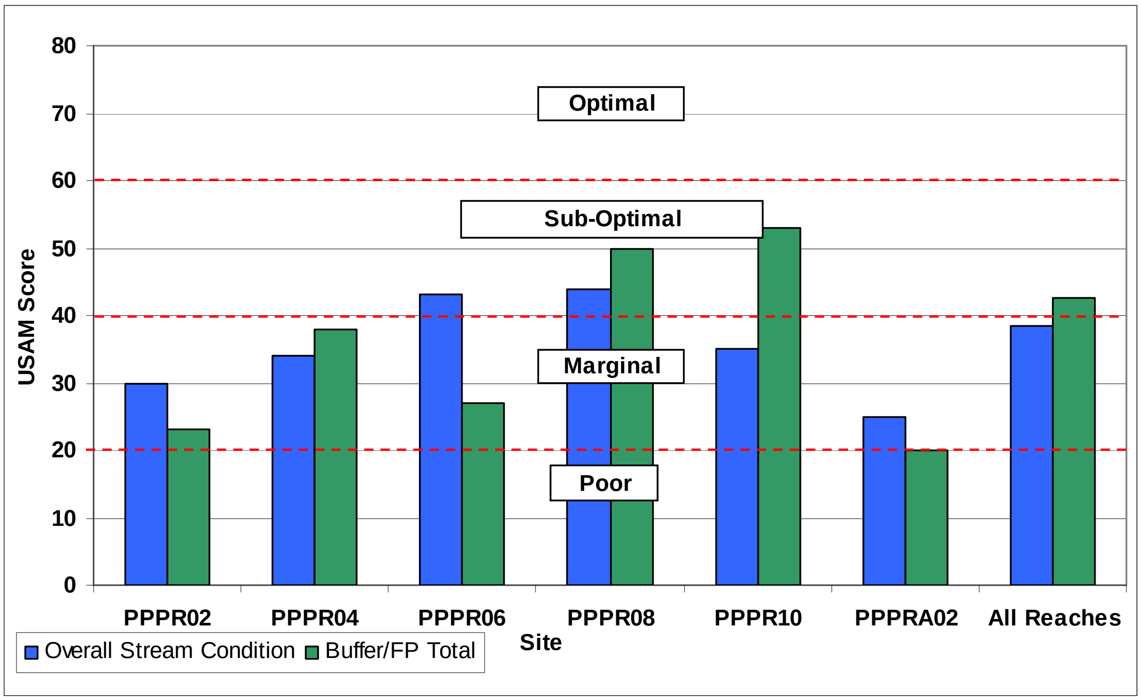


Figure 3-13: Results for Paul's Run USAM Components

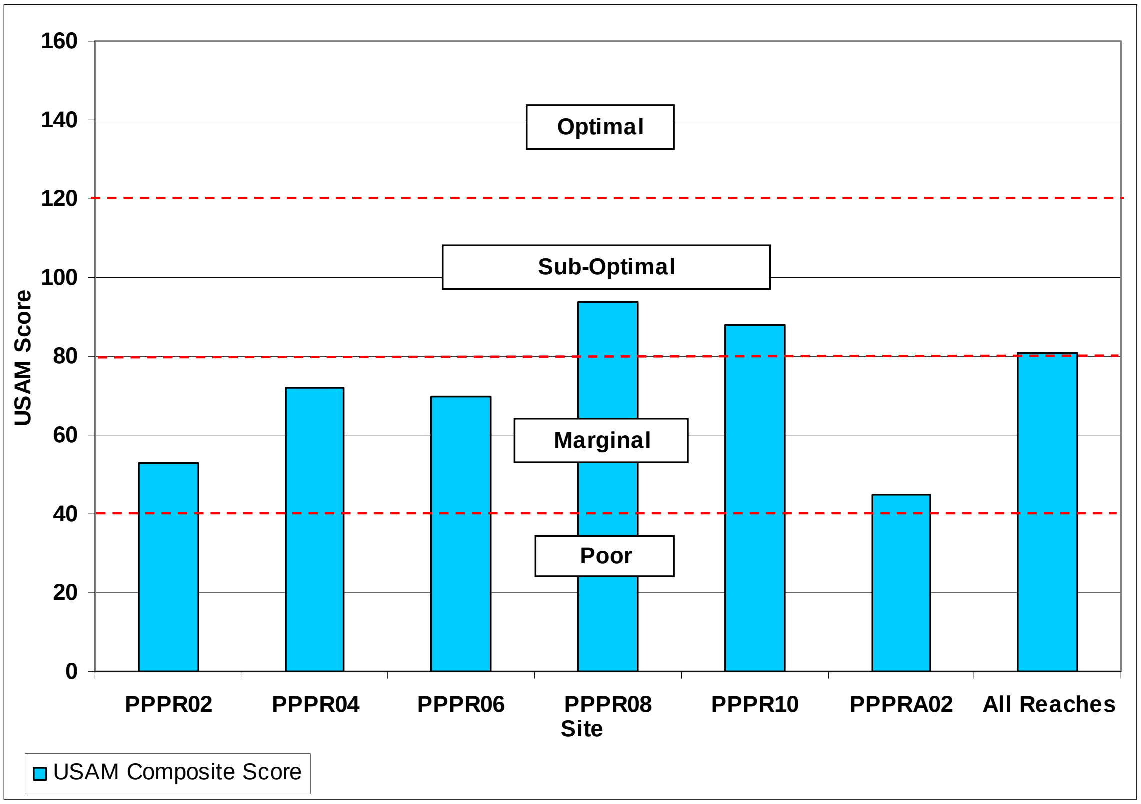


Figure 3-14: Paul's Run USAM Results

3.2.4.1 PPPRA02

Reach PPPRA02 was a 6,188 feet unnamed tributary to the main stem of Paul's Run. The reach began near a commercial facility at the intersection of Northeast Boulevard and Serota Drive and continued through a very narrow and highly developed stream corridor to the confluence with main stem Paul's Run. Due to its location within a heavily developed corridor, the reach was considerably impacted by stormwater conveyance infrastructure and channelization.

Reach PPPRA02 was classified as a Rosgen type B4c stream channel. The channel was moderately entrenched (entrenchment ratio = 1.4) and had a moderate width to depth ratio (15.6) as well. The substrate was dominated by gravel (64%) and sand (30%) and the D_{50} of the reach was 5.5 millimeters which corresponds to fine gravel. The large amount of fine sediment throughout the reach can be attributed to the presence of many large impervious surfaces which abut the stream, many of which have no vegetated buffer to intercept sediment and surface runoff. The overall USAM of the reach was 45/160 which was rated as "marginal".

3.2.4.2 PPPR02

Reach PPPR02 began as concentrated flow from a drainage swale on private property on Sandmeyer Lane. The reach was impacted considerably by infrastructure throughout its length. The stream channel flowed for approximately 1,000 feet before it entered into a 2,035 foot culvert (PPcul038) that conveyed the stream channel beneath residential development bounded by Red Lion Road and Verree Road. Aside from PPcul038, there were four other culverts, three dams, 2168 feet of channelization, as well as seven bridges. Reach PPPR02 was classified as a Rosgen type F4 stream channel and was characterized by an incised channel bed (ER=1.3), a moderate width to depth ratio (16.6) and a substrate particle size distribution dominated by gravel-sized particles. The D_{50} of the reach was 12.9 millimeters which corresponds to medium gravel. The composite USAM score for the reach was 53/160, which was the lowest score observed in the watershed after PPPRA02, which had a composite USAM score of 45/160. Scores for these two reaches were among the lowest scores observed in the Lower Pennypack Creek Watershed along with PPWBA02 (51/160).

3.2.4.3 PPPR04

Reach PPPR04 began 260 feet upstream of the confluence of the main stem of Paul's Run and Paul's Run Tributary A (PPPRA02). The upstream portion of the channel was largely unobstructed by infrastructure with the exception of PPcul040; however, downstream of cross section PPPR04, there were several channels, culverts and bridges that confined the channel. The reach was classified as a Rosgen type F4 stream channel. The stream channel was severely entrenched (entrenchment ratio = 1.2) and also had a large width to depth ratio (27.8), characteristic of F type stream channels. The substrate particle size distribution was dominated by gravel (54%) and sand (43%). The D_{50} of the reach was 2.9 millimeters which corresponds to very fine gravel. The overall USAM score was 72/160 which was classified as "marginal".

3.2.4.4 PPPR06

Reach PPPR06 was confined within a narrow corridor for the majority of its length – bounded by Walley Avenue to the north, Rising Sun Avenue to the south, Krewstown Road to the east and Alburger Street to the west. Downstream of Alburger Street, there was a 975 feet section of the reach that was not confined by roads and did not contain streamside infrastructure. The reach was classified as a Rosgen Type F4 stream channel. The width to depth ratio was 15.4 and the entrenchment ratio was 1.2. As was observed in the upstream reaches, the substrate was dominated by fine sediment with 64% gravel and 25% sand. The D_{50} of the reach was 13.3 which correspond to medium gravel. The overall USAM score for the reach was 70/160 which was rated as "marginal".

3.2.4.5 PPPR08

Reach PPPR08 served as a transition between the largely confined floodplains observed in the upstream segments of Paul's Run and the more open, unconfined floodplains in the lower portion of the creek. Due to the lack of floodplain confinement and in-stream channelization, the reach was considerably more sinuous than the upstream reaches. Upstream of cross-section PPPR08 there were two large mid-channel bars which were attributed to the high supply of fine sediment from the upstream reaches as well as the considerable amount of coarse woody debris that obstructed in-stream flow thereby promoting the deposition of fine sediment.

Reach PPPR08 was classified as a Rosgen Type F4 stream channel with channel morphology very similar to the upstream reaches. The width to depth ratio was very high

(24.1) and the stream channel was deeply entrenched (entrenchment ratio = 1.2). Like the upstream reaches, the substrate was dominated by gravel (73%) and the D_{50} (28.5 millimeters) corresponded to medium gravel. The overall USAM score for the reach was 94/160, which was the highest USAM score of all the reaches on Paul's Run.

3.2.4.6 PPPR10

Reach PPPR10 was the downstream-most reach in Paul's Run. It was the only reach entirely contained within Fairmount Park, thus the floodplain was extensive on both side of the creek. With the exception of a small culvert (PPcul334), the stream channel was free of infrastructure or other obstructions to flow. The reach was classified as a Rosgen type F4 stream channel. The channel morphology was similar to the upstream reaches however both the width to depth ratio and entrenchment ratio for the reach had extreme values. The higher degree of channel widening and incision in this reach compared to the upstream reaches may be attributed to the larger drainage area (1.76 square miles) and the associated higher flows. The substrate particle-size distribution was dominated by gravel (59%) and sand (29%) and the D_{50} of the reach corresponded to medium gravel. The USAM score for PPPR10 was 88/160 which was rated as "suboptimal".

3.2.5 SUMMARY OF UNIFIED STREAM ASSESSMENT RESULTS

Scores for each of the USAM components as well as the overall USAM scores for Paul's Run ranged from "marginal" to "suboptimal". Across all of the reaches in Paul's Run, the mean *Overall Buffer and Floodplain Condition* score and the mean *Overall Stream Condition* score were the same (38.3/80), however neither component nor the overall USAM score had a mean score higher than the respective all reaches averages (Table 3-10).

Table 3-10: USAM Results for Paul's Run

Reach ID	Sub-watershed	Overall Stream Condition	Overall Buffer/FP Condition	USAM Score
PPPRA02	Paul's Run	25	20	45
PPPR02	Paul's Run	30	23	53
PPPR04	Paul's Run	34	38	72
PPPR06	Paul's Run	43	27	70
PPPR08	Paul's Run	44	50	94
PPPR10	Paul's Run	35	53	88
Mean		**35.2**	**35.2**	**70.3**
All Reaches		**38.3**	**42.7**	**81.0**

3.2.5.1 Summary of Overall Stream Condition Scores in the Paul's Run Watershed

Overall Stream Condition scores for the Paul's Run Watershed ranged from "marginal" to "suboptimal". Scores were generally low throughout the watershed due to the prevalence of deeply incised and overwidened stream channels. The highest scores were observed in reaches PPPR06 (43/80) and PPPR08 (44/80) and the lowest score for this component was observed in PPPRA02 (20/80). All of the reaches in the watershed were rated as "poor" for the *Floodplain Connection* parameter. Scores were also low for the *Bank Erosion* and *Vegetative Protection* parameters, especially in PPPRA02 and the two upstream reaches of main stem Paul's Run (Table 3-11). The degraded conditions observed in Paul's Run can be attributed to the large amount of infrastructure within or abutting stream channels. There were vast amounts of outfalls, bridges, culverts and channelized portions which have the potential to impact streamflow characteristics such as discharge, velocity, depth and sediment transport.

Table 3-11: USAM Overall Stream Condition Scoring for the Paul's Run Watershed

Reach ID	Sub-watershed	Instream Habitat	Vegetative Protection		Bank Erosion		Floodplain Connection	Overall Stream Condition
			Left	Right	Left	Right		
PPPRA02	Paul's Run	8	3	4	2	4	4	20
PPPR02	Paul's Run	9	5	4	4	5	3	30
PPPR04	Paul's Run	7	5	7	5	8	2	34
PPPR06	Paul's Run	13	7	9	6	6	2	43
PPPR08	Paul's Run	15	8	7	6	6	2	44
PPPR10	Paul's Run	10	8	6	7	3	1	35
Mean		**10.3**	**6.0**	**6.2**	**5.0**	**5.3**	**2.3**	**34.3**
All Reaches		**11.1**	**6.3**	**6.1**	**5.0**	**5.8**	**4.0**	**43.0**

3.2.5.1.1 In-stream Habitat

Scores for the *In-stream Habitat* parameter ranged from "marginal" to "suboptimal". The mean score for the Paul's Run Watershed was 10.3/20 compared to the All Reaches average score of 11.1/20. The low scores observed in most of the watershed were attributed to several factors but the most obvious was the lack of coarse, stable substrate such as cobble and boulders. The proportion of the substrate composed of fine sediments ranged from a minimum of 77% in PPPR08 to a maximum of 97% in PPPR04. Another factor contributing to the low scores observed in the watershed was the prevalence of overwidened, deeply incised stream channels. These channels often lacked sufficient depths, especially in riffle habitats.

3.2.5.1.2 Vegetative Protection

Scores for the *Vegetative Protection* parameter ranged from "marginal" to "suboptimal" and generally increased along the upstream to downstream gradient. The highest scores were observed in the downstream reaches PPPR06, PPPR08 and PPPR10 where each had at least one bank rated as "suboptimal", although both banks were rated as "suboptimal" in reaches PPPR06 and PPPR08. The lowest scores were observed on the left (3/10) and right (4/10) banks of reach PPPRA02. The score for the left bank of PPPRA02 was the lowest score observed of all the tributaries assessed in the Lower Pennypack Creek watershed.

3.2.5.1.3 BANK EROSION

Severe to moderate bank erosion was characteristic of the upstream reaches on the main stem of Paul's Run as well as PPPRA02, however the score for the right bank of PPPR10 (3/10) was among the lowest assessed in the watershed. The very low scores in the upstream portion of the reach as well as PPPRA02 can be attributed to the large amount of stormwater outfalls that abut the stream channels. In the middle and downstream reaches, bank erosion was not severe although there were multiple locations where localized bank erosion was moderate to severe over short lengths of stream bank.

3.2.5.1.4 FLOODPLAIN CONNECTION

The *Floodplain Connection* parameter was the lowest scoring parameter of the *Overall Stream Condition* component of the USAM assessment for the Paul's Run Watershed. All of the reaches were rated as "poor". This parameter is a measure of the frequency of overbank flooding in a reach. All of the reaches assessed in Paul' Run were deeply entrenched therefore overbank flooding within these reaches occurs at flows much higher those associated with the return interval of the bankfull discharge for this watershed.

3.2.5.2 SUMMARY OF OVERALL BUFFER AND FLOODPLAIN SCORES IN THE PAUL'S RUN WATERSHED

There was a general trend of increasing *Overall Buffer and Floodplain* scores from upstream to downstream due to the high degree of floodplain confinement due to roads and residential and commercial development in the upstream portion of the corridor and PPPRA02. Scores ranged from "marginal" to "suboptimal". The two downstream-most reaches were rated as "suboptimal" and were both rated significantly higher than the All Reaches average (35.2/80) for this component of the USAM assessment. Scores for several parameters were observed to have trends similar to the *Overall Buffer and Floodplain* scores whereas there was a general trend of increasing scores from upstream to downstream. This trend was most pronounced in the *Floodplain Encroachment* parameter as the upstream reaches were rated as "poor" and "marginal" compared to the downstream ratings of "suboptimal" and "optimal".

Table 3-12: USAM Overall Buffer anf Floodplain Scoring for the Paul's Run Watershed

Reach ID	Sub-watershed	Vegatated Buffer Width		Floodplain Vegetation	Floodplain Habitat	Floodplain Encroachment	Buffer/FP Condition
		Left	Right				
PPPRA02	Paul's Run	3	3	7	4	3	20
PPPR02	Paul's Run	4	2	14	3	0	23
PPPR04	Paul's Run	7	10	13	2	6	38
PPPR06	Paul's Run	5	5	11	2	4	27
PPPR08	Paul's Run	10	10	13	2	15	50
PPPR10	Paul's Run	10	10	13	1	19	53
Mean		**6.5**	**6.7**	**11.8**	**2.3**	**7.8**	**35.2**
All Reaches		**5.0**	**5.0**	**11.0**	**2.0**	**4.0**	**81.0**

3.2.5.2.1 VEGETATED BUFFER WIDTH

The scores for this parameter varied tremendously throughout the watershed, ranging from "poor" to "optimal". Generally, most of the reaches within the Paul’s Run watershed had vegetated buffers on both sides of the creek that were in excess of 50 feet and rated as "optimal". The vegetated buffers in the upstream reach PPPR02 and PPPRA02 however, were very narrow and in some places there were no vegetated buffers as parking lots and other development abutted the stream channel.

3.2.5.2.2 FLOODPLAIN VEGETATION

There was not a high degree of variation in the scores for the *Floodplain Vegetation* parameter. All reaches, with the exception of PPPRA02, were rated as "suboptimal". Floodplain vegetation within these reaches was dominated by younger forest stands although there were also forbs, shrubs and grasses present as well. The lowest score was observed in PPPRA02 (7/20), which was rated as "marginal". Floodplain vegetation within this reach was dominated by shrubs, saplings, and grasses, although mature and young trees were also observed.

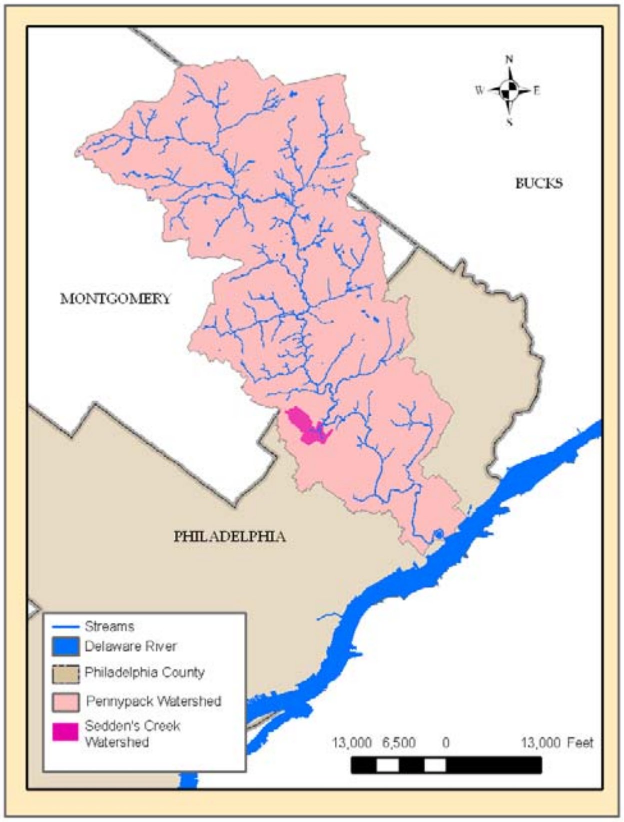
3.2.5.2.3 FLOODPLAIN HABITAT

Scores for this parameter were very low throughout the watershed. Aside from the prevalence of residential and commercial development within the floodplains of the Paul’s Run Watershed, the hydrology to support optimal floodplain habitat was not supported by the deeply entrenched reaches assessed in the study.

3.2.5.2.4 FLOODPLAIN ENCROACHMENT

Floodplain Encroachment scores increased steadily from upstream to downstream. The upstream reaches as well as PPPRA02 were severely impacted by both development and infrastructure on both sides of the corridor. The worst score (0/20) was observed in reach PPPR02. There were a series of dams, numerous outfalls and a very long culvert on this reach which severely impacted the dynamic interaction between the channel and the floodplain in this reach. Downstream of reach PPPR06, scores increased dramatically as the proximity of roads and amount of development decreased and floodplain widths increased.

3.3 MAIN STEM TRIBUTARY F (SEDDEN'S CREEK) WATERSHED AND REACH CHARACTERISTICS



Pennypack Creek Main Stem Tributary F, referred to as Sedden's Creek, is a second order tributary to Pennypack Creek. Sedden's Creek starts at the intersection of Solly Avenue and Verree Road. Sedden's Creek begins as a combination of flow from privately owned outfall PPout855 and direct runoff to 8801 Verree Road. The channel flows about 650 feet and then enters culvert PPcul341. The entrance to this culvert is a stormwater inlet and leads to what is identified as PWD outfall P-099-02. This 72 inch outfall is considered the headwaters of Sedden's Creek. From there Sedden's Creek flows for about 2,900 feet to its confluence with the Pennypack Creek Main Stem. Approximately 1,050 feet upstream from the confluence a small tributary adds flow from the small southeastern portion of the watershed. The tributary conveys flow from Apple Blossom Way and the rest of the neighborhood off of Rhawn Street. For reach maps refer to Appendix C. The dominant substrate of Sedden's Creek varies from very fine sand to very coarse gravel.

Sedden's Creek Watershed is 328 acres. The major land use types include residential: multi-family (33%), residential: single-family detached (30%), and wooded (18%). Almost the entire stretch of Sedden's Creek and its tributary are within Fairmount Park. Only about 800 feet of Sedden's Creek are outside of the park. The buffer width in the park can be as much as 1,000 feet.

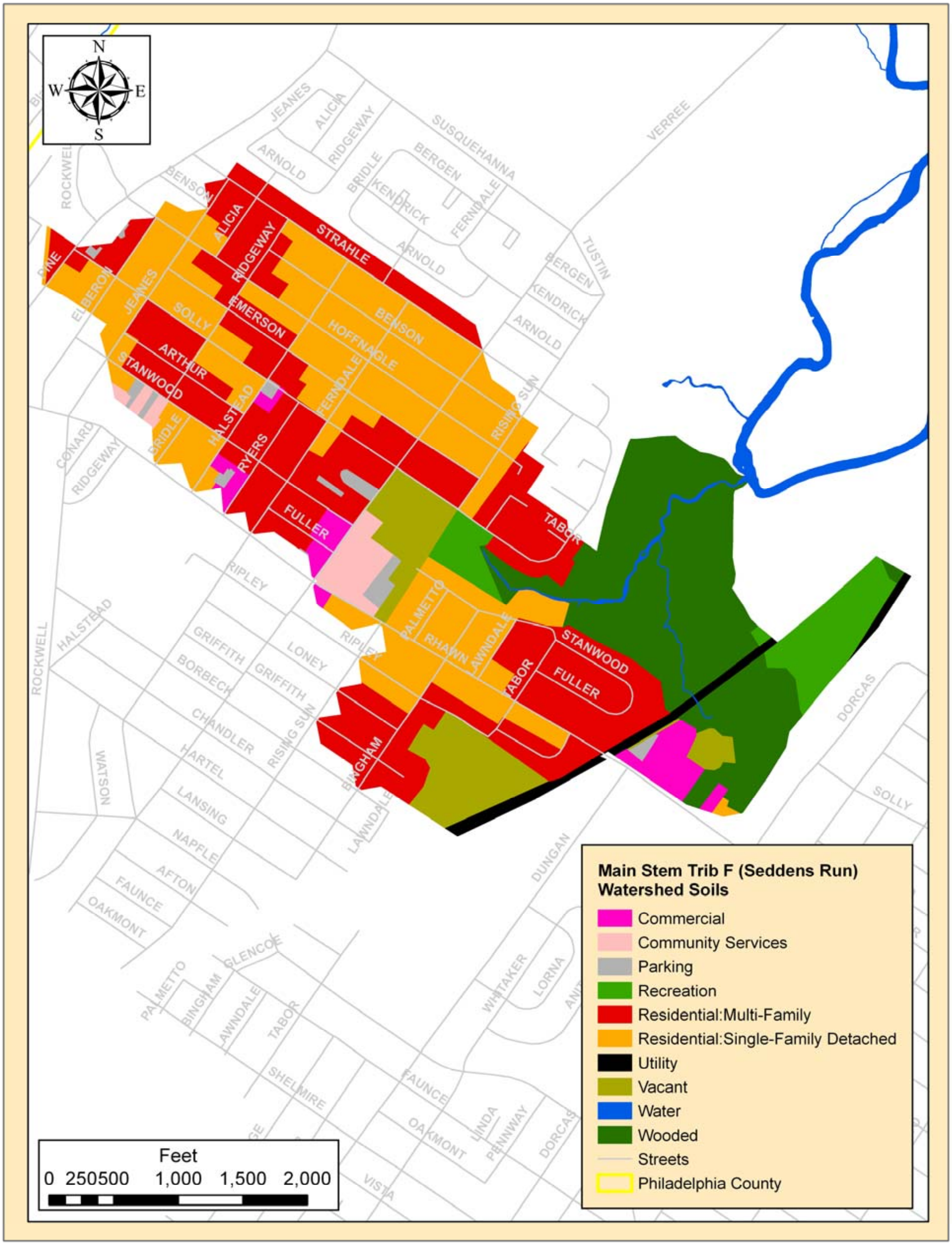


Figure 3-15: Main Stem Tributary F (Sedden's Creek) Land Use

3.3.1 GEOLOGY

Sedden's Creek's geology is characterized by the Wissahickon Formation. The majority of the watershed is underlain by oligioclase mica schist which is a main component of the Wissahickon Formation. The formation also consists of gneiss and quartzite. Exposed schist at the surface is highly weathered.

A small portion of the watershed is underlain by a mafic gneiss, hornblende bearing formation. This formation is composed of medium grained, dark colored, calcic plagioclase, hyperthene, augite, and quartz. Rocks included in this geologic arrangement are of sedimentary origin. This formation is very resistant to weathering, but has good surface drainage.

3.3.2 SOILS

According to the National Resource and Conservation Service Soil Survey (United States Department of Agriculture, 2006), over 80% of the soils in the Sedden's Creek Watershed are classified as Urban Land (Figure 3-17). Urban soils consist of material that has been disturbed by human activity during urbanization. Urban soils have been produced by mixing, filling and contamination of the native soils in both urban and suburban areas.

The rest of the watershed consists of hydrologic groups B, and C soils. Group B soils have a moderate rate of infiltration when the soils are wet (0.50-1.00 in/hr). Water movement through these soils is considered moderately rapid. B soils occupy most of the area within the Fairmount Park boundary and a small area outside the park. There is section of C soils located in the area directly surrounding the stream. Group C soils have a slow rate of infiltration when saturated (0.017-0.27 in/hr). Water movement through these soils is moderate or moderately slow.

Table 3-13: Distribution of NRCS Soil Types in Sedden's Creek Watershed

Group	Area (ft2)	Percent of Total Area
B	1,745,639	11.81%
C	567,523	3.84%
Urban Land	12,472,500	84.36%
Total Area	14,785,662	100%

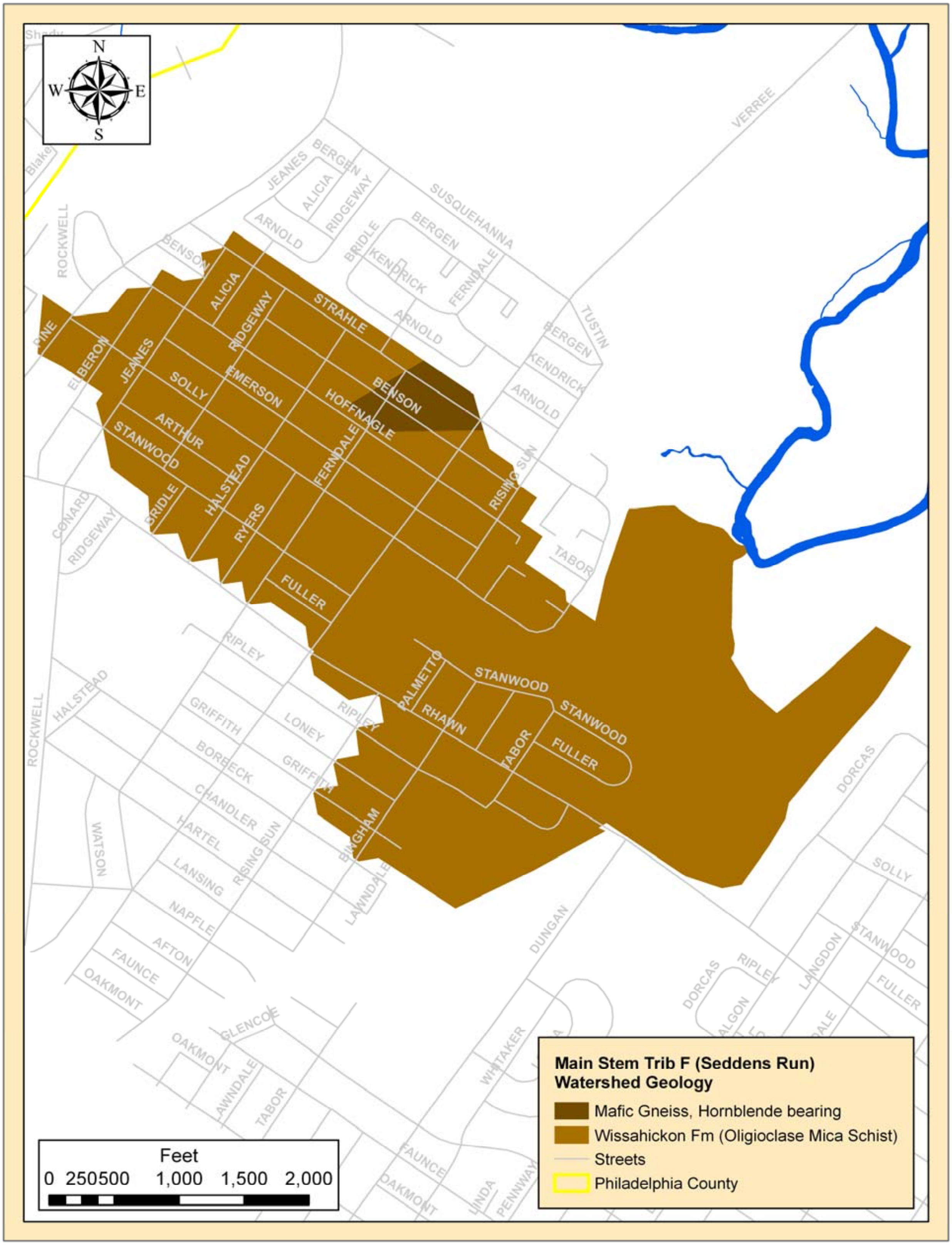


Figure 3-16: Geology of Main Stem Tributary F (Sedden's Creek) Watershed

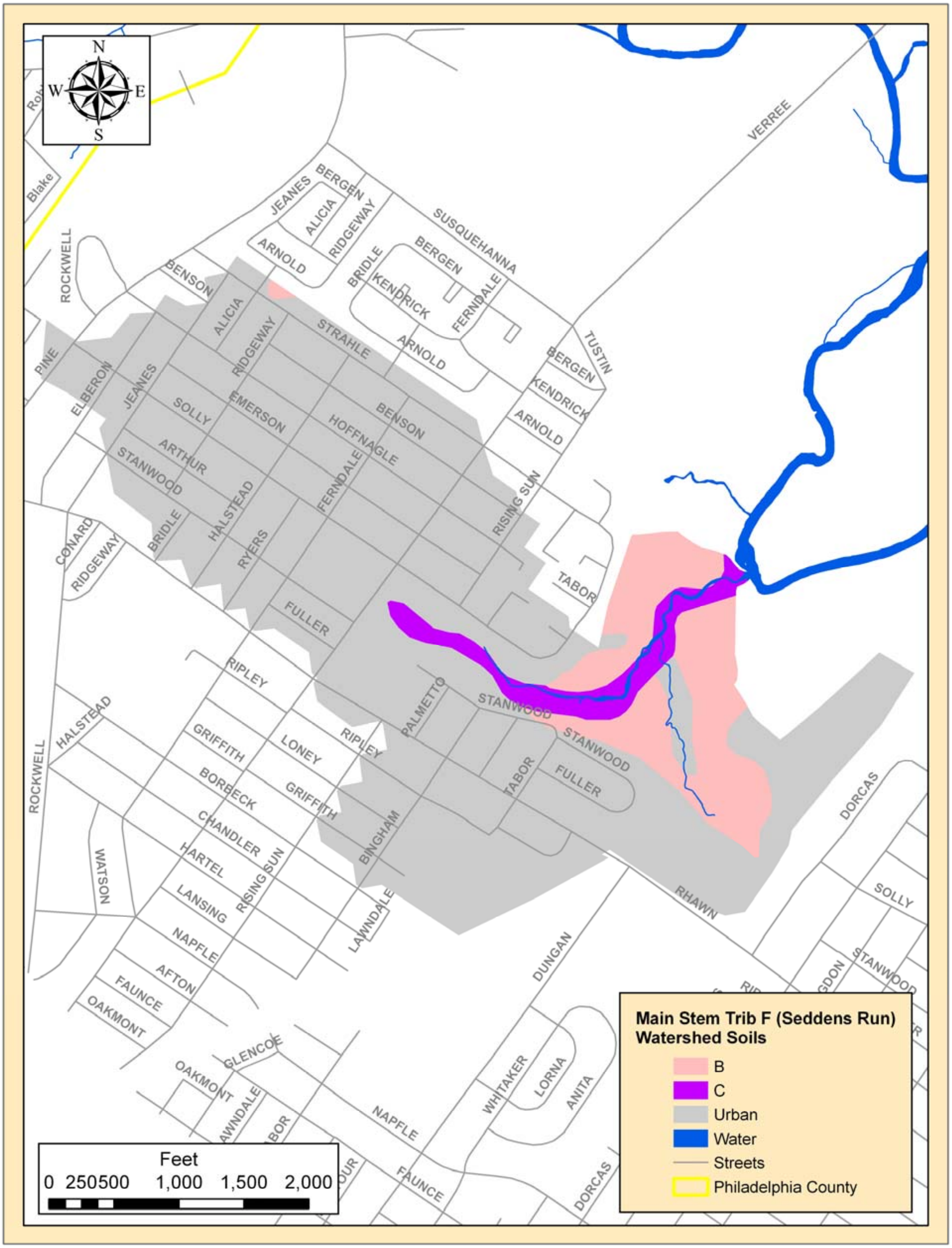


Figure 3-17: Distribution of NRCS Soil Types in Main Stem Tributary F (Sedden's Creek) Watershed

3.3.3 INFRASTRUCTURE TRACKDOWN SUMMARY

The infrastructure of Sedden's Creek (Main Stem Tributary F) is characterized by stream crossing and conveyance infrastructure, as well as drainage and stabilization amenities. The majority of the stream is located within Fairmount Park or nearby undeveloped land. The watershed surrounding the stream corridor however is highly developed with residential neighborhoods occupying over 60% of the watershed.

There were a total of 23 infrastructure elements recorded during the field study of Sedden's Creek. The most prevalent types of infrastructure in the Sedden's Creek Watershed were culverts (9) followed by channels (8). Many of the culverts can be attributed to the stream's location within Fairmount Park and trails crossing the stream. There was also a culvert to convey the flow from the tributary in the southeast under the railway and another that conveys Sedden's Creek below a swimming pool near Solly Street. The channels are mostly located around outlet structures such as outfall PPout1059 or the end of culvert PPcul341. At these locations stormwater from the drainage area is discharged to the stream channel. The channel walls were implemented at these points to prevent the localized erosion from the surge.

Culvert PPcul341 is a particularly important piece of infrastructure for Sedden's Creek. This culvert conveyed the northwest most portion of Sedden's Creek past the pool on Solly Street. It was actually a 6 feet diameter outfall, identified as PWD outfall P-099-02, at the end of the stormwater network that drains the northwestern portion of the watershed. Because of this the area associated with the orifice from PPcul341 was added to the combined outfall area for PPMSF and the length was removed from the culvert length (Table 3-14 and Table 3-15). This structure contributes a substantial amount of runoff to the stream during storm events. PPout1059 is a 5 feet by 6 feet stormwater conduit discharge point that contributes drainage from the southern portion of the watershed to Sedden's Creek. This outfall is the main contributor to the large outfall area (61.3 square feet) in Sedden's Creek. The majority of the infrastructure on Sedden's Creek was upstream of the confluence where the flow from PPout1059 enters the main channel of Sedden's Creek. Downstream of that point there is only a channel, bridge, and culvert.

Sedden's Creek had three infrastructure elements in poor condition observed during the survey. They were culvert PPcul342 and channels PPchan419 and PPchan421. PPcul342 appeared to have structural damage and the apron had become undermined by erosion. The stone channel PPchan419 was segmented and weathered. This is most likely due to the high flows impacting the bank and altering the stones. The concrete channel PPchan421 is the downstream right bank protection at the outfall PPout1059. The outfall appeared to have been undermined by erosion and eventually collapsed. A similar situation could occur at PPchan420 where the channel was also substantially undermined.

Table 3-14: Sedden's Creek Infrastructure Point Features

Section ID	Bridge Count	Channel Count	Culvert Count	Outfall Count	PipeSewer Count	Infra Points Count	Total Combined Outfall Area (ft^2)	Priority Infra Points Count
PPMSF02	1	8	9	4	1	23	61.3	3

Table 3-15: Sedden's Creek Infrastructure Linear Features

Section ID	Total Segment Length (ft)	Culvert Length (ft)	% Culverted	Channel Length, 1 side	Channel Length, 2 sides	Channel Length, 3 sides	Total Channel Length	Total Segment Length, 3 sides	% Channelized
PPMSF02	4535	344	7.6	314	138	0	590	13605	4.3

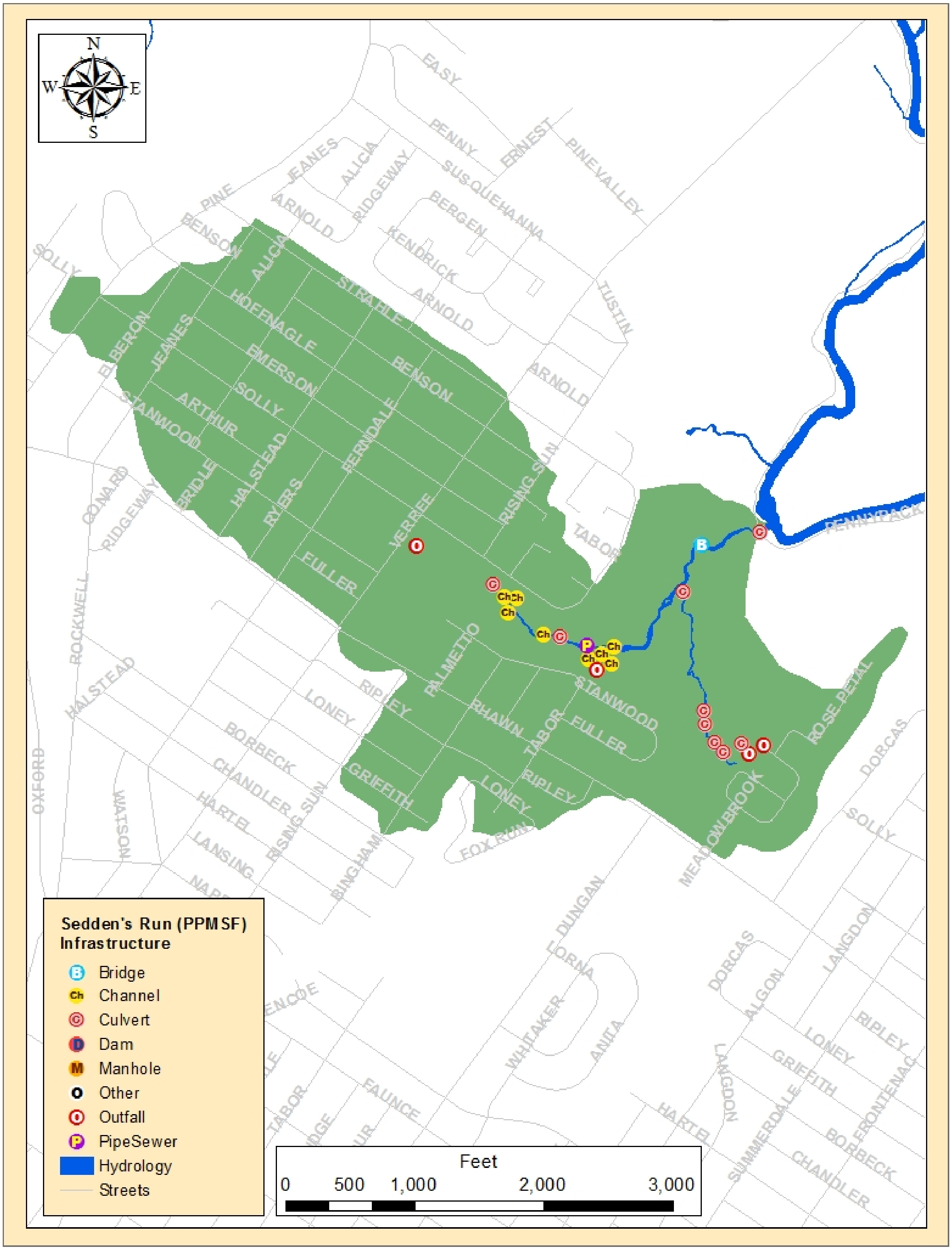


Figure 3-18: Main Stem Tributary F (Sedden's Creek) Watershed Infrastructure

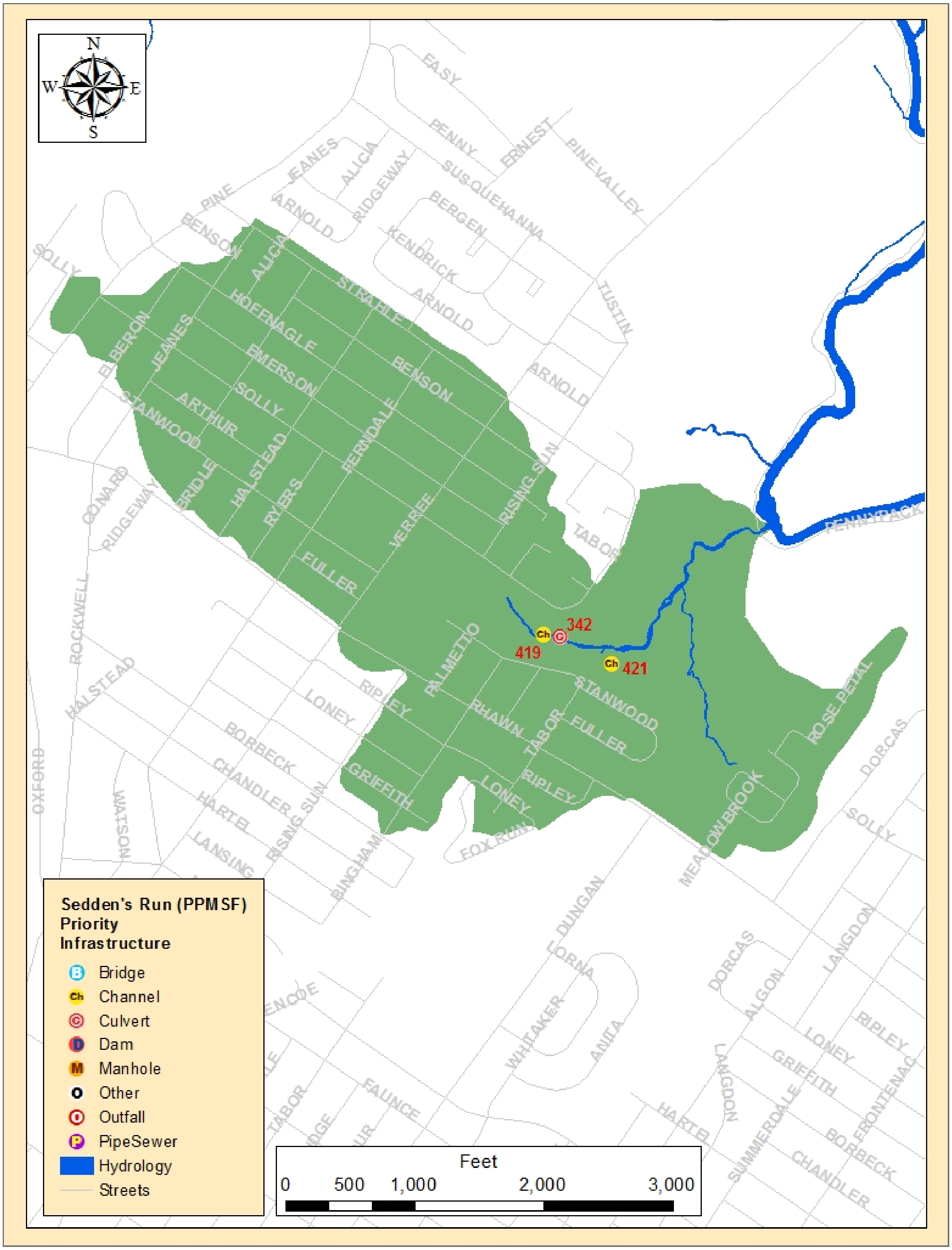


Figure 3-19: Main Stem Tributary F (Sedden's Creek) Watershed Priority Infrastructure

3.3.4 Unified Stream Assessment Results for the Main Stem Tributary F (Sedden's Creek) Watershed

Main stem tributary F, or Sedden's Creek was a relatively small second order tributary located on the west bank of Pennypack Creek. The downstream-most portion of the reach was within Fairmount Park whereas the headwaters of both branches were located on private land.

The Center for Watershed Protection's (CWP) Unified Stream Assessment Methodology (USAM) was used to score and rate the in-stream, riparian buffer and floodplain conditions of the stream corridor to allow for comparison to other reaches and watersheds within the Lower Pennypack Creek basin. The All Reaches parameter is the mean of the scores of all tributary reaches in the Lower Pennypack Creek study.

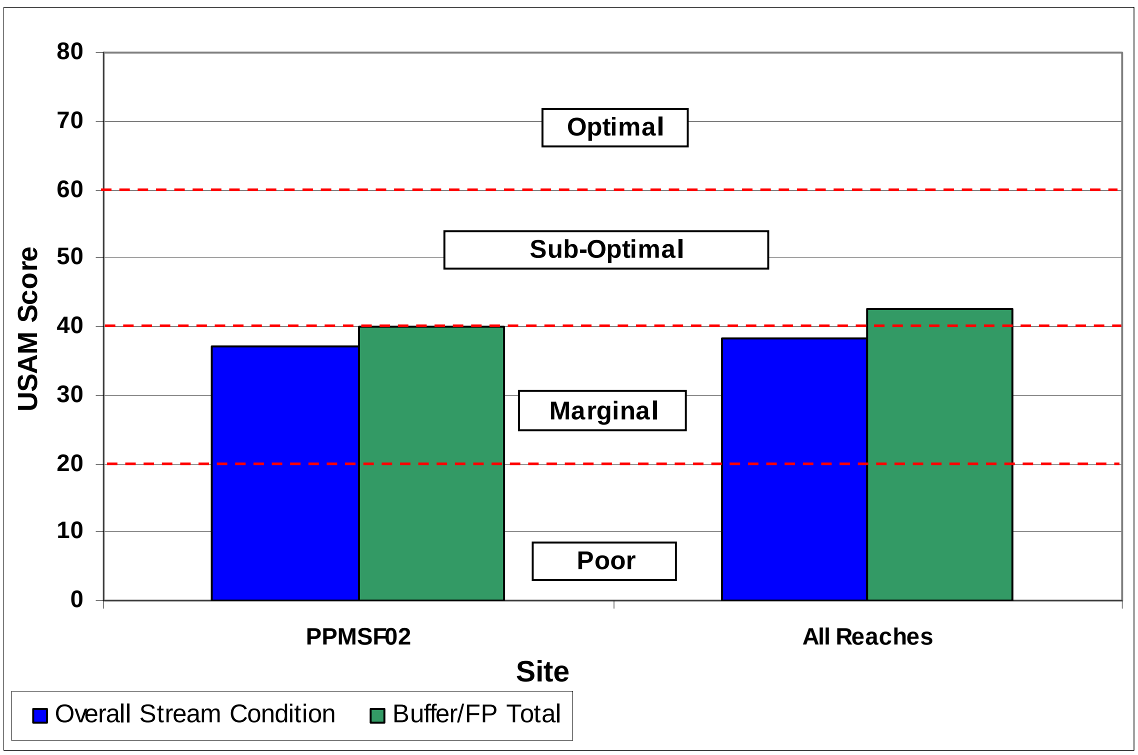


Figure 3-20: Results for Sedden's Creek (PPMSF02) USAM Components

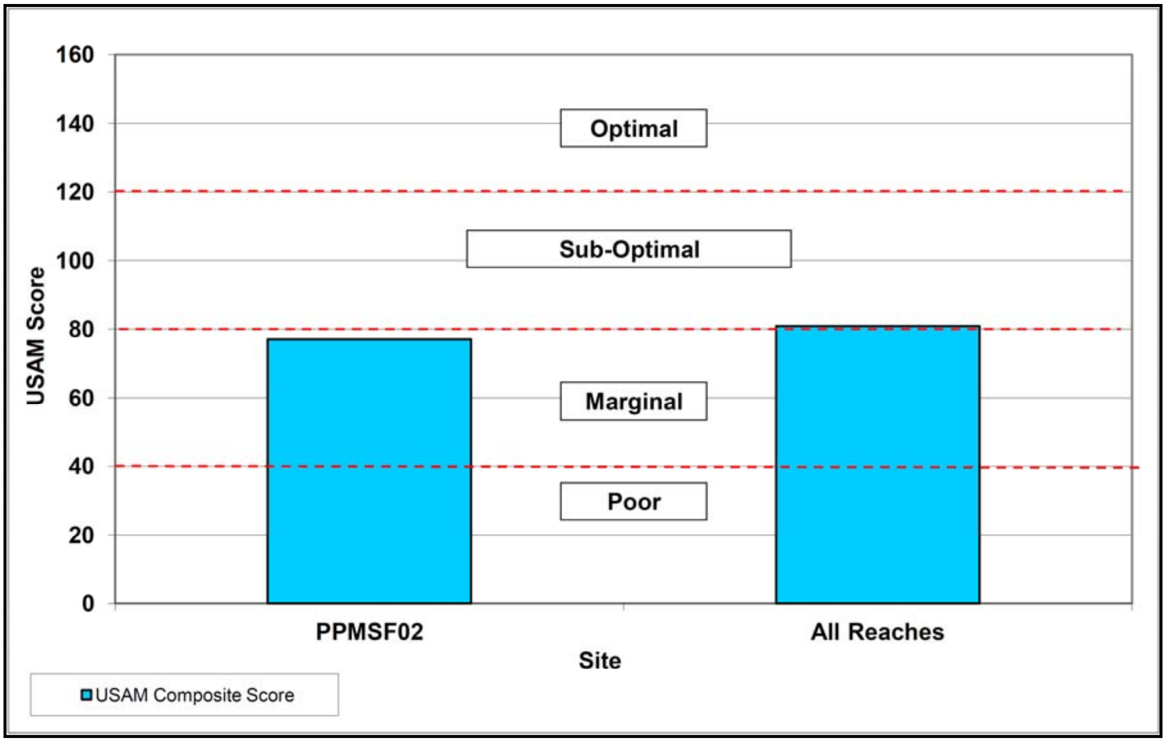


Figure 3-21: USAM Results for Sedden's Creek (PPMSF02)

3.3.4.1 PPMSF02

The main branch of PPMSF02 began on a private parcel on Stanwwod Street. Additional flow inputs derived from a wooded basin bounded by Verree Avenue to the west and Solly Street to the north. A smaller branch, referred to as Split-Rock Hollow Run, reached a confluence with the main branch at PPcul348. This channel was intermittently wet as most flow was derived from stormwater inputs from PPout856 and PPout857. The vast majority of the reach was located within Fairmount Park, thus the riparian buffer in the lower half of the reach was extensive and lacked significant infrastructure impacts.

PPMSF02 was classified as a Rosgen type F4 stream channel. The channel was entrenched (entrenchment ratio = 1.3) and the width to depth ratio was considerably high at 33.7. The substrate was dominated by finer particles as gravel comprised 53% of the substrate particle size distribution followed by sand at 29%. Overall, the reach was rated as "marginal" with a USAM score of 77/160, slightly below the All Reaches average for tributaries of 81/160 (Figure 3-21).

3.3.5 Summary of Unified Stream Assessment Results

Scores for the *Overall Stream Condition*, *Overall Buffer and Floodplain Condition* as well as the overall USAM score were all rated as "marginal". For both components as well as the overall USAM score, the All Reaches average was slightly higher than the score observed in PPMSF02. The scores for individual parameters ranged from "poor" to "suboptimal" although most were within the "marginal" range of scores.

Table 3-16: USAM Results for the Sedden's Creek Watershed

Reach ID	Sub-watershed	Stream Total	Buffer/FP Total	Overall Total
PPMSF02	Sedden's Creek	37	40	77
All Reaches Avg	-	**38.3**	**42.7**	**81**

3.3.5.1 Summary of Overall Stream Condition Scores in the Main Stem Tributary F Watershed

Scores for parameters within this component were representative of the average conditions observed within Lower Pennypack Creek tributaries. The highest scoring parameter was *Bank Erosion* on the downstream right bank of PPMSF02 which was rated at the upper extent of the "suboptimal" range of scores. Scores for both the right and left bank for this parameter were higher than the respective All Reaches averages. The lowest score observed for this component was the *Floodplain Connection* score (3/10) which was rated as "poor".

Table 3-17: USAM Stream Assessment Results for Sedden's Creek Watershed

Reach ID	Sub-watershed	Instream Habitat	Vegetative Protection		Bank Erosion		Floodplain Connection	Overall Stream Condition
			Left	Right	Left	Right		
PPMSF02	Sedden's Creek	10	4	5	6	9	3	37
All Reaches Avg		**11.1**	**6.3**	**6.1**	**5.0**	**5.8**	**4.0**	**38.3**

3.3.5.1.1 In-stream Habitat

The score for the *In-stream Habitat* parameter (10/20) was rated as "marginal". The low score in PPMSF02 was attributed to the lack of stable, coarse substrate throughout the reach. The substrate particle size distribution was dominated by sand and gravel. Similarly, the D_{50} of the reach (16.3 millimeters) corresponded to coarse gravel. In some portions of the reach, channel bars and point bars consisting of fine to medium grain sediment created narrow sections of stream channel that promoted depth heterogeneity. There were occurrences of larger substrate such as cobble and small boulders; however the prevalence of fine sediment promoted streambed embeddedness throughout the reach. The proximity of the stream channel to trails and eroding hillslopes could explain the presence of fine sediment within the reach.

3.3.5.1.2 VEGETATIVE PROTECTION

Scores for both the left (4/10) and right banks (5/10) were rated as "marginal". Due to the incised nature of the stream channel, many banks were denuded of vegetation due to erosion, or were composed of fine to medium sediment as a result of deposition. Both of these scores were below the tributaries All Reaches averages.

3.3.5.1.3 BANK EROSION

The *Bank Erosion* parameter was the only parameter of the Overall Stream Condition component to score higher than the All Reaches average scores for both the left and right banks. Bank erosion was more pronounced on the downstream left bank where severely undercut banks were observed. Some of these banks were protected by the presence of large boulders; however there are instances where the presence of large boulders diverted flow towards streambanks as opposed to offering a degree of protection.

3.3.5.1.4 FLOODPLAIN CONNECTION

The *Floodplain Connection* parameter was the lowest scoring parameter for this component of the USAM assessment. The channel was deeply incised which decreased the frequency of over bank flooding in the reach. As with most Rosgen type F stream channels, the deeply incised channel was also very wide such that at baseflow, flow depths remained relatively shallow, especially in riffles, throughout the reach.

3.3.5.2 SUMMARY OF OVERALL BUFFER AND FLOODPLAIN CONDITION SCORES IN THE MAIN STEM TRIBUTARY F WATERSHED

Scores for the *Overall Buffer and Floodplain Condition* were slightly higher than the *Overall Stream Condition* component. Much of the Sedden's Creek corridor had an extensive floodplain, mostly free of development and infrastructure. In the upper portion of the reach, near private development, there were several segments of the reach that were channelized. The branch of Sedden's Creek that emanated from the Peach Tree Lane development had three small culverts, but otherwise this branch was free of infrastructure. The scores for the *Vegetated Buffer Width* and *Floodplain Vegetation* parameters were relatively high and were rated as "suboptimal" except for the downstream right bank which was rated as "marginal" for the *Vegetated Buffer Width* parameter. The downstream right bank had a narrow vegetated buffer along most of the main stem of Sedden's Creek due to the presence of a paved trail to Fairmount Park. The Overall Buffer and Floodplain Condition score was 40/160 and was rated as "marginal" compared to the All Reaches average of 42.7/160 which was rated as "suboptimal" (Table 3-18).

Table 3-18: USAM Buffer and Floodplain Scoring for the Sedden's Creek Watershed

Reach ID	Sub-watershed	Vegetated Buffer Width		Floodplain Vegetation	Floodplain Habitat	Floodplain Encroachment	Overall Buffer/FP Condition
		Left	Right				
PPMSF02	Sedden's Creek	8	5	14	3	10	40
All Reaches Avg	**-**	**8.0**	**7.5**	**12.7**	**4.3**	**11.1**	**42.7**

3.3.5.2.1 VEGETATED BUFFER WIDTH

The score for the *Vegetated Buffer Width* parameter on the downstream left bank was the highest score observed among all of the parameters in the *Overall Buffer and Floodplain Condition* component of the USAM assessment. The downstream right bank had a considerable degree of development in the form of a paved trail that began at Tabor Road and abutted the main stem channel until the confluence with Pennypack Creek. The score of 8/10 for the downstream left bank was negligibly lower than the All Reaches average of 8.04/10 (Table 3-18).

3.3.5.2.2 FLOODPLAIN VEGETATION

The score for the Floodplain Vegetation parameter was rated as "suboptimal" for PPMSF02. The score of 14/20 was slightly higher than the All Reaches average score of 12.7/20 (Table 3-18). Floodplain vegetation was characterized by a predominantly young secondary forest although mature trees, shrubs and forbs were also abundant but with sparse distributions. In the vicinity of trails floodplain vegetation, especially shrubs and forbs, were impacted by runoff from the paved asphalt trails as well as rogue trails created to access the stream.

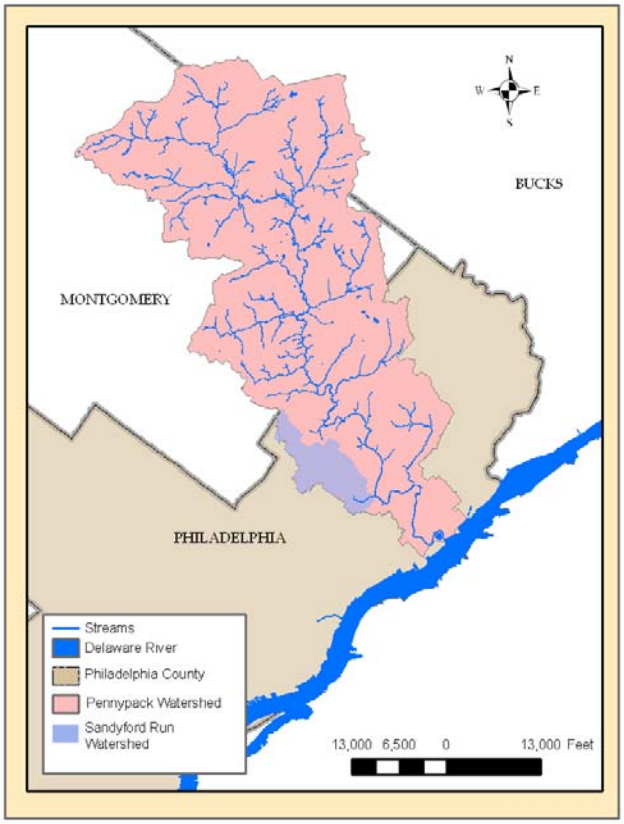
3.3.5.2.3 FLOODPLAIN HABITAT

The *Floodplain Habitat* parameter was the lowest scoring parameter in PPMSF02 with a score of 3/10 which was rated as "poor". The low score for the reach was attributed to the lack of floodplain connection as measured by the low entrenchment ratio (1.3). The low frequency of overbank flooding throughout the reach does not fully support the hydrology needed to maintain floodplain habitat such as vernal pools and small floodplain wetlands.

3.3.5.2.4 FLOODPLAIN ENCROACHMENT

There were several infrastructure elements that had considerable impacts to floodplain function throughout the reach. At the headwaters of both branches were private residential developments as well as culverts to convey the streams beneath streets and private roads. In the upper portion of the main stem, there were several channelized segments as well. The score of 10/20 was rated as "marginal", slightly lower than the All Reaches average of 12/20, which was also rated as "marginal".

3.4 SANDYFORD RUN WATERSHED AND REACH CHARACTERISTICS



Sandyford Run is a tributary to the main stem of the Pennypack Creek. Sandyford Run originates from two outfalls near the Roosevelt Boulevard and Brous Street intersection in the northeast section of the City of Philadelphia. The entirety of the subwatershed is located within the City of Philadelphia. Sandyford Run is a first-order tributary with no other tributaries entering it before its confluence with the Pennypack Creek Main Stem. For reach maps refer to Appendix C.

The stream channel of Sandyford Run flows for approximately 3,645 feet and has been substantially impacted by past and current land use. The entire Sandyford Run Watershed is 1,724 acres (2.7 square miles). Land use in the subwatershed is predominately residential (about 70%) with multifamily residential (56%) and residential – single family detached (14%). Other land use types within the subwatershed include transportation (7%), commercial/services (7%), community service (4%) and wooded (4%) (Figure 3-22).

Sandyford Run's drainage area includes some of the most densely populated and developed areas of the entire Pennypack Creek Watershed. This has resulted in severe modification of the stream's hydrologic regime, which is typical of many urban watersheds. Stormwater systems efficiently route runoff from impervious surfaces into storm sewers which eventually discharge into urban streams. The flows in Sandyford Run and many other urban streams are therefore extremely flashy, with very little flow in dry weather and extremely high flows in wet weather when the storm sewers are filled. Pollution is a concern because Sandyford Run is impacted by illegal wastewater contributions to the stormwater conduits, called defective laterals. In dry weather, flow is directed to the Northeast Wastewater Treatment Plant through flow diversion valves, but in wet weather when the system is overwhelmed with water, untreated discharges can occur. Trash and debris of various sizes were observed throughout the stream channel. Algae were also observed growing in abundance on rocks in the stream channel, an indicator of excessive nutrient loading in the stream.

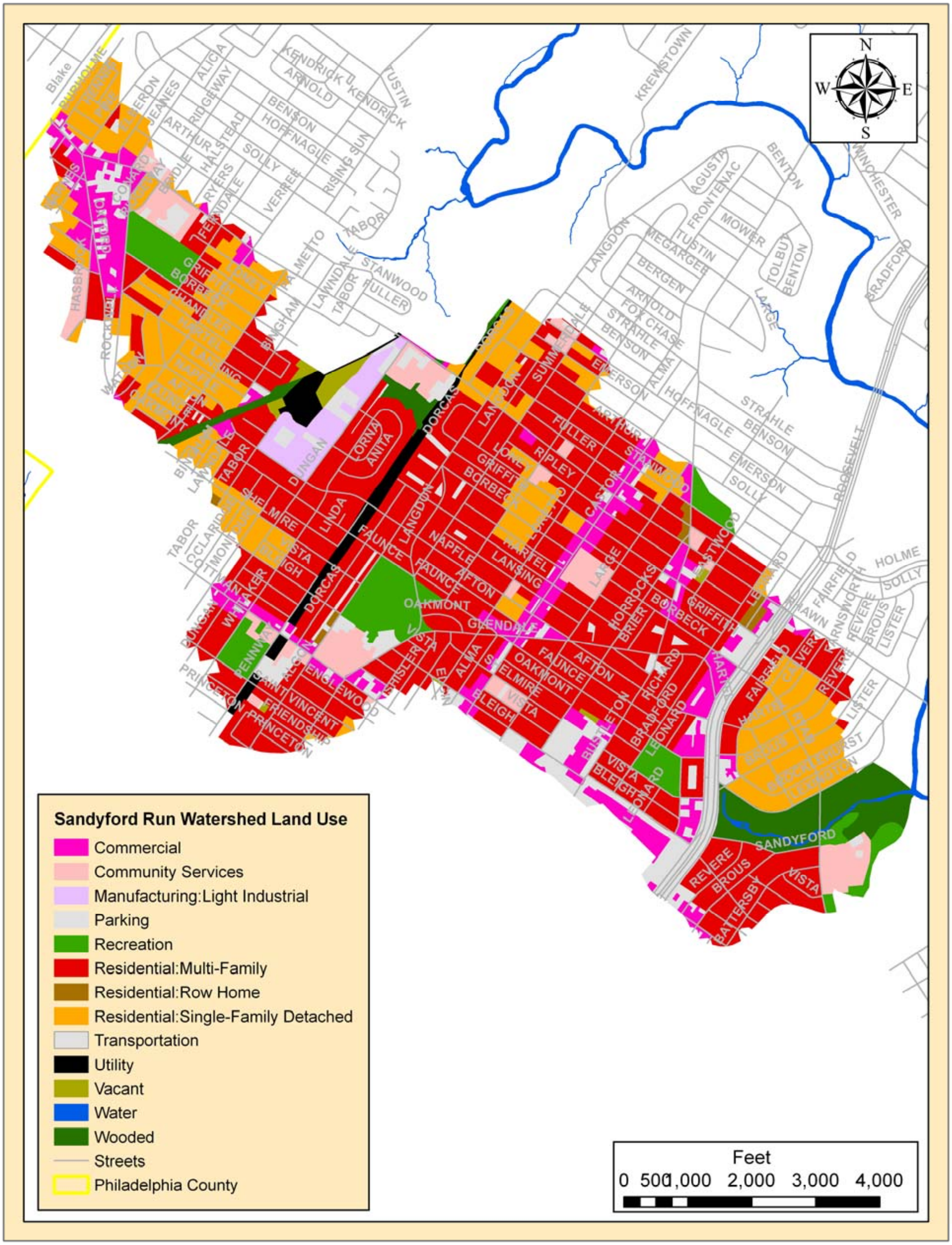


Figure 3-22: Sandyford Run Watershed Land Use

3.4.1 GEOLOGY

Sandyford Run is located entirely within the Lowland and Intermediate Upland Physiographic Province. The majority (about 74%) of the Sandyford Run Watershed is underlain by the Wissahickon Formation (Figure 3-23). The Wissahickon Formation consists of dense micaceous silver to brown garnet mica-schist with quartzite, gneiss, and migmatite. Color and mineralogy is variable with changes in metamorphic grade. Near the surface, the soft rock is deeply weathered.

Scattered other portions of the subwatershed is underlain by the Pennsauken and Bridgeton Formations, which consists of dark-reddish-brown, cross-stratified, feldspathic quartz sand and some thin beds of fine gravel and rare layers of clay or silt. The Pennsauken Formation in particular is a highly weathered floodplain formation.

3.4.2 SOILS

According to the National Resource and Conservation Service Soil Survey, over 95% of the soils in the Sandyford Run Watershed are classified as Urban Land (Figure 3-24). Urban soils consist of material that has been disturbed by human activity during development. Urban soils have been produced by mixing, filling and contamination of the native soils in both urban and suburban areas.

The rest of the watershed consists of hydrologic groups B and D soils. These soil groups are prevalent in the Fairmount Park area directly surrounding the stream. Group B soils have a moderate rate of infiltration when the soils are wet (0.50-1.00 in/hr). Water movement through these soils is considered moderately rapid. The area immediately around the stream belongs in category D for soils. These soils have a very slow infiltration rate when saturated (0.02-0.10 in/hr) resulting in a high runoff potential.

Table 3-19: Distribution of NRCSS Soil Types in Sandyford Run Watershed

Group	Area (ft2)	Percent of Total Area
B	1,591,618	2.15%
D	721,232	0.97%
Urban	71,691,724	96.87%
Total Area	74,004,574	100%

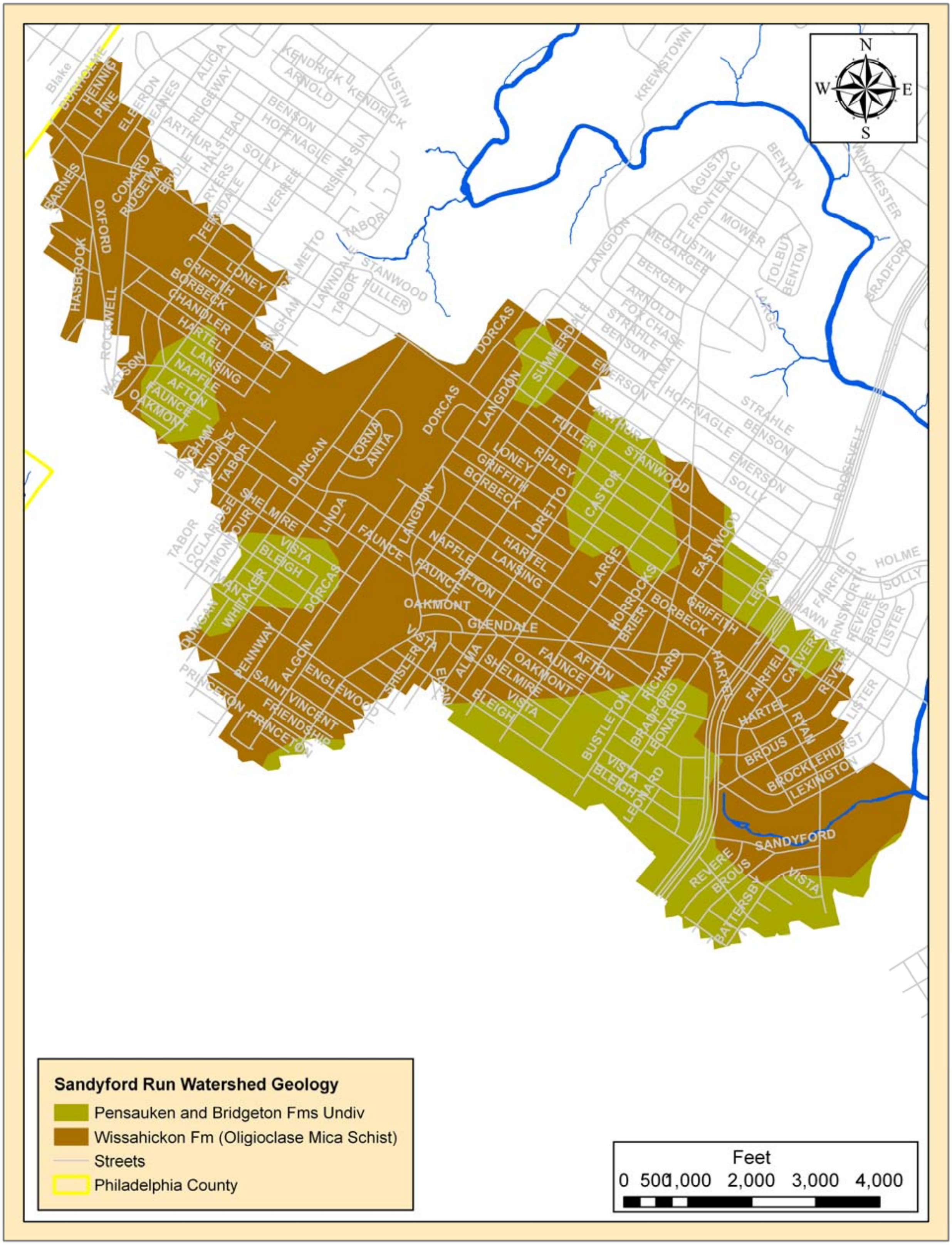


Figure 3-23: Geology of Sandyford Run Watershed

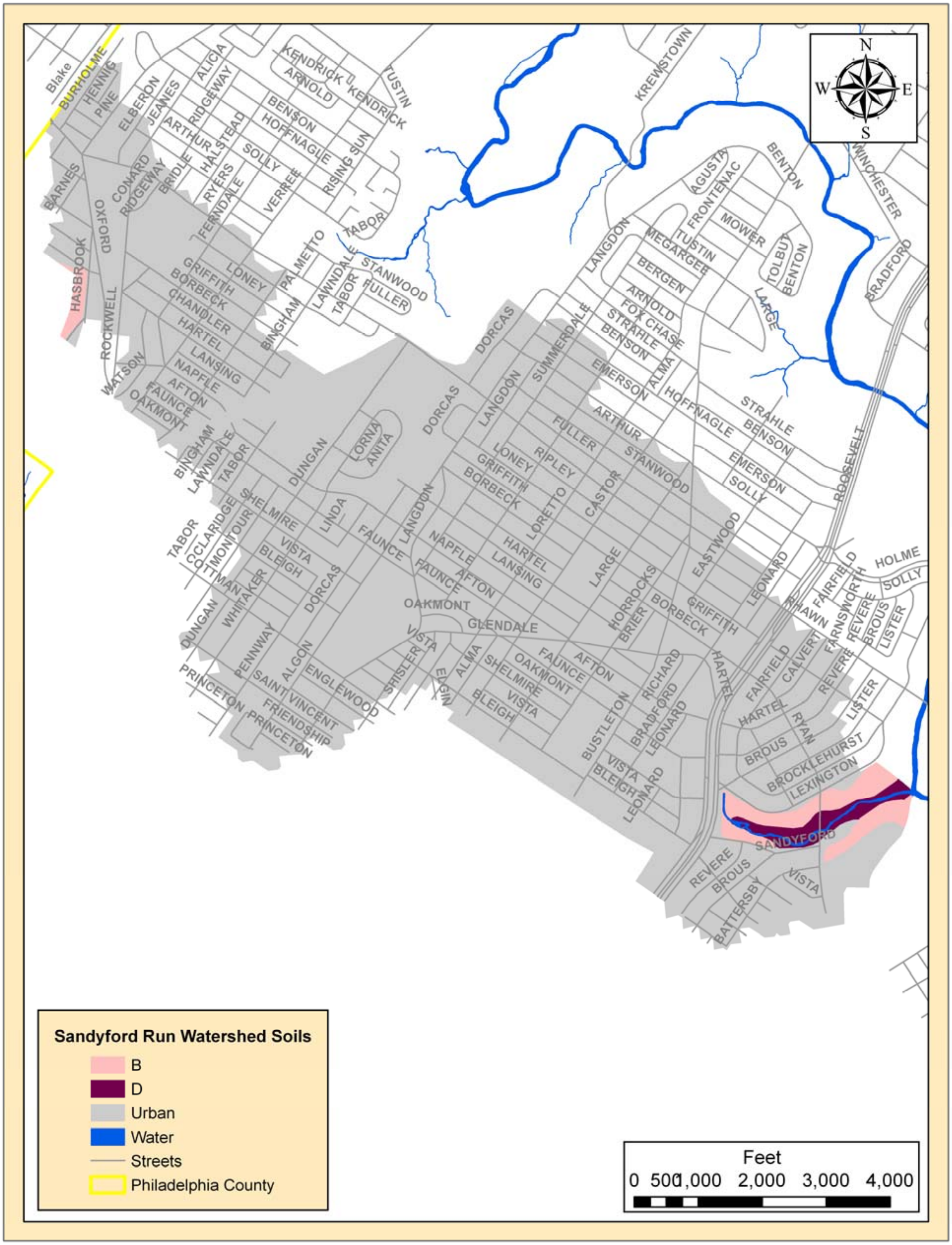


Figure 3-24: Distribution of NRCS Soil Types in Sandyford Run Watershed

3.4.3 INFRASTRUCTURE TRACKDOWN SUMMARY

Though the entire length of Sandyford Run is located within the Fairmount Park boundaries of Pennypack Park, the vast majority of the subwatershed drains from developed land. This accounts for the abundance of infrastructure that was found in the stream channel. There were 24 infrastructure points and 11 channels found along 3,830 feet of stream (Figure 3-25). Overall, the reaches most impacted by infrastructure were PPSR01 and PPSR03b since they contained more infrastructure of a detrimental nature to the stream channel, though all the reaches were impacted by infrastructure. PPSR03b also had the most infrastructure points (17 points), while PPSR02 had only one infrastructure point. It should be noted, however, that these were the second longest and the shortest reaches surveyed, respectively.

The most prevalent infrastructure elements in Sandyford Run are outfalls, accounting for almost half of the infrastructure (12 points) encountered in the stream. There are a few reaches where numerous outfalls were observed. PPSR03b had eight outfalls, and PPSR01 and PPSR03a each had two outfalls. Four outfalls in PPSR03b were located under the Ryan Avenue Bridge, and two were immediately after the bridge on either side of the stream. One outfall (PPout006) was far enough away from the stream that it created a small secondary channel from its scour pool. The previous survey of this site noted fine sediment in both this secondary channel and the scour pool.

PPSR01 had the most extensive outfall area at 163.1 square feet, followed by reach PPSR03b at 23.6 square feet and reach PPSR03a at 7.9 square feet. The large outfall area of PPSR01, despite its having only two outfalls, is due to the large 12 feet by 13 feet outfall at the head of the stream. This outfall drains a 2.4 square mile mostly residential drainage area.

The Sandy Run Interceptor pipe is an active waste water gravity main that runs along the stream channel and periodically crosses underneath it. Many of the infrastructure points observed were connected to this 30 inch diameter interceptor in some way. PPman003 and PPman004, connect directly to the interceptor. PPpip005 is another gravity main in the sanitary system which crosses the stream from Sandyford Road and connects with the Sandy Run Interceptor on the downstream right side. PPpip016 is the Sandy Run Interceptor itself crossing the stream, after which the interceptor follows the trail on the downstream right side of the stream until it joins the Pennypack Creek Interceptor. Though these pipes are currently in good condition and completely encased in concrete, they could become a concern over time if they are damaged by the periodic high flows in Sandyford Run.

There was a significant channelized portion found which extends 495 feet from the head of the stream at outfall PPout001. The channelized portion was about 32% of the length of reach PPSR01 and 10% of the whole stream, and it significantly impacts the hydrology and geomorphology of this reach as well as the entirety of Sandyford Run. There is a very large scour pool immediately after the channelized portion ends, the deepest part of which was too deep to be measured in this survey. The stream splits into a secondary channel with an island between it and the primary channel. This secondary channel appeared only to be filled with running water during high flows when the primary channel cannot contain all of the discharge.

There are two bridge crossings on Sandyford Run, the Ryan Avenue Bridge and a smaller foot bridge that connects trails on either side of the stream. The Ryan Avenue Bridge (PPbri001) impacts the stream hydraulically by creating a short, straight concrete stream channel which causes a deep scour pool immediately following it. The foot bridge (PPbri002) also had clear hydrologic impacts, though not as intense as the Ryan Avenue Bridge.

There is one dam (PPdam001) on Sandyford Run, with notable impacts on the stream channel. Above the dam, a large pool exists that is dominated by fine sediments that are held back by the dam, while the rest stream is dominated by larger materials. This infrastructure point was classified in this survey as a dam because of its hydraulic effects. However, it should be noted that the dam is actually the Pennypack Creek Interceptor crossing the stream. The pipe perpendicular to the dam was identified as an abandoned wastewater gravity main, which PPpip021 may also have been connected to at one time.

Most of the infrastructure in the Sandyford Run Watershed was in good or fair condition, though vandalism in the form of graffiti was observed on the channelized portion and underneath Ryan Avenue Bridge. There were also large slabs of concrete observed in the scour pool following the channelized portion which appeared to have previously been part of the channel but had broken apart. A future cause for concern may be PPman017, the wastewater manhole on the right side of the stream following the bridge. Though the manhole itself is in good condition, it appeared to have had at one time a protective brick structure which now has been completely broken apart. No other immediate threats to infrastructure were observed.

Table 3-20: Summary of Sandyford Run Infrastructure Points

Section ID	Bridge Count	Channel Count	Dam Count	Manhole Count	Other Count	Outfall Count	PipeSewer Count	Infra Points Count	Total Combined Outfall Area (ft^2)	Priority Infra Points Count
PPSR01	0	3	0	2	0	2	0	7	163.1	0
PPSR02	0	0	0	0	0	0	1	1	0.0	0
PPSR03a	0	3	0	0	0	2	0	5	7.9	0
PPSR03b	1	5	0	1	0	8	2	17	23.6	1
PPSR04	1	0	1	0	1	0	2	5	0.0	2
Total	**2**	**11**	**1**	**3**	**1**	**12**	**5**	**35**	**194.52**	**3**

Table 3-21: Summary of Sandyford Run Infrastructure Linear Features

Section ID	Total Segment Length (ft)	Channel Length, one side	Channel Length, two sides	Channel Length, three sides	Total Channel Length	Total Segment Length, 3 sides	% Channelized
PPSR01	1190	78	174	242	1152	3570	32.3
PPSR02	255	0	0	0	0	765	0.0
PPSR03a	695	0	0	25	75	2085	3.6
PPSR03b	1088	148	0	25	223	3264	6.8
PPSR04	602	0	0	0	0	1806	0.0
Total	**3830**	**226**	**174**	**292**	**1450**	**11490**	**12.6**

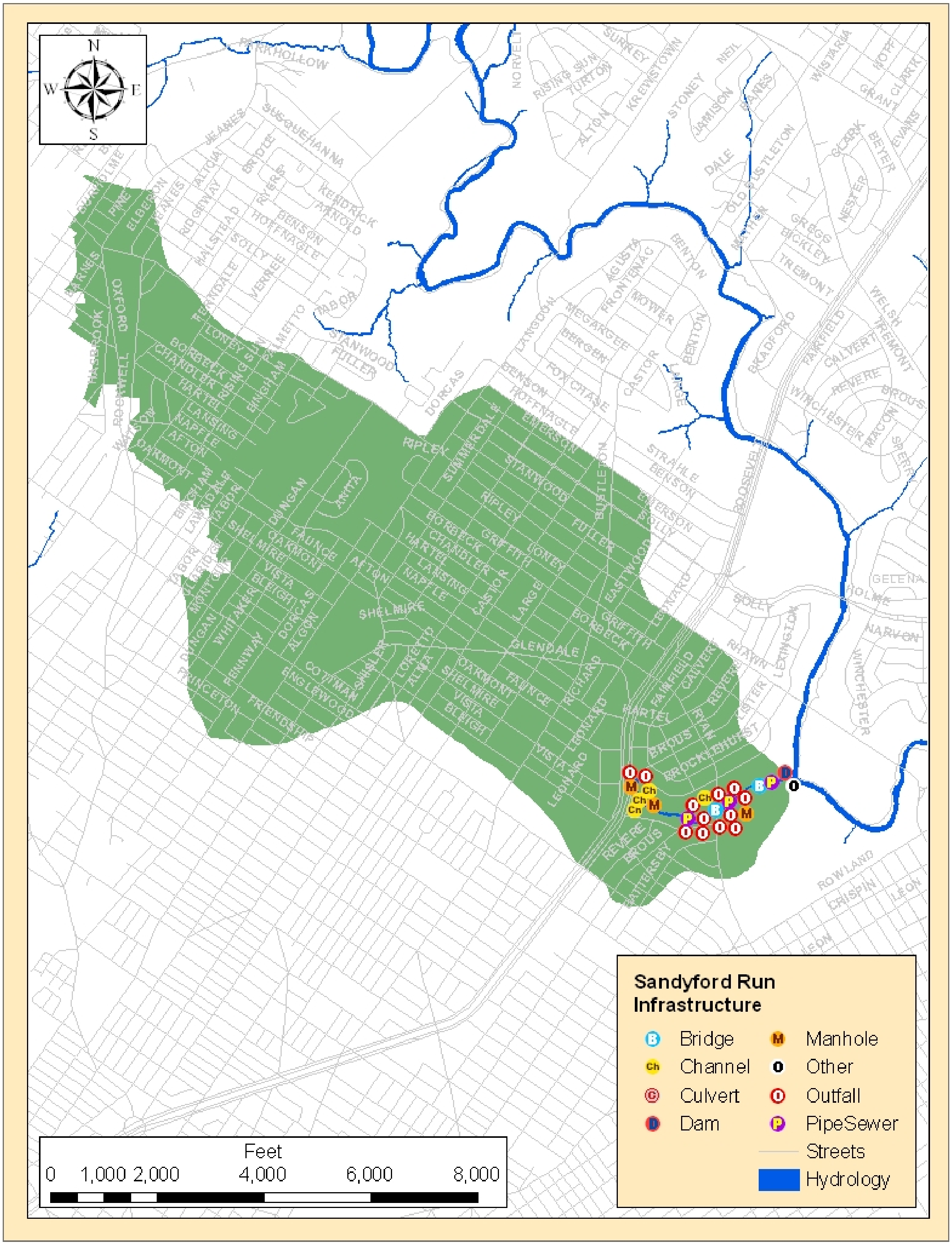


Figure 3-25: Sandyford Run Watershed Infrastructure

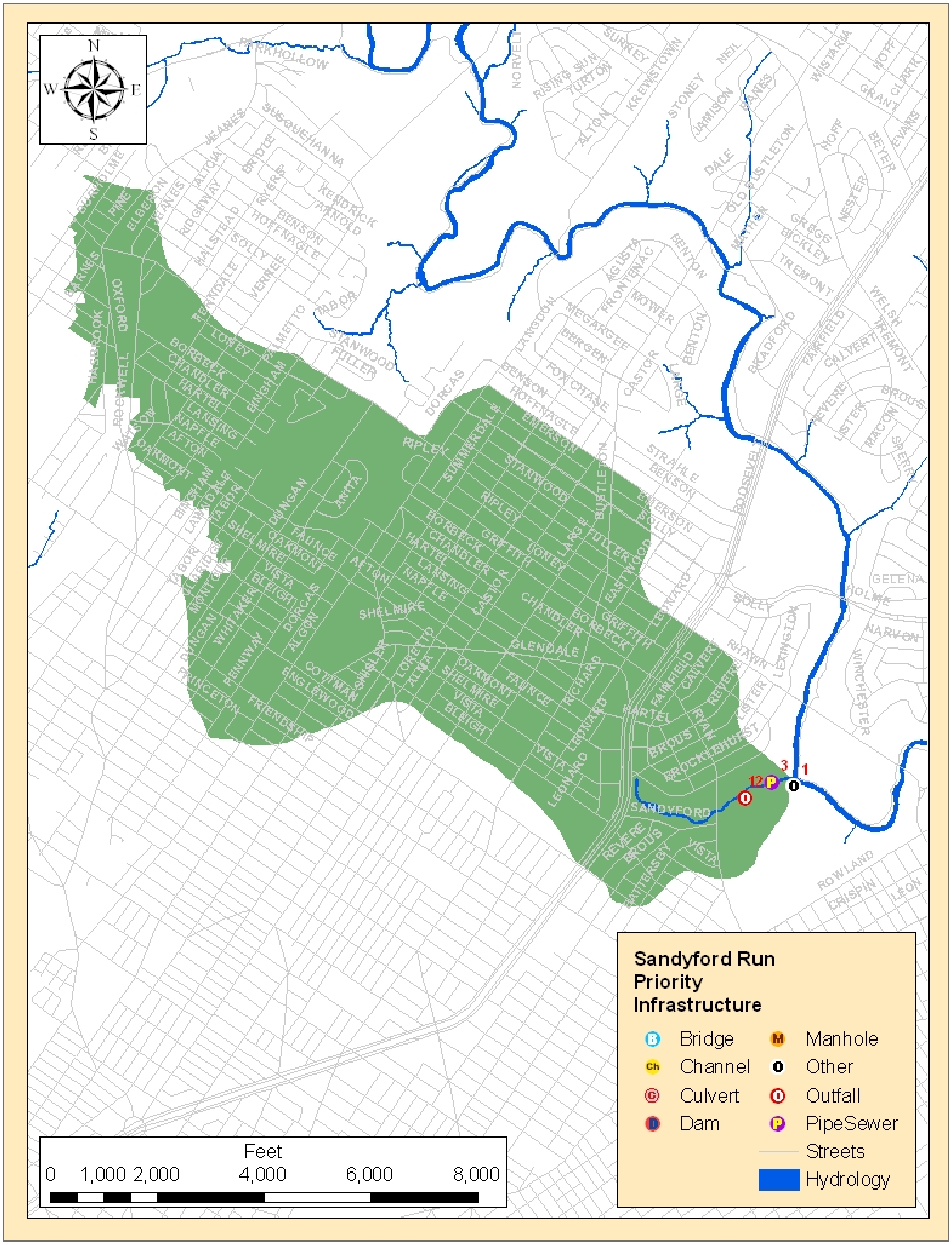


Figure 3-26: Sandyford Run Watershed Priority Infrastructure

3.4.4 UNIFIED STREAM ASSESSMENT RESULTS FOR THE SANDYFORD RUN WATERSHED

The Sandyford Run was a single-thread first order channel approximately 3,640 feet in length. The stream channel substrate distribution was dominated by gravel in every reach (38-57%) with the exception of PPSR03a which had 47% cobble and 38% gravel. Isolated areas in the upstream reaches of the channel stream were bedrock controlled as evidenced by bedrock outcroppings observed both within the channel as well on the stream banks. As expected, the portions of the stream channel impounded by the dam had significantly more fine sediment than any other part of the stream. The D_{50} of the reach within the impounded portion (PPSR04) was 18.3 millimeters (coarse gravel) compared to the D_{50} of the PPSR03b which was 50.6 millimeters and corresponded to very coarse gravel.

The Center for Watershed Protection's (CWP) Unified Stream Assessment Methodology (USAM) was used to score and rate the in-stream, riparian buffer and floodplain conditions of the stream corridor to allow for comparison to other reaches and watersheds within the Lower Pennypack Creek basin. The All Reaches parameter is the mean of the scores of all tributary reaches in the Lower Pennypack Creek study.

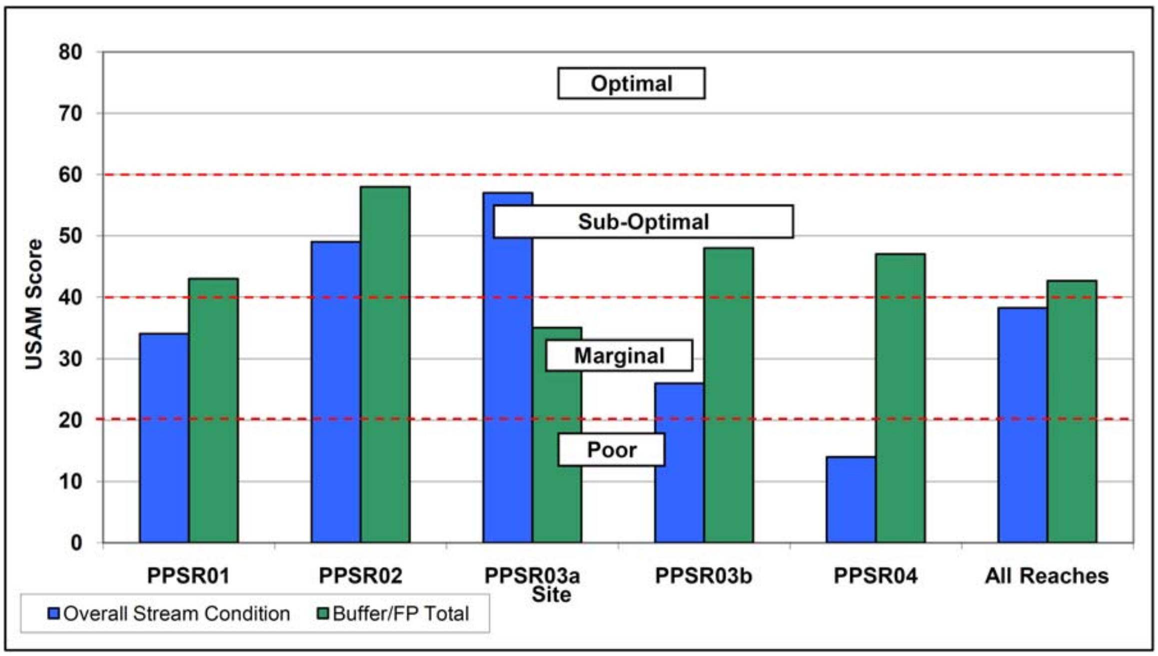


Figure 3-27: Results for Sandyford Run USAM Components

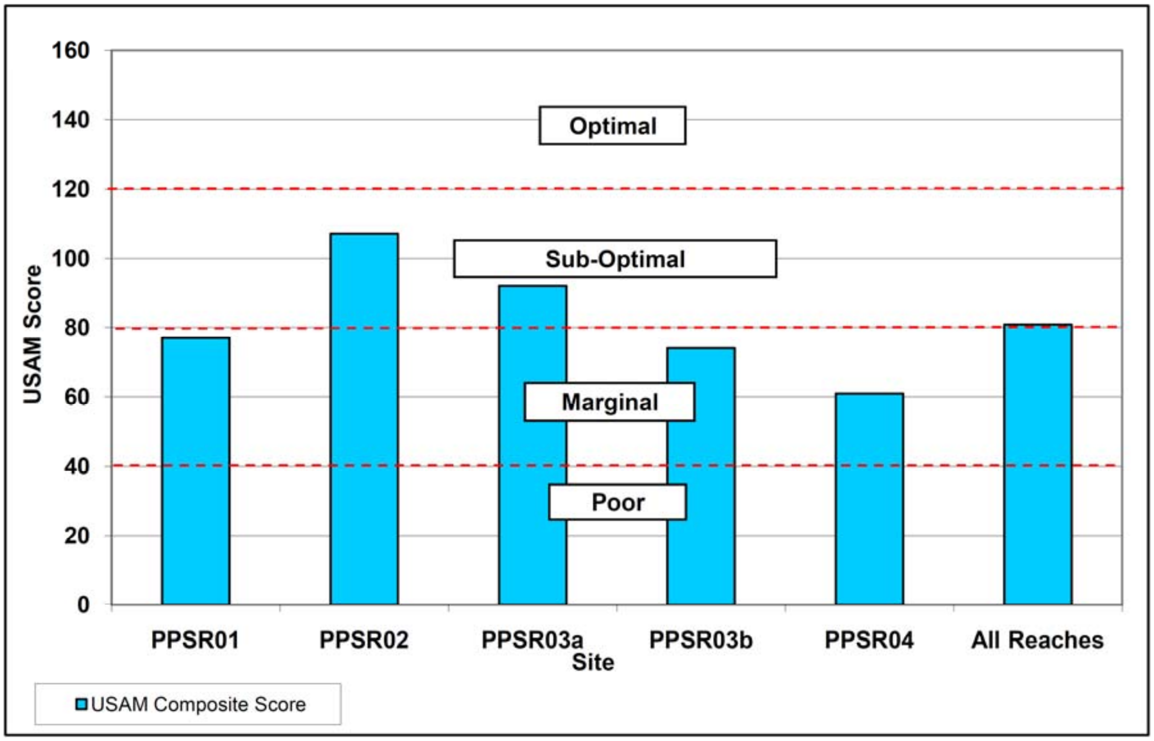


Figure 3-28: USAM Results for Sandyford Run

3.4.4.1 PPSR01

Reach PPSR01 formed the headwaters of Sandyford Run and began at the intersection of Roosevelt Boulevard, Lexington Avenue, and Brous Street. The source of flow for Sandyford Run was PPout001 and PPout002 which were 12 feet by 13 feet and 3 feet in diameter respectively. Unlike the other tributaries and sewersheds in the Pennypack Creek Watershed, the Sandyford Run sewershed is a combined system, thus during dry weather, there was very little flow observed in the channel.

There was severe geomorphologic and hydraulic alteration due to the impacts of infrastructure, primarily in the form of outfalls and channelized portions, in this reach. PPcha001, PPcha002 and PPcha003 form the left, right and bottom walls of an extensive 375 feet concrete apron, which at its downstream end was severely impaired as large slabs of concrete had broken off the end of all three channel segments. Immediately downstream of the apron, an extensive scour pool was observed in the channel as was severe erosion on both stream banks. Due to severe sedimentation, a mid-channel island formed downstream of the scour pool, which formed a secondary stream channel on the downstream left side of the corridor. This channel was dry at baseflow and likely only became active during wet weather events when flows overwhelmed the primary channel.

Cross section PPSR01 was located at the first riffle downstream of the scour pool and secondary channel complex. The substrate distribution was dominated by gravel (57%) although a considerable amount of cobble-sized particles were also observed. The D_{50} of the reach was 50.9 millimeters which corresponded to very coarse gravel. The reach was classified as a Rosgen-type F4 stream and had an overall USAM score of 77 / 160 which was rated as "suboptimal".

The individual scores for most parameters in the reach were impacted to some extent by stormwater and infrastructure. The *Overall Stream Condition* score was 34 / 80 which was rated as "marginal". The score for the *In-stream Habitat* parameter was 11/20, which was rated as "suboptimal". The low score was attributed to the predominance of fine sediment and lack of coarse woody debris throughout the reach. Though many banks were extensively vegetated beyond the bankfull elevation, minimal or disturbed vegetative bank protection was observed throughout much of the active channel with frequent instances of severe localized erosion and scour. The *Floodplain Connection* parameter was the lowest scoring parameter as the entrenchment ratio of 1.1 was the lowest observed in the watershed. The severe channel incision and overwidening observed in this reach was attributed to the presence of extensive channelization which both exacerbated the erosive impacts of stormflows during wet weather events and confined the channel for its length. The *Overall Buffer and Floodplain Condition* score was 43/80 which was rated at the low end of the "suboptimal" range of scores. The reach had high scores on both the downstream left and downstream right banks for the *Vegetated Buffer Width* parameter as the vegetated buffer extended for more than 50 feet on both banks throughout the entire corridor. The lowest score for this component was observed for the *Floodplain Encroachment* parameter which was rated as "poor" with a score of 5/20. The low score for this parameter was attributed to the presence of extensive infrastructure.

3.4.4.2 PPSR02

The reach PPSR02 began about 800 feet east of Roosevelt Boulevard and 200 feet north of Sandyford Road. This reach was classified as a Rosgen-type F4 stream and had a composite USAM score of 107 / 160, which was rated as "suboptimal". It was the highest overall score of all Sandyford Run reaches. The substrate distribution was dominated by gravel (48%) as in PPSR01 although cobble-sized particles were present in almost equal proportion (43%). The D_{50} of the reach was 56.9 millimeters which corresponded to very coarse gravel.

The *Overall Stream Condition* score was 49/80 which was rated as "suboptimal". The score for the *In-stream Habitat* parameter (15/20) was rated as "suboptimal" and was the highest score for this parameter in the watershed. Both downstream left and downstream right banks were rated as "optimal" for the *Vegetative Protection* parameter with a score of 9/10 on both banks. The majority of stream bank surfaces were covered by undisturbed herbaceous vegetation. The reach appeared to be relatively stable with respect to lateral adjustment as only isolated areas of bank failure or erosion were observed. However the reach was severely entrenched with an entrenchment ratio of 1.2.

The *Overall Buffer and Floodplain Condition* score was 58 / 80 which was rated as "suboptimal" and was the highest score observed for this component of the USAM among the Sandyford Run reaches. The reach had a well-established vegetated buffer of more than 50 feet in most areas. Floodplain vegetation was dominated by young forest with some areas of shrubs, herbaceous vegetation and woody vines. The only infrastructure observed in this reach was PPpip001 which crossed the stream channel at the bottom of the reach. The 2 feet diameter pipe was nearly buried at grade with the channel substrate thus it is likely that neither flow nor sediment was impounded behind the structure. PPSR02 had the highest score for the *Floodplain Encroachment* parameter of all the reaches of Sandyford Run, due to the lack of infrastructure, roads and other structures and it was the only parameter that had a rating of "suboptimal" in the *Overall Buffer and Floodplain Condition* component of the USAM.

3.4.4.3 PPSR03A

The reach PPSR03a began approximately 150 feet upstream of Sandyford Road immediately downstream of PPpip001 and continued to the upstream side of the Ryan Avenue Bridge (PPbri001). The reach had a substantial riparian buffer on the left bank but the buffer on the right bank was constrained by Sandyford Road and in some locations the buffer was less than 10 feet in width. In several locations on the downstream right side of the corridor, the streambanks were severely eroded and nearly vertical which made identification of bankfull indicators difficult in this reach. PPSR03a was classified as a Rosgen-type E3 (Rosgen 2006) stream and received an overall USAM score of 92 / 160. The D_{50} of the reach was 72.1 millimeters which corresponded to small cobble.

The *Overall Stream Condition* score was 57 / 80 which was rated as "suboptimal". The *In-stream Habitat* score (10/20) was rated as "marginal" and was characterized by a low proportion of stable habitat (i.e. cobble, boulder, coarse woody debris) and a relatively high proportion of frequently disturbed substrate. The *Vegetative Protection* parameter was rated as "suboptimal" for the downstream left bank and "marginal" on the downstream right however, on both banks, vegetation was relatively undisturbed though the downstream left bank was observed to have more stable and hardy vegetation than the downstream right bank. *Bank Erosion* scores were rated as "suboptimal" on both banks, although there were localized areas of scour observed throughout the reach. The reach was observed to have a high degree of connection with its floodplain with an entrenchment ratio of 6.8 and a score of 20/20 for the *Floodplain Connection* parameter; however the downstream right bank was constrained by the Sandyford Road and had a floodplain width of less than 10 feet in some locations. Along with PPWB10, reach PPSR03a had the highest score observed among Lower Pennypack Creek tributaries.

The *Overall Buffer and Floodplain Condition* score was 35 / 80 which was the lowest score in the Sandyford Run Watershed and rated as "marginal". While the left bank had a very wide buffer, the right bank had a minimal vegetated buffer and floodplain in some locations due to the presence of Sandyford Road on the downstream right side of the corridor. The *Floodplain Vegetation* score (11/20) was rated as "marginal" and was characterized as a young forest dominated by early successional tree species and a dense coverage of herbaceous forbs, grasses and woody shrubs in the understory and forest floor. Floodplain habitat was observed to be all non-wetland habitat as there was no evidence of standing water along the floodplain, however, following wet weather events it is likely that the floodplains in reach PPSR03a support vernal pools given the high entrenchment ratio and poorly drained floodplain soils in the reach. While the floodplain on the downstream left side of the corridor was not encroached upon by man-made activities, the downstream right floodplain was impinged upon by Sandyford Road restricting the floodplain to less than 10 feet along much of the reach.

3.4.4.4 PPSR03B

Reach PPSR03b included a portion of the stream that crossed under the Ryan Avenue Bridge (PPbri001) and ended at the footbridge crossing downstream (PPbri002). The stream was confined and effectively channelized as it flowed beneath the PPbri001, which resulted in high velocity flows downstream of PPbri001 that ultimately formed a deep scour pool immediately downstream the bridge. This reach was the second longest reach assessed in Sandyford Run (1,088 feet) and was observed to contain the highest number of infrastructure elements. There were a total of 8 outfalls in the reach, which far exceeded the number of outfalls in any of the other Sandyford Run reaches. The reach was heavily influenced by stormwater as evidenced by severe erosion downstream of outfalls however the morphology of the channel was relatively stable and was classified as a Rosgen-type B4 stream channel. The overall USAM score was 74/160 which was rated as "marginal". The D_{50} of the reach was 50.6 millimeters which corresponded to very coarse gravel.

The *Overall Stream Condition* score was 26/80 which was rated as "marginal." In-stream habitat within the reach was very limited and rated as "marginal" as the substrate was dominated by unstable gravel-sized particles and generally lacked a wide distribution of stable coarse woody debris. The *Vegetative Protection* scores for the downstream left and downstream right banks were both rated as "marginal". Scores for this parameter were observed to have a marked decrease beginning at reach PPSR03b which is likely due to the effect of PPbri001 on the downstream flow regime. Immediately downstream of the Ryan Avenue Bridge, localized scour was observed on both the downstream left and downstream right banks which limited the coverage of streambank vegetation, however, the downstream left was significantly less protected by vegetation. The severe bank erosion observed in the reach was likely directly correlated to the lack of vegetative protection in this reach. The downstream right bank side exhibited signs of active widening with moderate erosion, but the downstream left bank exhibited severe and active downcutting as tall, vertical banks were observed throughout the reach on this side of the corridor. The severe erosion in the reach could threaten the stability of PPman003. The manhole which was located in close proximity to the active channel was in extremely poor condition as its concrete façade exhibited signs of wear exposing the brick beneath it.

The *Overall Buffer and Floodplain Condition* score was 48/80 and was rated as "suboptimal". The relatively high score for this component of the USAM was mostly attributed to the high scores observed for the *Vegetated Buffer Width* parameter (10/10) which was rated as "optimal". The reach received the highest possible score on both banks for its wide riparian buffer, though the Pennypack Park trail cut through the buffer about 50 feet from the channel. Like most of Sandyford Run, the reach was dominated by young, mixed forest and floodplain habitat was all non-wetland. Floodplain function throughout the reach was maintained in general; however, much of the reach was encroached upon by the presence of infrastructure elements such as outfalls and channels that in some instances had a considerable impact on floodplain function.

3.4.4.5 PPSR04

The downstream-most reach was PPSR04 which extended from the pedestrian bridge (PPbri002) to the confluence of Sandyford Run and the main stem of Pennypack Creek. There was a dam (PPdam001) located downstream of the cross-section PPSR04 which was found to have a considerable impact on the hydraulics and sediment transport regime of the reach. The impoundment behind the dam was extensive and caused fine sediment to accumulate throughout its length. Consequently, the substrate particle size distribution in this reach was dominated by gravel-sized particles (52%) and had the highest proportion of sand (21%) than any of the other Sandyford Run reach. The reach was classified as an F4 stream with a D_{50} of 18.3 millimeters, which corresponded to coarse gravel. The reach was observed to have the lowest overall USAM score in the watershed at 61 / 160 which was rated as "marginal".

The *Overall Stream Condition* score was 14 / 80 which was the lowest score observed in the watershed for this component of the USAM. In-stream habitat was rated as "poor", due to the unstable nature of the substrate throughout the reach. The score for this parameter was the lowest score observed among all the reaches assessed in the Sandyford Run Watershed and all other tributary reaches assessed in the Lower Pennypack Creek USAM assessment. *Vegetative Protection* was rated as "marginal" with patches of bare soil and disturbed stream vegetation observed on both banks throughout the length of the reach. The score for downstream left bank (4/10) was the lowest score observed for this parameter among all the reaches assessed in the Sandyford Run Watershed and all other tributary reaches assessed in the Lower Pennypack Creek USAM assessment. Tall, vertical banks and active downcutting were frequently observed as bank erosion was very severe. The scores for this parameter (1/10) on both banks were the lowest scores observed among all the reaches assessed in the Sandyford Run Watershed and all other tributary reaches assessed in the Lower Pennypack Creek USAM assessment. Many of the trees on the banks had exposed roots and the banks were exposed to bare soil, which likely contributed more sediment to the impoundment behind the dam. The reach was deeply incised with an entrenchment ratio of 1.1 and a *Floodplain Connection* score of 1/20 which was rated as "poor".

The *Overall Buffer and Floodplain* condition score was 47/80 which was rated as "suboptimal". The vegetated buffer was over 50 feet on both sides with young forest dominating the vegetation observed on the floodplain. No wetland habitat or evidence of ponding water was observed, thus this reach was rated as "marginal" for the *Floodplain Habitat* parameter. The extended cross section analysis revealed a depression in the topography which appeared to be within the reach of flood-level flows and could possibly support high quality wetland habitat following flood events in excess of the bankfull discharge. Floodplain encroachment was moderate in the reach although manmade structures such as PPdam001 and a breached wall (PPmisc001) may likely have an adverse effect on floodplain function.

3.4.5 SUMMARY OF UNIFIED STREAM ASSESSMENT RESULTS

The mean score for all the reaches assessed in the Sandyford Run USAM assessment was 82.2/160 which was slightly higher than the mean score of 81/160 for all the tributary reaches assessed in Lower Pennypack Creek, however both mean scores were at the lower extent of the "suboptimal" range of conditions. Although the mean score for the watershed was rated as "suboptimal", of the five reaches assessed, three were rated as "marginal" (PPSR01, PPSR03b, and PPSR04). There were no spatial trends observed along the upstream-downstream gradient of Sandyford Run; however, there were localized trends observed at PPdam001 as there was a considerable shift in the distribution of substrate particle size from cobble-gravel dominated channels in the upper reaches to a gravel-sand dominated channel just upstream of the PPdam001.

In general, scores for the *Overall Buffer and Floodplain Condition* tended to be higher than scores for the *Overall Stream Condition* component of the USAM. The difference in scores for the two components was attributed to the presence of infrastructure and severe erosion which impacted in-stream functions and processes to a higher degree than floodplain functions and processes. The mean score for the *Overall Buffer and Floodplain Condition* component was 46.2/80 which was at the lower extent of the suboptimal range of conditions. This was higher than the mean score of 42.7/80 for all tributaries in the Lower Pennypack Creek Watershed. The mean score for the *Overall Stream Condition* component was 36/80 which was slightly lower than the All Reaches average score of 38.3/80.

Table 3-22: USAM Results for the Sandyford Run Watershed

Reach ID	Sub-watershed	Overall Stream Condition	Overall Buffer/FP Condition	USAM Score
PPSR01	Sandyford Run	34	43	77
PPSR02	Sandyford Run	49	58	107
PPSR03a	Sandyford Run	57	35	92
PPSR03b	Sandyford Run	26	48	74
PPSR04	Sandyford Run	14	47	61
Mean		**36.0**	**46.2**	**82.2**
All Reaches		**38.3**	**42.7**	**81.0**

3.4.5.1 SUMMARY OF OVERALL STREAM CONDITION SCORES IN THE SANDYFORD RUN WATERSHED

Among all sites evaluated in the Sandyford Run Watershed, the Overall Stream Condition component (Table 3-22) of the USAM was highest for site PPSR03a (57 / 80). PPSR03a and PPSR02 were the only sites within the subwatershed to score within the "suboptimal" range for the *Overall Stream Condition* component of the USAM. The mean *Overall Stream Condition* score for the Sandyford Run Watershed of 36/80 was within the "marginal" range of conditions. The site in the poorest condition was PPSR04 which had a score of 14/80 and was rated as "poor".

Table 3-23: USAM Overall Stream Condition Scoring for the Sandyford Run Watershed

Reach ID	Sub-watershed	In-Stream Habitat	Vegetative Protection		Bank Erosion		Floodplain Connection	Overall Stream Condition
			Left	Right	Left	Right		
PPSR01	Sandyford Run	11	7	4	6	5	1	34
PPSR02	Sandyford Run	15	9	9	7	7	2	49
PPSR03a	Sandyford Run	10	9	6	8	4	20	57
PPSR03b	Sandyford Run	6	4	6	2	4	4	26
PPSR04	Sandyford Run	5	3	3	1	1	1	14
Mean		**9.4**	**6.4**	**5.6**	**4.8**	**4.2**	**5.6**	**36.0**
All Reaches		**11.1**	**6.3**	**6.1**	**5.0**	**5.8**	**4.0**	**38.3**

3.4.5.1.1 IN-STREAM HABITAT

Scores for the *In-stream Habitat* parameter ranged from "poor" to "suboptimal". The highest score (15/20) was recorded at site PPSR02, followed by PPSR01 (11/20), both of which were rated as "suboptimal". The mean *In-stream Habitat* score for the entire subwatershed was 9.4/20, which was slightly lower than the All Reaches Average of 11.1/20. PPSR04 was the lowest scoring reach (5/20). The low score was attributed to the high proportion of fine sediments due to the dam downstream of the site (PPdam001). These fine sediments are highly unstable and thus unsuitable as fish and macroinvertebrate habitat.

Sites with scores in the "suboptimal" range were characterized as having 40%-70% of substrate suitable to serving as stable habitat for the establishment, colonization and maintenance of epiphyte, macroinvertebrate and fish populations. These sites also had additional substrate in the form of newfall (i.e. coarse woody debris (CWD)); however, this newfall may not yet be suitable for establishment of epiphyte or macroinvertebrate colonization, but may still serve as cover for fish. In a process known as "conditioning", organic material such as CWD and leaf litter are colonized by fungi that begin to degrade the hardy organic compounds like tannins, cellulose and lignin found in leaves, stems and CWD. Conditioning provides increased nutritional benefit to macroinvertebrates as the biofilms produced by fungi as well as the fungi themselves coat the surface area of organic material and thereby provide a source of lipids and protein, respectively.

Sites with “marginal" in-stream habitat was characterized as having 20%-40% of available substrate stable enough to function as benthic habitat. The patchy distribution of these substrates renders them susceptible to frequent disturbance (i.e. dislodgement by high flows, siltation by finer sediment). Habitat availability within this range is not suitable to host a diverse macroinvertebrate assemblage and macroinvertebrate communities present in these sites are composed of hardy species that can tolerate frequent and persistent disturbance (i.e. burial by fine sediment, scouring flows, turbidity, and low dissolved oxygen due to reduction of hyphoreic circulation).

3.4.5.1.2 VEGETATIVE PROTECTION

The *Vegetative Protection* parameter measures the extent to which stream banks and immediately adjacent riparian areas are covered by vegetation in the form of trees, shrubs and non-woody, emergent macrophytes. The average scores for the reach on the downstream left and downstream right banks was 6.4/10 and 5.6/10, both of which were higher than the All Reaches average for each bank. PPSR02 had the highest score for this parameter with 9/10 for both banks, classifying this site as "optimal". PPSR03a also had a score of 9/10 on the downstream left bank and 6/10, a "suboptimal" score, on the downstream right. The downstream left bank of PPSR01 was the only other bank that was rated within the "suboptimal" condition class as streambanks throughout all other reaches were rated as "poor" or "marginal".

3.4.5.1.3 BANK EROSION

There were no sites that scored within the "optimal" range (9-10) for the *Bank Erosion* parameter. On the left side of the corridor, three of the five assessment sites had "suboptimal" classifications (PPSR01, PPSR02 and PPSR03a) and the remaining two were classified as "poor". On the right bank, three of the five sites were classified as "marginal" (PPSR01, PPSR03a, and PPSR03b), one "suboptimal" (PPSR02), and one "poor" (PPSR04). The average score of all banks was in the "marginal" range at 4.5/10, with the right bank scoring slightly lower (4.2/10) than the left (4.8/10). Both banks of PPSR04 had scores of 1/10 and were the lowest scores observed among all reaches in the Lower Pennypack Creek USAM assessment. Both banks were rated as "poor" and were characterized by active downcutting and tall, vertical streambanks.

3.4.5.1.4 FLOODPLAIN CONNECTION

The highest degree of variation in the *Overall Stream Condition* parameters was observed in the *Floodplain Connection* parameter. This parameter evaluates the relative level of entrenchment present within assessment sites. Reach PPSR03a was rated as "optimal" with a score of 16/20 however all other reaches in Sandyford Run were rated as "poor". The classification levels differ in the relative levels of entrenchment at flows greater than bankfull such that at bankfull flows, floodwaters reach the floodplain in "optimal" and "suboptimal" sites, but will not reach the floodplain in "marginal" or "poor" sites. This parameter was determined through the calculation of the entrenchment ratio of each reach with Mecklenberg sheets (see Appendix A).

3.4.5.2 SUMMARY OF OVERALL BUFFER AND FLOODPLAIN CONDITION SCORES IN THE SANDYFORD RUN WATERSHED

The highest USAM score for the *Overall Buffer and Floodplain* component was observed at site PPSR02 (58/80), which was rated as "suboptimal" although three other reaches also had scores in the "suboptimal" range (PPSR01, PPSR03b, and PPSR04). The mean *Overall Buffer and Floodplain Condition* score for the subwatershed was 46.2 / 80, which is within the "suboptimal" class. "Suboptimal" buffer and floodplain conditions were characterized by a vegetated buffer or riparian width between 25-50 feet with evidence of only minimal impact to the buffer from human activity, an even mix of wetland and non-wetland habitat and a riparian plant community dominated by young forest.

One site (PPSR03a) scored in the "marginal" range at 35/80. It was characterized by a vegetated buffer between 10-25 feet with evidence of significant impact from human activity, moderate floodplain encroachment, either all wetland or all non-wetland habitat, and floodplain habitat dominated by shrub or old field. No assessment sites were classified as "optimal" or "poor" for this component of the USAM assessment. Site by site comparisons of each Buffer / Floodplain parameters are located in Appendix D.

Table 3-24: USAM Buffer and Floodplain Scoring for the Sandyford Run Watershed

Reach ID	Sub-watershed	Vegatated Buffer Width		Floodplain Vegetation	Floodplain Habitat	Floodplain Encroachment	Buffer/FP Total
		Left	Right				
PPSR01	Sandyford Run	9	9	14	6	5	43
PPSR02	Sandyford Run	10	9	14	10	15	58
PPSR03a	Sandyford Run	10	1	11	5	8	35
PPSR03b	Sandyford Run	10	10	13	7	8	48
PPSR04	Sandyford Run	10	10	13	7	7	47
Mean		**9.8**	**7.8**	**13.0**	**7.0**	**8.6**	**46.2**
All Reaches		**8.0**	**7.5**	**12.7**	**4.3**	**11.1**	**42.7**

3.4.5.2.1 VEGETATED BUFFER WIDTH

All of the reaches assessed in the Sandyford Run Watershed had a very wide riparian buffer (up to 500 feet at some points) due to the stream's location within the boundaries of Pennypack Park. All banks scored in the "optimal" range except for the right bank of PPSR03a which had a score of 1/10 and was rated as "poor". With the exception of this bank, the entire corridor had vegetated buffer zones greater than 50 feet in width and were relatively undisturbed by human activities (i.e. lawns, agriculture, and parking lots). The downstream right bank of PPSR03a was rated as "poor" with a riparian buffer of less than 10 feet and little riparian vegetation due to the close proximity of Sandyford Road to the floodplain.

3.4.5.2.2 FLOODPLAIN VEGETATION

Floodplain Vegetation classifications were based on vegetation type and relative stage of succession based on species observed. The mean *Floodplain Vegetation* score for the Sandyford Run Watershed was rated as "suboptimal" (13/20), with all scores falling in the "suboptimal" range. The riparian vegetation in Sandyford Run Watershed was characterized by a relatively young forest composed of early successional species, though there were occasional isolated occurrences of shrub- and vine- dominated areas.

3.4.5.2.3 FLOODPLAIN HABITAT

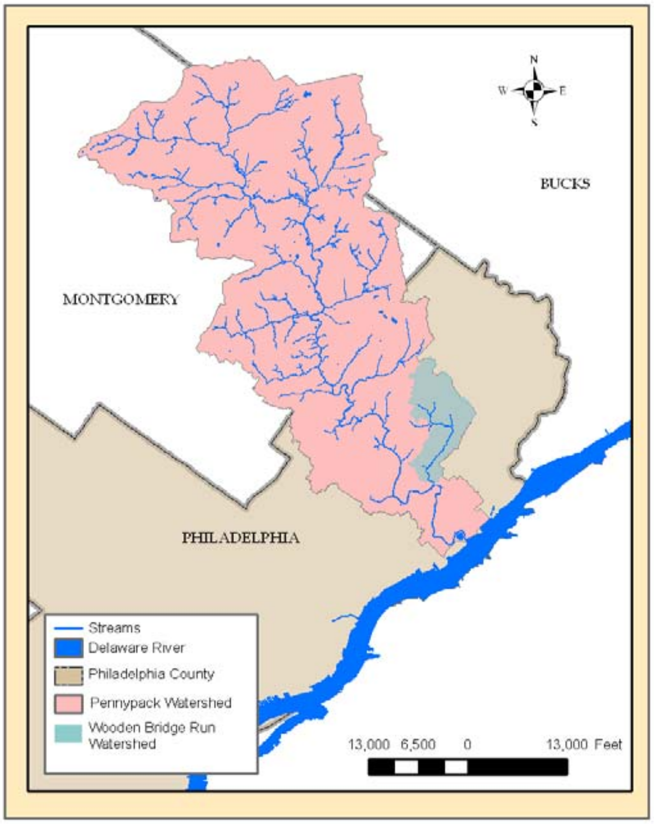
Floodplain Habitat classifications were based on the relative proportion of wetland and non-wetland habitat observed in an assessment site as well as visual evidence of standing water, which offers additional habitat in the form of ephemeral pools for amphibian and macroinvertebrate taxa. The mean *Floodplain Habitat* score for the entire subwatershed was 7/20, which was classified as "marginal". Four of the five sites were rated as "marginal" and the lowest scoring reach, PPSR03a, was rated as "poor".

3.4.5.2.4 FLOODPLAIN ENCROACHMENT

The *Floodplain Encroachment* parameter assesses the level of human activity or manmade obstructions on the floodplain of a reach. Examples of floodplain encroachment are manmade structures such as buildings, roads, sewers, and other infrastructure or fill material. The mean score for the watershed was 8.6/20, which is within the "marginal" classification range. This was slightly lower than the All Reaches Average of 11.1/20 which was also rated as "marginal". The relatively low scores for this parameter reflect the extent to which Sandyford Road and infrastructure elements impact floodplain function through constricting the width of the active floodplain, impounding sediment or confining flood flows.

The highest score was observed in reach PPSR02 (15/20) which was relatively free of infrastructure with the exception of PPpip001 located at the downstream reach break. The lowest scoring reach was PPSR01 (5/20) was rated as "poor". The large outfall (PPout001) and associated apron and wingwalls have considerable impact on floodplain function by confining flow to a wide concrete channel.

3.5 WOODEN BRIDGE RUN WATERSHED AND REACH CHARACTERISTICS



Wooden Bridge Run is a tributary to the Pennypack Creek Main Stem. The main channel of Wooden Bridge Run flows approximately 16,000 feet from PWD owned outfall PPout902 (P-105-13) to the confluence with Pennypack Creek. The watershed of Wooden Bridge Run is approximately 2,227 acres. The major land uses in the Wooden Bridge Run Watershed are transportation (22%), residential multi-family (16%), wooded (13%), manufacturing-light industry (13%), and residential single-family detached (11%). Wooden Bridge Run is a watershed that has been severely degraded by urban development. The dominate substrate in this watershed varies from coarse to very coarse gravel throughout the reaches.

About 2,100 feet downstream of the headwater outfall, a small unnamed tributary contributes flow from several outfalls including PPout903 (P-105-03) at its headwaters. This tributary is heavily influenced by the surrounding drainage area which is dominated by manufacturing land use and impervious surfaces, which is evidenced by the 20 outfalls located along its banks.

The major tributary to Wooden Bridge Run is designated as Wooden Bridge Run Tributary A. Tributary A enters the main stem of Wooden Bridge Run about 3,550 feet downstream of the headwaters. The tributary itself is 4,000 feet long and the drainage area is heavily impervious. The headwater outfall to Wooden Bridge Run Tributary A is a 78 inch concrete outfall, P-105-01. An outfall of that size infers that there is a substantial amount of stormwater conveyed to the channel via this conduit. The tributary flows for about 1,200 feet through commercial and residential landscapes. Once the stream passes the culvert below Blue Grass Road the landscape becomes more wooded with a more substantial riparian buffer width. The tributary then flows another 2,800 feet before entering the main stem of Wooden Bridge Run. The riparian buffer around the tributary and main stem narrows near the Northeast Airport where the stream crosses underneath Grant Avenue. For reach maps refer to Appendix C.

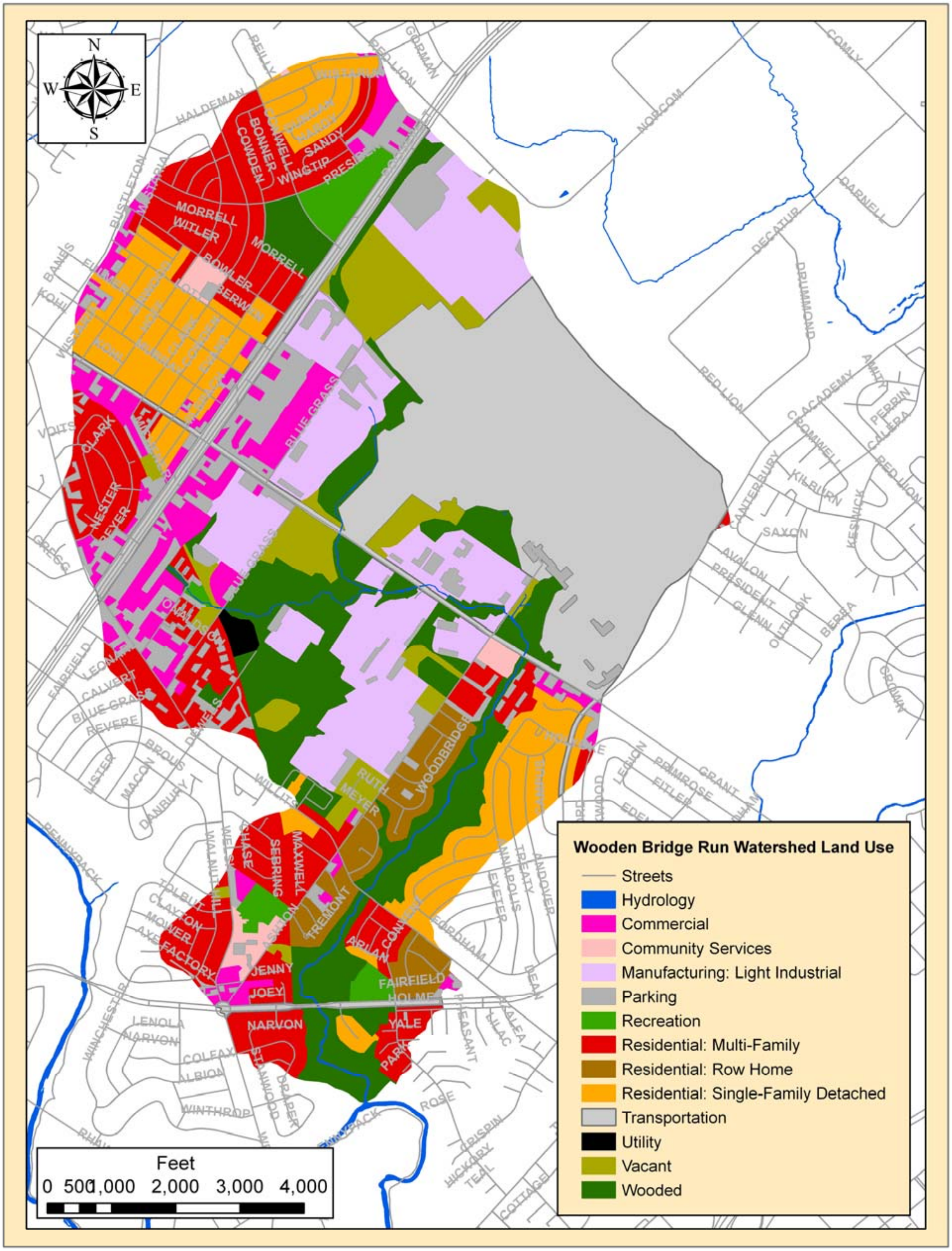


Figure 3-29: Wooden Bridge Run Watershed Land Use

3.5.1 GEOLOGY

The Wooden Bridge Run Watershed is almost entirely underlain by the Pennsauken and Wissahickon geologic formations. There is also a very small area designated to the Serpentine Formation.

The Wissahickon Formation is the most prevalent geology in the watershed. This formation makes up 54% of the Wooden Bridge Run Watershed, located mostly in the areas directly around the stream corridor and a large portion of the watershed's northern portion. The Wissahickon Formation consists of mica schist, gneiss, and quartzite. Exposed schist near the surface is highly weathered. There are also some metamorphosed sedimentary and igneous rocks within this formation.

The Pennsauken Formation is the geology of nearly all the remainder of the Wooden Bridge Run Watershed. It is 45% of watershed's total geology, located in the areas further away from the stream surrounding the Wissahickon Formations and underlying the perimeter of the watershed except for the northern portion. The Pennsauken Formation consists of yellow to dark reddish brown sand and gravel. It is mostly comprised of quartz, quartzite, and chert. This is a severely weathered floodplain formation.

The final geologic formation in the Wooden Bridge Run Watershed is the Serpentine Formation. This formation creates barren, rocky outcrops on low hills and ridges. Only small quantities of water are contained within the fractures and the water is hard and mineralized. Less than half of a percent of the Wooden Bridge Run Watershed falls into this designation.

3.5.2 SOILS

According to the National Resource and Conservation Service Soil Survey (United States Department of Agriculture, 2006), nearly all of the Wooden Bridge Run Watershed soils are classified as Urban Land soils. Over 93% of the Wooden Bridge Run Watershed consists of the disturbed urban soils. Urban soils consist of material that has been disturbed by human activity during urbanization. These soils have been produced by mixing, filling, and contamination of native soils in both urban and suburban areas.

The soil category B is just over 4% of the watershed. There are two areas where these soils are prevalent. They are in the northern portion and in the downstream most area of the watershed around the stream corridor. These soils have a moderate rate of infiltration when the soils are wet (0.50-1.00 in/hr). Water movement through these soils is considered moderately rapid.

There is a small area of C soils located in the southern most area of the watershed that is directly around the stream. Group C soils have a slow rate of infiltration when saturated (0.17-0.27 in/hr). Water movement through these soils is moderate or moderately slow. Similar to this is a strip of Group D soils surrounding the stream further upstream. These soils have a very slow rate of infiltration when saturated (0.02-0.10 in/hr) resulting in a high runoff potential.

Table 3-25: Distribution of NRCSS Soil Types in Wooden Bridge Run Watershed

Group	Area (ft2)	Percent of Total Area
B	4,119,777.00	4.20%
C	956,083.00	0.97%
D	1,077,353.00	1.10%
Urban	91,907,709.00	93.73%
Total Area	98,060,922.00	100.00%

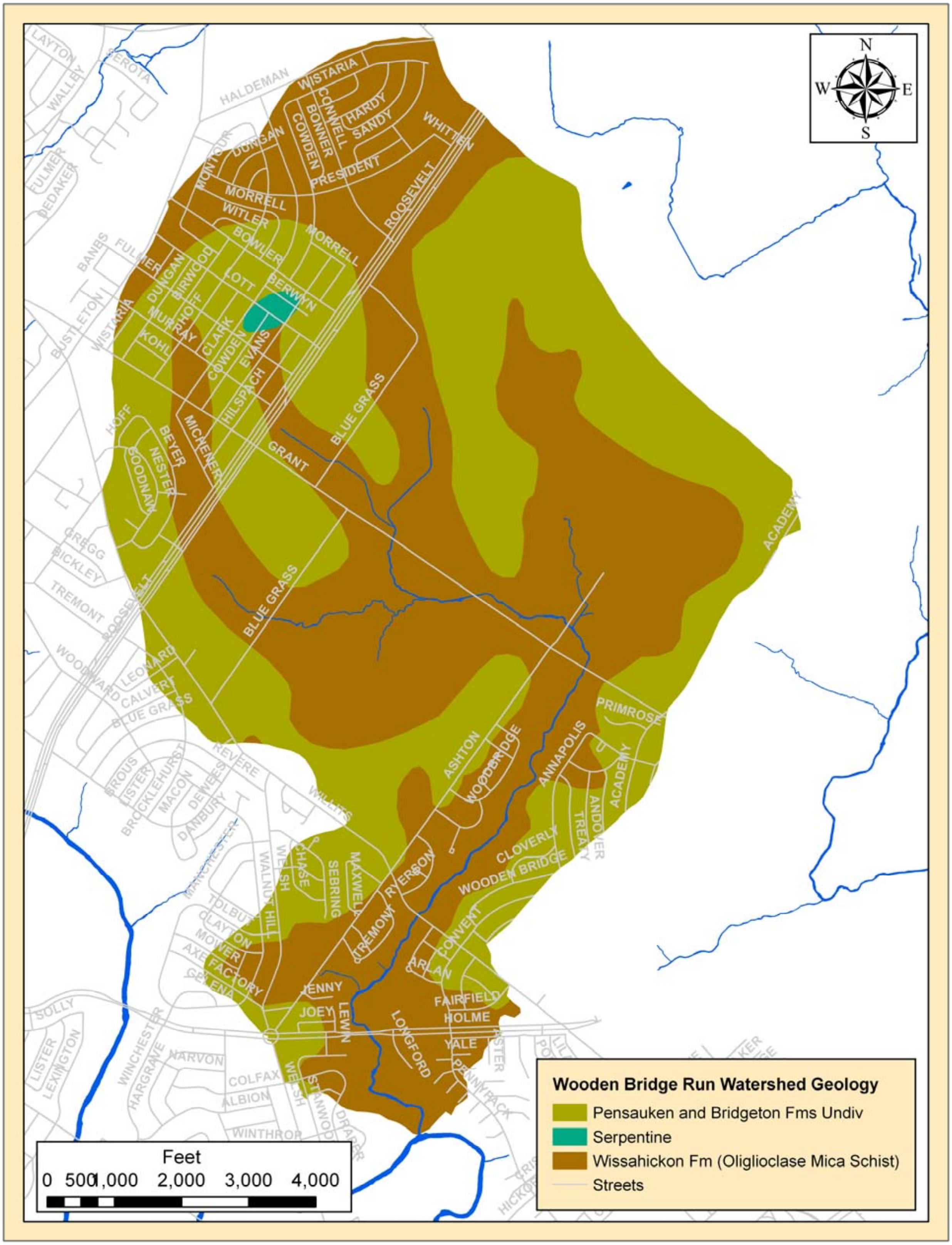


Figure 3-30: Geology of Wooden Bridge Run Watershed

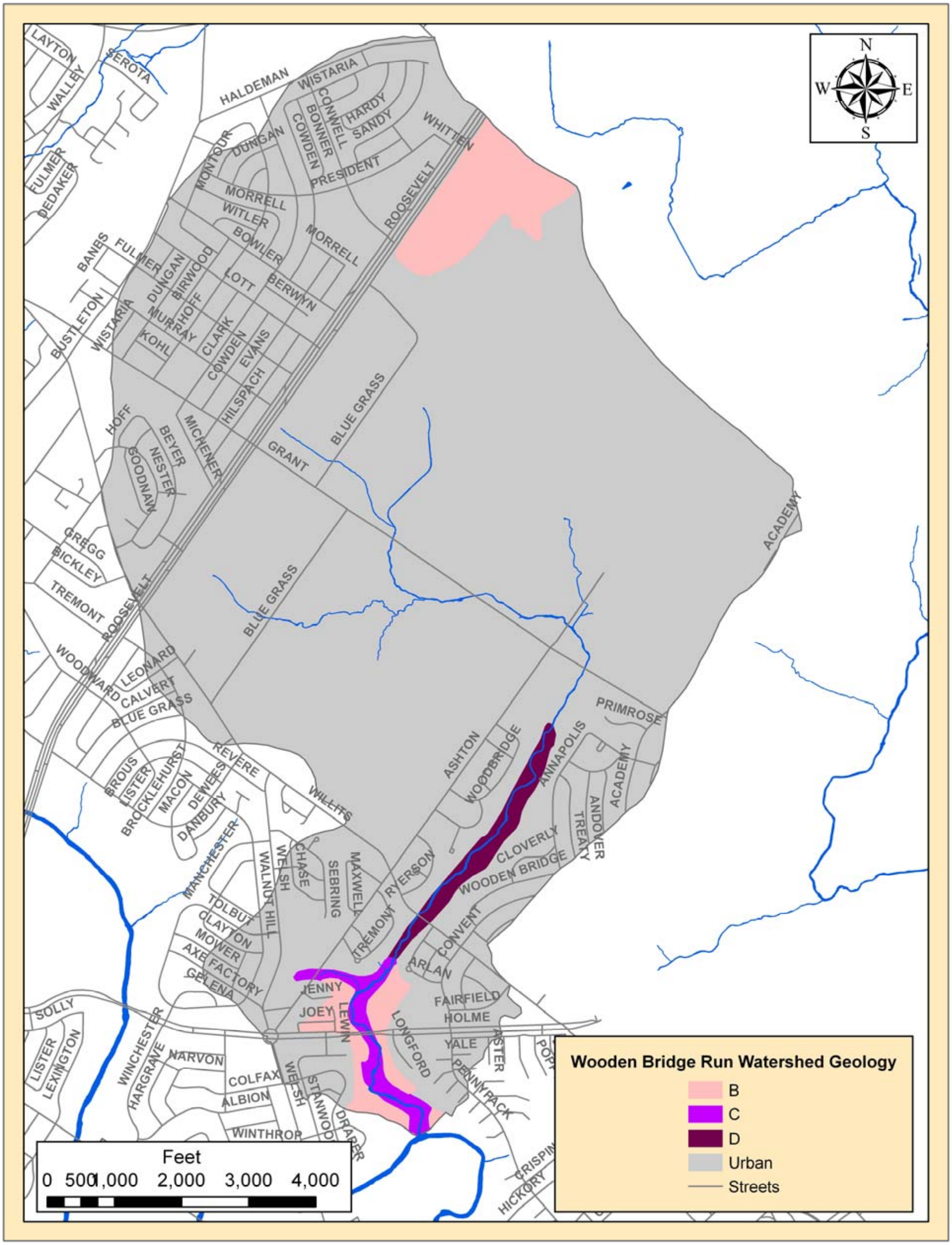


Figure 3-31: Distribution of NRCS Soil Types in Wooden Bridge Run Watershed

3.5.3 INFRASTRUCTURE TRACKDOWN SUMMARY

The infrastructure assessment of Wooden Bridge Run conveys the fact that the stream is impacted by the urban drainage areas that surround it. There was a substantial amount of infrastructure found in the Wooden Bridge Run Watershed during the study. There were a total of 165 elements of infrastructure discovered and recorded during the survey. The two most upstream reaches, PPWB04 and PPWB06, had the most infrastructure with 43 and 60 infrastructure elements recorded. The majority of the infrastructure points were attributed to outfalls and channels. The high values in those two categories indicate the requirement for stormwater conveyance and streambank stability.

The most prevalent type of infrastructure was outfalls. With 80 outfalls found during the assessment, stormwater management is a major factor impacting the stream. The two reaches with the most infrastructure elements, PPWB04 (43) and PPWB06 (60), also had the most outfalls. Both had over 20 outfalls. The total combined outfall area contributing stormwater runoff to Wooden Bridge Run was 330 square feet. This reiterates the amount of stormwater discharged to the stream during storm events. These two sections also had the highest percentages of channelization in the Wooden Bridge Run Watershed.

The stormwater runoff contributed to Wooden Bridge Run creates high flows that are unnatural for the channel and result in erosion of the banks and degradation of the channel. Due to these impacts on the stability of the banks and bed, a large amount of channelization was implemented to maintain the channel form and prevent further degradation. The channelization of the stream accounted for 41 infrastructure elements in Wooden Bridge Run. Reaches PPWB04 and PPWB06 each were over 13% channelized, while PPWBA02 was 12% channelized. This is a substantial amount of channelization considering that the fore mentioned two reaches are also the longest reaches assessed in the watershed. While protecting streambanks with concrete or stone channel walls can prevent erosion in a local area, they do little to slow the high flows and thus compound the erosion issues upstream and downstream.

Conveyance of the stream past civil amenities such as roads and trails is vital in the urban setting. Several culverts were discovered in the Wooden Bridge Run Watershed. A total of 22 culverts were observed and recorded during the infrastructure assessment. Culverts were created to convey the stream beneath the roads; however they constrict the flow, which causes degradation of the stream corridor upstream and downstream of the culvert. PPWB06 was the reach most heavily influenced by culverts. It had a total of 8 culverts and 460 feet of culvert length. This amounted to PPWB06 being 10.5% culverted. PPWB04 (7.1%), PPWB16 (8.6%), and PPWBA02 (7.3%) were each impacted by culverts as well.

The Wooden Bridge Run Interceptor is a sanitary pipeline that runs alongside the stream, connecting with several pipes that contribute flow from the surrounding neighborhoods before connecting to the Pennypack Creek Interceptor about 700 feet upstream of the confluence of Wooden Bridge Run and the Pennypack Creek Main Stem. The Wooden Bridge Run Interceptor starts as an 18 inch diameter pipe running parallel to Tributary A.

Another part of the interceptor starts as a 24 inch diameter pipe running along the stream starting where Grant Avenue passes over Wooden Bridge Run. At the junction where the sanitary flow is incorporated into the Pennypack Creek Interceptor, the Wooden Bridge Run Interceptor is 30 inches in diameter. While the interceptor crosses underneath Wooden Bridge Run several times, no exposed pipes were found that could be identified as the interceptor.

Eighteen pieces of infrastructure in the Wooden Bridge Run Watershed were found in poor condition. PPWB04 had the highest amount of priority infrastructure (8, Table 3-26). Seven of the eight pieces of infrastructure in PPWB04 were stormwater outfalls (Table 3-26). These poor condition outfalls were either buried by sediment and vegetation or the bank had been eroded away exposing the pipe leading to the outfall and in some cases the pipe had broken. There were four other instances of priority outfalls discovered in the rest of the watershed. Three dams located in the upper reaches of the watershed were found in poor condition. These were each low-head dams that served no modern purpose. PPdam154 appeared to be tipping into or sinking into the stream bed. Three channel segments were also found to be in poor condition and were designated as priority infrastructure. Their poor condition didn't appear to be having as detrimental of an impact as the outfalls and dams found in Wooden Bridge Run. In reach PPWB06, there was the exposed pipe PPpip028. This concrete pipe was found on the bank and had a large hole in it. The origin and nature of this pipe, however, was not determined during this study.

Table 3-26: Wooden Bridge Run Infrastructure Point Features

Section ID	Bridge Count	Channel Count	Culvert Count	Dam Count	Manhole Count	Other Count	Outfall Count	PipeSewer Count	Infra Points Count	Total Combined Outfall Area (ft^2)	Priority Infra Points Count
PPWB04	0	9	6	1	0	1	26	0	43	148.1	8
PPWB06	1	15	8	2	10	0	23	1	60	65.2	4
PPWB08	0	3	1	1	0	0	7	0	12	13.3	2
PPWB10	0	0	0	0	1	0	6	0	7	19.0	1
PPWB12	1	2	1	0	0	0	7	1	12	17.7	1
PPWB14	1	8	1	0	0	0	4	0	14	33.4	2
PPWB16	0	0	1	1	1	0	1	0	4	1.8	0
PPWBA02	0	4	3	0	0	0	5	0	12	30.2	0
PPWBA04	0	0	1	0	0	0	1	0	2	1.8	0
Total	**3**	**41**	**22**	**5**	**12**	**1**	**80**	**2**	**166**	**330.5**	**18**

Table 3-27: Wooden Bridge Run Infrastructure Linear Features

Section ID	Total Segment Length (ft)	Culvert Length (ft)	% Culverted	Channel Length, one side	Channel Length, two sides	Channel Length, three sides	Total Channel Length	Total Segment Length, 3 sides	% Channelized
PPWB04	6047	427	7.1	643	797	60	2417	18141	13.3
PPWB06	4361	460	10.5	63	191	431	1738	13083	13.3
PPWB08	2954	120	4.1	557	38	0	633	8862	7.1
PPWB10	2137	60	2.8	0	0	0	0	6411	0.0
PPWB12	1191	65	5.5	24	38	0	100	3573	2.8
PPWB14	2359	50	2.1	17	53	57	294	7077	4.2
PPWB16	2153	185	8.6	0	0	0	0	6459	0.0
PPWBA02	1586	115	7.3	159	4	135	572	4758	12.0
PPWBA04	3272	0	0.0	0	0	0	0	9816	0.0
Total	**26060**	**1482**	**5.7**	**1463**	**1121**	**683**	**5754**	**78180**	**7.4**

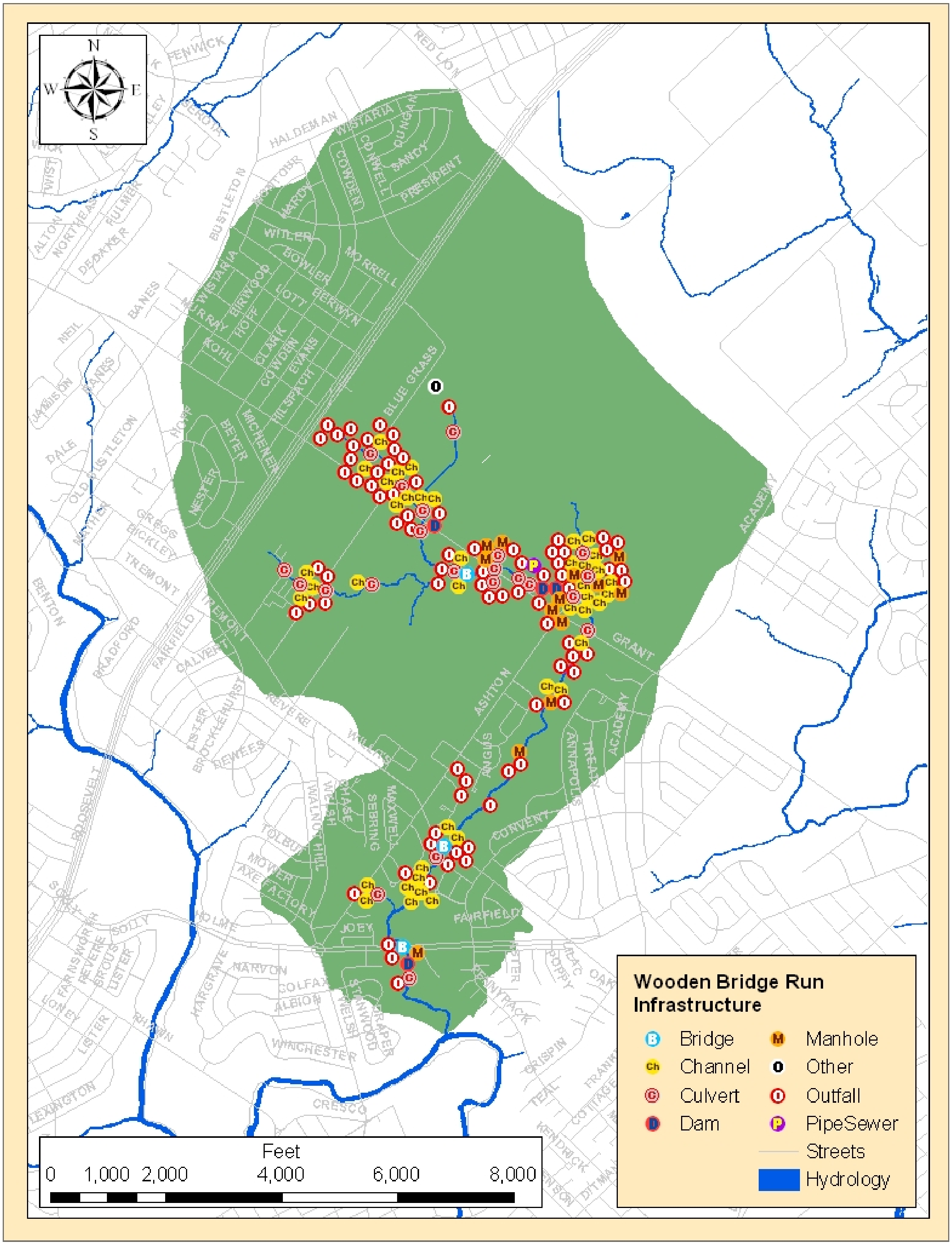


Figure 3-32: Wooden Bridge Run Watershed Infrastructure

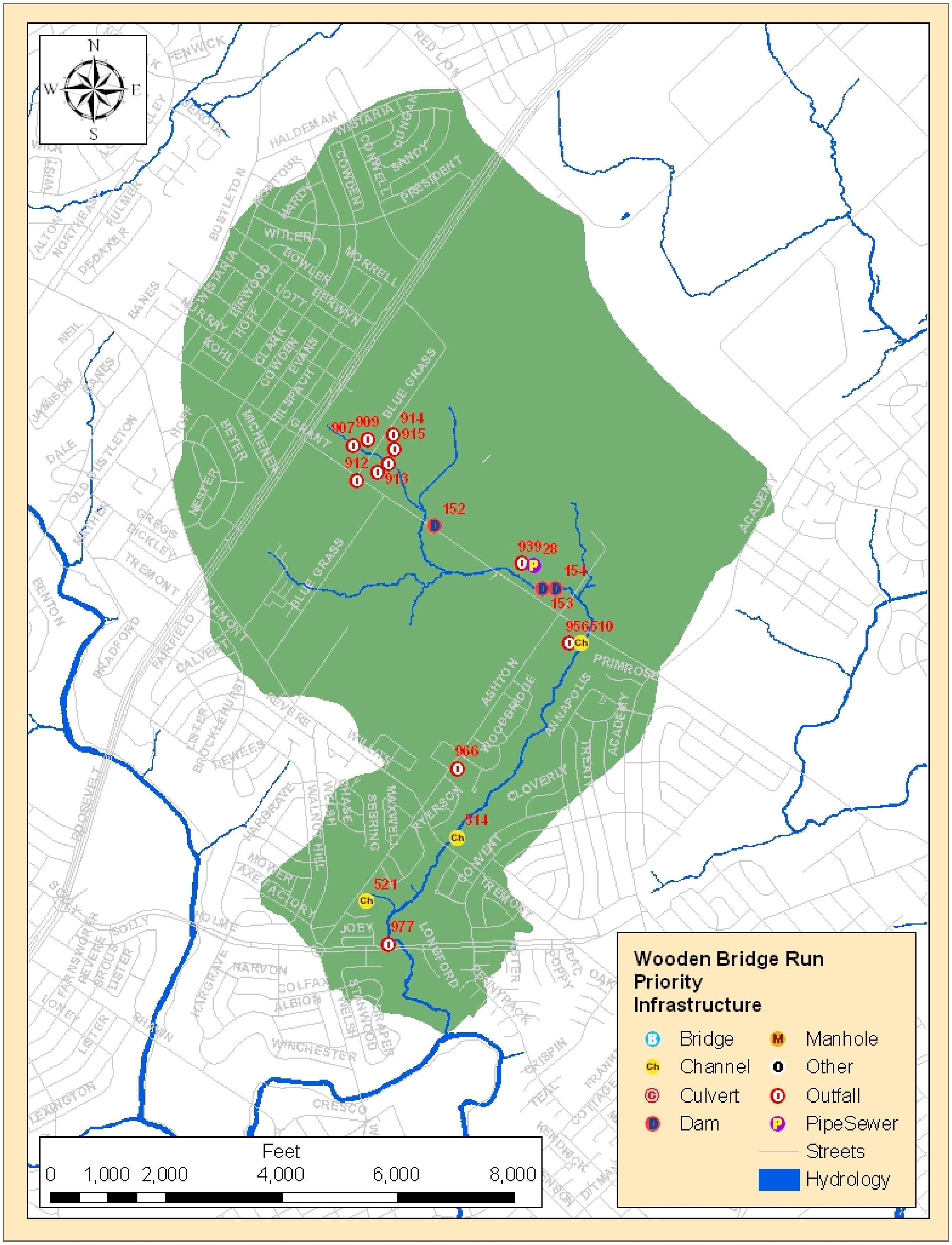


Figure 3-33: Wooden Bridge Run Watershed Priority Infrastructure

3.5.4 Unified Stream Assessment Results for the Wooden Bridge Run Watershed

The Wooden Bridge Run Watershed was the largest subwatershed within the Lower Pennypack Creek basin. The upper extent of the watershed was heavily influenced by the commercial and residential land use that abutted Wooden Bridge Run and its floodplain. Of significance were the Northeast Philadelphia Airport as well as the Whitman Plaza Shopping Center located in the headwaters of Wooden Bridge Run. There was one tributary, Duffield's Run (PPWBA), that came to a confluence with the main stem of Wooden Bridge Run at the downstream extent of reach PPWB04.

The Center for Watershed Protection's (CWP) Unified Stream Assessment Methodology (USAM) was used to score and rate the in-stream, riparian buffer and floodplain conditions of the stream corridor to allow for comparison to other reaches and watersheds within the Lower Pennypack Creek basin. The all reaches parameter is the mean of the scores of all tributary reaches in the Lower Pennypack Creek study.

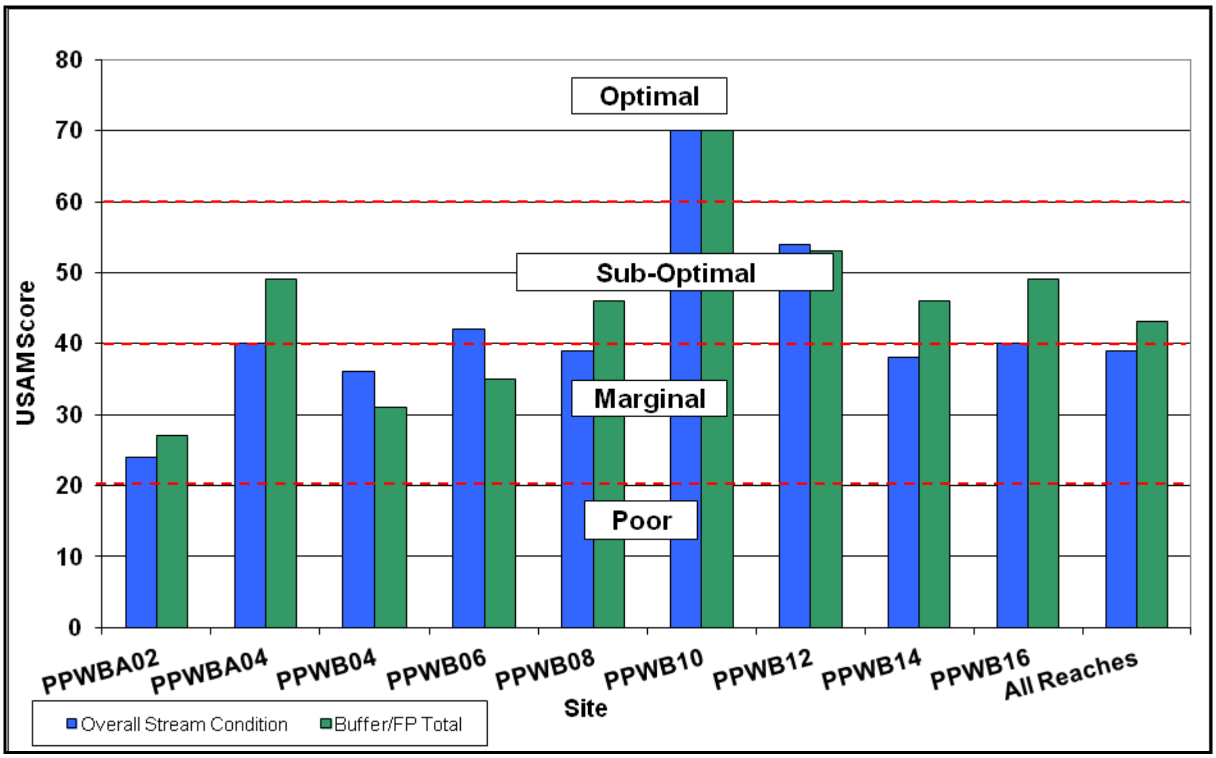


Figure 3-34: Results for Wooden Bridge Run USAM Components

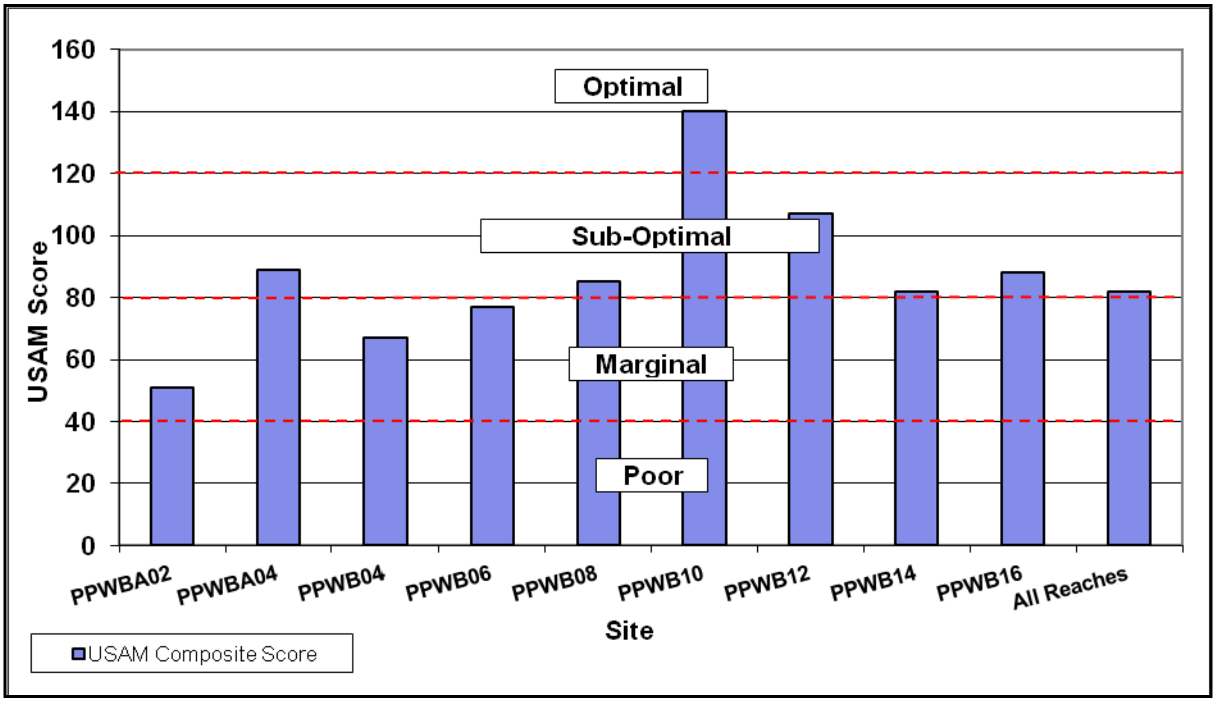


Figure 3-35: Wooden Bridge Run USAM Results

3.5.4.1 PPWBA02

Reach PPWBA02, also called Duffield's Run, was a small tributary to Wooden Bridge Run. It began as flow in a narrow swale between a multi-family residential complex and a commercial facility. There were several other large multi-family residential, commercial parcels with direct drainage to the reach via outfalls. The majority of the infrastructure elements within PPWBA02 were located at the center of reach where the channel was culverted and channelized to convey flow beneath of a rail line and Blue Grass Road.

The reach was classified as a Rosgen type F4 stream channel and was characterized by a moderate width to depth ratio (16.8) and a low entrenchment ratio (1.2). The substrate was dominated by gravel (76%), most of which were fine (38%) to medium (18%) sized particles. The D_{50} of the reach was 6.5 millimeters which corresponds to a fine gravel-sized particle. The cross section where pebble counts were conducted was upstream of the five outfalls that drain to the reach thus the high amount of fine sediment deposition observed in the reach may be attributed to sediment carried by overland flow as well as bank erosion. The overall USAM score for the reach was 51/160 which was rated as "marginal" (Figure 3-35).

3.5.4.2 PPWBA04

PPWBA04 began approximately 450 feet downstream of Blue Grass Road. The stream corridor was less confined than the PPWBA02 corridor although there were several light manufacturing facilities located on the floodplain of PPWBA04. There was a small tributary that contributed flow to the main stem of Duffield's Run. The small tributary came to a confluence with the main stem about 600 feet upstream of the confluence with Wooden Bridge Run.

Reach PPWBA04 was a Rosgen type F4 stream channel and had morphologic characteristics similar to that of PPWBA02. The width to depth ratio was moderate (15.6) and the channel was deeply entrenched (1.2). The substrate particle size distribution was dominated by gravel-sized particles (76%); however, the substrate composition was coarser than PPWBA02 with coarse gravel (58%) representing the dominant substrate class. Similarly, the D_{50} in PPWBA04 was 25.8 millimeters, which corresponds to coarse gravel. The overall USAM score for the reach was 89/160 which was rated as "suboptimal" (Figure 3-35).

3.5.4.3 PPWB04

There were two channels in reach PPWB04. The channels came to a confluence 50 feet upstream of PPcul371 which conveyed Wooden Bridge Run beneath Grant Avenue. The west branch of PPWB04 began as flow from PPout903. The channel was limited to a 50 feet corridor by commercial development on both banks. In this narrow corridor were 19 outfalls that drained the commercial facilities and parking lots on the west branch. The last 850 feet of the west branch, as well as portions upstream and downstream of Blue Grass Road were channelized. The east branch of PPWB04 began as flow from PPout902 which likewise drained a commercial facility. The floodplain was much more extensive on the east branch and there was minimal impact due to infrastructure. The downstream left bank and floodplain was heavily wooded however, much of the downstream right bank was maintained as turf grass by the Northeast Philadelphia Airport.

Downstream of PPcul371, the floodplain and stream corridor were relatively unconstrained by infrastructure and development. At the end of the reach, near the confluence with PPWBA04, there was a large manufacturing parcel which also contributed drainage to the reach. PPWB04 was classified as a Rosgen type F4 stream channel. The reach was characterized by a moderate width to depth ratio (16.0) and a deeply entrenched channel with an entrenchment ratio of 1.3. The D_{50} of the reach was 25.8 millimeters, which corresponds to coarse gravel. The overall USAM score for the reach was 67/160 which was rated as "marginal" (Figure 3-35).

PPWB04 was representative of many urban streams impacted by frequent stormwater inputs. The stream banks were severely eroded and vertical in several locations. At cross section PPWB04 the stream width was 19.4 feet compared to a wetted perimeter of 20.1 feet. The proximity in value of these parameters attests to the severe overwidening and channel incision observed throughout the reach.

3.5.4.4 PPWB06

Reach PPWB06 began at the upstream end of PPbri379 and ended approximately 350 feet upstream of Grant Avenue. The reach was heavily impacted by several types of infrastructure throughout its length. The portion of the reach bounded by PPbri379 and Ashton Road abutted a large manufacturing facility. Within this small portion of the reach were two dams, a pipe crossing, several culverted segments and twelve outfalls. There was a tributary to the reach which emanated from a wooded slope of the property of the Northeast Philadelphia Airport. This small tributary was also heavily impacted by infrastructure.

Like the upstream reaches, PPWB06 was classified as Rosgen type F4 stream channel. The channel had a moderate width to depth ratio (13.8) and was moderately entrenched with an entrenchment ratio of 1.5. The substrate in the reach was dominated by fine sediment, with the gravel (79%) being the most dominant substrate type. The D_{50} for the reach was relatively low at 27.2 millimeters which corresponds to coarse gravel. The overall USAM score for the reach was 77/160 which was rated as "marginal" (Figure 3-35).

3.5.4.5 PPWB08

Reach PPWB08 began approximately 300 feet upstream of PPcul386, which conveyed the stream channel beneath Grant Avenue. The upstream-most portion of the reach was channelized (PPcha510) and situated between several residential complexes which occupied both sides of the channel. Cross section PPWB08 was located approximately 100 feet from the end of the channelized portion of the reach. Close to the cross section were two outfalls (PPout959 and PPout960) which constituted the downstream-most infrastructure elements in the reach. Downstream of these outfalls, the floodplain on both banks was extensive and undeveloped.

Reach PPWB08 was Rosgen type F4 stream channel with morphologic characteristics similar to those observed in the upstream reaches. The width to depth ratio was moderate (16.9) and the entrenchment ratio was very low (1.2). The substrate was considerably coarser than the upstream-most reaches. The D_{50} of the reach was 37.2 millimeters which corresponds to the very coarse gravel size range. The overall USAM score for the reach was 85/160 which was rated as "suboptimal" (Figure 3-35).

3.5.4.6 PPWB10

Reach PPWB10 was the only reach that was not channelized or culverted beneath a major thoroughfare. There were very few infrastructure elements within the reach and only one, PPout965, was located within the stream channel. The floodplain on both banks was heavily vegetated and free of residential development or roads. The absence of significant in-stream or floodplain encroachment likely attributed to the favorable habitat and fluvial-geomorphic conditions observed in the corridor.

PPWB10 was classified as a Rosgen type C4 stream channel. Type C channels are characterized by a slight degree of entrenchment and moderate to high width to depth ratios and sinuosity. The entrenchment ratio was 3.1, which was considerably larger than all tributaries reaches assessed with the exception of PPSR03a (entrenchment ratio = 6.8). These conditions generally produce channel morphology conducive to overbank flooding and subsequent fine sediment deposition on the floodplain during the channel-forming discharge. The substrate particle-size distribution was dominated by gravel (57%) and cobble (25%) in reach PPWB10. The D_{50} was 40.6 millimeters which corresponds to the very coarse gravel size class. The combination of favorable channel morphology and relatively coarse substrate attributed to high scores in both of the USAM components as well as the composite USAM score. The *Overall Stream Condition* (70/80), *Overall Buffer Floodplain Condition* (70/80) and composite USAM score (140/160) for PPWB10 were all rated as "optimal" and were the highest scores observed of all of the tributaries assessed (Figure 3-34 and Figure 3-35).

3.5.4.7 PPWB12

Reach PPWB12 began approximately 150 feet upstream of Willits Avenue. The channel was conveyed beneath Willits Avenue via PPbri380. Several outfalls within the bridge structure flowed into the channel draining both Willits Avenue as well as surrounding residential development. PPbri380 was the sole floodplain encroachment within the reach although there was a pipe crossing (PPpip029) that had the potential to impound flow at very low rates of discharge. At the terminus of the reach there was a single outfall (PPout975) which drained residential development on the downstream left side of the corridor.

PPWB12 was classified as a Rosgen type F4 stream channel. It was characterized by a moderate width to depth ratio (17.5) and a deeply entrenched channel (entrenchment ratio = 1.3). The substrate composition was dominated by gravel (44%) and cobble (41%). More cobble was observed in reach PPWB12 than any other reach on Wooden Bridge Run. The D_{50} of the reach was 57.9 millimeters which corresponds to the very coarse gravel size class. The composite USAM score for the reach was 107/160 which was rated as "suboptimal" and was the second highest score observed on Wooden Bridge Run (Figure 3-35).

3.5.4.8 PPWB14

Reach PPWB14 had two small tributaries that conveyed flow from outfalls draining residential areas near Ashton Road. The first tributary was approximately 200 feet in length and began at PPout974. The second was approximately 900 feet in length and began at PPout976. At the end of the reach, the channel was conveyed beneath Holme Avenue by PPbri381. Aside from PPbri381 and an approximately 50 foot segment of channelization at the top of the reach, the corridor was free of floodplain encroachments and channel obstructions. On the downstream right bank between cross section PPWB14 and Holme Avenue, the floodplain and riparian corridor was reduced to less than 200 feet in width due to the presence of an abandoned rail line.

Reach PPWB14 was classified as a Rosgen type F4 stream channel. The channel was entrenched (entrenchment ratio = 1.2) at the bank full discharge (Q= 301 cubic feet per second (cfs)). The morphology of entrenched channels ultimately exacerbate bank erosion and channel incision as high energy flood flows infrequently access the floodplain where some of this energy can be dissipated. Other adverse impacts to channel morphology include deposition of fine sediment within the stream channel and overwidened channels with very shallow baseflow depths. These channels lack the heterogeneity in depth distribution commonly observed in stream systems that are not impacted by stormwater runoff.

The substrate distribution in reach PPWB14 was dominated by gravel (64%) and cobble (25%). The D_{50} of the reach was 40.2 which corresponded to the very coarse gravel size class.

3.5.4.9 PPWB16

Reach PPWB16 was the downstream-most reach in Wooden Bridge Run. The reach began about 10 feet upstream of PPman323 which is located on the downstream left bank approximately 70 feet downstream of Holme Avenue and ended at the confluence with the main stem of Pennypack Creek. The floodplain areas within the reach were free of infrastructure and development on both sides of the reach. On the downstream left floodplain an abandoned railroad formed the only point where the floodplain was restricted to less than 200 feet. Most infrastructure impacts were located within the stream channel. There was a low-head dam (PPdam155) and a culvert (PPcul389) that conveyed the channel beneath an abandoned railroad which likely impacted the channel's hydrology in this localized area.

Reach PPWB16 was classified as a Rosgen type F3 stream channel with a total drainage area of 3.46 square miles. The channel was entrenched (entrenchment ratio = 1.1) at the bankfull discharge (Q = 304 cfs) with a relatively high width to depth ratio of 28.8. The channel morphology data in reach PPWB16 was similar to that observed in PPWB14. PPWB16 was observed to have a terrace within the bankfull channel that created a more defined baseflow channel. This difference in cross-section geometry and/or the existence of dam PPdam155 may be responsible for the change in substrate between the two reaches. The substrate distribution in reach PPWB14 was dominated by finer-grained sediment particles when compared to the substrate particle size distribution in reach PPWB16. Substrate in PPWB16 was comprised of mostly cobble (48%) and gravel (41%). The D_{50} of the reach was 80.3 millimeters which corresponded to the small cobble size class. This was the largest D_{50} observed in the Wooden Bridge Run stream network.

3.5.5 SUMMARY OF UNIFIED STREAM ASSESSMENT RESULTS

Scores for each of the USAM components as well as the overall USAM scores for Wooden Bridge Run ranged from "marginal" to "optimal". Across all of the reaches in Wooden Bridge Run, the mean *Overall Buffer and Floodplain Condition* score was 46.7/80 and the mean *Overall Stream Condition* score was 43.8/80), both of which were higher than the respective all reaches averages. The overall USAM score at PPWB10 (140/160) was the highest score observed among all tributary reaches in the Pennypack Creek Watershed. Reach PPWBA02 had the lowest overall USAM score in the Wooden Bridge Run Watershed (51/160), which was also the lowest score observed among all tributary reaches assessed.

Table 3-28: USAM Results for Wooden Bridge Run

Reach ID	Sub-watershed	Overall Stream Condition	Overall Buffer/FP Condition	USAM Score
PPWBA02	Duffield's Run	24	27	51
PPWBA04	Duffield's Run	40	49	89
PPWB04	Wooden Bridge Run	36	31	67
PPWB06	Wooden Bridge Run	42	35	77
PPWB08	Wooden Bridge Run	39	46	85
PPWB10	Wooden Bridge Run	70	70	140
PPWB12	Wooden Bridge Run	54	53	107
PPWB14	Wooden Bridge Run	36	46	82
PPWB16	Wooden Bridge Run	53	63	116
Mean		**43.8**	**46.7**	**90.4**
All Reaches		**38.9**	**43.2**	**82.1**

3.5.5.1 SUMMARY OF OVERALL STREAM CONDITION SCORES IN THE WOODEN BRIDGE RUN WATERSHED

Overall Stream Condition scores for the Wooden Bridge Run reaches were generally low as all reaches were within the "marginal" range of scores with the exception of PPWB06, PPWB10, PPWB12 and PPWB16. The mean score for the entire watershed was within the "suboptimal" range of scores. The high mean score for the watershed was attributed to the score at PPWB10 which was rated as "optimal" with a score of 70/80. This was the highest score observed on any tributary in the Pennypack Creek Watershed. Reach PPWB10 also had the highest scores in the entire watershed for both the *Floodplain Connection* (20/20) and the *Bank Erosion* (10/10) parameters. The lowest *Overall Stream Condition* score in the watershed was observed in reach PPWBA02 (24/80). The score at PPWBA02 was also the lowest among all tributary reaches assessed.

The reach-wide mean scores for each of the parameters in the *Overall Stream Condition* component of the USAM assessment were higher than the all reaches average with the exception of the downstream left *Bank Erosion* parameter. There were no apparent longitudinal trends in scores for this component but higher scores were observed in reaches where infrastructure impacts were minimal.

Table 3-29: Overall Stream Condition Scoring for Wooden Bridge Run

OVERALL STREAM CONDITION								
Reach ID	Sub-watershed	In-Stream Habitat	Vegetative Protection		Bank Erosion		Floodplain Connection	Overall Stream Condition
			Left	Right	Left	Right		
PPWBA02	Duffield's Run	5	4	4	3	6	2	24
PPWBA04	Duffield's Run	14	8	6	6	4	2	40
PPWB04	Wooden Bridge Run	10	8	6	3	6	3	36
PPWB06	Wooden Bridge Run	11	5	9	3	9	5	42
PPWB08	Wooden Bridge Run	14	5	8	2	8	2	39
PPWB10	Wooden Bridge Run	12	9	9	10	10	20	70
PPWB12	Wooden Bridge Run	15	10	10	8	8	3	54
PPWB14	Wooden Bridge Run	12	8	7	5	4	0	36
PPWB16	Wooden Bridge Run	18	8	8	2	3	14	53
Mean		**12.3**	**7.2**	**7.4**	**4.7**	**6.4**	**5.7**	**43.8**
All Reaches		**11.1**	**6.3**	**6.1**	**5.0**	**5.8**	**4.6**	**38.9**

3.5.5.1.1 IN-STREAM HABITAT

Scores for the *In-stream Habitat* parameter ranged from "poor" to "optimal" throughout the watershed. The highest score was observed in PPWB16 (18/20) and the lowest score was observed in PPWBA02 (5/20) which was also the lowest score among all tributary reaches assessed. The mean score for the watershed was 12.3/20 which was rated as "suboptimal". The highest scores were generally observed in the downstream reaches. These reaches tended to contain less infrastructure and were thus less susceptible to some of the adverse impacts of stormwater (*i.e.* fine sediment deposition). Reach PPWB16 had the highest quality habitat largely due to the abundance of coarse substrate in the reach. PPWB16 had a substrate particle-size distribution dominated by cobble and a D_{50} of 80.3 millimeters which corresponded to small cobble.

3.5.5.1.2 VEGETATIVE PROTECTION

Scores for the *Vegetative Protection* parameter were moderate to high throughout the watershed. Of the nine reaches in the watershed, only one reach (PPWBA02), failed to have at least one bank rated in the "suboptimal" class or higher. The highest score was observed for both the downstream right and downstream left banks of PPWB12 (10/10). The mean scores for the left (7.2/10) and right (7.4/10) banks of Wooden Bridge Run were rated as "suboptimal" and both were higher than the respective All Reaches average

(Table 3-29). The lowest scores in the watershed were observed at PPWBA02 as both banks had a score of 4/10, which was rated as "poor". Scores classified as "poor" for this parameter are characterized by high levels of disturbance to the vegetative communities on the stream bank such that vegetation covers less than 50% of the streambank surface. The low scores for these parameters reflect the level of disturbance that vegetative communities are exposed to as a result severe bank erosion associated with stormwater runoff.

3.5.5.1.3 BANK EROSION

There was a high degree of variability among the scores for the *Bank Erosion* parameter as scores ranged from "poor" to "optimal". The watershed mean score for the left bank (4.7/10) was slightly lower than the all reaches average for tributaries however the mean score for the right bank (6.4/10) was higher than the all reaches average (5.8/10).

The lowest score (2/10), which was rated as "poor", was observed on the downstream left banks of PPWB08 and PPWB16. The worst reach overall was PPWB16 which had scores rated as "poor" for both the downstream left and downstream right banks. Three additional reaches, PPWBA02, PPWB04 and PPWB06, had banks that were also rated as "poor" with scores of 3/10.

The highest scores were observed on both the downstream left and downstream right banks of PPWB10 (10/10) where minimal evidence of bank erosion was observed due to presence of dense vegetation along the banks. A variety of tree, shrub and forbs species covered over 75% of the bank surfaces providing enhanced bank stability and cohesion of bank sediments. PPWB12 had scores of 8/10 on both banks for this parameter. The high degree of bank stability in this reach was also attributed to the presence of variety of vegetation types that covered a large proportion of the stream bank surface. Reaches PPWB06 and PPWB08 were rated as "suboptimal" with scores of 9/10 and 8/10 respectively for the downstream right bank. In both reaches, these banks were gently sloping and had a large proportion of the bank covered in vegetation. The opposite bank in each of these reaches was nearly vertical and thus lacked and vegetative cover. The severe erosion observed on these banks may be attributed to the presence of stormwater outfalls that drain the large industrial and commercial land-uses on this side of the corridor.

3.5.5.1.4 FLOODPLAIN CONNECTION

The *Floodplain Connection* parameter is a measure of the frequency in which high flows (i.e. greater than or equal to bankfull stage) are able to enter onto a stream channel's floodplain. The degree of floodplain connection was determined by the entrenchment ratio observed in each cross section in the reach. With the exception of PPWB10, Wooden Bridge Run was a deeply entrenched system characterized by highly incised and overwidened Rosgen type F4 stream channels. Each of the F4 stream channels were rated as "poor" for this parameter. The lowest score was observed in PPWB16 (1/20) as this reach had an entrenchment ratio of 1.1. Reach PPWB10 was classified as Rosgen type C4 stream channel respectively. This stream corridor was relatively free of infrastructure impacts and had a broad, undeveloped floodplain that extended beyond 200 feet in most locations.

3.5.5.2 SUMMARY OF OVERALL BUFFER AND FLOODPLAIN CONDITION SCORES IN THE WOODEN BRIDGE RUN WATERSHED

The scores for *Overall Buffer and Floodplain Condition* were rated as "suboptimal" for six of the nine reaches in the Wooden Bridge Run Watershed. There were three reaches (PPWBA02, PPWB04, and PPWB06) that scored poorly in this component of the USAM assessment due to impacts associated with the level of floodplain development and proximity of infrastructure encroachments observed in these reaches. The mean score of 46.7/80 was slightly higher than the All Reaches average of 43.2/80. The watershed mean scores for all parameters except *Floodplain Encroachment* were lower than the respective All Reaches averages (Table 3-30).

The highest score in the watershed as well as among all tributary reaches assessed was observed in PPWB10 (70/160). This reach was minimally impacted by adjacent residential development and the presence of infrastructure thus many of the individual parameter scores for the *Overall Buffer and Floodplain* component were rated as "optimal". Also of significance were the scores for the *Vegetated Buffer Width* parameter on the downstream left and downstream right banks of PPWB10, PPWB12 and PPWB16, which were the highest scores (10/10 on both banks) of all the tributary reaches assessed.

Table 3-30: USAM Buffer and Floodplain Condition Scoring for the Wooden Bridge Run Watershed

OVERALL BUFFER AND FLOODPLAIN CONDITION							
Reach ID	Sub-watershed	Vegatated Buffer Width		Floodplain Vegetation	Floodplain Habitat	Floodplain Encroachment	Buffer/FP Total
		Left	Right				
PPWBA02	Duffield's Run	6	6	9	2	4	27
PPWBA04	Duffield's Run	9	6	16	2	16	49
PPWB04	Wooden Bridge Run	3	5	15	3	5	31
PPWB06	Wooden Bridge Run	6	5	15	5	4	35
PPWB08	Wooden Bridge Run	7	8	15	2	14	46
PPWB10	Wooden Bridge Run	10	10	11	20	19	70
PPWB12	Wooden Bridge Run	10	10	11	3	19	53
PPWB14	Wooden Bridge Run	9	9	11	0	17	46
PPWB16	Wooden Bridge Run	10	10	11	14	18	63
Mean		**7.8**	**7.7**	**12.7**	**5.7**	**12.9**	**46.7**
All Reaches		**8.0**	**7.5**	**12.7**	**4.8**	**11.1**	**43.2**

3.5.5.2.1 VEGETATED BUFFER WIDTH

Scores for the *Vegetated Buffer Width* parameter were highest in the downstream-most reaches PPWB10, PPWB12, PPWB14 and PPWB16 as both banks in these reaches were rated as "suboptimal" or "optimal". The upstream reaches were located in dense commercial, industrial and residential corridors which considerably reduced the width of the riparian buffer throughout the corridor in these reaches. Most of the upstream reaches had buffers rated as "marginal" with vegetative buffers in the range of 25-50 feet, although the left side of the corridor in PPWBA04 had a score of 9/10 which was rated as "suboptimal". The averages scores for the left and right banks were 7.7/10 and 7.8/10 respectively. Both mean scores for the watershed were higher than the respective All Reaches averages for this parameter (Table 3-30).

3.5.5.2.2 FLOODPLAIN VEGETATION

The quality and abundance of floodplain vegetation was similar throughout Wooden Bridge Run. All reaches were rated as "marginal" with the exception of PPWBA02 which was rated as "suboptimal". Vegetation was characterized as young secondary forest; however saplings, shrubs and forbs were also abundant. The lack of older hardwood forests in this area may be attributed to the history of development in this watershed. Most of the development within this area was completed during the second half of the twentieth century, thus the natural process of succession has yet to produce the large, old growth forests of watersheds that were developed during previous eras. The score for PPWBA04 (16/20) was the highest score observed in the watershed although PPWB04, PPWB06 and PPWB08 had vegetation types similar to PPWBA04 with scores of 15/20. The mean watershed score was 12.7/20 which was equal to the All Reaches average (Table 3-30).

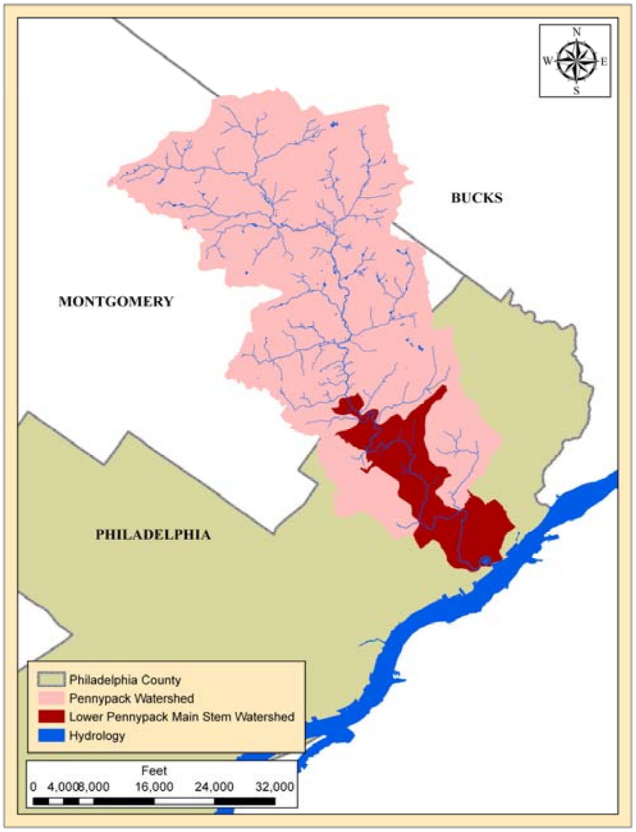
3.5.5.2.3 FLOODPLAIN HABITAT

Scores for the *Floodplain Habitat* parameter were generally low throughout the watershed. The mean watershed score of 5.7/20 was rated as "marginal" although it was higher than the All Reaches average of 4.8/20 which was rated as "poor". With the exception of PPWB10 and PPWB16, the floodplains within the other reaches were not observed to support the hydrology needed to maintain habitat features such as wetlands or vernal pools due to the lack of frequent overbank flooding. The highest score was observed in PPWB10 (20/20). In PPWB10, the stream channel is not severely entrenched which allows for more frequent overbank flooding and periodic inundation of the floodplain. Reach PPWB14 had the lowest score (0/20) in the watershed as well as all of the tributary reaches assessed.

3.5.5.2.4 FLOODPLAIN ENCROACHMENT

The *Floodplain Encroachment* parameter measures the extent to which residential, commercial, and industrial development or infrastructure impacts floodplain function in a reach. The most severe impacts usually are observed where development or infrastructure is located on the floodplain or abuts a stream channel. Scores in Wooden Bridge Run were highly variable and ranged from "poor" to "optimal". Generally there was a spatial trend observed whereas scores increased in the downstream-most reaches. The upstream reaches were highly impacted by the proximity of commercial, residential and industrial land uses within the corridor. Reaches PPWBA02, PPWB04, and PPWB06 had portions of the corridor that were abutted on both sides by development within 50 feet of the stream channel. The mean score of 12.9/20 was rated as "suboptimal" which was slightly higher than the All Reaches average score of 11.1/20.

3.6 LOWER PENNYPACK CREEK MAIN STEM WATERSHED AND REACH CHARACTERISTICS



The Pennypack Creek Main Stem is a tributary to the Delaware River. The headwaters of the Pennypack Creek Main Stem are at outfall PPout088. This outfall is located in Upper Dublin Township in Montgomery County. The main stem flows for approximately 13.4 miles before entering Philadelphia County, where it is known as the Lower Pennypack Creek Main Stem.

Pennypack Creek enters the city just under 1,000 feet upstream of the Pine Road bridge at Fox Chase Farm. From the city boundary to the confluence with the Delaware River, the Lower Pennypack Creek Main Stem flows for about 10.5 miles. At cross section PPMS56, the first cross section in the city, the drainage area is 38.3 square miles. At the confluence with the Delaware River the total drainage area is 55.8 square miles. About 6.6 square miles of the watershed drain directly to the lower Pennypack Creek Main Stem. There are five major tributaries to the Pennypack Creek Main Stem that are entirely within the city. They are Darlington Run, Paul's Run, Sedden's Run (Main Stem Tributary F), Sandyford Run, and Wooden Bridge Run. Rockledge Brook also has a confluence with Pennypack Creek within the city, however it is near the city boundary and most of the stream is outside the city. It was therefore excluded from the Lower Pennypack Watershed.

During this assessment several small unnamed tributaries were discovered and later identified and/or named. Tributaries found during this study include Verree Creek, Hower Creek, Staler's Run, Krewstown Creek, Three Springs Hollow Run, Tremont Creek, Benton Brook, Horrock's Creek, Axe Factory Run, Possum-Hollow Run, and Willets Run. These tributaries were discovered during the infrastructure assessment and through desktop analysis. There are still several small unnamed tributaries to the Pennypack Creek Main Stem inside the city.

Nearly the entire Lower Pennypack Creek Main Stem is located within Fairmount Park. Fairmount Park creates a substantial wooded riparian buffer around the stream. The wooded buffer can be over 1,500 feet wide in places. The major land uses in the Lower

Pennypack Creek Main Stem Watershed are wooded (25%), residential multi-family (25%), and residential single-family detached (8%). The dominate substrate in this watershed is very coarse gravel; however there is some variation in substrate throughout the reaches from medium gravel to small cobble. For reach maps refer to Appendix C.

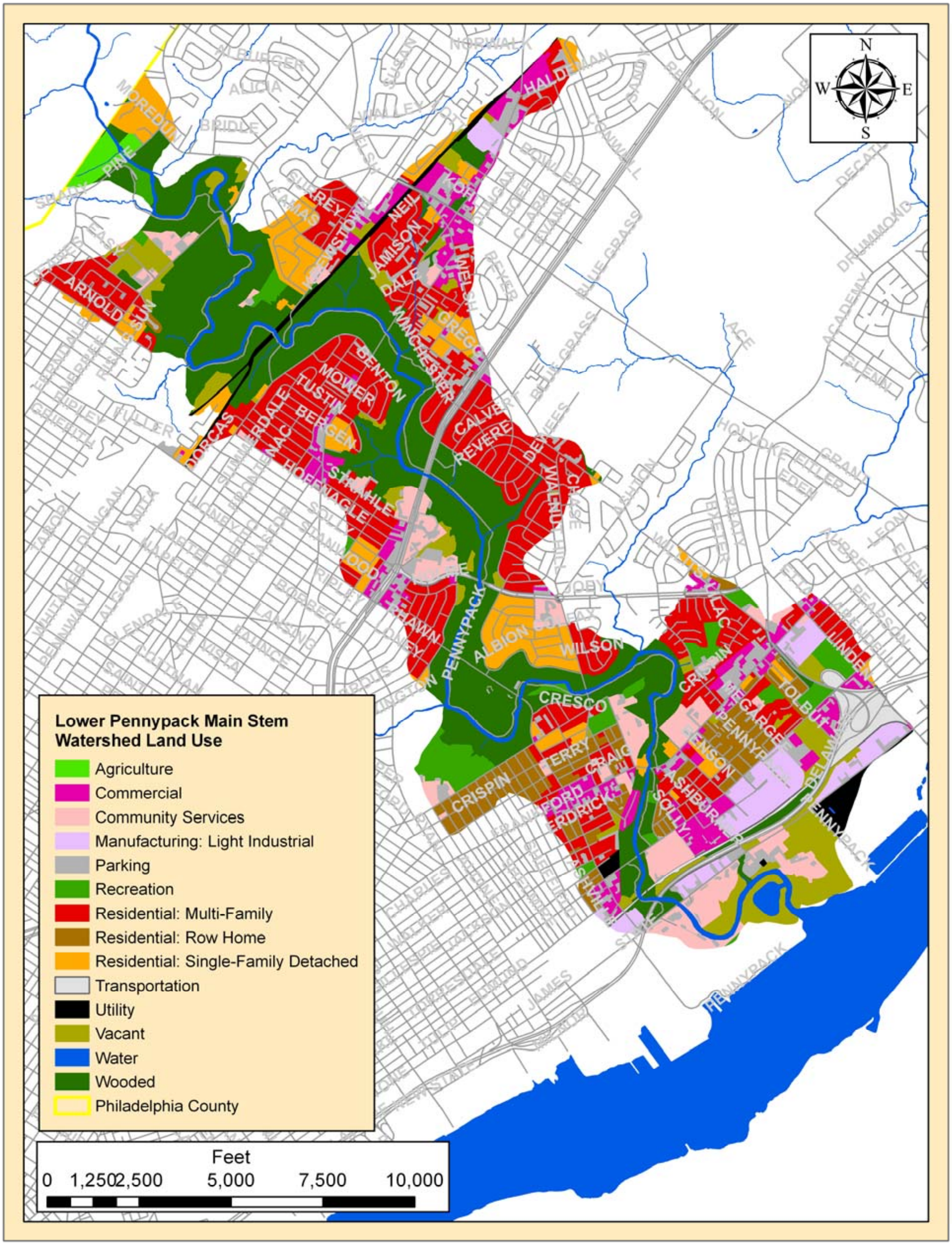


Figure 3-36: Lower Pennypack Creek Main Stem Watershed Land Use

3.6.1 GEOLOGY

The Lower Pennypack Creek Main Stem Watershed is underlain by five different geologic formations. The Wissahickon and Pennsauken Formations are the majority of the watershed and the Trenton Gravel Formation is most of the rest of the watershed. Those three formations are found in over 90% of the watershed. The remaining two formations occupy only 7% of the watershed. They are granitic gneiss and granite and mafic gneiss.

The Wissahickon Formation is the most prevalent geology in the watershed. This formation makes up 57% of the Lower Pennypack Creek Main Stem Watershed, located mostly in the areas directly around the stream corridor and a large portion of the watershed's northwestern portion. The Wissahickon Formation consists of mica schist, gneiss, and quartzite. Exposed schist near the surface is highly weathered. There are also some metamorphosed sedimentary and igneous rocks within this formation.

The Pennsauken Formation is the second most common geology of the Lower Pennypack Creek Main Stem Watershed. It is 22% of watershed's total geology, located in the areas further away from the stream surrounding the Wissahickon Formations and underlying the perimeter of the watershed except for the northwestern portion and the downstream most area. The Pennsauken Formation consists of yellow to dark reddish brown sand and gravel. It is mostly comprised of quartz, quartzite, and chert. This is a severely weathered floodplain formation.

The Trenton Gravel Formation is a gray or pale-reddish-brown, very gravelly sand interstratified formation with cross-bedded sand and clay-silt beds. The formation includes areas of Holocene alluvium and swamp deposits. The Trenton formation is entirely existent at the downstream most area of the watershed near the confluence with the Delaware River. This geologic formation is 14% of the Lower Pennypack Creek Main Stem Watershed.

3.6.2 SOILS

According to the National Resource and Conservation Service Soil Survey, nearly all of the Lower Pennypack Creek Main Stem Watershed soils are classified as Urban Land soils. Over 70% of the Lower Pennypack Creek Main Stem Watershed consists of the disturbed urban soils. Urban soils consist of material that has been disturbed by human activity during urbanization. These soils have been produced by mixing, filling, and contamination of native soils in both urban and suburban areas.

The soil category B occupies just over 22% of the watershed. There are two areas where these soils are prevalent. They are located directly around the majority of the stream corridor and in the northwestern portion of the watershed around the stream corridor. These soils have a moderate rate of infiltration when the soils are wet (0.50-1.00 in/hr). Water movement through these soils is considered moderately rapid.

There are areas of C soils located in the direct vicinity of the stream in the northwestern and middle portions of the watershed. Group C soils have a slow rate of infiltration when saturated (0.17-0.27 in/hr). Water movement through these soils is moderate or moderately slow. Similar to this is a few areas of Group D soils surrounding the stream throughout the stream length. These soils have a very slow rate of infiltration when saturated (0.02-0.10 in/hr) resulting in a high runoff potential.

Table 3-31: Distribution of NRCSS Soil Types in Lower Pennypack Main Stem Watershed

Group	Area (ft^2)	Percent of Total Area
B	42,329,911	22.23%
C	6,935,352	3.64%
D	1,082,648	0.57%
Urban	140,087,600	73.56%
Water	4,704,203	2.47%
Total Area	190,435,512	100.00%

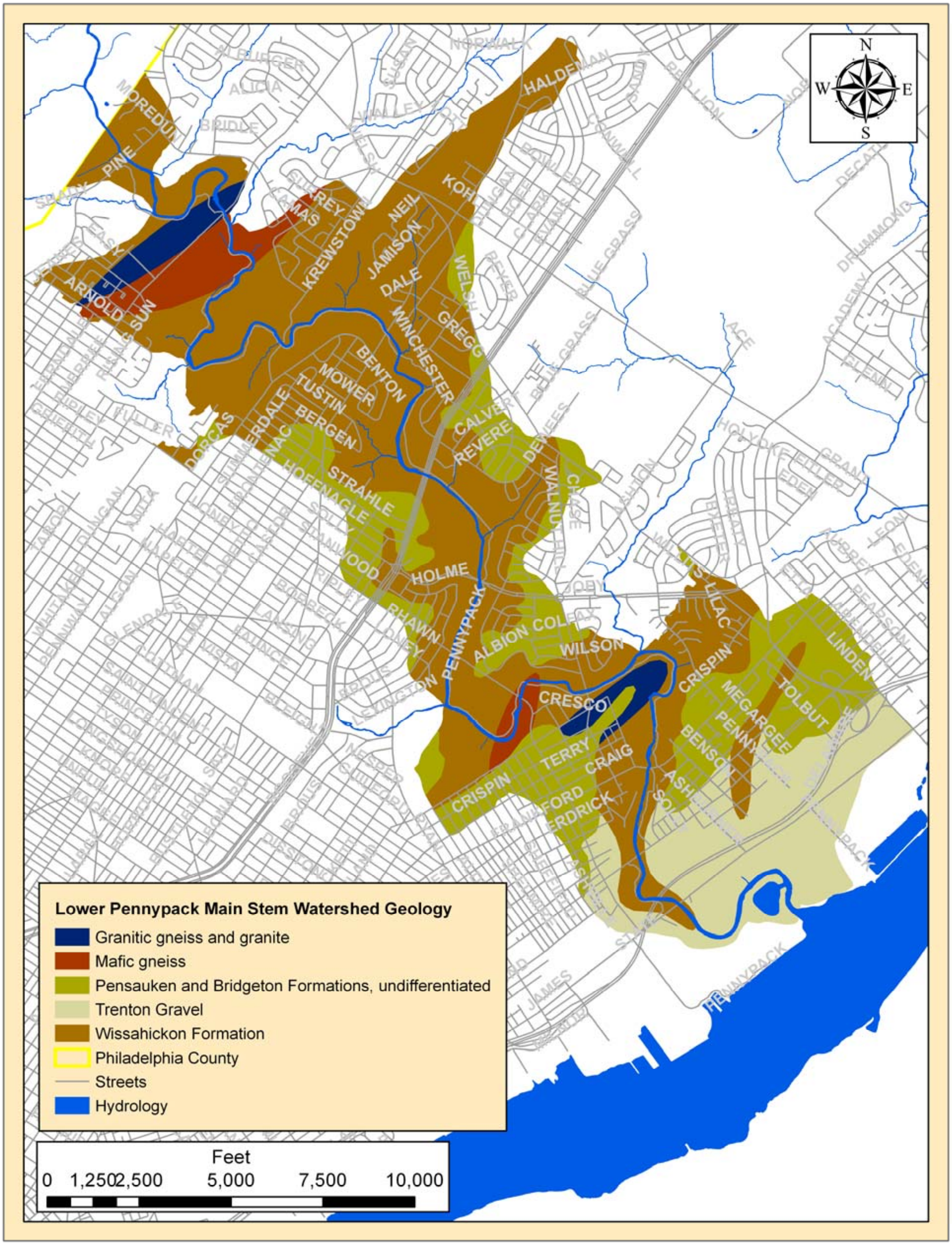


Figure 3-37: Geology of Lower Pennypack Creek Main Stem Watershed

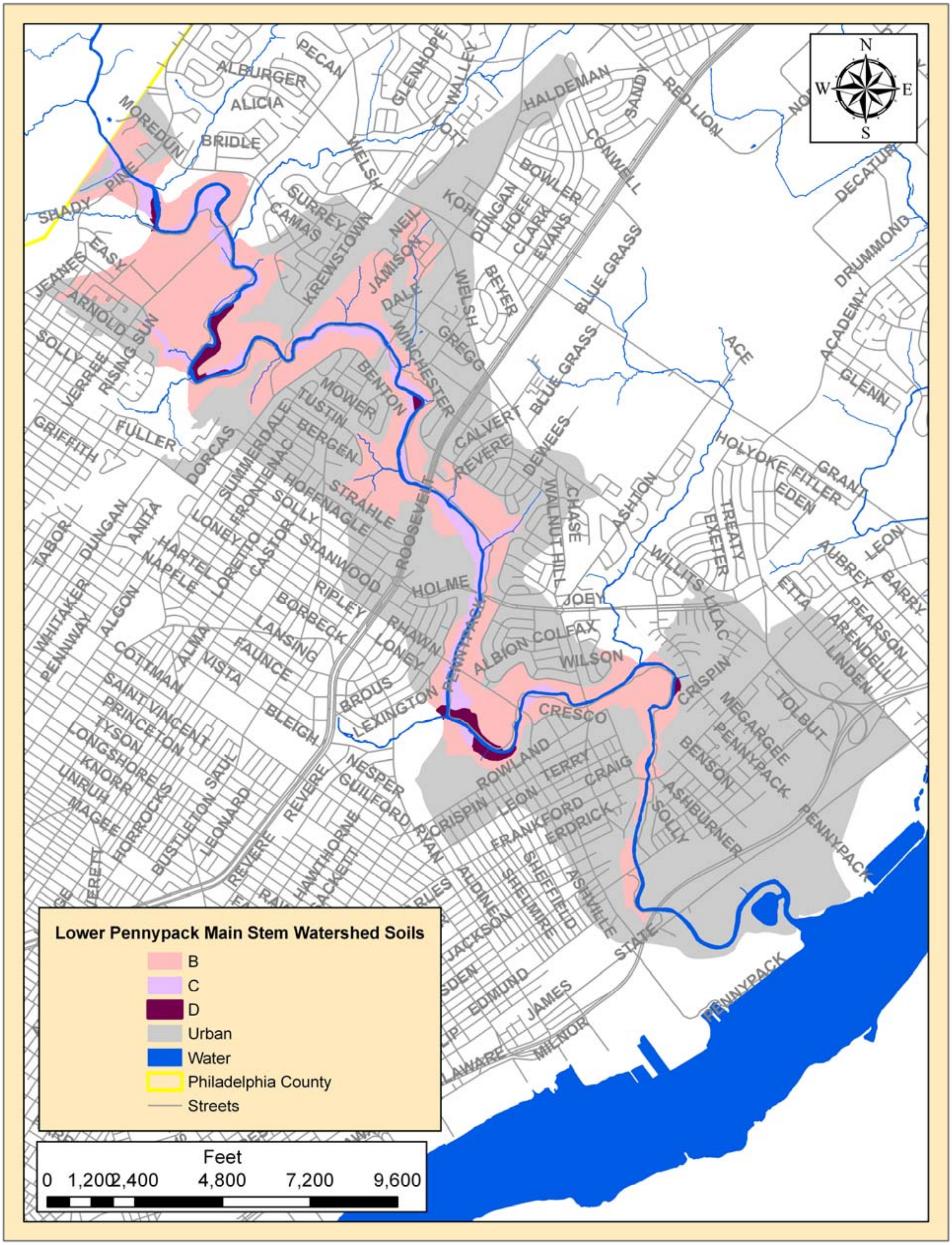


Figure 3-38: Distribution of NRCS Soil Types in the Lower Pennypack Creek Main Stem Watershed

3.6.3 INFRASTRUCTURE TRACKDOWN SUMMARY

The Lower Pennypack Creek Main Stem infrastructure corresponds directly to the land uses of the surrounding drainage areas and the urban development existing therein. As with many urban streams there is a substantial amount of infrastructure along the Pennypack Creek Main Stem for drainage, stabilization, and stream conveyance and crossings. Over the 10.5 miles from the city border to the confluence with the Delaware River the Lower Pennypack Creek Main Stem has 290 infrastructure elements total. The density of infrastructure along the Pennypack Creek Main Stem was relatively low in comparison to the tributaries. The low density of infrastructure on the main stem can be attributed to the entire length existing within Fairmount Park and the substantial buffer associated with it. However the infrastructure on the main stem was of substantial size and displayed tremendous detrimental impacts on the stream. There were also several previously unknown or unnamed tributaries that were discovered and assessed for infrastructure, but had no distinction as their own reaches and therefore contributed infrastructure data to main stem reaches.

The total amount of infrastructure for individual reaches ranged from 2 (PPMS86) to 66 (PPMS72) elements (Table 3-32). The high amount of infrastructure in PPMS72 can be attributed to the three tributaries that contribute flow to the main stem in this reach. The three tributaries that were previously unidentified have now been identified as Benton Brook, which has its own tributary identified as Horrock's Creek, and Axe Factory Run. The large amount of infrastructure elements associated with the tributaries contributing to the main stem reaches is a result of these small streams flowing through developed urban areas while the main stem flows through Fairmount Park. PPMS68 has a large amount of infrastructure (38) and this is because of Tremont Creek flowing through a heavily residential area. The infrastructure associated with PPMS90 is directly influential on the main stem Pennypack Creek stream corridor. This reach has 9 channels and 23 outfalls attributed to it (Table 3-33).

As with several of the subwatersheds, the Lower Pennypack Creek Main Stem exhibited the outfalls and channels that demonstrate the impact of the development of the watershed and the resulting impervious surfaces creating high flows from runoff, and the need to stabilize the stream because of degradation and stream bank erosion. There are 79 outfalls in the main stem watershed. The outfalls in the Lower Pennypack Creek Main Stem range in size from 6 inches in diameter to over 40 square feet in outfall area. Reach PPMS90 has the most outfalls of all the reaches with 23 and the second most outfall area with 79 square feet (Table 3-32). Despite having about half the number of outfalls of PPMS90 with 12, reach PPMS72 has the highest total outfall area at 91 square feet. This can be mostly attributed to PPout878, a 6 feet by 7 feet outfall that is the headwaters of Axe Factory Run. PPMS72 has 26 channels which are the result of having aprons and bank stabilization around nearly every outfall and a few channels along the banks of the main stem. Though the channels along the main stem of the reach are few in number they account for the majority of the channel length in the reach. PPMS72 also has the highest percent channelized of any of the reaches (14.7%). This is substantial considering the segment length associated with PPMS72 is the largest of all the main stem Pennypack Creek reaches.

Culverts serve the civil purpose of conveying the stream underneath roads, trails, parking lots, and buildings; however, they are also very detrimental to the function of the stream itself and are highly disruptive to the ecological health of the stream corridor. A total of 31 culverts were discovered in the Lower Pennypack Creek Main Stem Watershed during the assessment creating a total culverted length of 3,130 feet. PPMS68 stands out from the rest of the reaches as having the highest culverted length with 2,112 feet (Table 3-33) and percent culverted at 24.5%. There are five culverts in the PPMS68 reach including PPcul353 which is 600 feet long and the 1,200 feet long PPcul355. All of the culverts associated with PPMS68 are actually on Tremont Creek, a first-order tributary to Pennypack Creek's main stem discovered during the survey. None of the rest of the reaches has a culverted percentage over 7.5% and the majority of them are between 0% and 1.5%. Culverts were not as prevalent on the Pennypack Creek Main Stem proper; as they were on the small tributaries associated with the main stem reaches. Culverts constrict stream flow and can cause scour upstream and downstream and therefore could cause more damage on a larger stream. On the main stem of Pennypack Creek bridges were recorded in more instances.

The Pennypack Creek Interceptor is a sanitary pipeline that runs adjacent to the Pennypack Creek Main Stem. The Pennypack Creek Interceptor enters the City of Philadelphia approximately 1,300 feet northwest of Pine Road. The interceptor is a 20 inch diameter reinforced concrete pipe at the city border; however it transitions to a 36 inch pipe shortly thereafter. Numerous interceptors connect to the Pennypack Creek Interceptor as it makes its way to Delaware Avenue where it connects to the Upper Delaware Low Level Interceptor. At this junction the Pennypack Creek Interceptor is a 6 feet by 5 feet-9 inches pipe. The connecting pipes contribute sanitary flow from the neighborhoods surrounding Pennypack Park. In most cases the connecting pipes follow the tributaries to Pennypack Creek until they meet the main interceptor.

The main interceptor crossed beneath the stream in a few places, but an exposed pipe attributed to it wasn't found during the assessment. Three pipes across the Pennypack Creek Main Stem were found however. In reach PPMS72, PPpip025 was discovered exposed in the stream and acting as a low-head dam. This pipe was the 16 inch interceptor that runs along Axe Factory Run. The pipe was completely encased in concrete, exposed about 1 foot out of the substrate and for the entire width of the stream. PPpip027, in reach PPMS74, was a 10 inch sanitary pipe that connected to the main interceptor about 140 feet upstream of the Rhawn Street bridge (PPbri375). This pipe was also encased in concrete, but was uncovered and acting as a low-head dam. The last pipe found on the main stem of Pennypack Creek was PPpip030 in reach PPMS86. This was a 16 inch pipe leading from Pennypack Road. The pipe was again exposed and acting as a low-head dam. These exposed pipe crossings are already having detrimental effects on the geomorphic nature of the stream and could become a hazard should they become damaged and leak sanitary flows into the creek.

There were 25 infrastructure elements identified as being in poor condition along the Pennypack Creek Main Stem. Of those 18 were channels, 5 were outfalls, and there was a culvert and a manhole as well. The Pennypack Creek Main Stem proper had 8 channels found in poor condition. Most of these consisted of broken concrete scattered along the bank, while a few were stone walls that had fallen apart. One of the channels was a wooden wall that appeared to be collapsing into the stream. The other 10 channels in disrepair were located on tributaries to the main stem. Reach PPMS72 contained 13 pieces of priority infrastructure, including 10 channels. Within this reach the other three priority infrastructure elements were a manhole and two outfalls. Axe Factory Run accounted for 8 of the 13 priority infrastructure elements in PPMS72, including 7 channels.

Table 3-32: Lower Pennypack Creek Main Stem Infrastructure Point Summary

Section ID	Bridge Count	Channel Count	Culvert Count	Dam Count	Manhole Count	Other Count	Outfall Count	PipeSewer Count	Infra Points Count	Total Combined Outfall Area (ft^2)	Priority Infra Points Count
PPMS56	1	1	0	0	4	0	3	0	9	15.7	0
PPMS58	1	2	0	1	0	0	2	0	6	12.0	0
PPMS60	0	8	3	0	1	1	1	0	14	9.6	0
PPMS62	1	9	4	2	2	0	2	0	20	29.0	1
PPMS64	1	2	0	1	0	0	0	0	4	0.0	0
PPMS66	2	12	2	0	2	2	2	0	22	10.2	0
PPMS68	3	18	5	0	3	0	9	0	38	38.5	3
PPMS72	3	26	3	1	19	0	12	2	66	91.4	13
PPMS74	1	1	2	0	3	0	1	1	9	12.6	2
PPMS76	1	0	1	0	0	1	4	0	7	10.2	0
PPMS78	0	1	1	0	4	0	3	0	9	24.2	1
PPMS80	2	2	3	0	0	0	2	0	9	2.1	1
PPMS82	1	0	0	0	0	0	9	0	10	11.5	0
PPMS84	0	2	2	0	1	0	1	0	6	25.0	1
PPMS86	1	0	0	0	0	0	0	1	2	0.0	0
PPMS88	1	3	3	0	0	0	5	0	12	20.0	0
PPMS90	3	9	2	0	9	1	23	0	47	79.4	3
Total	**22**	**96**	**31**	**5**	**48**	**5**	**79**	**4**	**290**	**391.4**	**25**

Table 3-33: Lower Pennypack Creek Main Stem Linear Infrastructure Summary

Section ID	Total Segment Length (ft)	Culvert Length (ft)	% Culverted	Channel Length, one side	Channel Length, two sides	Channel Length, three sides	Total Channel Length	Total Segment Length, 3 sides	% Channelized
PPMS56	3823	0	0.0	511	0	0	511	11469	4.5
PPMS58	2578	0	0.0	43	88	0	219	7734	2.8
PPMS60	3411	41	1.2	684	18	13	759	10233	7.4
PPMS62	4802	55	1.1	92	132	79	592	14406	4.1
PPMS64	2940	0	0.0	621	0	0	621	8820	7.0
PPMS66	7087	92	1.3	1177	64	10	1335	21261	6.3
PPMS68	8606	2112	24.5	337	327	76	1219	25818	4.7
PPMS72	8004	110	1.4	2527	427	47	3522	24012	14.7
PPMS74	5310	265	5.0	36	0	0	36	15930	0.2
PPMS76	1868	10	0.5	0	0	0	0	5604	0.0
PPMS78	3064	7	0.2	24	0	0	24	9192	0.3
PPMS80	2163	130	6.0	144	36	0	216	6489	3.3
PPMS82	1561	0	0.0	0	0	0	0	4683	0.0
PPMS84	1974	86	4.4	7	9	0	25	5922	0.4
PPMS86	2108	0	0.0	0	0	0	0	6324	0.0
PPMS88	1992	150	7.5	480	0	0	480	5976	8.0
PPMS90	11950	72	0.6	927	108	0	1143	35850	3.2
Total	**73241**	**3130**	**4.3**	**7610**	**1209**	**224.5**	**10701.5**	**219723**	**4.9**

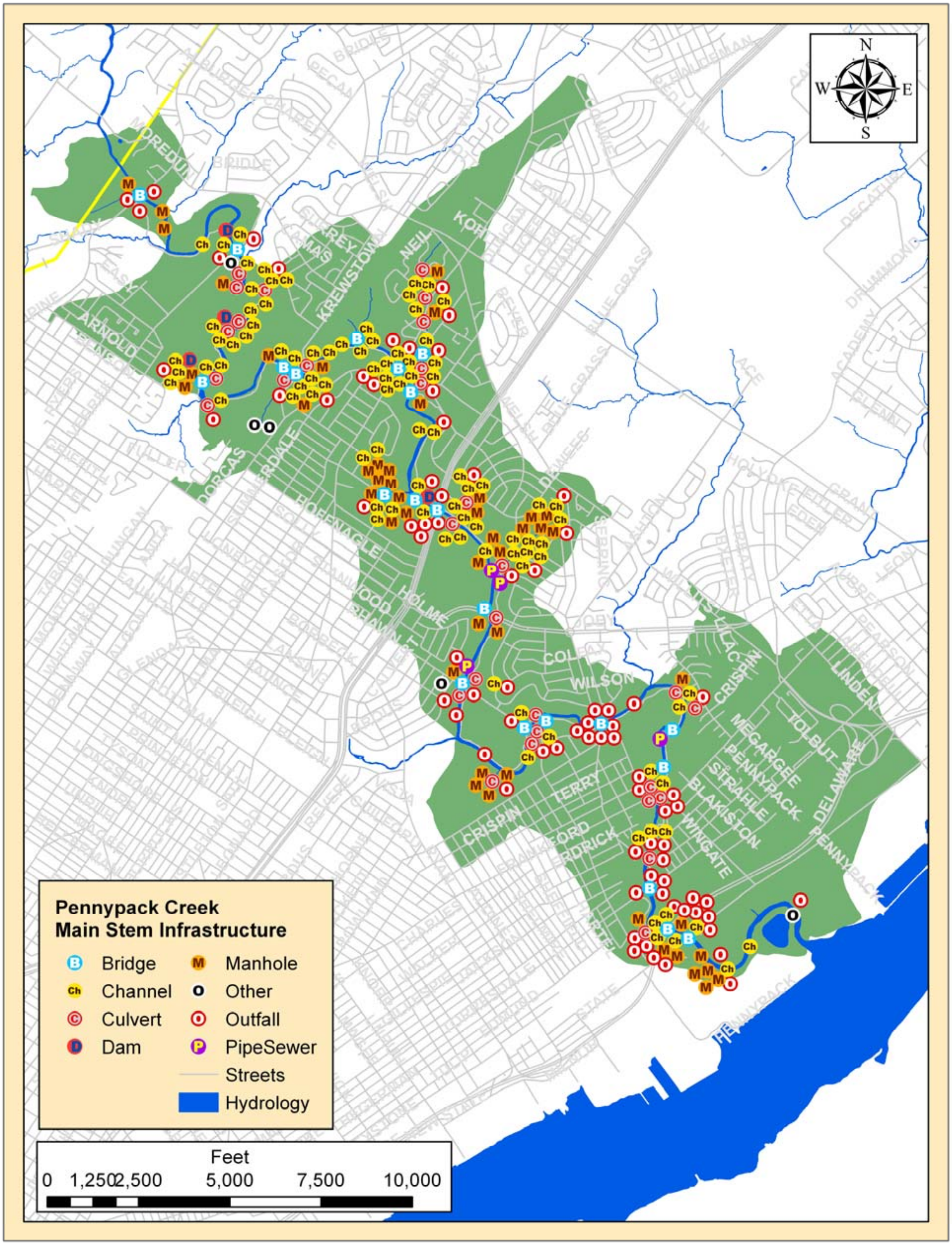


Figure 3-39: Lower Pennypack Main Stem Watershed Infrastructure

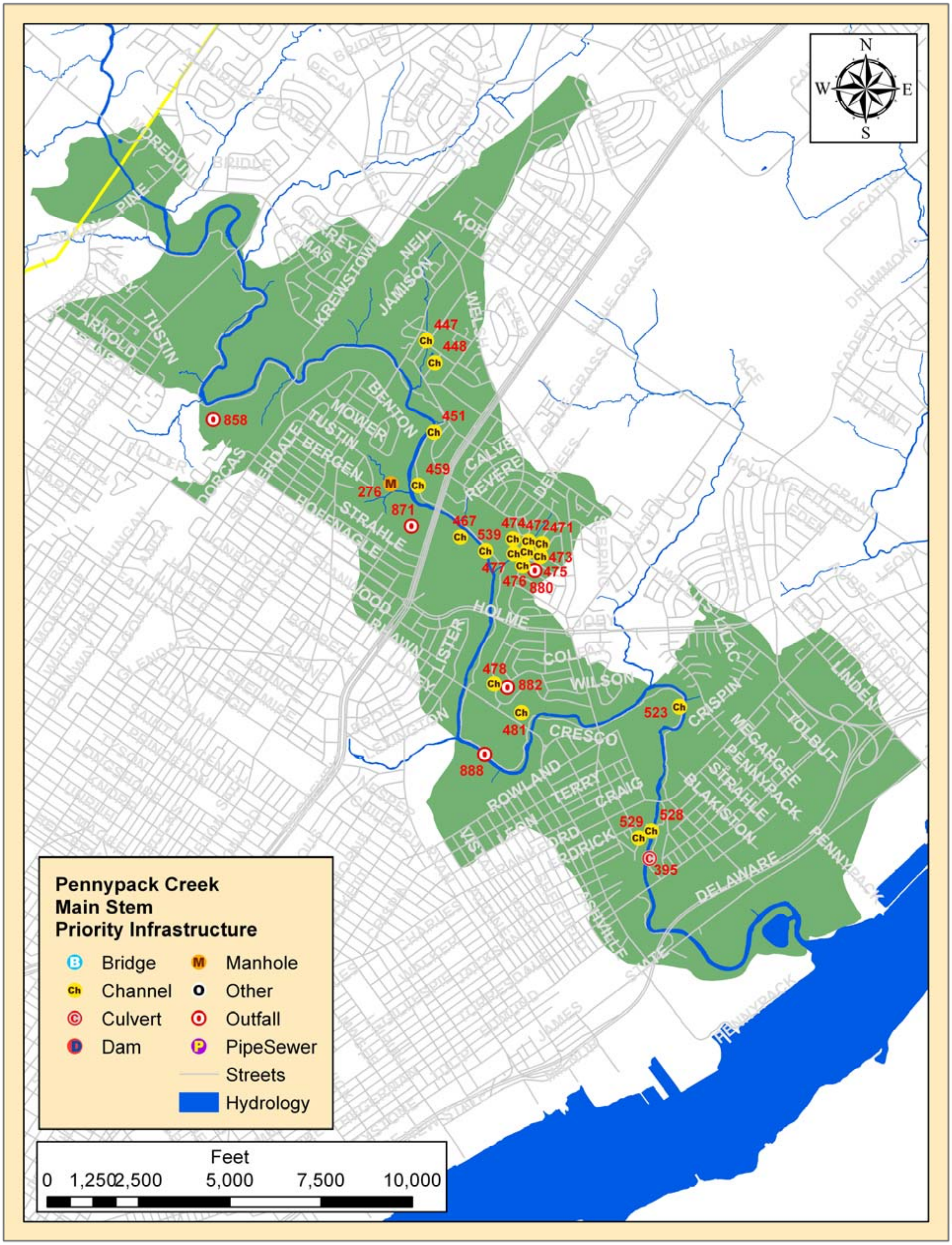


Figure 3-40: Lower Pennypack Main Stem Watershed Priority Infrastructure

3.6.4 Unified Stream Assessment Results for the Lower Pennypack Main Stem Watershed

The Pennypack Creek Main Stem is the stream corridor that all of the previously mentioned subwatersheds contribute flow into. The main stem of Pennypack Creek has a large riparian buffer and few infrastructure elements, which is attributed to Fairmount Park's Pennypack Park being established around it. The major ecological impact to the main stem is the substantial amount of stormwater that the channel encounters due to the tributaries and their heavily developed drainage areas.

The Center for Watershed Protection's (CWP) Unified Stream Assessment Methodology (USAM) was used to score and rate the in-stream, riparian buffer and floodplain conditions of the stream corridor to allow for comparison to other reaches and watersheds within the Lower Pennypack Creek basin. The all reaches parameter is the mean of the scores of all reaches in the Lower Pennypack Creek Main Stem.

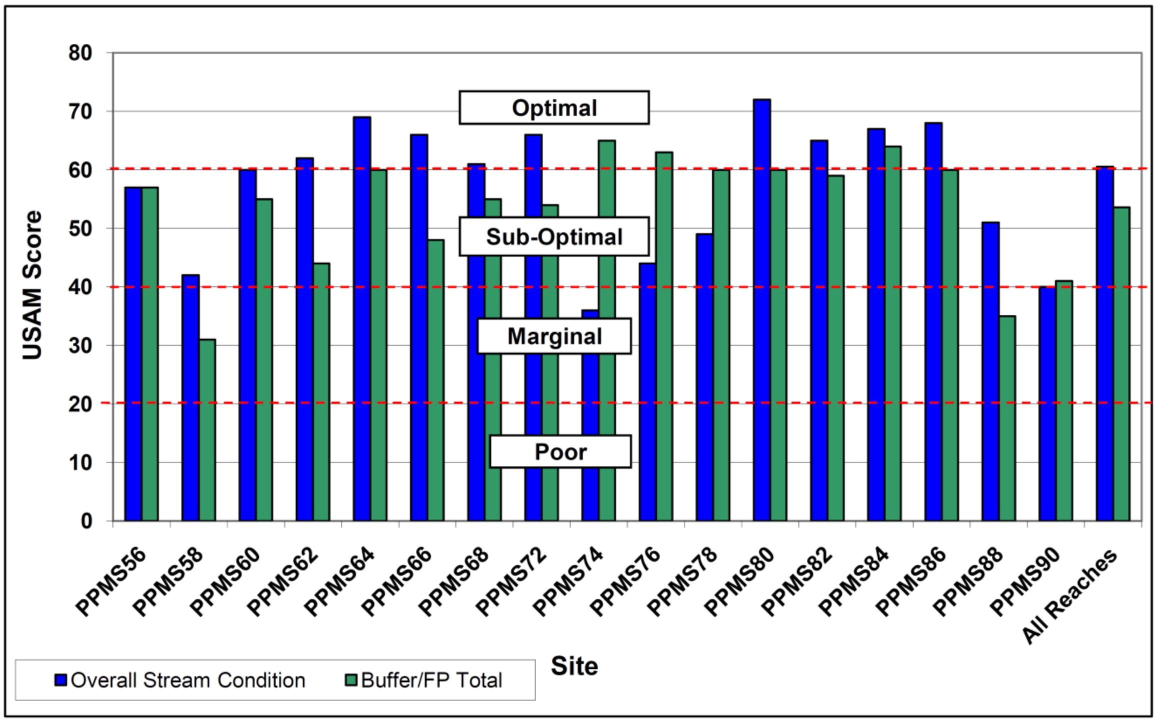


Figure 3-41: Results for Lower Pennypack Creek Main Stem USAM Components

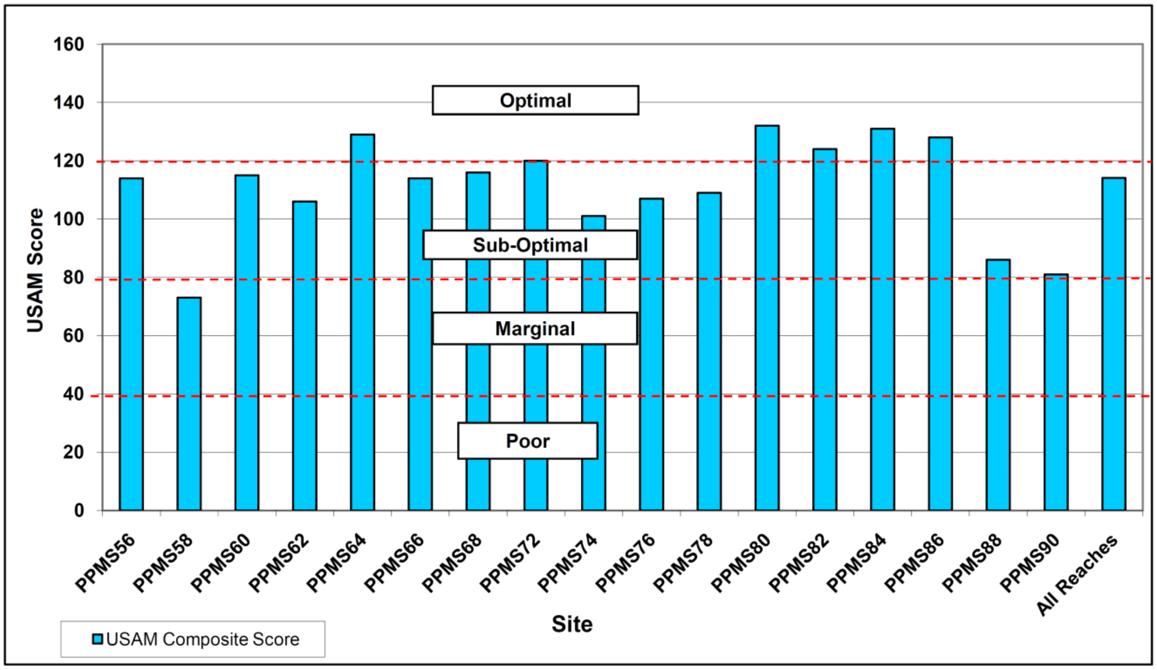


Figure 3-42: Lower Pennypack Creek Main Stem USAM Results

3.6.4.1 PPMS56

Reach PPMS56 was the first main stem reach located entirely within the City of Philadelphia. The reach began downstream of the Pine Road Bridge and ended 3,823 feet downstream. The confluences of Darlington Run and Rockledge Brook were both located within the upstream extent of the reach. A large proportion of the channel was a located within a large oxbow meander such that two segments of the reach ran parallel – separated by an expansive floodplain on the downstream left side of the valley. The asphalt-paved, Pennypack multi-use trail abutted the stream channel for the entire length of the reach on the downstream right bank. With the exception of a 511 feet long channel in the downstream portion of the reach, the channel and floodplain were relatively free of infrastructure. The dominant land cover within the stream corridor was woodland as the reach was located entirely within Fairmount Park.

The reach was classified as a Rosgen type C4 stream channel. The channel morphology allowed overbank flooding and inundation of the floodplain at flows in excess of the bankfull discharge with an entrenchment ratio of 3.4. The moderate width to depth ratio (21.7) likely attributed to the relatively high maximum depth of 4.9 feet observed in the riffle cross section at the bankfull discharge. The substrate distribution was dominated by gravel (53%) although cobble-sized particles (36%) were also present in relatively high abundance. The D_{50} of the reach was 41 millimeters, which corresponded to very coarse gravel. The overall USAM score for this reach was 114/160, which was rated as "suboptimal."

3.6.4.2 PPMS58

Reach PPMS58 was located entirely within Fairmount Park and extended from the meander upstream of the Verree Avenue Dam (PPdam145) to a point 120 feet downstream of the confluence of Paul's Run and the main stem of Pennypack Creek. The Pennypack Environmental Center (PEC) and its support facilities were located on the downstream left side of the corridor. PEC also had a moderate sized parking lot on the downstream right side of the corridor although it was in excess of 500 feet from the stream channel, thus it likely had no impacts on floodplain function. Other than the PEC facilities, the stream corridor in the reach was relatively free of development.

Downstream of PPdam145, the reach was classified as Rosgen type F4 stream channel. The channel was severely overwidened with a width to depth ratio of 30.8, which was the second highest observed on the main stem after PPMS62 (44.3). The channel was also observed to be severely entrenched with an entrenchment ratio of 1.2. The substrate distribution was dominated by fine grained sediment classes (55% gravel and 29% sand) likely due to the presence of the impoundment upstream of PPdam145. Low-head dams such as PPdam145 sequester sediment within dam impoundments. The D_{50} of the reach was 23.1 millimeters which corresponded to coarse gravel. The overall USAM score for this reach was 73/160 and was rated as "marginal". The USAM score for this reach was the lowest observed among all main stem reaches.

3.6.4.3 PPMS60

Reach PPMS60 was located entirely within Fairmount Park and was not impacted by development within its corridor. The Pennypack multi-use recreational trail abutted the downstream right streambank for the entire length of the reach and in some locations the trail was as close as 25 feet to the top of the downstream right stream bank. There were no stream crossings on the main stem channel although there were three culverts (PPcul335, PPcul336, and PPcul337) that conveyed two small tributaries beneath road crossings to the main stem channel. On the downstream right side of the corridor a 540 feet long tributary locally known as Verree Run, emanated from a small wetland (PPmisc027) and was conveyed beneath the Pennypack multi-use recreational trail via culverts PPcul335 and PPcul336. On the downstream left side of the corridor, a 390 feet long tributary emanated from PPout853 and was conveyed beneath an access road by PPcul337. There were five channelized segments in the main stem channel that comprised the only infrastructure elements on the main stem channel in this reach. Two of the channelized segments, PPcha404 and PPcha405, were extensive in length at 275 feet and 312 feet respectively.

The reach was classified as a Rosgen type C3 stream channel. The entrenchment ratio for the reach was 3.4. Generally, entrenchment ratios above 2.2 are indicative of channels that have the capacity to convey flows above the bankfull discharge onto the floodplain. These channels are prone to be highly stable as high flows are not contained entirely within the active channel which can cause channel incision and bank erosion. The substrate distribution in the reach was dominated by cobble (44%) and gravel (39%). The D_{50} of the reach was 65.4 millimeters which corresponded to small cobble. The overall USAM score was 115/160 and was rated as "suboptimal".

3.6.4.4 PPMS62

Reach PPMS62 was 4,802 feet in length and had confluences with two small tributaries, including Sedden's Creek. The first, Tabor Creek, was an overflow "chute" channel that originated on the downstream left bank of PPMS60 and reached a confluence with the main stem of Pennypack Creek at PPcul339. The second tributary, Staler's Run, was 815 feet in length and originated from PPout854. Staler's Run reached its confluence with the main stem 15 feet downstream of PPbri363, which conveyed the tributary beneath the Pennypack multi-use recreational trail. There were four channelized segments in the reach, the longest of which was 380 feet in length. Aside from the channelized portions, there were no infrastructure elements within the main stem channel. The most significant infrastructure was located on Staler's Run where a 15 feet vitrified clay pipe (VCP) trunk sewer was encased in PPdam150 where it crossed the stream.

The reach was classified as a Rosgen type B4 stream channel. The channel was moderately entrenched with an entrenchment ratio of 2.0 and severely overwidened. The width to depth ratio was 44.3, which was the highest width to depth ratio observed on main stem Pennypack Creek. The substrate distribution was dominated by gravel (64%) although cobble was observed in relatively high abundance as well (21%). The D_{50} of the reach was 32.0 millimeters which corresponded to coarse gravel. The overall USAM score was 106/160 and was rated as "suboptimal".

3.6.4.5 PPMS64

Reach PPMS64 began as a channelized segment (PPcha424) 930 feet upstream of cross section PPMS64 and ended 75 feet downstream of the CSX freight rail bridge (PPbri365). A small channelized segment just upstream of PPbri365 was the only other infrastructure element within the main stem channel. The Pennypack multi-use recreational trail abutted the entire length of the reach on the downstream right side of the corridor and in some locations; the trail was within 25 feet of the active channel. The valley wall on the downstream right side of the corridor was very steep and limited the width of the downstream right floodplain for most of the reach. The downstream right floodplain was wide and expansive only in the vicinity of the large meander at the downstream end of the site. Aside from the trail, there were no other floodplain encroachments on either side of the reach. On the downstream left side of the corridor the floodplain was as wide as 250 feet in some locations although the steep valley wall limited the width of the floodplain in downstream portion of the reach.

Reach PPMS64 was classified as a Rosgen type C4 stream channel. The channel morphology was characteristic of a stable channel with an entrenchment ratio of 3.3 and a width to depth ratio of 18.5. The substrate distribution was dominated by gravel (43%) although cobble (35%) was present in considerable abundance. The D_{50} of the reach was 24.9 millimeters which corresponded to coarse gravel. The overall USAM score for the reach was 129/160, which was rated as "optimal".

3.6.4.6 PPMS66

Reach PPMS66 was located in a narrow corridor bounded by Krewstown Road to the north, Algon Road to the south, Bustleton Avenue to the east, and the CSX railroad to the west. Krewstown Road also crossed the stream channel at PPbri366 in the upstream portion of the reach within a channelized section of the reach (PPcha426). There were two small tributaries that reached a confluence with the main stem of Pennypack Creek within the reach. Krewstown Creek reached its confluence in the upstream portion of the reach 70 feet upstream of PPbri366. Three Springs Hollow Run reached its confluence at a channelized segment (PPcha437) of the reach 630 feet upstream of the end of reach. There was also a small, ephemeral conveyance channel on the downstream right which conveyed stormwater from PPout860.

Reach PPMS66 was classified as a Rosgen type C3 stream channel. The channel morphology was similar to that of Reach PPMS64 with a moderate width to depth ratio (20.5) and a high entrenchment ratio (3.0). The substrate distribution was dominated by cobble (42%) and gravel (36%) with sand present in moderate abundance (20%). The D_{50} of the reach was 42.5 millimeters which corresponded to very coarse gravel. The overall USAM score for the reach was 114/160, which was rated as "suboptimal".

3.6.4.7 PPMS68

Reach PPMS68 was 4,090 feet along the main stem of Pennypack Creek and included a tributary that was determined to be Tremont Creek. Tremont Creek begins at the end of a stormwater conveyance culvert at Welsh Road and flows for 4,770 feet until its confluence with Pennypack Creek. Reach PPMS68 begins approximately 740 feet upstream of bridge PPbri368 which conveys Bustleton Avenue over Pennypack Creek. After the Bustleton Avenue bridge, the reach continues for another 3,255 feet before the start of reach PPMS72. The Pennypack Creek Interceptor runs along the stream for most of this reach and crosses underneath the stream twice. The interceptor has a 54 inch diameter at the upstream limit of the reach and has a 60 inch diameter at the downstream limit. The first crossing underneath Pennypack Creek is about 315 feet downstream of the confluence with Tremont Creek and the second crossing is 600 feet further than that. There is also an 18 inch sanitary water main that connects to the Pennypack Interceptor 30 feet upstream of the Tremont Creek confluence. None of these pipe crossings were exposed or found during the infrastructure assessment, they were later found using PWD’s GIS data (DataConv.GISAD.Waste Water Network, 2013).

This reach was classified as a Rosgen type C4b-stream channel. The channel morphology was characteristic of a stable channel with a high entrenchment ratio (4.0) and a moderate width to depth ratio (19.1). The substrate distribution was dominated by gravel (55%). Cobble (31%) and sand (14%) are the other sediment types that were found during the sediment analysis. The D_{50} of the reach was 32 millimeters which corresponded to very coarse gravel. The overall USAM score for the reach was 116/160, which was rated as "suboptimal".

3.6.4.8 PPMS72

Reach PPMS72 was the second longest reach (8,004 feet) assessed after PPMS90 (11,950 feet). Within PPMS72, 3,496 feet is attributed to the tributaries and 4,508 feet is the main stem proper. There were three tributaries that reached a confluence with the main stem channel in the reach. Benton Brook, a second order tributary, reached a confluence with main stem Pennypack Creek in the upstream portion of the reach approximately 825 feet upstream of the Roosevelt Boulevard Bridge (PPbri373). There was a small bridge (PPbri372) upstream of PPbri373, which provided a connection between the Pennypack multi-use recreational trail on the downstream left and an access road on the downstream right. A relatively small unnamed tributary reached a confluence with the main stem channel 590 feet downstream of PPbri373. A 10 inch vitrified clay pipe (VCP) branch of the Pennypack Creek Interceptor was aligned adjacent to the unnamed tributary for most of its length before heading northwest and crossing the channel at Roosevelt Boulevard (PPbri373). The downstream-most tributary, Axe Factory Run, emanated as flow from PPout845. Another 10 inch VCP branch of the interceptor sewer system ran parallel to Axe Factory Run until the confluence where it crossed the main stem channel at PPpip025 to join the main Pennypack Creek Interceptor on the downstream right bank. The Roosevelt Dam (PPdam151) was another significant infrastructure element located within the reach. The presence of the dam, as well as multiple stream crossings required multiple areas of the reach to be channelized either along the channel bed or on the stream bank. In total, 14.7% of the reach was channelized which was the highest percentage observed among all main stem reaches. This value includes the stream length and channelization of the tributaries. Channelization was very prevalent along the main stem. Within PPMS72, 2,048 feet of the 4,508 feet of the main stem had channelized banks.

The reach was classified as a Rosgen type C4c-stream channel. The channel morphology was characteristic of a stable channel with a high entrenchment ratio (3.5) and a moderate width to depth ratio (21.3). The substrate distribution was dominated by gravel (49%) although sand (21%) and cobble-sized particles (29%) were present in a relatively high abundance. The D_{50} of the reach was 33.2 millimeters which corresponded to very coarse gravel. The overall USAM score for the reach was 120/160, which was rated as "suboptimal".

3.6.4.9 PPMS74

Reach PPMS74 was 5,310 feet in length and began 590 feet upstream of the Holme Avenue Bridge. The stream corridor within the reach was bound on the east and west by Lexington Avenue and Winchester Avenue respectively. The corridor was forested on both sides with some areas having a riparian buffer as wide as 575 feet on the downstream right. The Pennypack multi-use trail was located on the downstream left side of the corridor and restricted the width of the riparian buffer to within 30 feet of the streambank in some locations.

The presence of infrastructure was minimal throughout the reach, with most elements being located in the downstream portion of the reach. There was a small conveyance channel located on the downstream left that conveyed flow from PPout882. A culvert (PPcul362) conveyed the channel beneath the Pennypack multi-use trail. The most pervasive infrastructure element was a pipe-crossing (PPpip027) upstream of the Rhawn Avenue Bridge, which was the crossing of the 10 inch VCP Pennypack Interceptor. Albeit small, the obstruction acted as a low-head dam at low flow and had the potential to limit bedload sediment transport as well as impede the passage of small fish.

The reach was classified as a Rosgen type C4c- stream channel. The channel morphology was characteristic of a stable channel with a high entrenchment ratio (3.3) and a moderate width to depth ratio (24.9). The substrate distribution was dominated by gravel (54%) although cobble-sized particles were present in a relatively high abundance (33%). The D_{50} of the reach was 45.9 millimeters which corresponded to very coarse gravel. The overall USAM score for the reach was 101/160, which was rated as "suboptimal".

3.6.4.10 PPMS76

Reach PPMS76 was a relatively straight reach that began at the Rhawn Street Bridge and continued downstream to a point approximately 250 feet downstream of the confluence of Sandyford Run and the main stem of Pennypack Creek. The corridor was relatively free of infrastructure and development thus the floodplain on the downstream left was expansive and exceeded 600 feet in some areas of the reach. The steep valley wall on the downstream right limited the floodplain to 70 feet in some locations. There were numerous outfalls distributed throughout the reach but infrastructure impacts were minimal.

The reach was classified as a Rosgen type C4c stream channel. The channel morphology was characteristic of a stable channel with a very high entrenchment ratio (4.5) and a moderate width to depth ratio (21.0). The substrate distribution was dominated by gravel (57%) although cobble-sized particles were present in high abundance (39%). The D_{50} of the reach was 55.4 millimeters which corresponded to very coarse gravel. The overall USAM score for the reach was 107/160, which was rated as "suboptimal".

3.6.4.11 PPMS78

Reach PPMS78 was located on a large meander northeast of the campuses of Austin Meehan Middle School and Abraham Lincoln High School. The stream corridor was free of infrastructure impacts with the exception of a narrow conveyance channel from PPout889 and a small channelized portion of the channel (PPcha479). The Pennypack multi-use trail had the most significant impact on corridor as the trail was aligned adjacent to the downstream left bank throughout the reach. At several locations the trail was within 10 feet of the downstream left bank, which likely contributed to a considerable amount of erosion on the downstream left bank.

The reach was classified as a Rosgen type C4 stream channel. The channel morphology was characteristic of a stable channel with a very high entrenchment ratio (3.5) and a moderate width to depth ratio (20.7). The substrate distribution was dominated by gravel (48%), although sand (24%) and cobble-sized particles were present in high abundance (22%). The D_{50} of the reach was 30.5 millimeters which corresponded to coarse gravel. The overall USAM score for the reach was 109/160, which was rated as "suboptimal".

3.6.4.12 PPMS80

Reach PPMS80 began 300 feet upstream of the Rhawn Street Bridge. Due to the alignment and meander pattern of the main stem channel, Pennypack Creek crosses

Rhawn Street at two different locations. Downstream of the second Rhawn Street crossing, a pedestrian footbridge spanned the main stem channel and served as a crossing for the Pennypack multi-use trail. Reach PPMS80 was unique among the main stem reaches as it was the only reach that maintained a vegetated mid-channel island. The stream channel corridor was well vegetated and relatively free of infrastructure impacts with the exception of the trail. Development was limited to a parking lot in the upstream section of the reach and a small Fairmount Park facility in the downstream portion.

The reach was classified as a Rosgen type C5 stream channel. The channel morphology was characteristic of a stable channel with a very high entrenchment ratio (3.8) and a moderate width to depth ratio (25.2). The substrate distribution was dominated by fine sediment as sand (49%) and gravel (39%) comprised the vast majority of the pebble count observations. There were some cobble-sized particles present in limited abundance (3%). The D_{50} of the reach was only 1.4 millimeters which corresponded to very coarse sand. This was the smallest D_{50} observed on any reach in the Pennypack Creek Watershed. The overall USAM score for the reach was 132/160, which was rated as "optimal". The score for this reach was the highest USAM score observed among all main stem reaches.

3.6.4.13 PPMS82

Reach PPMS82 began 300 feet upstream of the Welsh Avenue Bridge (PPbri378) and continued to a point located 30 feet downstream of PPout901. The reach was the shortest main stem reach assessed at 1,561 feet in length. The stream corridor was heavily forested and free of development; however, development on both sides of the valley limited the width of the forested corridor. On the downstream left side of the corridor the dominant land cover was residential development and on the downstream right was the campus of Father Judge High School. Steep topography confines the width of the floodplain, especially on the downstream right side of the corridor where the valley wall was as close as 50 feet in many locations. The Pennypack multi-use trail was also located on the downstream right bank which further limited the width of the floodplain on the downstream right side of the corridor. The presence of infrastructure was limited as most infrastructure elements were concentrated near PPbri378. In the vicinity of the bridge there were eight outfalls. The Pennypack Creek interceptor sewer crossed the stream at two locations in the reach via subsurface conduits. The first crossing was located 70 feet downstream of PPbri378. The 5 feet-3 inches box interceptor ran parallel to the trail throughout the remaining length of the reach before it changed course on a SSE bearing. It was joined by a 30 inch VCP sewer that serviced the residential development on the downstream left side of the corridor.

The reach was classified as a Rosgen type C4 stream channel. The channel morphology was characteristic of a very stable channel with a very high entrenchment ratio (3.9) and a low width to depth ratio (16.3). The substrate distribution was dominated by gravel (49%) however cobble-sized particles were present in relatively high abundance (37%). Boulders were also relatively abundant throughout the reach as they comprised 9% of pebble count observations. The D_{50} of the reach was 56.9 millimeters which corresponded to very coarse gravel. The overall USAM score for the reach was 124/160, which was rated as "optimal".

3.6.4.14 PPMS84

Reach PPMS84 was located on a large meander bend that abutted the downstream right valley wall for much of the length of the reach. The proximity of the channel to the downstream right valley as well as the presence of a railroad limited the width of the forested stream corridor on the downstream right. The confluence of Wooden Bridge Run was located on the downstream left just upstream of the meander bend. The downstream left floodplain, located on the inside of the meander, was extensive and reached widths in excess of 3,300 feet although the Pennypack Creek multi-use trail was aligned adjacent to the stream channel throughout the reach. At the downstream end of the reach there was a narrow conveyance channel that received flow from PPout980, which drained the residential development in the proximity of Pennypack Street. Two culverts (PPcul325 and PPcul391) conveyed the small channel into Fairmount Park and beneath the railroad. Given the steep topography in this section of the reach, the presence of these infrastructure elements likely had little influence on floodplain function.

The reach was classified as a Rosgen type C4 stream channel. The channel morphology was characteristic of a stable channel with a very high entrenchment ratio (5.1) and a moderate width to depth ratio (15.7). The substrate distribution was dominated by gravel (72%) however cobble-sized particles present in relatively high abundance (20%). The D_{50} of the reach was 36.8 millimeters which corresponded to very coarse gravel. The overall USAM score for the reach was 131/160, which was rated as "optimal". The score for PPMS84 was the second highest score observed in the main stem USAM assessment.

3.6.4.15 PPMS86

Reach PPMS86 was 2,108 feet in length and was located in a narrow forested corridor bounded by multiple types of land cover. The campus and recreational facilities of Father Judge High School were located on the downstream right side of the corridor. On the downstream left side of the corridor, a railroad separated the heavily forested riparian corridor from the back of the St. Dominic's Church cemetery on located on Frankford Avenue. The Pennypack Creek multi-use trail was located on the downstream right bank before it crossed over to the downstream left side of the channel at a pedestrian footbridge (PPbri382). A 15 inch VCP gravity main crossed the stream channel at PPpip030 where it joined the Pennypack Creek Interceptor on the downstream right bank.

The reach was classified as a Rosgen type C4 stream channel. The channel morphology was characteristic of a stable channel with a very high entrenchment ratio (3.7) and a moderate width to depth ratio (19.1). The substrate distribution was dominated by gravel (44%) however cobble-sized particles (42%) were present at an almost equivalent proportion as gravel. Boulders comprised 9% of pebble count observations for this reach which was tied for the highest percentage of boulders along with reach PPMS82. The D_{50} of the reach was 66 millimeters which corresponded to the small cobble size class. The overall USAM score for the reach was 128/160, which was rated as "optimal".

3.6.4.16 PPMS88

Reach PPMS88 was a very straight channel located in a narrow, highly developed corridor. The level of development in close proximity necessitated a considerable amount of infrastructure within the stream channel to optimize channel stability as well as convey the channel through obstructions. At the upstream end of the reach, PPbri383 conveyed the channel beneath the Conrail railroad. Farther downstream, the downstream right bank was channelized with stone and boulders to stabilize the bank as the channel approached PPcul393 which was the crossing of Frankford Avenue. There were five outfalls in the vicinity of PPcul393 that received drainage from the commercial and residential parcels on Frankford Avenue.

Cross section PPMS88 was located downstream of PPcul393. The reach was classified as a Rosgen type B4c stream channel. Reaches PPMS62 and PPMS88 were the only reaches with channels that were classified as Rosgen type B. The channel morphology was relatively stable channel although there was evidence of erosion and localized scour on both banks. The presence of dense vegetation on both banks conferred a high degree of stability, especially where woody vegetation was established. The entrenchment ratio was low at 1.5, which was the second lowest ratio observed on the Pennypack Creek Main Stem after PPMS58. The substrate distribution was dominated by gravel (46%); however cobble-sized particles were present in relatively high abundance (34%). The D_{50} of the reach was 55 millimeters which corresponded to very coarse gravel. The overall USAM score for the reach was 86/160 and was rated as "suboptimal". The low score for this reach reflected the impacts of development in close proximity to the stream corridor.

3.6.4.17 PPMS90

Reach PPMS90 was the longest reach assessed at 11,950 feet in length. The reach was located in very narrow corridor with minimal forested cover. The cross section for this reach was located in the upstream portion of the reach given the degree of development in the downstream portion of the reach as well as the sensitive nature of the land-uses in the downstream portion of the reach. Upstream of Torresdale Avenue, the dominant land cover was residential development. Downstream of Torresdale Avenue, the channel crossed a railroad as well as the Delaware Expressway (I-95) via PPcul394 and PPbri385. The downstream-most stream crossing was the State Road Bridge (PPbri396), downstream of which the main stem channel entered the Curran-Fromhold Correctional Facility (CFCF). Closer to the confluence of Pennypack Creek and the Delaware River, the stream corridor was open and the vegetative land cover was dominated by open meadow as opposed to woodland as in the upper part of the reach. Due to the high level of security in this part of the reach, it was difficult to conduct more traditional fluvial geomorphic assessments; furthermore the channel was tidal in nature given the close proximity to the Delaware River. Just upstream of the mouth of Pennypack Creek was a large 11.6 acre man-made palustrine wetland on the downstream right bank. The wetland was created as compensatory mitigation for impacts along the Delaware River in 1999.

The reach was classified as a Rosgen type C4 stream channel. The channel morphology was characteristic of a moderately stable channel with an entrenchment ratio of 2.6 and a width to depth ratio of 25.6. The substrate distribution was dominated by gravel (63%) and sand and the D_{50} of the reach was 16 millimeters which corresponded to medium gravel. The overall USAM score for the reach was 131/160, which was rated as "optimal". It should be noted that the channel morphology in the upstream portion of the reach was likely not representative of the channel morphology present in the downstream-most portion of the reach near the mouth due to the tidal hydrologic and sediment transport regimes.

3.6.5 Summary of Unified Stream Assessment Results

The mean scores for the *Overall Buffer and Floodplain Condition*, *Overall Stream Condition*, and composite USAM score were classified as "suboptimal" (Table 3-34). Average conditions within the Lower Pennypack Creek Main Stem's stream channels (57.4/80) were slightly better than conditions observed within the buffers and floodplains (53.6/80). The scores for individual parameters ranged from poor to optimal, displaying similar levels of variability between reaches.

Table 3-34: USAM Results for Lower Pennypack Creek Main Stem

Reach ID	Sub-watershed	Overall Stream Condition	Overall Buffer/FP Condition	USAM Score
PPMS56	Mainstem	57	57	114
PPMS58	Mainstem	42	31	73
PPMS60	Mainstem	60	55	115
PPMS62	Mainstem	62	44	106
PPMS64	Mainstem	69	60	129
PPMS66	Mainstem	66	48	114
PPMS68	Mainstem	61	55	116
PPMS72	Mainstem	66	54	120
PPMS74	Mainstem	36	65	101
PPMS76	Mainstem	44	63	107
PPMS78	Mainstem	49	60	109
PPMS80	Mainstem	72	60	132
PPMS82	Mainstem	65	59	124
PPMS84	Mainstem	67	64	131
PPMS86	Mainstem	68	60	128
PPMS88	Mainstem	51	35	86
PPMS90	Mainstem	40	41	81
All Reaches		**57.4**	**53.6**	**110.9**

3.6.6 SUMMARY OF OVERALL STREAM CONDITION SCORES ON THE MAIN STEM PENNYPACK CREEK WATERSHED

Scores for the Overall Stream Condition (OSC) component of the USAM assessment were generally high throughout the watershed (Table 3-34). Scores ranged from "marginal" to "optimal" and the average score of all the main stem reaches (57.4/80) was rated as "suboptimal". Of the 17 reaches assessed 10 were rated as "optimal", 6 were rated as "suboptimal" and only one reach, PPMS74, had a score rated as "marginal". The high scores for this component of the USAM assessment tended to be higher than *Overall Buffer and Floodplain* (OBF) scores as only 4 of the 17 reaches had an OBF score higher than the respective OSC score. Three of these sites, PPMS74, PPMS76 and PPMS78, were located in areas of Fairmount Park where the stream corridor was wide and relatively free of development. The highest scores were observed for the *In-stream Habitat* and *Floodplain Connection* parameters. For the *In-stream Habitat* parameter, most scores were rated as "optimal" or "suboptimal" as only 2 of the 17 reaches had scores rated as "marginal" or "poor". Likewise, most reaches were rated as "optimal" for the *Floodplain Connection* parameter and only 4 of the 17 reaches were rated below "optimal".

Table 3-35: Overall Stream Condition Results for Lower Pennypack Creek Main Stem

Reach ID	Sub-watershed	Instream Habitat	Vegetative Protection		Bank Erosion		Floodplain Connection	Overall Stream Condition
			Left	Right	Left	Right		
PPMS56	Main Stem	14	7	3	8	5	20	57
PPMS58	Main Stem	17	8	5	7	3	2	42
PPMS60	Main Stem	16	6	5	6	7	20	60
PPMS62	Main Stem	17	10	7	10	8	10	62
PPMS64	Main Stem	17	7	10	6	9	20	69
PPMS66	Main Stem	15	7	7	7	10	20	66
PPMS68	Main Stem	15	8	4	7	7	20	61
PPMS72	Main Stem	17	7	6	8	8	20	66
PPMS74	Main Stem	8	2	2	2	2	20	36
PPMS76	Main Stem	5	7	3	6	3	20	44
PPMS78	Main Stem	12	4	4	5	4	20	49
PPMS80	Main Stem	13	9	10	10	10	20	72
PPMS82	Main Stem	17	7	7	6	8	20	65
PPMS84	Main Stem	12	9	8	9	9	20	67
PPMS86	Main Stem	17	5	10	6	10	20	68
PPMS88	Main Stem	14	8	8	7	9	5	51
PPMS90	Main Stem	4	4	3	7	6	16	40
All Reaches		**13.5**	**6.8**	**6.0**	**6.9**	**6.9**	**17.2**	**57.4**

3.6.6.1 IN-STREAM HABITAT

Scores for this parameter were high throughout the watershed as all but three reaches were rated below the "suboptimal" standard. The lowest score (Table 3-35) was observed in reach PPMS90 (4/20) where the substrate was dominated by fine grained sediment. Only 3% of the substrate distribution was comprised of cobble which is more stable and allows for colonization of a variety of macroinvertebrate species. Fine sediment such as silt, sand, and fine gravel provide suitable albeit unstable habitat for a limited number of highly tolerant burrowing species. The high scores observed for this parameter in the other reaches were attributed to the relatively high abundance of very coarse gravel, cobble, and boulder observed in most of the main stem reaches.

3.6.6.2 VEGETATIVE PROTECTION

Scores for this parameter were highly variable. There were no spatial trends observed with respect to scores however the watershed average score for the left bank (6.8/10) was higher than the average score for the right bank (6/10). Scores for this parameter were highly correlated with bank erosion although there were several reaches where stone or concrete channelization promoted stable stream banks yet were denuded of vegetation. The lowest scores were observed in PPMS74 where both the left and right banks were rated as "poor" with scores of 2/10 respectively. A total of four reaches (PPMS62, PPMS66, PPMS80 and PPMS86) had at least one bank that had a score of 10/10.

3.6.6.3 BANK EROSION

Scores for the *Bank Erosion* parameter were highly variable throughout the watershed although both banks tended to share similar states of stability in most reaches. The watershed average for both the right and left banks was 6.9/10 which was rated as "suboptimal". There were only three reaches where scores for each bank were rated in different condition classes. The lowest scores were observed in PPMS74 where both the left and right banks were rated as "poor" with scores of 2/10 respectively. Both banks had steep vertical faces and exposed tree roots. The soil that comprised these banks was generally not as cohesive as the soil observed in other reaches with more stable banks. This may ultimately have exacerbated erosion as the non-cohesive characteristic of the soil likely promoted the uprooting of large trees that destabilized large portions of the respective banks. A total of four reaches (PPMS62, PPMS64, PPMS80 and PPMS86) had at least one bank that had a score of 10/10 for this parameter.

3.6.6.4 FLOODPLAIN CONNECTION

Scores for this parameter were generally high throughout the watershed. There were only three reaches, PPMS58, PPMS62 and PPMS88, that were not rated as "optimal" for this parameter. The average score of 17.2/20 was the highest average score in any of the watersheds assessed for this parameter. Most of the main stem reaches were classified as Rosgen type "C" stream channels. The morphology associated with this type of channel tends to support floodplain inundation on at least one side of the channel at flows above bankfull.

3.6.7 Summary of Overall Buffer and Floodplain Condition Scores on the Main Stem Pennypack Creek Watershed

Scores for the *Overall Buffer and Floodplain Condition* tended to be slightly lower than the scores observed for the *Overall Stream Condition* component. The watershed average for most parameters was rated as either "marginal" or "suboptimal" although the average score for the *Floodplain Habitat* parameter was rated as "optimal". Scores for the *Floodplain Vegetation* parameter had a very narrow range as all reaches were rated as "suboptimal". There was considerable variation although no obvious spatial trends (i.e. upstream to downstream) were observed in scores for the *Floodplain Encroachment* parameter. Scores ranged from ratings of "poor" to "suboptimal" with 8 reaches rated as "suboptimal", 6 rated as "marginal" and 3 rated as "poor".

Table 3-36: Overall Buffer and Floodplain Results for the Lower Pennypack Creek Main Stem

Reach ID	Sub-watershed	Vegatated Buffer Width		Floodplain Vegetation	Floodplain Habitat	Floodplain Encroachment	Overall Buffer/FP Condition
		Left	Right				
PPMS56	Main Stem	8	10	14	20	5	57
PPMS58	Main Stem	6	7	11	2	5	31
PPMS60	Main Stem	7	7	13	20	8	55
PPMS62	Main Stem	10	5	12	10	7	44
PPMS64	Main Stem	8	7	12	20	13	60
PPMS66	Main Stem	3	8	12	20	5	48
PPMS68	Main Stem	3	10	13	20	9	55
PPMS72	Main Stem	7	9	12	20	6	54
PPMS74	Main Stem	8	10	12	20	15	65
PPMS76	Main Stem	7	9	11	20	16	63
PPMS78	Main Stem	6	8	11	20	15	60
PPMS80	Main Stem	9	8	11	20	12	60
PPMS82	Main Stem	6	5	12	20	16	59
PPMS84	Main Stem	9	7	11	20	17	64
PPMS86	Main Stem	7	7	11	20	15	60
PPMS88	Main Stem	6	7	11	5	6	35
PPMS90	Main Stem	5	5	11	16	4	41
All Reaches		**6.8**	**7.6**	**11.8**	**17.2**	**10.2**	**53.6**

3.6.8 Vegetated Buffer Width

Scores for this parameter were generally high throughout the watershed as all but one reach (PPMS90) had at least one side of the corridor with a score rated as "optimal" or "suboptimal". These scores corresponded to vegetated buffer width observations that were in excess of 50 feet and those between 25-50 feet respectively. With the exception of reach PPMS90, all reaches were contained entirely within Fairmount Park and tended to be heavily forested. Reaches where lower scores were observed were heavily impacted by private development or the presence of the Pennypack Creek multi-use trail in some instances. The worst reach was PPMS90 which was heavily developed along the entire length of the reach, with the exception of the lowest portion of the reach where the Pennypack Creek Main Stem approached the confluence with the Delaware River.

3.6.9 FLOODPLAIN VEGETATION

Scores for this parameter were rated as "suboptimal" in all reaches. These scores reflect forest cover that is dominated by younger, early successional tree species. There were large, mature trees observed, but these were generally located in the upland-most portions of the reach. There were several other vegetation types present in abundance which included an array of forbs, shrubs, saplings and herbaceous groundcover species. In most reaches, the presence of predominantly young forests can be attributed to the construction of the Pennypack Creek Interceptor and other larger stormwater or wastewater conveyance conduits.

3.6.10 FLOODPLAIN HABITAT

The *Floodplain Habitat* parameter is a measure of the presence and quality of floodplain habitats such as vernal pools or wetlands and more structural habitats such as snags and fallen trees. Of these habitats, the most productive are wetland habitats which require periodic inundation of the floodplain. Generally, reaches that contained channels with high entrenchment ratios were rated higher than those with low entrenchment ratios. Along the main stem channel, entrenchment ratios were generally very high as all but 3 of the 17 reaches were rated as "optimal" for this parameter. The lowest scores, which were rated as "poor", were observed in reaches PPMS58 and PPMS88. These sites had very low entrenchment ratios thus it was concluded that these reaches have an extremely low probability of supporting favorable floodplain habitats due to the lack of frequent floodplain inundation associated with overbank flooding at the bankfull discharge.

3.6.11 FLOODPLAIN ENCROACHMENT

Scores for this parameter were highly variable throughout the watershed and ranged from "poor" to "optimal". There was a spatial trend observed in the scores for this parameter whereas scores in the upper and lower portions of the watershed were considerably lower than scores for reaches located in the central region (PPMS74 to PPMS86) of the watershed. The low scores observed in the upstream-most reaches were attributed to the presence of roads, residential development and channelization. In the downstream-most reaches, low scores were attributed to roads, commercial development, channelization, and the large correctional facility between State Road and the Delaware River.

3.7 SUMMARY

Over time, the Lower Pennypack Creek Watershed has experienced continual and extensive urban land development. More than half of the Lower Pennypack Creek Watershed is covered by residential development with single family residential and row home residential making up the bulk of that development. A large portion of the riparian corridor of the Pennypack Creek and its tributaries has remained covered as wooded land, mostly protected through long-term preservation efforts. Additionally, large tracts of privately owned open space such as agricultural land remain undeveloped and are dispersed throughout the watershed, perhaps presenting opportunities for future preservation efforts.

Geology and soils play a role in the hydrology, water quality, and ecology of a watershed. The Lower Pennypack Creek Watershed is within the Piedmont Upland physiographic region, which is underlain by a variety of sedimentary, metamorphic and igneous rocks. The geology of the Lower Pennypack Creek Watershed is mostly underlain by the Wissahickon Formation. Soils beneath the Lower Pennypack Creek Watershed are mainly comprised of Group B soils.

3.7.1 LOWER PENNYPACK WATERSHED TRIBUTARIES

3.7.1.1 INFRASTRUCTURE

The following tables are a summary of the data presented in previous sections. The purpose of these tables is to allow comparisons between individual reaches such that the relative impacts of point and linear infrastructure elements within each respective reach can be clearly distinguished.

In Table 3-39, select infrastructure metrics have been presented in order to identify the reaches in the infrastructure assessment most impacted by certain types of infrastructure.

Table 3-37: Lower Pennypack Tributaries Infrastructure Points Summary

Section ID	Bridge Count	Channel Count	Culvert Count	Dam Count	Manhole Count	Other Count	Outfall Count	PipeSewer Count	Infra Points Count	Total Combined Outfall Area (ft^2)	Priority Infra Points Count
PPDR02	0	3	3	1	3	1	18	0	29	145.6	2
PPDR04	0	0	0	0	1	0	2	0	3	3.1	0
PPDR06	0	5	2	0	3	1	4	1	16	29.8	0
PPDR08	1	4	1	2	0	0	8	0	16	34.0	1
PPMSF02	1	8	9	0	0	0	4	1	23	61.3	3
PPPR02	7	20	5	3	4	0	25	0	64	104.0	4
PPPR04	2	11	3	0	0	0	7	0	23	12.9	0
PPPR06	6	44	3	0	1	0	12	0	66	75.7	17
PPPR08	0	8	1	0	1	0	5	0	15	50.5	1
PPPR10	0	3	1	0	1	0	2	0	7	12.9	0
PPPRA02	1	21	4	0	4	0	29	0	59	121.8	3
PPSR01	0	3	0	0	2	0	2	0	7	163.1	0
PPSR02	0	0	0	0	0	0	0	1	1	0.0	0
PPSR03a	0	3	0	0	0	0	2	0	5	7.9	0
PPSR03b	1	5	0	0	1	0	8	2	17	23.6	1
PPSR04	1	0	0	1	0	1	0	2	5	0.0	2
PPWB04	0	9	6	1	0	1	26	0	43	148.1	8
PPWB06	1	15	8	2	10	0	23	1	60	65.2	4
PPWB08	0	3	1	1	0	0	7	0	12	13.3	2
PPWB10	0	0	0	0	1	0	6	0	7	19.0	1
PPWB12	1	2	1	0	0	0	7	1	12	17.7	1
PPWB14	1	8	1	0	0	0	4	0	14	33.4	2
PPWB16	0	0	1	1	1	0	1	0	4	1.8	0
PPWBA02	0	4	3	0	0	0	5	0	12	30.2	0
PPWBA04	0	0	1	0	0	0	1	0	2	1.8	0
Total	**23**	**179**	**54**	**12**	**33**	**4**	**208**	**9**	**522**	**1176.65**	**52**

Table 3-38: Lower Pennypack Tributaries Infrastructure Linear Summary

Section ID	Total Segment Length (ft)	Culvert Length (ft)	% Culverted	Channel Length, one side	Channel Length, two sides	Channel Length, three sides	Total Channel Length	Total Segment Length, 3 sides	% Channelized
PPDR02	2624	109	4.2	259	0	0	259	7872	3.3
PPDR04	2348	0	0.0	0	0	0	0	7044	0.0
PPDR06	2608	52	2.0	0	0	21	63	7824	0.8
PPDR08	2524	101	4.0	607	0	32	703	7572	9.3
PPMSF02	4535	344	7.6	314	138	0	590	13605	4.3
PPPR02	6522	2184	33.5	943	11	401	2168	19566	11.1
PPPR04	2700	185	6.9	637	43	31	816	8100	10.1
PPPR06	6198	310	5.0	861	802	281	3308	18594	17.8
PPPR08	2743	80	2.9	33	52	48	281	8229	3.4
PPPR10	1743	18	1.0	15	5	40	145	5229	2.8
PPPRA02	6188	314	5.1	424	317	80	1298	18564	7.0
PPSR01	1190	0	0.0	78	174	242	1152	3570	32.3
PPSR02	255	0	0.0	0	0	0	0	765	0.0
PPSR03a	695	0	0.0	0	0	25	75	2085	3.6
PPSR03b	1088	0	0.0	148	0	25	223	3264	6.8
PPSR04	602	0	0.0	0	0	0	0	1806	0.0
PPWB04	6047	427	7.1	643	797	60	2417	18141	13.3
PPWB06	4361	460	10.5	63	191	431	1738	13083	13.3
PPWB08	2954	120	4.1	557	38	0	633	8862	7.1
PPWB10	2137	60	2.8	0	0	0	0	6411	0.0
PPWB12	1191	65	5.5	24	38	0	100	3573	2.8
PPWB14	2359	50	2.1	17	53	57	294	7077	4.2
PPWB16	2153	185	8.6	0	0	0	0	6459	0.0
PPWBA02	1586	115	7.3	159	4	135	572	4758	12.0
PPWBA04	3272	0	0.0	0	0	0	0	9816	0.0
Total	**32802**	**3365**	**10.3**	**3654**	**1046**	**814**	**8188**	**98406**	**8.3**

Table 3-39: Summary of Lower Pennypack Tributary Infrastructure by Reach

Parameter	Max	Mean
Total Infrastructure	PPPR06 (66)	21
Priority Infrastructure	PPPR06 (17)	2.1
Culverts	PPMSF02 (9)	2.2
Bridges	PPPR02 (7)	0.9
Outfalls	PPPRA02 (29)	8
Channels	PPPR06 (44)	7.2
Dams	PPPR02 (3)	0
Manholes	PPWB06 (10)	1
Pipes	PPSR03b & PPSR04 (2)	0
Outfalls > 3 ft diameter	PPPRA02 (4)	0.84
Outfall Area	PPSR01 (163.1 ft^2)	37.3 ft^2
Mean Outfall Area	PPSR01 (81.5 ft^2)	-
Single Outfall	PPSR01 (156 ft^2)	-
Segment Length	PPPR02 (6522 ft)	3644.7 ft
Culvert Length	PPPR02 (2184 ft)	373.9 ft
Percent Culverted	PPPR02 (33.5%)	7.30%
Total Channel Length	PPPR06 (3308 ft)	909.8 ft
Percent Channelized	PPPR06 (17.8%)	6.70%

3.7.1.2 UNIFIED STREAM ASSESSMENT

The following table has been presented as a means of quickly assessing the performance of individual reaches within the Lower Pennypack Creek Watershed tributaries USAM assessment. The reaches presented correspond to the extreme values among the dataset; however by comparing these values to the mean value for each respective metric, it is possible to quickly gauge the variability of conditions within the tributaries of the Lower Pennypack Creek Watershed. The USAM scores for each tributary watershed are included in Appendix D.

Table 3-40: Summary of Lower Pennypack Watershed Tributary Results by Reach

Overall Stream Condition							
Parameter	**Instream Habitat**	**Vegetative Protection**		**Bank Erosion**		**Floodplain Connection**	**OSC Score**
		Left	**Right**	**Left**	**Right**		
MIN	PPSR04 PPWBA02 (5)	PPDR02 PPSR04 PPPRA02 (3)	PPDR04 (2)	PPSR04 (1)	PPSR04 (1)	PPWB14 PPWB16 (0)	PPWBA02 (24)
MAX	PPWB16 (18)	PPWB12 (10)	PPWB12 (10)	PPWB10 (10)	PPWB10 (10)	PPWB10 PPSR03a (20)	PPWB10 (70)
MEAN	11.1	6.3	6.1	5.0	5.8	4.0	38.3

Overall Bufffer and Floodplain Condition						
Parameter	**Vegetated Buffer Width**		**Floodplain Vegetation**	**Floodplain Habitat**	**Floodplain Enchroachment**	**OBF Score**
	Left	**Right**				
MIN	PPWB04 PPPRA02 (3)	PPSR03a (1)	PPPRA02 (7)	PPWB14 PPWB16 (0)	PPPR02 (0)	PPRK02 (18)
MAX	PPDR04 PPDR06 PPPR08 PPPR10 PPSR02-04 PPWB10 PPWB12 PPWB16 (10)	PPDR04 PPDR06 PPPR08 PPPR10 PPSR03b PPSR04 PPWB10 PPWB12 PPWB16 (10)	PPWBA04 (16)	PPWB10 (20)	PPDR04 (20)	PPWB10 (70)
MEAN	8.0	7.5	12.7	4.3	11.1	42.7

3.7.2 LOWER PENNYPACK CREEK MAIN STEM

3.7.2.1 INFRASTRUCTURE

The following tables are a summary of the data presented in previous sections. The purpose of these tables is to allow comparisons between individual reaches such that the relative impacts of point and linear infrastructure elements within each respective reach can be clearly distinguished.

In Table 3-43, select infrastructure metrics have been presented in order to identify the reaches in the infrastructure assessment most impacted by certain types of infrastructure.

Table 3-41: Lower Pennypack Main Stem Infrastructure Point Summary

Section ID	Bridge Count	Channel Count	Culvert Count	Dam Count	Manhole Count	Other Count	Outfall Count	PipeSewer Count	Infra Points Count	Total Combined Outfall Area (ft^2)	Priority Infra Points Count
PPMS56	1	1	0	0	4	0	3	0	9	15.7	0
PPMS58	1	2	0	1	0	0	2	0	6	12.0	0
PPMS60	0	8	3	0	1	1	1	0	14	9.6	0
PPMS62	1	9	4	2	2	0	2	0	20	29.0	1
PPMS64	1	2	0	1	0	0	0	0	4	0.0	0
PPMS66	2	12	2	0	2	2	2	0	22	10.2	0
PPMS68	3	18	5	0	3	0	9	0	38	38.5	3
PPMS72	3	26	3	1	19	0	12	2	66	91.4	13
PPMS74	1	1	2	0	3	0	1	1	9	12.6	2
PPMS76	1	0	1	0	0	1	4	0	7	10.2	0
PPMS78	0	1	1	0	4	0	3	0	9	24.2	1
PPMS80	2	2	3	0	0	0	2	0	9	2.1	1
PPMS82	1	0	0	0	0	0	9	0	10	11.5	0
PPMS84	0	2	2	0	1	0	1	0	6	25.0	1
PPMS86	1	0	0	0	0	0	0	1	2	0.0	0
PPMS88	1	3	3	0	0	0	5	0	12	20.0	0
PPMS90	3	9	2	0	9	1	23	0	47	79.4	3
Total	**22**	**96**	**31**	**5**	**48**	**5**	**79**	**4**	**290**	**391.40**	**25**

Table 3-42: Lower Pennypack Main Stem Infrastructure Linear Summary

Section ID	Total Segment Length (ft)	Culvert Length (ft)	% Culverted	Channel Length, one side	Channel Length, two sides	Channel Length, three sides	Total Channel Length	Total Segment Length, 3 sides	% Channelized
PPMS56	3823	0	0.0	511	0	0	511	11469	4.5
PPMS58	2578	0	0.0	43	88	0	219	7734	2.8
PPMS60	3411	41	1.2	684	18	13	759	10233	7.4
PPMS62	4802	55	1.1	92	132	79	592	14406	4.1
PPMS64	2940	0	0.0	621	0	0	621	8820	7.0
PPMS66	7087	92	1.3	1177	64	10	1335	21261	6.3
PPMS68	8606	2112	24.5	337	327	76	1219	25818	4.7
PPMS72	8004	110	1.4	2527	427	47	3522	24012	14.7
PPMS74	5310	265	5.0	36	0	0	36	15930	0.2
PPMS76	1868	10	0.5	0	0	0	0	5604	0.0
PPMS78	3064	7	0.2	24	0	0	24	9192	0.3
PPMS80	2163	130	6.0	144	36	0	216	6489	3.3
PPMS82	1561	0	0.0	0	0	0	0	4683	0.0
PPMS84	1974	86	4.4	7	9	0	25	5922	0.4
PPMS86	2108	0	0.0	0	0	0	0	6324	0.0
PPMS88	1992	150	7.5	480	0	0	480	5976	8.0
PPMS90	11950	72	0.6	927	108	0	1143	35850	3.2
Total	**73241**	**3130**	**4.3**	**7610**	**1209**	**225**	**10702**	**219723**	**4.9**

Table 3-43: Summary of Lower Pennypack Main Stem Infrastructure by Reach

Parameter	Max	Mean
Total Infrastructure	PPMS72 (66)	17
Priority Infrastructure	PPMS72 (13)	1.5
Culverts	PPMS68 (5)	1.8
Bridges	PPMS68, PPMS72, PPMS90 (7)	1.3
Outfalls	PPMS90 (23)	5
Channels	PPMS72 (26)	5.6
Dams	PPMS62 (2)	0
Manholes	PPMS72 (19)	3
Pipes	PPMS72 (2)	0
Outfalls > 3 ft diameter	PPMS90 (2)	0.53
Outfall Area	PPMS72 (91.4 ft^2)	23 ft^2
Mean Outfall Area	PPMS62 (14.5 ft^2)	-
Single Outfall	PPSR01 (156 ft^2)	-
Segment Length	PPMS90 (11950 ft)	4308.3 ft
Culvert Length	PPMS68 (2112 ft)	184.1 ft
Percent Culverted	PPMS68 (24.5%)	3.20%
Total Channel Length	PPMS72 (3522 ft)	726.5 ft
Percent Channelized	PPMS72 (14.7%)	3.90%

3.7.3 UNIFIED STREAM ASSESSMENT

The following table has been presented as a means of quickly assessing the performance of individual reaches within the Lower Pennypack Creek Main Stem USAM assessment. The reaches presented correspond to the extreme values among the dataset; however by comparing these values to the mean value for each respective metric, it is possible to quickly gauge the variability of conditions within the main stem of the Lower Pennypack Creek Watershed. The USAM scores for the Lower Pennypack Main Stem are included in Appendix D.

Table 3-44: Summary of Lower Pennypack Main Stem USAM Results by Reach

Overall Stream Condition							
Parameter	Instream Habitat	Vegetative Protection		Bank Erosion		Floodplain Connection	OSC Score
		Left	Right	Left	Right		
MIN	PPMS90 (4)	PPMS74 (2)	PPMS74 (2)	PPMS74 (2)	PPMS74 (2)	PPMS58 (2)	PPMS74 (36)
MAX	PPMS58, PPMS62 PPMS64, PPMS72 PPMS82, PPMS86 (17)	PPMS62 (10)	PPMS64 PPMS80 PPMS86 (10)	PPMS62 PPMS80 (10)	PPMS66 PPMS80 PPMS86 (10)	PPMS56, PPMS60 PPMS64-86 (20)	PPMS80 (72)
MEAN	13.5	6.8	6.0	6.9	6.9	17.2	57.4

Overall Bufffer Floodplain Condition						
Parameter	Vegetated Buffer		Floodplain Vegetation	Floodplain Habitat	Floodplain Enchroachment	OBF Score
	Left	Right				
MIN	PPMS66 PPMS68 (3)	PPMS62 PPMS82 PPMS90 (5)	PPMS58 PPMS76-80 PPMS84-90 (11)	PPMS58 (2)	PPMS90 (4)	PPMS58 (31)
MAX	PPMS62 (10)	PPMS56 PPMS68 PPMS74 (10)	PPMS56 (14)	PPMS56, PPMS60, & PPMS 86 (20)	PPMS84 (17)	PPMS74 (65)
MEAN	6.8	7.6	11.8	17.2	10.2	53.6

3.8 RECOMMENDATIONS

Stream restoration is a general term that may be used to describe a broad spectrum of activities undertaken to correct problems affecting streams or improve stream habitat, structure and function. However, stream restoration and streambank reinforcement activities that do not take into account the stream's current morphological state and the tendency of streams to adjust to new hydrologic conditions may not be successful, and in some cases may be counterproductive. In order to be successful, stream restoration activities should:

1.) work with the stream's tendency to establish a dynamic equilibrium between land and water
2.) take into account new hydrologic conditions that accompany changes in land use, and
3.) seek establishment of a natural stream dimension, pattern, and profile. Stream corridors represent a micro-ecosystem within a watershed, consisting not only of the channel, but also of the adjacent floodplain and a transitional area where the floodplain ends and merges into an upland area. Stream restoration, therefore is the restoration of multiple micro-habitats that are a part of a larger watershed.

A comprehensive approach to watershed management and restoration is essential and should be planned and prioritized according to representative watershed indicators and identified issues. All information should be organized, maintained and be made easily accessible to residents. Components of an ideal watershed master plan should include information organized on a watershed basis for existing channel condition, impervious cover, sewer and storm drain infrastructure, drainage network, stormwater outfalls, stormwater problem locations, industrial sites, open space, and natural areas. All strategies should complement existing regulations, management strategies, and community efforts.

Restoration strategies that would alleviate or minimize identified direct and future cumulative impacts to the Pennypack Creek Watershed are discussed in the following section. These strategies have been divided into three categories:

- ✓ Restoration Strategy Category I: Channel Stability & Infrastructure
- ✓ Restoration Strategy Category II: Habitat
- ✓ Restoration Strategy Category III: Land Management

3.8.1 RESTORATION STRATEGY CATEGORY I: CHANNEL STABILITY & INFRASTRUCTURE

3.8.1.1 BANK STABILIZATION

Many of the parameters that were evaluated throughout the Lower Pennypack Creek Watershed may be applied as metrics to gauge the applicability of bank stabilization techniques for a given reach. Bank stabilization measures can vary, based on the severity of the erosion and whether it is localized or continues for some distance along a bank, from small plantings to the installation of boulder walls. Bank stabilization measures may consist of boulder bank and/or boulder "toe of slope" reinforcement in areas where the greatest erosive potential exists. Boulder structures may also be used in smaller channels when the stream is eroding and overwidening to the point where property is being, or is expected to be, lost. Other more natural bank stabilization methods such as bioengineering, root wads, plantings, and log and woody structures should be used in areas where the bankfull channel has not been severely overwidened and significant additional channel changes are not expected. These methods are best suited to small local areas of bank erosion scattered throughout the smaller tributaries where discharges are the lowest. Structures within the stream channel that force the thalweg and shear stress away from the bank such as bendway weirs or rock vanes are another means of reducing bank erosion. Bank stabilization can reduce erosion, sediment supply, tree fall, channel widening, and migration.

3.8.1.2 BED STABILIZATION

Bed stabilization is recommended for those reaches that are currently degrading through incising or downcutting. Bed stabilization measures such as rock/log vanes with grade control, rock/log cross vanes, and using naturally occurring boulders and bedrock are examples of methods that could be used to stabilize channel beds. Rock/log vanes differ from cross vanes because they do not extend the entire width of the channel. However, both structures provide grade control while diverting flow away from the channel banks. Bed stabilization should be used to eliminate headcuts or knickpoints. Advantages of bed stabilization consist of bank protection through diverting flow and elimination of migrating bed scour through providing grade control. Bed stabilization techniques can also aid in re-establishing natural pool-riffle-run sequences that are often lacking in degraded reaches.

In general, bank and bed stabilization restoration potential should be evaluated together such that the maximum amount of stream improvement value may be obtained for the funds allotted for a particular project. This is also important because of the implicit relationship that one has with the other. For example, spacing and alignment of bed stabilization structures must also be coordinated with bank stabilization features so that the restoration design features complement one another and work with the stream’s natural meander pattern rather than against it. It is also often necessary to secure stream-crossing structures such as rock and log vanes by trenching them into the streambanks.

3.8.1.3 REALIGNMENT AND RELOCATION

Stream channel realignment and relocation are the most severe restoration measures involving the greatest amount of channel changes. These methods should be employed when it is more advantageous to realign the channel than it is to stabilize degrading, out-of-pattern sections. Channel realignment and relocation are commonly implemented for shorter portions of a channel rather than for extensive lengths of channel due to construction and maintenance costs, and the amount of disturbance that occurs to existing natural habitat. Stream channel realignment and relocation is best suited to consecutive severely degraded reaches where existing land uses are threatened.

3.8.1.4 INFRASTRUCTURE IMPACTS

Large structures or facilities within stream channels can interrupt natural flow patterns and alter the hydrology and hydraulics of the creek in which they are present. Anthropogenic alterations to the natural balance or progression towards the natural balance between land and water generally have adverse impacts on the channel. For example, some features, such as dams, can disrupt the natural movement of sediment and block upstream migration of stream biota. Other infrastructure features, such as stormwater outfalls or culverts, can create local erosion by causing stormwater shear forces to be directed at a small area or creating high velocity scour at constrictions. These local disturbances often serve as "knickpoints", from which additional destabilizing erosion, scour, and sediment transport problems may propagate.

3.8.1.5 STORMWATER OUTFALLS

In the Lower Pennypack Creek Watershed 196 outfalls greater than 12 inches diameter were found. Of those, 30 outfalls were greater than three feet in diameter. Due to their size and density within the watershed and the degree to which they may cause local erosion, stormwater outfalls are considered one of the most important factors in assessing stream reach stability. Outfalls often drain large areas of impervious surfaces and efficiently deliver large volumes of water to small streams. Streambank erosion and bed erosion (scour pools) were often observed at these outfalls, and in some cases, this local erosion served as a knickpoint, causing headcutting in an upstream direction. Because outfalls may be positioned to direct flow at banks from a disadvantageous angle, it may be necessary to armor the opposite bank or install energy dissipating structures where the outfall meets the stream. The presence of a large outfall or outfalls may also constrain the final pattern and profile of a stream restoration design.

3.8.1.6 CULVERTS

Culverts may have many of the same destabilizing influences as dams and stormwater outfalls and must also be considered in stream restoration design. In some cases, a large culvert may serve as a stable starting or end point for a stream restoration project, with the remainder of the restoration designed to mitigate the destabilization and sediment transport issues at the site.

3.8.1.7 DAM REMOVAL PROJECTS

There were 15 dams present within the Lower Pennypack Creek Watershed that provide little or no positive value to the hydraulic regime of the stream. Observations made during the various field investigations and infrastructure assessment suggested that most dams accrued large amounts of fine sediments upstream, and that reaches downstream of these structures are likely to have undergone a greater amount of channel degradation than those channels not influenced by dams.

Despite these facts, their installation may also have created some beneficial habitat. Additional consideration must be given to the fact that beneficial habitat may rely on the existence of these dams. Overall, dam removal has been presented as possible channel stability restoration measures. A careful evaluation of all environmental costs and benefits, specifically habitat and any potential historical significance associated with each structure must be taken into consideration.

3.8.1.8 REMEDIATION OF INFRASTRUCTURE IN POOR CONDITION

Products of the infrastructure assessment conducted during this study were observations and locations of infrastructure in poor condition. This classification was attributed to those dams, bridges and outfalls that exhibited the characteristics of being broken, exposed, or the potential of such issues based upon their proximity to the stream and ongoing bank erosion. Reach by reach summaries, statistics, and location maps of all points of infrastructure are documented in detail in Appendix D.

3.8.2 RESTORATION STRATEGY CATEGORY II: HABITAT

3.8.2.1 RIPARIAN BUFFER EXPANSION/IMPROVEMENT

Riparian buffer expansion and improvement are strategies which can significantly improve the habitat characteristics of the associated stream reaches. Several parameters were qualitatively and quantitatively evaluated along each reach which can be utilized in the prioritization of stream sections with respect to this strategy. Although priority reforestation areas consist of floodplains, steep slopes, and wetlands, smaller areas such as public right-of-ways, parks, schools, and neighborhoods also provide reforestation opportunities. Benefits of reforestation are numerous. Cooler temperatures, stream shading, rainfall interception, reduced runoff, reduced sediment load, reduced discharge velocities, increased groundwater recharge, increased species diversity and habitat, and improved air quality and aesthetics are all positive effects associated with a healthy riparian buffer.

3.8.2.2 INVASIVE SPECIES MANAGEMENT

Maintaining a healthy riparian plant community within the Lower Pennypack corridor will retain biodiversity and support a healthy stream ecosystem. Invasive species provide little value to native animals that depend on native species for habitat and/or food. Because of this threat to the biodiversity of native communities, an invasive species management plan would assist natural succession within the riparian buffer through decreasing possible further impacts of invasive species. An invasive species management plan will require, at a minimum, a three-year commitment to ensure success. Planting plans for all restoration efforts should complement the invasive species management plan by recommending appropriate native planting to supplement areas where invasive species have been eliminated. Although invasive species management priority areas are considered those that contain 80% or greater invasive species, invasive species management should also be implemented for all preliminary recommended channel restoration sites.

3.8.2.3 WETLAND CREATION

Land currently available for reforestation located adjacent to the channel is also ideal for wetland creation. Wetland creation adjacent to the channel is best suited to those areas where stream relocation and realignment are suitable. Because stream relocation and realignment typically involve large quantities of grading, replanting the disturbed areas can be customized to create specific habitats. Wetlands, a rich habitat that relies on saturated soils and vegetation adapted to these conditions, could be created concurrently with channel relocation and realignment. Therefore, the best opportunities for wetland creation may be adjacent to those channels that are also suitable relocation /realignment sites.

Further investigation of all potential wetland creation sites should include the following: rainfall data collection and evaluation, runoff calculations, soils investigation, water budget, native species investigation, and groundwater monitoring. Ideally, groundwater levels for all potential wetland creation sites should be monitored to determine their suitability prior to design. Advantages of wetland creation are groundwater recharge, increased habitat, increased plant and animal species diversity, and improved water quality.

3.8.2.4 PRESERVATION OF EXISTING FORESTED AREAS

Existing forests are valuable habitat and should be protected. All of these areas throughout the watershed should be protected and managed, if necessary, to preserve the forested riparian buffer present surrounding all creeks within the watershed. Educational/informational signage, creating small parks or designated green space, and installing fences or prohibiting access in areas where the riparian area has been disturbed are additional strategies to help preserve existing forests.

3.8.3 RESTORATION STRATEGY CATEGORY III: LAND MANAGEMENT

3.8.3.1 REDUCE DIRECTLY CONNECTED IMPERVIOUS SURFACES

Stream channels within each watershed have responded to high density development and increased runoff through downcutting and overwidening in an attempt to accommodate higher flows. In addition to preserving land available for reforestation or to protect from becoming developed, the amount of existing impervious surfaces should be reduced. Examples of strategies to reduce the amount of existing impervious surfaces and/or decrease the severity of runoff include:

- ✓ Stormwater management basins – both wet/dry ponds have the ability to collect storm flow, hold water temporarily and release water to a stream at a constant rate. Disadvantages of basins are finding the available land to build them and the associated maintenance over many years. In areas where additional development is still possible, or re-development may occur, stormwater management ponds are a suitable method to reduce runoff. Planned species selection for vegetating the pond perimeter, banks, and edges may also help reduce nutrients delivered to streams. Similarly, in areas where adequate space is not available, grass swales can be used to increase infiltration while decreasing the velocity of runoff prior to delivering it to the creeks.

- ✓ Bioretention – bioretention facilities are similar to stormwater management ponds in their function, but differ since they are much better suited for small areas. Bioretention facilities can be installed next to parking lots, curbs, major roads, etc. to immediately catch runoff, filter sediment and allow rainwater to infiltrate back into the groundwater table.

- ✓ Parking Lot Island Installation and Plantings – parking lot islands can be installed and planted within large paved areas to create less contiguous impervious surfaces. Islands can be depressed to catch stormwater and planted to provide water quality benefits, shade and aesthetic value. Often, planted parking lot islands can serve dual purposes and provide water quality benefits if they are also bioretention facilities. At a minimum, efforts should aim to steady the existing percent impervious surfaces associated with parking lots. When and if the opportunity arises, unnecessarily paved and oversized parking lots could be converted to have smaller spaces and contain islands to create less contiguous paved surfaces. Parking lots and other paved right-of-ways should also be evaluated when adding or relocating utilities. To fully utilize existing paved surfaces instead of creating new impervious surfaces utilities could be located underneath existing pavement.

3.8.3.2 APPROPRIATE ROAD AND CULVERT MAINTENANCE

Often inappropriately sized culverts or poorly stabilized roads will impact a channel through eroding the bed and banks. Bed scour may cause a headcut or knickpoint that is capable of migrating upstream. A headcut or knickpoint will continue to scour the bed and deepen the channel as it moves upstream until it is inhibited by a natural bed formation or man-made structure resistant to erosion. Although the headcut or knickpoint may have stopped migrating, it is still present in the channel and if channel conditions change may begin to migrate again.

3.8.3.3 PUBLIC EDUCATION

Watersheds are so diverse in their land use and ownership, therefore a public educated in the ways and means of being a good steward to their watershed is perhaps one the best ways of addressing its restoration. Disturbances such as footbridges, landscaping, and mowing adjacent to the channel will continue so long as public education and awareness are not increased. Public education provides opportunities to relate the importance of stream habitat and stability and to influence and/or change the behavior of residents.

Public education begins with public involvement. One principal avenue for educating residents is through forming local watershed groups. Local watershed groups are most effective when strong, mutually beneficial relationships are established early between the volunteers and local government agencies. Planning agencies and volunteers could then communicate and work together to educate neighbors through activities such as stream clean-ups, re-vegetating stream banks, long-term monitoring, and publishing articles in the local newspaper(s), among many others. Additional opportunities for the community to participate in all aspects of the planning/development phase increases not only public education, but also recreation and habitat enhancement opportunities.

In 2004, the Pennypack Watershed Partnership was formed, consisting of a consortium of proactive environmental groups, community groups, government agencies, businesses, residents and other watershed stakeholders interested in improving their watershed. The goals of the partnership initiative are to protect, enhance, and restore the beneficial uses of the waterways and riparian areas. The partnership seeks to achieve greater levels of environmental improvement by sharing information and resources.

More information about the Pennypack Watershed Partnership can be found on the Philadelphia Water Department's website (http://www.phillywatersheds.org/).

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