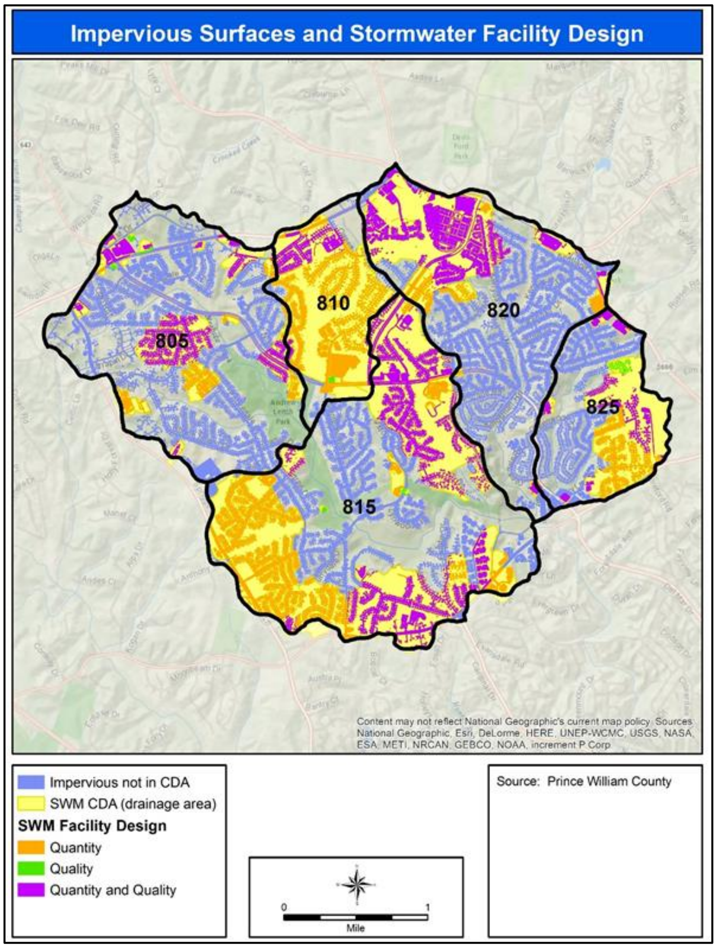
NEABSCO CREEK WATERSHED STUDY, PRINCE WILLIAM COUNTY, VIRGINIA



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March 31, 2017

Disclaimer

This watershed characterization report is a management tool for the use in planning and prioritizing Capital Improvement Projects. The information in this report is not designed, intended, or to be construed in any way as a complete listing or comprehensive evaluation of all issues or needs within the area studied.

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CHAPTER 1: INTRODUCTION

1.1 PURPOSE AND APPROACH

During 2016-2017, Prince William County, Virginia, sponsored a study of the upper portion of the Neabsco Creek watershed. The purpose of the Neabsco Creek Watershed Study was to characterize current conditions in the watershed and to identify a suite of candidate restoration and stormwater management upgrade and retrofit project opportunities. Recommendations focused on solutions that address watershed degradation, reduce pollutant runoff, and provide for greater treatment of impervious surfaces. The watershed study area included five selected subwatersheds of the Neabsco Creek watershed: subwatersheds 805, 810, 815, 820, and 825.

The study's watershed assessment and restoration planning process used both desktop analysis and field investigations to identify and rank project opportunities. Initial steps included a watershed characterization based on a compilation and analysis of geospatial data describing the natural and human-influenced features in the Neabsco Creek study area. Following this initial characterization, the study employed desktop analyses to select sites for field investigations to identify specific project opportunities that Prince William County can implement. The following types of opportunities were identified:

- stormwater facility upgrades and retrofits, including both improvements at existing facilities and recommendations for new Best Management Practices (BMPs) in areas currently lacking stormwater treatment;
- stormwater outfall improvements, including a range of options from simple outfall channel stabilization to more extensive restoration;
- reforestation; and
- stream restoration.

Analyses of field and geographic information system (GIS) data were used to rank and prioritize candidate projects. Pollutant reduction benefits, in terms of sediment and nutrient reductions, were estimated by modeling. These results will give the County quantitative pollutant estimates to use in long-term planning and to help address current and future water quality regulatory requirements such as the Chesapeake Bay Total Maximum Daily Load (TMDL) and its associated Watershed Implementation Plan (WIP) stages.

This watershed study report summarizes the current conditions and proposes watershed management recommendations and strategies for the upper part of Neabsco Creek watershed. Restoration options and recommendations presented within this report, including expected pollutant reductions, will provide a basis for future implementation of restoration projects in the upper Neabsco Creek watershed. Planning-level estimates of pollutant reduction benefits are provided for proposed projects. Development of the Neabsco Creek watershed study included two meetings with the general public, (1) to gain input during the initial characterization and opportunity identification process and (2) to share results of the watershed study.

1.2 BACKGROUND

The Neabsco Creek Watershed Study is one in a series of watershed studies conducted by Prince William County's Department of Public Works, Watershed Management section. The studies are intended to aid in planning watershed restoration projects and will help the County to address degradation of existing stream and watershed resources and to make progress toward countywide pollutant reduction targets for nitrogen, phosphorus, and sediment. As such, pollutant reduction credits estimated in this report are based on Chesapeake Bay Program guidance, including guidance on specific types of restoration practices provided in the Bay Program's Expert Panel reports.

1.3 STAKEHOLDER INVOLVEMENT

Effective implementation of watershed restoration strategies is often achieved with the involvement of diverse watershed partners and the participation of local stakeholders. For the Neabsco Creek Watershed Study, initial public outreach included conducting two local community meetings and coordination with Prince William County Public Schools environmental management staff throughout the project. In addition, Prince William County and project team staff coordinated with Virginia American Water, the company providing water and sewer service in the Dale City area.

Community Meeting # 1

The Neabsco Creek Watershed Study was introduced to the community during a public meeting that was held at Chinn Park Regional Library on March 10, 2016. Project team staff gave a presentation about the watershed planning process, some of the key existing conditions and characteristics of the Neabsco Creek watershed, proposed issues to be addressed in the watershed study, and strategies that may be used to address those issues. After the presentation, project staff were available for individual discussion of particular issues. Attendees provided input on what major water-related issues they were aware of and would like to see addressed and what locations they would recommend to be targeted for field visits. Participants were invited to mark specific areas of concern on watershed maps.

Community Meeting # 2

A second community meeting will be held on April 6, 2017 at the Prince William County government center. The Neabsco Creek Watershed Study report will be introduced to the community during this public meeting. Project team staff will give a presentation about the watershed planning process, review the plan's goals and objectives, desktop and field investigations, and present findings. Results of the watershed study will be summarized, along with recommendations for actions to improve water quality.

Coordination with Prince William County Public Schools

The project team coordinated with the Environmental Project Manager for Prince William County Public Schools, Office of Facilities Services throughout the watershed study. The Environmental Project Manager provided information on previous and planned restoration activities at county school properties. The Environmental Project Manager also helped coordinate access to school properties and, most importantly, accompanied the project team staff on field visits to exchange information and ideas on potential restoration and retrofit projects at school locations.

Coordination with Virginia American Water

Virginia American Water oversees both water and wastewater service for the area of Dale City. Prior to field work, Prince William County staff met with Virginia American Water regarding access to streams on treatment facility property. In addition, the County relayed concerns about exposed sewer mains and manholes that were discovered by the field teams during stream assessments. A future goal that would benefit planning efforts would be to have digital data on water and sewer infrastructure in the watershed, which were not currently available.

1.4 REPORT ORGANIZATION

This report is organized into the following 10 chapters:

Chapter 1 explains the purpose of this report, provides background on the initiation of the Neabsco Creek Watershed Study, summarizes the public's involvement in the project, and gives an overview of the report.

Chapter 2 summarizes the watershed characteristics obtained from GIS analyses. This includes information about the natural landscape features such as soils, forest cover, wetlands, streams, and riparian areas as well as information pertaining to the human modified landscape such as impervious cover, stormwater management, zoning, planned land uses, floodplain designations, and water quality impairments.

Chapter 3 presents general descriptions of the types of restoration strategies that are applicable to the Neabsco Creek watershed and that were sought as opportunities to reduce pollutant loading and improve watershed condition.

Chapter 4 presents desktop analyses that were conducted prior to field work and that were used to select sites for field investigation.

Chapter 5 summarizes the field assessments that were conducted for each of the five types of opportunities sought: stormwater facility conversion, new BMPs, outfall stabilization, reforestation, and stream restoration, beginning with descriptions of the field methods employed. This chapter also describes the use of an electronic data collection system, field team calibration, obtaining of landowner permissions to access properties, and quality assurance (QA) procedures used during data collection and management.

Chapter 6 presents a summary of stream conditions observed, based on the Rapid Stream Assessment Technique (RSAT).

Chapter 7 gives a detailed summary of the restoration opportunities proposed throughout the study area.

Chapter 8 explains the computation of estimated pollutant load reductions for each of the opportunities identified.

Chapter 9 includes an explanation of project rankings, including an overview of methods and a presentation of ranked project opportunities.

Chapter 10 provides a list of sources that are cited within this report.

Five appendices include fact sheet summaries for each of the proposed opportunities, by type, including photographs, site location maps, key project data, and narrative descriptions of existing conditions and the proposed project opportunities.

CHAPTER 2: WATERSHED CHARACTERIZATION

The Neabsco Creek watershed study area includes 5,840 acres (9.1 square miles) in the upstream portion of the entire 14,210-acre (22.2 square mile) Neabsco Creek watershed, located in eastern Prince William County, Virginia, in the Middle Potomac River Basin (Figures 2-1 and 2-2). Prince William County staff designated five subwatersheds to be included in this watershed study: 805, 810, 815, 820, and 825. Aerial photography imagery (2011-2013) showing the land features in these subwatersheds is displayed in Figures 2-3 through 2-7. The study area includes the mainstem Neabsco Creek upstream of the confluence with Hoadly Run, Hoadly Run, and tributaries to both creeks. The study area is bounded roughly by Prince William Parkway (Route 294) to the east, Minnieville Road to the south, Spriggs Road to the west, and Hoadly Road (Route 642) to the north; Dale Boulevard runs through the center of the watershed study area, running generally on a northwest-southeast diagonal. The study area is in the vicinity of Dale City and Woodbridge, Virginia, and includes some of the northwest subdivision extensions of Dale City. The southern border of the area includes part of the community of Minnieville, the northeast corner is known as Hoadly, and the entire five-subwatershed area drains to a point just west of Center Plaza Shopping Center.

The Neabsco Creek watershed has been highly developed due to its proximity to Interstate 95 and Washington, D.C. As of 2008, 51 percent of the Neabsco Creek watershed was classified as developed land, ranging from low-density residential to high-density commercial (Virginia Department of Environmental Quality 2008). Insufficient stormwater infrastructure and loss of natural land cover were noted in earlier efforts to address water quality and stream habitat degradation issues in Neabsco Creek (U.S. EPA 1994).

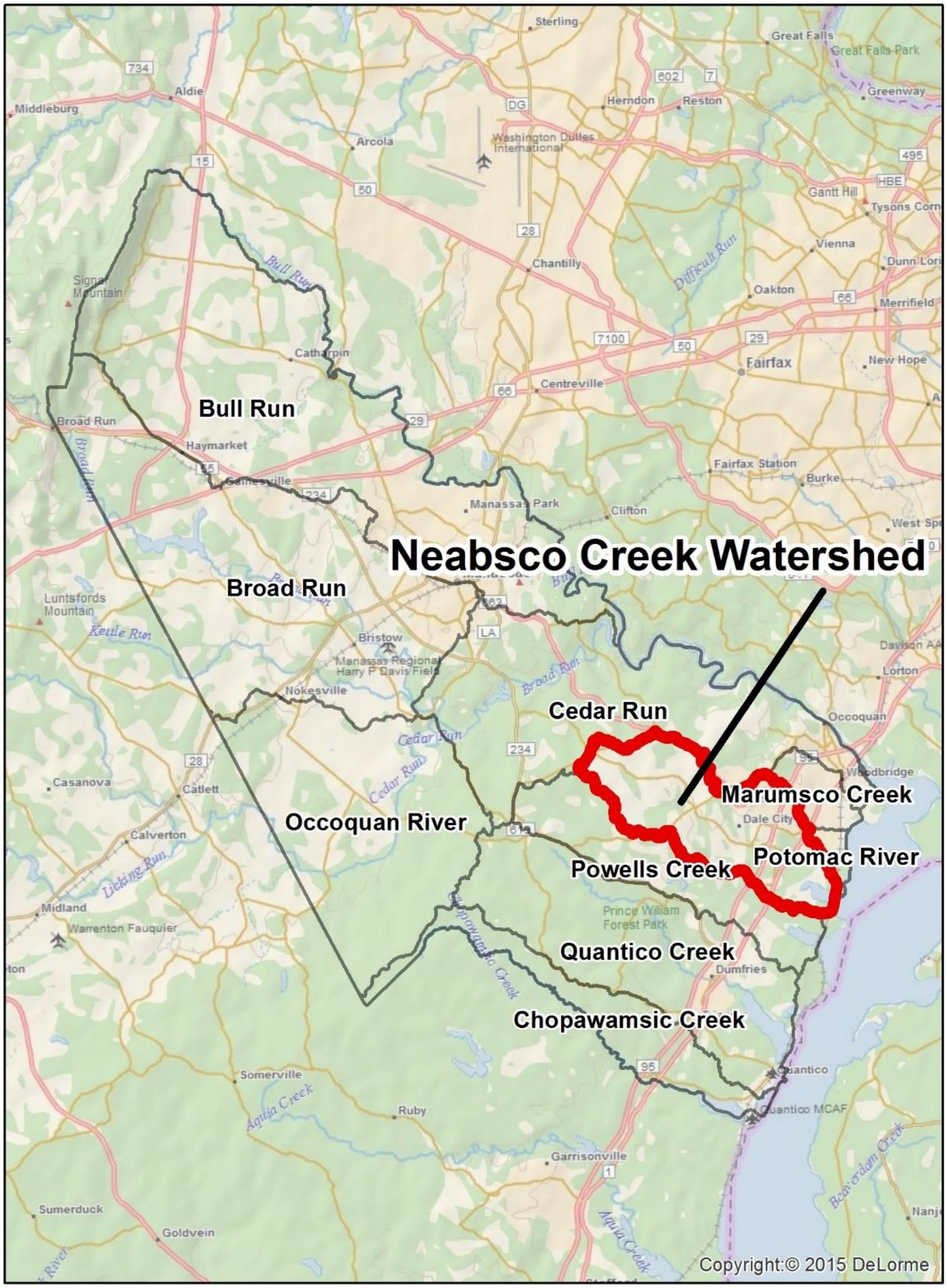

Figure 2–1. Location of Neabsco Creek watershed in southeastern Prince William County, Virginia (Source: Prince William County)

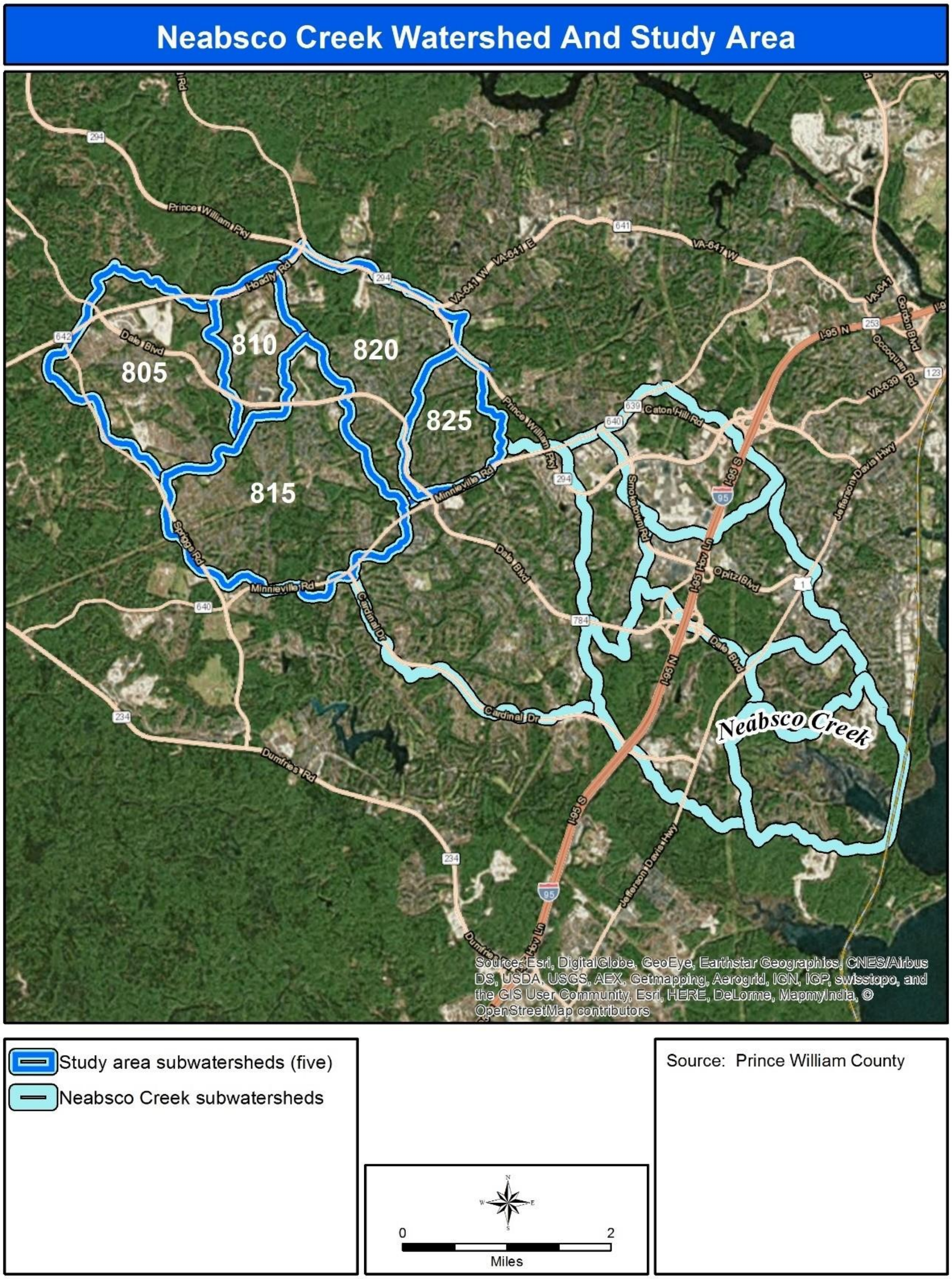

Figure 2–2. Neabsco Creek study area (five subwatersheds) as part of the main Neabsco Creek watershed.

Figure 2–3. Aerial photograph and base features of subwatershed 805

Figure 2–4. Aerial photograph and base features of subwatershed 810

Figure 2–5. Aerial photograph and base features of subwatershed 815

Figure 2–6. Aerial photograph and base features of subwatershed 820

Figure 2–7. Aerial photograph and base features of subwatershed 825

The current conditions assessed in the five subwatersheds of the Neabsco Creek watershed study area include both natural characteristics and human-influenced modifications to the landscape that may affect the water quality in Neabsco Creek, Hoadly Run, and their respective tributaries. Human-modified landscape parameters, such as impervious cover and land use, strongly influence the quantity and quality of watershed runoff. For example, the amount and rate at which precipitation will be absorbed by the ground surface depends on the infiltration capacity of a soil for pervious areas. Impervious surfaces (e.g., paved areas and rooftops) impede rainfall infiltration, which can result in greater runoff rates and volumes, along with a decrease in groundwater supply. In addition, the type and extent of pollutants carried by stormwater are affected by land use characteristics. The information derived from background and contextual investigations, and analysis of spatial data within a GIS framework, provided qualitative and quantitative assessments with which to characterize the five component subwatersheds of the Neabsco Creek watershed study area. This knowledge provided the framework to inform the designs and strategies for subsequent steps in the watershed study: to identify potential watershed restoration opportunities in the study area for projects to address water quality and quantity problems.

Development in the Neabsco Creek watershed study area has been largely driven by expansions of Dale City, by real estate developer Cecil D. Hylton, as summarized by the Dale City Civic Association (DCCA) on its website (2016). Mr. Hylton established Dale City in 1960, as a suburb of Woodbridge, Virginia. The initial sections of Dale City were built in the Neabsco Creek watershed, southeast of Minnieville Road (therefore, outside of the study area). During the 1970s, development included northward expansions of the city; the communities of Glendale, Hillendale, and Kerrydale, built northwest of Minnieville Road, were established in the watershed study area. Beginning in the 1980s and continuing today, more land has been converted to communities of residences and commercial centers within the study area, including Lindendale, Mapledale, Nottingdale, Princedale, Queensdale, Ridgedale, Silverdale, and Trentdale.

During the early buildout period, County and Virginia regulations did not require stormwater management for these developments, although flooding was a main concern. Efforts in the early 1980s emphasized stormwater management plans for water quantity to control water flow volumes and paths. Over time, increasing concerns related to water quality (e.g., nutrients and sediment in storm runoff from developed areas) ushered new requirements for stormwater facilities to incorporate water quality treatment approaches to reduce levels of pollutant inputs to local waterways (Pachhai 2013). Prince William County now participates in numerous programs that provide guidance for or regulate stormwater management; within these programs, the County has implemented requirements for controls of stormwater volume and flow, and also, under the latest regulations, for water quality treatment. The County has also worked to improve mapping and documentation of its stormwater infrastructure, augment some existing stormwater facilities to improve efficiency, create watershed plans focused on reducing pollutant inputs to local waterways, and protect and restore streams and wetlands and their vegetated buffers.

For the current study, Prince William County provided data sets to facilitate an assessment of the current conditions in the five regions in the study area. Through GIS analysis, these data sets and several others provided material for the watershed characterization, including the land uses and drainage patterns of the five subwatersheds, and clues to the environmental conditions that have developed in the region as a consequence of the watershed influences. The GIS data sets that provided the information summarized in this chapter are presented in Table 2-1. Prince William County provided some data sets; others came from supplemental sources, as noted.

Table 2-1. GIS data received from Prince William County used in the Neabsco Creek Watershed Characterization
Comprehensive Plan classification areas
Hydrography
Impervious surfaces
Resource Protection Areas
Stormwater facility drainage areas (called Contributing Drainage Areas or CDAs)
Soils (modified from the original Natural Resources Conservation Service data set)
Subwatershed boundaries
Woods
Zoning classification areas
Note: Other data used include digital imagery from aerial photography, National Wetlands Inventory wetlands, and Federal Emergency Management Agency Flood Hazard data

2.1 NATURAL LANDSCAPE

2.1.1 Soils

Patterns of urban development, particularly along rivers, tend to follow historical agricultural uses, as the soils with the best qualities for agriculture (with fewer limiting factors, such as steep slopes) have also been sought for development; thus urban sprawl often easily expands into lands suitable for and possibly actively used for farming and other agricultural practices (Imhoff, Lawrence, Stutzer, and Elvidge 1998). The development of the Neabsco Creek study area follows this pattern. Woodbridge, Virginia, was established along the banks of the Occoquan River. Development expansion of Woodbridge toward the northwest (away from the river) proceeded following farmland subdivision and acquisition for development (Phinney 1995). Dale City was initially an extension of Woodbridge, and over the decades, modules of the city plan also converted farmland to developed, mostly residential, areas. As agriculturally useful soils are covered by impervious surfaces and turf, the characteristics of the surrounding areas may also be modified: faster overland flows increase the potential for erosion and flooding; increases in runoff speed, volume, and pollutant-carrying-capacity during storm events affect the quality of the receiving streams; the decreases in deep-rooted vegetation reduce stream bank stability, and the reduced diversity of natural habitats in a watershed limits the resources for aquatic species and wildlife. Development activities associated with conversions from open land to urban uses may also remove the soil layer or alter soil characteristics; such activities may include, but are not limited to, filling, leveling, compacting, and artificially saturating soils. Data based on historical soil surveys may not represent current conditions; thus, maps and tables derived from these sources should be considered with caution. Prince William County provided a data set representing soil type delineations and classifications, which was a modified version of the source data. The original source of the data was the National Cooperative Soil Survey developed by the Natural Resources Conservation Service (NRCS) and published in 1989; this data set incorporates delineations created in 1965 and classifications determined in 1985.

Soil Series

Seventeen different soils series are present in the five Neabsco Creek subwatersheds, and these range from silt and clay loams to sandy loams. These soil series include the following:

- Aden silt loam, 0 to 2 percent slopes
- Buckhall loam, 7 to 15 percent slopes
- Delanco fine sandy loam, 0 to 4 percent slopes
- Fairfax loam, 2 to 7 percent slopes
- Gaila sandy loam, 15 to 25 percent slopes
- Gaila sandy loam, 7 to 15 percent slopes
- Glenelg-Buckhall complex, 15 to 25 percent slopes
- Glenelg-Buckhall complex, 2 to 7 percent slopes
- Glenelg-Buckhall complex, 7 to 15 percent slopes
- Hatboro-Codorus complex, 0 to 2 percent slopes
- Meadowville loam, 0 to 5 percent slopes
- Minnieville clay loam, 2 to 7 percent slopes, severely eroded
- Minnieville clay loam, 7 to 15 percent slopes, severely eroded
- Neabsco loam, 7 to 15 percent slopes
- Quantico sandy loam, 7 to 15 percent slopes
- Spriggs silt loam, 15 to 25 percent slopes
- Urban land-Udorthents complex, 0 to 7 percent slopes

These soils have various characteristics that influence development potential, ecological features (such as wetlands and streams), and the ability to infiltrate and move water through the landscape. These features may affect approaches to stormwater planning, flood management, and stream and wetland restoration within the watershed. These characteristics are described in the following sections.

Hydric and Non-Hydric Soils

Hydric soils are those that are formed under conditions of saturation, flooding, or ponding long enough during the growing season to develop anaerobic conditions in the upper parts (USDA, 2011). Hence, these soils are often indicative of areas where naturally occurring wetlands, streams, or other water bodies may occur. Within the five subwatersheds of the study area, there are approximately 1,311 acres (about 22 percent of the study area) of soils mapped as hydric, with the remaining soils mapped as non-hydric soils (Table 2-2). Non-hydric soils are typically more suitable for development or agricultural uses.

Table 2-2. Summary of hydric soils, Neabsco Creek watershed study area (Source: NRCS, modified; delineations, 1965; classifications, 1985)

Subwatershed ID	Subwatershed Area (acres)	Hydric Soils (acres)	Hydric Soils (percent)
805	1455.3	321.7	22.1
810	536.0	97.5	18.2
815	1990.3	623.9	31.4
820	1267.3	153.8	12.1
825	591.0	114.4	19.4
Total Study Area	**5839.9**	**1311.3**	**22.5**

Though many of the soil characteristics in developed areas within these subwatersheds have been altered, it is still important to review the soil types and features to understand the limitations that may affect the implementation of certain retrofit and BMP approaches, such as infiltration. A map of the hydric and non-hydric soils is depicted in Figure 2-8.

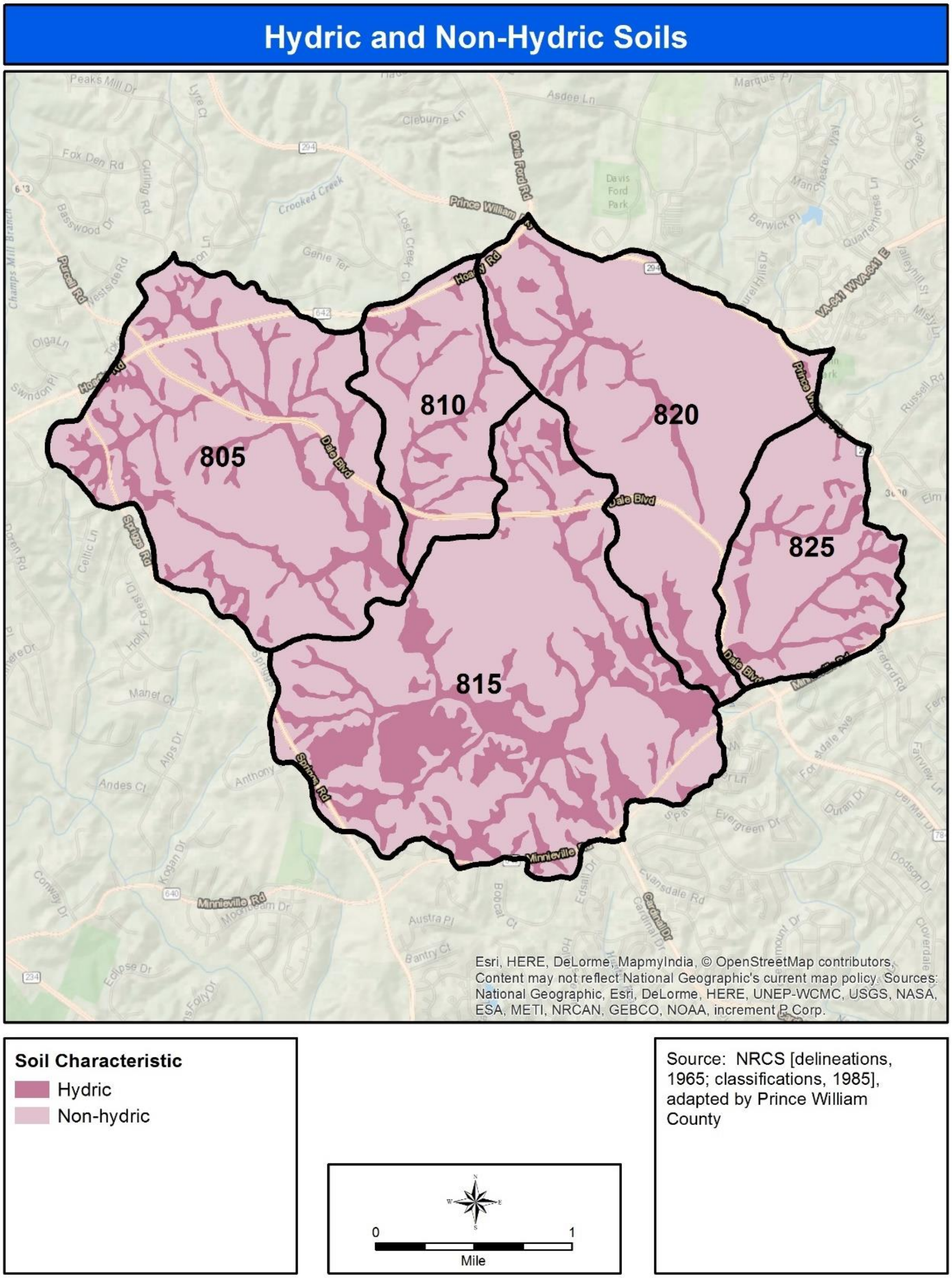

Figure 2–8. Hydric and non-hydric soils within the Neabsco Creek watershed study area

Hydrologic Soil Groups

Hydrologic soil groups are groupings of soils based on their physical and runoff characteristics. Four soils groups are defined by the Natural Resources Conservation Service (NRCS) and are labeled A through D (U.S. Department of Agriculture 2007). These groups are used in determining runoff coefficients which are used in various hydrologic calculations; for instance, determining runoff volumes used to compute channel size for stream restoration projects and water quality treatment volumes for stormwater management facilities. Soils in Group A have the lowest runoff potential, while soils in Group D have the highest runoff potential. Within the five Neabsco Creek subwatersheds, the majority of the soils have an NRCS characterization of Group C or Group D, indicating a predominance of poorly drained soils. Table 2-3 depicts the area and percent area for each Hydrologic Soil Group within each of the five subwatersheds. A map showing the hydrologic soils groups within the subwatersheds is depicted in Figure 2-9.

Table 2-3. Hydrologic soil groups, Neabsco Creek watershed study area; note that hydrologic soil Group A did not occur in these subwatersheds (Source: NRCS, modified: delineations, 1965; classifications, 1985)

	Area (Acres)				Percent Area			
Subwatershed ID	**B**	**C**	**D**	**Water**	**B**	**C**	**D**	**Water**
805	819.1	494.5	139.7	2.1	56.3	34.0	9.6	0.2
810	157.2	238.9	138.0	2.0	29.3	44.6	25.7	0.4
815	800.5	774.8	414.4	0.6	40.2	38.9	20.8	0.0
820	324.4	278.1	663.3	1.6	25.6	21.9	52.3	0.1
825	236.3	128.5	226.2	0.0	40.0	21.8	38.3	0.0
Total Study Area	**2337.4**	**1914.8**	**1581.5**	**6.3**	**40.0**	**32.8**	**27.1**	**0.1**

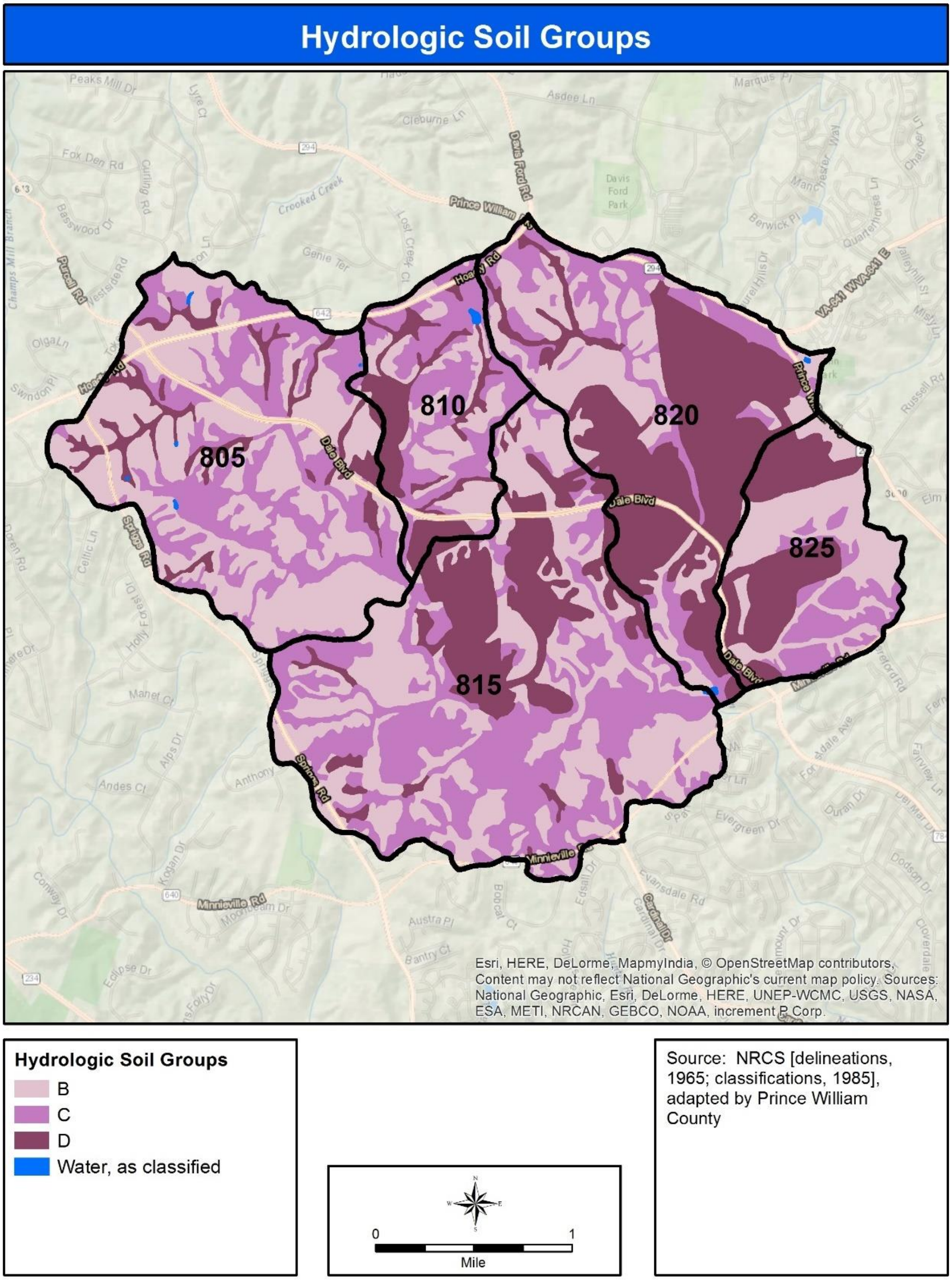

Figure 2–9. Hydrologic soil groups within the Neabsco Creek watershed study area

Highly Erodible and Highly Permeable Soils

Soil erosion is a major cause of water quality degradation; therefore, mapping soils with high erosion potential is essential in watershed planning. Many factors, including rainfall intensity, steepness and length of slopes, vegetative cover, and management practices contribute to the potential for soils to erode. Additionally, there are inherent properties of soil that can influence its erosion potential, or the ease with which water can detach and transport soil particles downstream. These components are expressed as an erodibility index, which is calculated using the following equation:

$$\text{Erodibility Index} = R*K*LS / T$$

Where:

- R = rainfall and runoff
- K = soil susceptibility to water erosion in the surface layer
- LS = combined effects of slope length and steepness
- T = soil loss tolerance

As defined by the Prince William County Comprehensive Plan (Prince William County 2008), highly erodible soils are soils with an Erodibility Index of eight or higher. Overall, highly erodible soils compose almost half (48 percent) of all the mapped soils within these five subwatersheds (Table 2-4); in Subwatershed 820, they are approximately 71 percent. A map showing the erodible soils within the subwatersheds is provided in Figure 2-10.

Table 2-4. Summary of erodible soils, Neabsco Creek watershed study area (Source: NRCS, modified: delineations, 1965; classifications, 1985)

Subwatershed ID	Subwatershed Area (acres)	Erodible Soils Area (acres)	Erodible Soils (percent)
805	1455.3	605.5	41.6
810	536.0	172.7	32.2
815	1990.3	748.8	37.6
820	1267.3	897.9	70.9
825	591.0	373.2	63.1
Total Study Area	**5839.9**	**2798.0**	**47.9**

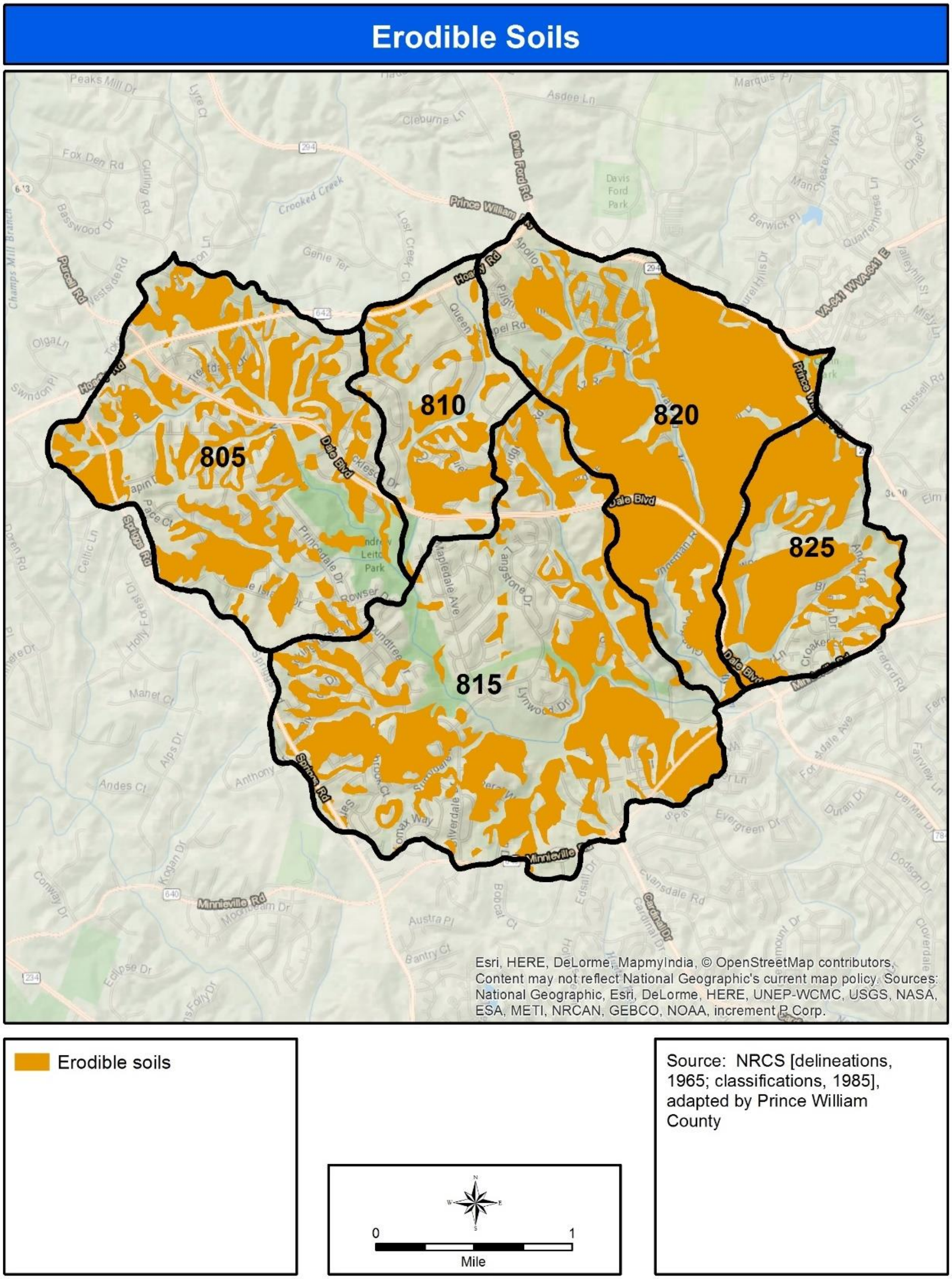

Figure 2–10. Erodible soils within the Neabsco Creek watershed study area

Soil permeability refers to the potential transmission of water through a soil profile; higher permeability can be helpful in reducing stormwater runoff and, in turn, soil erosion. Highly permeable soils have permeability equal to or greater than 6 inches of water movement per hour in any part of the soil profile to a depth of 72 inches (Prince William County 2008). It is important to identify areas with high permeability rates during watershed planning as these areas have the potential to be utilized for infiltration facilities. A map showing the highly permeable soils within the study area is presented in Figure 2-11. Note that only 1.6 acres of highly permeable soils are present in the study area; these soil types are all contained within subwatershed 825 (Table 2-5).

Table 2-5. Summary of highly permeable soils, Neabsco Creek watershed study area (Source: NRCS, modified; delineations, 1965; classifications, 1985)

Subwatershed ID	Subwatershed Area (acres)	Highly Permeable Soils Area (acres)	Highly Permeable Soils (percent)
825	591	1.6	0.27
Total Study Area	**5839.9**	**1.6**	**< 0.1**

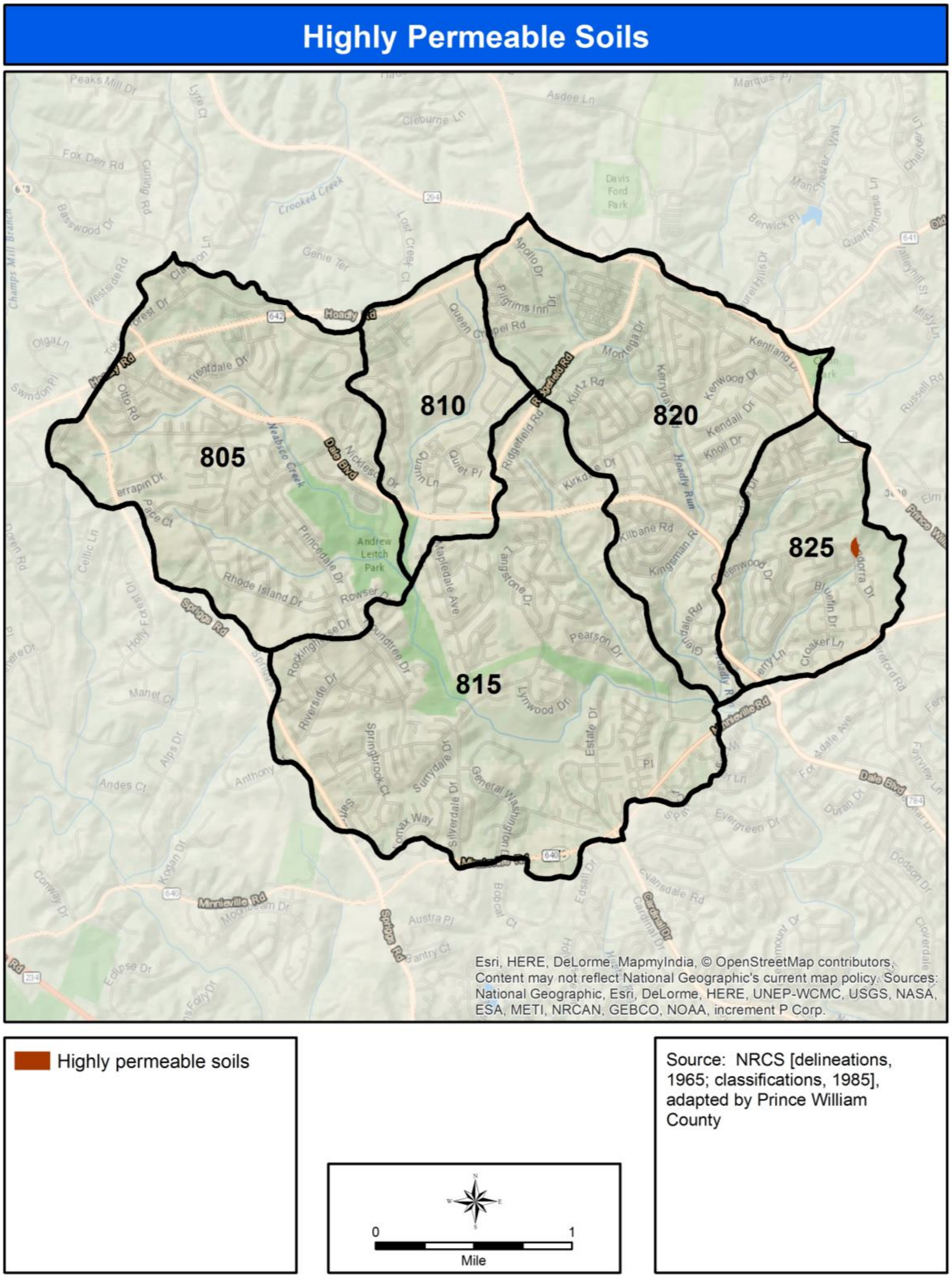

Figure 2–11. Highly permeable soils within the Neabsco Creek watershed study area

2.1.2 Forested and Resource Protection Areas (RPA)

Retaining and re-establishing forest cover can be an important part of watershed protection and restoration efforts. As a commitment to protect the Chesapeake Bay, Prince William County adopted the Chesapeake Bay Preservation Act (Bay Act) into its local ordinance in 1990, which provides a regulatory framework for protecting and improving waters that flow into the Chesapeake Bay. One component of the Bay Act is the protection of riparian buffers from encroaching urban development. Riparian buffers are vegetated, transitional boundaries between upland and water environments that generally consist of trees, shrubs, and grasses. These areas slow and absorb runoff and filter pollutants entering waterways and other sensitive environmental features and provide essential habitat for wildlife. Under the Prince William County Chesapeake Bay Preservation Ordinance, these buffers are called Resource Protection Areas (RPAs) and include tidal wetlands, non-tidal wetlands connected by surface flow and contiguous to tidal wetlands and water bodies with perennial flow, tidal shores, water bodies with perennial flow, and a 100-foot-wide buffer adjacent to and landward of any of the previously listed components.

Most areas of the Neabsco Creek study subwatersheds are in effect developed. Numerous environmental resources, however, are still present, including 2,323 acres of forested cover (about 40 percent of the study area; Table 2-6 and Figure 2-12) and about 503 acres of RPA (about 9 percent of the study area; Table 2-7 and Figure 2-13). The majority of the development in the study area occurred before the Bay Act of 1990, so the established RPAs included existing structures that may remain in place, resulting in a discontinuous vegetated buffer network. Within the RPAs, stream buffers in all five subwatersheds exhibit gaps because of man-made features and landscape modifications; these may include residential homes and lots, roads, maintained utility easements, parking lots, and commercial buildings.

Table 2-6. Summary of forested areas, Neabsco Creek watershed study area (Source: Woods.shp ESRI digital data set, derived from NAIP imagery, second edition; published 12/5/2014; Prince William County, VA)

Subwatershed ID	Subwatershed Area (acres)	Forested Area (acres)	Forested Area (percent)
805	1455.3	525.8	36.1
810	536.0	179.6	33.5
815	1990.3	902.3	45.3
820	1267.3	446.0	35.2
825	591.0	269.8	45.7
Total Study Area	**5839.9**	**2323.4**	**39.8**

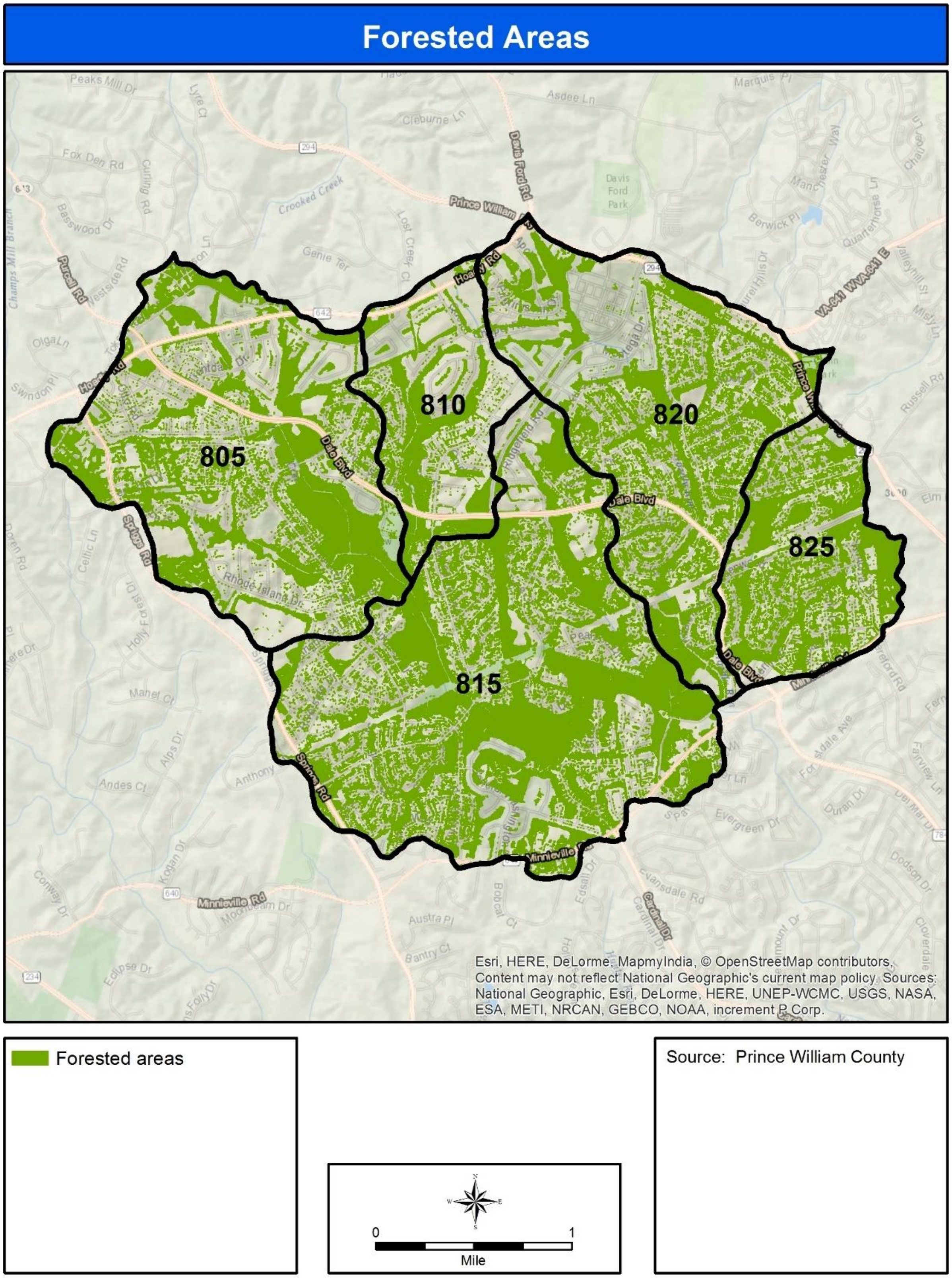

Figure 2–12. Forested areas within the Neabsco Creek watershed study area

Table 2-7. Summary of Resource Protection Areas (RPAs), Neabsco Creek watershed study area (Source: RPA.shp ESRI digital data set; Prince William County, VA; received 8/27/2015)

Subwatershed ID	Subwatershed Area (acres)	RPA Area (acres)	RPA Area (percent)
805	1455.3	143.0	9.8
810	536.0	60.6	11.3
815	1990.3	177.0	8.9
820	1267.3	99.5	7.9
825	591.0	23.3	3.9
Total Study Area	**5839.9**	**503.3**	**8.6**

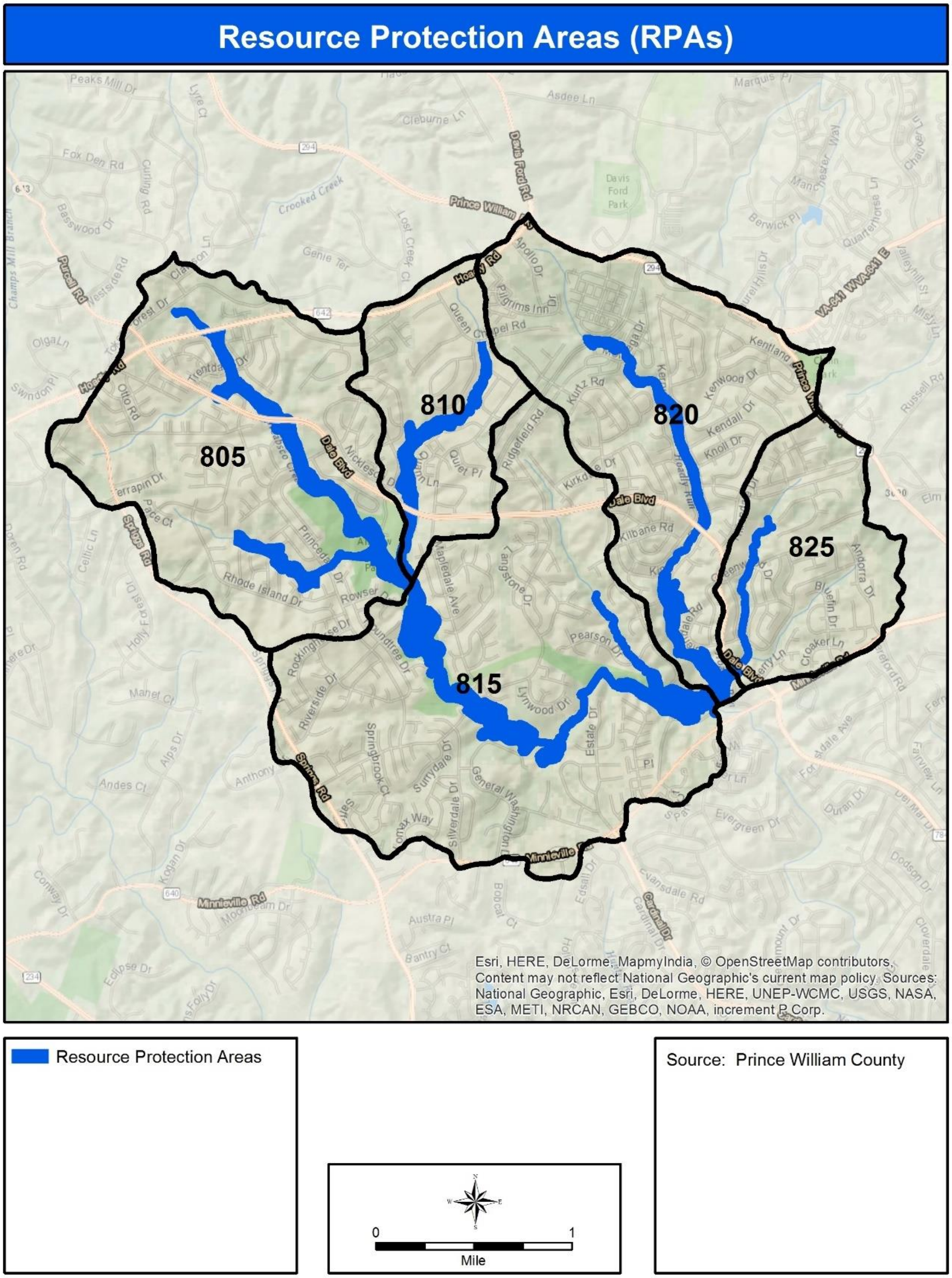

Figure 2–13. Resource Protection Areas within the Neabsco Creek watershed study area

2.1.3 Wetlands and Streams

Wetlands and streams are important natural resources, but are sensitive to disturbance and may exhibit water quality or habitat degradation in developed areas. Within the study area, there are approximately 262 acres of wetlands indicated on National Wetlands Inventory (NWI) mapping (about 4.5 percent of the total area; Table 2-8). The majority of all wetlands in the area (218 acres) are mapped as forested types**.** The study area includes nearly 165,660 linear feet (31.4 miles) of stream channel, adapted from hydrography data provided by Prince William County (Table 2-9). A map showing the wetlands and waterways within the study area is provided in Figure 2-14.

Table 2-8. Summary of NWI Wetlands, Neabsco Creek watershed study area (Source: HU8_02070010_Wetlands.shp ESRI digital data set; published 10/1/2010; U.S. Fish and Wildlife Service)

Subwatershed ID	Subwatershed Area (acres)	Emergent Wetland (acres)	Forested Wetland (acres)	Freshwater Pond (acres)	Other (acres)	Total NWI Wetland Area (acres)	Total NWI Wetland Area (percent)
805	1455.3	10.8	57.4	2.9	0.4	71.4	4.9
810	536.0	4.6	39.6	7.4	0.0	51.6	9.6
815	1990.3	5.2	94.1	1.0	0.0	100.4	5.0
820	1267.3	9.9	26.7	1.7	0.0	38.3	3.0
825	591.0	0.0	0.0	0.0	0.0	0.0	0.0
Total Study Area	**5839.9**	**30.4**	**217.8**	**13.0**	**0.4**	**261.7**	**4.5**

Table 2-9. Summary of stream lengths, Neabsco Creek watershed study area (Source: Adapted from single-line stream hydrography data, Hydrolines.shp ESRI digital data set; published 01/16/2006; Prince William County, VA)

Subwatershed ID	Stream Length (feet)	Stream Length (miles)	Percent of Total Length
805	47,179.6	8.9	28.5
810	16,859.0	3.2	10.2
815	56,984.0	10.8	34.4
820	32,550.1	6.2	19.7
825	12,086.8	2.3	7.3
Total Study Area	**165,659.5**	**31.4**	**100.0**

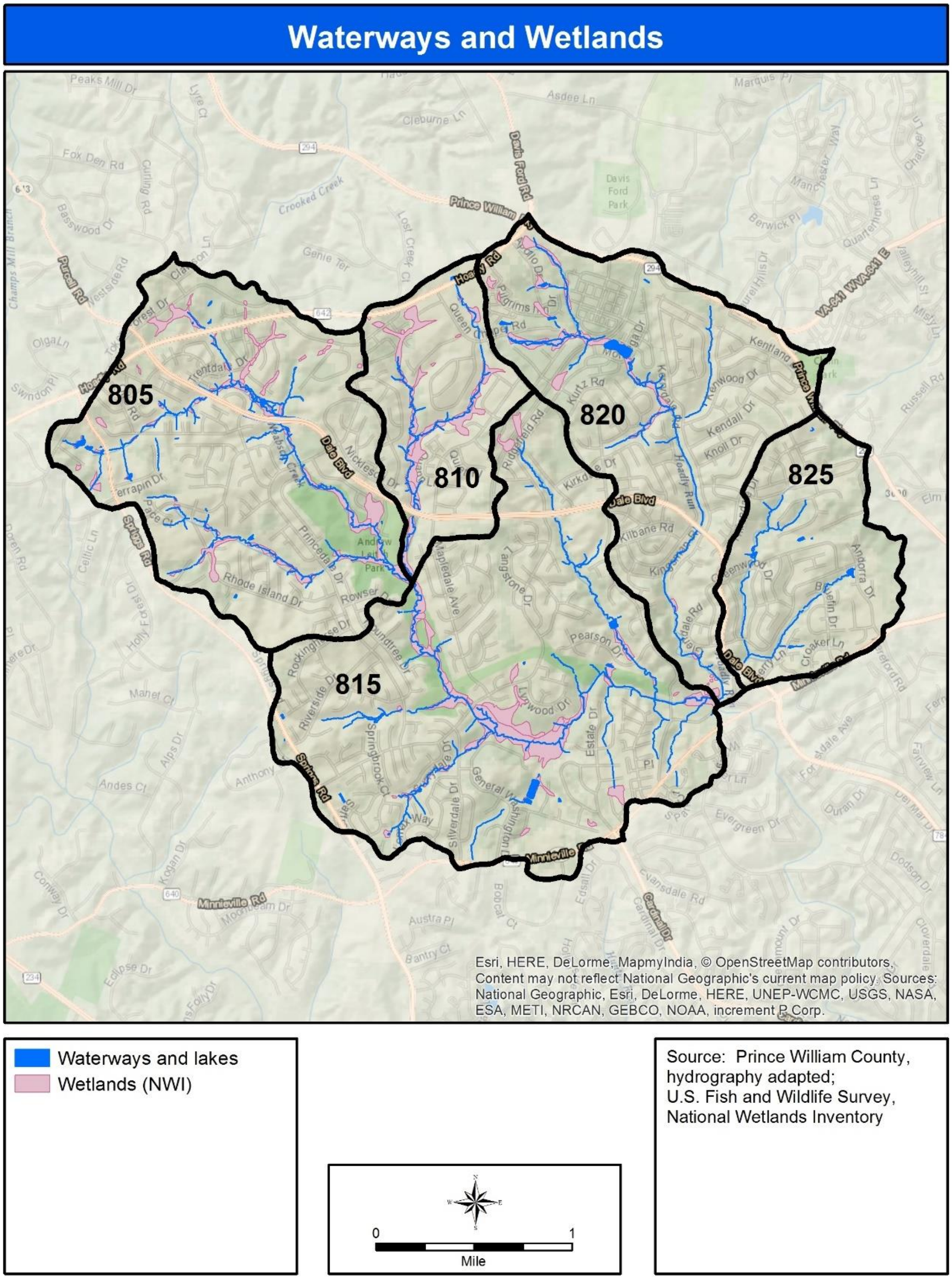

Figure 2–14. Waterways and wetlands within the Neabsco Creek watershed study area

2.2 MODIFIED LANDSCAPE

A recent aerial photography composite image shows the extent of developed land, forest, and other land cover present in the study area (Figure 2-15). Orthophotography data from Virginia's ArcGIS Map Service (VBMP Program; http://gismaps.vita.virginia.gov/arcgis/services) represent conditions as of 2011-2013 (year not specified).

2.2.1 Existing Impervious Cover

Studies have shown a negative correlation between the percentage of a watershed's drainage area that is covered in impervious surfaces and the health of the watershed's streams (e.g., Giddings et al. 2009; Schueler et al. 2009). Surfaces impervious to rain and surface runoff (e.g., hard or paved surfaces and the roofs of buildings) prevent natural infiltration into the ground. The water is, instead, conveyed more rapidly downhill across the landscape, and carries with it any contaminants that it accumulates. Under some circumstances, the higher speed and volume of water can damage the land through erosion, especially along stream banks when the runoff finally reaches the natural watercourses. High, forceful flows in the waterways also alter stream habitat, at least temporarily; the changes can be significant enough to cause long-term habitat destruction and poor stream health.

The extent of development in a watershed may have significant consequences to stream condition. Development usually results in increased impervious surface area, as new roads facilitate access to new buildings. Urbanization brings a variety of pollutant sources such as oils, paints, salts, loose sediment, and other contaminants which are deposited on the impervious surfaces. Rainwater then washes these materials and other contaminants (e.g., heavy metals, pesticides, fertilizers, and dyes) from the land, across impervious surfaces, and into nearby streams, either directly or through the storm drain network.

As a general trend, watersheds with less impervious surface per area are more likely to have better local stream water quality than watersheds with more impervious surface (Giddings et al. 2009; Schueler et al. 2009). Urban development is typically associated with the extent of impervious surface in a given watershed, although there are numerous other factors affecting stream health. Schueler, et al. (2009) provided a model based on studies linking stream condition indicators to the contributing amount of impervious cover (Figure 2-16). Among the ranges described, the researchers noted that watersheds with 10-25 percent impervious cover often have negatively affected streams; typical characteristics include clear signs of degradation such as erosion, channel widening, and a decline in habitat quality. Watersheds with 25 to 60 percent impervious cover generally have damaged streams; these streams exhibit fair to poor water quality, unstable channels, severe erosion, and an inability to support aquatic life and provide habitat (streams in this category may be piped or channelized as a factor of running through complex roadway systems). Degraded streams may have potential for restoration to a somewhat natural functioning system; damaged streams may not regain natural functions, but efforts to reduce pollutant loads to these streams (e.g., by installing or upgrading stormwater management facilities) may ease the contaminant and sediment burdens to waterways further downstream.

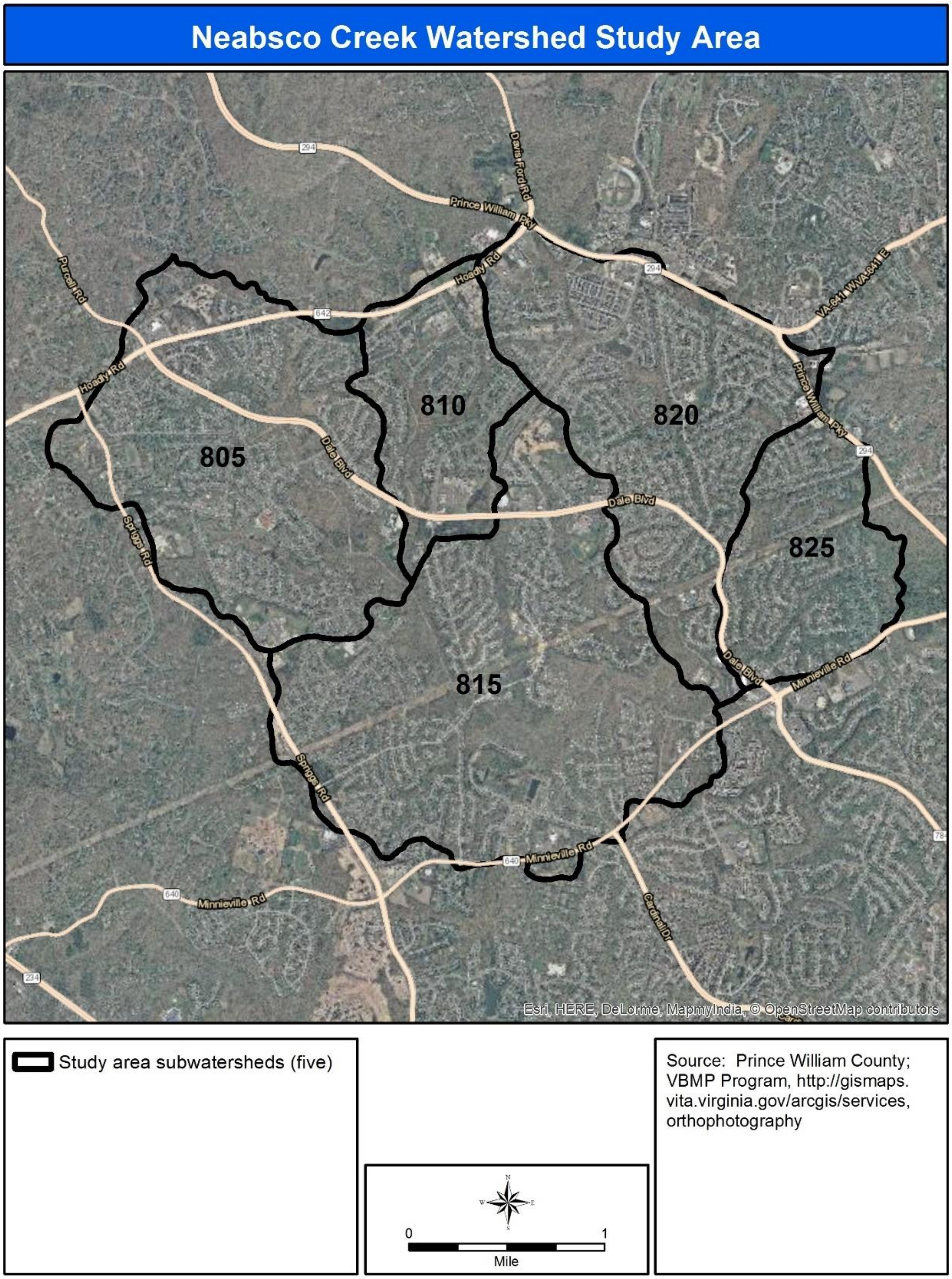

Figure 2–15. Aerial photography image of the Neabsco Creek watershed study area

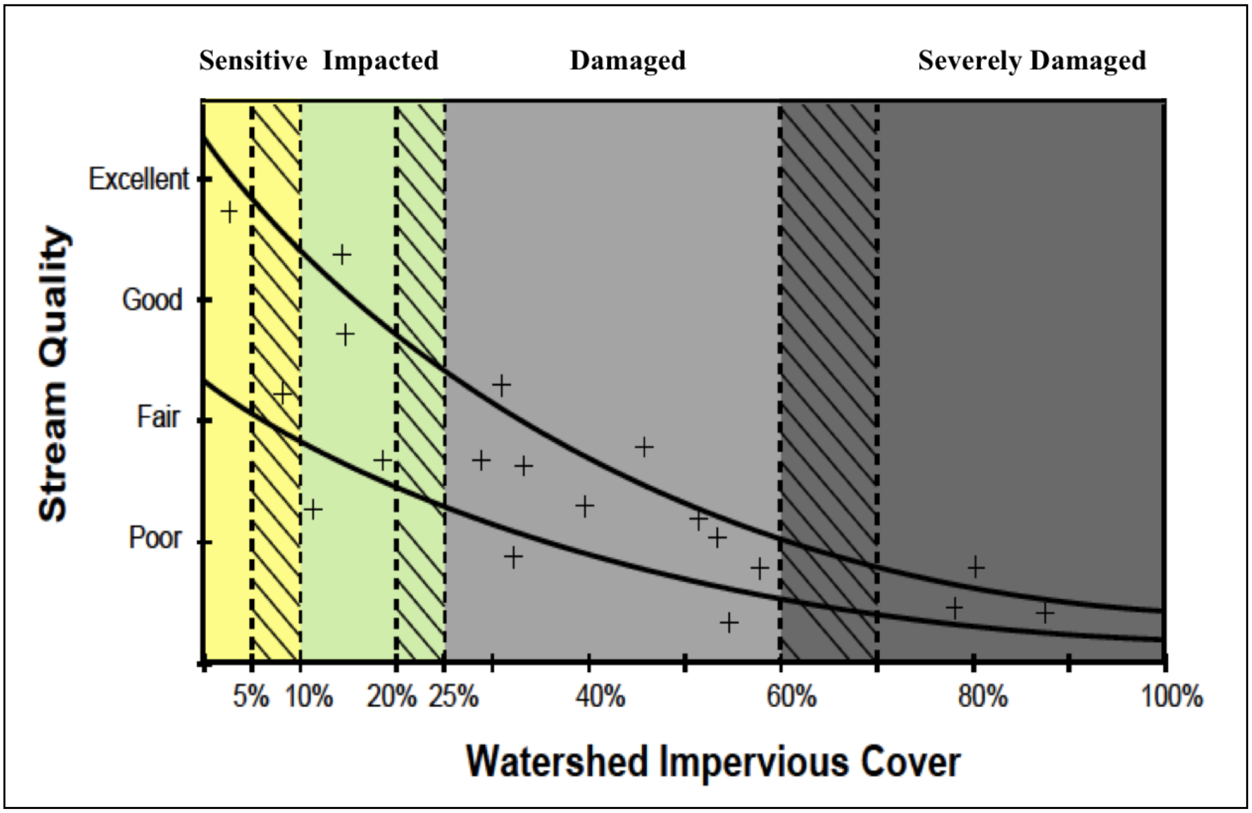

Figure 2–16. General relationship between the amount of impervious cover in a watershed and the watershed's stream quality (adapted from Schueler et al. 2009)

The Prince William County GIS data layer for impervious cover (from March 2011) provided the basis for assessing each subwatershed's potential to have impaired stream quality (Figure 2-17). Area and percent impervious cover for each subwatershed are listed in Table 2-10. The amount of impervious cover in the subwatersheds on the west side of the study area (Subwatersheds 805, 810, and 815), contributing to Neabsco Creek proper and its related tributaries, correlate with the category of "impacted" streams (10-25 percent impervious), according to the relationship illustrated in Figure 2-16. The subwatersheds contributing to Hoadly Run on the east side of the study area (Subwatersheds 820 and 825) have slightly greater percentages of impervious cover, within the range for “damaged” streams (25-60 percent impervious). The overall percent impervious cover in the study area is 24.6 percent. While impervious cover is a relevant and significant indicator of watershed condition, it is only one of many different factors affecting stream health and contributing to the cumulative impacts of development on water quality; for example, current and historical land uses can influence habitat conditions and water quality to varying degrees, depending on the management practices employed. Proper stormwater management may reduce the potential impacts of flow, sediment, nutrients, and contaminants to receiving waters.

Table 2-10. Summary of impervious cover, Neabsco Creek watershed study area (Source: Impervious.shp ESRI digital data set; published 3/2011; Updated 10/22/2015; Prince William County, VA)

Subwatershed ID	Subwatershed Acres	Impervious Area (Acres)	Impervious Area (Percent)
805	1455.3	350.2	24.0
810	536.0	122.8	22.9
815	1990.3	461.5	23.2
820	1267.3	355.0	28.0
825	591.0	147.7	25.0
Total Study Area	**5839.9**	**1437.1**	**24.6**

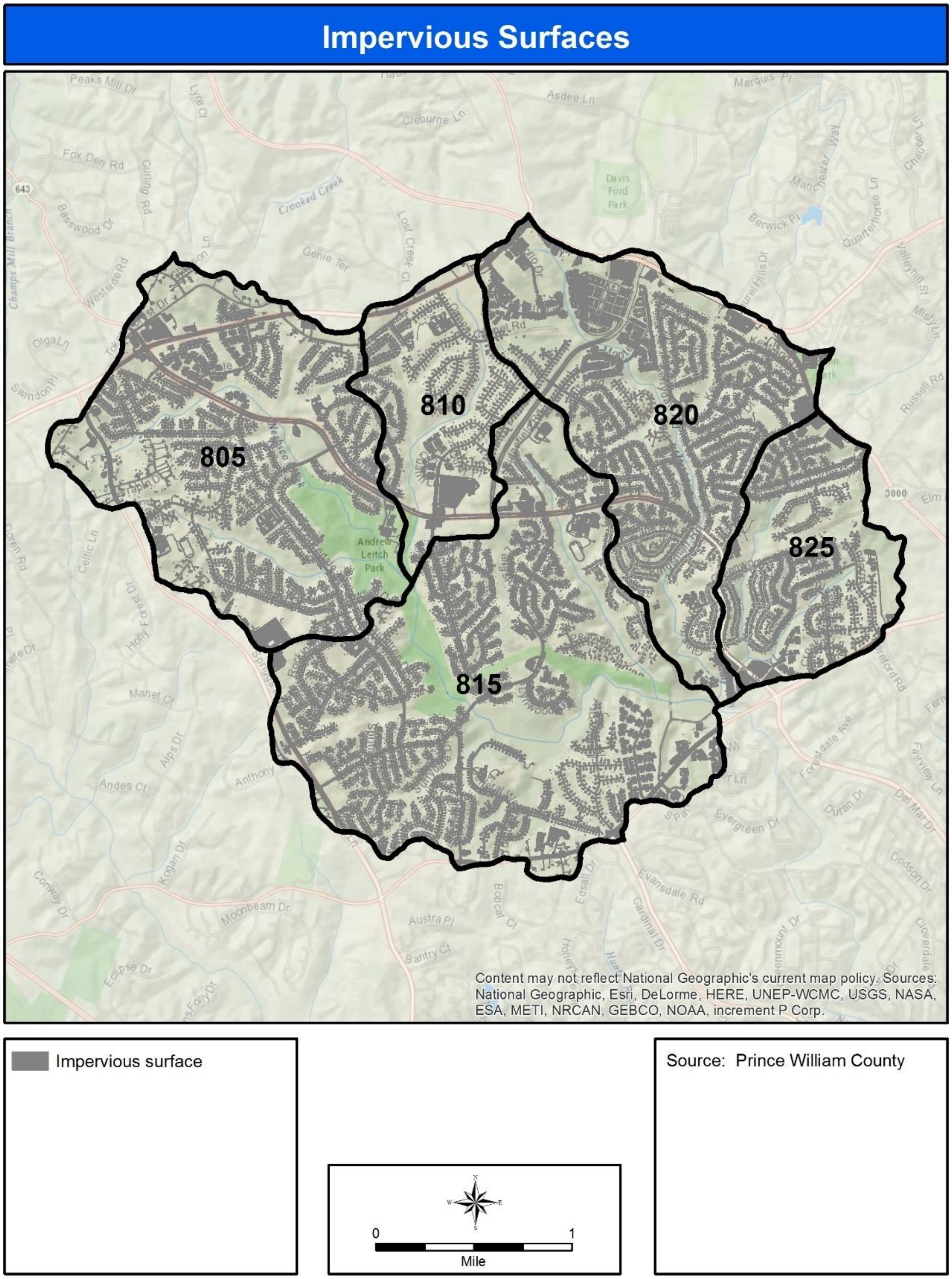

Figure 2–17. Existing impervious surface in the Neabsco Creek watershed study area

2.2.2 Existing Impervious Treatment

Stormwater management (SWM) facilities have the potential to partially control stormwater runoff for both flow and water quality characteristics. Impervious surfaces that drain to a SWM are considered to be managed by stormwater controls, although the extent of effectiveness of the SWM depends on design, capacity, maintenance, and the nature of the input to the system. In the subwatersheds of the Neabsco Creek watershed study area, 90 SWM facilities manage runoff from portions of the impervious surface in developed areas, based on the data provided by the County. Prince William County staff provided the Contributing Drainage Areas (CDAs) for these SWMs (Figure 2-18). Some of the watershed's impervious surfaces are located within the CDAs of these SWM facilities; however, many areas, particularly those with older development, are not. In general, the stormwater management facilities in the study area are designed to provide control for water quantity (i.e., to reduce potential flooding or flow-related impacts downstream), quality (i.e., pollutants are removed or reduced by the facility before the stormwater enters the stream network), or both. The relative amounts of impervious cover that drain to the three general types of management facilities are shown in Figure 2-19; Table 2-11 provides a summary of the allocations, based on the available data. The percent of impervious cover that remains unmanaged, by subwatershed, ranges from almost 12 percent, in Subwatershed 810, to over 75 percent, in Subwatershed 805. Less than 50 percent of the impervious cover in the watershed study area as a whole is managed by any existing SWM. Opportunities to improve this ratio include implementing additional stormwater treatment in existing developed areas where no practices are currently in place. Improved treatment may also derive from converting existing facilities to better-functioning systems to provide additional treatment before stormwater reaches the stream system.

Table 2-11. Summary of impervious cover currently managed by SWM facilities and not managed, Neabsco Creek study area

Subwatershed ID	Impervious Cover in CDA with Quantity and Quality Management (acres)	Impervious Cover in CDA with Quantity Management (acres)	Impervious Cover in CDA with Quality Management (acres)	Impervious Cover Not Managed (acres)	Percent of Total that is Not Managed
805	58.5	26.1	2.2	263.3	75.2
810	25.2	82.0	1.1	14.6	11.9
815	144.7	129.1	1.0	186.8	40.5
820	105.1	20.4	0	229.5	64.6
825	29.5	27.3	2.4	88.6	60.0
Total Study Area	**363.0**	**284.9**	**6.7**	**782.7**	**54.5**

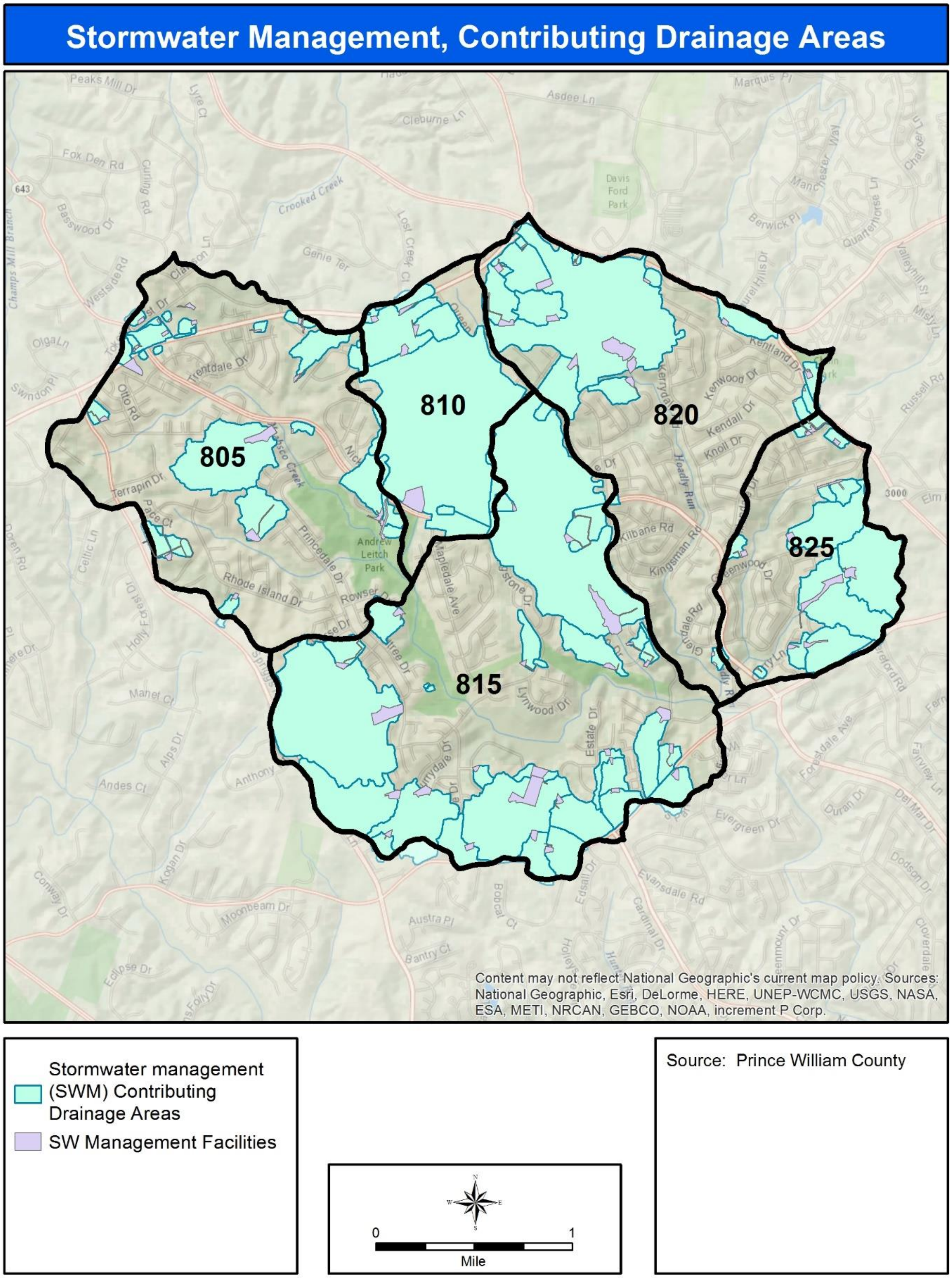

Figure 2–18. Stormwater management facility drainage areas in the Neabsco Creek watershed study area

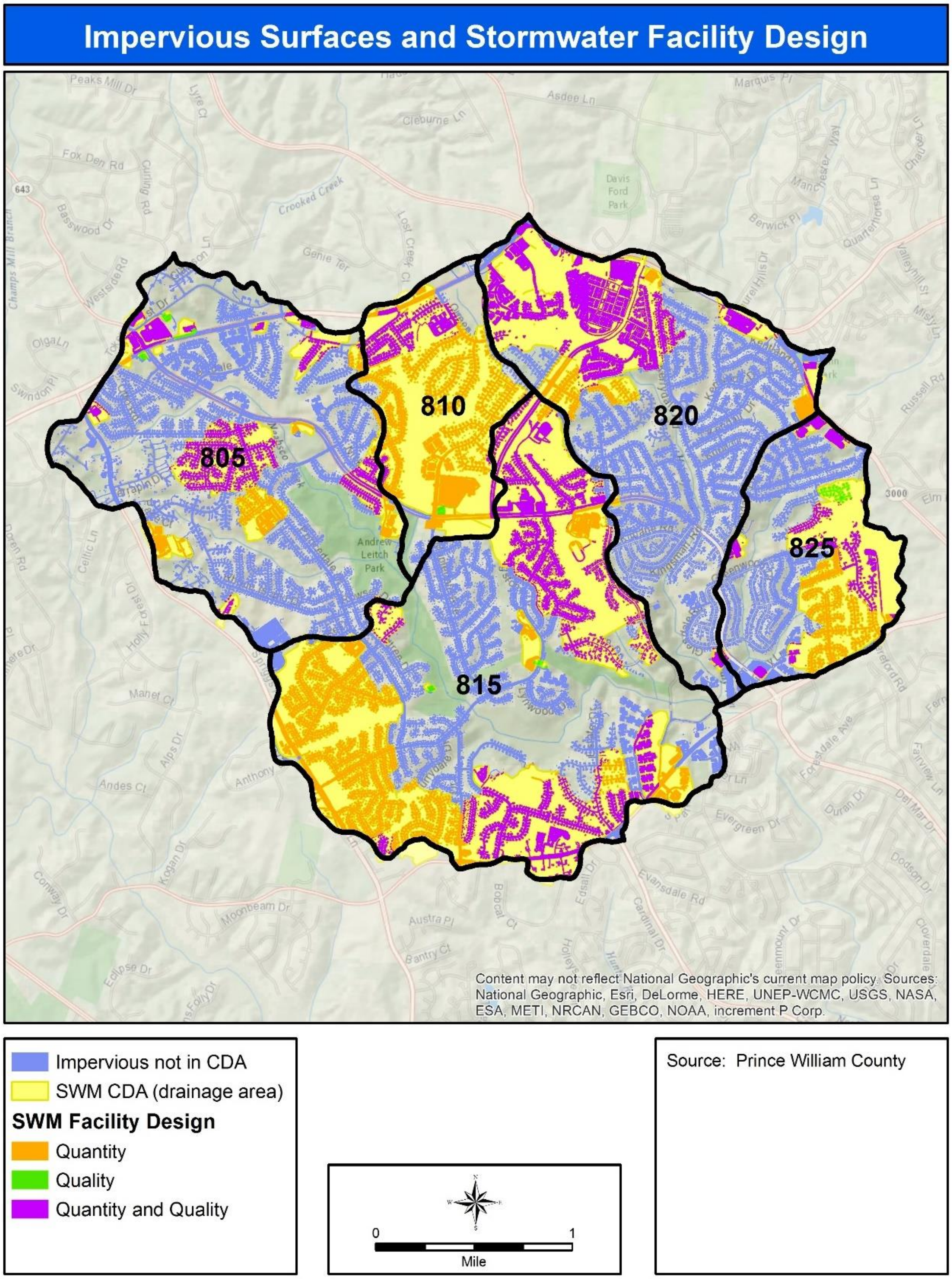

Figure 2–19. Existing impervious surface, showing areas not managed by SWM facilities and those within SWM facility drainage areas (CDAs) designed to control stormwater quantity, quality, or both, in the Neabsco Creek watershed study area

2.3 COUNTY PLANS

2.3.1 Zoning

Each county has the authority to regulate its lands to promote the desired functions of the land use and infrastructure to support the county's residents and visitors; this authority, granted by the state, is manifested in zoning ordinances. Through zoning, a county can promote business, agriculture, residential developments, parkland, and historical preservation. The zoning ordinance is a representation of the most recent accepted plan for the distribution and density of land uses. Prince William County provided GIS data for zoning, dated May 2008. Figure 2-20 illustrates the distribution of zoning categories in the Neabsco Creek watershed study area. The vast majority of the study area is intended to support residential communities; 59 percent of the area is allocated to Residential Planned Community (RPC); the extent of the existing impervious layer suggests that most of this zone is already filled with residential communities. Parcels along the southwestern edge of Prince William Parkway (Route 294) contribute commercial businesses to the Hoadly Run subwatersheds on the east side of the watershed study area. There are some relatively large parcels zoned agricultural around the edges of the study area. Parcels with more concentrated residential zoning densities are physically associated with the communities of Hoadly, in the northeast corner, and Minnieville, in the south-central region.

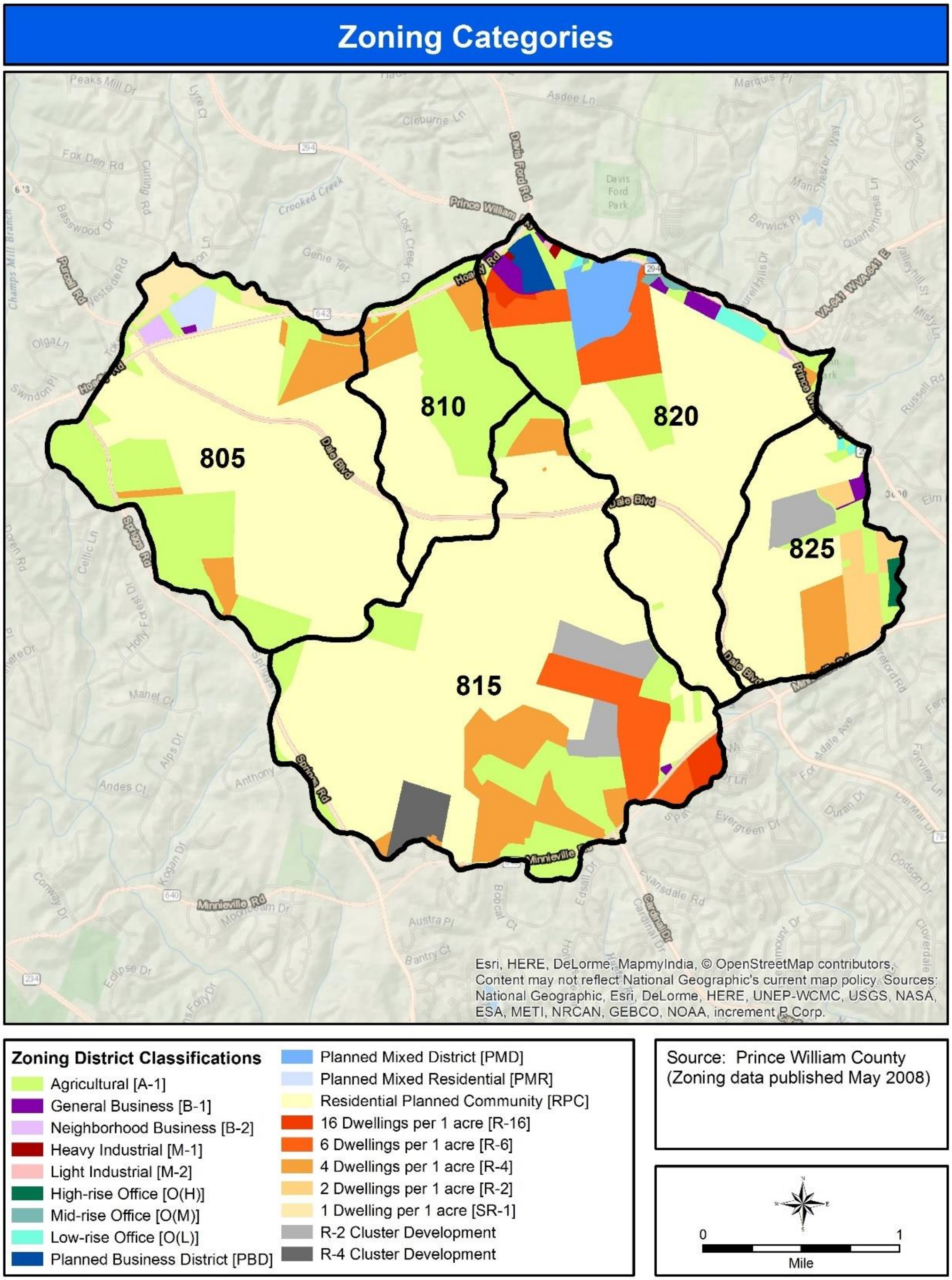

Figure 2–20. Zoning classifications in the Neabsco Creek watershed study area

2.3.2 Comprehensive Plan

Data from Prince William County's Comprehensive Plan can be used as a spatial representation of the extent of proposed or anticipated land use. A comprehensive plan incorporates information on land uses, transportation, historic areas, environmental resources, and public services and facilities, to account for the uses and needs of future residents, business owners, and visitors in the county. The plan serves to guide development decisions (by the Planning Commission and the Board of County Supervisors) and account for infrastructure needs for future growth and modifications. The plan is reviewed every five years to incorporate any revisions in zoning and subdivisions, changes in needs for services, and updates in Capital Improvement Projects. Prince William County provided GIS data for the Comprehensive Plan's spatial land use data (publication date: April 2015) for the assessment included in this report. Figure 2-21 illustrates the allocations for the areas represented in the data set. As is reflected in the Zoning map (Figure 2-20), the Comprehensive Plan projects that most of the watershed will be targeted for residential uses, a portion along Prince William Parkway for business uses, and concentrations of higher density residential use and commercial centers near Hoadly and Minnieville. Unlike the Zoning data, the allocations for the Comprehensive Plan include areas for public land and open space, generally along the lower sections of Neabsco Creek, and Environmental Resource Areas along Hoadly Run and several tributaries in the Neabsco Creek study area's hydrology network. Most of the agriculture areas in the Zoning map are assigned to low-density or semi-rural residential areas in the Comprehensive Plan. Note that the County's impervious cover data suggest that many of these conversions have already been implemented.

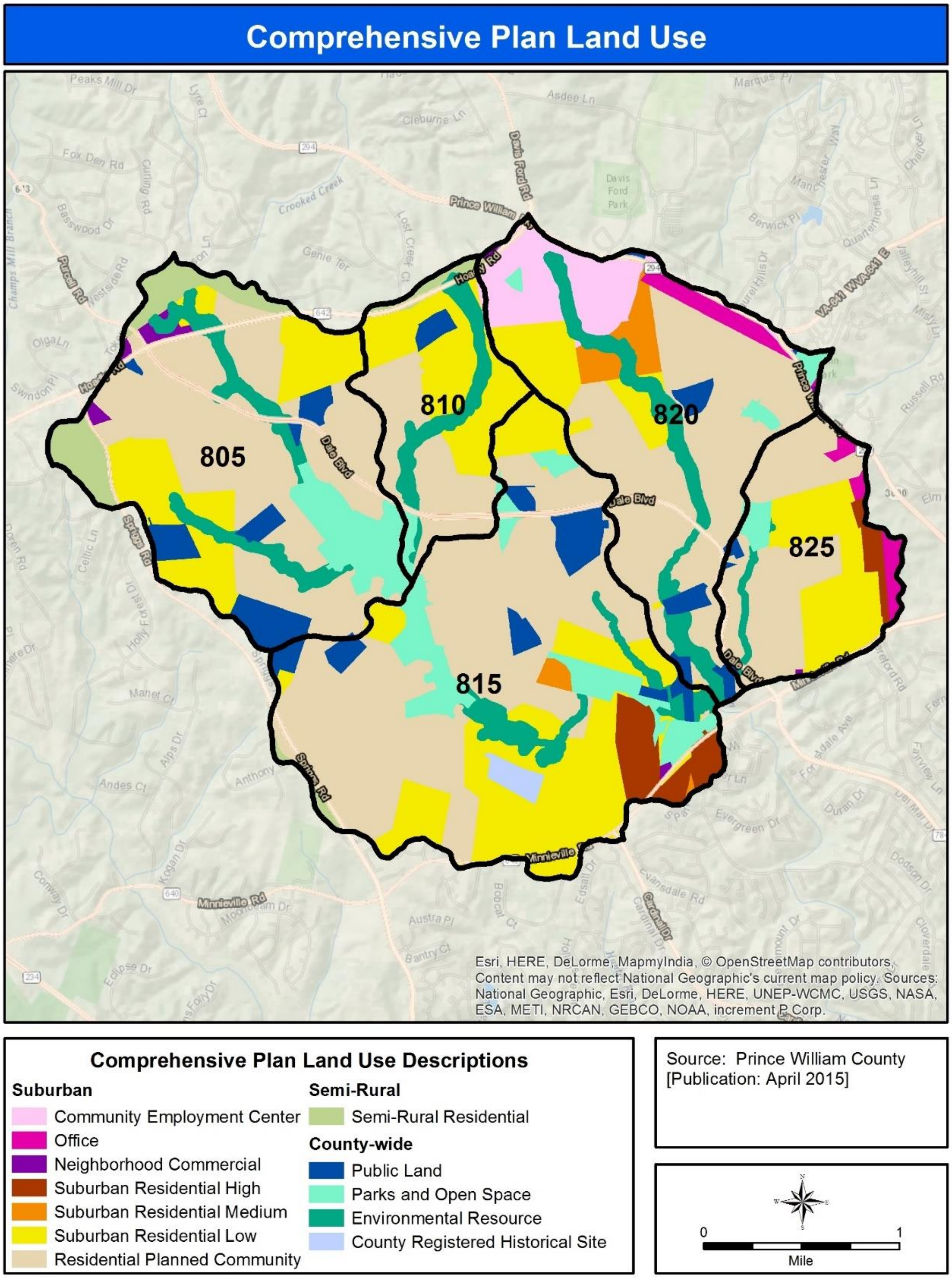

Figure 2–21. Comprehensive Plan classifications in the Neabsco Creek watershed study area

2.4 FLOODPLAINS AND FEMA

In a suburban landscape, as exists in the Neabsco Creek watershed study area, flood waters can damage property, threaten and take lives, erode stream beds, quickly distribute pollutants, and alter and destroy habitats. Natural patterns in a watershed — including soils, vegetation, and land forms — establish drainage pathways for groundwater and rain water. During rain events, waterways in the network convey more water than they would in dry periods, and lower areas adjacent to stream and river banks stream beds become flooded with accumulating waters; these inundated areas are natural floodplains. Modifications to the landscape that influence drainage patterns — such as removing trees, changing vegetation types, adding impervious surfaces, grading land, excavating land, changing soil characteristics, creating ditches, damming waterways for in-line lakes, and installing stormwater maintenance pipes and ponds — necessarily alter the potential flow patterns of rainwater. In light of this, local regulations may incorporate guidelines and restrictions regarding the manner and placement of any significant changes to the landscape, as they pertain to stormwater, to attempt to accommodate (and possibly correct for) the expected changes in drainage patterns and minimize flooding hazards. Flooding in portions of Neabsco Creek has been noted as a key concern by the Prince William Conservation Alliance (undated).

The Prince William County government has incorporated concerns about flooding in its designs for land use management. Specifically, the Resource Protection Areas (RPAs) have been designated throughout the county to encompass and help to protect floodplains along streams; vegetation management programs for the RPAs are intended to buffer the streams from the effects of storm runoff flows and restrict development that would alter the protective environment and the natural flow patterns for the streams. Some of the lands draining to headwaters in the Neabsco Creek watershed have networks of ditches and culverts; presumably, these were installed to control floodwaters. Ditches also appear along major roadways; these typically manage stormwater flow from the pavement. Development plans now need to incorporate stormwater management to control flows and pollution loads to streams [http://www.pwcgov.org/government/dept/publicworks/environment/Pages/Floodplains-and-Flood-Control.aspx]. Prince William County's Design and Construction Standards Manual (DCSM; Prince William County 2015) defines a floodplain as any land area that would be inundated by floodwater during a 100-year flood event (likely to occur once every 100 years; one percent chance of occurring in any year). As per the DCSM, the County requires floodplain studies when a construction project is proposed within a drainage area of at least 100 acres, and includes specific restrictions on lots smaller than 100 acres. Floodplain management regulations do not allow development which would raise the elevation of the 100-year floodplain, and thus extend the boundaries of the plain. These precautions help to constrain potential development that may have damaging effects to the waterways and their natural flow patterns.

A tool that provides information about the extent of floodplains and the predicted areas that may be hazardous in major storm events is the Federal Emergency Management Agency (FEMA) National Flood Hazard Layer (NFHL) data set. The NFHL includes floodways (channels that need to be reserved to discharge the flood waters from a 100-year flood) and floodplains. The NFHL data sets acquired from FEMA illustrate areas within the Neabsco Creek study area subwatersheds that have been designated as floodways or floodplains (100-year and 500-year). These features are shown in Figure 2-22. All five Neabsco Creek study area subwatersheds contain 100-year floodplains, associated with Neabsco Creek, Hoadly Run, and their main tributaries. Floodways are associated with the mainstems of both Neabsco Creek and Hoadly Run (subwatersheds 805, 815, and 820). The Environmental Services department of Prince William County's Department of Public Works encourages property owners to investigate the nature and extent of floodways and floodplains on their parcels, as restrictions apply to construction in these areas.

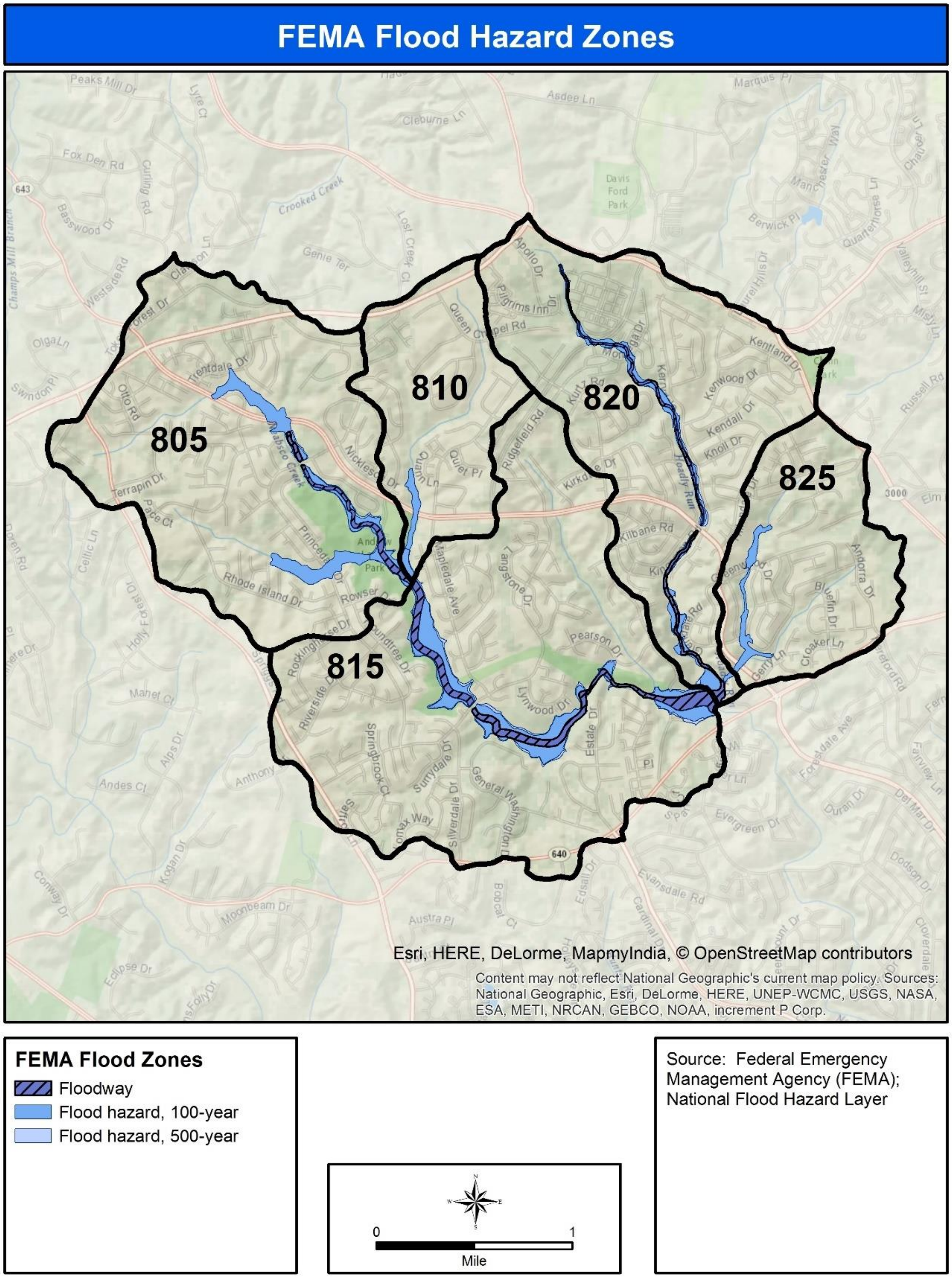

Figure 2–22. FEMA floodways and flood hazard zones in the Neabsco Creek watershed study area

2.5 TMDL STATUS AND IMPAIRED WATERS

Prince William County participates in several state and federal programs intended to improve water quality, ultimately to the receiving waters of the Chesapeake Bay. One of these programs, the Total Maximum Daily Load (TMDL) program, sets limits on the nitrogen, phosphorus, and other pollutants that any jurisdiction is allowed to release to an impaired waterway. The Virginia Department of Environmental Quality (DEQ) compiles lists of impaired waters, published in the biennial 303(d) report, and develops TMDLs as a pollutant load limit for each of the listed waters. In the TMDL, DEQ identifies the potential sources of the contaminants involved. The published TMDL document includes a strategy for addressing the point and non-point sources of this pollution.

In 2008, Virginia DEQ developed a TMDL for a portion of Neabsco Creek that was impaired due to the levels of bacteria (*E. coli*) found that exceeded the criteria for state water quality standards for recreation (Virginia Department of Environmental Quality 2008). DEQ tested for fecal coliform from 1974 to 2005, and *E. coli* from 2005 to the present; the TMDL includes a translation to present the results as *E. coli*. Neabsco Creek had been included on the 303(d) list of impaired waters for the years 2002, 2004, and 2006 prior to the TMDL (Cause Group Code: A25R-01-BAC, Recreation); the 2014 303(d) list still includes Neabsco Creek for the same impairment. The affected portion of Neabsco Creek is 8.42 miles long. It extends from a confluence with an unnamed tributary downstream of and northwest of the Minnieville area to the Route 1 bridge crossing southeast of Dale City (the location of the main sampling station). A subsection of the impaired segment of Neabsco Creek – the upstream portion – flows within subwatershed 815 (Figure 2-23).

In the 2008 TMDL, Virginia DEQ stated that the levels of bacteria in Neabsco Creek would need to be reduced by 71 percent to meet water quality criteria; the department also used models to identify several probable sources of the bacteria in the watershed. The TMDL suggested that both point and non-point sources contribute the bacteria to the waterways. Animal sources of bacteria may include waste from wildlife (including waterfowl), pets, and livestock. The Virginia DEQ allows point source discharges through permitted releases through either the Virginia Pollutant Discharge and Elimination System (VPDES) permits for individual facilities or the Municipal Separate Storm Sewer System (MS4) permits. The TMDL identified two VPDES-permitted sewage treatment plants and four MS4 permittees within the watershed draining to the impaired stream segment (Prince William County, Virginia Department of Transportation, Prince William County Public Schools, and Northern Virginia Community College). The County notes that regular maintenance and inspection of sewer infrastructure is essential since much of the infrastructure is gravity-fed and occurs in stream valleys.

The TMDL analyses concluded that the reductions in bacteria needed to meet the 71-percent goal were to come from the MS4s, collectively, and wildlife-plus-pet loads — each reducing the contributions by 75 percent (Virginia Department of Environmental Quality 2008). To address the MS4 loads, Virginia DEQ suggested that reductions might be achieved through best management practices (BMPs) that target pet waste, through ordinances; improved garbage collection and control; and improved street cleaning. The first stage of implementation proposed in the TMDL addresses only anthropogenic sources. To reduce the contributions of bacteria from wildlife, the TMDL suggests wildlife population management (in a second phase of implementation, after additional testing clarified how much of the loads had been reduced by implementing the approaches in the first phase). The Virginia DEQ contemplated the possibility of removing or redesigning the recreational use designation, specifically for waterways that could not meet the state water quality criteria under limited conditions that were not likely to be remedied.

In addition to the local TMDL for bacteria, the entire watershed is subject to the Chesapeake Bay TMDL for nutrients and sediment. Watershed Implementation Plans (WIPs) have been developed to provide a roadmap for achieving the nutrient and sediment reductions necessary to implement the Bay TMDL. Prince William County is taking steps and implementing programs to reduce the total loads of nitrogen, phosphorus, and sediment entering local streams, creeks, and rivers. The County is actively pursuing a countywide program of stormwater pond retrofits, stream restoration, and urban nutrient management that will enable the County to work toward the pollutant reduction targets set by the Bay TMDL.

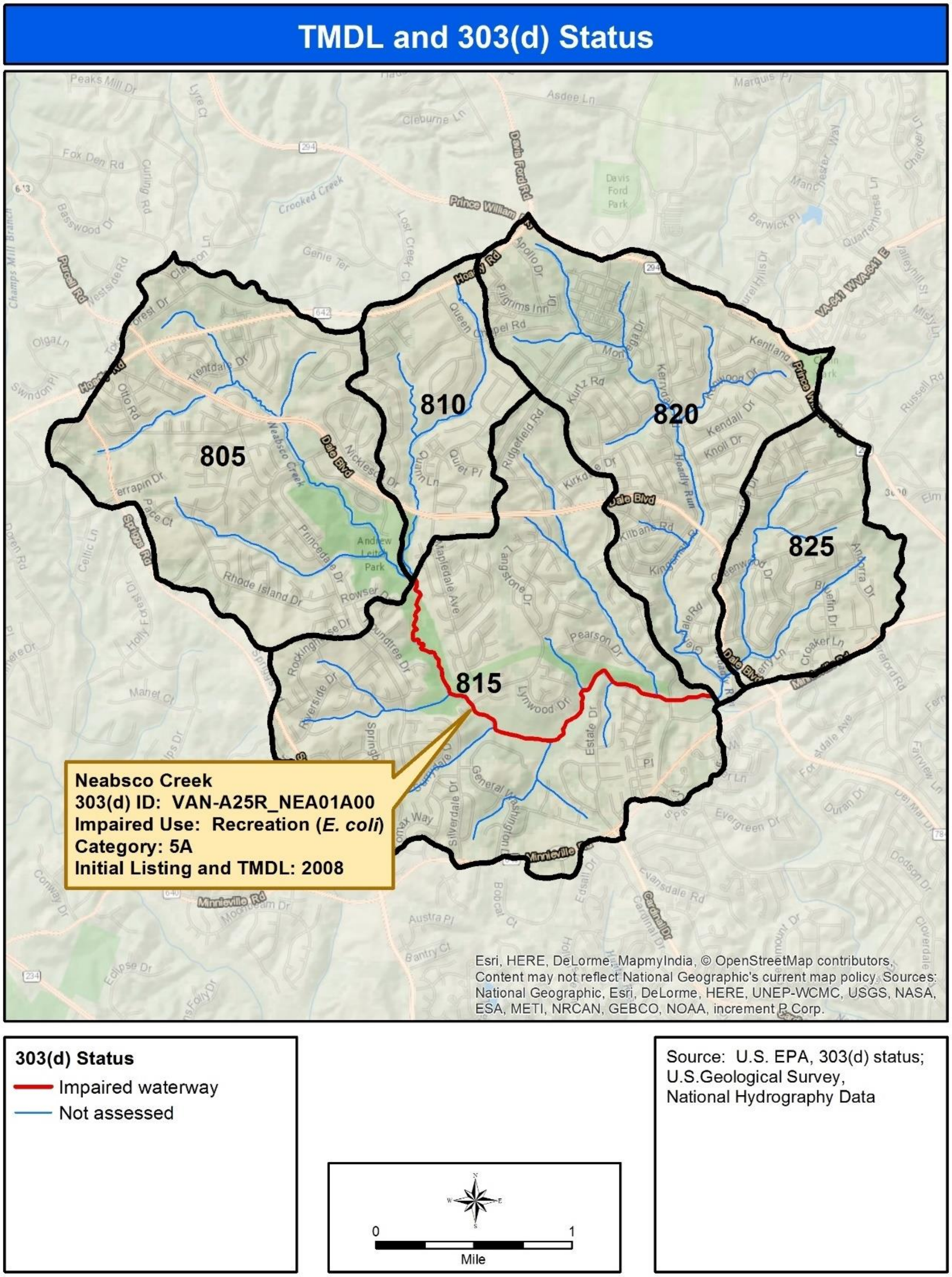

Figure 2–23. TMDL status and 303(d) listing category for the portion of Neabsco Creek in the watershed study area

CHAPTER 3: BEST MANAGEMENT PRACTICES: OPPORTUNITIES FOR RETROFIT AND RESTORATION

There were five categories of retrofit and restoration opportunities considered for the current watershed assessment: (1) upgrading or retrofitting existing stormwater (SW) Facilities, (2) proposing new BMPs, (3) stabilizing stormwater outfalls, (4) reforestation of riparian and upland areas, and (5) restoring streams. Prince William County, along with other jurisdictions in the region, has implemented stormwater BMPs and other watershed management practices since the 1980s. The initial focus of stormwater management was detention of large flows to reduce flooding. Later designs addressed water quality treatment and stream channel protection in accordance with revised design criteria. Most recently, “green” BMPs known as Environmental Site Design (ESD) or green stormwater infrastructure are being encouraged for new and re-development and to facilitate restoration of watersheds.

The following categories of stormwater and watershed management practices were considered in this watershed study as the major strategies to address Prince William County’s interest in reducing pollutant loads, reducing streambank erosion, and restoring water quality and habitat. Each has the potential to yield benefits in water quality improvement and in quantity control for channel protection and reduced flooding.

1. Conversion of dry ponds and extended detention dry ponds to modern facilities with greater pollutant removal efficiencies, which include:

    - Extended detention dry ponds (if dry pond is present and no other viable option is practical)
    - Extended detention wet ponds, shallow wetlands
    - Bioretention
    - Non-bioretention filtering practices
    - Infiltration practices
    - Swales
    - Addition of pre-treatment or post-treatment BMPs within existing dry or wet pond boundaries
    - New BMP retrofits outside of existing dry or wet pond boundaries but which would drain into an existing pond or capture and treat stormwater just outside of the existing pond (e.g. bioretention, sand filter).

2. Retrofitting untreated impervious surfaces with new stormwater BMP facilities, which include:

    - Underground storage
    - Bioretention

- Non-bioretention filtering practices
- Infiltration practices
- Swales

3. Restoring degraded ephemeral and intermittent outfall channels through stabilization techniques, which include:

   - Step Pool Stormwater Conveyance (SPSC)/Regenerative Stormwater Conveyance (RSC) stabilization
   - Rip-rap stabilization
   - Installing a drop structure or other stabilization of the outfall channel

4. Reforestation of stream buffers and upland areas

5. Restoring degraded stream channels for erosion control and enhanced nutrient processing

3.1 STORMWATER FACILITY CONVERSIONS

Stormwater (SW) Facility Conversions (Figure 3-1) consist of the re-design of existing stormwater ponds, frequently including dry stormwater management detention ponds, to provide additional water quantity control or water quality treatment. These facilities typically treat the largest area of impervious cover because they have the largest drainage areas and were originally built as a low-cost option for flood control, channel protection, and/or water quality control. Conversion of these existing devices is among the most cost effective of pollutant reduction measures because the existing ponds do not require acquisition of new property, the pipe infrastructure is already in place, most of the excavation is already complete, maintenance responsibilities and easements have already been established, and stormwater flows already concentrate at these devices. Pollution reduction credits may depend on specific design characteristics affecting both runoff time and treatment. Possible constraints regarding these options include acceptance by local residents and pond owners of the proposed pond's aesthetics, the revised maintenance needs, and construction or maintenance costs.

Specific features of SW Facility conversions from dry detention ponds may include:

- Increasing storage capacity by additional excavation or raising the high flow riser.
- Providing water quality treatment features at facilities that currently have only water quantity control, if the space is available. Examples include: micropools, sediment forebays, or constructed stormwater wetlands.

Figure 3–1. Example of stormwater facility conversion. Dry Pond facility (top) converted to constructed wetland with riser structure (bottom). Photo credit Prince William County

- Modifying or replacing existing outlet controls to reduce the discharge rate from the stormwater management facility.
- Where soil types are appropriate, adding infiltration (sometime referred to as exfiltration) features to promote groundwater recharge and improve pollutant removal.
- Adding bioretention or a surface sand filter as pretreatment or post treatment to significantly increase pollutant removal efficiency.

Specifically, the following types of conversions are recommended in the upper Neabsco Creek watershed:

- Dry Extended Detention (ED) Basins are depressions that temporarily store ("detain") runoff and release it at a prescribed rate via surface flow or groundwater infiltration following storms. Dry ED basins are designed to dry out between storm events, in contrast with wet ED ponds, which contain standing water permanently. As such, they (ED type) are similar in construction and function to simple dry or wet detention basins which are primarily for flood control or channel protection, except that the duration of detention of stormwater is designed to be longer, theoretically improving treatment effectiveness by increasing residence time of pollutants which encourages settling of sediments and allows more time for biological and physical processing of nutrients.

- Constructed Wetlands are ideal stormwater treatment facilities in areas where the facility is expected to be continually wet because of a high water table or presence of a baseflow stream. Wetlands take advantage of both a wet pond's ability to promote settling of particulate matter and wetland plants' inherent ability to take up and process nutrients and other pollutants from the water column. Additionally, wetland plants provide habitat and food sources for local wildlife.

- Surface Sand Filters may be installed as standalone facilities or incorporated into a portion of the existing pond footprint as a forebay. Sand filtration practices are the preferred method for treatment of runoff from impervious surfaces in industrial and heavily utilized commercial areas. Heavy metal pollutants adsorb onto the sand particles in the media bed, resulting in lower concentrations in the discharge.

- Bioretention may be installed within the entirety of an existing facility footprint or may be installed in multiple, offline cells where a facility has baseflow and an existing low flow leader channel. Bioretention consists of plantings in an engineered soil bed in a recessed area to promote infiltration and pollutant concentration reduction using natural processes in the root zones of plants. Bioretention facilities typically include an underdrain to carry treated stormwater back to the storm drain network and an overflow drain.

- Urban Infiltration Practices are depressions created to allow the collection and infiltration of stormwater in order to trap sediments and nutrients in soil media and simultaneously recharge groundwater aquifers. No underdrains are associated with infiltration basins and trenches, because by definition these systems provide complete infiltration. Infiltration basins and trenches cannot be constructed on poor soils, such as C and D soil types. These urban infiltration practices may include vegetation and sand which increases the removal of phosphorus by 5% on average compared to infiltration practices without sand or vegetation.

3.2 NEW BMPS

New BMP Installation (Figure 3-2) involves placing new stormwater treatment features, such as bioretention, surface sand filters, and underground storage at locations that currently have no stormwater quantity or quality controls or where existing facilities are inadequate and where space is available for a new BMP. The size of the new BMP is governed by both need and available space. New BMPs can range from large, regional facilities that treat a large geographic area, or a portion of a neighborhood or developed commercial area to smaller, site specific facilities that treat a portion of a parking lot or other impervious area. Micro-BMPs (in the context of ESD) include the use of innovative practices designed to mimic natural flows by reducing the volume of stormwater runoff at the source. Distributed Micro-BMP features are a series of smaller landscape features that function as retention/detention areas integrated with developed areas. New BMP installations recommended for the upper Neabsco watershed include the following:

- Underground Storage is recommended for treatment of large expanses of impervious areas (such as parking at schools or shopping centers) that have little or no available land for installation of traditional wet ponds, dry ponds, or wetlands to treat a potentially large volume of runoff. Underground storage is especially advantageous if the area to be treated is constructed on a raised bed of fill that would provide ample room for an array of large diameter (e.g., six feet) pipes to provide temporary storage. The underground storage facility functions in a similar fashion to traditional large pond facilities, except the temporary storage is provided by an array of stainless steel, perforated pipes. The outlet from the underground storage facility is typically a concrete weir that consists of a low-flow orifice. Underground storage facilities may feature pre-treatment cells consisting of media filters to achieve additional water quality improvement.

- Bioretention is a common term for a shallow depression designed to detain and treat stormwater runoff from small, frequent storms by using a conditioned planting soil bed, planting materials, and mulch. As with rain gardens, pollutants are adsorbed by the soil and plant material, improving water quality. These planted shallow basins temporarily pond stormwater runoff, filter it through the bed components and treat it through biological and biochemical reactions within the soil matrix and root zones of the plants. Bioretention areas typically include an underdrain system to carry both treated water draining through the system and, importantly, overflows from heavier events, to an existing stormdrain network. Bioretention areas themselves are usually only used to treat the water quality event and not for flood control or channel protection, but can be paired with an extended detention facility that provides these benefits.

- Dry Swales allow treatment and conveyance simultaneously and can be used as effective enhancement for existing ponds, both as pretreatment or post treatment, when site topography allows it or as stand-alone new retrofits anywhere that stormwater is conveyed on the surface.

- Sand Filter & Cartridge Systems use filtration media to reduce pollutant concentrations in stormwater runoff. Sand filters may be configured in above ground facilities (i.e., “surface” sand filters) or in underground chambers. Sand filtration facilities are typically installed to treat runoff from industrial or auto maintenance land uses in which heavy metals are a primary concern. Cartridge systems consist of filtration media oriented into cartridges and are enclosed within underground vaults in line with storm drain conduits. Cartridges in such systems can be removed and replaced when the medium is in need of replacement to maintain removal efficiency.

Figure 3–2. Example of bioretention facility. Photo credit Virginia Water Resources Research Center

The suite of available ESD practices is diverse and many are advocating for a more expansive use of lower-cost vegetation and tree-based practices, especially near outfalls, within existing conveyances, adjacent to parking lots, and as green streets. In general, ESD practices most conducive to residential landscapes include rain gardens (typically in yards), permeable pavement (typically for driveways), rain barrels or cisterns, turf conversion or sustainable landscaping, dry wells, green roofs, tree canopy, soil decompaction, and pavement removal. ESD opportunities in rights-of-way may include bioretention (in medians, cul-de-sac islands, street bump outs, adjacent open space, as well as behind curbs or sidewalks), permeable pavement (in parking or bike lanes, sidewalks), turf conversion or sustainable landscaping, street trees (including tree pits), and step-pool stormwater conveyances in roadside channels.

3.3 OUTFALL STABILIZATION

Outfall Stabilization (Figure 3-3) describes restoration that reduces the impact of stormwater outfalls on downstream stream condition. Historically, storm drain outfalls were placed to provide easy access for the urban stormwater collection system to a receiving channel and ultimately to a stream. Depending on the placement of the outfall, concentrated storm flows over time can cause scouring out of a plunge pool in the immediate vicinity of the outfall, erosion of banks in down-gradient ephemeral channels, and contribute to erosion in streams. The goal of stabilization is to reduce the ability of the outfall to continue to erode, contribute excess sediment to the stream ecosystem, and threaten stormwater or utility infrastructure. The outfall stabilization options considered for Neabsco Creek watershed consist of the following:

- Step Pool Stormwater Conveyances/Regenerative Stormwater Conveyances are open-channel conveyance systems that convert surface stormwater flow to shallow ground water flow through surface pools and subsurface sand seepage filters (Anne Arundel County 2012). These practices can be used to stabilize degraded ephemeral and intermittent channels while also providing water quality treatment for the contributing drainage area, allowing for pollutant removal opportunities that do not exist with traditional outfall stabilization techniques. Specific site conditions will dictate whether these practices are appropriate. Pollutant reductions for regenerative stormwater conveyances will be credited using the Chesapeake Bay Program Stream Restoration Expert Panel’s Protocol 4 (Schueler and Stack 2014), as described in Section 3.5 below.

- Installation of Rip-rap can reduce erosion where step pool conveyances are not feasible due to access challenges or insufficient space. Armoring of stream banks helps to distribute and dissipate the energy of stormwater flows and thus reduces erosion in the immediate vicinity of the outfall.

- Installation of Drop Structures is another option to consider if step pool conveyances are not feasible, especially due to steep relief. The drop structure is a prefabricated stormwater conduit that allows stormwater to flow in a controlled fashion from a high elevation to a lower elevation. This option is ideal if an outfall is perched or the receiving channel is severely down-cut.

Figure 3-3. Example of outfall rip-rap stabilization. Photo credit Versar.

3.4 REFORESTATION

Among land cover types, forest provides the greatest protection for water and soil quality. In pristine systems, forest and soils co-evolve, shaping the hydrologic cycle; these systems operate within a natural range of variability, assuring healthy habitat and water quality. The entire Potomac River basin, including the Neabsco Creek watershed, consisted overwhelmingly of old-growth forest at the time of European settlement. In human-impacted systems, forest cover can still provide many benefits and protect water quality if judiciously planned and conserved. While the forested area has been greatly reduced in the Neabsco Creek watershed since European settlement, some subwatersheds have maintained a higher percentage of forest cover than others, as in many urbanized watersheds in the region.

For these purposes, reforestation (Figure 3-4) essentially consists of two types of tree planting, including riparian buffers and upland buffers. Both of these types provide ancillary benefits of enhancing wildlife and amenity values. Planting trees reduces runoff through interception and uptake/transpiration of precipitation, while also providing nutrient uptake, soil stability, heat island reduction, and wildlife habitat benefits. This watershed study sought to identify good sites for reforestation of both riparian and upland areas in the Neabsco Creek study area.

Riparian Forest Planting sites are areas of trees, shrubs, and other vegetation adjacent to water or wetlands. The riparian area, typically at least 35 feet wide (on each side of a stream or water body), is managed to maintain the integrity of stream channels, and to reduce the impacts of upland sources of pollution by trapping, filtering, and converting sediment, nutrients, and other chemicals. Enhancing existing streamside vegetation with native varieties of trees, shrubs, and wildflowers restores many of the water quality, wildlife, and aesthetic benefits associated with riparian buffers. Vegetation filters sediments and other pollutants from stormwater runoff, moderates water temperatures in streams, and provides shelter and food to both terrestrial and stream organisms. These sites can convert urban open space or agricultural land to forest land and provide a nitrogen, phosphorus, and sediment reduction benefit proportional to the amount of land converted.

Figure 3-4. Example of reforestation. Photo credit Prince William County.

Upland Tree Planting sites prescribe planting of trees on currently urban or other open pervious areas (e.g., regularly mowed turf, occasionally maintained field) at a density that would produce a forest-like condition over time. Benefits include reductions in nutrient and sediment runoff as well as improvements in wildlife habitat and aesthetics.

3.5 STREAM RESTORATION

Stream Restoration practices (Figure 3-5) are used to improve the appearance, stability, and ecological function of damaged urban streams through redesign and repair of stream channels.

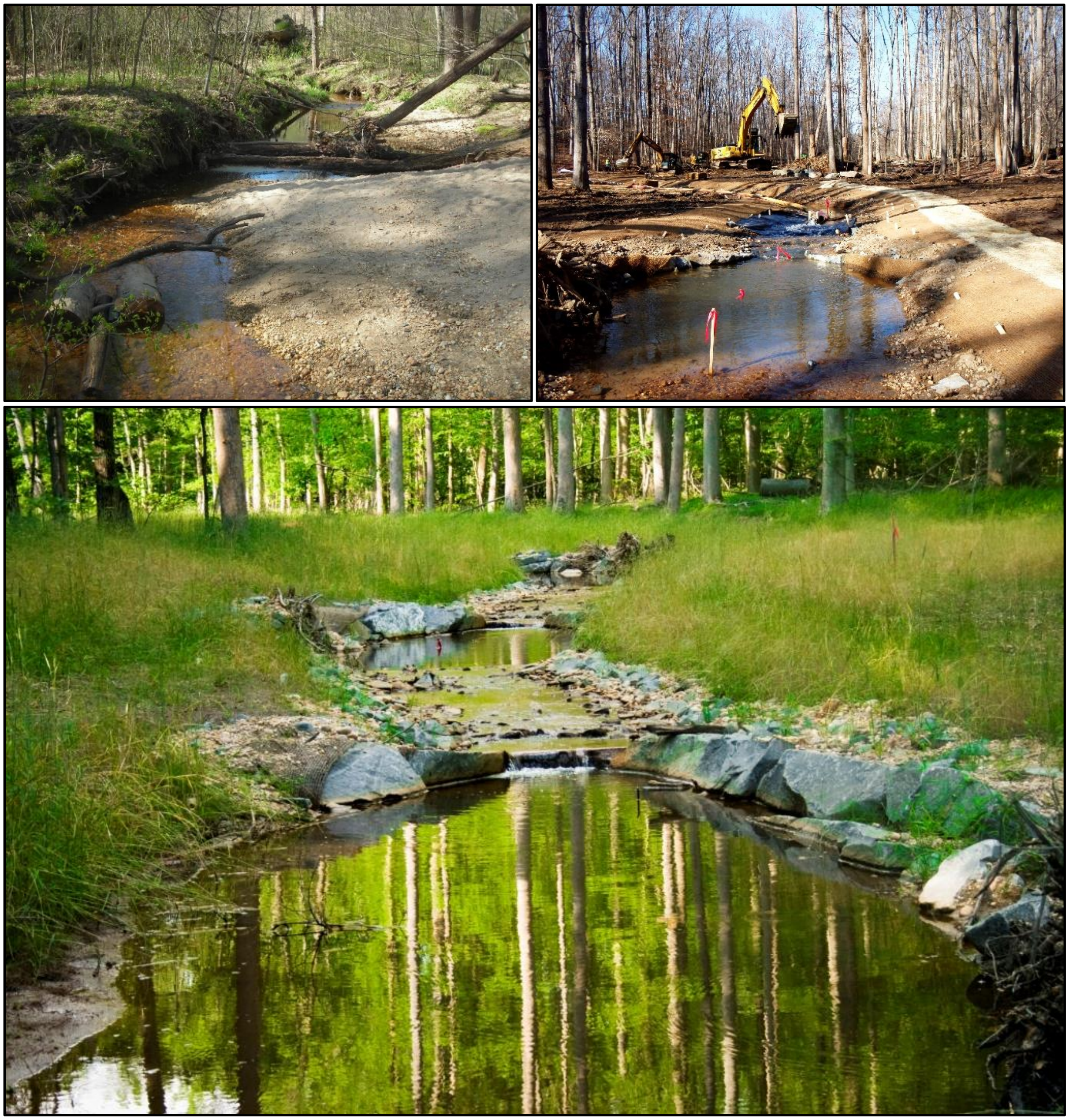

Figure 3-5. Example of stream restoration at Locust Shade Park. Figure shows a degraded stream (top-left), active construction (top-right), and restored stream (bottom). Photo credit Angler Environmental and Prince William County Department of Public Works.

Degradation of urban streams arises from the impacts of uncontrolled stormwater runoff from impervious surfaces, which include bank erosion, channelization, reduction in water quality, and destruction of habitat. Stream restoration practices range from simple stream repairs, such as vegetative bank stabilization and localized grade control, to comprehensive repairs, such as full channel redesign and realignment. Stabilizing stream channels improves water quality by preventing eroded soils, and the pollutants contained in them, from entering the stream and making their way to the lower reaches of Neabsco Creek, the Potomac River, and Chesapeake Bay. Preferred techniques to repair these damaged or degraded streams are often based on mimicking natural stream channels and the range of natural variability exhibited by nearby stable streams. Termed ***natural stream channel design***, such repairs focus on establishing natural stream channel shape, size, and habitat features. Design approaches can also include raising stream bed elevations to reestablish floodplain connectivity.

Credits may vary depending on the extent and type of stream restoration undertaken. In general, nutrient and sediment load reductions associated with stream restoration may be estimated using rates derived from regional studies. The Chesapeake Bay Program's Expert Panel to Define Removal Rates for Individual Stream Restoration Projects (Schueler and Stack 2014) has defined interim rates, which are acceptable for watershed planning purposes and which were used in the Neabsco Creek watershed study (for further details, see Section 7.2).

The Expert Panel also provides further guidance that can be used to calculate pollution reduction credits once a project design has been developed. Recognizing that every stream restoration project is unique with respect to its design, stream order, landscape position and function, the Expert Panel developed four protocols for determining pollutant reduction credits for individual projects, once site-specific design details are known. These protocols are as follows (from Schueler and Stack 2014):

> ***Protocol 1: Credit for Prevented Sediment during Storm Flow.*** *This protocol provides an annual mass nutrient and sediment reduction credit for qualifying stream restoration practices that prevent channel or bank erosion that would otherwise be delivered downstream from an actively enlarging or incising urban stream.*
>
> ***Protocol 2: Credit for Instream and Riparian Nutrient Processing during Base Flow.*** *This protocol provides an annual mass nitrogen reduction credit for qualifying projects that include design features to promote denitrification during base flow within the stream channel through hyporheic exchange within the riparian corridor.*
>
> ***Protocol 3: Credit for Floodplain Reconnection Volume.*** *This protocol provides an annual mass sediment and nutrient reduction credit for qualifying projects that reconnect stream channels to their floodplain over a wide range of storm events.*
>
> ***Protocol 4: Credit for Dry Channel Regenerative Stormwater Conveyance (RSC) as an Upland Stormwater Retrofit.*** *This protocol provides an annual nutrient and sediment reduction rate for the contributing drainage area to a qualifying dry channel RSC project. The rate is determined by the degree of stormwater treatment provided in the*

upland area using the retrofit rate adjustor curves developed by the Stormwater Retrofit Expert Panel.

An individual stream restoration project may qualify for credit under one or more of the protocols, depending on its design and overall restoration approach.

CHAPTER 4: DESKTOP ANALYSIS AND SELECTION OF SITES FOR FIELD ASSESSMENTS

4.1 DESKTOP ANALYSIS APPROACH

As a first step to identify candidate sites for restoration within the Neabsco Creek watershed study area, the Versar project team performed a desktop analysis using spatial data and other information on potential sites. The process included clarifying areas most in need of restoration, conducting GIS analysis, obtaining metadata for GIS data sets, and determining priorities within the list of potential candidate sites based on specific sets of criteria for each restoration type. Details of the desktop analyses, by category of restoration, are provided below. The product of the desktop analyses was a suite of candidate sites of each category to be included in field investigations.

Prior to initiating the desktop analysis, Prince William County staff provided information about locations within the study area where restoration efforts were already underway or where potential projects would be excluded from consideration for other reasons. These areas were removed from further consideration during the desktop analyses.

Existing Stormwater Facilities for Upgrade or Conversion

According to data provided by Prince William County during the development of the project, there were 93 stormwater facilities serving the Neabsco Creek watershed study area. During the desktop analysis phase to identify SW facilities that may be suitable for upgrade or conversion, Versar staff used GIS tools and orthophotography to review conditions at all facilities that were classified as publicly owned dry ponds. Of these, staff identified several dry ponds that appeared to be unsuitable for conversion due to conflicts with trees, the presence of baseflow streams, or associations with adjacent SW facilities. As a result of the in-house review, Versar staff determined that a subset of publicly owned dry ponds (12) and a subset of publicly owned extended-detention dry ponds (19) should be included in field investigations. Additionally, Versar consulted with Prince William County Public Schools staff to obtain information on restoration efforts already underway or that were being considered, in order to avoid duplication of effort. After County staff reviewed the 31 facilities, 30 were approved for field assessment.

Areas Suitable for New BMPs

Versar staff used GIS analysis to identify areas within the study area that currently lack storm-water management for existing impervious surfaces and that would be appropriate to evaluate as potential locations for implementation of new BMPs. With County-provided GIS data, staff created a digital data subset of turf areas that satisfied specific, relevant criteria:

- The land was not included in the drainage of an existing stormwater facility, as determined by the polygons depicting facility drainage areas that had been provided by the County;
- The grounds were not within a 100-year floodplain; and

- The land was part of a parcel being used for a school or commercial business, with a large amount of impervious surface within the estimated drainage area.

Additionally, Versar consulted with Prince William County Public Schools staff to obtain information on restoration efforts that were completed, underway, or that were being considered on school grounds.

Versar staff inspected the areas that met these criteria along with supporting data sets (e.g., Virginia aerial photography and contours) to identify turf areas and adjacent impervious areas that appeared to be suitable for new stormwater treatment. To identify additional opportunities, staff also inspected residential and other commercial areas that satisfied the first set of criteria but may have not been identified via the initial GIS analysis. Staff combined small targets into larger field assessment zones to improve field survey efficiency. After County review and adjustment of the 22 sites so identified, the field assessment included 18 revised target areas for investigation for new BMPs.

<u>Outfall Stabilization</u>

Versar staff developed a target set of outfalls to investigate for stabilization issues by applying selection criteria to a digital data subset of outfalls derived from the "NeabscoPoints" GIS data provided by Prince William County. The purpose of applying these criteria was to identify those outfalls that (a) would be most likely in need of stabilization, (b) were outfalls from uncontrolled areas of the County storm drain network (i.e., located outside of drainage areas contributing to existing SW facilities), and (c) provided sufficient room to install regenerative stormwater conveyances or rip-rap in receiving channels to provide stabilization. Staff used GIS tools to assess each outfall data point for its qualifications, based on the following criteria:

- Greater than 30 inches in diameter,
- Not in an existing SW Facility,
- Not discharging in line with a perennial or single-line stream,
- Not associated with a culvert,
- Not within a Virginia Department of Transportation (VDOT) right-of-way, and
- Distance from stream greater than 10 feet.

This analysis resulted in a data set of 45 outfalls for subsequent field investigations. The County approved 41 of these draft selections to be included in the final target set for field inspections.

<u>Upland and Riparian Reforestation</u>

Upland Reforestation

Versar staff used GIS tools to qualitatively inspect large parcels of open land throughout the watershed by employing tax parcel information (included in the County's digital data set of parcels), land use data, aerial photographs, and various printed maps. The Unified Subwatershed and Site Reconnaissance (USSR) manual by the Center for Watershed Protection (Wright et al., 2004) recommends that site selection for field assessments of suitability for new tree planting areas include publicly owned pervious areas greater than two acres and privately owned areas greater than five acres. Versar staff also considered non-private parcel sizes between one and two acres to increase the number of potential sites for review within the heavily developed Neabsco Creek study area. Positive factors included existing turf or wetland areas with few trees, adjacent forests or parks, and sites in or adjacent to riparian corridors (within 100 feet of a stream bank); negative factors included sites that appeared to provide beneficial turf areas for public or private use, sites within utility or other service infrastructure corridors, sites within median strips and road rights-of-way, and areas of turf on school grounds that may be commonly used for sport or recreation.

The staff employed GIS analysis, using a data set of parcel boundaries provided by the County, to investigate candidate upland forest restoration sites including the following series of criteria:

- Turf areas within parcels with a Premise Classification Type of Open (OPN), Non-building (NON), or Public (PUB), noting County properties, parks, and schools;
- Selected turf polygons from the result of the first step that were larger than one acre, and identified parcels that had at least one acre of segregated turf areas in total; and
- The forest and wetland expert who would be conducting the field assessments then reviewed the selection results with GIS tools to visually evaluate potential sites for their suitability as field sites, and assigned a score based on this evaluation: 1 = good comments like "Yes" and areas greater than 2 acres (19); 2 = other "Yes," "Possible, may have SW Facility," and "Has potential" (usually schools; 16); 3 = other "Possible" (13).

Prince William County staff reviewed the 47 sites selected and revised the list based on personal knowledge of sites and constraints. After the County's review, there were 41 sites included in the data set for field assessments for upland tree planting.

Riparian Reforestation

The staff employed GIS analysis, using a data set of parcel boundaries provided by the County and the derived data set used in the project to identify stream locations, to investigate candidate riparian buffer restoration sites, including the following criteria:

- Turf areas of at least 0.25 acres;
- Of those, identify which ones are associated with SW Facilities or parcels with a Premise Classification Type of Open (OPN);
- Of those, select areas that were within 100 feet of a stream; and
- Staff used GIS tools to inspect these selected turf areas in a manner similar to the review for the upland sites; those sites with evaluation values of "Yes" and "Possible" (that were not already included in the Upland Reforestation site selection) qualified as candidate field sites (17).

Prince William County staff reviewed these initial 17 sites selected and revised the list based on personal knowledge of sites and constraints. After this review, 13 riparian sites were chosen for field investigations.

Stream Reaches for Restoration

Versar staff identified candidate stream reaches for field assessment through a series of GIS analysis steps and visual inspections of digital data. To assign values to stream segments and to derive a target subset from the overall 21.9 miles of stream in the project's stream data set, staff followed the step-wise process summarized below:

- Removed sections within designated areas to be excluded (i.e., Andrew Leitch Park and three Hylton properties, as indicated by Prince William County staff);
- Selected all remaining segments in Resource Protection Areas (RPAs, total of 8.7 miles);
- Delineated catchment areas (19) for the majority of the remaining segments;
- Derived impact indicators present within each catchment – indicators included catchment area, impervious area, riparian impervious area, and riparian turf area;
- Assigned impact scores to the catchments based on high values for indicators; and
- Reviewed stream access information based on the Premise Classification Type of adjacent parcels, and information about the locations of schools, parks, and County Public Works jurisdictions.

In addition to streams within the RPAs, the initial stream selection identified three tiers of impact to streams (based on data summarized by catchment), as summarized in Table 4-1. County staff reviewed the 15.2 stream miles in the “RPA plus Tier II” group and further refined the selection to arrive at a final selection of 14.83 stream miles for field assessments.

Table 4-1. Breakdown of stream miles by RPA and catchment impact score

	Stream Length within RPA	Other streams (non-RPA), Ranked by Catchment Impacts		
		Tier I	Tier II	Tier III
Stream length for field assessment (miles)	8.7	5.0	1.5	1.4
Cumulative total length for field assessment (miles)	13.7		15.2	16.6

4.2 DESKTOP ANALYSIS SUMMARY – RESULTS

As described above, the project team selected field site locations to evaluate conditions for five categories of projects to improve water quality conditions in the Neabsco Creek watershed:

conversion or upgrade of existing SW Facilities, establishment of new BMPs, outfall stabilization, reforestation in upland areas and riparian buffers, and stream restoration. County staff contributed to this process by providing comments and guidance based on knowledge of local issues and reviewing the initial selections to refine the proposed set of candidate sites. After County review and approval, Versar staff prepared to evaluate 147 sites and almost 15 miles of stream within the five subwatersheds of the study area. The selection process was employed to assess watershed condition and evaluate sites as candidates for restoration in the most critical areas, as defined by the desktop analysis. The results are provided in Table 4-2.

Table 4-2. Sites to investigate for potential projects

Category	Number of Field Sites
Converting Existing Stormwater Facilities	30
Establish new BMPs (parcel-level evaluation)	18
Evaluate outfall stability	45
Reforestation of upland areas (parcel-level)	41
Reforestation of riparian areas	13
Stream miles to assess for issues and possible restoration	14.83 miles

CHAPTER 5: FIELD ASSESSMENT

5.1 DEVELOPMENT AND IMPLEMENTATION OF FIELD PROTOCOLS

Field protocols for the Neabsco Creek watershed study were developed for each of the five categories of sites and focused on (1) assessing current conditions and (2) identifying and describing restoration opportunities. Specific protocols in many instances drew from existing methodologies, but with customization to ensure that data collected in the field met the needs for this project. Details are provided in the following sections.

- **Conversion of existing stormwater facilities** - methods were derived from the Center for Watershed Protection's Retrofit Reconnaissance Investigation (RRI) protocol, from the Urban Subwatershed Restoration Manual 3 (CWP 2007);
- **Establishment of new stormwater BMPs for impervious surfaces not currently treated** - also from the RRI protocol (CWP 2007);
- **Outfall stabilization** - methods were primarily derived from the Stream Corridor Assessment (SCA) protocols (Yetman 2001);
- **Reforestation** - methods were drawn from Pervious Area Assessments (PAA), Unified Subwatershed and Site Reconnaissance, Manual 11 (CWP 2005) and Urban Reforestation Site Assessment (URSA), Urban Watershed Forestry Manual, Part 3: Urban Tree Planting Guide (CWP 2006); and
- **Stream restoration** - methods were a combination of the Rapid Stream Assessment Technique (RSAT, originally from Galli 1996, as modified by Prince William County) and the SCA protocols (Yetman 2001) for characterizing erosion and other stream features.

5.1.1 Stormwater Facilities Conversion Field Investigations

Field investigators developed concepts for SW conversions by conducting site visits to target dry pond facilities in the watershed. Site visits were made during June and September 2016. Data pertaining to conversion type, feasibility, and potential impact were recorded for each facility. Details about the concept (e.g., number of cells, infrastructure upgrade needs) were recorded in the notes portion of the electronic field sheet.

Staff completed the site visits by performing the following steps.

1. Characterizing the pond

   This step includes taking an inventory of stormwater infrastructure, assessing current condition of the pond, and evaluating the contributing drainage.

   a. Locate the stormwater infrastructure of the pond. This step involves entering the pond footprint and locating the riser and any stormwater delivery outfalls to the pond.
   b. Review characteristics of the pond to verify that it is a dry pond, which is mainly accomplished by examining the outlet structure.
   c. Inspect the riser for maintenance concerns, such as a blocked low flow orifice or damage.
   d. Note condition of vegetation in the footprint, whether mature trees, wetland plants, grass, or mowed turf.
   e. Check for baseflow streams traversing the pond.
   f. Note the land use of contributing drainage and check for potential pollution hotspots. The land use will help narrow the options for conversion.

2. Determining feasibility of concept

   This step involves determining whether a conversion should proceed based on existing conditions in the dry pond. Conversions should be feasible without expensive, time-consuming efforts and be physically possible based on hydrology.

   a. Determine whether pond can be accessed easily via a maintenance easement, other public route, or would require crossing private property.
   b. Note whether access route or location is excessively sloping, which would make the use of heavy equipment prohibitive.
   c. Evaluate whether the presence of plants in the dry pond have caused "self-conversion" of the pond to a bioretention facility. If plants are invasive, consider removal.
   d. Characterize the hydrological "drop" of stormwater entry points in relation to the exit. If the drop is less than two feet, then a conversion may not be feasible.
   e. Note other potential constraints, such as utilities.

3. Preparing conversion recommendation

   Decisions about the custom design of the new facility, such as treatment type, arrangement of treatment elements, and flow pathways are made and finalized in this step.

   a. Determine best treatment approach within existing footprint (e.g., no conversion, conversion to extended detention dry pond, bioretention, filtration), considering upland land use, ecological benefit, potential constraints, and stormwater credit benefit.
   b. Conceptualize stormwater flow path by considering the presence of baseflow, leader channel, the need for a settling forebay, installation of individual cells within a footprint, orientation of cells in series or in parallel, and method of stormwater delivery to the components of the new facility.
   c. Include provisions for emergency overflows and baseflow in the concept.
   d. Determine whether volume control can be improved by raising the riser, berm, and reducing the size of the low flow outlet without jeopardizing neighboring properties or the integrity of utilities or stormwater infrastructure.
   e. Note any maintenance needs or structural improvements that would be needed to complete the conversion. Also, note any new stormwater structures, such as weirs, checkdams, or splitters that would be needed to distribute stormwater within the facility.

5.1.2 New BMP Assessments Field Investigations

New BMPs were recommended in areas where built up areas currently did not have stormwater management of any type or had drainage features (such as grassy swales) that could be augmented. Field teams visited sites that were identified during the desktop analysis as being promising locations for new stormwater treatment. Site visits were made during June, September, and October 2016. Investigators identified areas of impervious surfaces and adjacent areas that could accommodate a treatment facility. At some sites, new BMP opportunities were identified that were already within the drainage of a dry pond; the presence of a dry pond did not disqualify an opportunity since pre-treatment by the new BMP would augment the functioning of the existing facility.

Data pertaining to the characterization of a target impervious area, proposed new BMP type, and feasibility were recorded in the field. Staff also drew polygons of the proposed BMP footprint and approximate drainage area that would contribute runoff to the new BMP.

Staff completed the site visits by performing the following steps.

1. Identify impervious surfaces that require stormwater control.

   For this step, field investigators identified concrete or asphalt surfaces, preferentially large in size, which could benefit from a new upland BMP facility.

   a. Locate any stormwater infrastructure such as curb inlets or yard drains that may currently service the impervious area.
   b. Locate and identify any upland treatment that had been overlooked during the desktop analysis step. If current water quality treatment exists and appears adequate, then the site would not be considered further for treatment.
   c. Note the land use of contributing drainage and check for potential pollution hotspots. The land use type will help narrow the options for new BMP type.

2. Identify adjacent or down-gradient space that may accommodate the new BMP and determine adequacy.

   For this step, investigators identify areas where the new BMP could be installed and be ideally situated to receive runoff from the impervious area targeted for treatment.

   a. Note the size of adjacent space and the type of vegetation that occupies it. Preference should be placed on areas of underutilized, impervious cover (such as old, broken up parking areas or abandoned pads or walkways), mowed turf, or overgrown spaces where invasive plants have established.
   b. Note the morphology of the candidate space. The existing shape may accommodate a new BMP without a large construction effort, such as installation of a bioswale or linear bioretention in an existing grassy swale.
   c. Examine the outfall of the local stormwater collection system and determine whether a new facility could be installed offline and receive runoff via a splitter (provided there is space available).
   d. Note the size of the available space and tailor the proposed BMP to the space available. Avoid proposing the removal of mature trees to increase the space available for a new BMP.
   e. Check for the presence of utilities or other buried infrastructure that may impact the size and feasibility of the new BMP.
   f. If a large impervious area, such as a parking lot, is in need of stormwater control, and there is insufficient adjacent space for an at-grade facility, consider underground treatment.

3. Preparing new BMP recommendation

   Decisions about the custom-design details of the new facility, such as treatment type, position of the facility vis-à-vis the receiving network or channel, are made and finalized in this step.

   a. Check for sufficient drop between the upland treatable area and the outlet of the proposed facility. The drop should be no less than two feet. If underground facilities are contemplated, the elevation need may be larger.
   b. Review the stormwater delivery to and discharge from the new facility. Consider what modifications to the curb or existing inlets may be needed to deliver stormwater to the facility for treatment. Determine the flow path of the underdrain from the new facility, if installed, and how it will reconnect to the storm drain network or whether it will need a standalone outfall.
   c. Note any educational opportunities for the new facilities, if in a public area.
   d. Determine whether a settling forebay will be needed, depending on the size of the contributing impervious area.

5.1.3 Outfall Stabilization Field Investigations

Field crews from Versar conducted field investigations for outfall stabilization opportunities within the Neabsco Creek watershed. Field investigations were conducted from June through July 2016. Field crews located the potential outfall stabilization sites that had been selected in the desktop analysis and assessed each site for any damage to the existing outfall channel and potential for stabilization. Using predetermined criteria, the outfall and surrounding area were assessed for severity of impact and opportunities for stabilization. In addition, new potential outfall stabilization points noticed during stream walks were marked using the TerraGo software. If warranted, outfall assessment data were collected to characterize these new outfall points.

Aside from noting obvious damage or need for repair, field crews collected photographs and assessed the outfall stabilization locations for a variety of criteria and detailed information about the location using the TerraGo software including:

- Accessibility
- Weather (recent and at the time of investigation)
- Outfall dimensions (height and width)
- Outfall type
- Outfall shape
- Outfall material
- Need for repair
- Need for maintenance
- Baseflow presence

- Trash presence
- Evidence of erosion below outfall
- Detailed location of erosion
- Length of erosion (either in outfall channel or stream channel)
- Severity of erosion/degradation
- Distance from outfall to stream
- Height of pipe above stream bed
- Potential for outfall stabilization
- Potential for stream restoration

If after assessing a site for outfall stabilization potential it was determined that the site had potential for stabilization or restoration, the field team characterized the site using TerraGo to provide information for determining the most feasible outfall stabilization opportunities based on a number of criteria. In assessing the potential for restoration, the field crew determined the proper type of project to address the problems cause by the damaged outfall channel and assessed the feasibility and effectiveness of the potential project.

Based upon the type of damage seen at the site, a potential stabilization project type (rip rap, drop structure, regenerative stormwater conveyance, or other) was selected. The potential project opportunity was characterized by highlighting the type of project, specifying potential project length, determining the length of affected area by the project, and pointing out constraints to the project. The project selection process was highly affected by anticipated project implementation constraints.

Project implementation constraints could be a matter of access or other physical constraints. Access could be restricted by private ownership, tree barriers, physical structures, or topography of the land. If site access was limited to foot traffic or small vehicles, it greatly reduced the potential for larger and more intensive projects. Other constraints such as utilities, roadways, and impacts to wetlands influenced the potential project type and the ranking of the potential project. The site was given an overall potential stabilization ranking of high, medium, or low.

Those sites with a clear potential project type, limited project implementation constraints, and a high potential for successful restoration of the area were given a potential stabilization ranking of high. Sites ranked in the medium category often had slightly less potential for successful restoration or had some sort of constraint on implementation (whether it be access or any other constraint). Those ranked as low showed potential for stabilization, but lacked clear access to the site, provided minimal potential restoration success, or were less feasible to implement for some specified reason. These overall preliminary assessments of restoration potential (based on field observation) were later used along with other data to yield a final ranking score for each proposed project.

5.1.4 Reforestation Sites Field Investigations

Versar conducted investigations for reforestation opportunities on both upland and riparian sites within the Neabsco Creek watershed. Field investigations took place from June 2016 through

July 2016. The following subsections describe the methods used to evaluate the reforestation sites. Upon visiting the sites identified in the office, field staff conducted assessments to determine if sites possessed sufficient space and met criteria for restoration. In some cases, additional areas of sites were identified for reforestation opportunities, based on what was observed in the field.

The entire property of each reforestation opportunity site was walked by the field team to collect necessary data and take photographs. To thoroughly evaluate each site, detailed information was collected using TerraGo software on electronic tablets, including these criteria:

- Site accessibility
- Site hydrology
- Sunlight exposure
- Wind exposure
- Re-reflected heat load
- Slopes
- Primary vegetative cover
- Invasive species and noxious weeds
- Off-site forest connectivity
- Browsing by deer
- Beaver activity
- Evidence of previous tree planting
- Soil type and texture, compaction, erosion, contamination, debris and rubble, and recent disturbance
- Stormwater runoff scenario and types
- Constraints, such as overhead wires; pavement; structures; signs; lighting; underground utilities; trash and debris dumping; deer and beaver impacts; mowing scenario
- Wetlands present
- Insect infestations
- Site ownership
- Heavy pedestrian traffic
- Notes on limiting factors
- Access for planting materials
- Temporary storage for soils and mulch
- Access for heavy equipment
- Parking area and facilities for volunteers

- Water sources available
- Site preparation required
- Educational value; and
- Overall reforestation potential

Access to a site is important when considering its restoration potential. The field team determined in the field whether the reforestation opportunities sites could be accessed by foot, vehicle, and/or heavy equipment. A site that can only be accessed by foot may have less potential for restoration if it requires greater disturbance or costs to restore (e.g., constructing an access road). Ownership is also important because different approaches may be used to coordinate with private versus public institutions. Current management describes the current use of the land including the following: school, park, right of way, or other. The presence and type of connected pervious areas are also relevant to the restoration potential of tree planting site. For example, if a site connects existing forested areas, reforesting the site would help to continue the forested corridor for wildlife habitat or stream buffer purposes. If a site is connected to an existing wetland area, it could be reforested to protect the wetland or re-vegetated to extend the wetland area. Some of the criteria assessed are briefly described below.

The current vegetative cover was assessed including the proportion of the site covered by maintained turf, herbaceous, shrubs, trees, or bare soil. Turf management status was also recorded including turf height, mowing frequency, and condition (e.g., thick, sparse, continuous, etc.). The presence of invasive species was noted including percent of site with invasive species and type.

Impacts were assessed to indicate the amount of site preparation required to restore the pervious area. Possible impacts noted include soil compaction, erosion, trash and dumping, and poor vegetative health. Significant impacts from any of these factors will influence site preparation required, species of trees and other plants that can survive and success of an implemented project.

Similar to impacts, information regarding factors that may impede reforestation efforts was collected. The type of sun exposure was recorded as full sun, partial sun, or shade. The field team noted whether there was a nearby water source for supplemental water if necessary.

Other constraints related to reforestation that were noted include overhead wires, underground utilities, pavement, and buildings. Private ownership was noted as a potential constraint.

Based on the field observations, the overall recommendation was rated as Low, Medium, or High potential for reforestation of the sites. This preliminary assessment of restoration potential was incorporated as one of many factors, during subsequent ranking and prioritization of opportunities. A notation was also available to request further review of the site by the County, if necessary.

5.1.5 Stream Restoration Assessment Field Investigations

Field crews from Versar conducted field investigations for stream restoration opportunities within the Neabsco Creek watershed. Field investigations were conducted from June through September 2016. Field crews located the potential stream restoration sites that had been selected during desktop analysis, and assessed each site for its potential as a stream restoration opportunity. Using predetermined criteria and the Rapid Stream Assessment Technique (RSAT), streams were assessed moving upstream (right and left bank determined facing downstream). When a significant change in biological, physical, or geomorphic condition of the stream was encountered, a new polygon was drawn using the TerraGo software, establishing the boundaries of a new RSAT "reach." As areas with restoration potential were encountered, a polygon with the attached data was placed using the TerraGo software. In addition to assessing streams for restoration potential, points were placed where outfalls were encountered. These outfall points were then visited as potential outfall stabilization candidates.

Aside from assessing streams using the RSAT, which focuses on channel stability, bank stability, riparian habitat, water quality, and aquatic habitat (major components of restoration potential), field crews also took photographs and assessed the stream for a variety of other criteria. Field crews also recorded observations on overall stream health and other detailed information about the location using TerraGo software and include:

General

- Stream type and presence of flow
- Water and sediment characteristics
- Biological observations (presence of fish, aquatic plants, algae, benthic macroinvertebrates)

Rapid Stream Assessment Technique (RSAT)

- Channel stability (channel type, incision, deposition/aggradation)
- Bank stability (slumping, height, angle, material, vegetation)
- Riparian habitat (buffer width, type, shading)
- Water quality (benthic community, litter, substrate, odor)
- Aquatic habitat (channel modification, riffle substrate/embeddedness, pools, cover)

Channel Alteration

- Presence and type (concrete/riprap etc.)
- Length
- Bed width
- Severity

Extreme Erosion Site (point)

- Erosion type (headcut, downcut, widening)
- Length (each bank)
- Height (each bank)
- Bank Material
- Headcut height, angle, and length
- Threat to infrastructure
- Overall severity
- Restoration potential

Extreme Inadequate Buffer Site (point)

- Inadequate buffer bank (left/right)
- Length
- Existing buffer type and width
- Overall severity
- Restoration potential

Pipe Outfall Site (point)

- Outfall number (when available)
- Type of outfall
- Material
- Dimensions and shape
- Location in relation to stream (which bank and length of outfall channel)
- Discharge type (quality and source)
- Evidence of dry weather flow (Illicit discharge potential)
- Trash rating
- Erosion presence/severity

Unusual Condition (point)

- Near-stream construction
- Illicit discharge
- Illegal dumping
- Exposed/threatened utility
- Unusual water characteristic
- Fish blockage

Each stream reach assessed was ranked high, medium, or low, depending on instream restoration potential, based on the field team's judgment of the degree of degradation that could be addressed and the feasibility and potential benefit that could be realized through restoration. Length of restoration was also a factor in determining the desirability of a restoration project.

Placing a polygon in TerraGo allowed the exact linear extent (in linear feet) of each potential project to be measured in GIS.

The overall potential of a stream restoration project is also contingent on anticipated implementation constraints. Project implementation constraints could be physical barriers, or a matter of property ownership or accessibility. While ease of access (physically) may impact the feasibility or scale of a project, property ownership can dictate whether the project occurs at all. Other constraints taken into account when assessing the potential of a stream restoration project include impact to existing trees, presence of utilities or roadways, space, safety, and permitting factors. Permitting factors greatly influence each reach's restoration potential, and may include impacts to wetlands, floodplain filling, and impact to specimen trees.

The reaches of stream which were longest, most in need of restoration, and had limited project implementation constraints were given a potential restoration ranking of "high". Sites were scored in the "medium" category when there were more constraints, access was more difficult, or the stream was not as degraded. Those ranked as "low" would still show potential for restoration, but conflicts with utilities or property ownership make implementation of these projects less feasible. These preliminary assessments of restoration potential (based on field observation), as well as other data, were later used to calculate a final ranking score for each proposed project.

5.2 CALIBRATION AND QA/QC

5.2.1 Electronic Data Collection

Field assessment data were collected with mobile tablet devices through the TerraGo Edge application. This software allowed for custom forms to be built for each project type. Digital photographs were taken at each assessment site and included in the field data forms. Basemaps were pre-loaded onto the mobile devices with the relevant GIS data layers, enabling teams to see their exact location and view nearby features (e.g., stormwater network, aerial imagery) while in the field. The electronic collection of data allowed for data to be entered directly into a TerraGo server in the field and removed the step of having to manually enter data from paper datasheets in the office.

5.2.2 Calibration of Field Teams

Three field assessment calibration days were held to ensure that field personnel were familiar with the methods being used to collect field data and to create a consistent perspective between County and consultant personnel for recording field observations. The first calibration day, held on June 9, 2016, covered coordination with Public Schools and New BMP and Tree Planting field assessment protocols. The second calibration day, held on June 24, 2016 covered SW facility conversion, Tree Planting, and Outfall Stabilization field assessment protocols. The final calibration day, held on July 15, 2016, covered the Stream Assessment field protocol. Each of the calibration days consisted of a review, discussion, and revisions to field assessment protocols during visits to representative sites of the various assessment types.

5.2.3 Landowner Permissions and Coordination with Prince William County Public Schools

Because stream assessments involve field staff walking along stream corridors that run across both public and private lands, before beginning fieldwork the project team worked with Prince William County staff to identify landowners along streams to be assessed and to obtain permission to access private lands. Once the complete list of stream assessment sites was created, a geodatabase was provided to County staff listing all properties containing stream assessment sites. County staff cross-checked the properties with ownership information derived from county tax assessment data. For private properties, the parcel address was used to identify the property owner, who was then contacted via a letter from the County requesting permission for field crews to access the property. County staff sent out letters and field staff were instructed to wait an initial period of two weeks after letters were sent before beginning field work on private properties, to allow time for responses to be received by the County. In a few cases, County staff made direct contact with managers of larger properties (e.g., Hylton properties, water treatment plant) to coordinate permission and access to those sites. For public lands, County staff confirmed that sites were accessible and no letters were sent.

All letters sent and responses received, along with the landowner review process performed by the County, were tracked in a geodatabase. A map layer was developed by the project team to use in recording permission responses and was kept up-to-date as responses were received. Data fields were added to the data for each parcel to capture permission status (Granted, Notify Prior to Accessing, or Denied). The map was color-coded to reflect parcel permission status. All information was readily available to field crews through the TerraGo application.

Site visits on Public School property were coordinated with Andrew Uglow, the Environmental Project Manager for Prince William County Public Schools. When available, Mr. Uglow would join field crews for site visits on school property. When he was unavailable, the schools were contacted and informed that Versar field crews would be visiting, and field crews presented identification and signed in at each school.

5.2.4 Field Data Collection and Quality Assurance/Quality Control

Versar field teams collected data during the period of June through October 2016. Field teams communicated with County staff as needed to answer questions that arose about BMP data, site access, or other issues. Data were collected using field tablets using portable wireless hotspots, or saving locally and uploading to the server each evening.

At the completion of the field and desktop assessments, all of the data was copied from the TerraGo Server in the form of a file geodatabase for each project type. Versar went through these databases and checked for logical data, use of correct site IDs, matching assessment and recommendation data, and overall completeness. Photos were attached and the databases were merged into a StreamDatabase and a NonStreamDatabase.

CHAPTER 6: STREAM CONDITION ASSESSMENT FINDINGS

6.1 STREAM MILES SURVEYED

RSAT surveys were successfully conducted along 79 reaches in all five subwatersheds of the Neabsco Creek watershed study area. Stream miles assessed ranged from 1.6 miles in subwatershed 825, up to 4.6 miles in subwatershed 820 (Table 6-1), covering 43% of the total stream length in the watershed study area.

Table 6-1. Miles of stream assessed by subwatershed

Subwatershed	Miles Surveyed	Percent of Survey
805	1.9	13.6%
810	1.7	12.7%
815	3.8	27.7%
820	4.6	34.1%
825	1.6	11.9%
Total	13.6	100.0%

6.2 RSAT SURVEY GENERAL FINDINGS

Overall Scores

Overall total RSAT scores for the stream reaches assessed ranged from a low of 24 (Fair) to a high of 49 (Good) (Table 6-2) out of a maximum possible score of 57. For total RSAT scores across all categories, the majority of stream miles were rated as Good, with 71.3% of stream miles surveyed receiving this rating. For individual categories (Table 6-3), sites consistently ranked highest for riparian habitat, with 90% of reaches achieving an Excellent or Good rating. The other scoring categories showed more concern, with at least one third of reaches rated Fair or Poor in these categories (Table 6-3).

Table 6-2. Neabsco Creek Watershed Overall RSAT ratings

Rating	Scoring Range	Stream Miles	Percent of Stream Miles
Excellent	51 - 57	0.0	0.0%
Good	34 - 50	9.7	71.3%
Fair	17 - 33	3.9	28.7%
Poor	0 - 16	0.0	0.0%
Total		13.2	100%

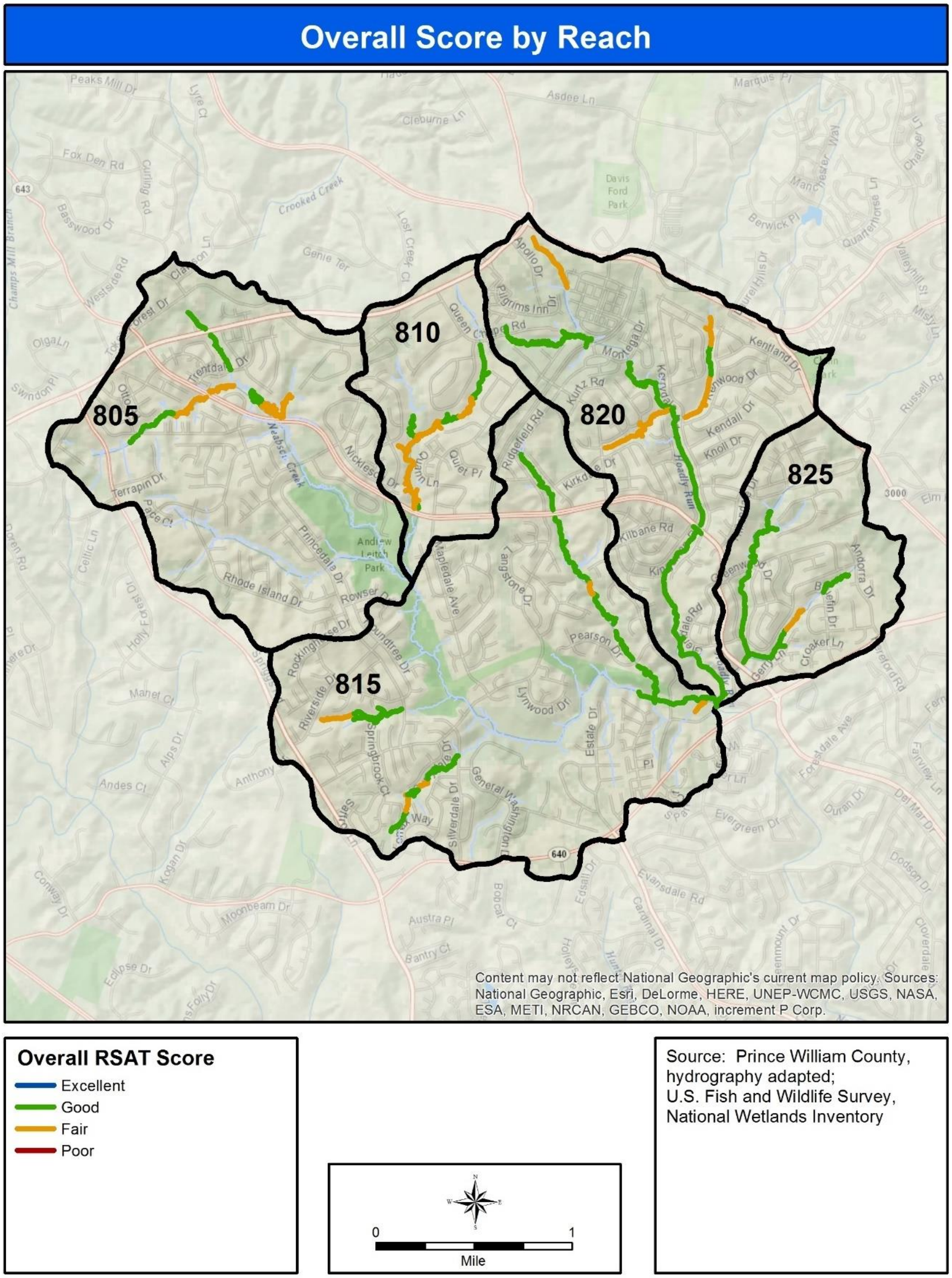

Figure 6–1. Neabsco Creek Watershed overall RSAT scores

Table 6-3. Neabsco Creek Watershed RSAT ratings by category

Category	Ratings by Stream Miles							
	Excellent		Good		Fair		Poor	
	Miles	%	Miles	%	Miles	%	Miles	%
Channel Stability	0.5	4%	8.3	61%	4.0	30%	0.8	6%
Bank Stability	0.0	0%	7.4	55%	5.6	41%	0.5	4%
Riparian Habitat	2.0	15%	10.2	75%	1.2	9%	0.2	1%
Water Quality	0.0	0%	8.3	61%	4.6	34%	0.6	5%
Aquatic Habitat	0.4	3%	7.9	58%	4.8	36%	0.5	4%

6.3 RSAT FINDINGS FOR INDIVIDUAL EVALUATION CATEGORIES

Channel Stability

RSAT scores for channel stability generally rated well across the study area, with 65% of reaches surveyed in the top two rankings (Table 6-4). Reaches with rankings in the lower tier (Fair to Poor) were found in all subwatersheds (Figure 6–2). In the absence of pipe infrastructure, even a severely degraded channel could receive a high score on the Exposed Pipe RSAT evaluation category. To account for this bias, reaches which did not contain pipe infrastructure were scored differently: the Exposed Pipe category was omitted from scoring and the metrics were scaled accordingly.

Table 6-4. Neabsco Creek Watershed channel stability ratings

Subwatershed	Stream Miles			
	Excellent	Good	Fair	Poor
805	0.0	1.4	0.2	0.3
810	0.0	0.9	0.9	0.0
815	0.3	2.3	1.1	0.0
820	0.2	2.6	1.3	0.5
825	0.0	1.0	0.6	0.0
Percentage of All Stream Miles	4%	61%	30%	6%

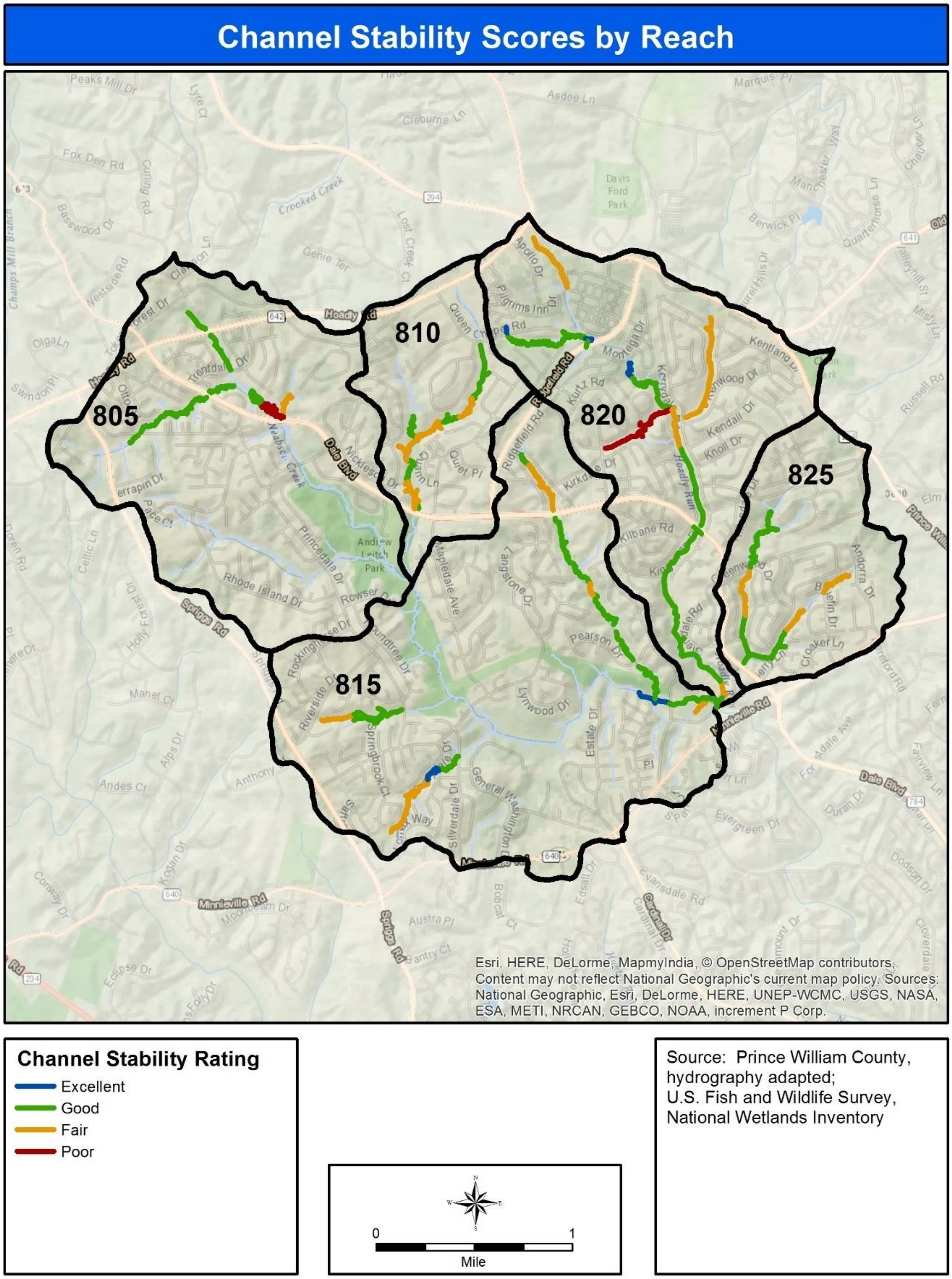

Figure 6–2. Neabsco Creek Watershed channel stability scores

Bank Stability

RSAT scores for bank stability were ranked Good for 55% of the reaches surveyed (Table 6-5) while 41% of stream miles fell in the Fair category. Rankings of Fair were found in all subwatersheds, while a ranking of Poor was found only in subwatershed 820 (Figure 6-3). Bank stability scores excluded the Bank Height Above Channel metric, to better represent bank conditions. Individual scores for the Bank Height Above Channel metric skewed somewhat lower than the scores for the entire Bank Stability category, with 11% of surveyed reaches being ranked as Poor, as shown in Table 6-6 and Figure 6–4. In addition, to characterize bank erosion, isolated sections of high stream banks that were not characteristic of the larger reach were captured in data collected at extreme erosion points (see Section 6.4).

Table 6-5. Neabsco Creek Watershed bank stability ratings

Subwatershed	Stream Miles			
	Excellent	**Good**	**Fair**	**Poor**
805	0.0	0.6	1.3	0.0
810	0.0	0.9	0.8	0.0
815	0.0	1.4	2.4	0.0
820	0.0	3.3	0.8	0.5
825	0.0	1.2	0.4	0.0
Percentage of All Stream Miles	0%	55%	41%	4%

Table 6-6. Neabsco Creek Watershed bank height above channel ratings

Subwatershed	Stream Miles			
	Excellent	**Good**	**Fair**	**Poor**
805	0.0	0.7	1.1	0.0
810	0.0	1.3	0.4	0.1
815	0.1	1.2	2.0	0.4
820	0.1	3.5	0.4	0.6
825	0.1	0.8	0.4	0.4
Percentage of All Stream Miles	3%	55%	31%	11%

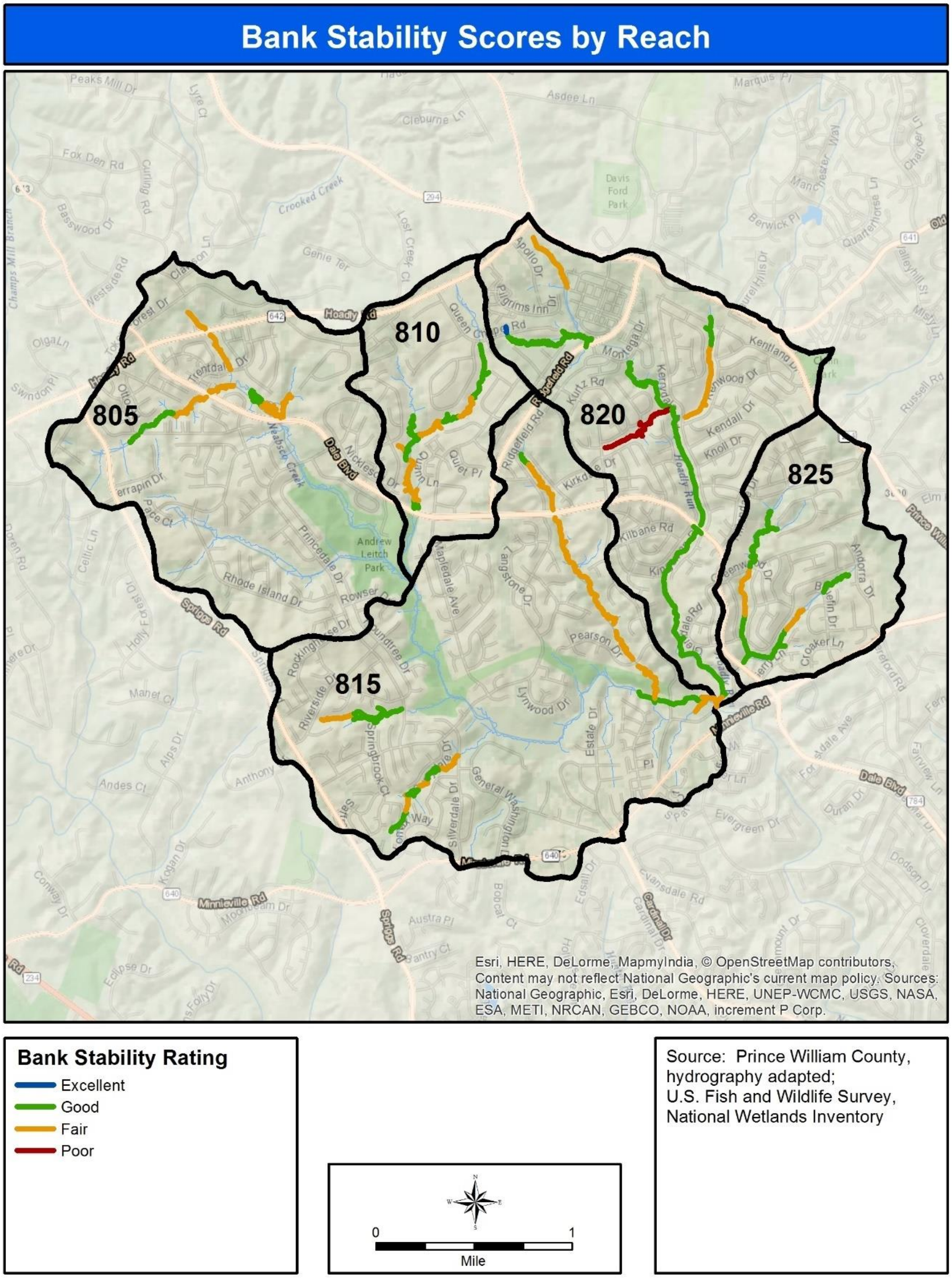

Figure 6–3. Neabsco Creek Watershed bank stability scores

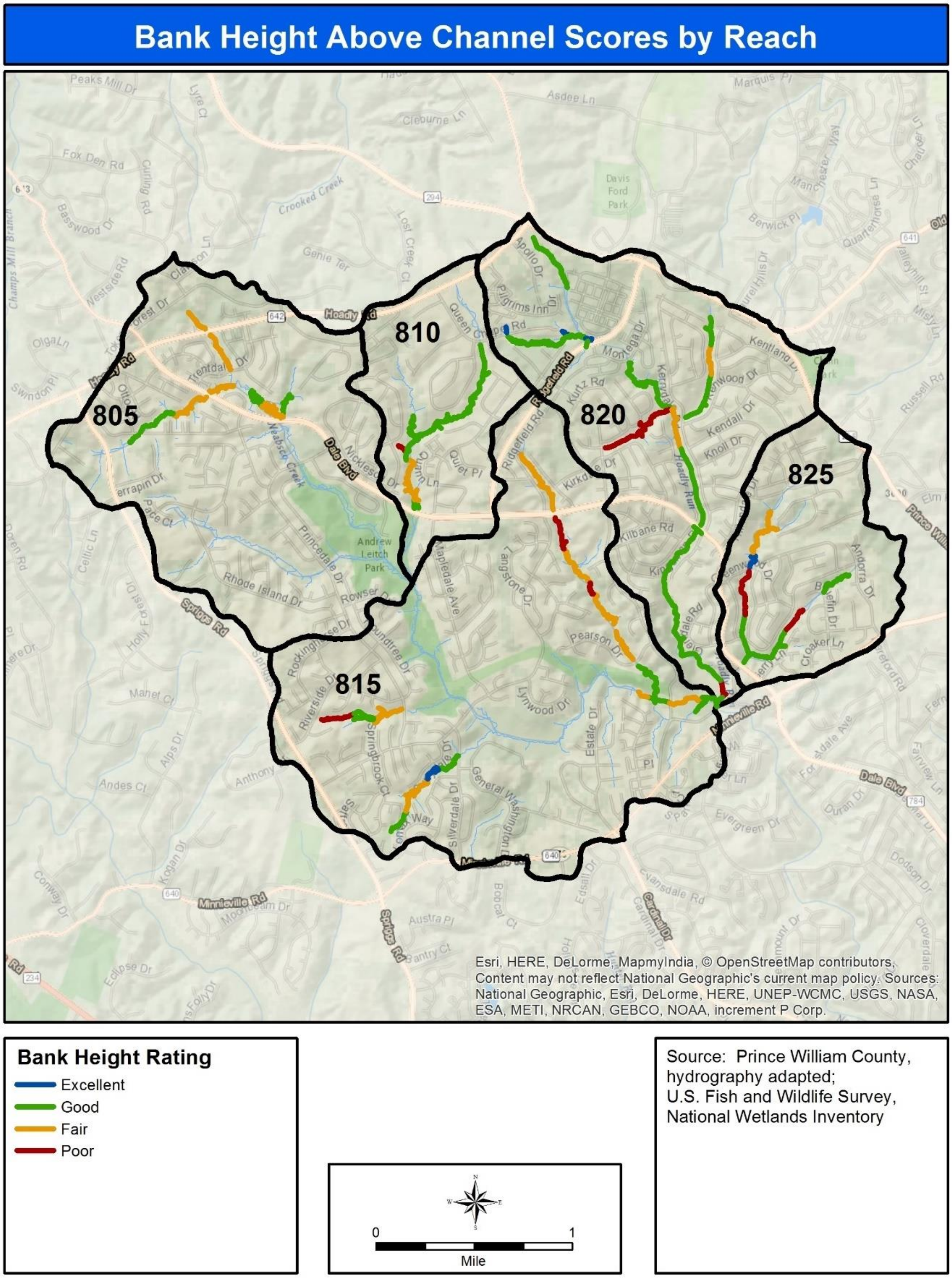

Figure 6–4. Neabsco Creek Watershed bank height above channel scores

Riparian Habitat

RSAT scores for riparian habitat were ranked Good or Excellent along 90% of the reaches surveyed (Table 6-7). The reaches with scores in the lowest tier were found in subwatershed 810 (Figure 6–5).

Table 6-7. Neabsco Creek Watershed riparian habitat ratings

Subwatershed	Stream Miles			
	Excellent	Good	Fair	Poor
805	0.2	1.4	0.3	0.0
810	0.0	1.1	0.4	0.2
815	1.4	2.0	0.4	0.0
820	0.1	4.5	0.0	0.0
825	0.3	1.2	0.1	0.0
Percentage of All Stream Miles	15%	75%	9%	1%

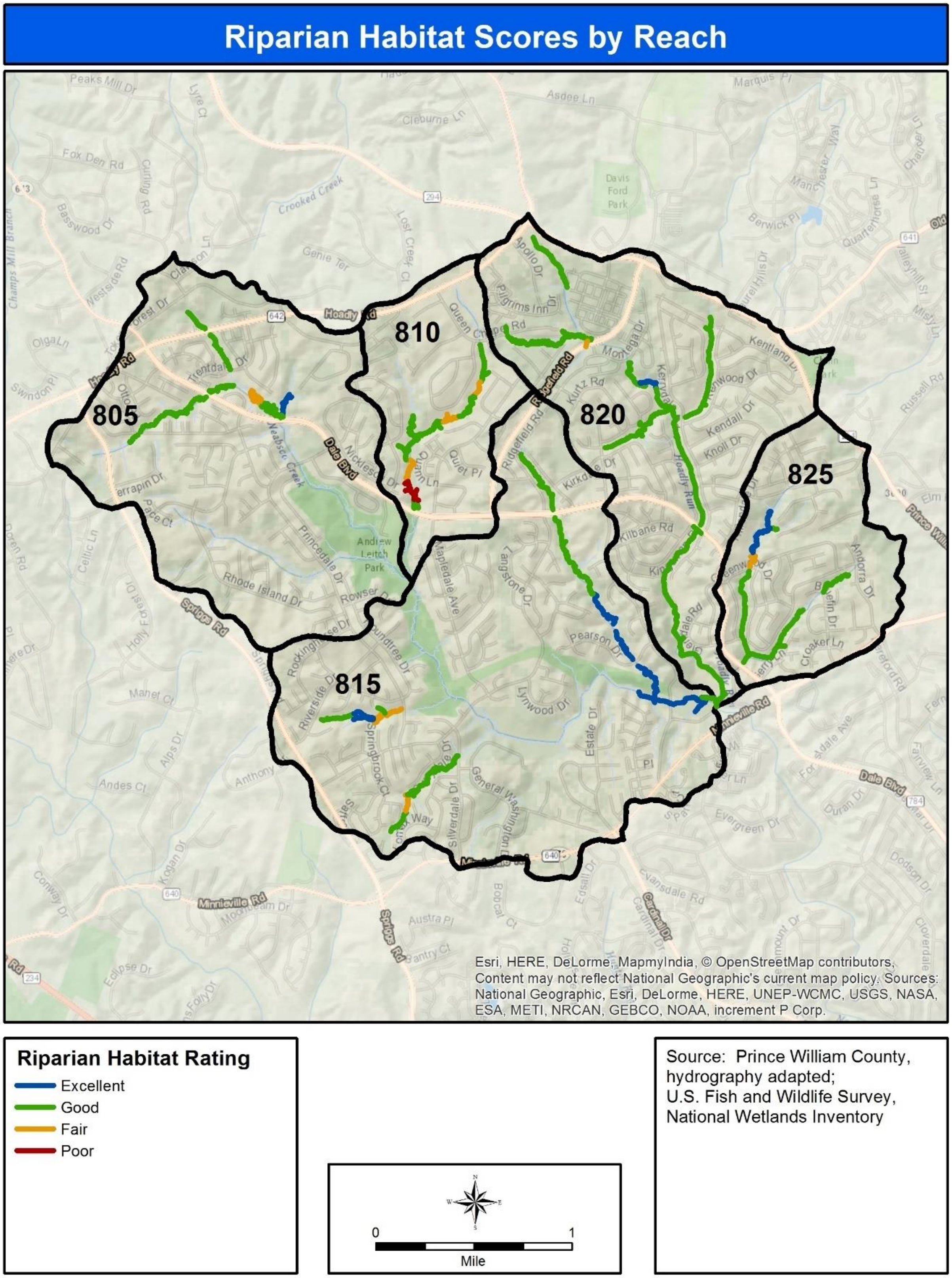

Figure 6–5. Neabsco Creek Watershed riparian habitat scores

Water Quality

RSAT scores for water quality generally ranked Good with 61% of the reaches surveyed falling in this category (Table 6-8). Reaches with lower tier scores of Fair or Poor were found in all subwatersheds in the study area (Figure 6–6).

Table 6-8. Neabsco Creek Watershed water quality ratings

Subwatershed	Stream Miles			
	Excellent	Good	Fair	Poor
805	0.0	0.0	1.9	0.0
810	0.0	0.4	1.3	0.0
815	0.0	3.4	0.3	0.0
820	0.0	3.2	0.8	0.6
825	0.0	1.3	0.3	0.0
Percentage of All Stream Miles	0%	61%	34%	5%

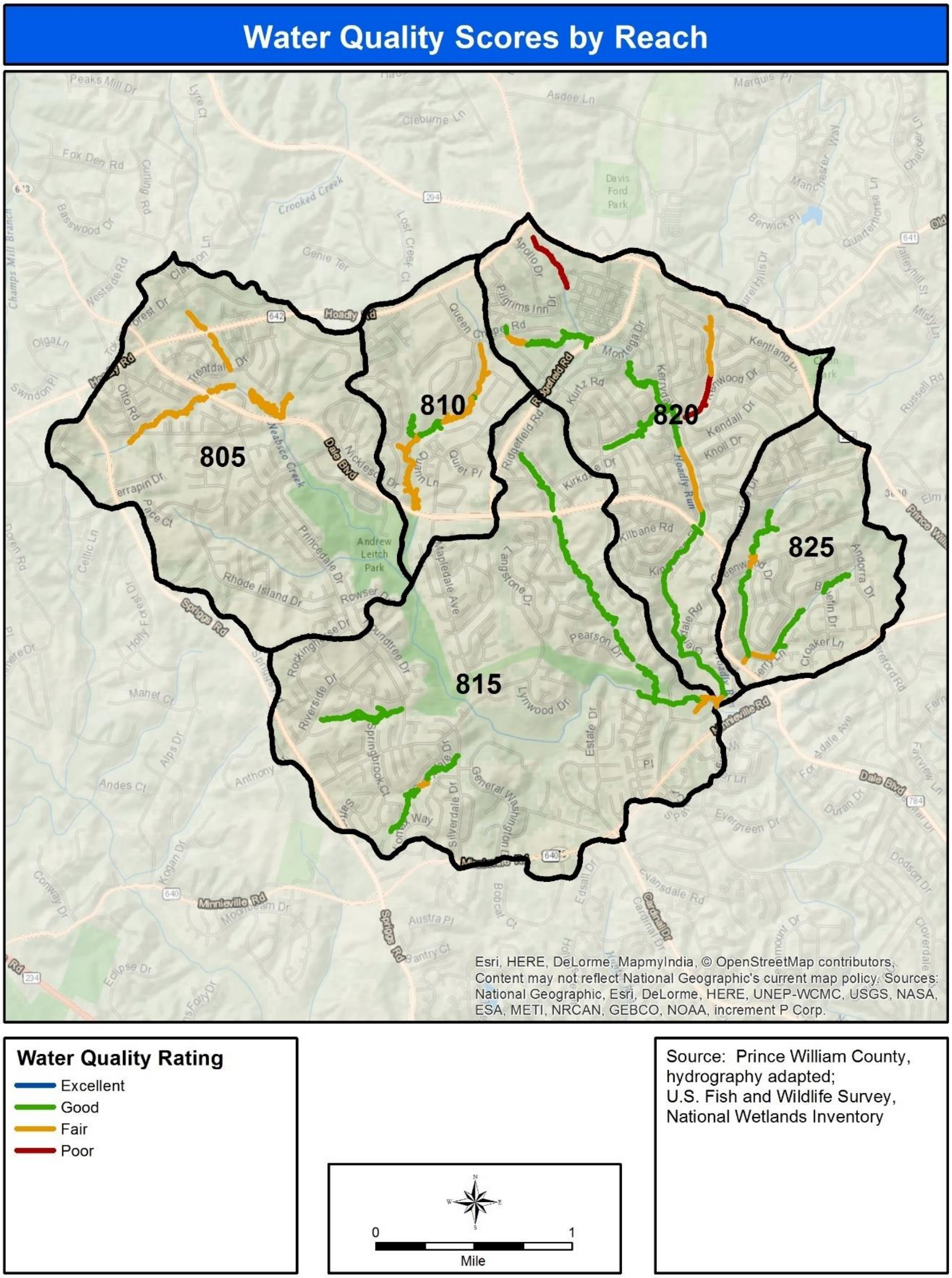

Figure 6–6. Neabsco Creek Watershed Study - water quality scores

Aquatic Habitat

RSAT scores for aquatic habitat were generally ranked Good with 58% of the reaches surveyed receiving this score (Table 6-9). Reaches with lower tier scores of Fair or Poor were found in all subwatersheds in the study area (Figure 6–7).

Table 6-9. Neabsco Creek Watershed aquatic habitat ratings

Subwatershed	Stream Miles			
	Excellent	Good	Fair	Poor
805	0.0	0.6	1.2	0.0
810	0.0	0.4	1.4	0.0
815	0.4	2.9	0.4	0.0
820	0.0	2.8	1.5	0.3
825	0.0	1.2	0.3	0.1
Percentage of All Stream Miles	3%	58%	36%	4%

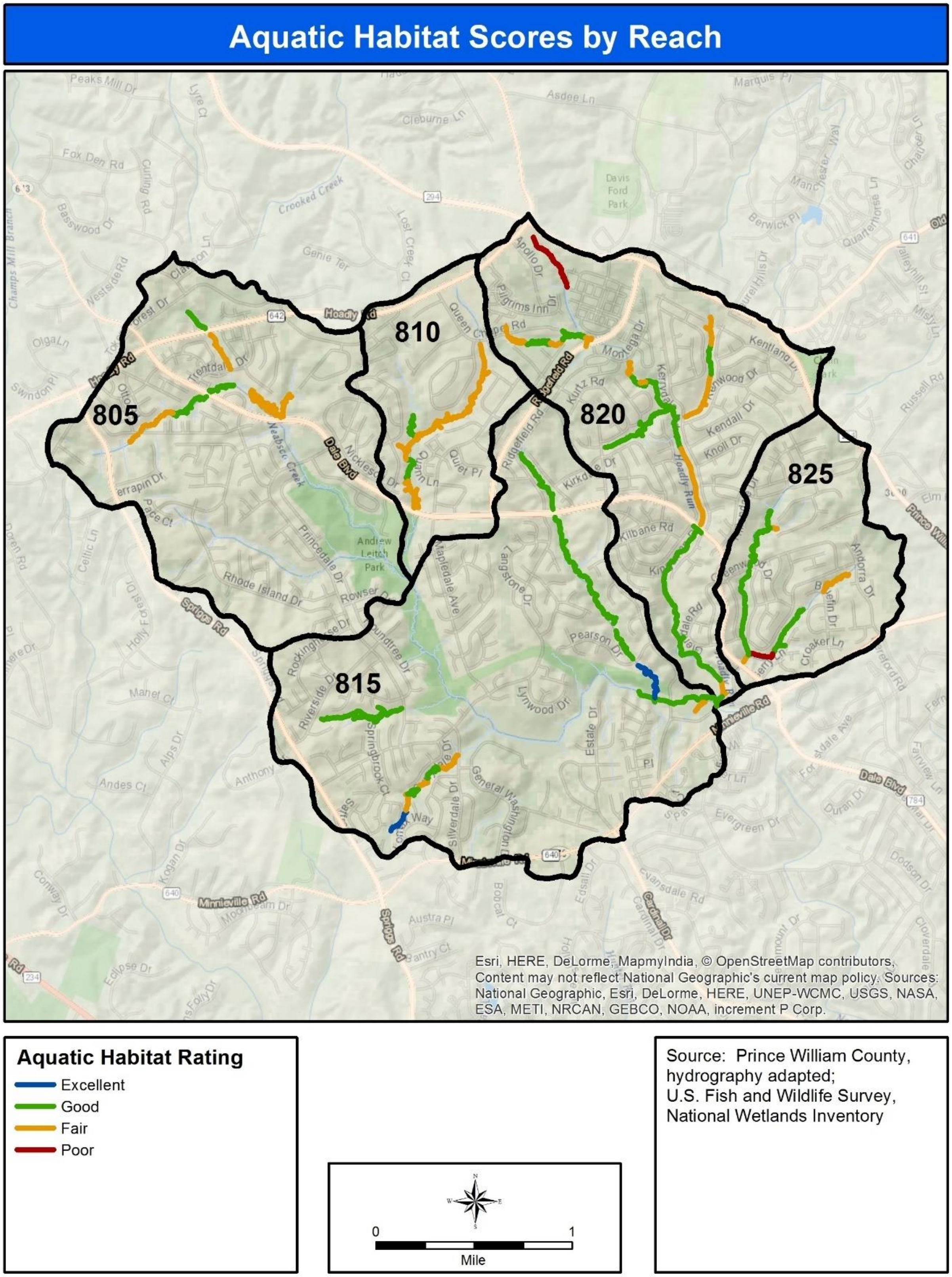

Figure 6–7. Neabsco Creek Watershed Study - aquatic habitat scores

6.4 ENVIRONMENTAL ISSUE FINDINGS

There were 123 environmental issues recorded as point locations during RSAT surveys and these are summarized in Table 6-10. While the RSAT survey assigns a score along an entire reach, these points indicate specific locations where there are areas of concern, acute impacts, or potential hazards (Figure 6-10). Note that the sanitary sewer data points collected do not reflect environmental problems, but simply record the presence of sanity sewer manholes near the stream corridor, as requested by County staff.

Table 6-10. Neabsco Creek Watershed environmental issues

Subwatershed	Unusual Condition	Buffer Deficiency	Extreme Erosion	Outfall Channel Erosion	Other Environ-mental Interest	Presence of Sanitary Sewer Infrastruc-ture	Total
805	0	5	1	1	2	0	9
810	0	4	4	0	0	3	11
815	0	10	11	7	2	11	41
820	5	11	14	8	6	10	54
825	2	3	0	0	0	3	8
Total	7	33	30	16	10	27	123

Erosion and inadequate stream buffers were the most commonly occurring problems with multiple locations identified in each subwatershed. Figure 6–8 shows a photograph from extreme erosion point es301, collected inside subwatershed 820 along stream reach R2504. Figure 6–9 shows a photograph from inadequate buffer point ib001, collected inside subwatershed 820 along stream reach sa003.

Outfall erosion points were collected when field crews observed outfalls that were not flagged for assessment as outfall stabilization sites, but that still warranted inspection. These points can include outfall channel headcuts at the stream channel, damaged outfall structures, or candidates for illicit discharge testing. Unusual conditions were only encountered in subwatersheds 820 and 825 where several locations had problems requiring special attention, primarily exposed pipes and serious undercuts. Field crews found these areas required a greater sense of urgency. Other interest points were generally less urgent, but served simply to record points of interest like beaver dams or debris blockages in the stream channel.

Outfall channel erosion problems and other areas of environmental interest (e.g., beaver dam, debris in channel) were less frequent but also found in most subwatersheds with 810 being the only exception. Overall, subwatersheds 815 and 820 showed the most locations of concern, and while they did encompass a majority of stream miles walked (67%), they accounted for a larger than expected percentage of problems (76%).

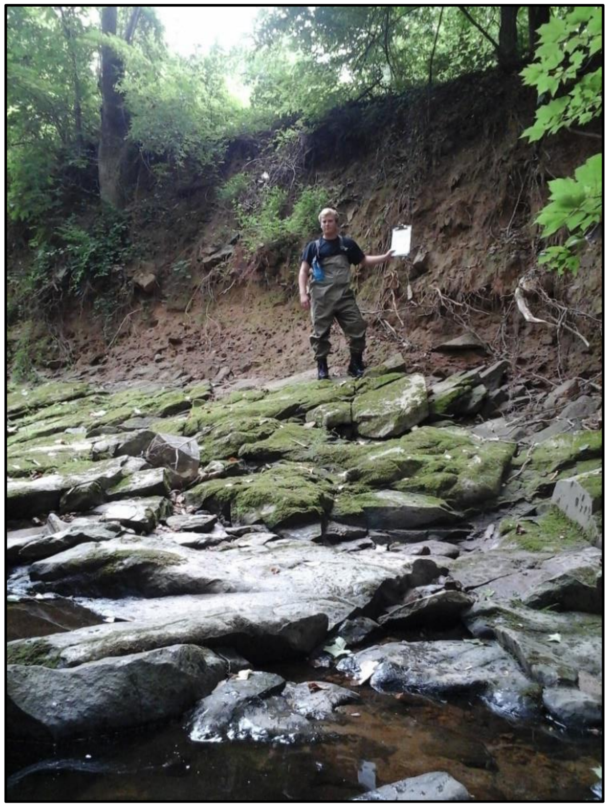

Figure 6–8. Example of extreme erosion. Photo from extreme erosion point es301.

Figure 6–9. Example of lack of riparian buffer vegetation. Photo from inadequate buffer point ib001.

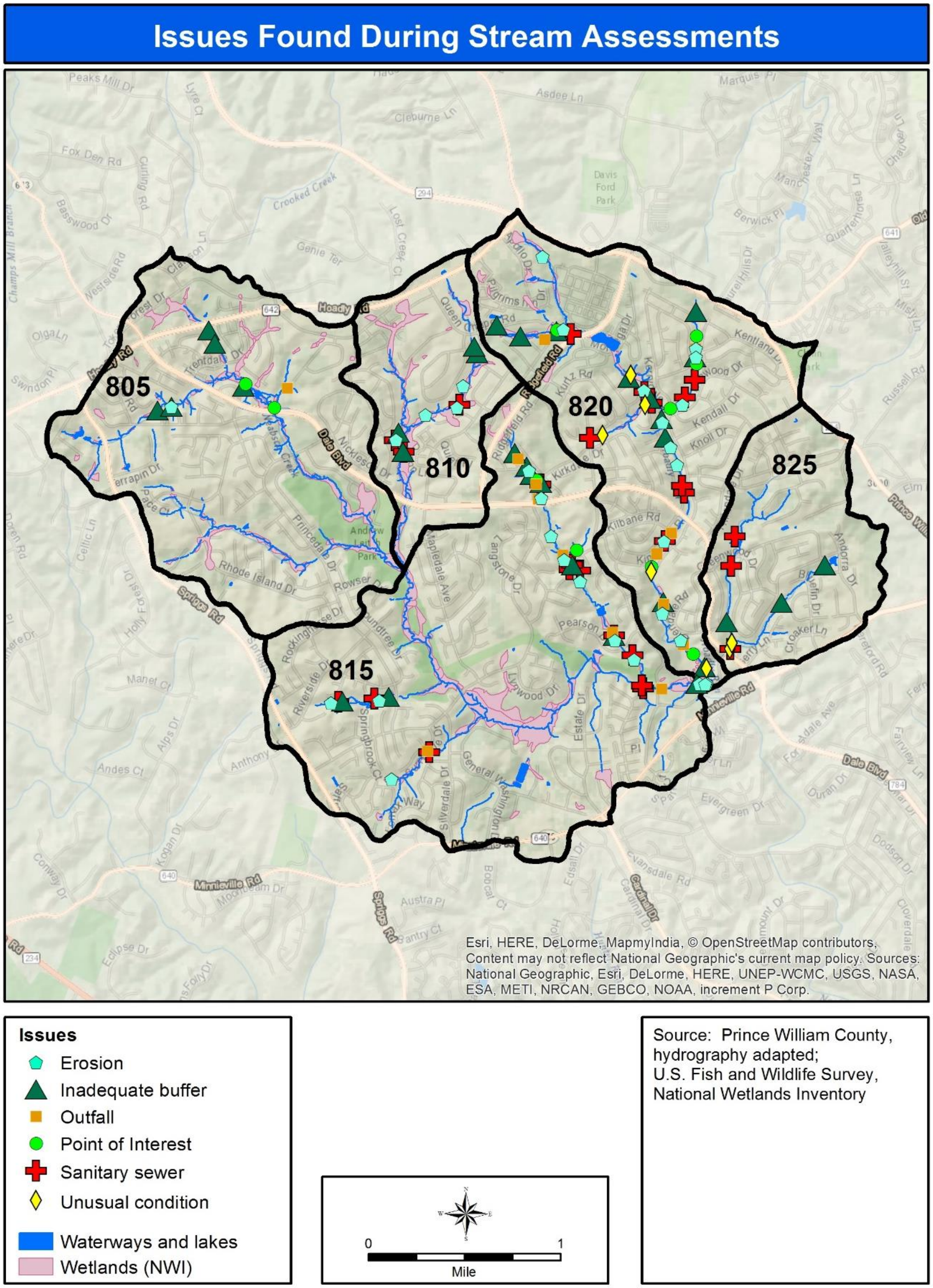

Figure 6–10. Neabsco Creek Watershed Study – environmental issues

CHAPTER 7: SUMMARY OF WATERSHED RESTORATION OPPORTUNITIES

Recommended opportunities for SW Facility Conversion, New BMPs, Outfall Stabilization, Reforestation, and Stream Restoration based on field assessments and further analysis are described in this chapter. Table 7-1 summarizes the total numbers of sites visited within the Neabsco Creek watershed study area and project opportunities recommended. Not all sites selected were able to be assessed due to access or permission issues. For all recommendations made, field crews assigned an initial assessment of restoration potential, rating the recommendation as High, Medium, or Low potential, based on field findings and other available information and observations. Opportunities were further assessed using a scoring system to quantify project benefits and other factors, in order to rank opportunities in priority order (see Chapter 8 for details). Sections 6.1 to 6.5 highlight key findings and describe the types of opportunities identified, by category. Maps showing the project opportunities within each of the five subwatersheds are provided in Section 6.6. Summary fact sheets for all opportunities are found in Appendices A-E and include photographs and local area maps.

Table 7-1. Numbers of sites assessed and project opportunities recommended within the Neabsco Creek watershed study area, Prince William County, Virginia

Assessment Category	Sites Selected (Desktop)	Sites Assessed (Field)	Project Opportunities Recommended
Stormwater Facility Retrofit	30	27	24
New BMP	18	18	24 (individual BMP footprints within the sites)
Outfall Stabilization	45	41	17
Reforestation	54 (13 riparian, 41 upland)	52 (12 riparian, 40 upland)	45 (12 riparian, 33 upland)
Stream Restoration	14.83 miles	13.59 miles	3.56 miles (15 projects)

7.1 STORMWATER FACILITY CONVERSION OPPORTUNITIES

Field teams considered 30 dry pond facilities within the Neabsco Creek watershed as candidates for converting SW facilities to enhance water quantity and quality treatment. Teams recommended opportunities for converting 24 dry pond facilities in commercial, residential, and institutional land uses, encompassing impervious drainage areas of between one-half acre and over 15 acres (Figure 7-1). Dry ponds were selected for investigation to maximize the value of the retrofit from both ecological and pollution reduction crediting standpoint. Dry ponds can also be retrofit into a variety of improved treatment practices to address both water quality and water quantity problems.

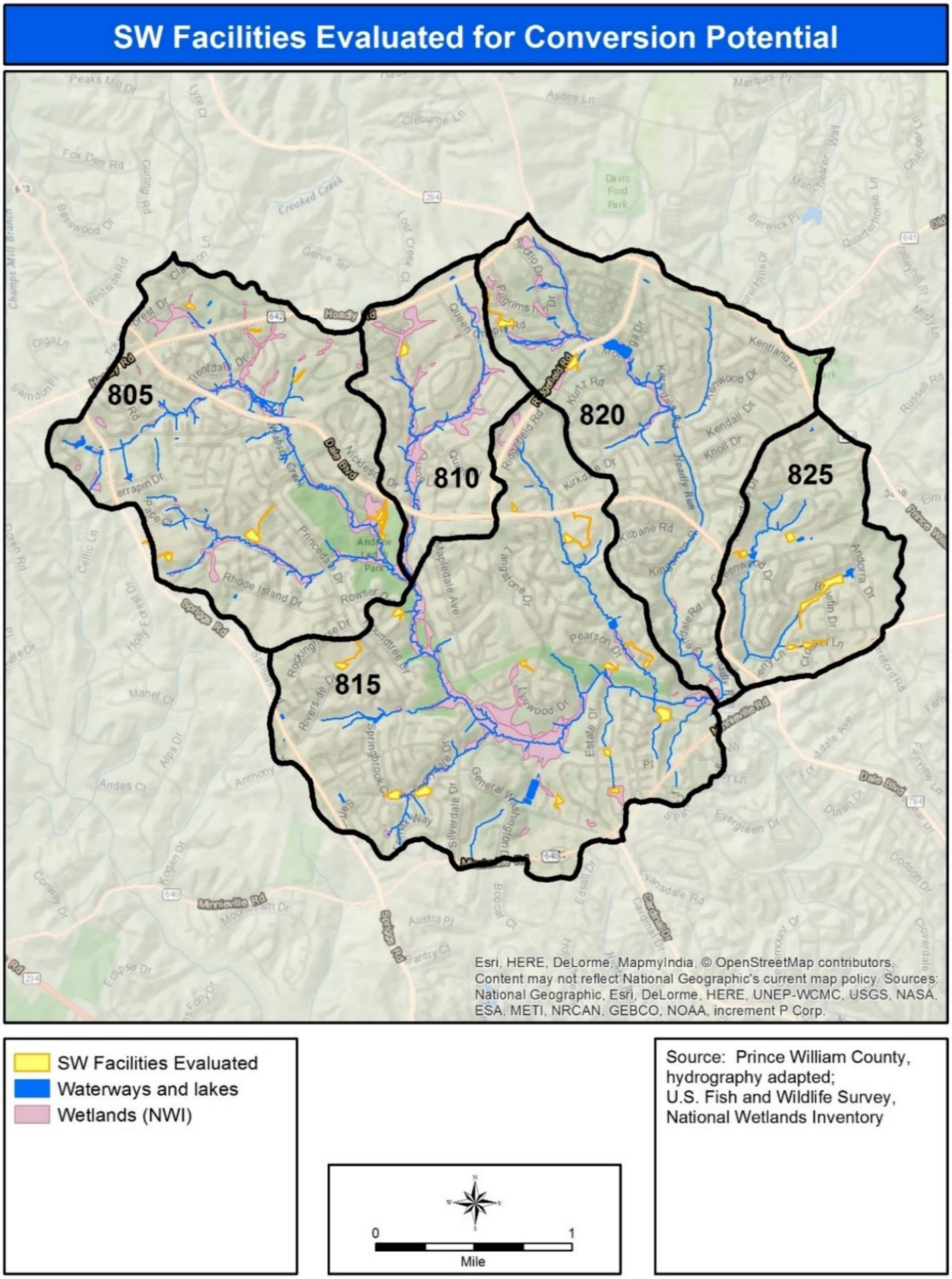

Figure 7–1. Stormwater facilities evaluated as candidates for conversion in the Neabsco Creek watershed study area

Of the original of 30 SW Facilities with potential for conversion that had been identified during the site selection process, three sites were evaluated, but did not receive recommendations. Two were self-converted ponds with extensive vegetation that do not require intervention, but may be eligible for nutrient reduction crediting for the benefits they now provide. One was a reach of stream that had been designated a pond. Three other sites were not able to be evaluated due to access or permission issues.

In all, 24 of the 30 sites were evaluated and received retrofit recommendations, which were:

- 7 bioretention areas
- 7 extended detention dry ponds
- 10 wetland areas

A summary of SW Facility conversion opportunities, including facility identification, ownership and maintenance responsibility, conversion potential, impervious area treated, assessment score, and project rank is provided in Table 7-2.

All of the SW facilities assessed were considered dry ponds because of the size of the low-flow orifice, frequently approximately eight inches in diameter but was in many instances much larger. Some facilities featured mowed interiors and showed little evidence of stormwater treatment. In these cases, stormflows passed through the facilities along concrete, rip-rap lined, or natural leader channels with no detention. Other facilities were overgrown and appeared abandoned, with copious vegetation growth that obscured pond features and in some cases reduced pond function. Some vegetation growth exhibited wetland characteristics if the ponds retained water for extended periods of time. In some cases, the ingrowth of vegetation appeared beneficial as the facilities showed bioretention features. Several facilities had been constructed atop baseflow streams, which entered via natural channel or storm drain outfall and passed through the outflow riser unimpeded. Several facilities had reduced or absent treatment capability due to visible accumulation of debris or sediment leading to the partial or total blockage of the low flow orifice of the riser. In one extreme case, the only avenue for water to exit the facility was by overtopping the high flow riser so that the facility was operating as, effectively, a wet pond. In one instance, damage to the upland approaches caused most stormwater to bypass the facility and cause erosion in other areas.

Some facilities, especially those with grassy turf interiors, were candidates for bioretention as it would provide the best water quality improvement. Facilities with ingrowth of meadow plants, wetland plants, or trees were recommended for extended dry detention or conversion to stormwater wetlands to take advantage of the existing conditions. In isolated cases, the lack of elevation difference between inlet and outlet pipe inverts made the installation of new water quality treatment features more challenging. In all cases where a concrete leader channel was present, Versar recommended replacing it with a vegetated swale to promote infiltration and a reduction in velocity. Most existing risers were recommended for replacement or retrofit to reduce low flow orifice sizes and/or to raise the height of the high flow spillway to increase storage and detention time.

Table 7-2. Summary of Dry Pond Facility conversion opportunities identified in the Neabsco Creek watershed study area

Sub-watershed	Site ID	FAC ID	Facility Type (from County inventory)	Owner	Major Maintenance	Potential Conversion Type	Impervious Area (acres)	Retrofit Potential	Score	Rank
815	BCON120	70	BMP Dry Detention	Private	Public Works	Bioretention Underdrain A/B soils (constructed wetland could also be considered)	1.19	High	87	1 of 23
805	BCON105	132	BMP Dry Detention	Private	Public Works	Improved extended dry detention.	3.21	High	86	2 of 23
810	BCON107	88	BMP Dry Detention	Private	Public Works	Constructed wetland with improved extended detention.	19.32	High	85	3 of 23
805	BCON106	5048	Dry Detention	Schools	Schools	Extended dry detention.	10.21	High	82	4 of 23 (tie)
825	BCON128	685	Dry Detention	Private	Public Works	Constructed wetland. Add riser for extended dry detention.	9.88	High	82	4 of 23 (tie)
815	BCON110	871	BMP Dry Detention	Private	Public Works	Bioretention No Underdrain A/B soils (constructed wetland could also be considered)	6.69	High	81	6 of 23
810	BCON108	617	BMP Dry Detention	Private	Public Works	Bioretention Underdrain A/B soils (constructed wetland could also be considered)	10.02	High	78	7 of 23
815	BCON116	5035	Dry Detention	BOCS	Parks	Bioretention Underdrain A/B soils. (Add riser for extended dry detention. Constructed wetland could also be considered)	2.25	High	76	8 of 23
825	BCON126	846	BMP Dry Detention	Private	Public Works	Constructed wetland.	3.81	High	75	9 of 23
805	BCON101	313	BMP Dry Detention	Private	Public Works	Constructed wetland (bioretention could also be considered)	11.19	High	74	10 of 23 (tie)
815	BCON117	5036	Dry Detention	BOCS	Parks	Add riser for extended dry detention. Improve conveyance to facility.	1.63	High	74	10 of 23 (tie)
805	BCON102	186	BMP Dry Detention	BOCS	Parks	Constructed wetland (bioretention could also be considered)	3.3	High	73	12 of 23 (tie)
815	BCON112	5786	Dry Detention	Schools	Schools	Extended dry detention (constructed wetland could also be considered)	6.03	Medium	73	12 of 23 (tie)

Table 7-2. (Continued)										
Sub-watershed	**Site ID**	**FAC ID**	**Facility Type (from PWC inventory)**	**Owner**	**Major Maintenance**	**Potential Conversion Type**	**Impervious Area (acres)**	**Retrofit Potential**	**Score**	**Rank**
815	BCON113	368	BMP Dry Detention	Private	Public Works	Constructed wetland	5.78	High	68	14 of 23 (tie)
815	BCON114	5886	Dry Detention	Schools	Schools	Extended dry detention (bioreten-tion could also be considered)	9.9	Medium	68	14 of 23 (tie)
815	BCON122	121	Dry Detention	Private	Public Works	Extended dry detention (bioreten-tion could also be considered)	1.79	Medium	67	16 of 23
815	BCON118	112	BMP Dry Detention	Private	Public Works	Constructed wetland (bioretention could also be considered)	5.67	High	65	17 of 23
815	BCON111	932	BMP Dry Detention	Private	Public Works	Bioretention Underdrain A/B soils (constructed wetland could also be considered)	0.85	High	63	18 of 23 (tie)
815	BCON115	5078	BMP Dry Detention	Private	Private	Extended dry detention	3.51	High	63	18 of 23 (tie)
820	BCON123	803	BMP Dry Detention	Private	Public Works	Constructed wetland (bioretention could also be considered)	12.39	Medium	62	20 of 23
815	BCON121	73	BMP Dry Detention	Private	Public Works	Constructed wetland (bioretention could also be considered)	8.48	Medium	57	21 of 23
820	BCON125	872	BMP Dry Detention	Private	Public Works	Bioretention Underdrain C/D soils	1.83	Medium	54	22 of 23
820	BCON124	873	BMP Dry Detention	Private	Public Works	Bioretention Underdrain C/D soils	0.58	Medium	51	23 of 23 (tie)
825	BCON127	202	BMP Dry Detention	Private	Public Works	Constructed wetland	7.51	Medium	51	23 of 23 (tie)

Three of the dry ponds featured baseflow streams traversing the interior. In one case (Beville Middle School retrofit, BCON114), we recommend a conversion to extended detention but also consider the possibility of off-line bioretention, requiring a strategically placed splitter to divert low stormwater flows from the baseflow channel to the treatment cells while allowing heavy runoff events to pass through. Such flow splitters could be incorporated into the storm drain outfalls to the facility or as a diversionary weir placed in the vegetated swale. The other facilities with baseflow streams were recommended for conversion to an extended detention dry pond and to a stormwater wetland, the latter because wetland plants had become established in the vicinity of the baseflow stream.

7.2 NEW BMP OPPORTUNITIES

Field teams evaluated 18 public school, commercial, residential, and other institutional sites for potential new BMP installations (Figure 7–2) in areas not currently managed for stormwater.

The field team generally considered impervious areas that did not currently have stormwater treatment or were situated up-gradient of dry pond facilities that provided quantity control only. Staff prepared summaries of new BMP opportunities for 24 footprints at 12 sites. As staff investigated sites, three dry pond facilities that had not originally been targeted for conversion in this study were identified for conversion and included in the analysis.

A summary of new BMP opportunities, including constraints, potential impact to trees, ease of access, impervious area treated, assessment score, and project rank is provided in Table 7-3. New BMP recommendations included the following project types:

- 10 bioretention areas
- 6 bioswales
- 5 surface sand filters
- 3 underground storage systems with cartridge filtration pretreatment

Field staff proposed solutions wherever practical and that would maximize stormwater pollution reduction. Most surfaces identified for new BMPs were asphalt or concrete; however, hardened turf areas were also included. Larger impervious surfaces were given priority. For example, the Dale City Commuter Lot on Gemini Way and rear loading dock area of the adjacent Giant Food (total 2.24 acres) provided ample evidence of the effects of uncontrolled stormwater runoff in the form of a severely undermined concrete receiving channel downslope of the outfall. The large student parking lot at C.D. Hylton High School is another example of a sizable (9.46 acres) impervious area, however, it is currently served by a dry pond facility. In two areas, staff considered new BMPs for neighborhoods that currently do not have stormwater treatment. Examples include Baneberry Circle and Savannah Drive, the latter of which has a drainage that includes an entire neighborhood and has an outfall that is severely downcut. Other impervious areas were targeted for smaller facilities, such as the loading dock area behind Ace Hardware and adjacent businesses in Glendale Plaza or portions of the several schools that teams visited.

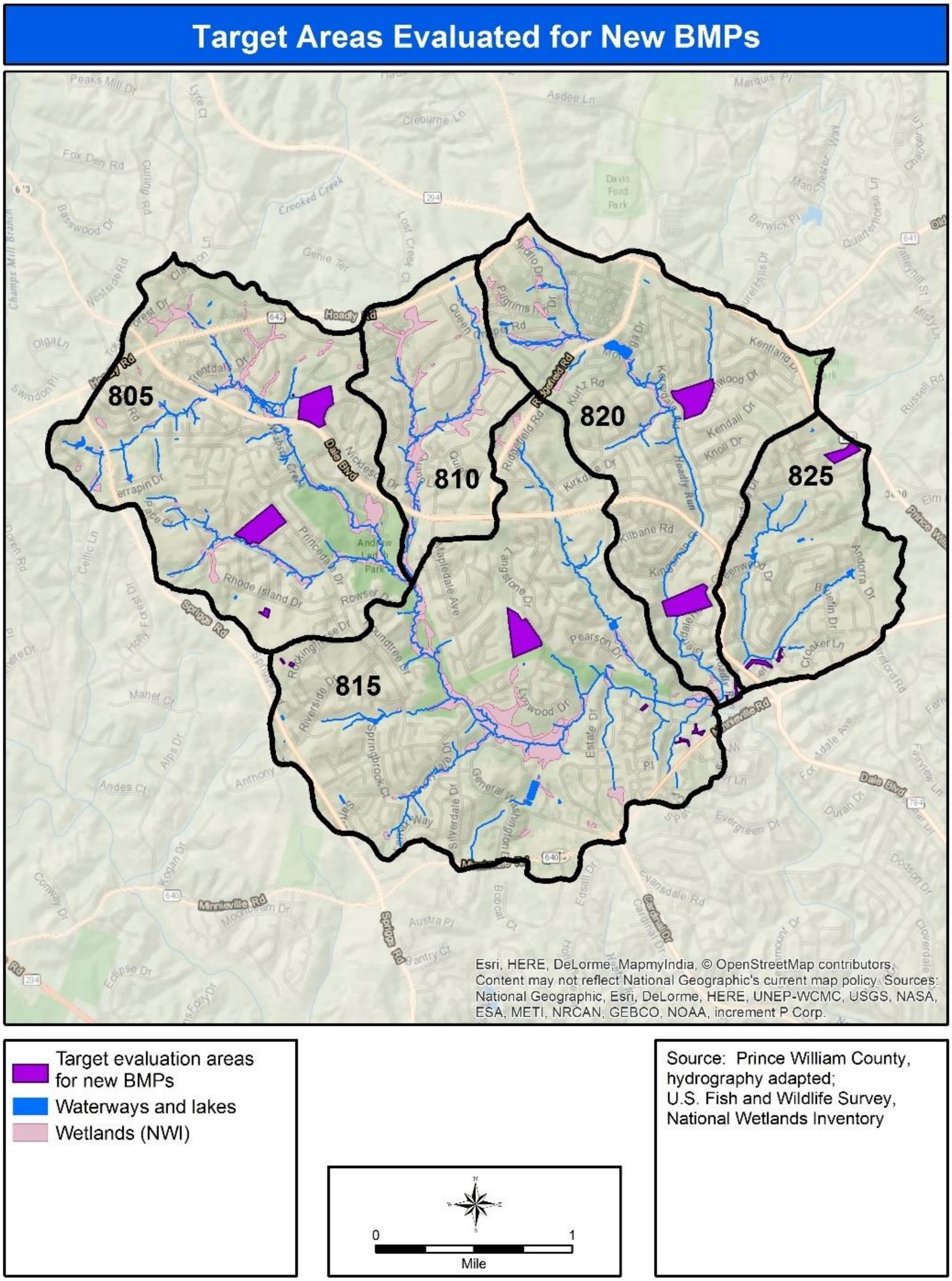

Figure 7–2. Target areas evaluated for potential to add new stormwater BMPs in the Neabsco Creek watershed study area

Table 7-3. Summary of new BMP project opportunities identified in the Neabsco Creek watershed study area

Site ID	Sub-watershed	Proposed BMP Type	Impervious Area Treated (acres)	Retrofit Potential	Score	Rank
NewBMP_104_a	805	Bioretention Underdrain A/B soils	2.76	High	77	1
NewBMP_105_a	815	Bioretention Underdrain C/D soils	1.82	High	76	2
NewBMP_103_a	820	Bioswale	0.95	Medium	75	3
NewBMP_115_b	825	Bioswale	0.72	High	75	3
NewBMP_106_a	815	Bioretention Underdrain A/B soils	0.44	High	73	5
NewBMP_115_a	825	Bioswale	0.09	High	73	5
NewBMP_105_e	815	Underground Storage with Filter Cartridge System	9.46	High	71	7
NewBMP_106_b	815	Surface Sand Filter	0.2	High	71	7
NewBMP_105_f	815	Bioswale	0*	High	71	7
NewBMP_105_d	815	Bioswale	0.01*	High	71	7
NewBMP_115_c	825	Bioretention Underdrain A/B soils	0.28	High	70	11
NewBMP_105_c	815	Bioswale	0*	High	69	12
NewBMP_102_a	805	Bioretention Underdrain C/D soils	0.34	High	65	13
NewBMP_102_b	805	Bioretention Underdrain C/D soils	0.53	High	65	13
NewBMP_107_b	815	Bioretention Underdrain A/B soils	0.58	Medium	65	13
NewBMP_105_b	815	Surface Sand Filter	0.67	High	62	16
NewBMP_107_a	815	Surface Sand Filter	0.13	Medium	60	17
NewBMP_108_a	815	Bioretention Underdrain C/D soils	7.45	Medium	57	18
NewBMP_114_a	825	Underground Storage with Filter Cartridge System	2.24	Medium	55	19
NewBMP_118_a	825	Bioretention Underdrain C/D soils	8.64	Medium	50	20
NewBMP_113_a	820	Surface Sand Filter	0.63	Medium	48	21
NewBMP_111_a	820	Surface Sand Filter	0.37	Medium	43	22
NewBMP_112_a	820	Bioretention Underdrain C/D soils	0.19	Medium	43	22
NewBMP_110_a	820	Underground Storage with Filter Cartridge System	0.57	Medium	38	24

* Drainage areas to these bioswales will be re-calculated during concept design.

The new BMP type recommended most frequently was bioretention (with underdrain) because of its versatility and efficiency in reducing pollution. This BMP type was recommended in a total of ten residential, commercial, institutional, and school land uses. Bioswales were recommended in six areas, most commonly where grassy swales already existed or minor channelization was evident. Bioswales were recommended for C.D. Hylton High School and Logan Park. Surface sand filters were recommended mostly for areas of high volumes of truck traffic (e.g., rear of the Giant Food or Ace Hardware) and higher likelihood of heavy metal deposition on impervious surfaces. A severe hotspot was identified at C.D. Hylton High School, where the proposed sand filter, in conjunction with other appropriate corrective measures, will reduce polluted runoff. Underground storage, with cartridge filtration pre-treatment, was recommended for three areas, including two of the largest areas of impervious cover. Underground storage was recommended when adjacent areas of turf were inadequate but enough relief was available to excavate an underground storage array and effectively provide treatment.

7.3 OUTFALL STABILIZATION OPPORTUNITIES

A total of 45 sites were selected for outfall stabilization assessment in the Neabsco Creek subwatershed. Of the 45 total sites, four sites could not be properly assessed either because of landowner restrictions or physical barriers to access, and one case in which the site runoff was already managed by a Virginia Department of Transportation owned pond. Figure 7–3 displays the distribution of all outfall sites selected for assessment across the Neabsco Creek subwatershed.

Out of the 40 sites that were assessed by the field teams, 17 were identified as having potential for outfall stabilization projects. Eight sites had opportunities for construction of Regenerative Stormwater Conveyance (RSC) systems, while another nine sites presented opportunities for using rip-rap, drop structures, or other channel stabilization techniques. Based on field observations, the 17 sites with opportunities were given a preliminary rating category of high, medium, or low potential for suggested outfall stabilization projects. Sites were later scored and ranked using additional factors, as described in Chapter 8.

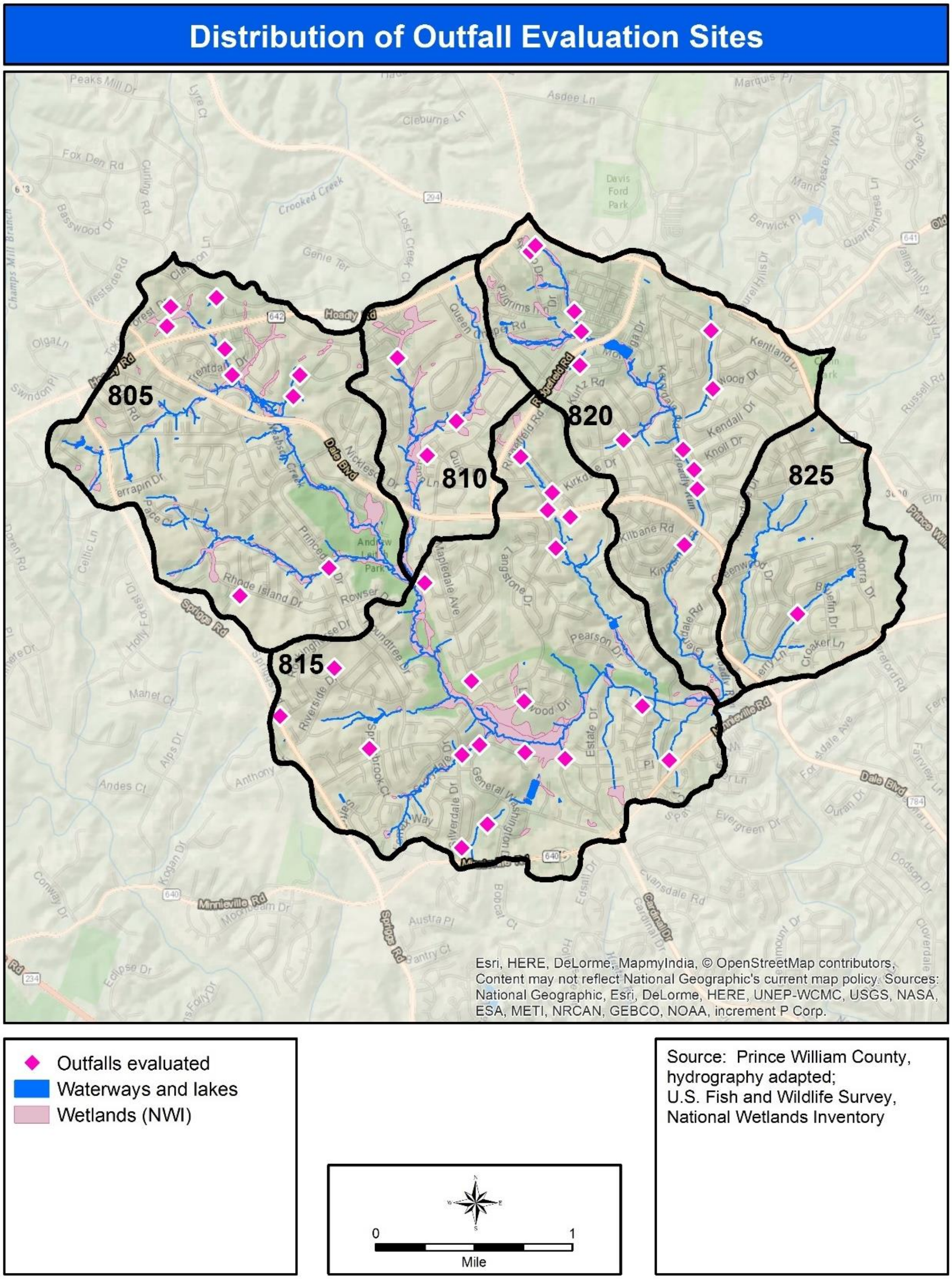

Figure 7–3. Candidate outfall stabilization site locations evaluated in the Neabsco Creek watershed study area

The 17 sites that were recommended for outfall stabilization projects can be found in Table 7-4, ranked from high to low in their potential for establishing a project. Along with their outfall IDs, Table 7-4 lists the type of recommended stabilization project, constraints noted in the field, and the overall stabilization potential rating. See Section 3.3 for an overview of these stabilization practices, benefits, and their applicability.

Table 7-4. Summary of outfall stabilization project opportunities identified in the Neabsco Creek watershed study area

Outfall Site ID	County STRUC ID	Sub-watershed	Recommended Stabilization Project	Constraints	Impervious Area Draining to Outfall (acres)	Overall Stabilization Potential	Score	Rank
OUTF132	15647	820	Regenerative Stormwater Conveyance	utilities, significant impact to trees, access	37.38	Medium	71	1
OUTF140	46501	820	Regenerative Stormwater Conveyance	access	13.87	Medium	69	2
OUTF110	1243	810	Regenerative Stormwater Conveyance	slope, significant impact to trees	9.56	Medium	68	3
OUTF119	2573	815	Regenerative Stormwater Conveyance	utilities, significant impact to trees, property ownership, access	14.56	Medium	68	3
OUTF117	9795	815	Regenerative Stormwater Conveyance	utilities, significant impact to trees	13.65	Medium	66	5
OUTF104	321	805	Other: Regenerative Stormwater Conveyance and Drop structure combination	slope, utilities, significant impact to trees, access	2	Medium	64	6
OUTF113	57731	815	Rip Rap	utilities, significant impact to trees, access	8.9	Low	63	7
OUTF141	54818	820	Regenerative Stormwater Conveyance	significant impact to trees	6.86	Medium	62	8
OUTF111	2645	810	Regenerative Stormwater Conveyance	significant impact to trees, access	3.85	Medium	61	9
OUTF139	15547	820	Rip Rap	property ownership, access	8.59	Low	61	9
OUTF115	3471	815	Other type of structural improvement to stabilize the outfall	significant impact to trees, property ownership, access	8.27	Medium	56	11
OUTF124	15764	815	Drop Structure	potentially space insufficient, significant impact to trees, access	7.04	High	52	12
OUTF114	9965	815	Drop Structure	potentially space insufficient, significant impact to trees, property ownership, safety concerns	14.56	High	52	12
OUTF108	50169	805	Rip Rap	significant impact to trees, access	3.98	Low	47	14
OUTF135	48641	820	Drop Structure	slope, property ownership, access	2.11	High	45	15
OUTF102	50063	805	Regenerative Stormwater Conveyance	slope, access, proximity to neighboring properties	4.21	Low	35	16
OUTF133	47918	820	Drop Structure	slope, wetland impacts, access, proximity to neighboring properties	23.98	Medium	32	17

7.4 REFORESTATION OPPORTUNITIES

A total of 45 reforestation sites were recommended within the Neabsco Creek subwatershed, with potential planting areas totaling 46 acres. Figure 7–4 shows the location of the assessed sites and the location and relative size of individual reforestation opportunity sites within the Neabsco Creek watershed study area.

Totals of potential planting areas at the sites ranged from 0.09 acre to 7.09 acres (Table 7-5). All sites surveyed were considered as open pervious cover type, based on GIS information, but in reality were a mixture of treed, shrubby, and open areas.

A summary of reforestation opportunities results, including site name, total parcel size, total size of replanting areas, ease of access, site preparation effort, and notes on type of preparation required is provided in Table 7-5. Site IDs beginning with 'U' and 'R' denote upland and riparian sites respectively, as defined during the site selection process.

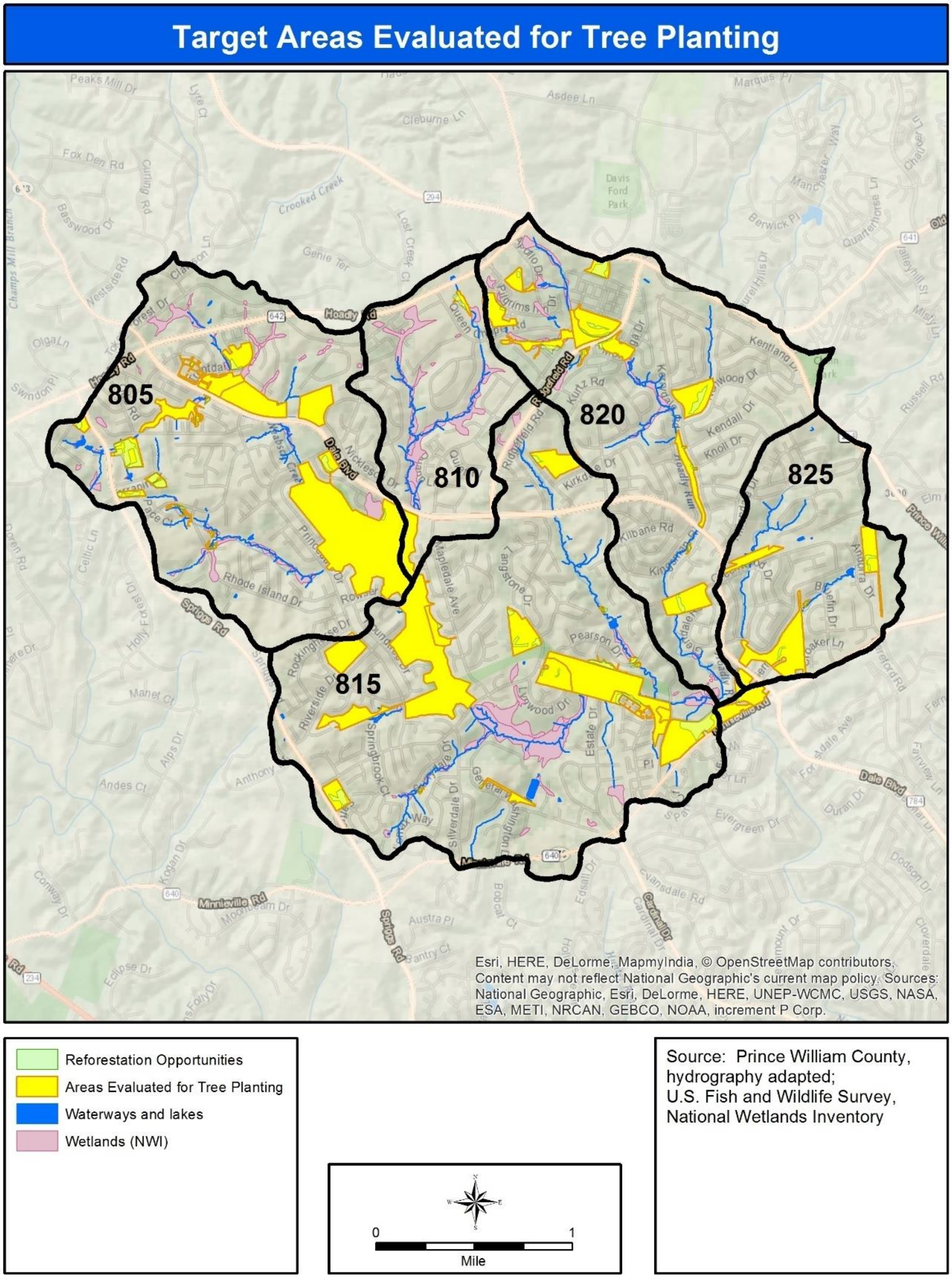

Figure 7–4. Candidate reforestation site locations evaluated in the Neabsco Creek watershed study area

Table 7-5. Summary of watershed reforestation project opportunities identified in the Neabsco Creek watershed study area

Site ID	Sub-watershed	Total Parcel Size (acres)	Total Potential Planting Area (acres)	Ease of Access	Site Prep Effort	Type of Prep Notes	Restoration Potential	Score	Rank
UFOR119	815	15.23	2.39	Easy	None	None	High	71	1
UFOR118	815	15.04	2.09	Easy	None	None	High	68	2
UFOR124	815	31.16	7.09	Easy	Medium	Building/structure removal, pavement removal	High	68	2
UFOR139	825	15.22	1.35	Easy	None	None	High	68	2
UFOR116	815	8.81	0.93	Easy	None	None	High	66	5
UFOR111	805	4.43	1.55	Easy	None	None	High	63	6
UFOR141	825	218.11	0.72	Easy	None	None	High	63	6
UFOR102	805	4.47	1.37	Easy	Low	Minor grading may be required	High	61	8
UFOR134	820	9.64	5.92	Moderate	None	None	High	61	8
RFOR109	815	0.51	0.4	Easy	Low	Check with VDOT for temporary removal of fence	Medium	58	10
UFOR114	810	13.82	0.6	Easy	None	None	High	58	10
RFOR105	805	1.03	0.32	Easy	None	None	High	57	12
UFOR101	805	7.83	2.31	Easy	Low	Loosen up surface soils	Medium	56	13
UFOR105	805	2.1	1.45	Moderate	Medium	May require temporary removal of fence	Medium	56	13
UFOR121	815	2.06	1.14	Easy	None	None	Medium	56	13
RFOR107	805	0.55	0.2	Easy	None	None	High	55	16
RFOR111	815	0.291	0.09	Easy	None	None	Medium	55	16
UFOR123	815	9.99	0.62	Easy	None	None	Medium	53	18
UFOR112	805	1.71	1.23	Easy	None	None	Medium	52	19
UFOR126	815	7.43	1.34	Moderate	Medium	May require temporary removal of fence	Medium	52	19
UFOR104	805	4.99	2.71	Easy	None	None	High	50	21
UFOR115	815	4.33	0.31	Easy	None	None	High	50	21
UFOR132	820	6.23	0.93	Easy	Low	May require removal of fitness trail structures	Medium	49	23
UFOR135	820	30.31	0.55	Easy	Low	Minor grading could be needed	Medium	49	23
RFOR110	815	0.32	0.25	Easy	Low	Check with VDOT for temporary removal of fence	Medium	48	25
UFOR109	805	1.54	1.08	Easy	None	None	Medium	47	26
RFOR103	805	0.29	0.25	Easy	Low	May require temporary removal of fence	Medium	46	27
UFOR133	820	7.35	0.66	Moderate	Medium	Some veg clearing could be needed	Medium	45	28
UFOR113	805	12.15	0.47	Easy	None	None	Medium	39	29
RFOR106	805	0.29	0.1	Moderate	Medium	May require temporary removal of fence	Medium	38	30
UFOR107	805	2.62	1.09	Moderate	Low	Some vegetation clearing could be needed	Medium	37	31
UFOR136	820	8.62	0.36	Moderate	None	None	Medium	37	31
RFOR104	805	1.38	0.25	Moderate	Medium	May require temporary removal of fence	Medium	36	33
RFOR113	825	0.26	0.2	Moderate	Low	May require temporary removal of fence	Low	35	34
UFOR128	820	5.65	0.23	Moderate	Low	May require temporary removal of fence	Medium	35	34
UFOR110	805	13.33	0.79	Easy	Low	Minor grading may be required	Medium	34	36

Table 7-5 Continued

Site ID	Sub-watershed	Total Parcel Size (acres)	Total Potential Planting Area (acres)	Ease of Access	Site Prep Effort	Type of Prep Notes	Restoration Potential	Score	Rank
UFOR127	815	12.77	0.36	Moderate	Low	Minor grading may be needed	Medium	34	36
UFOR106	805	2.61	0.64	Moderate	Low	Some vegetation clearing could be needed	Medium	32	38
UFOR108	805	11.5	0.88	Moderate	Low	Minor grading could be needed	Medium	32	38
UFOR137	820	7.2	0.1	Moderate	Low	Minor grading could be needed	Medium	32	38
RFOR112	815	0.269	0.24	Difficult	None	None	Low	31	41
RFOR102	820	1.09	0.17	Moderate	Medium	May require temporary removal of fence	Low	30	42
UFOR120	815	3.55	0.18	Moderate	Low	Some vegetation clearing could be needed	Low	30	42
RFOR108	820	0.32	0.23	Difficult	Low	May require temporary removal of fences and outbuildings	Medium	29	44
UFOR103	805	1.96	0.15	Difficult	Low	Access could be difficult	Low	27	45

7.5 STREAM RESTORATION OPPORTUNITIES

A total of 79 reaches of stream, totaling 13.60 miles, were assessed during field stream walk investigations within the Neabsco Creek watershed study area. Figure 7–5 shows the distribution of streams assessed, for which RSAT and other data were collected. Within the stream reaches assessed, the project team identified 15 potential restoration projects, with a length totaling 3.555 miles (18,771 feet). The length of proposed individual restoration projects ranged from 0.07 to 0.5 stream miles, or about 357 to 2,615 linear feet (Table 7-6). All stream reaches assessed are shown on the map in Figure 7–5; however, only those identified as restoration opportunities are presented in Table 7-6.

A summary of stream restoration opportunities results, including site name, restoration potential, constraint type, impact to trees, ease of access, length, assessment score, and project rank is provided in Table 7-6.

Nearly all streams that were assessed in the Neabsco Creek watershed were found to have been adversely impacted by development. Much of the lower portions of Neabsco Creek mainstem and Hoadly Run were found to be stable, due to armoring of the banks, and not in need of restoration. The banks of the lower portion of Hoadly Run were constructed of rip-rap overlain with sediment. Restoration opportunities were generally identified in upstream portions of Neabsco Creek and Hoadly Run that were assessed, and in contributing tributaries. Many of these first and second order streams, located downstream of developed residential, institutional, or commercial areas, were found to be undergoing active degradation (i.e., down-cutting, widening).

Table 7-6. Summary of stream restoration project opportunities identified in the Neabsco Creek watershed study area

Site ID	Sub-watershed	Length (mi)	Length (ft)	Constraint Type	Impact to Existing Trees	Ease of Access	Stream Restoration Potential	Score	Rank
RST2602	805	0.3	1579	Moderate Impact to Trees	Moderate	Moderate	High	135	1
RST2604	805	0.23	1218	Access	Minimal	Easy	High	118	2
SR001	820	0.5	2615	Utility, Access, Moderate Impact to Trees	Moderate	Moderate	High	108	3
RST2603	805	0.48	2520	Access, Moderate Impact to Trees	Moderate	Moderate	Medium	106	4
SA710	815	0.28	1487	Access, Moderate Impact to Trees	Moderate	Moderate	Medium	93	5
RST2501	815	0.1	502	Moderate Impact to Trees	Moderate	Easy	Medium	91	6
RST2601	805	0.16	844	Moderate Impact to Trees	Moderate	Moderate	High	91	6
SR301	825	0.14	736	Ownership, Access, Moderate Impact to Trees	Moderate	Moderate	High	91	6
SA503	815	0.18	941	Access, Utility, Structures	Moderate	Moderate	Medium	89	9
SR108	815	0.33	1738	Ownership, Access, Moderate Impact to Trees	Moderate	Moderate	Medium	87	10
SA711	815	0.2	1072	Access, Moderate Impact to Trees	Moderate	Moderate	Medium	85	11
SR300	825	0.25	1340	Utility, Structures, Access, Moderate Impact to Trees	Moderate	Difficult	Medium	78	12
SR700	815	0.27	1415	Utility	Minimal	Moderate	Medium	76	13
SR963	815	0.08	407	Structures, Ownership, Access, Significant Impact to Trees	Significant	Difficult	Medium	76	13
SR701	815	0.07	357	Access, Moderate Impact to Trees	Moderate	Moderate	Medium	74	15

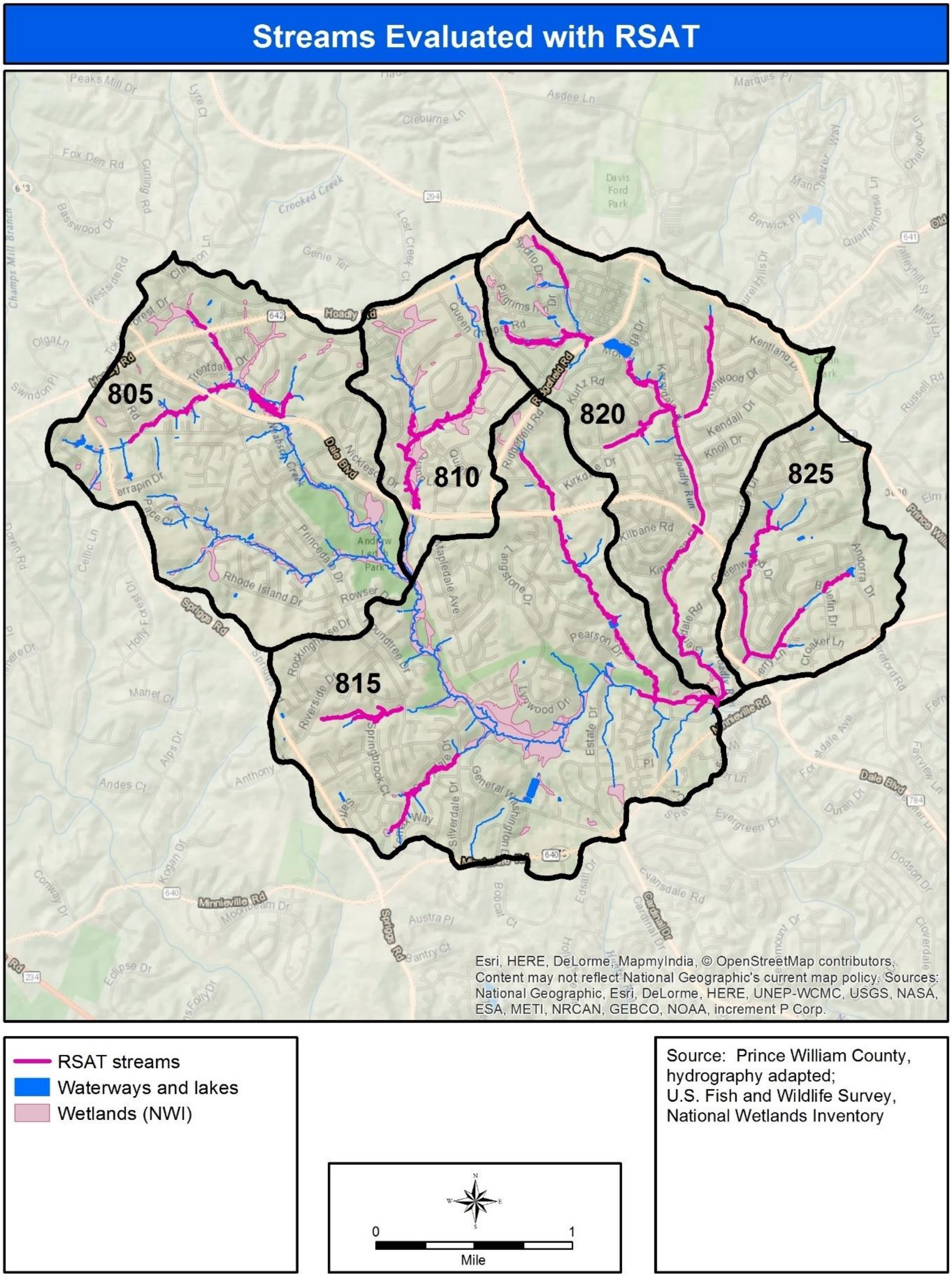

Figure 7–5. Streams assessed as candidates for restoration in the Neabsco Creek watershed study area

Restoration opportunities were recommended in those areas that were found to be unstable as shown by evidence of erosion, aggradation, and transport of debris and trash. An example of an unstable stream can be found bordering Beville Middle School (sites SA711, SA710, and SR701), where erosion in areas upstream has deposited sediments and debris in the channel, which is also undergoing down-cutting and widening. The headwaters of Neabsco Creek, upstream of Dale Blvd. (site RST2603), was found to be in the process of down-cutting caused by a series of headcuts along the impacted reach. At site SR001, a west to east tributary to Hoadly Run and originating at Delaney Road, has been severely impacted in an area immediately downstream of a major outfall draining residential land use, including down-cutting and transport of sediment and trash. Downstream of the highly-impacted upland area along the tributary and within the lower gradient area near the floodplain of Hoadly Run, the channel is more stable.

Other, smaller restoration opportunities were identified, such as sites SA503 (concrete channel removal proposed), SR963 (localized severe downcutting downstream of dry pond facility), and SR301 (downstream of dry pond facility). The latter two opportunities illustrate the need to better control stormwater runoff volumes at the source so that the benefits of stream restoration can be realized and maintained. Both dry pond facilities have been identified as SW Facility conversion opportunities elsewhere in this report.

7.6 SUMMARY OF OPPORTUNITIES BY SUBWATERSHED

Figure 7–6 through Figure 7–10 show the locations and site names of opportunities identified, in each of the study area's five subwatersheds, for projects in all categories. Details on each identified opportunity, including photographs, site location maps, summary facts, and narrative descriptions of opportunities, are provided in project fact sheets in the following Appendices:

- Appendix A. Stormwater Facility Conversion Opportunity Fact Sheet Summaries
- Appendix B. New BMP Opportunity Fact Sheet Summaries
- Appendix C. Outfall Stabilization Opportunity Fact Sheet Summaries
- Appendix D. Reforestation Opportunity Fact Sheet Summaries
- Appendix E. Stream Restoration Opportunity Fact Sheet Summaries

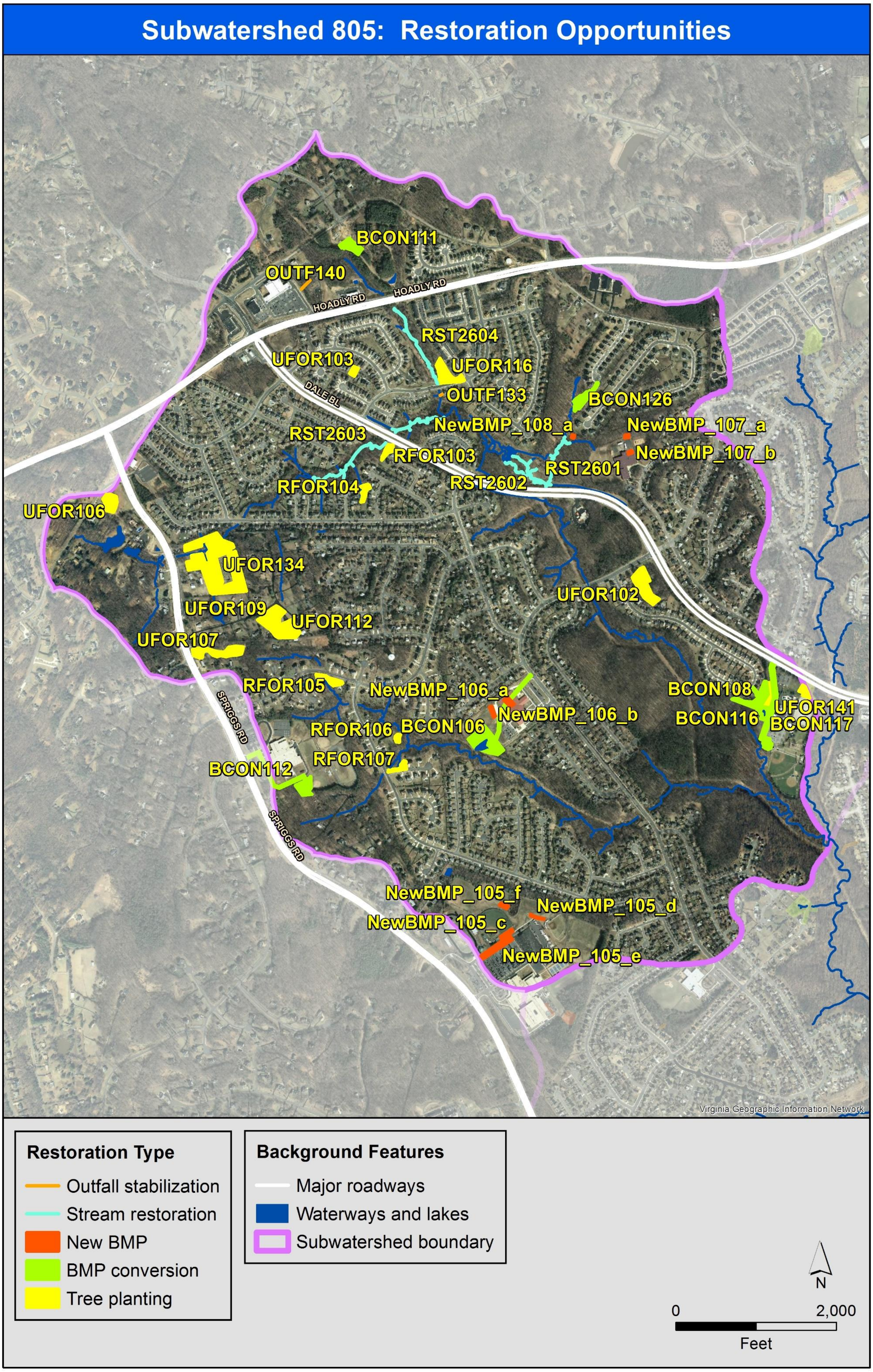

Figure 7–6. Restoration project opportunities identified in Subwatershed 805 within the Neabsco Creek watershed study area

Figure 7–7. Restoration project opportunities identified in Subwatershed 810 within the Neabsco Creek watershed study area

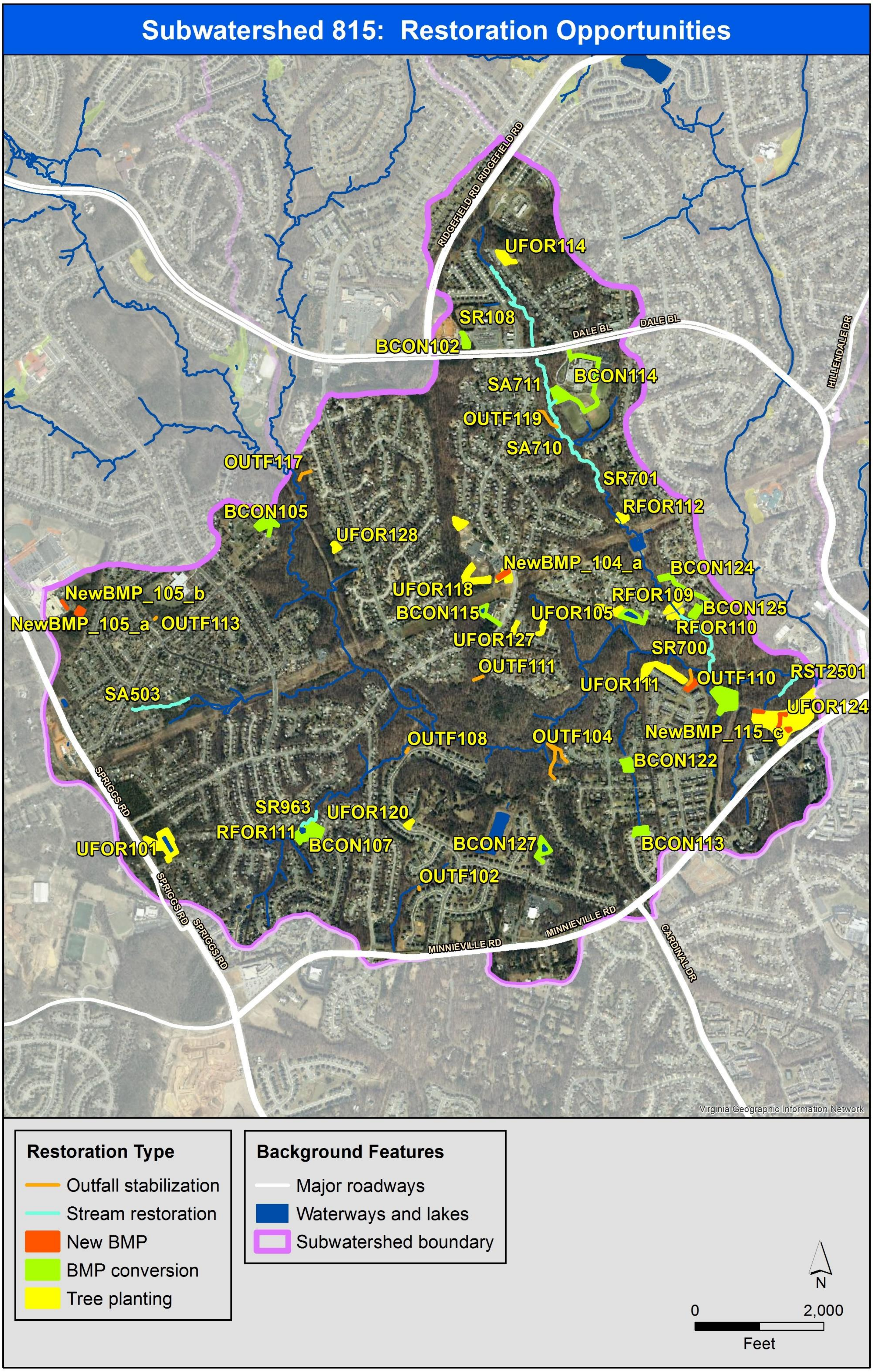

Figure 7–8. Restoration project opportunities identified in Subwatershed 815 within the Neabsco Creek watershed study area

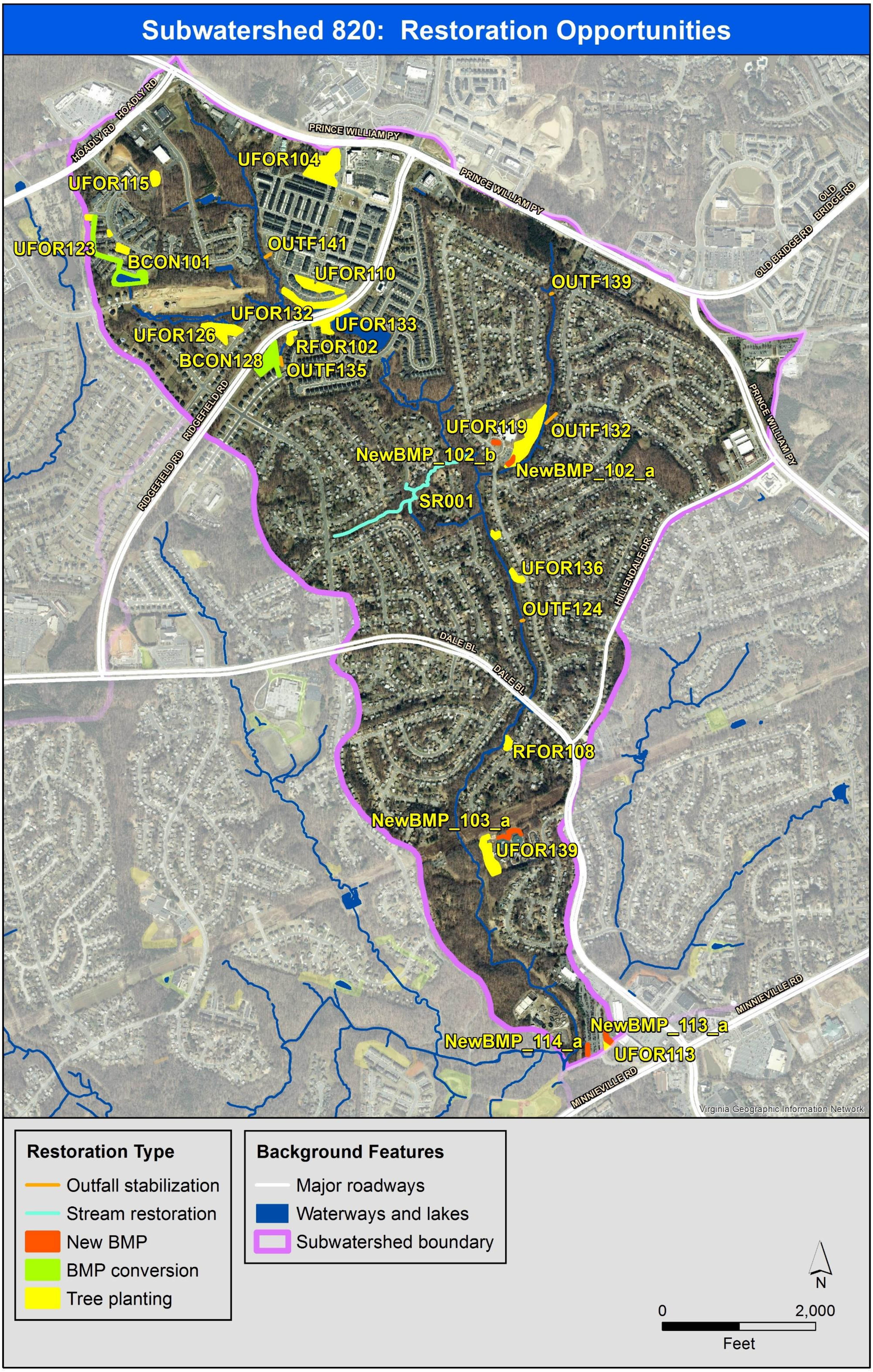

Figure 7–9. Restoration project opportunities identified in Subwatershed 820 within the Neabsco Creek watershed study area

Figure 7–10. Restoration project opportunities identified in Subwatershed 825 within the Neabsco Creek watershed study area

CHAPTER 8: MODELING

This chapter presents results of the watershed pollutant loading analysis performed using a spreadsheet model to estimate pollutant removal calculations for proposed stormwater Best Management Practices (BMPs) and other watershed management practices that could be implemented to make progress toward TMDL or other pollutant reduction goals for the Neabsco Creek watershed. A custom spreadsheet model was developed for the watershed to estimate reductions from current and proposed BMPs. The Chesapeake Assessment Scenario Tool (CAST) was used as the source of baseline loading rates for the County along with BMP pollutant reduction factors.

The section below discusses the pollutant removal amounts that would result from implementing key restoration strategies.

8.1 EXISTING LOADS

A pollutant loading analysis was performed to estimate total nitrogen, phosphorus, and sediment loads currently generated by urban runoff draining to existing and proposed BMPs within the Neabsco Creek watershed. Estimates were based on pollutant loading rates developed by the Chesapeake Bay Program (CBP) as implemented in the Chesapeake Assessment Scenario Tool (CAST – see casttool.org) for all land uses.

Watershed-specific pollutant loading rates were derived for nitrogen, phosphorus, and sediment based on the Chesapeake Bay Program (CBP; Linker and Shenk, 2013) – Watershed Model Phase 5.3.2, July 2011 model run, using specific rates for the urban areas of Prince William County. The Chesapeake Assessment Scenario Tool (CAST) based on the CBP's model was used to develop loadings rates for all land uses except for wetlands, the rate for which was set the same as forest land cover. Pollutant loading rates for different land cover types in the Neabsco watershed that were used to estimate pollutant loadings from the watershed are summarized in Table 8-1 for Total Nitrogen (TN), Total Phosphorus (TP) and Total Suspended Solids (TSS).

Table 8-1. CAST loading rates (lbs/acre/yr); from 2010 baseline Neabsco - Prince William County Potomac, run of 9Dec2016.

Land Use	TN	TP	TSS
Urban Impervious	13.41	1.4	1318.4
Urban Pervious	9.01	0.32	214.4
Urban Blended	9.92	0.55	442.5
Forest	2.75	0.077	54.5

8.2 ESTIMATED LOAD REDUCTIONS

The following sections present a quantitative analysis of pollutant load removal capabilities of the existing and proposed practices to ensure that the required reduction in nutrient loads from urban runoff in the Neabsco watershed can be achieved. Note that removal efficiencies used to estimate pollutant and runoff reductions are based on peer-reviewed and CBP-approved nonpoint source BMP tables developed for the Phase 5.3 CBP Watershed Model and various expert panels sponsored by the CBP as reported by the Chesapeake Stormwater Network (see http://chesapeakestormwater.net/bay-stormwater/urban-stormwater-workgroup/)

8.2.1 Stormwater Management Conversions

Preliminary investigations found that 24 dry ponds could potentially be converted to facilities with higher capacity for nutrient removal. Pollutant reductions for SW Facility conversions are calculated based on the approximate pollutant load received from the drainage area (DA) and the increase in removal efficiency (RE) based on BMP efficiencies in CAST from dry detention to a more efficient type, including bioretention, extended detention, and wetlands.

The equation used to estimate total nitrogen (TN) load reductions for BMP conversion is expressed as:

$$[13.4 \text{ (lbs/ac/yr)} * \text{IDA (ac)} + 9.1 \text{ (lbs/ac/yr)} * \text{PDA (ac)}] * \text{RE (\%)}$$

The equation used to estimate total phosphorus (TP) load reductions for BMP conversion is expressed as:

$$[1.4 \text{ (lbs/ac/yr)} * \text{IDA (ac)} + 0.32 \text{ (lbs/ac/yr)} * \text{PDA (ac)}] * \text{RE (\%)}$$

The equation used to estimate total suspended sediment (TSS) load reductions for BMP conversion is expressed as:

$$[1318 \text{ (lbs/ac/yr)} * \text{IDA (ac)} + 214 \text{ (lbs/ac/yr)} * \text{PDA (ac)}] * \text{RE (\%)}$$

The pollutant load received from the impervious (I) and pervious (P) drainage areas to the SW facility is denoted by the expression in brackets in the equations above. Similar to new BMPs, the pollutant loadings shown are the impervious and pervious urban rates used in the pollutant loading analysis since this represents the likely sources of runoff being treated. The increased pollutant removal capacity is represented by the last expression in the equations above. This is the difference between percent pollutant removal efficiencies of the facilities, based on CAST (http://www.casttool.org/Documentation.aspx). SW Facility conversion load reduction calculations are summarized by conversion type in Table 8-2 and for each facility in Table 8-3. Although we considered multiple conversion techniques for certain facilities, a single proposed BMP type was calculated and reported in Table 8-3.

Table 8-2. SW facility conversion load reductions

Pollutant	DA for SW Facility Conversion (ac)	Original RE	New RE	Increase in Efficiency	Maximum Potential Load Reduction (lbs/yr)
Convert Dry Ponds to Bioretention, No Underdrain AB soils					
TN	62.21	5%	80%	75%	486.7
TP	62.21	10%	85%	75%	31.2
TSS	62.21	10%	90%	80%	28,423
Convert Dry Ponds to Bioretention with Underdrain AB soils					
TN	71.78	5%	70%	65%	483.1
TP	71.78	10%	75%	65%	30.3
TSS	71.78	10%	80%	70%	27,725
Convert Dry Ponds to Bioretention with Underdrain CD soils					
TN	95.45	5%	20%	15%	199.2
TP	95.45	10%	45%	35%	22.4
TSS	95.45	10%	60%	50%	24,552
Convert Dry Ponds to Extended Detention Ponds					
TN	113.34	5%	20%	15%	169.6
TP	113.34	10%	20%	10%	6.3
TSS	113.34	10%	60%	50%	25,878
Convert Dry Ponds to Wetland					
TN	138.81	5%	20%	15%	215.8
TP	138.81	10%	45%	35%	31.7
TSS	138.81	10%	60%	50%	38,473

Table 8-3. SW facility conversion load reductions for individual ponds

Project Number	County ID	Proposed BMP Type	Current Type	Total Drainage Area	Impervious Area	Pervious Area	TN Reduction (lbs/yr)	TP Reduction (lbs/yr)	TSS Reduction (lbs/yr)
BCON108	617	Bioretention Underdrain A/B soils	Dry Pond	27.80	10.02	17.78	191.5	12.8	11,916
BCON110	871	Bioretention No Underdrain A/B soils	Dry Pond	25.97	6.69	19.28	197.6	11.7	10,363
BCON111	932	Bioretention Underdrain A/B soils	Dry Pond	12.77	0.85	11.92	77.2	3.3	2,574
BCON116	5035	Bioretention Underdrain A/B soils	Dry Pond	7.67	2.25	5.42	51.3	3.2	2,887
BCON120	70	Bioretention Underdrain A/B soils	Dry Pond	8.04	1.19	6.85	50.5	2.5	2,126
BCON124	873	Bioretention Underdrain C/D soils	Dry Pond	3.91	0.58	3.33	7.6	0.7	665
BCON125	872	Bioretention Underdrain C/D soils	Dry Pond	5.23	1.83	3.40	11.0	1.3	1,414
BCON101	313	Constructed Wetland	Dry Pond	25.15	11.19	13.96	41.4	7.0	8,873
BCON102	186	Constructed Wetland	Dry Pond	4.88	3.30	1.58	8.8	1.8	2,345
BCON107	88	Constructed Wetland	Dry Pond	64.54	19.32	45.22	100.0	14.5	17,583
BCON113	368	Constructed Wetland	Dry Pond	18.57	5.78	12.79	28.9	4.3	5,181
BCON118	112	Constructed Wetland	Dry Pond	48.43	5.67	42.76	69.2	7.6	8,322
BCON121	73	Constructed Wetland	Dry Pond	28.27	8.48	19.79	43.8	6.4	7,712
BCON123	803	Constructed Wetland	Dry Pond	49.63	12.39	37.24	75.3	10.2	12,160
BCON126	846	Constructed Wetland	Dry Pond	21.12	3.81	17.31	31.1	3.8	4367
BCON127	202	Constructed Wetland	Dry Pond	32.08	7.51	24.57	48.3	6.4	7,584
BCON128	685	Constructed Wetland	Dry Pond	31.86	9.88	21.98	49.6	7.3	8,869
BCON105	132	Extended Dry Detention	Dry Pond	17.79	3.21	14.58	26.2	0.9	3,679
BCON106	5048	Extended Dry Detention	Dry Pond	28.55	10.21	18.34	45.3	2.0	8,696
BCON112	5786	Extended Dry Detention	Dry Pond	10.33	6.03	4.30	17.9	1.0	4,436
BCON114	5886	Extended Dry Detention	Dry Pond	23.26	9.90	13.36	38.0	1.8	7,958
BCON115	5078	Extended Dry Detention	Dry Pond	12.98	3.51	9.47	19.9	0.8	3,329
BCON117	5036	Extended Dry Detention	Dry Pond	3.99	1.63	2.36	6.5	0.3	1,330
BCON122	121	Extended Dry Detention	Dry Pond	7.89	1.79	6.10	11.8	0.4	1,834
			TOTAL	**520.71**	**147.02**	**373.69**	**1,248**	**112**	**146,203**

8.2.2 New Stormwater Control Measures

Proposed stormwater facilities ("new BMPs") for the purposes of this watershed management plan refer to implementing BMPs to capture and treat runoff from urban pervious and impervious surfaces (e.g., parking lots) which are currently untreated. This includes a suite of sites identified for retrofit potential during field reconnaissance surveys. Pollutant and runoff reductions for stormwater retrofits are calculated based on the approximate pollutant loads received from the urban impervious and pervious drainage areas (DA) and removal efficiency (RE) of bioretention, bioswale, sand filter and other BMPs.

The equation used to estimate total nitrogen (TN) load reductions for new stormwater BMPs is expressed as:

$$[13.4 \text{ (lbs/ac/yr)} * \text{IDA (ac)} + 9.1 \text{ (lbs/ac/yr)} * \text{PDA (ac)}] * \text{RE (\%)}$$

The equation used to estimate total phosphorus (TP) load reductions for new stormwater BMPs is expressed as:

$$[1.4 \text{ (lbs/ac/yr)} * \text{IDA (ac)} + 0.32 \text{ (lbs/ac/yr)} * \text{PDA (ac)}] * \text{RE (\%)}$$

The equation used to estimate sediment load reductions for new stormwater BMPs is expressed as:

$$[1318 \text{ (lbs/ac/yr)} * \text{IDA (ac)} + 214 \text{ (lbs/ac/yr)} * \text{PDA (ac)}] * \text{RE (\%)}$$

The pollutant load received from the impervious (I) and previous (P) drainage areas to the BMP facility is denoted by the expression in brackets in the equations above. Similar to conversion of existing BMPs, the pollutant loadings shown are the impervious and pervious urban rates used in the pollutant loading analysis since this represents the likely sources of runoff being treated. The pollutant removal capacity is represented by the last expression in the equations above, based on the percent pollutant removal efficiencies of the facilities, from CAST (http://www.casttool.org/Documentation.aspx). Since proprietary devices such as a filter cartridge system are not currently credited by CBP or Virginia DEQ, these are credited only as underground storage units.

Load reduction calculations for proposed new facilities are shown in Table 8-4.

Table 8-4. Proposed stormwater retrofit load reduction

Project Name	BMP Type	Impervious Acres	Total Acres	Pervious Acres	TN Removal Efficiency	TP Removal Efficiency	TSS Removal Efficiency	TN Reduction (lbs/yr)	TP Reduction (lbs/yr)	TSS Reduction (lbs/yr)
NewBMP_104_a	Bioretention Underdrain A/B soils	2.760	4.918	2.158	70%	75%	80%	39.520	3.416	3,281.4
NewBMP_106_a	Bioretention Underdrain A/B soils	0.443	0.450	0.007	70%	75%	80%	4.204	0.467	468.4
NewBMP_107_b	Bioretention Underdrain A/B soils	0.581	0.581	0.001	70%	75%	80%	5.454	0.610	612.5
NewBMP_115_c	Bioretention Underdrain A/B soils	0.276	0.883	0.607	70%	75%	80%	6.423	0.436	395.6
NewBMP_102_a	Bioretention Underdrain C/D soils	0.345	0.515	0.170	25%	45%	55%	1.539	0.242	270.1
NewBMP_102_b	Bioretention Underdrain C/D soils	0.526	0.716	0.190	25%	45%	55%	2.192	0.359	403.8
NewBMP_105_a	Bioretention Underdrain C/D soils	1.815	2.043	0.228	25%	45%	55%	6.599	1.176	1,343.2
NewBMP_108_a	Bioretention Underdrain C/D soils	7.455	21.901	14.446	25%	45%	55%	57.532	6.777	7,109.2
NewBMP_112_a	Bioretention Underdrain C/D soils	0.194	0.219	0.024	25%	45%	55%	0.706	0.126	143.7
NewBMP_118_a	Bioretention Underdrain C/D soils	8.636	20.023	11.388	25%	45%	55%	54.601	7.080	7,604.7
NewBMP_103_a	Bioswale	0.950	1.850	0.900	70%	75%	80%	14.594	1.214	1156.4
NewBMP_105_c	Bioswale	0.000	0.852	0.852	70%	75%	80%	5.377	0.205	146.5
NewBMP_105_d	Bioswale	0.006	0.453	0.447	70%	75%	80%	2.872	0.113	82.6
NewBMP_105_f	Bioswale	0.000	1.034	1.034	70%	75%	80%	6.524	0.248	177.4
NewBMP_115_a	Bioswale	0.092	0.861	0.769	70%	75%	80%	5.713	0.281	229.1
NewBMP_115_b	Bioswale	0.721	1.164	0.443	70%	75%	80%	9.561	0.863	836.1
NewBMP_105_b	Surface Sand Filter	0.666	0.666	0.000	40%	60%	80%	3.571	0.559	702.0
NewBMP_106_b	Surface Sand Filter	0.202	0.205	0.003	40%	60%	80%	1.094	0.170	213.7
NewBMP_107_a	Surface Sand Filter	0.131	0.131	0.001	40%	60%	80%	0.704	0.110	138.1
NewBMP_111_a	Surface Sand Filter	0.368	0.368	0.000	40%	60%	80%	1.972	0.309	387.7
NewBMP_113_a	Surface Sand Filter	0.628	0.691	0.063	40%	60%	80%	3.595	0.540	673.2

Table 8-4. (Continued)										
Project Name	**BMP Type**	**Impervious Acres**	**Total Acres**	**Pervious Acres**	**TN Removal Efficiency**	**TP Removal Efficiency**	**TSS Removal Efficiency**	**TN Reduction (lbs/yr)**	**TP Reduction (lbs/yr)**	**TSS Reduction (lbs/yr)**
NewBMP_105_e	Underground Storage and Filter Cartridge System	9.457	10.793	1.336	5%	10%	10%	6.943	1.367	1,275.5
NewBMP_110_a	Underground Storage and Filter Cartridge System	0.568	0.640	0.072	5%	10%	10%	0.413	0.082	76.5
NewBMP_114_a	Underground Storage and Filter Cartridge System	2.238	3.161	0.923	5%	10%	10%	1.917	0.343	314.9
	TOTAL	**39.058**	**75.112**	**36.061**				**243.621**	**27.092**	**28,042.2**

8.2.3 Stream Buffer Reforestation

The current vegetative condition of the stream riparian buffer (at least 100 feet on either side of the stream system) was analyzed in Chapter 4 and evaluated for reforestation opportunities during field investigations. Buffer conditions were classified as impervious, open pervious, or forested areas. Open pervious areas were identified as candidate areas to initially target for restoration, prior to field assessments. In all, approximately 2.6 acres of open pervious area (along 690 feet of stream length) were identified for riparian reforestation.

Pollutant and runoff reductions for stream buffer reforestation are calculated based on a land use conversion from pervious urban to forest plus an additional reduction efficiency per BMP performance guidance from CBP (see http://www.chesapeakebay.net/documents/SB_Documentation_V24_01_04_2013.pdf, and http://www.chesapeakebay.net/documents/UFS_SBU_Expert_Panel_Draft_Report_Decision_Draft_FINAL_WQ_GIT_APPROVED_JUNE_9_2014.pdf.) The equation used to estimate total nitrogen (TN) load reductions for the land use conversion portion of stream buffer reforestation is expressed as:

Land Use Conversion (TN) = [9.0 (lbs/ac/yr) – 2.8 (lbs/ac/yr)] * Open Pervious Area (ac)

The equation used to estimate total phosphorus (TP) load reductions for the land use conversion portion of stream buffer reforestation is expressed as:

Land Use Conversion (TP) = [0.32 (lbs/ac/yr) – 0.08 (lbs/ac/yr)] * Open Pervious Area (ac)

The equation used to estimate sediment load reductions for the land use conversion portion of stream buffer reforestation is expressed as:

Land Use Conversion (sediment) = [214 (lbs/ac/yr) – 55 (lbs/ac/yr)] * Open Pervious Area (ac)

The first expression in brackets in the equation above represents the difference between pervious urban and forest loading rates used in the watershed pollutant loading analysis. This reduction in loading rate is then multiplied by the available open pervious area for reforestation to determine the loads from land use conversion.

An additional pollutant removal factor is added to the land use conversion to determine the total removal capacity of buffer reforestation for nutrients and sediment. Per the CBP BMP performance guidance, one acre of buffer treats approximately one acre of upland area for nitrogen with an efficiency of 25 percent for urban and mixed open buffers. The total nitrogen (TN) load reduction for the removal efficiency portion of buffer reforestation can be expressed as:

Buffer BMP Removal (TN) = [Open Pervious Area (ac)] * 9.9 (lbs/ac/yr) * 25%

Similarly, one acre of buffer treats approximately one acre of upland area for phosphorus with an efficiency of 50 percent for urban and mixed open buffers. The total phosphorus (TP) load reductions for the removal efficiency portion of buffer reforestation can be expressed as:

Buffer BMP Removal (TP) = [Open Pervious Area (ac) * 0.55 (lbs/ac/yr] * 50%

Similarly, one acre of buffer treats approximately one acre of upland area for sediment with an efficiency of 50 percent for urban and mixed open buffers. The sediment load reductions for the removal efficiency portion of buffer reforestation can be expressed as:

Buffer BMP Removal (sediment) = [Open Pervious Area (ac) * 442.5 (lbs/ac/yr] * 50%

The loading rates shown in the equation above, 9.9 lbs TN/ac/yr, 0.55 TP/ac/yr, and 442.5 lbs sediment/ac/yr, represent the area-weighted average of urban impervious and pervious watershed loading rates, as the likely land use draining through the stream buffer. The land use conversion and additional removal efficiency are added to yield a total pollutant load reduction. A summary of stream buffer reforestation reduction calculations and results are shown in Table 8-5.

Table 8-5. Stream buffer reforestation load reductions

Site ID	Total Area (acres)	Riparian Length (ft)	Land Use Conversion			Buffer Efficiency			TOTAL		
			TN Reduction (lbs/yr)	TP Reduction (lbs/yr)	TSS Reduction (lbs/yr)	TN Reduction (lbs/yr)	TP Reduction (lbs/yr)	TSS Reduction (lbs/yr)	TN Reduction (lbs/yr)	TP Reduction (lbs/yr)	TSS Reduction (lbs/yr)
RFOR102	0.174	130	1.09	0.04	28	0.43	0.05	38.48	1.52	0.09	66.29
RFOR103	0.253	95	1.58	0.06	40	0.63	0.07	55.86	2.21	0.13	96.24
RFOR104	0.250	75	1.56	0.06	40	0.62	0.07	55.25	2.18	0.13	95.18
RFOR105	0.324	50	2.03	0.08	52	0.80	0.09	71.59	2.83	0.17	123.33
RFOR107	0.197	25	1.23	0.05	31	0.49	0.05	43.53	1.72	0.10	74.99
RFOR108	0.234	75	1.47	0.06	37	0.58	0.06	51.83	2.05	0.12	89.29
RFOR109	0.404	20	2.53	0.10	65	1.00	0.11	89.43	3.53	0.21	154.07
RFOR110	0.247	20	1.54	0.06	39	0.61	0.07	54.55	2.16	0.13	93.98
RFOR111	0.092	20	0.58	0.02	15	0.23	0.03	20.32	0.80	0.05	35.01
RFOR112	0.237	55	1.49	0.06	38	0.59	0.06	52.54	2.08	0.12	90.51
RFOR113	0.195	125	1.22	0.02	31	0.48	0.05	43.17	1.71	0.10	74.37
TOTAL	**2.606**	**690**	**16.31**	**0.63**	**417**	**6.46**	**0.71**	**577**	**22.78**	**1.34**	**993**

8.2.4 Upland Reforestation

Open upland areas with reforestation potential have been identified in the Neabsco watershed equaling 43.7 acres. Pollutant and runoff reductions for upland reforestation are calculated based on land use conversion from pervious urban to forest. The equation used to estimate total nitrogen (TN) load reductions for upland reforestation is expressed as:

Land Use Conversion (TN) = [9.0 (lbs/ac/yr) – 2.8 (lbs/ac/yr)] * Open Pervious Area (ac)

The equation used to estimate total phosphorus (TP) load reductions for the land use conversion portion of stream buffer reforestation is expressed as:

Land Use Conversion (TP) = [0.32 (lbs/ac/yr) – 0.08 (lbs/ac/yr)] * Open Pervious Area (ac)

The equation used to estimate sediment load reductions for the land use conversion portion of stream buffer reforestation is expressed as:

Land Use Conversion (sediment) = [214 (lbs/ac/yr) – 55 (lbs/ac/yr)] * Open Pervious Area (ac)

Upland reforestation would involve converting open pervious area to forest. Therefore, the loading rate would be reduced by a factor equal to the difference between the existing pervious urban and forest loading rates used in the watershed pollutant analysis as shown in the first expression in brackets in the equations above. The approximate reduction in pollutant load and runoff volume is then the reduced loading rate multiplied by the open pervious area available for reforestation. A summary of upland (pervious area) reforestation reduction calculations and results are shown in Table 8-6. This table contains one “R” site that, despite its initial designation, did not result in recommended planting areas within 100’ of a stream.

Table 8-6. Upland Reforestation Load Reductions

Site ID	Total Area (acres)	Land Use Conversion		
		TN Reduction (lbs/yr)	TP Reduction (lbs/yr)	TSS Reduction (lbs/yr)
RFOR106	0.104	0.65	0.03	17
UFOR101	2.313	14.48	0.56	370
UFOR102	1.367	8.56	0.33	219
UFOR103	0.149	0.93	0.04	24
UFOR104	2.709	16.96	0.66	433
UFOR105	1.446	9.05	0.35	231
UFOR106	0.638	4.00	0.16	102
UFOR107	1.092	6.83	0.27	175
UFOR108	0.878	5.50	0.21	140

Table 8-6. (Continued)				
		Land Use Conversion		
Site ID	Total Area (acres)	TN Reduction (lbs/yr)	TP Reduction (lbs/yr)	TSS Reduction (lbs/yr)
UFOR109	1.079	6.76	0.26	173
UFOR110	0.793	4.97	0.19	127
UFOR111	1.554	9.73	0.38	249
UFOR112	1.228	7.69	0.30	196
UFOR113	0.467	2.93	0.11	75
UFOR114	0.601	3.76	0.15	96
UFOR115	0.313	1.96	0.08	50
UFOR116	0.929	5.81	0.23	149
UFOR118	2.094	13.11	0.51	335
UFOR119	2.388	14.95	0.58	382
UFOR120	0.183	1.15	0.04	29
UFOR121	1.139	7.13	0.28	182
UFOR123	0.621	3.89	0.15	99
UFOR124	7.091	44.39	1.72	1,134
UFOR126	1.344	8.42	0.33	215
UFOR127	0.363	2.27	0.09	58
UFOR128	0.231	1.45	0.06	37
UFOR132	0.931	5.83	0.23	149
UFOR133	0.658	4.12	0.16	105
UFOR134	5.922	37.07	1.44	947
UFOR135	0.548	3.43	0.13	88
UFOR136	0.358	2.24	0.09	57
UFOR137	0.103	0.64	0.02	16
UFOR139	1.350	8.45	0.33	216
UFOR141	0.721	4.51	0.18	115
TOTAL	**43.708**	**273.61**	**10.62**	**6,989**

8.2.5 Stream Restoration

Preliminary analysis showed several sites, identified during the stream assessments, where stream restoration could potentially be employed to address stream stability issues (i.e., significant erosion and channel alterations) and improve water quality. These sites are discussed in Section 6.5. Pollutant load reduction estimates in pounds per linear foot of stream restoration were developed by Schueler and Stack (2014). These were also used to calculate load reductions for proposed stream restoration activities (i.e., restoration lengths (RL)) in the Neabsco watershed. The equation used to estimate total nitrogen (TN) reductions for stream restoration is expressed as:

$$0.075 \text{ (lbs/ft)} * RL \text{ (ft)}$$

The equation used to estimate total phosphorus (TP) load reductions for stream restoration is expressed as:

$$0.068 \text{ (lbs/ft)} * RL \text{ (ft)}$$

The equation used to estimate sediment load reductions for stream restoration is expressed as:

$$44.88 \text{ (lbs/ft)} * RL \text{ (ft)}$$

Edge-of-Stream interim removal rates per linear foot of qualifying stream restoration were obtained from Table 3 in Schueler and Stack (2014). These may need revision once specific designs are developed for each site.

Potential stream restoration sites were identified for stream lengths totaling up to 18,770 feet. A summary of stream restoration reduction calculations and results are shown in Table 8-7.

Table 8-7. Stream corridor restoration load reduction

Site ID	Length (mi)	Length (ft)	TN Reduction (lbs/yr)	TP Reduction (lbs/yr)	Sediment Reduction (lbs/yr)
RST2501	0.095	502	37.7	34.2	22,542
RST2601	0.160	844	63.3	57.4	37,886
RST2602	0.299	1,579	118.5	107.4	70,883
RST2603	0.477	2,520	189.0	171.4	113,110
RST2604	0.231	1,218	91.4	82.9	54,683
SA503	0.178	941	70.6	64.0	42,221
SA710	0.282	1,487	111.5	101.1	66,719
SA711	0.203	1,072	80.4	72.9	48,090
SR001	0.495	2,615	196.1	177.8	117,361
SR108	0.329	1,737	130.3	118.1	77,962
SR300	0.254	1,340	100.5	91.1	60,129
SR301	0.139	736	55.2	50.1	33,052
SR700	0.268	1,415	106.1	96.2	63,491
SR701	0.068	357	26.8	24.3	16,024
SR963	0.077	407	30.5	27.7	18,255
TOTAL	**3.555**	**18,770**	**1,407.8**	**1,276.4**	**842,407**

8.2.6 Regenerative Stormwater Conveyance

Regenerative Stormwater Conveyance (RSC) practices are a type of outfall stabilization that can be used for retrofitting unstable and degraded stormwater conveyance channels and receive nutrient and sediment reduction credits. When these practices are used in ephemeral or dry channels as retrofits to capture the runoff from one inch of rainfall, the pollutant removal efficiencies from the most similar BMP type may be used. The stream restoration panel decided, and the other panels concurred, that dry-channel regenerative stormwater conveyance projects could be treated as an upland BMP to treat runoff from new development projects or as a new retrofit to treat existing development (Schueler and Lane, 2015). In both cases, the removal rate is determined by using the Runoff Reduction curve for the depth of runoff treated per impervious acre.). The RSC performs very similar to a filtration practice, therefore, the pollutant removal efficiencies can be applied to the drainage area treated assuming a 1" runoff treatment depth. The equation used to estimate nutrient and sediment load reductions for RSC practices is expressed as:

The equation used to estimate total nitrogen (TN) load reductions for RSC is expressed as:

$$[13.4 \text{ (lbs/ac/yr)} * \text{IDA (ac)} + 9.1 \text{ (lbs/ac/yr)} * \text{PDA (ac)}] * 69.9 \text{ (\%)}$$

The equation used to estimate total phosphorus (TP) load reductions for RSC is expressed as:

$$[1.4 \text{ (lbs/ac/yr)} * \text{IDA (ac)} + 0.32 \text{ (lbs/ac/yr)} * \text{PDA (ac)}] * 59.8 \text{ (\%)}$$

The equation used to estimate sediment load reductions for new stormwater RSC is expressed as:

$$[1318 \text{ (lbs/ac/yr)} * \text{IDA (ac)} + 214 \text{ (lbs/ac/yr)} * \text{PDA (ac)}] * 74.9 \text{ (\%)}$$

The pollutant load received from the impervious (I) and previous (P) drainage areas to the BMP facility is denoted by the expression in brackets in the equations above. Similar to new BMPs, the pollutant loadings shown are the impervious and pervious urban rates used in the pollutant loading analysis since this represents the likely sources of runoff being treated. The pollutant removal capacity is represented by the last expression in the equations above, based on the percent pollutant removal efficiencies of the facilities, from the Runoff Reduction equations assuming a 1" runoff treatment depth (equations from Schueler and Lane, 2015).

Load reduction calculations for proposed new facilities are shown in Table 8-8.

Table 8-8. Regenerative stormwater conveyance load reductions

Outfall ID	County ID	Outfall Length (ft)	Upstream Drainage Areas (acres)	Upstream Impervious Area (acres)	Upstream Pervious Area (acres)	TN Reduction (lbs/yr)	TP Reduction (lbs/yr)	TSS Reduction (lbs/yr)
OUTF102	50063	41	14.69	4.21	10.48	90.12	6.46	5,837
OUTF110	1243	246	22.60	9.56	13.04	146.79	12.27	11,537
OUTF111	2645	155	9.97	3.85	6.12	63.77	5.13	4,781
OUTF117	9795	244	42.82	13.65	29.17	266.40	19.88	18,164
OUTF119	2573	412	53.44	14.56	38.89	325.97	22.94	20,621
OUTF132	15647	179	102.59	37.38	65.20	650.56	51.17	47,394
OUTF140	46501	152	30.30	13.87	16.42	199.59	17.25	16,340
OUTF141	54818	81	14.94	6.86	8.08	98.44	8.52	8,070
TOTAL		**1,509**	**291.3**	**103.9**	**187.4**	**1841.6**	**143.6**	**132,743**

CHAPTER 9: RESTORATION PROJECT RANKING AND PRIORITIZATION

9.1 RANKING METHODS – OVERVIEW

During the various field assessments, crews determined which locations were best suited for potential projects, as reported in Chapter 7. In all, 125 potential projects were identified. The large list of possible projects generated, as well as the multiple goals this watershed assessment aims to address (e.g., impervious surface treatment, pollutant reductions, etc.), makes it challenging to select the best projects for implementation. To address this challenge, an automated, standardized method was developed for comparing, ranking, and prioritizing the projects. This method relied on a combination of data collected in the field, the known costs and benefits of various BMP types, and GIS analyses. The method was applied to select a set of projects for which restoration was recommended.

Each project was ranked against all other projects of the same type. This will allow Prince William County, for example, to target grant funding that must be applied to forest canopy improvement to the areas in the watershed that were identified as having the best tree planting opportunities. This type of ranking also allows for the incorporation of more specialized ranking factors. For example, the length and severity of erosion at an outfall is a useful way to compare stabilization projects, but would not apply to rankings that also include tree planting sites or locations for new BMP installations.

Some factors were generally applicable across all project types (see details noted as level "A" in tables in Section 9.2). Level "A" factors were divided into four main categories:

- Pollutant reduction benefit – how a project will help towards meeting Countywide goals for nutrient and sediment load reductions
- Biological uplift – if a project will provide additional benefits, such as building onto existing green infrastructure or protecting wetlands
- Programmatic benefit – if a project has value beyond its primary functional purpose, such as visible demonstration projects or public education. The proximity, or clustering score was assigned to all sites belonging to a cluster, where a cluster was defined as 3 or more sites of any type within 500 feet of each other.
- Feasibility – estimation of the ease or difficulty of project implementation, including public versus private ownership, site accessibility, or whether a repair is already required at a site providing an opportunity to minimize costs by upgrading the facility during the course of other required construction activities

Each factor was scored according to various criteria (see Tables in Section 9.2). The sum of all the factor scores was used to rank each project, with higher total scores representing higher priority projects. Tables of all projects, with scores, are found in Chapter 7.

9.2 RANKING AND PRIORITIZATION WITHIN PROJECT TYPES

9.2.1 SW Facility Conversions and New BMPs

The similar nature of these two project categories led to them sharing a set of ranking criteria, though they were ranked separately. Prior to scoring and ranking, some projects were eliminated from the candidate pool. Pond conversion candidates that seemed to be naturally converting to a wetland facility were not included in the ranking, as it was unlikely that the County would want to disturb an area that was already providing additional water quality benefits.

	Factor	Criteria	Score
A.	**Factors for all site types**		
	1. Pollutant reduction benefit		
1.a	Acres of impervious treatment (Total acres used for new BMPs)	> 10 acres (>8 for new BMP)	20
		5 - 10 acres (3-8 for new BMP)	15
		1 - 5 acres (1-3 acres for new BMP)	10
		< 1 acre	5
1.b	Pollutant load reduction factor (Sum of % load reductions for TN, TP, and sediment) Calculated as the difference from current treatment for SW Facility Conversions.	>200	10
		100-200 (125-200 for new BMP)	6
		<100 (<125 for new BMP)	3
1.c	Cost per acre of impervious treatment SW Facility conversion costs derived from the Loudon County 2013 Phase II WIP New BMP costs derived from King and Hagan's 2011 "Costs of Stormwater Management Practices in Maryland Counties"	< $50,000 (<$20k for new BMP)	10
		$50,000 - $100,000 ($20-40k for new BMP)	8
		$100,000 - $200,000 ($40-100k for new BMP)	5
		> $200,000 (>$100k for new BMP)	2
	2. Ecological uplift		
2.a	Significant erosion at outfall (for SW Facility Conversions only)	Yes	5
		No	0
2.b	Facility is not currently classified as BMP (for SW Facility Conversions only)	Yes	5
		No	0
	3. Programmatic benefit		
3.a	Site has educational value and/or is visible for public demonstration	Yes	2
3.b	Site is near 2 or more other potential projects allowing for easier monitoring and demonstration of benefit (Clustering)	Yes	3

	Factor	Criteria	Score
	4. Feasibility		
4.a	Ease of access	Easy	10
		Moderate	6
		Difficult	3
4.b	Conflicts with infrastructure or other site constraints	None	10
		Some	6
		Many	3
4.c	Adverse impacts to nearby trees	Minimal	10
		Moderate	6
		Significant	3
4.d	Ownership / Maintenance	Public / Public	10
		Private / Public	8
		Private / Private	0
4.e	Pond/infrastructure already in need of repair	Yes	15
4.f	Field assessment – high potential for restoration/retrofit	Yes	5

9.2.2 Reforestation

In the case of reforestation projects, there were a few minor variations from the standard factor scoring. In the case of structural and pond BMPs, there are many different types, allowing for a wide range of pollutant reduction efficiencies per drainage acre and costs per unit treatment across different projects. In the case of reforestation projects, these values would be the same across all projects; for this reason, factors 1.b and 1.c were not scored. Additionally, for reforestation projects, where the impact to surrounding trees would not be a concern, the level of site preparation required for planting was substituted as a factor (see 4.c).

	Factor	Criteria	Score
A.	**Factors for all site types**		
	1. Pollutant reduction benefit		
1.a	Acres of planting area	> 1.20 acres	20
		0.80 – 1.20 acres	15
		0.40 - 0.80 acres	10
		< 0.40 acres	5
	2. Ecological uplift		
2.a	Planting is within 100 feet of wetlands	Yes	5
		No	0
2.b	Area is turf and riparian	Yes	5
		No	0
	3. Programmatic benefit		
3.a	Site has educational value/visible for public demonstration	Yes	2
3.b	Site is near 2 or more other potential projects allowing for easier monitoring and demonstration of benefit (Clustering)	Yes	3

	Factor	Criteria	Score
	4. Feasibility		
4.a	Ease of access	Easy	10
		Moderate	6
		Difficult	3
4.b	Conflicts with infrastructure or other site constraints	None	10
		Some	6
		Many	3
4.c	Site preparation required before planting	None	10
		Minimal	8
		Moderate	5
		Extensive	0
4.d	Ownership – public vs. private	Public / County	10
		Hylton / HOA	5
		Private	0
4.e	County Designated Priority (taken from Site Selection)	High	5
		OK	2
		Low	0
4.f	Field assessment – high potential for restoration/retrofit	Yes	5

9.2.3 Outfall Stabilizations

Outfall stabilization projects, for the purposes of ranking, were divided into broad categories: traditional stabilizations (e.g., rip-rap); regenerative stormwater conveyances (RSC); and other (e.g. Drop Structures). These three methods of stabilization vary greatly from one another in both cost and benefit and were thus used to help differentiate the projects in scoring. Beyond the standard level ranking factors (A), an additional factor (B) was included to characterize the length and severity of erosion each project would address.

	Factor	Criteria	Score
A.	**Factors for all site types**		
	1. Pollutant reduction benefit		
1.a	Length of outfall stabilization (feet)	> 500 feet	20
		125-500 feet	15
		50-125 feet	10
		< 50 feet	5
1.b	Pollutant load reduction factor (Note: standard outfall stabilizations receive no pollution reduction credits)	RSC	10
		All other types	0
1.c	Cost per length of treatment (Note: Riprap is the less expensive option and receives more points)	Riprap	10
		RSC	3
		Other	0
	2. Ecological uplift		
2.a	Stabilization is within 100 feet of wetlands	Yes	5
		No	0

	Factor	Criteria	Score
	3. Programmatic benefit		
3.a	Site has educational value/visible for public demonstration	Yes	2
3.b	Site is near 2 or more other potential projects allowing for easier monitoring and demonstration of benefit (Clustering)	Yes	3
	4. Feasibility		
4.a	Ease of access	Easy	10
		Moderate	6
		Difficult	3
4.b	Conflicts with infrastructure or other site constraints	None	10
		Some	6
		Many	3
4.c	Adverse impacts to nearby trees	Minimal	10
		Moderate	6
		Significant	3
4.d	Ownership – public vs. private	Public	10
		Private, other	0
4.e	Outfall/infrastructure already in need of repair	Yes	15
4.f	Field assessment – high potential for restoration/retrofit	Yes	5
4.g	Site may be candidate for level spreader	Yes	2
B.	**Erosion factor**		
1	Length and severity of erosion (Length of erosion in feet x erosion severity rating)	> 1,000	15
		500 – 1,000	10
		< 500	5

9.2.4 Stream Restorations

As noted for the tree planting project ranking, pollutant reduction efficiencies and costs per unit treatment are the same among all stream restoration projects, and therefore 1.b and 1.c were not scored. Beyond the standard level "A" ranking factors, two additional levels of factors were incorporated into the stream restoration prioritization. A level "B" factor was included, similar to that used for the outfall stabilization ranking, which characterizes the length and severity of erosion each project would be able to address. Three level "C" factors were also included, which address factors unique to streams, such as habitat quality and other problems identified during stream corridor assessments.

	Factor	Criteria	Score
A.	**Factors for all site types**		
	1. Pollutant reduction benefit		
1.a	Length of proposed restoration (miles)	> 0.40 miles	20
		0.25-0.40 miles	15
		0.10-0.25 miles	10
		<0.10 miles	5
	2. Ecological uplift		
2.a	Restoration is within 100 feet of wetlands	Yes	5
		No	0
	3. Programmatic benefit		
3.a	Site has educational value/visible for public demonstration	Yes	2
3.b	Site is near 2 or more other potential projects allowing for easier monitoring and demonstration of benefit (Clustering)	Yes	3
	4. Feasibility		
4.a	Ease of access	Easy	10
		Moderate	6
		Difficult	3
4.b	Conflicts with infrastructure or other site constraints	None	5
		Some	3
		Many	1
4.c	Adverse impacts to nearby trees	Minimal	10
		Moderate	6
		Significant	3
4.d	Ownership: Will the project limit of disturbance affect private residences?	No	10
		Yes (<5 owners)	5
		Yes (>5 owners)	0
4.e	Field assessment – high potential for instream restoration	Yes	5
	B. Erosion factor		
1	Erosion Severity Factor (Length of restoration (miles) x erosion severity rating. Severity rating derived from Channel Shape and Downcutting metrics, higher value represents lower RSAT scores)	> 4.0	20
		2.0-4.0	15
		1.20-2.0	10
		<1.20	5
	C. Stream condition factors		
1	RSAT Bank Factor This factor represents "distance from ideal conditions" for the bank stability (BS) metrics. Maximum score for BS (of 10) minus the average score of the six BS metrics measured	>6.50	20
		6.00-6.50	15
		5.00-6.00	10
		<5.00	5
2	RSAT Riparian Habitat Factor This factor represents "distance from ideal conditions" for the Riparian Habitat (RH) metrics. Maximum score for RH (of 10) minus the average score of the three RH metrics measured	>6.50	20
		6.00-6.50	15
		5.00-6.00	10
		<5.00	5

	Factor	Criteria	Score
3	RSAT Aquatic Habitat Factor This factor represents "distance from ideal conditions" for the aquatic habitat (AH) metrics. Maximum score for AH (of 7) minus the average score of the five AH metrics measured	>6.50	20
		6.00-6.50	15
		5.00-6.00	10
		<5.00	5
4	Number of other issues along reach (exposed pipes, pipe outfalls, inadequate buffers, extreme erosion, unusual conditions, etc.)	Other issues > 2	10
		Other issues = 2	5
		Other issues < 2	0

CHAPTER 10: REFERENCES

Anne Arundel County (Maryland). 2012. Regenerative Step Pool Storm Conveyance (SPSC) Design Guidelines. Anne Arundel County Government, Department of Public Works, Bureau of Engineering. Available at: http://www.aacounty.org/departments/public-works/wprp/watershed-assessment-and-planning/step-pool-conveyance-systems/

Center for Watershed Protection (CWP). 2005. Unified Subwatershed and Site Reconnaissance: A User's Manual. Version 2.0. Available at: http://owl.cwp.org/mdocs-posts/urban-subwatershed-restoration-manual-series-manual-11/

Center for Watershed Protection (CWP). 2006. Urban Watershed Forestry Manual. Part 3: Urban Tree Planting Guide. Center for Watershed Protection, Ellicott City, MD.

Center for Watershed Protection (CWP). 2007. Urban Subwatershed Restoration Manual 3: Urban Stormwater Retrofit Practices. Center for Watershed Protection. Ellicott City, MD. August.

Dale City Civic Association. 2016. History of Dale City. Available at: http://www.dalecitycivic.org/pages/about.html. (accessed April 7, 2016).

Giddings, E.M.P, A.H. Bell, K.M. Beaulieu, T. F. Cuffney, J.F. Coles, L.R. Brown, F.A. Fitzpatrick, J. Falcone, L.A. Sprague, W.L. Bryant, M.C. Peepler, C. Stephens, and G. McMahon. 2009. Selected Physical, Chemical, and Biological Data Used to Study Urbanizing Streams in Nine Metropolitan Areas of the United States, 1999-2004. U.S. Geological Survey Data Series 423. Available at: http://pubs.usgs.gov/ds/423/index.html.

Imhoff, M., W. Lawrence, D. Stutzer, and C. Elvidge. 1998. "Assessing the Impact of Urban Sprawl on Soil Resources in the United States Using Nighttime 'City Lights' Satellite Images and Digital Soils Maps." *Perspectives on the Land Use History of North America: A Context for Understanding Our Changing Environment.* Ed. Thomas Sisk. Biological Science Report USGS/BRD/ITR–1998-003, developed by the U.S. Geological Survey, Biological Resources Division, and the U.S. Department of the Interior.

King, D. and P. Hagan. 2011. Costs of Stormwater Management Practices in Maryland Counties. University of Maryland Center for Environmental Science. Technical Report Series No. TS-626-11. Solomons, MD.

Linker, L., and G. Shenk. 2013. Development and Application of the 2010 Chesapeake Bay Watershed Total Maximum Daily Load Model. Journal of the American Water Resources Association. 49(5): 981–1224. Available at: http://onlinelibrary.wiley.com/doi/10.1111/jawr.12109/full

Pachhai, B. 2013. Evolution of Stormwater Management in Communities. Presentation given by Bel Pachhai of the Watershed Management Branch of the Prince William County Government on September 5, 2013 in Manassas, VA. Retrieved from the Prince William Conservation Alliance Web site on March 22, 2016. (http://www.pwconserve.org/streamstewards/stormwater_pachhai_2013.html)

Phinney, S. 1995. "Woodbridge is 200 Years Old!" Obtained from the Historic Prince William Web site on March 23, 2016. (http://www.historicprincewilliam.org/county-history/stories/woodbridge-is-200.html)

Prince William Conservation Alliance. Undated. Neabsco Creek. Prince William Conservation Alliance, Woodbridge, VA. http://www.pwconserve.org/issues/watersheds/neabscocreek/index.htm (accessed February 24, 2016).

Prince William County (Virginia). 2008. 2008 Comprehensive Plan for Prince William County, Virginia. Prince William County Office of Planning, Prince William, VA.

Prince William County (Virginia). 2015. Prince William County Design and Construction Standards Manual (original effective date, February 1, 1981). Section 700; updated and effective August 13, 2015. Development Services, Land Development Division. Prince William, VA. Available from http://www.pwcgov.org/government/dept/development/ld/Documents/005015.pdf.

Schueler, T., L. Fraley-McNeal, and K. Cappiella. 2009. Is Impervious Cover Still Important? Review of Recent Research. Journal of Hydrologic Engineering 14(4): 309-315.

Schueler, T., and B. Stack. 2014. Recommendations of the Expert Panel to Define Removal Rates for Individual Stream Restoration Projects. Available at: http://chesapeakestormwater.net/wp-content/uploads/dlm_uploads/2013/05/stream-restoration-merged.pdf), as of 3January2017

Schueler, T., and C. Lane. 2015. Updated Frequently Asked Questions (FAQ) for Stormwater Retrofits and Urban BMPs Built to State Stormwater Performance Standards. Available at: http://chesapeakestormwater.net/download/3809/, as of 3January2017.

United States Department of Agriculture (USDA). 2007. Hydrology National Engineering Handbook; Chapter 7, Hydrologic Soil Groups. USDA Publication 210-VI-NEH. United States Department of Agriculture, Washington, D.C.

United States Department of Agriculture (USDA). 2011. A Guide to Hydric Soils in the Mid-Atlantic Region. Version 2.0. Mid-Atlantic Hydric Soils Committee, United States Department of Agriculture, Washington, D.C.

United States Environmental Protection Agency (U.S. EPA). 1994. New Watershed Approach in Prince William County. Office of Water, Watershed Events, September. EPA 840-N-94-002.

Virginia Department of Environmental Quality. 2008. Bacteria TMDL for Neabsco Creek Prince William County, Virginia. Submitted by the Virginia Department of Environmental Quality (to the U.S. Environmental Protection Agency). Richmond, VA.