POLICY AND GOVERNANCE OF WATER RESOURCES IN THE NATIONAL PARK SYSTEM: A CASE STUDY OF FIRST STATE NATIONAL HISTORICAL PARK ALONG THE BRANDYWINE RIVER

by

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A thesis submitted to the Faculty of the University of Delaware in partial fulfillment of the requirements for the degree of Master of Science in Water Science and Policy

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LIST OF ABBREVIATIONS

ANC: Acid Neutralizing Capacity

BIBI: Benthic Index of Biotic Integrity

DEP: Department of Environmental Protection

DGS: Delaware Geological Survey

DNREC: Delaware Department of Natural Resources and Environmental Control

DO: Dissolved Oxygen

DOC: Dissolved Organic Carbon

EPA: Environmental Protection Agency

EVW: Exceptional Value Waters

MBSS: Maryland Biological Stream Survey

NHP: National Historical Park

NP: Nitrogen Phosphorus

NPS: National Park Service

PHI: Physical Habitat Index

SC: Specific Conductance

TAN: Total Ammonia Nitrogen

TDS: Total Dissolved Solids

TMDL: Total Maximum Daily Load

TN: Total Nitrogen

TP: Total Phosphorus

UDWRC: University of Delaware Water Resources Center

ABSTRACT

The United States National Park Service is required to manage the water resources of the National Park System in accordance with applicable federal and state laws and regulations and programs that have been established to assist in the management of the park's water resources. The Inventory and Monitoring Program is responsible for the inventorying and monitoring of natural resources under the National Park Service. There are 32 program networks that are responsible for performing Natural Resource Condition Assessments which are used by park managers and employees to complete a State of the Park Report. The condition and reporting of water resources and approaches to water resources management of First State National Historical Park is compared to Valley Forge, Minute Man, and Harpers Ferry National Historical Parks. The policies, management approaches, and scientific information of water resources is conveyed in Natural Resource Condition Assessments and State of the Park Reports that differs among First State and other historical parks due to their location and classification. All four national historical parks are affected by activities outside of the park, so they depend on public and private partnerships to help manage the park's water resources. In Minute Man and Valley Forge National Historical Parks, the condition status/trend of water resources was displayed graphically in terms of spatial and temporal trends.

Chapter 1

INTRODUCTION

1.1 Research Objectives and Scope

The goal of this research is to conduct a comparative analysis of structures and programs of monitoring, reporting, and managing water resources in the First State National Historical Park in Delaware and Pennsylvania as compared to other national historical parks. Much attention has been given to water resource management, but there has been little to no scholarly literature focusing specifically on the approaches to water resources management within the national historical parks of the United States.

This research identifies the condition, monitoring, reporting, and approaches to water resources management of national historical parks at First State (DE), Valley Forge (PA), Minute Man (MA), and Harpers Ferry (WV) in the northeastern U.S. (Figure 1.1). The research identifies the differences in water quality standards, the condition and status of water resources, and monitoring and reporting of water resources among these four national historical parks. Valley Forge, Minute Man, and Harpers Ferry were chosen for comparison to First State National Historical Park due to their similar designation as national historical parks. These three historical parks are similar in size to First State NHP and are located in the northeastern United States with similar climate and geography.

The focus of this research is First State National Historical Park, situated along the Brandywine River in Delaware and Pennsylvania. First State is Delaware's first

and only national historical park and was designated as a National Monument in 2013 and later designated a National Historical Park in 2015. The main focus in planning for the new First State National Historical Park is to establish a general management plan for the park, which will provide foresight for how to strategically manage the parks resources, engage the community and youth, and build partnerships. As First State NHP is in its infancy, this research will hopefully provide meaningful information on monitoring, reporting and conveying complex information on water resources to the public and uses of the historical park.

1.2 Research Questions

Monitoring, reporting, policies, and management of water resources vary among units managed by the National Park Service due to their location, size, status, and condition. Water quality standards are provisions of federal or state law approved by Environmental Protection Agency that "describe the desired condition of a waterbody or the level of protection or mandate how the desired condition will be expressed or established for such waters in the future" (EPA, 2016). Water quality standards vary between states and the National Park Service is required to meet the state requirements where the park is located. Therefore, the approach to managing water resources may differ among national park sites due to their location. This research will attempt to answer the following questions:

1. How are water resources science and policies managed in watersheds in the National Park System?
2. How do water resources policies and management vary among Valley Forge, Harpers Ferry, and Minute Man National Historical Parks as compared to First State National Historical Park in Delaware?

The objective of this paper is to compare the programs, monitoring, reporting, standards, policies, and approaches to water resources management of First State National Historical Park to other historical parks, particularly Valley Forge, Harpers Ferry, and Minute Man National Historical Parks.

1.3 Thesis Organization

This thesis is organized as follows:

Chapter 1: Introduces and describes the research goals and objectives.

Chapter 2: Provides a broad overview of the mission, history, organization, and policies and laws of the National Park Service.

Chapter 3: Briefly discusses the history and physical characteristics of First State National Historical Park.

Chapter 4: Discusses water quality monitoring in First State National Historical Park.

Chapter 5: Examines water-related laws, standards, programs, monitoring networks, and reports of National Park Units.

Chapter 6: Provides conclusions and recommendations for future research related to water resources management in the National Park System.

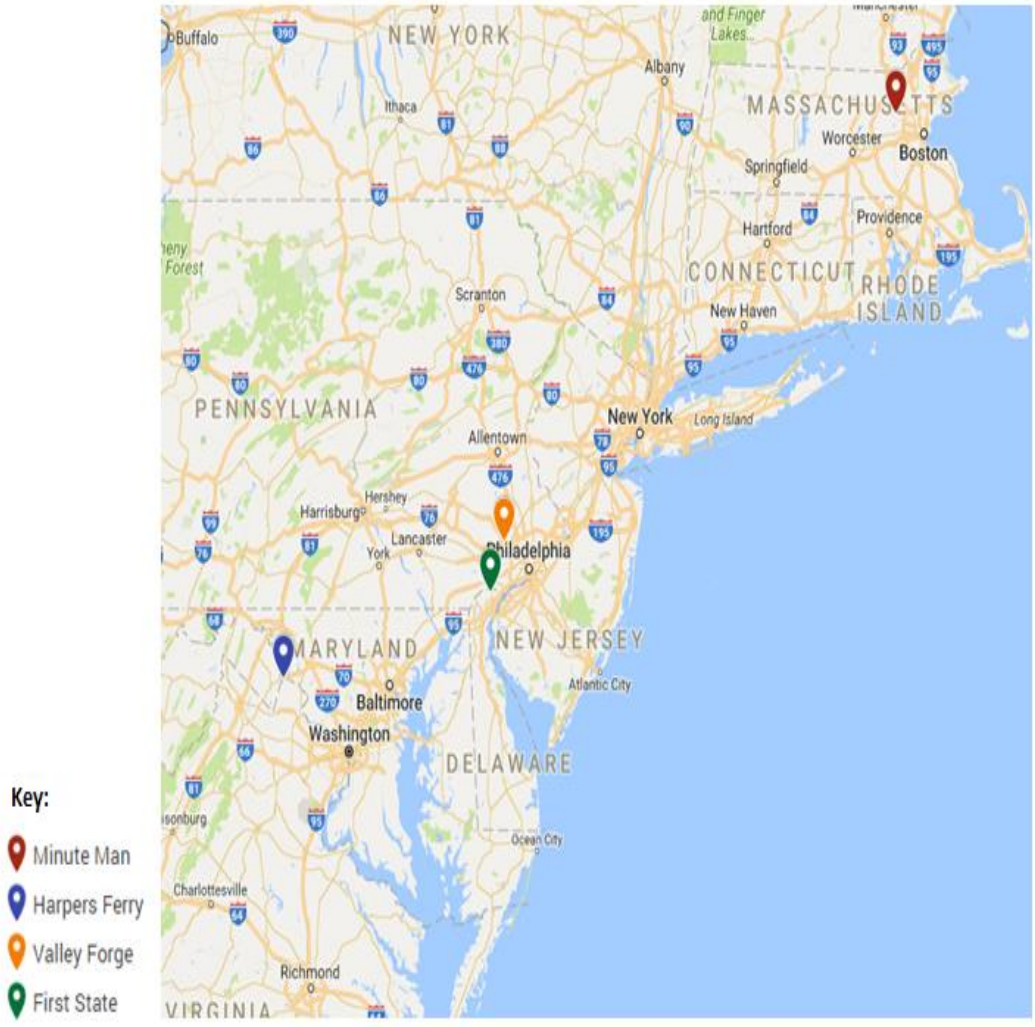

Figure 1.1 Map of National Historical Parks in Northeastern U.S.

Chapter 2

NATIONAL PARK SERVICE

2.1 Introduction

This chapter provides an overview of the U.S. National Park Service. This chapter also describes the mission, history, organizational structure, and laws and policies the National Park Service is required to follow to manage water resources.

2.2 Mission

On August 25, 1916, President Woodrow Wilson signed the Organic Act which established the National Park Service to protect and conserve unimpaired many of the country's most spectacular places. The National Park Service's mission is to preserve "the natural and cultural resources and values of the National Park System for the enjoyment, education, and inspiration of this and future generations" (NPS, 2017e).

2.3 Organization

Located in the United States Department of the Interior, the National Park Service is responsible for managing over 400 units covering more than 84 million acres (131,250 mi^2) in 50 states, the District of Colombia, American Samoa, Guam, Puerto Rico, Saipan, and the Virgin Islands (NPS History, 2017b). The National Park Service is comprised of 417 sites with at least 19 different designations (NPS, 2017c). These include 129 historical parks, 87 national monuments, 59 national parks, 25 battlefields, 19 preserves, 19 recreation areas, 10 seashores, 4 parkways, 4 lakeshores, and 2 reserves.

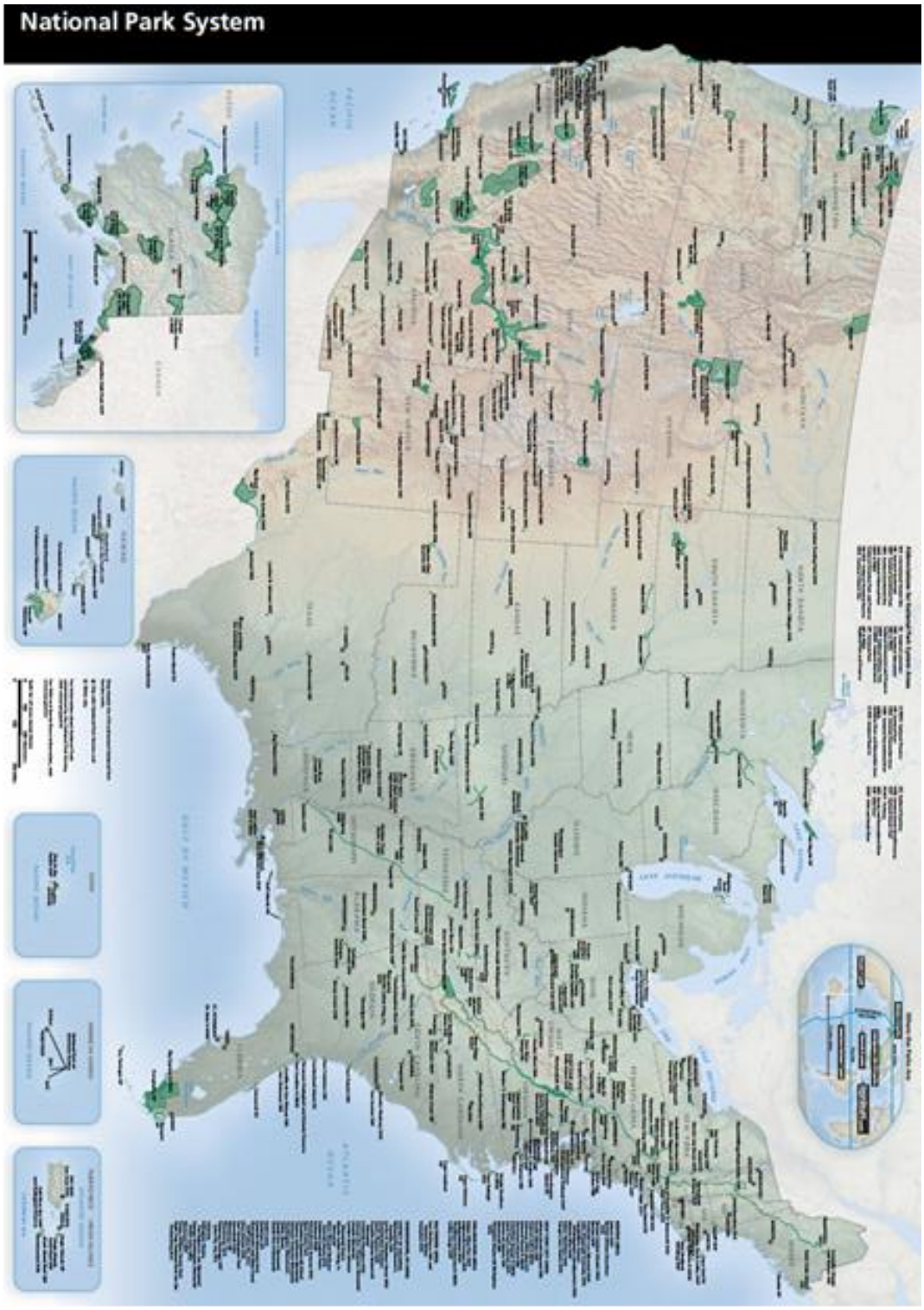

Figure 2.1 Map of the National Park System (NPS, 2016a)

The National Park Service employs over 20,000 individuals whom are responsible for preserving these lands designated by the nation for their cultural, historical, and environmental worth. The NPS employees are assisted by 440,000 Volunteers-In-Parks who donate more than 7 million hours every year. Together they help care for America's national parks and work with communities across the nation to help preserve local history and create close-to-home recreational opportunities. They also fill roles such as environmental advocate, partner in community revitalization and leader in the drive to protect America's open spaces (NPS, 2017c).

The National Park System represents something special to Americans and the world. It represents the common ownership by the American people of some of the most spectacular places in the United States. Thousands of people from all over the world come to visit the United States' national parks to experience their overwhelming beauty. President Theodore Roosevelt called the conservation of natural resources "essentially democratic in spirit, purpose, and method" (Skoglund, 2009). It has been said by many, including American novelist Wallace Stegner, that our national parks system is the best idea the United States has ever had (NPS, 2003).

2.4 History

Yellowstone National Park Act of 1872: On March 1, 1872, President Ulysses S. Grant signed the Yellowstone National Park Act, establishing Yellowstone as the country's and world's first national park (Table 2.1). Under the act, over two million acres of public land in the Montana and Wyoming territories were withdrawn from settlement, occupancy, or sale to be "set apart as a public park or pleasuring-ground for the benefit and enjoyment of the people." The public park was placed under the exclusive control of the Secretary of Interior. The Secretary of Interior was

responsible for establishing rules and regulations that provide for the preservation of all resources in the park, including timber, mineral deposits, and geologic wonders (NPS, 2000). The establishment of Yellowstone National Park started a movement for placing other natural reserves under federal jurisdiction. This new idea of a national park started a worldwide movement that quickly spread to over 100 countries. As interest grew in preserving the natural wonders of the western United States, the desire to protect cultural lands and sites associated with Native American culture also developed (“NPS History: National Park System Timeline,” n.d.).

Antiquities Act of 1906: On June 8, 1906, President Theodore Roosevelt signed the Antiquities Act to protect prehistoric cliff dwellings, pueblo ruins and early missions in the Southwestern United States (Table 2.1). The Act gave Presidents the authority to proclaim and reserve lands owned or controlled by the United States that contained "historic landmarks, historic and prehistoric structures, and other objects of historic or scientific interest" as national monuments. The excavation or appropriation of antiquities on federal lands became unlawful without prior permission from the department having jurisdiction (“American Antiquities Act of 1906,” n.d.). Approximately a quarter of the units currently in the National Park System originated from the Antiquities Act (“NPS History: National Park System Timeline,” n.d.).

National Park Service Organic Act of 1916: By the beginning of August 1916, the Department of Interior was responsible for the management of 14 national parks, 21 national monuments, and the Hot Springs and Casa Grande reservations. However, there was no organization to operate these parks at the time and this left the parks and monuments vulnerable to competing interests. Many interest groups, including future directors Stephen T. Mather and Horace Albright, voiced their

opinion to Congress to establish an organization to manage the parks and monuments. On August 25, 1916, President Woodrow Wilson signed the act, often known as the Organic Act, which established the National Park Service. The Organic Act stated that:

> The Service thus established shall promote and regulate the use of the Federal areas known as national parks, monuments and reservations hereinafter specified by such means and measures as conform to the fundamental purpose of the said parks, monuments and reservations, which purpose is to conserve the scenery and the natural and historic objects and the wild life therein and to provide for the enjoyment of the same in such manner and by such means as will leave them unimpaired for the enjoyment of future generations. (NPS, 2000)

National Park Service Reorganization: The number and diversity of parks within the organization continued to grow as a result of a significant reorganization in 1933, following the Second World War, and during the 1960s. An Executive Order by President Franklin Roosevelt in 1933 transferred 56 national monuments and military sites from the Forest Service and the War Department to the National Park Service ("NPS History: National Park System Timeline," n.d.). This reorganization was a significant event in the evolution of the National Park Service, as it was a major step in the development of today's national system of parks. Areas of scenic and scientific importance as well as historical significance became places that were worth protecting. Historic preservation became a primary mission of the National Park Service. Thirty seven years later, Congress declared in the General Authorities Act of 1970 that the National Park System has grown to include "natural, historic, and recreation areas in every major region of the United States…in one national park system…and that it is the purpose of this Act to include all such areas in the System…"

Recent Additions to the National Park System: Additions to the National Park System are made through acts of Congress, and national parks can be created only through such acts. The President has authority, under the Antiquities Act of 1906, to proclaim national monuments on lands already under federal jurisdiction (NPS, 2006). A proposed addition to the national park system must possess nationally significant natural or cultural resources, be a suitable and feasible addition to the system, and require direct NPS management instead of protection by other public agencies or the private sector (NPS, 2006).

Between March 2009 and January 2017, the administration of President Barack Obama added 26 new parks to the National Park System ("NPS Facts & Figures: Recent Changes in the National Park System," n.d.). During this time, President Obama granted protected status to more than 265 million acres of land and water, which is more than any other president in history ("NPS Presidents Who Paved the Way for National Parks," n.d.). In 2012, Delaware was the only state in the country without a national park. In 2013, President Obama designated the First State National Monument under the Antiquities Act, which became America's 400th national park site and the first unit of the National Park System in Delaware. In December 2014, Congress passed legislation, signed by President Obama that created the First State National Historical Park in Delaware and Pennsylvania.

National Park Service Centennial: The National Park Service turned 100 years old on August 25, 2016, and celebrations occurred throughout the year with partners and visitors across the country. To celebrate the Centennial, the National Park Service kicked off a campaign called Find Your Park, to raise awareness of these spectacular places, educate people on the inspirational stories that the national parks

tell, and to encourage people across the country to get out and explore, enjoy nature, and connect with the historical, cultural, and natural resources throughout the country (NPS, 2017f). The NPS also kicked off a second century of stewardship of the national parks, and strengthening community engagement through recreation, conservation, and historic preservation programs.

Table 2.1 Historic Timeline of the National Park Service

Date	Act/Event	Description
1872	Yellowstone National Park Act	Established Yellowstone as the country's first national park
1906	Antiquities Act	Protected lands containing historic landmarks, structures, or objects as national monuments
1916	NPS Organic Act	The NPS was established
1970	General Authorities Act	Natural, historic, and recreation areas became a part of the National Park System
2013	First State National Historical Park	The First State became Delaware's first unit in the National Park System
2016	Centennial	The NPS celebrated its 100th anniversary on August 25, 2016

2.5 Water Resources

Water Resources Division: The Water Resources Division of the NPS Natural Resource Stewardship and Science Directorate in Fort Collins, Colorado is authorized to manage 11,000 miles of coast, 2.5 million acres of ocean and Great Lakes waters, including coral reefs, kelp forests, glaciers, estuaries, beaches, wetlands, historic forts and shipwrecks, 100,000 miles of perennial rivers and streams, and over 2.3 million acres of lakes and reservoirs in the National Park System. The National Park Service is required to manage all National Park System units according to the

1916 Organic Act and other applicable laws so as not to be "in derogation of the values and purposes for which these various areas have been established" ("General Authorities Act 1970," n.d.). Water resources within the National Park System are protected by the federal government under the General Authorities Act.

Clean Water Act: The Clean Water Act was first enacted in 1948 and amended in 1972 and is designed to restore and maintain the chemical, physical, and biological integrity of the nation's waters, including the waters of the national park system ("NPS Laws," 2017). Congress recognized the primary role of the states in managing and regulating the nation's water quality as part of the Clean Water Act (NPS, 2017c). All federal agencies are required to follow the requirements of state law for water quality management, regardless of other jurisdictional status or landownership. States implement the protection of water quality through water quality standards and best management practices. Water quality standards are based on the "designated uses of a water body or segment of water, the water quality criteria necessary to protect that use or uses, and an anti-degradation provision to protect the existing water quality" (NPS, 2017c).

A state's anti-degradation policy is a three-tiered approach to maintaining and protecting various levels of water quality. The first level is to minimally protect and maintain the existing uses of a water segment and the level of quality necessary to protect the uses must be maintained (NPS, 2017a). The second level provides protection of "existing water quality in water segments where quality exceeds the fishable/swimmable goals of the Clean Water Act" (NPS, 2017a). The third level provides protection of the state's highest quality waters where ordinary use classifications may not be adequate. These waters are classified as Outstanding

National Resources Waters (ONRW). Many states have levels of protection that are similarly protective but may allow more flexibility when making water quality determinations. “Outstanding Natural Resource Waters,” “Outstanding State Resource Waters,” or “Exceptional Waters” are examples of such designations. ONRW status is often a desirable designation to acquire for National Park Service units with substantial water resources management responsibilities. For waters designated as ONRW, “water quality must be maintained and protected and only short-term changes may be allowed” (NPS, 2017a). Parks can apply for ONRW designations for water segments outside boundaries of NPS units, which can also ensure the protection of water that flows into a park unit.

National Environmental Policy Act: Passed by Congress in 1969, and signed into law by President Richard Nixon on January 1, 1970, the National Environmental Policy Act (NEPA) established a national policy of “encouraging productive and enjoyable harmony between human beings and the environment for present and future generations” (NPS, 2015). To further this policy, NEPA requires federal agencies, such as the National Park Service, to evaluate the environmental impacts of its actions and to involve the public in the decision-making process. Within the National Park Service, the NEPA process is a crucial tool for making certain informed decisions that conserve park resources and values. The National Park Service uses four pathways, or levels of analysis and documentation, to comply with NEPA (NPS, 2015). The description of each of these pathways located in the National Park Service NEPA Handbook is listed below.

1. Categorical Exclusion for which No Documentation is Required:

> This pathway is applicable to actions that have been found to have no potential for significant environmental impacts under ordinary

circumstances and whose potential for environmental impacts of any kind is so minimal the NEPA review does not require formal documentation (NPS, 2015).

2. Categorical Exclusion for which Documentation is Required:

> This pathway is applicable to actions that have been found to have no potential for individual or cumulative significant environmental impacts under ordinary circumstances, but whose potential for environmental impacts warrants some level of analysis and formal documentation (NPS, 2015).

3. Environmental Assessment (EA):

> An EA is a means for documenting compliance with NEPA and assisting in the planning and decision-making process when a categorical exclusion is not appropriate but an Environmental Impact Statement is not necessary (NPS, 2015).

4. Environmental Impact Statement (EIS): This pathway is applicable to proposals that could result in adverse environmental impacts.

> EIS is normally required for the following type of actions: General Management Plans of national park system units, proposals to designate Wild and Scenic Rivers, National Trails, or Wilderness, grants, including multi-year grants whose size and/or scope will result in major natural or physical changes, including interrelated social and economic changes and residential and land use changes within the project area or its immediate environs; and grants which foreclose other beneficial uses of mineral, agricultural, timber, water, energy, or transportation resources important to national or state welfare. (NPS, 2015)

2.6 Inventory and Monitoring Program

Overview: Located in the National Park Service Natural Resource Stewardship and Science Directorate in Fort Collins, Colorado, the Inventory and Monitoring (I&M) Program was formed in response to the Natural Resource Challenge of 1999. The goals of the Program are to inventory the natural resources under NPS stewardship to determine their nature and status. There are 32 I&M

networks established as part of the NPS Inventory and Monitoring Program that were determined based on geography and shared natural resource characteristics. Some networks follow watershed delineations, such as the Upper Columbia Basin, and others follow mountain ranges, such as the Rocky Mountains in the Rocky Mountain network and the Appalachian Mountains in the Appalachian Highlands network. Knowing the condition of natural resources in national parks is fundamental to the NPS's ability to manage park resources. Natural resource monitoring provides site-specific information needed to understand and identify change in complex, variable, and imperfectly understood natural systems and to determine whether observed changes are within natural levels of variability (NPS, 2016).

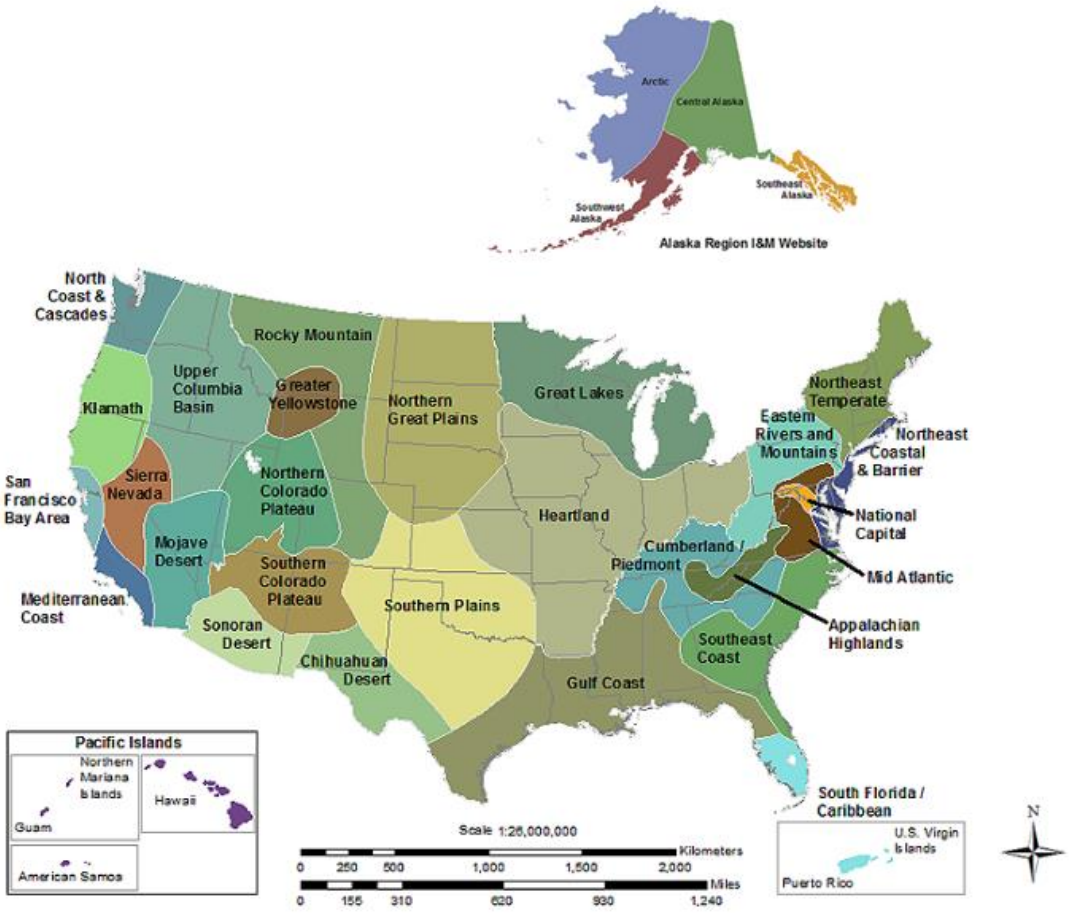

Figure 2.2 National Park Service Inventory and Monitoring Program Networks (NPS, 2016)

Mid-Atlantic Network: The Mid-Atlantic Network (MIDN) is one of 32 I&M networks established as part of the NPS Inventory and Monitoring Program (Figure 2.2). Valley Forge is one of 10 units in the Mid-Atlantic Network (NPS, 2016). First State National Historical Park will be officially added to this network in the near future. The MIDN provides scientific data and expertise for natural resources in 10 parks, including Valley Forge NHP. The majority of parks in the MIDN network were established for their historical or cultural interest, but these parks also contain diverse

natural resources. Park managers use the data and related analysis about the natural resources investigated by the MIDN network to make decisions about park resources.

National Capital Region Network: The National Capital Region Network (NCRN) is also one of 32 I&M networks nationwide (Figure 2.2). Harpers Ferry NHP is one of 11 park units in Virginia, West Virginia, Maryland, and the District of Columbia that make up the NCRN. These 11 sites are a collection of natural areas that fall within the immense deciduous forest ecosystem and span four distinct physiographic provinces (NPS, 2016). Parks within the NCRN are small and face many challenges, including being negatively impacted by urbanization.

Northeast Temperate Network: The Northeast Temperate Network (NETN) was established by the National Park Service to monitor ecological conditions in 13 national parks, including Minute Man, located in seven northeastern states as well as six additional states through which the Appalachian National Scenic Trail passes (Figure 2.2). The broad-based, scientifically sound information obtained through long term natural resource monitoring will have multiple applications for management decision-making, research, education, and promoting public understanding of park resources (NPS, 2016).

Natural Resource Condition Assessment: The Mid-Atlantic Network, National Capital Region Network, and Northeast Temperate Network are responsible for performing Natural Resource Condition Assessments (NRCAs) at each of their respective national park units. NCRAs provide a structured resource assessment and reporting framework for individual resources and indicators, as well as provide a meaningful discussion of overall findings and recommendations (NPS, 2014). Focal study resources and indicators are selected on a park-by-park basis, and therefore, vary

at each of the national parks. Focal study resources and indicators may include forest cover, wetland resources, birds, deer density, air quality, water quality, land-use change, invasive plants and insects, reptile communities, and groundwater contamination. The NRCA will assist park managers in resource planning and decision making and be used to communicate condition status to interested stakeholders and the general public. As of May 2013, NRCAs have been completed for 70 parks, and are ongoing, at varying stages of completion, for more than 90 additional parks. Funding to conduct a similar assessment at approximately 110 other parks with significant natural resources over the next few years have been recommended. The information contained in the NRCAs will also be used by park managers to create a State of the Park Report. Valley Forge, Minute Man, and Harpers Ferry National Historical Parks have completed NRCAs.

State of the Park Report: The State of the Park Report summarizes the NRCAs complex scientific, scholarly, and park operations information using non-technical language and a visual format. It also summarizes other inventories, surveys and data compilations, and institutional knowledge, and provides a snapshot of the status and trend in the condition of a park's resources and values. The State of the Parks reporting was launched as a part of the NPS Call to Action which established a startup goal of 50 completed reports by 2016 ("State of the Parks," n.d.). The NPS is on track to meet or exceed this goal. As of May 2014, 11 reports were completed, 21 were in process, and 31 parks were on a list to develop one by 2016. The long term goal is for most if not all parks to develop an initial State of the Park Report followed by a new report at least once every five years. Of the four national historical parks,

Valley Forge National Historical Park is the only park to have completed a State of the Park Report.

2.7 Summary

Established in 1916, the National Park Service is an agency of the United States government that manages 417 units of land designated for their cultural, historical, and environmental worth. The Water Resources Division of the National Park Service's Natural Resource Stewardship and Science Directorate in Fort Collins, Colorado is authorized to manage water resources contained in the 417 units of the National Park System. The National Park Service is required to manage its units in accordance to all applicable federal and state laws and regulations, including the Clean Water Act and National Environmental Policy Act. Also located in the Natural Resource Stewardship and Science Directorate, the National Park Service's Inventory and Monitoring Program is responsible for the inventory and monitoring of natural resources, including water resources, in all units of the National Park System. Natural Resource Condition Assessments and State of the Park Reports provide a structured framework to communicate the results and conclusions of resource inventory and monitoring to interested stakeholders and the public. The following chapter describes the history and physical characteristics of the National Park Service unit as the focus of this research, First State National Historical Park.

Chapter 3

FIRST STATE NATIONAL HISTORICAL PARK

3.1 Overview

In 2013, President Obama signed an Executive Order under the authority of the 1906 Antiquities Act that established First State National Monument. Later, under the authority of the National Park Service Organic Act, Congress approved legislation in 2015, and with the President's signature on the bill, First State became designated as a National Historical Park. First State NHP includes seven units: Beaver Valley, Fort Christina, Old Swedes Church, New Castle Court House, The Green (Dover), John Dickinson Plantation, and Ryves Holt House, that tell the story of Delaware's early settlement and role of being the first state to ratify the Constitution (Figure 3.1). The following chapters of this thesis focus on the Beaver Valley Unit of First State National Historical Park. The Beaver Valley unit of First State National Historical Park is 1,100 acres (1.7 mi^2), established on the Woodlawn Property, and located in Northern Delaware and Pennsylvania (Figure 3.2). The Beaver Valley unit contains streams and watersheds that are the focus of this research. The other six units consist of historic buildings and structures. In this chapter we discuss the history, climate, soils, geology, hydrology, and land use of the Beaver Valley Unit of First State National Historical Park.

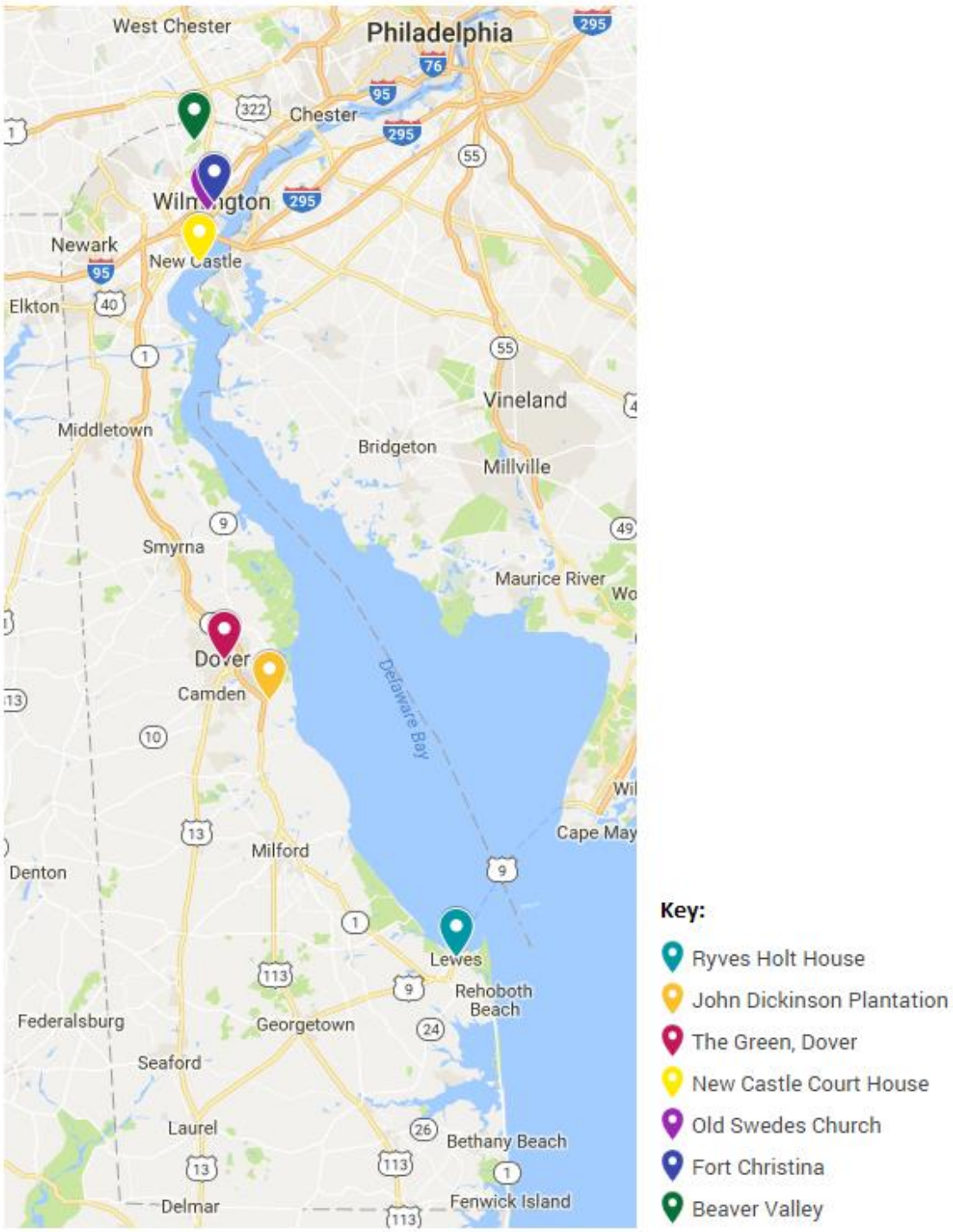

Figure 3.1 Map of First State National Historical Park

3.2 History

Located three miles north of Wilmington, Delaware along the Brandywine River, the Woodlawn property in Beaver Valley has served as a wildlife preserve, urban park and recreation destination for more than five million people (Figure 3.2). Of the property's 1,100 acres, 880 are in Delaware with the remainder in Pennsylvania (The Conservation Fund, n.d.). In 1682, William Penn acquired Rockland Manor, which included the Woodlawn property, from the Duke of York. Industrialist William Bancroft purchased the land in the 1900s, and the property had been maintained as open space up until its designation as a National Park site. Recognizing the historical significance and value of the property, elected officials, including Delaware Governor Jack Markell, the Delaware and Pennsylvania congressional delegations and New Castle County Council, all endorsed the Woodlawn as a property worthy of national recognition.

The Woodlawn Trustees long kept the Woodlawn property unspoiled for the community and visitors to enjoy, with land preservation a top goal, but it became time to sell the property (The Conservation Fund, n.d.). In 2012, the Conservation Fund purchased the historic 1,100-acre Woodlawn property to protect it for the public. The acquisition of the Woodlawn property was made possible by Mt. Cuba Center, a non-profit botanical garden with a focus on Appalachia forest research located in Hockessin, Delaware, as well as the desire of the property's trustees to see the land protected. This desire to see the land protected for the public fueled the community's overwhelming support to see the property designated as a national monument. Hundreds of people attended a public hearing in 2012, more than a thousand people sent in letters of support to congressional offices and many more voiced their support through stories and editorials supporting the effort in making the Woodlawn property

a key component of a new national conservation land. The National Park Service evaluated the land and pointed out that it was special and belonged to all Americans. The Conservation Fund donated the land to the National Park Service as a gift for future generations to enjoy. On March 25, 2013, President Barack Obama signed an Executive Order by authority of Theodore Roosevelt's 1906 Antiquities Act that created First State National Monument that includes the 1,100 acre Woodlawn Unit along the west bank of the Brandywine Creek in Delaware and Pennsylvania. In December 2014, First State was re-designated from a National Monument to a National Historical Park by an act of Congress.

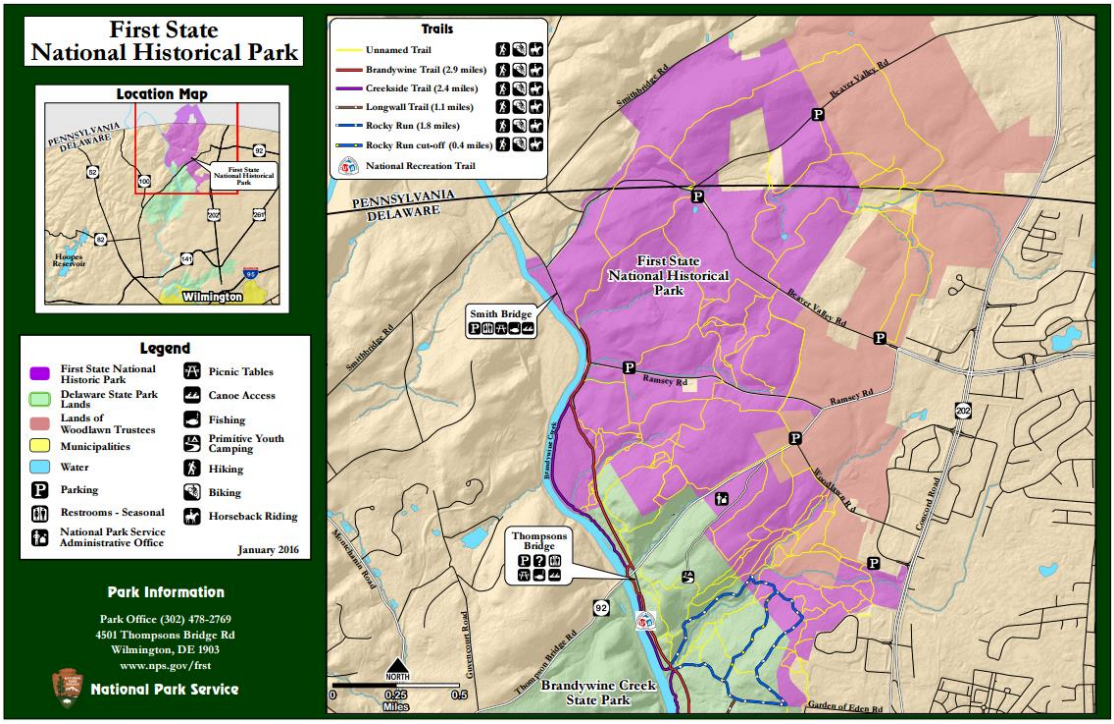

Figure 3.2 Map of Beaver Valley Unit of First State National Historical Park ("Beaver Valley," n.d.)

3.3 Climate

Situated in Northern Delaware and Pennsylvania, First State NHP experiences a humid continental climate with cold winters and hot summers. Rainfall is fairly constant throughout the year, with the region receiving 43 inches of rainfall on average each year (Office of the State Climatologist, n.d.). The mean annual temperature is 54° F. The highest annual temperatures are observed in July with a mean of 76.2° F and the lowest annual temperatures are observed in January with a mean of 31.8° F. The region is affected by seasonally occurring severe weather, and most of the precipitation is produced by winter and spring nor-easters, autumn tropical systems, and spring and summer severe thunderstorms.

3.4 Soils

According to the USDA soil survey, 3% of First State NHP at Beaver Valley Unit watershed soils are classified as quarry/water/urban bedrock, 10% are hydrologic soil group A, 57% are hydrologic soil group B, 28% are hydrologic soil group C, and 1% are hydrologic soil group D (Figure 3.3 and 3.4).

Group A soils have a high infiltration rate (low runoff potential) when thoroughly wet. These consist mainly of deep, well drained to excessively drained sands or gravelly sands (USDA, 2005). They typically contain less than 10 percent clay and more than 90 percent sand or gravel and have gravel or sand textures.

Group B soils have a moderate infiltration rate (and moderately low runoff potential) when thoroughly wet. These consist chiefly of moderately deep or deep, moderately well-drained or well-drained soils that have moderately fine texture to moderately coarse texture. These soils have a moderate rate of water transmission (USDA, 2007).

Group C soils have moderately high runoff potential when thoroughly wet and water transmission through the soil is somewhat restricted. These soils typically have between 20-40 percent clay and less than 50 percent sand and have loam, silt loam, sandy clay loam, clay loam, and silty clay loam textures (USDA, 2007).

Group D soils have a high runoff potential (and very slow infiltration rate) when thoroughly wet and are commonly hydric or wetland soils. These consist chiefly of clays that have a high shrink-swell potential, soils that have a high water table, soils that have a clay pan or clay layer at or near the surface, and soils that are shallow over nearly impervious material (USDA, 2005). They also have a very slow rate of water transmission. They typically have greater than 40 percent clay, less than 50 percent sand, and have clayey textures (USDA, 2007).

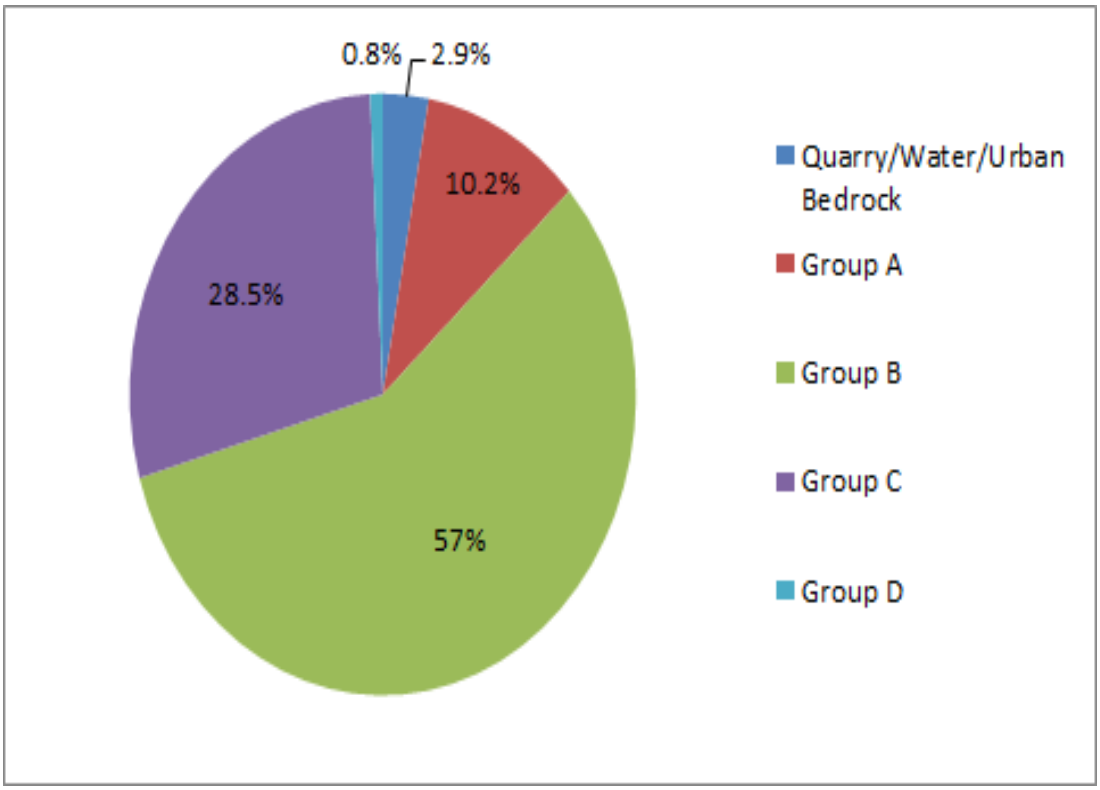

Figure 3.3 First State National Historical Park Soils (USDA, 2007)

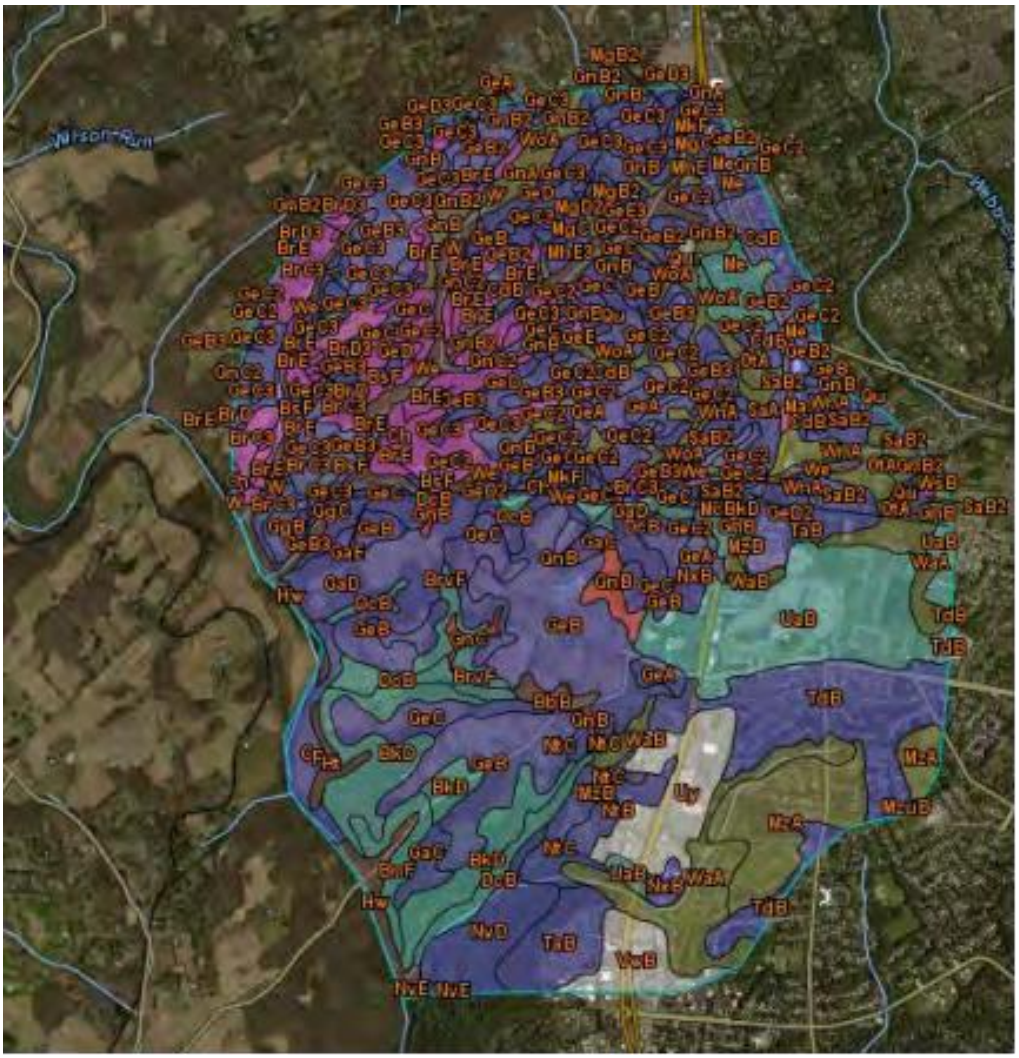

Figure 3.4 Hydrologic Soil Groups in First State National Historical Park (USDA, 2007)

3.5 Geology

Watersheds in First State NHP are underlain by outcrops of the Wissahickon Formation gneiss (DGS, n.d.). Often referred to as the Wilmington Blue Rock, the Wissahickon Formation gneiss are blue-green in color and form large erosion resistant boulder and cobble complexes in the beds of the streams that tumble through the

Piedmont (Figure 3.5). The rock types in First State NHP include mainly Wissahickon Formation and Cockeysville Marble (Figure 3.6). In Delaware, Wissahickon Formation gneiss contains interlayered psammitic and pelitic gneiss with amphilbolite, and Cockeysville Marble is predominantly a pure, coarsely crystalline, blue-white dolomite marble interlayered with calcium-schist.

Figure 3.5 Geology of First State National Historical Park (DGS, n.d.)

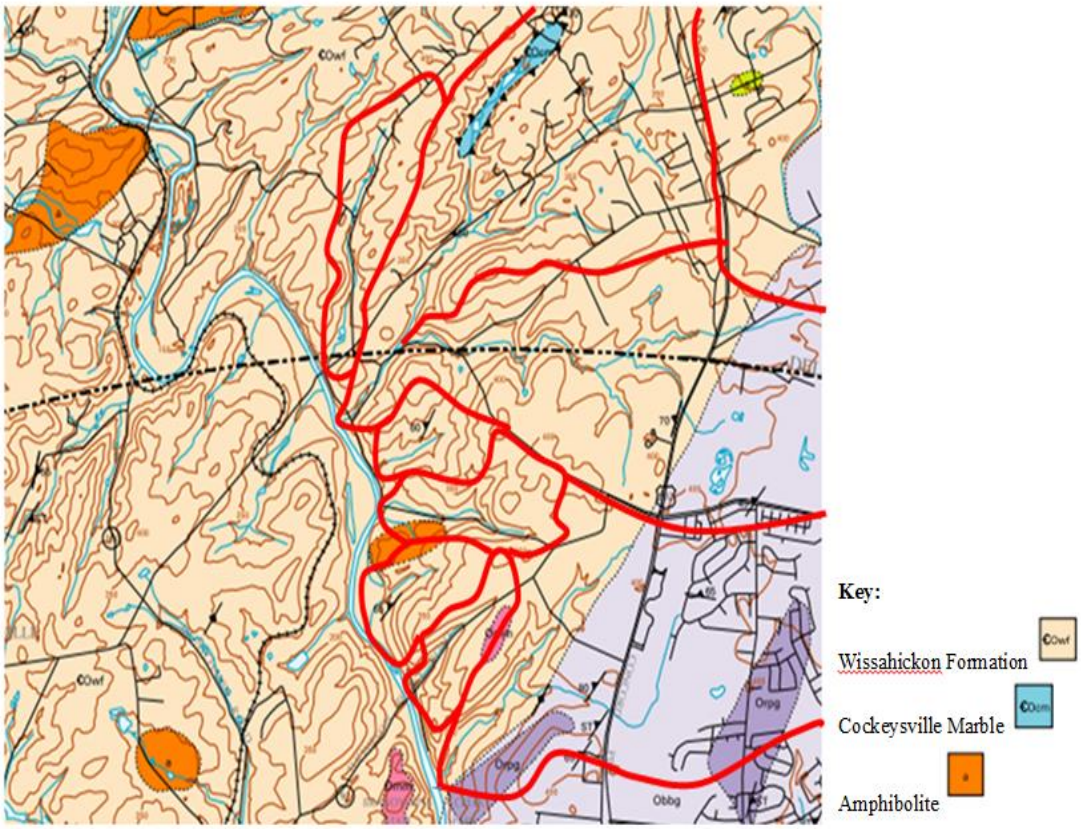

Figure 3.6 Geology of First State National Historical Park Watersheds (DGS, n.d.)

3.6 Hydrology

There are six streams that flow through First State National Historical Park and capture a drainage area of 4,485 acres or 7.0 mi^2 (Figure 3.7). Beaver Creek is the largest watershed, followed by Rocky Run, Ridge Run, Ramsey Run, Talley Run, and Carney Run.

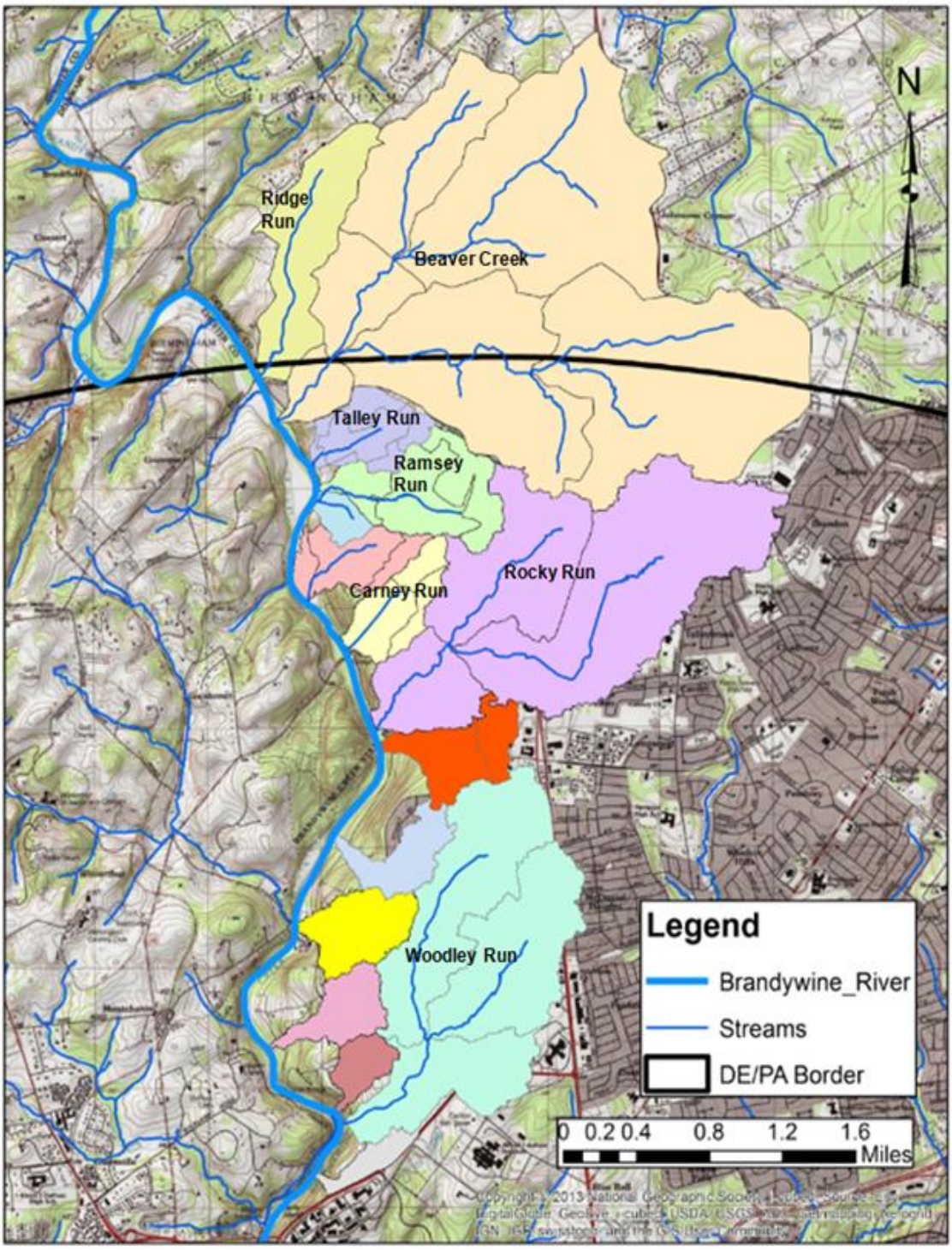

Figure 3.7 Watersheds of First State National Historical Park (UDWRC, 2017).

Ridge Run: The 262-acre Ridge Run watershed borders the northern boundary of the First State Woodlawn unit and forms in the headwaters in Pennsylvania and flows for 1.5 miles into Delaware to the confluence with the Brandywine Creek at Smith's Bridge (Figure 3.8). The watershed is lightly developed (0.3% impervious) and land use is 19% forest/wetlands, 5% urban/suburban, and 77% agriculture. The watershed is steeply sloped (12% slopes) and is covered by soils in all four hydrologic soil groups, and the geology is the Wissahickon Formation gneiss (UDWRC, 2017).

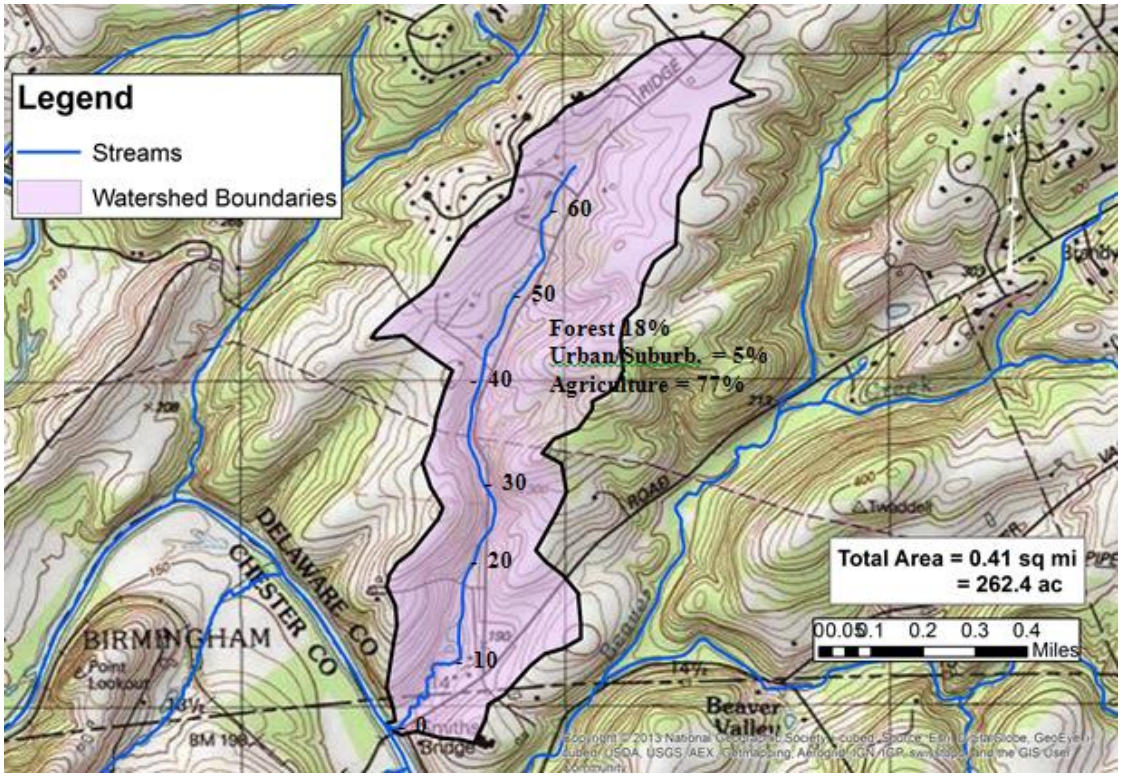

Figure 3.8 Ridge Run Watershed

Beaver Creek: The Beaver Creek watershed drains 4 square miles from the north and south forks and main stem of the stream and covers the northerly third of the First State (Figure 3.9). The north fork of Beaver Creek originates near the developed shopping centers and neighborhoods along Concord Pike in Pennsylvania and flows southwest for three miles through several horse farms into the First State before joining the main stem about a half mile upstream from the Brandywine Creek. The south fork forms along the Delaware/Pennsylvania state line near the Brandywine Town Center and flows west for four miles under Concord Pike. It then flows through horse farms and forested sections of the First State before combining with the north fork near Beaver Valley Road. The main stem flows for a half mile along Beaver Valley Road to the confluence with the Brandywine at an area known as Peter's Rock. The watershed is moderately developed (9% impervious) mostly in the upper third near Concord Pike and mostly undeveloped in the stream valleys down below near the Brandywine. Watershed land use is 41% forest/wetlands, 28% urban/suburban, and 31% agriculture. The watershed is steeply sloped (9% slopes) and is covered by soils of hydrologic soil group A. The geology of the watershed is mostly formed by the Wissahickon Formation gneiss, although the north fork is underlain by an outcrop of the Cockeysville marble, which is a high water yield carbonate rock that provides buffering capacity to the stream for trout populations.

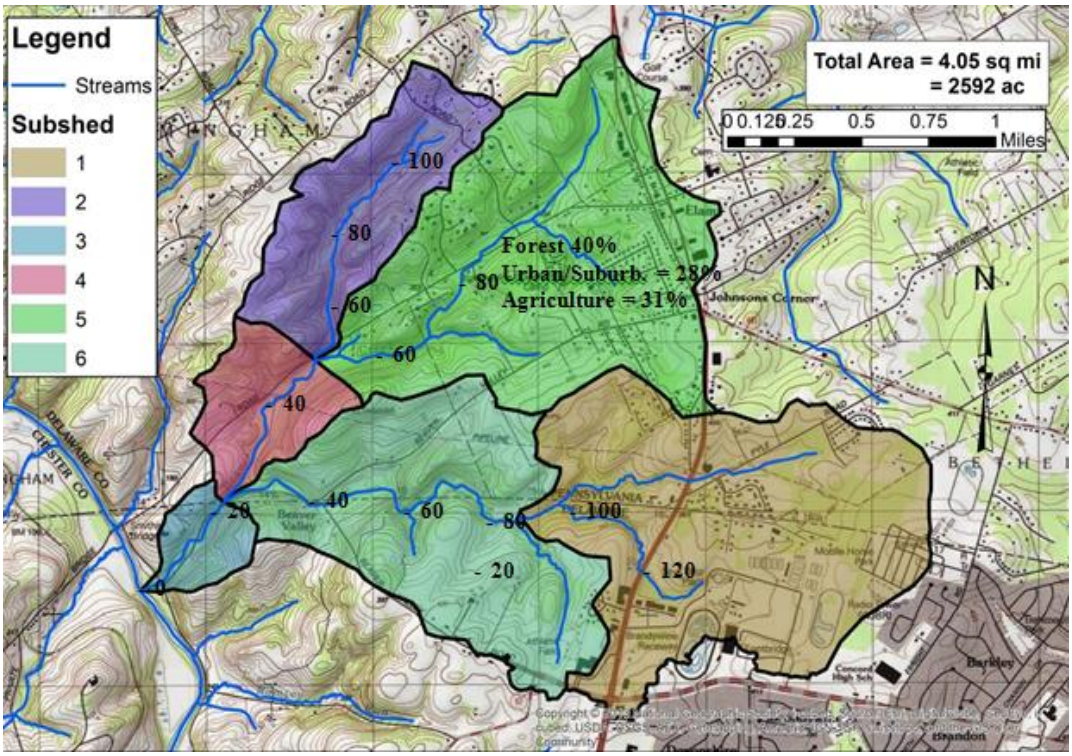

Figure 3.9 Beaver Creek Watershed

Talley Run: The 128-acre Talley Run watershed lies entirely within the First State NHP and forms on a 400 ft. high hill near Beaver Valley Road and flows less than a mile to feed the Brandywine Creek (Figure 3.10). The watershed is lightly developed (0% impervious) and land use is 54% forest/wetlands, 3% urban/suburban, and 43% agriculture. The watershed is steeply sloped (13%) and covered by soils of hydrologic soil group A and B. The geology of the watershed is the Wissahickon Formation gneiss.

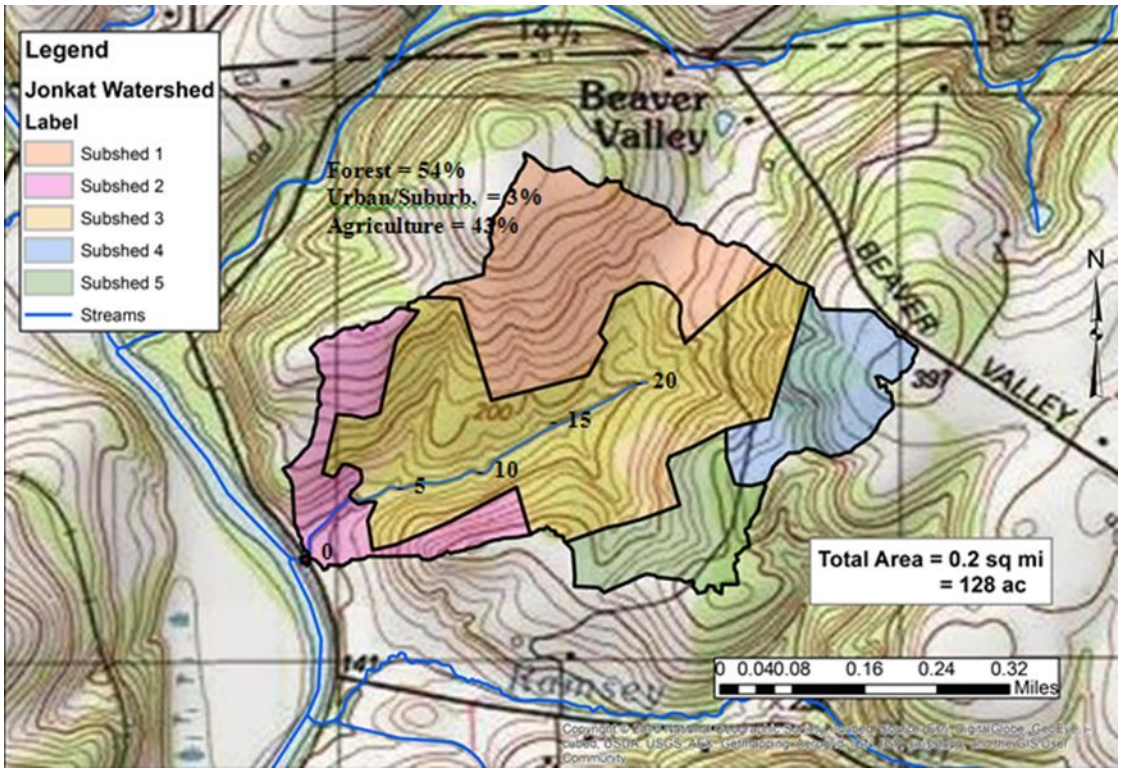

Figure 3.10 Talley Run Watershed

Ramsey Run: The 230-acre Ramsey Run watershed drains the Ramsey Farm and flows for a mile along the road and then through a bridge under the foot trail along Brandywine Creek (Figure 3.11). The watershed is almost entirely undeveloped (0.2% impervious) and land use is 36% forest/wetlands, 5% urban/suburban, and 59% agriculture. The watershed is steeply sloped (11%) and covered by soils in hydrologic soil group A. The geology of the watershed is the Wissahickon Formation gneiss with an outcrop of amphibolite downstream near the Brandywine.

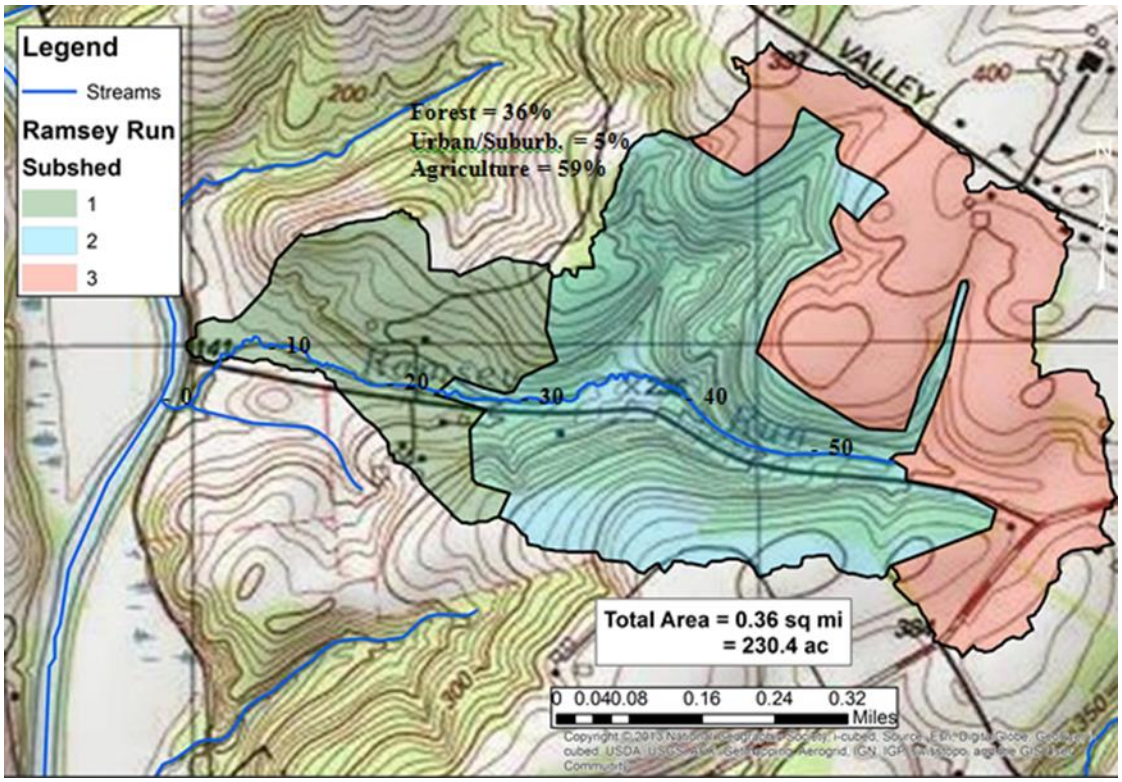

Figure 3.11 Ramsey Run Watershed

Carney Run: Originating at 400 feet above sea level, the 122-acre Carney Run watershed flows for almost a mile along the road to join the Brandywine Creek just upstream of Thompson's Bridge (Figure 3.12). The watershed is lightly developed (0.1% impervious) and land use is 61% forest/wetlands, 3% urban/suburban, and 36% agriculture. The watershed is steeply sloped (15%) and is covered by soils in hydrologic soil group A. The geology of the watershed is the Wissahickon Formation gneiss.

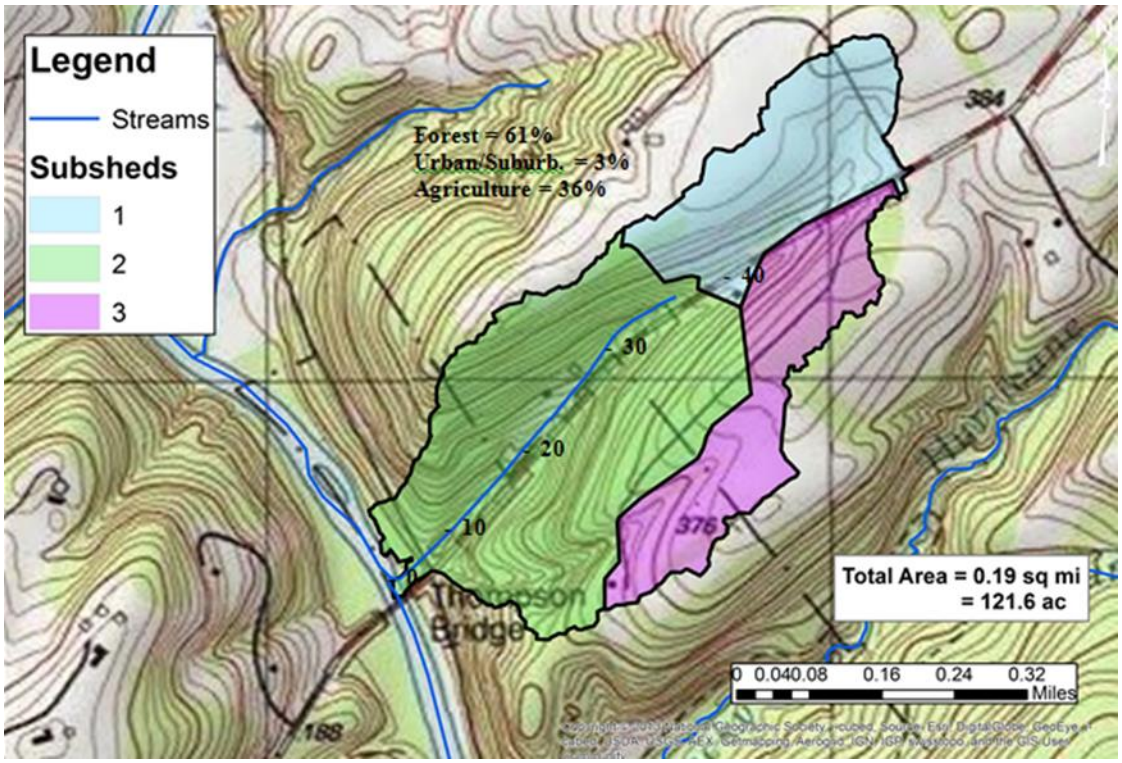

Figure 3.12 Carney Run Watershed

Rocky Run: The Rocky Run watershed drains 1.8 square miles from the north (Hurricane Run) and south forks and main stem of the stream and covers the southerly portion of First State before flowing west through Brandywine Creek State Park (Figure 3.13). Hurricane Run originates near the densely developed shopping centers and neighborhoods along Concord Pike in Pennsylvania and flows southwest for two miles through a forested section of the First State before joining the main stem about a half mile upstream from the Brandywine Creek. The south fork forms in the neighborhoods of New Castle County behind Concord Mall near the Brandywine Town Center and flows west for four miles under Concord Pike then into the Brandywine Creek State Park. The main stem flows for a half mile to the confluence

with the Brandywine about a half-mile south of Thompson's Bridge. The upper third of the watershed near Concord Pike is highly developed (19% impervious), while the stream valleys down below near the Brandywine are mostly undeveloped. Watershed land use is 28% forest/wetlands, 40% urban/suburban, and 32% agriculture. The watershed is steeply sloped (10% slopes) and is covered by soils from hydrologic soil group A, and geology is mostly formed by Wissahickon Formation gneiss. However, the north fork is underlain by an outcrop of the Cockeysville marble.

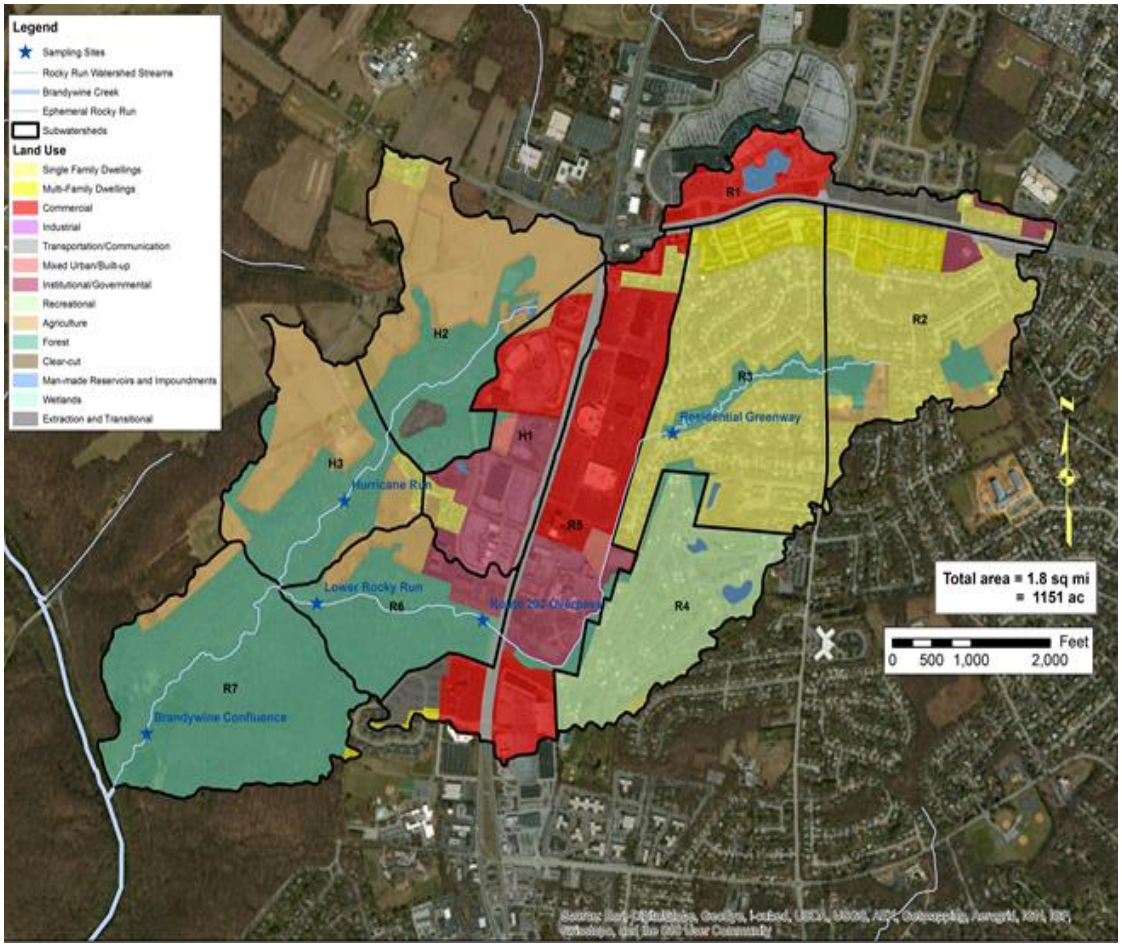

Figure 3.13 Rocky Run Watershed

3.7 Land Use

Land use in the six watersheds covers 36% forest, 1% wetlands, 27% urban/suburban, and 36% agriculture, and has an overall impervious coverage of 10% (Table 3.1 and Figure 3.14). Land use in the watershed is primarily urban/suburban and commercial to the East of Concord Pike (Route 202) and changes to agriculture as the streams flow west and downstream through the steeply sloped forested valleys to the Brandywine Creek. The flat land areas were developed and farmed and the forested, steeply sloped stream valleys were conserved in a nearly natural state. The least developed watersheds are small catchments (less than 300 acres), such as Ridge Run, Talley Run, Ramsey Run, and Carney Run that do not extend too far east from the banks of the Brandywine into the urbanized/commercialized Route 202 corridor. The Rocky Run Watershed is highly developed, Beaver Creek is moderately developed and Ridge Run, Ramsey Run, Carney Run, and Talley Run are lightly developed (Figure 3.15).

Table 3.1 Land Use in the Brandywine Piedmont Watersheds

Watershed	**Area (ac)**	**Forest (ac)**	**Wetlands (ac)**	**Urb./Sub. (ac)**	**Ag. (ac)**	**Imp. Cover (ac)**
Ridge Run	262	47	1	13	202	0.8
Beaver Creek	2,592	1037	21	726	804	233
Talley Run	128	69	0	4	55	0
Ramsey Run	230	83	0	12	136	0.5
Carney Run	122	74	0	4	44	0.1
Rocky Run	1,151	322	2	460	368	218
Total	**4,485**	**1,633**	**24**	**1,218**	**1,608**	**452**
Watershed	**(ac)**	**(%)**	**(%)**	**(%)**	**(%)**	**(%)**
Ridge Run	262	18%	0.4%	5%	77%	0.3%
Beaver Creek	2,592	40%	0.8%	28%	31%	9.0%
Talley Run	128	54%	0.0%	3%	43%	0.0%
Ramsey Run	230	36%	0.0%	5%	59%	0.2%
Carney Run	122	61%	0.0%	3%	36%	0.1%
Rocky Run	1,151	28%	0.2%	40%	32%	19.0%
Total	**4,485**	**36%**	**1%**	**27%**	**36%**	**10.0%**

(UDWRC, 2017)

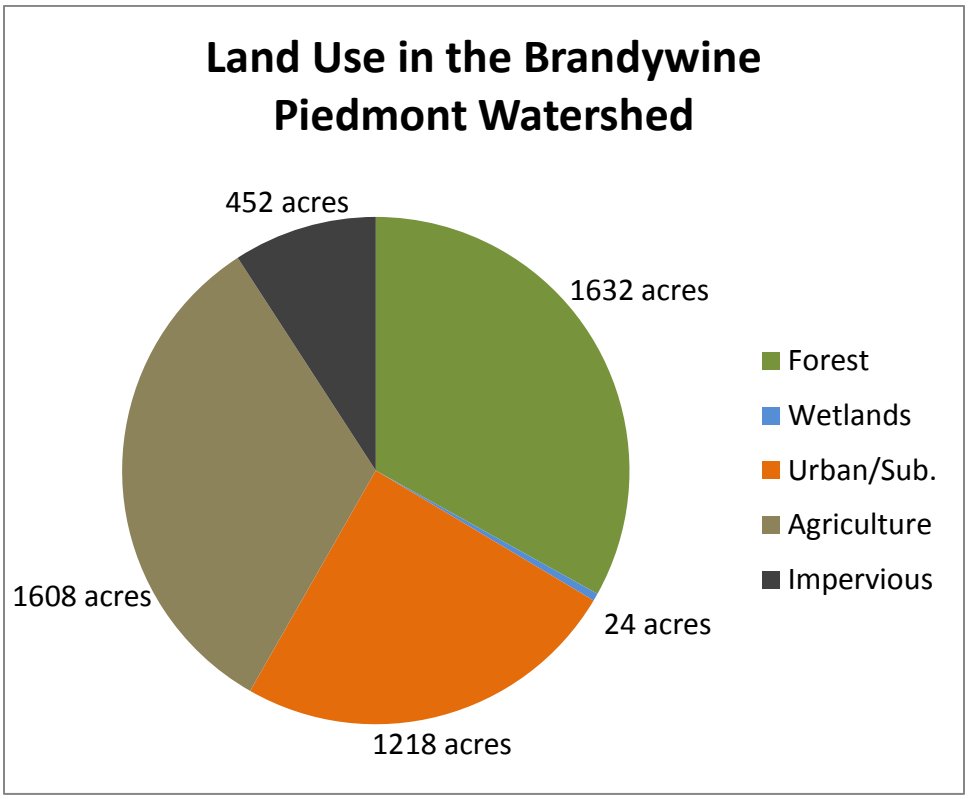

Figure 3.14 Land Use in Brandywine Piedmont Watersheds (UD WRC, 2017)

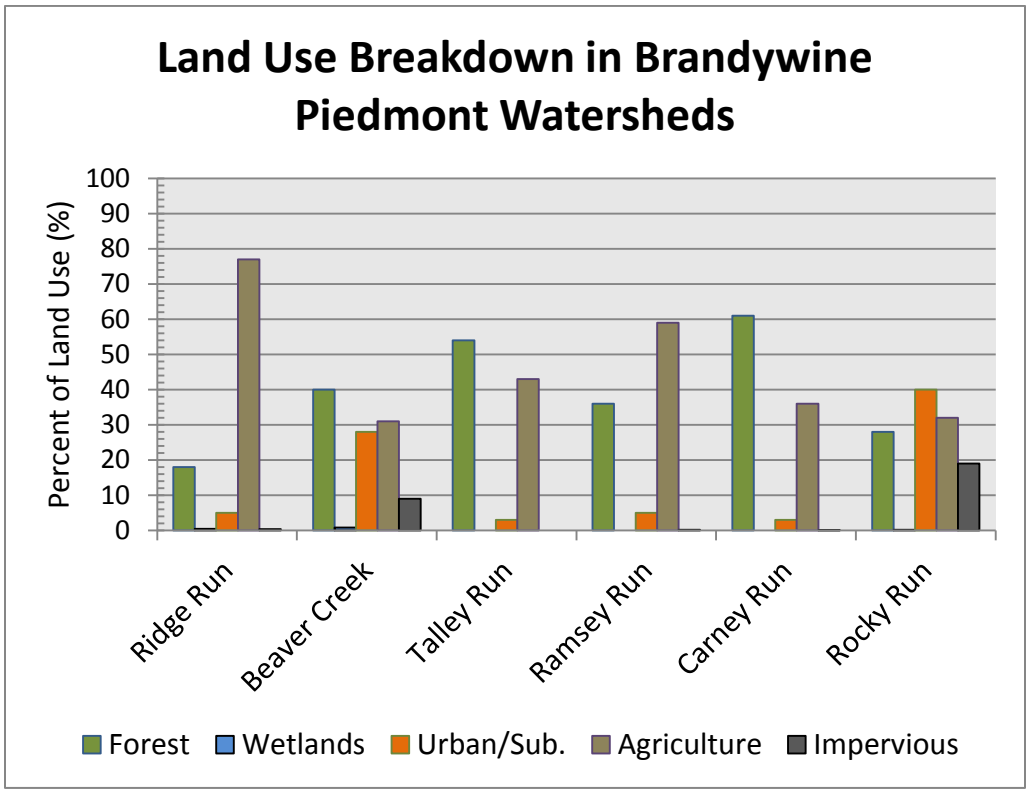

Figure 3.15 Land Use by Subwatershed in the Brandywine Piedmont

3.8 Summary

The Beaver Valley unit of First State National Historical Park is 1,100 acres (1.7 mi^2) and contains six sub-watersheds of the Brandywine Piedmont Watershed that flow through the park and capture a drainage area of 4,485 acres (7.0 mi^2). Land use in the six watersheds covers 36% forest, 1% wetlands, 27% urban/suburban, and 36% agriculture, and has an overall impervious coverage of 10%. The watershed experiences a humid continental climate, its soil type consists primarily of Group B and Group C, and its geology is made up of the Wissahickon Formation and Cockeysville Marble boulder complex. The following chapter of this thesis discusses

water quality conditions assessed in the 6 watersheds in First State National Historical Park.

Chapter 4

WATER QUALITY IN FIRST STATE NATIONAL HISTORICAL PARK

4.1 Introduction

During the months of June, July, October, November, and December in 2015 and March through October in 2016, student research assistants and interns from the UD Water Resources Center conducted a water quality sampling project that focused on 6 streams feeding into the Brandywine Creek at the First State National Historical Park in Beaver Valley, Delaware. Water quality sampling was conducted at 12 sites located in six sub-watersheds of the Brandywine Piedmont watershed in First State National Historical Park (Figure 4.1). The purpose of this project was to further characterize the Piedmont streams that flow west to the Brandywine Creek.

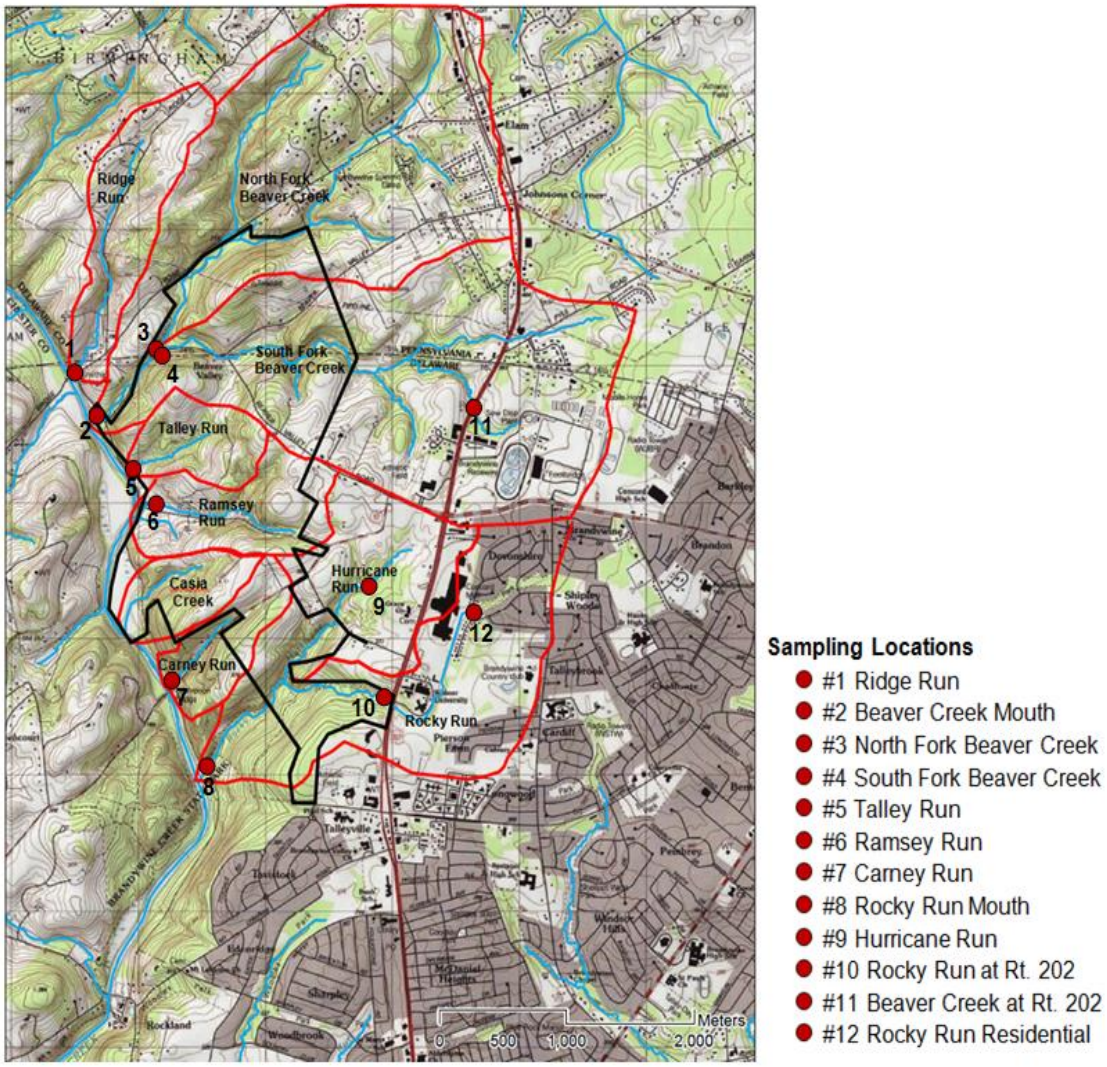

Figure 4.1 Water Quality Sampling Site Locations (UDWRC, 2017)

4.2 Site Descriptions

Site 1: Ridge Run is located along the border of Pennsylvania and Delaware and meanders into a private parcel of land containing a horse farm, grassy lawns, and housing areas along Smithbridge Road. The sampling site is downstream near the mouth of the tributary.

Site 2: Water samples were taken at the mouth of Beaver Creek before the stream flows into Brandywine Creek.

Site 3: Beaver Creek North Fork is located upstream of the confluence of north and south forks at Beaver Creek.

Site 4: Beaver Creek South Fork is heavily developed area that flows past Concord Pike and into the National Historical Park.

Site 5: The Talley Run site is located near the mouth of the tributary several feet upstream of where it crosses underneath Brandywine Creek Road.

Site 6: Ramsey Run flows underneath Ramsey Road before the stream converges with the Brandywine Creek. The sampling site is upstream from the bridge where Ramsey Run crosses the road.

Site 7: Carney Run flows directly alongside Thompson's Bridge Road, and the sampling site is located at the mouth of the tributary and directly downstream of a pedestrian trail bridge.

Site 8: Rocky Run stream sampling site is at the mouth of the tributary and near a new pedestrian trail bridge that was built after the old bridge was wiped out in a large storm. This section is located downstream of the Hurricane Run and Rocky Run's confluence, to assess water quality from all six of Rocky Run's subwatersheds.

Site 9: Hurricane Run is located upstream of where the tributary crosses beneath Woodlawn Road and flows into an extensive hiking/biking trail system.

Site 10: Rocky Run at Route 202 is located between the National Park Boundary and downstream (west) of the Concord Pike (Route 202) overpass. Slightly upstream and through the tunnels (Figure 3.16), the stream banks are channelized with concrete through the Concord Mall complex. On several occasions, there was a

discoloration of the stream that made it look opaque/milky. There are also large pipes leading into Rocky Run that most likely drain the roadways and nearby urbanized areas, which may have an influence on water quality.

Site 11: Beaver Creek runs underneath Concord Pike before the stream enters the National Historical Park.

Site 12: Rocky Run Residential site is located downstream of a suburban community but directly upstream of the Concord Mall and Route 202 area. A deep pool of water is collected right downstream of the sampling site before the stream enters the tunnel and becomes channelized by concrete.

4.3 Methodology

Sampling for the summer of 2015 began on June 22 and ended on July 28. Field teams collected the data once a week at the 12 stream locations in Beaver Valley. The parameters tested at each of the sampling locations include pH, conductivity, water temperature, turbidity, and dissolved oxygen (DO). Water samples were collected on June 30 and July 20 and sent to the City of Wilmington Water Quality lab to test for Enterococci bacteria and turbidity (total suspended solids). Sampling during fall 2015 began on October 9 and ended on December 4 and was conducted every other week. On October 9, nutrient samples from each of the sites were sent to the Soil Testing Program at the University of Delaware College of Agriculture and Natural Resources. Sampling during 2016 was conducted in March and April. Measurements for the summer/fall of 2016 collected conductivity and turbidity (UDWRC, 2017).

4.4 Results

Water temperature is an important indicator for addressing water quality as it can influence other parameters, such as dissolved oxygen, conductivity, and pH, as well as alter the physical and chemical properties of water. Temperature can affect the biologic activity and metabolic rates of aquatic organisms ("Water Temperature," 2014). Temperature fluctuations can affect the success of aquatic organisms, as some organisms may have a higher tolerance to temperature changes than others. The Delaware water temperature standard is 82.0°F (27°C). Our results show that Ridge Run has the highest median temperature of 22.5°C (72.5°F), followed by Rocky Run at Route 202 at 21.5°C (70.7°F) (Figure 4.2). The lowest median temperature of 17.7°C (63.9°F) is recorded at Carney Run. Carney Run, Talley Run and Ramsey Run have the lowest medians and range, which is likely attributed to these tributaries containing the highest percent of forested areas and lowest percent of impervious surfaces and development. Overall, our results show that water temperature observations at each sampling site meet water quality standards in Delaware for temperature. (UDWRC, 2017).

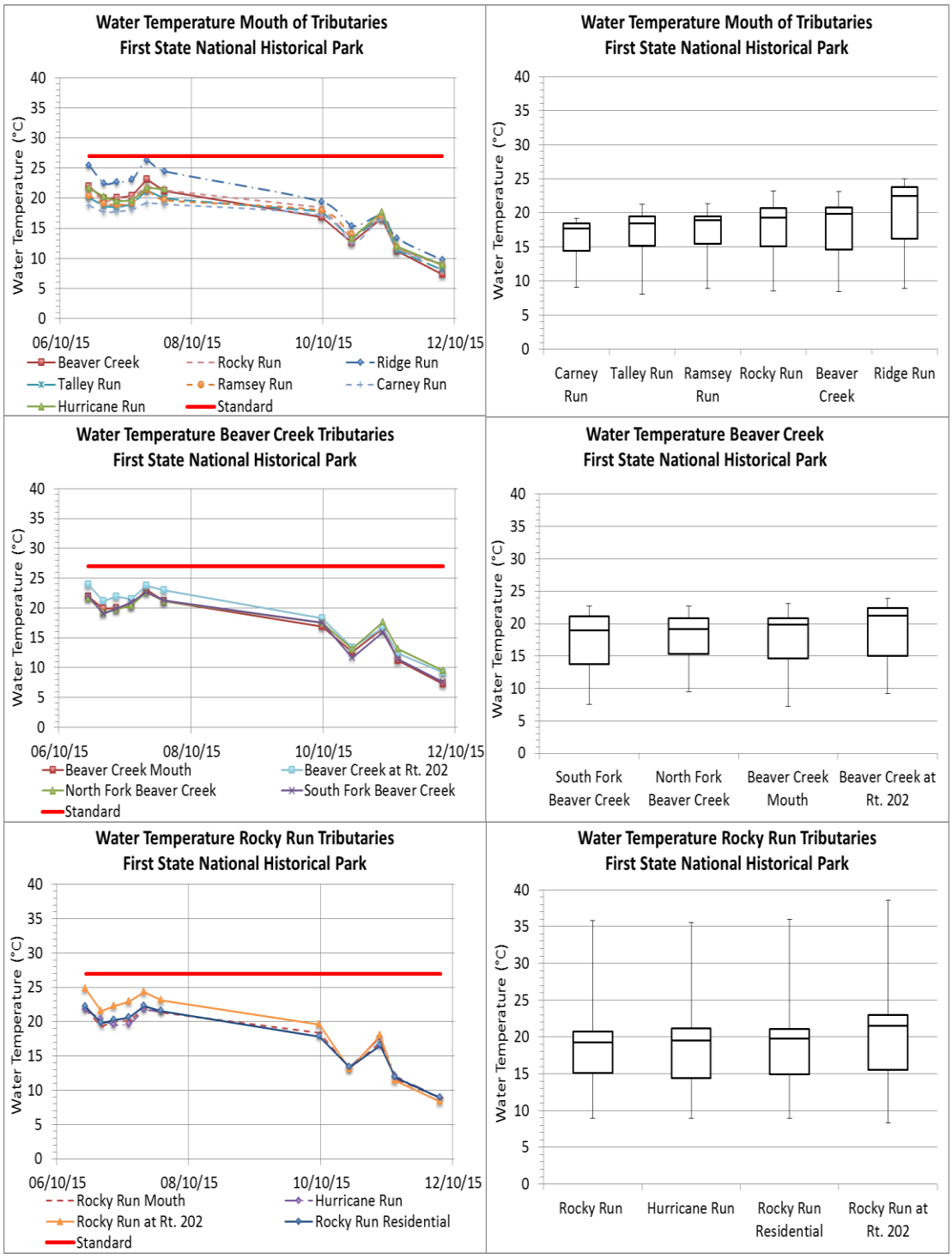

Figure 4.2 Water Temperatures in First State National Historical Park Tributaries

pH is the measure of the acidity of water and will affect the types of organisms that live in the stream. If pH is too high or too low, the aquatic organisms living within the stream can die. The pH of water determines the solubility and biological availability of elements and compounds, such as phosphorus, nitrogen, lead, copper, and arsenic. Extreme pH levels often increase the solubility of elements and compounds, making toxic chemicals, such as lead and arsenic, more "mobile" and increases the risk of absorption by aquatic organisms, which then can lead to declines in functioning, reproduction, or death of aquatic organisms (Perlman, 2016). According to Delaware Water Quality Standards, waters in the state of Delaware should have a pH in the range of 6.5 and 8.5 units. The pH levels of the tributaries observed at each sampling site all fit within this range (Figure 4.3). Rocky Run Residential has the lowest median pH value at 7.0 whereas Beaver Creek Mouth has the highest median pH at a value of 7.9. The neutral to slightly basic pH of the tributaries is due to the geology of the watershed. The geology of the watershed is mostly formed by the Wissahickon Formation gneiss and Cockeysville marble, which are high water yield carbonate rocks that provide buffering capacity to the streams. Therefore, there are no impairments in the pH levels.

Figure 4.3 pH of First State National Historical Park Tributaries

Turbidity measures suspended and dissolved particulate matter in water, and are a measure of relative water clarity. The higher the turbidity, the "cloudier" or "muddier" the water is. Turbidity is an important factor for water quality analysis because it may be a sign of pollution, such as phosphorus pollutants that cause algae blooms. High turbidities have a variety of harmful effects on aquatic wildlife, including prevented development of fish eggs and larvae, reduced growth rate, modified movement and migrations, reducing food availability, decreasing resistance to disease, or death (Minnesota Pollution Control Agency, 2008). Additionally, high turbidities can increase the cost of water treatment for drinking and reduce the aesthetic quality of streams, which can have a harmful impact on recreation and tourism. Turbidity should not exceed a level of 10.0 NTUs. The upper Rocky Run sites (Rocky Run Residential and Rocky Run at Route 202) have the most concern for exceeding 10.0 NTUs or FNUs. There were two instances where the values observed at Rocky Run Residential were higher than the standard. The turbidity was recorded as 10.8 NTU on July 20, 2015 and 12.2 NTU on July 27, 2016. Rocky Run Residential had the highest median turbidity (7.5 NTU) and Rocky Run at Route 202 had the second highest median turbidity (5.3 NTU). These sites have higher recorded levels of turbidity due to increased urban/suburban development and impervious surfaces and reduced forested areas and riparian buffers, which allow increased amounts of pollutants and sediments to reach the stream. However, Rocky Run Mouth has the lowest median turbidity out of all twelve sites (0.85 NTU), so there is little concern for turbid water entering the Brandywine Creek due to the cleansing effect of the forests in the national historical park. (UDWRC, 2017). Sites located in the mouth of the tributaries have lower turbidity values, which suggest that as the streams flow through

the forested areas of the historical park it filters out pollutants and nutrients. Therefore, establishing forested buffers in the upper parts of the watershed could help reduce the turbidity by helping filter out pollutants from reaching the stream.

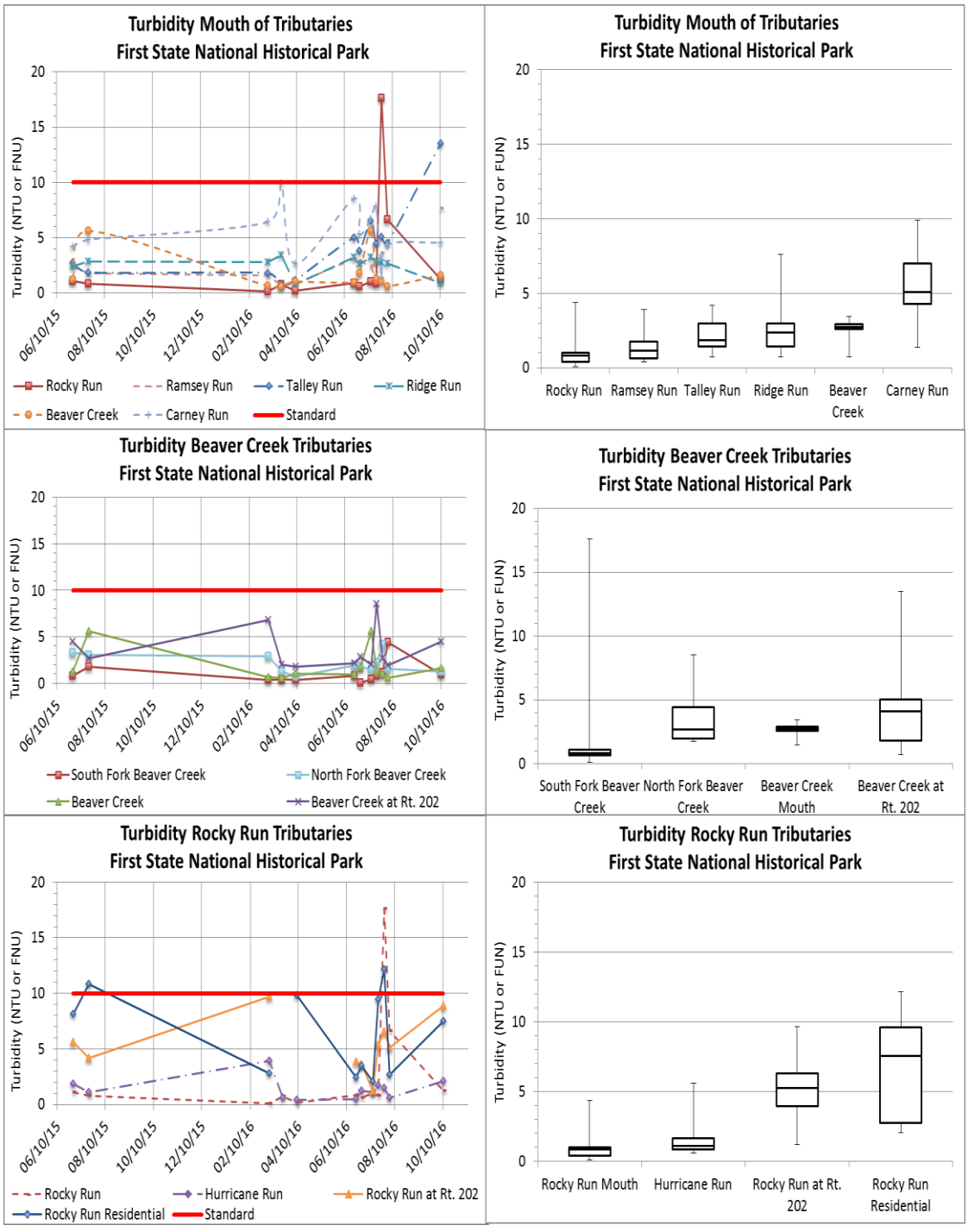

Figure 4.4 Turbidity of First State National Historical Park Tributaries

Fish, macroinvertebrates, plants and bacteria all rely on dissolved oxygen to survive. According to the Delaware Water Quality Standards (1970), a healthy stream should not have a DO average below 5.5 mg/L. Low oxygen levels in a stream can affect growth rates, reproduction, behavior, and survival of aquatic organisms (Batiuk et al., 2009). Low oxygen conditions might occur in slow-moving, narrow waterways with little aquatic plant life. Fish species exposed to less than 5.5 mg/L of DO will have impaired functionality and lower survival rates. Looking at Figure 4.5, the tributaries in the First State all have median DO levels between 7.2 mg/L and 9.8 mg/L. The tributary with the lowest median DO (7.2 mg/L) is Beaver Creek at Route 202 and the tributary with the highest median DO (9.8 mg/L) is Beaver Creek Mouth. Rocky Run at Route 202 had three instances of coming within 0.2 mg/L of the standard in the month of July 2015, which may indicate an area of concern for the tributary but not for the Brandywine (UDWRC, 2017). Since DO is inversely related to temperature, it makes sense that Talley Run and Ramsey run have the second and third highest medians because they also have the coolest recorded temperatures and largest amount of forests. The lowest recorded DO values are recorded at the suburban/residential areas of the watershed, which also have higher recorded temperature and lower forested areas. Therefore, establishing forested buffers should be established in the upper parts of the watershed to increase dissolved oxygen levels in the streams.

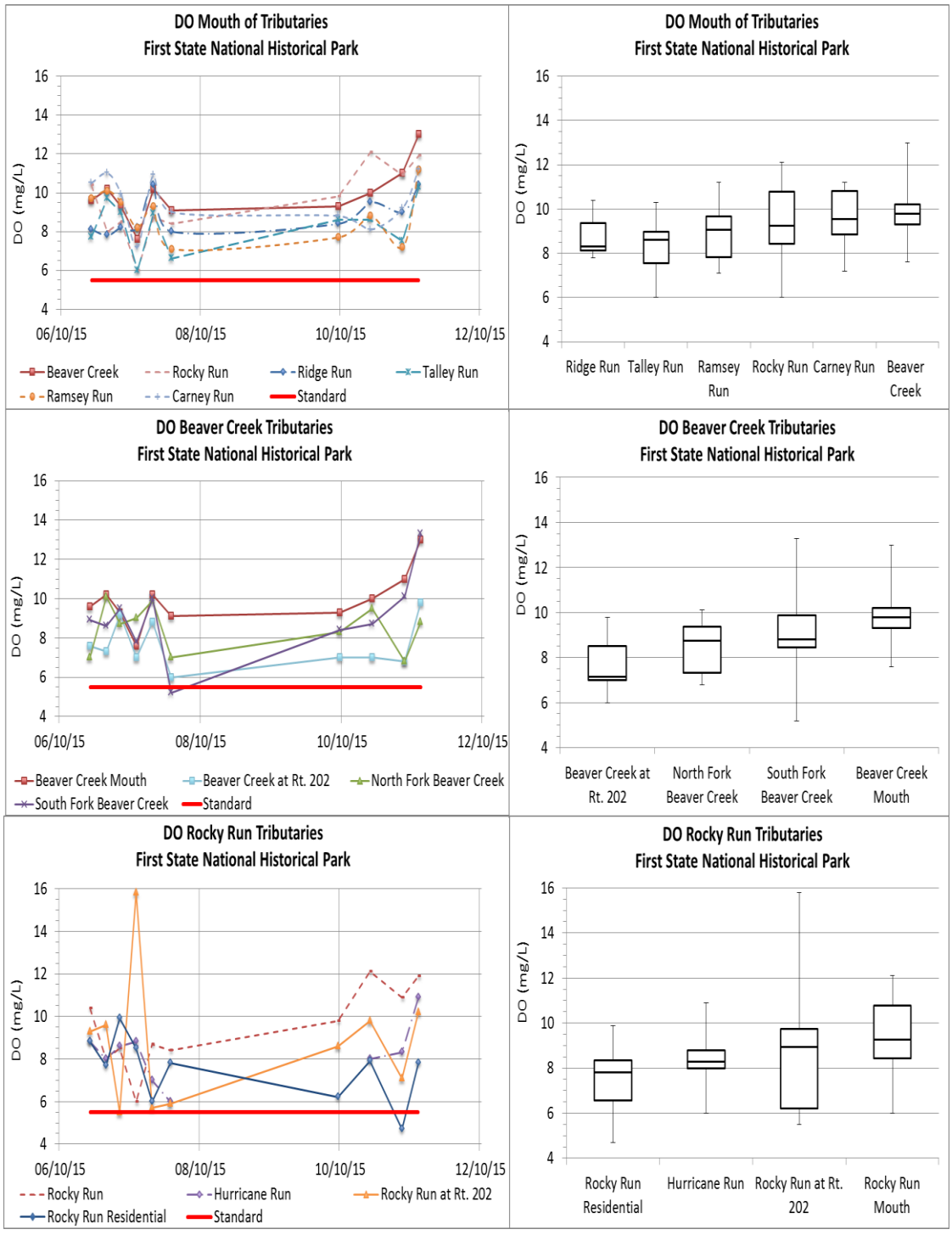

Figure 4.5 Dissolved Oxygen in First State National Historical Park Tributaries

Conductivity is a measure of the ability of water to pass an electrical current through the presence of dissolved solids such as phosphate, nitrate, and sulfate (Fondriest Environmental Inc., 2014). A change in conductivity can indicate pollution due to an increased influx of dissolved solids from an external source such as agricultural runoff, sewage, or residential waste leakage. Conductivity is also affected by temperature, the warmer the water, the higher the conductivity. Ideal conductivity levels for aquatic organisms range between 150µS and 500µS. In Figure 4.6, the highest median conductivity is found at Beaver Creek at Route 202 with a mean of 899µS. This high value is not ideal for aquatic organisms and may be damaging to the ecosystem. On March 4, 2016, the conductivity for Beaver Creek at Route 202 spiked at a dangerously high level of 1720µS. It is expected that this was due to agricultural runoff from the adjacent horse farm. The highest median occurring at Beaver Creek at Route 202 makes sense because it has some of the highest water temperatures in the watershed, and has more development, impervious surfaces, and lower percent of forested areas and buffers, which increase the potential for pollutants to enter the stream. Talley Run has the lowest median conductivity at a value of 110µS. This is due to the lower recorded water temperatures, lower percent of development and impervious surfaces, and increased amount of forested areas and stream buffers that act as a buffer to pollutants.

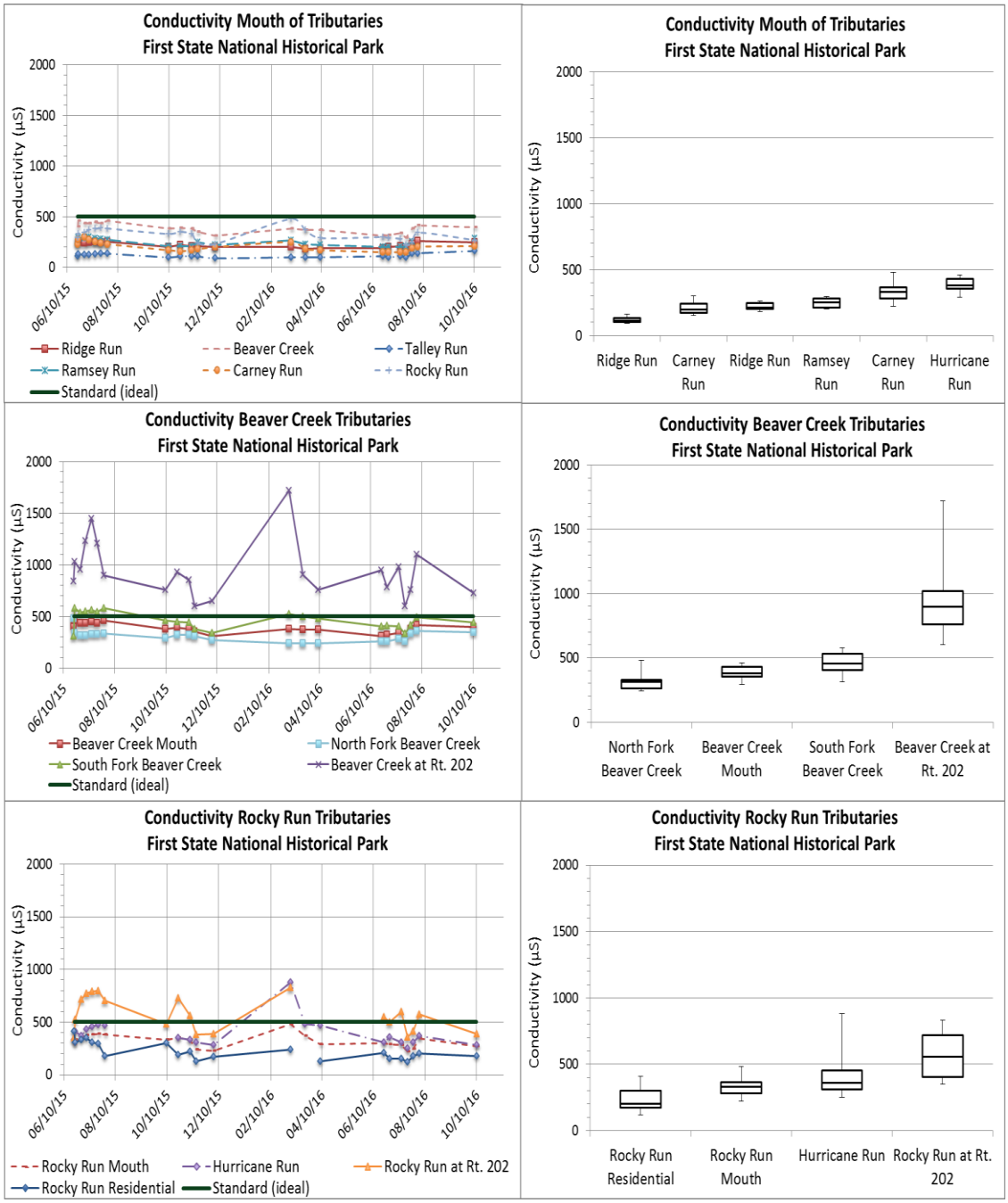

Figure 4.6 Conductivity of First State National Historical Park Tributaries

Bacteria monitoring is important because it can help detect the presence of harmful pathogens that can negatively affect human health. The most common bacteria indicators are E. coli and enterococci as they both help indicate sewage contamination. In Delaware, healthy primary contact recreation fresh waters (swimming, fishing, and drinking) should have a maximum single-sample value of 185 MPN. Secondary contact recreation fresh waters (wading, boating, rafting) can have up to 925 MPN for it to be a safe environment to be used recreationally. Results from the City of Wilmington Water Quality Laboratory indicate that the enterococci levels vary throughout the locations tested. Sampling sites that have enterococci levels higher than a mean of 925 MPN include Ridge Run, Hurricane Run, Beaver Creek at Route 202 and Rocky Run Residential Greenway. The lowest mean value was 322 MPN at Carney Run, which is still almost double the standard for recreational fresh waters. It is recommended that bacterial sampling should be re-done at these sample sites as the bacterial levels seemed abnormally high. If after additional sampling the bacteria levels continue to be high, it is recommended that further measures to enforce people from swimming in these tributaries should be taken.

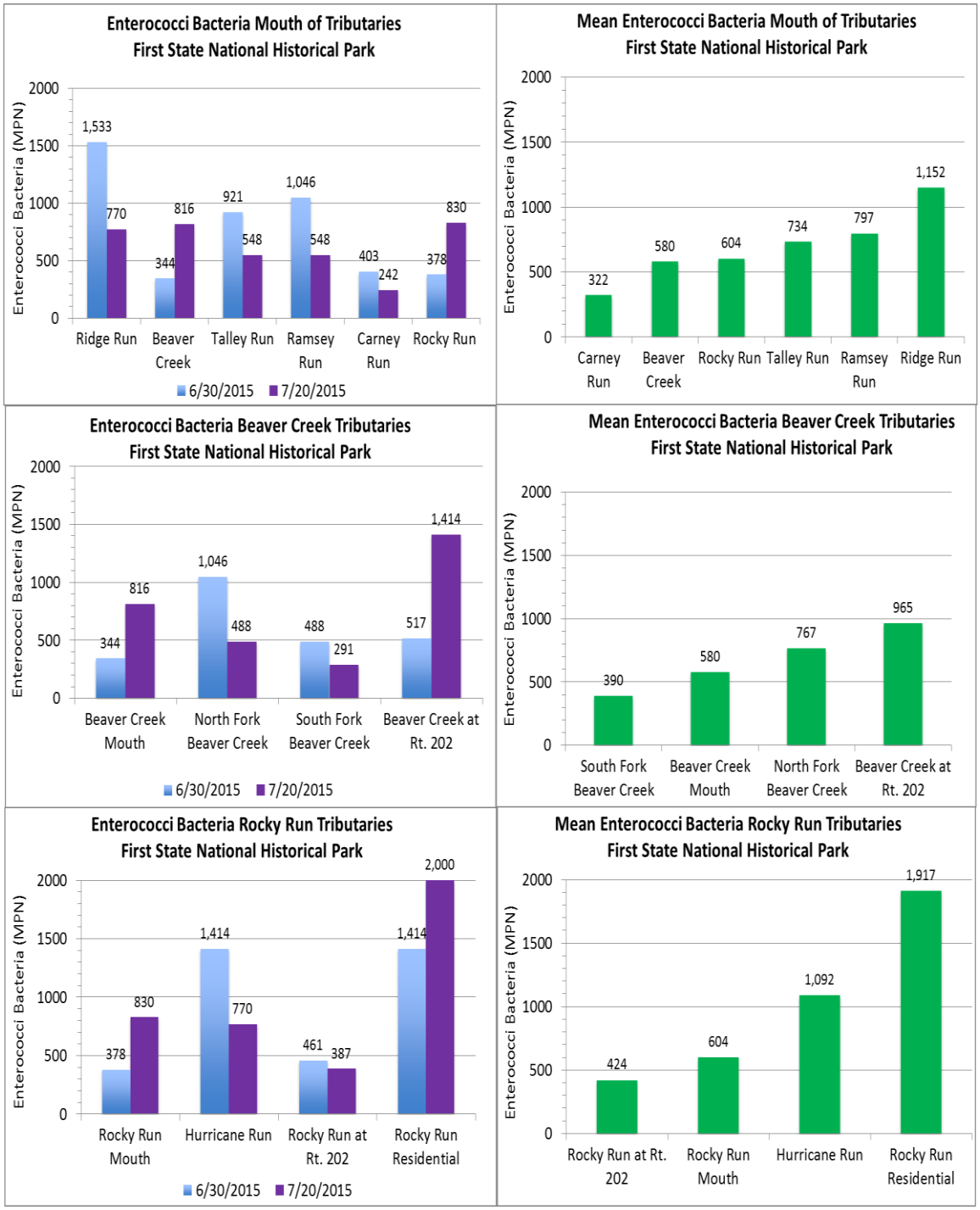

Figure 4.7 Enterococci Bacteria of First State National Historical Park Tributaries

4.5 Summary

Water quality sampling was conducted at 12 sites located in six sub-watersheds of the Brandywine Piedmont watershed. Six parameters (pH, conductivity, water temperature, turbidity, and dissolved oxygen, and enterococci bacteria) were used to assess the water quality condition during 2015 and 2016. Overall, the results indicate that the water quality is good among the six-sub-watersheds. However, there are concerns in the upper parts of the watershed, in the residential and more suburbanized/urbanized areas near Route 202 (Concord Pike), due to several high-recorded turbidity and conductivity readings. Heavily forested and less-developed parts of the watershed near the mouth of the tributaries along the Brandywine River have excellent water quality. It is recommended to install riparian buffers and increase the amount of forested areas in the upper parts of the tributaries to help improve the water quality and potentially reduce the amount of pollutants entering the historical park.

The next chapter of this thesis discusses the water quality conditions of Valley Forge, Harpers Ferry, and Minute Man National Historical Parks, and differences in policies and reporting water quality information contained in State of the Park Reports and Natural Resource Condition Assessments prepared by the National Park Service.

Chapter 5

WATER RESOURCES MANAGEMENT AND POLICIES OF THE NATIONAL PARK SERVICE

5.1 Introduction

The following chapter of this thesis describes water quality conditions discussed in State of the Park Reports and Natural Resource Condition Assessments of National Historical Parks at Valley Forge (PA), Harpers Ferry (WV), and Minute Man (MA). I discuss differences in reporting, policies, and approaches to water resources management among First State, Valley Forge, Harpers Ferry, and Minute Man National Historical Parks.

5.2 Valley Forge National Historical Park

Valley Forge National Historical Park is a 3,466 acre (5.4 mi^2) unit located 20 miles northwest of Philadelphia in Pennsylvania (Figure 5.1). Valley Forge is approximately three times the size of First State NHP. Valley Forge is nationally significant as it was the site of the 1777-78 winter encampment of the Continental Army under General George Washington (NPS, 2015b). The purpose of Valley Forge is to educate people about the people, events, and legacy of the American Revolution, as well as preserving the cultural and natural resources within the park.

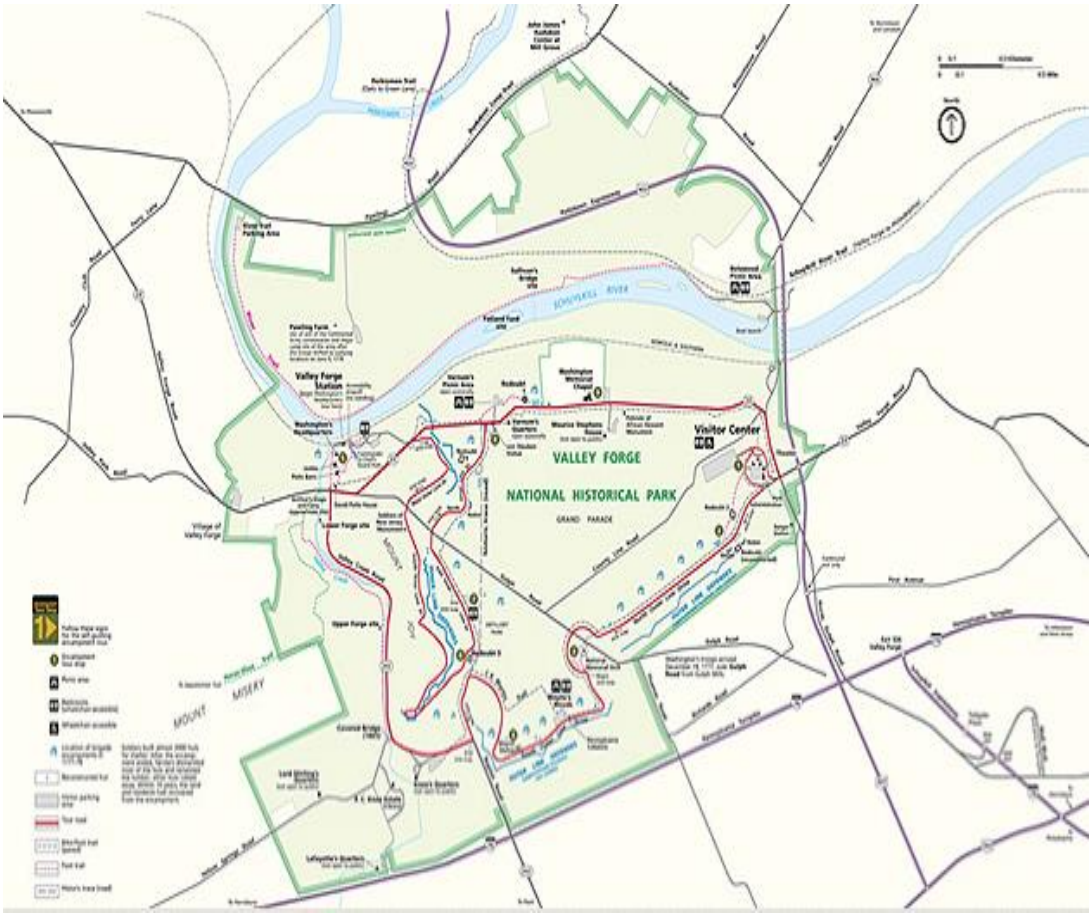

Figure 5.1 Valley Forge National Historical Park ("Valley Forge Maps and Brochures," n.d.)

Valley Forge published a State of the Park Report in 2015 that describes the Valley Creek and Schuylkill River. The State of the Park Report summarizes a Natural Resource Condition Assessment and other inventories and assessments to determine the condition and trend of the park's water resources (NPS, 2015b).

Valley Creek is designated a Pennsylvania "Exceptional Value" waterway, as it has the highest level of protection from the Pennsylvania Department of Environmental Protection as a spring-fed, cold-water fishery and a Class A Wild Trout

Stream. Therefore, it is regulated for the "maintenance or propagation, or both, of fish species including the family Salmonidae and additional flora and fauna which are indigenous to a cold water habitat" (PADEP, 2001). Valley Creek flows through a 23 square mile watershed, with only the last two miles of the creek flowing within the National Historical Park (NPS, 2015b).

In the park's Natural Resource Condition Assessment, Sherwin et al. 2013 rated the overall water quality for Valley Creek as good with a decreasing trend based on the synthesis of water quality measurements (Table 5.1). These measurements include DO, pH, temperature, alkalinity, specific conductivity, phosphorus, nitrite/nitrate, ammonia, chloride, macroinvertebrates, and fish communities (NPS, 2015b). The authors suggest that the decreasing trend is likely due to the increased development activities outside of the park boundaries within the Valley Creek watershed. Since the condition of the creek is mainly dependent on activities outside of the park, building and strengthening partnerships is crucial in helping manage the quality of creek.

The Schuylkill River is a designated Warm Water Fishery and is regulated for the "maintenance and propagation of fish species and additional flora and fauna which are indigenous to a warm water habitat" (PADEP, 2001). The Schuylkill River was the first waterway to be designated as a Pennsylvania Scenic River and is a nationally designated heritage area (NPS, 2015b). The stream is designated as a Migratory Fishes water body, meaning it is also regulated for the protection of "passage, maintenance and propagation of anadromous and catadromous fishes and other fishes which move to or from flowing waters to complete their life cycle in other waters" (PADEP, 2001). Three miles of the 1,916 mi^2 Schuylkill River watershed is located within Valley

Forge. Like Valley Creek, most of the watershed is located upstream of the park and its water quality depends on activities not controlled by the National Park Service. Land uses within the watershed include forested, agricultural and urban areas, with areas becoming increasingly more urbanized downstream of the park. Approximately 34 miles of the Schuylkill River, including 3 miles that flow through the park, have been designated impaired by the Pennsylvania DEP due to industrial runoff including polychlorinated biphenyl and chlordane contamination (NPS, 2015b). About one-third of the streams in the Schuylkill River watershed are listed as impaired for aquatic life use (EPA, 2010).

According to an assessment conducted by Sherwin et al. 2013, water quality parameters such as turbidity, nitrate/nitrite, and DO have direct impact on biotic communities and are considered "good" based on the PA code for Warm Water fisheries. Overall, water chemistry was rated as good and improving for the Schuylkill River based on several water quality measurements including DO, turbidity/total suspended solids, nitrate/nitrogen, and phosphorus (Table 5.1).

Table 5.1 Water Quality Status of Valley Creek and Schuylkill River

Name of Creek/River	Indicators of Condition	Condition Status/Trend
Valley Creek	Water Quality	
Schuylkill River	Water Quality	

Adapted from: (State of the Park Report, 2015)

Table 5.2 Water Quality Reference Conditions

Water Quality Parameter	Reference Condition[1]	Source[1]	Reference Condition[2]	Source[2]
pH	6.0-9.0 (cold water)	PA Code, 2001	6.0-9.0 (warm water)	PA Code, 2001
DO	Min. 7.0 mg/L (cold water fisheries, EVW)	PA Code, 2001	Daily avg. 5.0 mg/L Min. 4.0 mg/L (warm water fisheries)	PA Code, 2001
Water Temperature	37.4 ≤ °F ≤ 66.2 (cold water fisheries)	PA Code, 2001	37.4 ≤ °F ≤ 66.2 (warm water fisheries)	PA Code, 2001
Alkalinity	140 mg/L[3] 20 mg/L as CaCO3 (cold water fisheries)[4]	Botts, 2005 PA Code, 2001	No data recorded Min. 20 mg/L as CaCO3 (warm water fisheries)[4]	PA Code, 2001
Specific conductivity	No data recorded 150-500 µS/cm (cold water fisheries)[4]	EPA, 2009	No data recorded No standard (warm water fisheries)	
Nitrate+Nitrite	Max. 10 mg/L (cold water fisheries)	PA Code, 2001	Max. 10 mg/L (warm water fisheries)	PA Code, 2001
Phosphorus	< 0.1 mg/L (cold water fisheries)[5]	Correll, 1998	< 0.1 mg/L (warm water fisheries)[5]	Correll, 1998
Ammonia	Max. 0.2 mg/L (cold water fisheries)	Murphy, 2002	No data recorded 17 mg TAN/L, 1.9 mg TAN/L at pH 7 and 20°C, 4.8 mg TAN/L as a 4-day average (warm water fisheries).	EPA, 2009
Chloride	Max. 250 mg/L (cold water fisheries)	PA Code, 2001	Max. 250 mg/L(warm water fisheries)	PA Code, 2001
Total Dissolved Solids	No data recorded 750 mg/L or 500 mg/l monthly average (cold water fisheries)[4]	PA Code, 2001	Median monthly 40 mg/L (warm water fisheries)[5]	Valley Forge

[1]Reference condition and source for Valley Creek, [2]Reference condition and source for Schuylkill River, [3]Used to assess the condition and trend, [4] PA State Standard (not used to determine condition and trend), [5]This is only a recommended standard as there is no state required standard.
Adapted from (State of the Park Report, 2015)

Figure 5.2 Status and Trend Symbols in the State of the Park Report
(State of the Park Report, 2015)

5.3 Harpers Ferry National Historical Park

Harpers Ferry is a 3661 acre (5.7 mi^2) unit located at the confluence of the Potomac and Shenandoah Rivers in West Virginia, Virginia, and Maryland (Figure 5.3). Harpers Ferry is similar in size to Valley Forge NHP and approximately three times the size of First State NHP. Harpers Ferry was established in 1944 as a public national memorial commemorating a diverse number of historic people and events that influenced the course of our nation's history (Thomas et al., 2013). The park is primarily located in West Virginia, and contains riparian habitats, floodplains, agricultural fields, unique geologic features, rare limestone glades, upland forests, historic buildings, and developed areas.

Although the Potomac and Shenandoah Rivers flow through the park boundaries, these waterways are not considered part of Harpers Ferry NHP. Several small tributaries cross the park, such as a 500-foot section of Elk Run as a major water supply for the town. A short section of Piney Run crosses the national park before it also enters the Potomac River. Flowing Springs Creek also flows through the park and winds for about one mile along the park before it enters the Shenandoah River.

Figure 5.3 Map of Harpers Ferry National Historical Park (NPS, 2008)

Every few years, Harpers Ferry NHP assesses the condition of its natural resources and releases a natural resource condition assessment with the most recent report published in 2013. Harpers Ferry has not released a State of the Park report. In 2013, water resources within Harpers Ferry meet federal and state water quality standards. Thomas et al. collected data on 9 metrics: pH, dissolved oxygen, water temperature, acid neutralizing capacity, salinity/specific conductance, nitrate, total phosphorus, Benthic Index of Biotic Integrity, and Physical Habitat Index, during 2004-2011 to determine the overall status of water resources within the historical park

(Thomas et al., 2013). Data was collected in Flowing Springs Creek by I&M staff during 2005-2011 for pH, dissolved oxygen, water temperature, acid neutralizing capacity, specific conductance, and nitrate. Data for total phosphorus was collected during the period of 2007-2011, and data on Benthic Index of Biotic Integrity and Physical Habitat Index was collected during 2004.

Reference conditions were established for each of the 9 metrics (Table 5.3) and the data were compared to these reference conditions to obtain the percent attainment and converted to the condition assessment for that metric (Figure 5.4). Harpers Ferry National Historical Park scored "very good" for pH, water temperature, acid neutralizing capacity (100% attainment), and dissolved oxygen (96% attainment). Benthic Index of Biotic Integrity scored "degraded" (45% attainment), Physical Habitat Index scored "partially degraded" (67% attainment), and nitrate, specific conductance, and total phosphorus scored "very degraded" (7.2%, 2.9%, and 0% attainment) (Table 5.3). This resulted in an overall water resources condition attainment of 58% or moderate condition. (Thomas et al., 2013)

The source of the reference conditions for pH, dissolved oxygen, and water temperature are from the West Virginia criteria for Designated Use Category C: Water Contact Recreation (State of West Virginia, 2008). The source of the reference conditions for acid neutralizing capacity, nitrate, Benthic Index of Biotic Integrity, and Physical Habitat Index are from the Maryland Biological Stream Survey (MBSS). The source of the reference condition for specific conductance is from Buchanan et al. 2011 and the source of the reference condition for total phosphorus is from the U.S. Environmental Protection Agency Eco-regional Nutrient Criteria.

Table 5.3 Harpers Ferry National Historical Park Water Resources Assessment

Water Quality Parameter	Reference Condition	Source	Observed Median	% Attainment	Condition
pH	6.0 ≤ pH ≤9	State of West Virginia, 2008	8.2	100	Very Good
DO (mg/L)	≥ 5.0	State of West Virginia, 2008	8.4	96	Very Good
Water Temperature (°F)	≤87.0 May-Nov; ≤73 Dec-Apr[6]	State of West Virginia, 2008	66.4 May-Nov; 45.3 Dec-Apr	100	Very Good
ANC (µeq/L)	≥ 200	MBSS	4,820	100	Very Good
Specific conductance (µS/cm)	≤ 500	Buchanan et al., 2011	660	2.9	Very Degraded
Nitrate (mg/L)	≤ 2	MBSS	4.1	7.2	Very Degraded
Total phosphorus (mg/L)	≤ 0.01	EPA, 2000	0.14	0	Very Degraded
BIBI	1.0-1.9, 2.0-2.9, 3.0-3.9, 4.0-5.0	MBSS from BIBI	2.8	45	Poor
PHI	0-50, 51-65, 66-80, 81-100	MBSS	75	67	Partially Degraded

Adapted from (Thomas et al., 2013)

Table 4.12a. Categorical ranking of reference condition attainment categories for pH, dissolved oxygen, temperature, acid neutralizing capacity, specific conductance, nitrate, and total phosphorus.

Attainment of reference condition	Natural resource condition
80–100%	Very good
60–<80%	Good
40–<60%	Moderate
20–<40%	Degraded
0–<20%	Very degraded

Table 4.12b. Categorical ranking of the reference condition attainment categories for the Benthic Index of Biotic Integrity and the Physical Habitat Index.

Reference conditions	Attainment of reference condition	Natural resource condition
Benthic Index of Biotic Integrity (BIBI)		
4.0–5.0	100%	Good
3.0–3.9	scaled linearly	Fair
2.0–2.9		Poor
1.0–1.9	0%	Very poor

Reference conditions	Attainment of reference condition	Natural resource condition
Physical Habitat Index (PHI)		
81–100	75–100% (scaled)	Minimally degraded
66–80	50–75% (scaled)	Partially degraded
51–65	25–50% (scaled)	Degraded
0–50	0–25% (scaled)	Severely degraded

Figure 5.4 Reference Conditions for Natural Resource Condition Assessment (Thomas et al., 2013)

5.4 Minute Man National Historical Park

Minute Man National Historical Park is a 967 acre (1.5 mi²) unit located 22 miles outside of Boston within Lexington, Lincoln, and Concord, Massachusetts (Figure 5.5). Of the three National Historical Parks described in this chapter, Minute Man NHP is the closest in size to First State NHP. Minute Man National Historical Park celebrates the opening battles of the American Revolution by preserving the historic sites, structures, landscapes, and ideas embodied by these events. (“Plan Your Visit," n.d.). Minute Man National Historical Park contains diverse habitats, including

forested uplands, wetlands, freshwater ponds, meadows and fields, and active agricultural land farmed under the park's agricultural leasing program (Pirri, 2009).

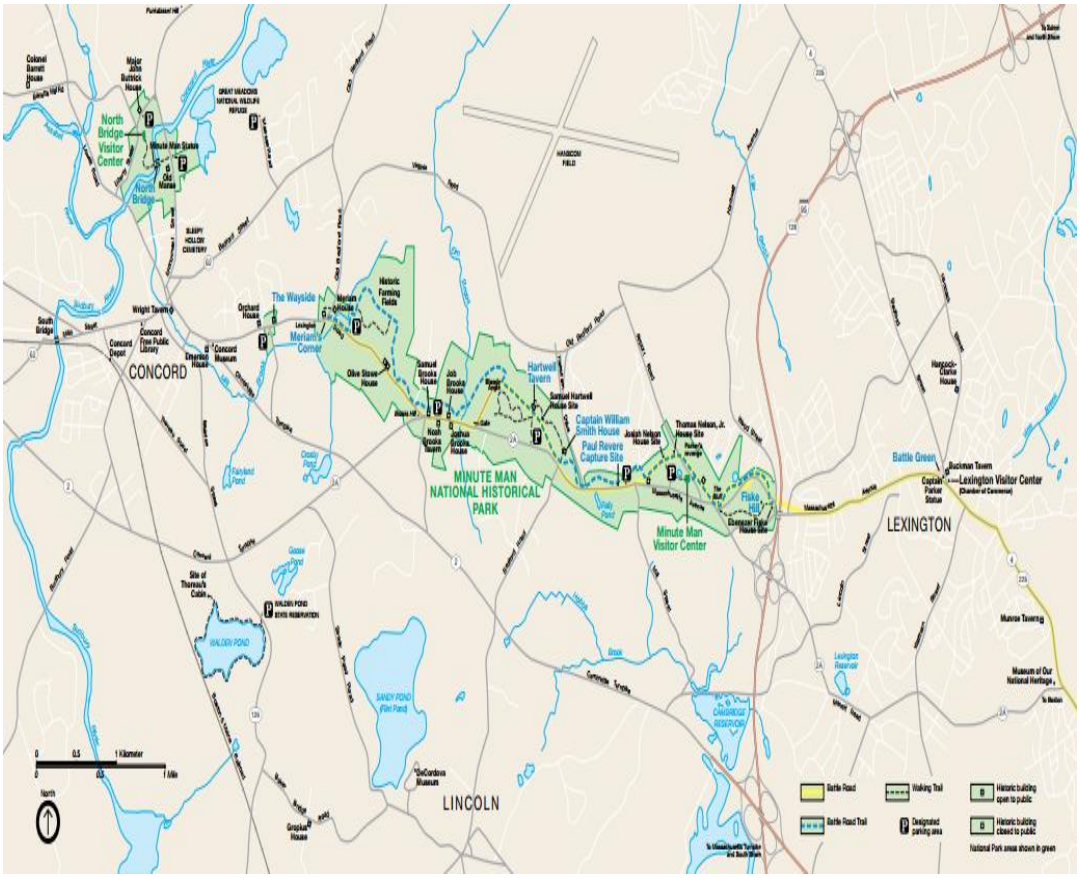

Figure 5.5 Map of Minute Man National Historical Park ("Minute Man National Historical Park Maps," n.d.)

Every few years, Minute Man NHP assesses the condition of its natural resources and releases a report. The most recent Natural Resource Condition Assessment Report, published in 2009, includes the condition of its water resources. Minute Man NHP has not yet released a State of the Park Report. Water quality is

assessed throughout Massachusetts on a regular basis as part of the requirement of the Clean Water Act. Waters are evaluated every two years and a report is provided to the US EPA. Three stream/river segments (Elm Brook, Mill Brook, and the Concord River) that have portions in Minute Man NHP have been routinely evaluated for water quality by the Commonwealth of Massachusetts (Pirri, 2009).

The condition of water resources was quantified by rating the condition as "good," "caution," or "significant concern" (Table 5.4). NETN threshold values for assessments from established monitoring programs (water quality monitoring) were used to estimate the condition of Minute Man NHP's water resources. Trends in water resource condition were also evaluated. Trends were assigned a condition of "improving condition," "stable condition" or "declining condition" after reviewing historical and recent data (Table 5.4). The reliability and quality of data used to assess the condition were rated using three rating categories: "good," "satisfactory," and "limited" (Table 5.4). Following these guidelines, the overall condition of water resources in the park was determined and is considered declining (Pirri, 2009). The water quality was rated as significant concern, the trend was considered declining, and the data reliability was good.

The segment of the Concord River has been assessed for water quality by the state of Massachusetts since 1998. The Concord River is a Class B, warm water fishery, and is a treated water supply river. This segment is listed by the state of Massachusetts as impaired or threatened and needing a TMDL. It was recently assessed in 2008 as impaired for metals, nutrients, pathogens (fecal coliform) and exotic species (non-native aquatic macrophytes).

Mill Brook is a Class B water and cold water fishery and is designated as habitat for fish, other aquatic life, and wildlife and for primary and secondary contact recreation. Mill Brook was most recently assessed in 2008 as impaired by the non-pollutant stressor of "other habitat alterations" (Pirri, 2009). Other habitat alterations are defined as the "degradation, loss, or alteration of aquatic habitat due to physical degradation, riparian alteration, channel modification, or hindrance of fish passage or migration" (Pirri, 2009).

Elm Brook is a cold water fishery and is listed by the State of Massachusetts as impaired or threatened and needing a TMDL. Elm Brook was most recently assessed in 2008 as impaired by pathogens, turbidity, and other habitat alterations. The impairments by pathogens and turbidity are due to unknown sources, municipal sources, such as high-density urbanized areas, and urban runoff.

Table 5.4 Rating Categories and Numerical Scores

Condition	**Icon**	**Numerical Score**
		Condition midpoint score (range)
Good		0.84 (0.68 to 1.0)
Caution		0.50 (0.34 to 0.67)
Significant concern		0.16 (0 to 0.33)
Unknown condition		No value given
		Trend midpoint score (range)
Improving trend		0.84 (0.68 to 1.0)
Stable trend		0.50 (0.34 to 0.67)
Declining trend		0.16 (0 to 0.33)
Unknown trend		No value given
		Data reliability midpoint score (range)
Good data		0.84 (0.68 to 1.0)
Satisfactory data		0.50 (0.34 to 0.67)
Limited data		0.16 (0 to 0.33)

Water quality monitoring was conducted in 2013 at Minute Man NHP and a report was published on the findings (Gawley et al., 2014). This report includes data gathered by the Northeast Temperate Network (NETN) in the 2013 monitoring season (May-October). The data address the NETN objective to detect change in the status of physical, chemical, or biological attributes of park freshwater bodies. The same monitoring sites of the Natural Resource Condition Assessment Report were analyzed in this report. As of 2013, most water quality parameters for the monitored streams were within state standards and were generally within the ranges of the historic NETN monitoring data from Minute Man NHP (Table 5.5). Exceptions were high temperature readings in July at Mill Brook and Elm Brook, and low DO readings from Mill Brook (June and July) and the Concord River (July). Additionally, although there is no state standard for chloride, the values were very high and likely reflect runoff of road de-icing chemicals (Gawley et al., 2014).

Table 5.5 Water Resources Assessment in Minute Man National Historical Park (Gawley et al., 2014)

Water Quality Parameter	**Reference Condition**	**Source**	**Results**
pH	6.5-8.3	MADEP, 2007	Values were within the Massachusetts water quality standards
DO	Min. 6 mg/L	MADEP, 2007	Above the standard except June and July at Mill Brook and July at Concord River
Water Temp.	82.9°F warm water; 68°F cold water	MADEP, 2007	Most measurements met the standards except in July at Mill Brook and Elm Brook
Turbidity	0-10 NTU	EPA, 1999	All values are within this standard
Nitrogen	0.71 mg/L	EPA, 2000	All but one value within criterion of 0.71 mg/L
Total phosphorus	31.25 µg/L	EPA, 2000	All values above criterion of 31.25µg/L

5.5 First State National Historical Park

Beaver Creek, Talley Run, and Rocky Run in First State National Historical Park are listed on the Draft Delaware Department of Natural Resources and Environmental Control 2014 Clean Water Act Section 303(d) list for impaired habitat and biology (Figure 5.6). The impaired streams lists designate the cause of these impairments from land erosion, agriculture or waste/storm water runoff.

Delaware Final 2014 303(d) List

WATERBODY ID	WATERSHED NAME	SEGMENT	Overall CALM Code	DESCRIPTION	SIZE	POLLUTANT OR STRESSOR	PROBABLE SOURCE(S)	YEAR LISTED	TARGET DATE FOR TMDL	TMDL DATE	Pollutant CALM Code	Year Changed from Category 5 Per 303(d) Assesment and Methodolgy	Notes
DE040-002	Brandywine Creek	Upper Brandywine	5	From State Line to Wilmington	9.3 miles	Bacteria	PS, NPS, SF	1996	2004	2005	4a		Bacteria, listed in 1996, delisted 2006 , relisted 2008
						Nutrients		1996		2000	1	2014	Nutrients, Listed 1996, Delisted 2014
						PCBs		1996	2003	2003	4a	2012	EPA TMDL for PCBS in Delaware River Zone 5 and tributaries
						Dioxin		2002	2017		5		Target date changed to 2017 in the 2012 Cycl, per the WATAR plan in the appendix
				From State line to the confluence with the Christina River	8.0 miles	Habitat	NPS	1998	2009		5		
DE040-003	Brandywine Creek	All tributaries on Brandywine Creek from the headwaters at PA-DE line to the confluence with the Christina River	5	Eastern tributary of Beaver Creek, from headwaters to the confluence with mainstem Beaver Creek	0.96 miles	Biology and Habitat	NPS	1998	2009		5		
				Tributary originating in Pennsylvania on the western side of Brandywine Creek	0.26 miles	Biology and Habitat	NPS	1998	2009		5		
				Tributary of Brandywine Creek, off Route 100 (near PA-DE border)	0.92 miles	Habitat	NPS	1998	2009		5		
				Tributary of Brandywine Creek just below Beaver Creek	0.85 miles	Habitat	NPS	1998	2009		5		
				Eastern tributary of the headwaters of Rocky Run(upper half)	1.16 miles	Habitat	NPS	1998	2009		5		
				Eastern tributary of the headwaters of Rocky Run(lower half)	1.16 miles	Biology and Habitat	NPS	1998	2009		5		
				From the confluence of the headwaters of Wilson Run to the next larger stream order (lower half)	0.64 miles	Habitat	NPS	1998	2009		5		
				From the confluence of the headwaters of Wilson Run to the next larger stream order (upper half)	0.64 miles	Biology and Habitat	NPS	1998	2009		5		
				Wilson Run, from start of the third order stream to the confluence with Brandywine Creek	0.88 miles	Biology	NPS	1998	2009		5		
				Tributary of Wilson Run on Montchanin Road from the headwaters to the first confluence	0.45 miles	Habitat	NPS	1998	2009		5		

Figure 5.6 Draft Delaware Section 303d list of Impaired Streams (DNREC, 2014)

Water quality data (see Chapter 4) was compared with water quality standards for each of the 20 metrics (Table 5.1) to obtain percent attainment and convert to the condition assessment for that metric using the methods described in the Harper Ferry's State of the Park Report (Figure 5.4). The percent attainment for each of the 12 sampling sites for each parameter was found and then averaged to find the overall percent attainment for each parameter. Streams in First State National Historical Park scored "very good" for water temperature (100% attainment), pH (98% attainment), turbidity (97% attainment), DO (98% attainment), and electrical conductivity (84% attainment).

Table 5.5 Water Resources Assessment in First State National Historical Park

Parameter	**Unit**	**Water Quality Standard**	**Attainment (%)**	**Condition**
Temperature	°C	Max. 27.7°C	100%	Very Good
pH	standard pH unit	6.5-8.5	98%	Very Good
Turbidity	NTU	10	97%	Very Good
DO	mg/L	Min. 5.5	98%	Very Good
Conductivity	µS	150-500	84.1%	Very Good
Enterococci Bacteria	#/100mL	925/100	71%	Good

Adapted from (UDWRC, 2017)

Based on chemical parameters monitored over the sampling period and water quality standards, the overall results from this study indicate that there are little

chemical impairments, no nutrient impairments, and some bacterial impairments in the tributaries flowing through First State National Historical Park into the Brandywine River.

Our results indicate values are close to the borderline of impaired waters in a few tributaries. Beaver Creek at Route 202 has the highest conductivity values and a 0% attainment for conductivity because recorded observations are above the 150-500μS standard. Water quality of this stream may be affected by runoff from nearby Concord Pike and heavy impact of urban development as runoff flows downstream from these areas to the sampling site. High levels of bacteria were also recorded from this site, which may be an indication of sewage runoff issues from the surrounding residential, highway, and business areas directly upstream.

Rocky Run at Residential Greenway is another example of a tributary that may be impacted more seriously by commercialized areas as indicated by high turbidity and dangerous levels of bacteria. This site had the lowest recorded DO values and the second highest turbidity values of our twelve testing sites. It had an attainment of 90% for DO due to one observed reading that fell below the minimum standard of 5.5 mg/L and had an attainment of 83% for turbidity due to two observed readings that fell above the (10 NTU) standard. However, other results show that water quality conditions at the mouth of Rocky Run are within the healthy range in our measured parameters, which suggests that the protected vegetation in the First State NHP may help restore the water quality of unhealthy streams.

The mouth of Beaver Creek has the highest median pH of 7.9 when compared to the other 11 sampling sites. Both Beaver Creek North and South Fork sites have

higher mean pH values as they converge into Beaver Creek, the highest pH value may be a result of these two streams combining.

Talley Run attained 100% for all parameters except for turbidity. Talley Run had the second highest recorded turbidity reading out of the 12 sites and had an attainment of 92% for turbidity due to one observed reading that fell above the (10 NTU) standard. However, it had the fourth highest median turbidity.

To improve the water quality of the tributaries, native vegetated buffers should be planted along roadways where there is little to no vegetation between the road and stream. Since Beaver Creek, Talley Run and Rocky Run are listed as impaired for habitat and biology by the DNREC Section 303d list, implementing reforestation techniques along heavily eroded banks is recommended to prevent further degradation. Since Brandywine State Park and the adjacent First State National Historical Park contain many horse and agricultural farms, it is important to take preventative measures to prevent nutrient runoff and bacteria from further endangering the adjacent waterways. (UDWRC, 2017)

5.6 Comparative Analysis of Water Management in National Park Units

All of the national historical parks, except Harpers Ferry, have impaired waterways. One of two rivers that flow through Valley Forge NHP is considered impaired. The Schuylkill River in Valley Forge NHP is on the 303d list under the Clean Water Act and fails to meet water quality standards of the Pennsylvania DEP. Water quality of rivers and creeks in Minute Man NHP fail to meet all applicable water quality standards. The Concord River is impaired for metals, nutrients, pathogens, and exotic species, Mill Brook is impaired by other habitat alterations, and Elm Brook is impaired by pathogens, turbidity, and other habitat alterations. In First

State NHP, Beaver Creek, Talley Run, and Rocky Run are listed on the Draft Delaware DNREC 2014 Clean Water Act Section 303(d) list for impaired habitat and biology. Water quality of rivers and creeks in Harpers Ferry NHP meet or exceed all applicable water quality standards for West Virginia streams.

Water quality regulations and standards vary between Minute Man, Harpers Ferry, Valley Forge and First State National Parks due to differences in state regulations and differing classifications of the streams in each of the four parks in the different states. Valley Forge NHP is required to follow federal and Pennsylvania state water quality regulations and Minute Man NHP is required to follow federal and Massachusetts state water quality regulations. Harpers Ferry NHP is required to follow federal and West Virginia state water quality regulations. First State NHP is required to follow federal and Delaware state water quality regulations.

All 4 national historical parks follow similar standards for pH and DO. Valley Forge NHP and Harpers Ferry NHP follow the same standard for pH, and Harpers Ferry NHP and Valley Forge NHP follow similar standards for DO. All 4 national parks follow similar standards for water temperature; however, Harpers Ferry NHP has a slightly higher standard for water temperature and Valley Forge NHP has the lowest standard for temperature. Valley Forge NHP and First State NHP follow similar standards for alkalinity, while Minute Man NHP and Harpers Ferry NHP are not required to follow a standard. Harpers Ferry, Valley Forge, and First State National Historical Parks are required to meet a nitrogen standard for domestic water supply (human health). Minute Man NHP does not have water sources used for public water supply so it is not required to follow a drinking water nitrogen standard. All of the national historical parks are not required to follow EPA Regional Criteria for

nitrogen, phosphorus, and turbidity as these are only suggested criterions and are non-regulatory. Harpers Ferry NHP had the lowest recommended criteria for nitrogen, followed by Valley Forge, First State and Minute Man National Historical Parks. Harpers Ferry NHP had the lowest recommended criteria for phosphorus and turbidity, followed by Minute Man, Valley Forge and First State National Historical Parks. Harpers Ferry, Valley Forge, and First State National Historical Parks all follow similar standards for bacteria, while Minute Man NHP does not follow a standard. Minute Man, Harpers Ferry and Valley Forge National Historical Parks follow the same standard for TDS, while First State NHP has a much lower standard it is required to meet. Minute Man, Harpers Ferry and Valley Forge National Historical Parks follow the same standards for chloride, while First State NHP does not follow a standard. Valley Forge and First State National Historical Parks follow the same standard for alkalinity, while Minute Man NHP and Harpers Ferry NHP do not follow a standard.

Water quality monitoring and reporting is varied among the four national parks. Valley Forge NHP is the only park to have released a State of the Park Report. Valley Forge, Harpers Ferry, and Minute Man National Historical Parks have released Natural Resource Condition Assessment Reports. Valley Forge NHP and Harpers Ferry NHP both released Natural Resource Condition Assessment Reports in 2013, which are the most recent Natural Resource Condition Assessment Report released by both parks. The most recent Natural Resource Condition Assessment Report for Minute Man NHP was released in 2009. First State NHP has not released a State of the Park Report or Natural Resource Condition Assessment as it is still in an early stage of development.

The sampled water quality parameters at each of the parks vary. At Minute Man National Historical Park, twelve water quality parameters have been tested/sampled at all of the streams found in the park (Table 5.7). At Valley Forge NHP, thirteen water quality parameters have been tested/sampled at all of streams found in the park (Table 5.7). At Harpers Ferry National Historical Park, nine water quality parameters have been tested/sampled at all of streams found in the park (Table 5.7). At First State NHP, six water quality parameters have been tested/sampled (Table 5.7).

How the results and findings are communicated in these reports vary among the national historical parks. Minute Man and Valley Forge National Historical Parks both used similar rating categories and numerical scores in the assessment of condition, trend, and data reliability of their water resources. The condition status/trend of the park's water resources was displayed pictorially using traffic light symbols. The symbol was either a dashed circle, solid, or bolded circle, colored either red, yellow, or green, and included either a up, down or sideways arrow (Figure 5.2 and Table 5.4). Harpers Ferry NHP, however, uses a slightly different method to evaluate the condition of its water resources. Harpers Ferry NHP did not determine the trend and data reliability of the parks water resources. However, Harpers Ferry NHP found the percent attainment, which was then converted to the condition assessment for each of the metrics (Figure 5.4). Although Harpers Ferry NHP did not use traffic light symbols to illustrate their results, a similar color scheme of red, yellow, and green was used to communicate the water resources condition (Figure 5.4).

Table 5.6 Water Quality Standards in Natural Park Units

	Minute Man	**Harpers Ferry**	**Valley Forge**	**First State**
Parameters	**Criteria**	**Criteria**	**Criteria**	**Criteria**
pH	6.5-8.3[1]	6.0 ≤ pH ≤9.0[3]	6.0-9.0[7]	6.5-8.5[9]
DO	≥ 6.0 mg/L[1]	≥ 5.0 mg/L[3]	≥ 5.0 mg/L; 4.0 mg/L (Warm Water). ≥ 7.0 mg/L (Cold Water Fisheries and Exceptional Value Waters)[7]	Avg. ≥ 5.5 mg/L[9]
Water Temperature	≤ 82.9°F warm water; ≤68°F cold water[1]	≤ 87°F May-Nov; ≤73°F Dec-Apr[6]	Max: 37.4 ≤ °F ≤ 66.2 [7]	Max. 82°F[9]
Total Nitrogen	≤ 0.71 mg/L[2]	≤ 0.31 mg/L[4] ≤ 2 mg/L[12] ≤ 10 mg/L[5]	≤ 0.69 mg/L[8] ≤ 10 mg/L[5]	≤ 0.69 mg/L [10] ≤ 10 mg/L[5]
Total phosphorus	≤ 31.25 µg/L[2]	≤ 0.01mg/L[4]	≤ 36.56 µg/L[8] 0.1 mg/L[12]	≤ 36.56 µg/L[10]
Bacteria	No standard	200/100 mL, 400/100 mL[6]	≤ 200/100 mL (May 1-September 30), 400/100 mL, 2,000/100 mL[7]	≤ 2,400/100 mL, 1,000/100 mL[9]
Turbidity	0-10 NTU[1]	≤ 1.7 FTU[4] ≤10 NTU[6]	≤ 5.7 FTU[8] ≤10 NTU[7]	≤ 5.7 FTU[10] ≤ 10 NTU or 10 FTU[9]
TDS	≤500 mg/L[1]	≤500 mg/L[6]	≤ 500 mg/L; ≤ 750 mg/L[7]	≤ 250 mg/L (Sulfate portion max.: 100 mg/L)[9]
Chloride	≤250 mg/L[1]	≤ 250 mg/L[6]	≤ 250 mg/L[7]	No standard
Alkalinity	No standard	No standard	≥ 20 mg/L as CaCO3.[7] Min. 140 mg/L[11]	≥ 20 mg/L as CaCO3. [9]

[1] MassDEP (2007),[2] EPA (2001), [3] State of West Virginia (2011), [4] EPA (2000a), [5] EPA Criteria for Human Health Protection, [6] State of West Virginia (2008) [7] PA Code (2001), [8] EPA (2000b), [9]EPA State of Delaware Surface Water Quality Standards, [10]Abrams and Jarrell (1995), Correll (1998), [11]Botts (2005), [12]MBSS

Table 5.7 Water Quality Parameters in National Park Units

Historical Park	State of the Park Report	Natural Resource Condition Assessment	Water Quality Parameters
First State			Water temp., pH, turbidity, DO, conductivity, enterococci bacteria
Valley Forge	✓	✓	Water temp., SP, alkalinity, TDS, ammonia, Cl^-, NP, P, pH, DO, B, macroinvertebrate and fish sampling
Minute Man		✓	SP, DOC, bacteria, turbidity, TN, TP, water temp., DO, pH, and ANC, Cl^-, and sulfate
Harpers Ferry		✓	pH, DO, water temperature, ANC, salinity/SP, nitrate, TP, BIBI, PHI

All four of these national historical parks are affected by activities and development outside of the park, so building and maintaining partnerships is crucial in helping manage the quality of water resources. All four of these national historical parks use a whole-watershed management approach to protect the park's water resources. Taking a watershed management approach means that managers and employees at each of the parks is actively engaged in local and regional initiatives to help protect, enhance, and restore the water quality of the watershed. In addition, it means that all stakeholders (both public and private) are involved in the planning and approaches to water resources management within the watershed.

Valley Forge NHP's General Management Plan specifically directs that whole-watershed management strategies are utilized to protect the park's water resources (NPS, 2007). Park staff and employees actively participate in local and regional initiatives to protect, enhance, and restore the water quality of Valley Creek and the

Schuylkill River and their tributaries (NPS, 2007). Valley Forge NHP embraces the belief that their mission and message is strengthened through the collaborative efforts of many park partners (NPS, 2007). In Valley Forge NHP, the foundation of many visitor experiences and park initiatives is the result of work with three formal partners: friends and colleagues from The Encampment Store, the Friends of Valley Forge Park, and the Valley Forge Tourism and Convention Bureau. Valley Forge NHP also collaborates with local schools and universities, youth groups, neighboring national and state parks, cultural and natural resource agencies, public health and safety groups, and commercial businesses in order to support summer camps, special education events aimed at educating people about the parks history and natural resources, and helping inspire visitors and neighbors to find meaning in the park (NPS, 2007).

In addition to the implementation of best management practices for pollution generating activities and facilities, Harpers Ferry NHP works with many Chesapeake Bay program partners to manage the Chesapeake Bay watershed as a cohesive ecosystem and work toward restoration, conservation and interpretation of the bay's resources (NPS, 2008). The General Management Plan for Harpers Ferry NHP states that river banks will be stabilized and degraded sections of the streams restored within the national historical park (NPS, 2008).

Minute Man NHP staff and employees partner with many public and private stakeholders, including the Advisory Council on Historic Preservation (ACHP), U.S. Department of Transportation, the Friends of Minute Man National Park, the town of Lexington, and private companies such as CRJA-IBI Group, to help protect and preserve the parks natural and cultural resources.

First State NHP works with many partners in order to create a cohesive story of Delaware's history, as well as the nation's history. These partners include the UDWRC, Mt. Cuba Center, The Conservation Fund, and The Nature Conservancy.

5.7 Summary

This chapter has provided an overview of water resources information within State of the Park Reports and Natural Resource Condition Assessments of Valley Forge, Harpers Ferry, Minute Man and First State National Historical Parks. The differences in water resources condition, reporting, water quality standards, and water resources management approaches among the four historical parks were discussed. The following chapter provides a summary of my analysis, conclusions, and recommendations for future research.

Chapter 6

SUMMARY OF FINDINGS

6.1 Summary of Analysis

This thesis describes the policies and management of water resources of the National Park Service, focusing specifically on First State National Historical Park. This thesis begins with an overview of the National Park Service, which describes the National Park Service's mission, history, organizational structure, and laws and policies of managing water resources. I provide an overview of First State NHP and its history and physical characteristics, and also discuss water resources information contained in the water quality monitoring report of First State NHP. Lastly, this research compares the structures, programs, monitoring, water quality standards, reporting, and approach to water resources management of First State NHP with that of Valley Forge, Harpers Ferry, and Minute Man National Historical Parks. Valley Forge, Harpers Ferry, and Minute Man were chosen based on their classifications as a Historical Parks with similar size, climate, and geography to First State NHP, and are located in the Northeastern United States. Overall, this research sought to understand the policies and management of water resources within the National Park Service, specifically that of the First State National Historical Park and other similar National Historical Parks.

6.2 Conclusions

This research into the water management policies of the National Park Service and First State, Valley Forge, Harpers Ferry, and Minute Man National Historical Parks offers the following conclusions:

1. National Park Service: Established in 1916, the National Park Service, located in the U.S. Department of the Interior, is responsible for managing over 400 areas covering more than 84 million acres with 100,000 miles of perennial rivers and streams, and over 2.3 million acres of lakes and reservoirs in the National Park System. Water resources within the National Park System are protected by the federal government under the General Authorities Act, and the National Park Service is required to manage all water resources in accordance to applicable federal and state laws, including the Clean Water Act and NEPA. There are 32 Inventory and Monitoring networks established as part of the National Park Service Inventory and Monitoring Program that are responsible for the inventory of natural resources under National Park Service stewardship to determine their nature and status. Each of the 32 I&M networks are responsible for performing Natural Resource Condition Assessments at each of their respective national park units. Natural Resource Condition Assessment assists park managers in resource planning and decision making. The information contained in the Natural Resource Condition Assessment will be used by park managers to create a State of the Park Report, which is created to convey complex scientific information to interested stake holders and the public.

2. First State National Historical Park: Established in 2013 as the 400th unit of the National Park System and first unit of the National Park System in the State of Delaware, First State National Historical Park contains 7 units that tell the story of Delaware's early settlement and role of being the first State to ratify the Constitution.

The Woodlawn property of the Beaver Valley unit of First State NHP contains 6 subwatersheds of the Brandywine Piedmont Watershed that capture a drainage area of 4,485 acres (7.0 mi^2). The streams that flow from east to west through the Piedmont and First State NHP to the Brandywine River include: Beaver Creek, Rocky Run, Ridge Run, Ramsey Run, Talley Run, and Carney Run. Land use in the Brandywine Piedmont Watershed is made up of approximately 36% forest, 1% wetlands, 27% urban/suburban, and 36% agriculture. The geology of the watershed consists mainly of Wissahickon Formation and Cockeysville Marble, and soil types primarily consist of Group B and Group C soils.

3. Water Quality in First State National Historical Park: During 2015 and 2016, we conducted a water sampling project at tributaries of Brandywine Piedmont Watershed in First State NHP. Water quality sampling was conducted at twelve sites located in six subwatersheds of the Brandywine Piedmont watershed. During 2015, water quality was tested for pH, conductivity, water temperature, turbidity, DO, and Enterococci bacteria. During 2016, water quality was monitored for conductivity and turbidity. Water quality analysis at First State National Historical Park indicates that Delaware Water Quality Standards are met for pH, temperature, and dissolved oxygen, but there are concerns regarding high turbidity, conductivity, and Enterococci bacteria levels in headwaters of the streams.

4. Water Resources Management and Policies of the National Park Service: The State of the Park Reports and Natural Resource Condition Assessments vary among the national historical parks. For Minute Man and Valley Forge National Historical Parks, the condition of the parks water resources is displayed using traffic light with a dashed circle, solid, or bolded circle, colored either red, yellow, or green,

and included either a up, down or sideways arrow. Harpers Ferry NHP used a slightly different method to evaluate the condition of its water resources that includes the percent attainment, which is converted to a condition assessment for each of the water quality metrics. Harpers Ferry does not use traffic light symbols to illustrate water quality condition, although a similar color scheme of red, yellow, and green is used to communicate water resources condition. Water quality regulations and standards vary between Minute Man (MA), Harpers Ferry (WV), Valley Forge (PA) and First State (DE) National Historical Parks due to differences in State Water Quality Standards and different classifications of streams in each of the four historical parks. Valley Forge NHP is required to follow Federal and Pennsylvania state water quality regulations, Minute Man NHP is required to follow Federal and Massachusetts state water quality regulations, First State NHP is required to follow Federal and Delaware state water quality regulations, and Harpers Ferry NHP is required to follow Federal and West Virginia state water quality regulations.

6.3 Recommendations for Future Research

From this research we recommend the following water governance and policy approaches to manage and protect watersheds in units of the National Park System:

1. Water Quality Criteria: As a relatively new unit of the National Park System, First State NHP has yet to complete a general management plan and Natural Resource Condition Assessment. First State NHP should manage its water resources similarly to the policies followed at Valley Forge, Minute Man and Harpers Ferry National Historical Parks. These historical parks have the same designation as a National Historical Park to First State NHP, and are similar in size, geography, climate

and Physiographic province. These northeastern U.S. National Historical Parks provide an excellent reference on how First State should manage its water resources.

2. Condition Assessments: Policies and approaches to water resources management often vary among national park sites due to location, size, status, and history. First State NHP should prepare natural resource condition assessments and state of the park reports and communicate water resources condition using similar traffic symbols used by Valley Forge and Minute Man National Historical Parks in their state of the park report and natural resource condition assessment. I recommend using traffic symbols, as compared to percent attainment used by Harpers Ferry NHP, because I believe it communicates the results in a clear and precise format that the public of all age groups could understand. Most people are familiar with traffic symbols, so using this format to convey water resources condition and trend would allow for increased public understanding of water resources in First State NHP. Using the percent attainment shows what percent of the data meet water quality standards, but does not communicate the temporal trend like it does using traffic symbols.

3. Water Quality Monitoring: First State NHP should continue monthly monitoring of the existing parameters of the 12 sampling sites in the historical park to assess spatial and temporal trends. In addition to continuing the monitoring of the existing parameters, I suggest to expand the water quality network of First State NHP to include other parameters. Suggested parameters include nutrients, such as nitrogen, and phosphorus, and metals, such as zinc, copper, and lead, and pathogens such as E .Coli. Expanding the network to include these parameters will allow for a more accurate understanding of the water quality condition in First State.

4. Best Management Practices Implementation: Best management practices to reduce streamflow and improve water quality should be implemented in First State NHP. From this analysis, sampling sites located at the mouths of the tributaries have better water quality compared to sampling sites located in the urban headwaters of the tributaries. Forests near the Brandywine River act as a buffer to filter out pollutants from entering tributaries. Best management practices should include reforestation throughout the watershed, and establish stream buffers in the headwaters of the tributaries, near residential and urban areas outside the First State National Historical Park's boundaries.

5. Streamline National Park Service Reporting Framework: The framework of reporting water resources information varies among the historical parks evaluated in this thesis. Methods vary among the historical parks in determining water quality condition and how water quality conditions are displayed in State of the Park Reports and Natural Resource Condition Assessments. It would be beneficial for the National Park Service to compile all available data in a consistent format that can be easily accessed and regularly updated. It would also be beneficial to discuss and display water resources information and condition using the same format among all of the National Park Service units. This would be valuable to future researchers carrying out any analyses of similar in nature within units of the National Park Service.

6. Revise National Park Service Waterbody Designation/Water Quality Standards: The National Park Service is required to follow Federal water quality standards under the Clean Water Act. There are various levels of designated uses for aquatic life that vary slightly among states. Designations include Warm Water Fishes, Cold Water Fishes, Migratory Fishes, High Quality Fishes, and Outstanding Natural

Resource Waters/Exceptional Value waterbodies. Warm Water streams require the minimum amount of protection to sustain designated uses, and Exceptional Value streams require the maximum amount of protection to sustain designated uses. Exceptional Value and High Quality streams, "water quality should not be lowered, except in the event that a discharge into a High Quality stream is the result of "necessary" social or economic development" (Jackson, 2009).

Water quality standards are based on the designated uses of a water body that vary from park to park. Valley Forge has one stream designated as an exceptional value waterway, and one stream designated a migratory fishes waterbody. The other historical parks discussed in here include waterbodies designated as warm water and cold water fishes. Waterbodies in units managed by the National Park Service should be held to a higher than minimum designation. Lands managed by the National Park Service represent the most spectacular places of high cultural, historical, and environmental worth. Therefore, I believe that these streams should have higher designations more rigorous water quality standards. Park units should be held to higher designations and work with partners and communities to gain support and momentum for increasing the protection of water bodies. Due to infrequent public participation, there is few water bodies designated as Outstanding Natural Resource Waters. Ideally, units in the national park system should automatically have higher designated uses and follow stricter water quality standards than other water bodies. However, since most watersheds are not completely contained in National Park Service unit boundaries, they are affected by activities and development occurring outside of National Park Service lands. Although higher designations and stricter water quality standards would allow for increased long term protection of water

resources in National Park Service units, it would require stricter water quality standards and regulations that many people would not support. Therefore, realistically, the National Park Service should aim to improve water resources condition, strengthen partners to help improve water quality of stream segments located outside of the park boundaries, and help gain support from the community to increase the designation of waterbodies.

7. Establish Partnerships: President Trump's proposal calls for a 12% decrease in the Department of the Interior's budget for fiscal year 2018. It is not yet known how the Department of Interior secretary would distribute a 12% cut across his nine agencies, which include the National Park Service, Bureau of Land Management, and U.S. Fish and Wildlife Service, is unknown. This decrease in budget could negatively affect the ability of National Park Service managers and employees to maintain park facilities and operations and reduce the monitoring of natural resources and delay restoration projects in units of the National Park System. Therefore, it is recommended that First State NHP establish and strengthen partnerships with organizations, such as the UD Water Resources Center, to assist in monitoring of the historical park's natural resources. In addition to decreased funding, development and activities outside of the park boundaries can greatly impact the condition of natural resources contained in the park, so establishing partnerships with organizations and the public can help increase awareness of ways to help protect the watershed, and develop strategies to improve water quality outside of the historical park's boundaries.

8. Future Research: This research focuses on the policies and management of water resources in First State, Valley Forge, Harpers Ferry, and Minute Man National Historical Parks. As discussed in Chapter 5, there are varying structures, programs,

water quality standards, methods of conveying scientific information, and approaches to water resources management of the First State, Valley Forge, Harpers Ferry, and Minute Man National Historical Parks. In the future, it would be beneficial to research other national historical parks throughout the Northeastern United States, as well as other national park sites throughout the country in order to determine how they manage water resources. This would allow for a deeper understanding of differences in water resources management of National Park Service units throughout the United States.

9. Interview Managers, Employees, and Visitors of National Parks

To obtain a more accurate understanding of the approaches to water resources management in these national historical parks, it would be beneficial to meet with park managers and employees at each of the national historical parks. Meeting with park managers and employees to learn about how they manage their park's water resources would allow for a more complete picture of how the parks manage their water resources, which might not be included in published reports or documents. It would also be beneficial to survey visitors at each of these historical parks. The survey could include questions on how they view the parks water quality, if their experiences in the park have been enjoyable, and suggestions to make their experience in the park even better. Questions on Natural Resources Condition Assessments and State of the Park Reports could also be given to visitors to gage whether the park is effectively communicating complex scientific data to the public. This information could then be used by park managers and employees to help improve visitor experience, future planning, and management of natural resources in the parks.

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Appendix A

WATER TEMPERATURE IN BRANDYWINE CREEK TRIBUTARIES

Site	1	2	3	4	5	6	7	8	9	10	11	12
Date	**Ridge Run**	**Beaver Creek Mouth**	**North Fork Beaver Run**	**South Fork Beaver Run**	**Talley Run**	**Ramsey Run**	**Carney Run**	**Rocky Run Mouth**	**Hurricane Run**	**Rocky Run @ Rt. 202**	**Beaver Creek @ Rt. 202**	**Rocky Run Residential**
6/23/15	25.5	21.9	21.7	22.0	20.1	20.4	18.8	21.8	21.7	24.8	23.9	22.2
6/30/15	22.5	19.9	19.2	19.0	18.7	19.1	17.7	19.3	20.3	21.5	21.2	19.8
7/6/15	22.7	20.0	19.8	19.9	18.5	18.9	17.8	20.0	19.5	22.3	21.9	20.2
7/13/15	23.1	20.4	20.4	20.9	19.0	19.2	18.1	20.1	19.6	22.9	21.5	20.6
7/20/15	26.3	23.1	22.7	22.7	21.3	21.4	19.2	21.9	21.7	24.3	23.7	22.3
7/28/15	24.5	21.2	21.2	21.3	19.9	19.7	19.0	21.3	21.5	23.1	23.0	21.5
10/9/15	19.4	16.9	17.5	17.5	17.8	17.9	17.1	18.4		19.6	18.3	17.8
10/23/15	15.4	12.6	13.1	11.6	13.3	14.0	12.5	13.2	13.3	13.1	13.3	13.3
11/6/15	17.1	16.6	17.6	15.9	17.0	16.9	16.4	17.0	17.7	18.0	16.7	16.5
11/13/15	13.4	11.2	13.1	11.4	11.3	11.9	11.7	11.7	12.0	11.4	12.4	11.9
12/4/15	9.7	7.3	9.5	7.6	8.1	8.9	9.1	8.9	8.9	8.3	9.2	8.9
Min	9.7	7.3	9.5	7.6	8.1	8.9	9.1	8.9	8.9	8.3	9.2	8.9
25th Per.	16.3	14.6	15.3	13.8	15.2	15.5	14.5	15.1	14.4	15.6	15.0	14.9
Median	22.5	19.9	19.2	19.0	18.5	18.9	17.7	19.3	19.6	21.5	21.2	19.8
75th Per.	23.8	20.8	20.8	21.1	19.5	19.5	18.5	20.7	21.2	23.0	22.5	21.1
Max	26.3	23.1	22.7	22.7	21.3	21.4	19.2	21.9	21.7	24.8	23.9	22.3

Appendix B

PH DATA IN BRANDYWINE CREEK TRIBUTARIES

Site	1	2	3	4	5	6	7	8	9	10	11	12
Date	Ridge Run	Beaver Creek Mouth	North Fork Beaver Run	South Fork Beaver Run	Talley Run	Ramsey Run	Carney Run	Rocky Run Mouth	Hurricane Run	Rocky Run @ Rt. 202	Beaver Creek @ Rt. 202	Rocky Run Residential
6/23/15	7.7	7.8	7.6	7.7	7.4	7.3	7.3	7.7	7.5	7.1	7.2	7
6/30/15	7.7	7.8	7.6	7.7	7.5	7.6	7.6	7.7	7.4	7.2	7.3	6.9
7/6/15	7.7	7.6	7.6	7.7	7.6	7.4	7.5	7.4	6.9	6.8	7.2	7
7/13/15	7.8	7.9	7.7	7.7	7.5	7.5	7.5	7.7	7.6	7.2	7.2	7.2
7/20/15	7.8	8.1	7.6	7.9	7.6	7.4	7.7	7.7	7.4	6.8	7.3	7
7/28/15	7.8	7.9	7.7	7.6	7.6	7.4	7.5	7.6	7.4	7	7.4	6.8
10/9/15	7.7	7.6	8.7	8.6	7.3	7.5	7.4	7.6		7.2	7.5	6.8
10/23/15	7.6	8	7.7	7.7	7.6	7.4	7.4	7.6	7.5	7.2	7.5	7.4
11/6/15	7.7	8.1	7.6	7.8	7.8	7.9	7.9	7.9	7.5	7.2	7.6	7
11/13/15	7.7	8.1	7.8	7.9	7.5	7.3	7.5	7.8	7.5	7	7.2	7.6
12/4/15	7.6	8	7.7	7.9	7.2	7.2	7.3	7.7	7.4	6.9	7.2	6.9
Averages	7.7	7.9	7.7	7.8	7.5	7.4	7.5	7.6	7.3	7.0	7.3	7.0
Min	7.6	7.6	7.6	7.6	7.2	7.2	7.3	7.4	6.9	6.8	7.2	6.8
25th Per.	7.7	7.8	7.6	7.7	7.45	7.35	7.4	7.6	7.4	6.95	7.2	6.9
Median	7.7	7.9	7.7	7.7	7.5	7.4	7.5	7.7	7.45	7.1	7.3	7
75th Per.	7.75	8.05	7.7	7.9	7.6	7.5	7.55	7.7	7.5	7.2	7.45	7.1
Max	7.8	8.1	8.7	8.6	7.8	7.9	7.9	7.9	7.6	7.2	7.6	7.6

Appendix C

TURBIDITY DATA IN BRANDYWINE CREEK TRIBUTARIES

Site	8	4	9	6	5	1	3	2	11	7	10	12
Date	Rocky Run Mouth	South Fork Beaver Run	Hurricane Run	Ramsey Run	Talley Run	Ridge Run	North Fork Beaver Run	Beaver Creek Mouth	Beaver Creek @ Rt. 202	Carney Run	Rocky Run @ Rt. 202	Rocky Run Residential
6/30/15	1.1	0.838	1.87	2.36	2.72	2.44	3.28	1.23	4.48	4.18	5.62	8.15
7/20/15	0.81	1.79	1.07	1.77	1.86	2.83	3.09	5.62	2.71	4.82	4.18	10.8
3/4/16	0.12	0.33	3.9	1.57	1.8	2.77	2.93	0.63	6.79	6.42	9.67	2.8
3/21/16	0.75	0.42	0.62	0.73	0.75	3.45	1.24	0.6	1.98	9.92		
4/8/16	0.19	0.36	0.39	0.82	1.17	0.75	0.72	1	1.78	2.64		9.8
6/22/16	0.88	0.84	0.5	3.08	5.02	3.25	1.9	0.96	2.18	8.53	3.85	2.42
6/29/16	0.57	0.09	1.23	2.9	3.81	2.63	1.77	1.77	2.8	5.34	3.59	3.48
7/13/16	1.03	0.44	1.08	2.44	6.52	3.22	1.51	5.62	1.99	6.7	1.23	2.04
7/20/16	0.81	0.84	1.71	1.27	4.43	2.85	2.25	1.3	8.56	7.82	5.39	9.43
7/27/16	17.6	1.19	1.45	3.63	5.07	2.72	4.2	1.03	2.69	1.4	6.53	12.16
8/3/16	6.62	4.37	0.6		4.48	2.64	1.55	0.6	1.9	4.35	5.1	2.7
10/10/16	1.24	0.96	2.08	7.62	13.5	0.88	1.22	1.6	4.47	4.56	8.88	7.53
Min	0.12	0.09	0.39	0.73	0.75	0.75	0.72	0.6	1.78	1.4	1.23	2.04
25th Per.	0.70	0.405	0.615	1.42	1.84	2.58	1.442	0.877	1.987	4.307	3.93	2.75
Median	0.84	0.839	1.155	2.36	4.12	2.74	1.835	1.13	2.7	5.08	5.24	7.53
75th Per.	1.13	1.017	1.75	2.99	5.03	2.94	2.97	1.642	4.472	6.98	6.30	9.615
Max	17.6	4.37	3.9	7.62	13.5	3.45	4.2	5.62	8.56	9.92	9.67	12.16

Appendix D

DISSOLVED OXYGEN IN BRANDYWINE CREEK TRIBUTARIES

Site	1	2	3	4	5	6	7	8	9	10	11	12
Date	**Ridge Run**	**Beaver Creek Mouth**	**North Fork Beaver Run**	**South Fork Beaver Run**	**Talley Run**	**Ramsey Run**	**Carney Run**	**Rocky Run Mouth**	**Hurricane Run**	**Rocky Run @ Rt. 202**	**Beaver Creek @ Rt. 202**	**Rocky Run Residential**
6/23/15	8.1	9.6	7.0	8.9	7.7	9.7	10.5	10.4	8.8	9.3	7.6	8.8
6/30/15	7.8	10.2	10.1	8.6	9.7	10.1	11.0	8.0	8.0	9.6	7.3	7.7
7/6/15	8.2	9.3	8.7	9.5	9.0	9.5	9.9	8.5	8.6	5.5	9.2	9.9
7/13/15	8.2	7.6	9.0	7.8	6.0	8.2	7.2	6.0	8.8	15.8	7.0	8.5
7/20/15	10.4	10.2	9.9	10.0	8.9	9.3	10.9	8.7	7.0	5.7	8.8	6.0
7/28/15	8.0	9.1	7.0	5.2	6.6	7.1	9.0	8.4	6.0	5.9	6.0	7.8
10/9/15	8.4	9.3	8.3	8.4	8.6	7.7	8.8	9.8		8.6	7.0	6.2
10/23/15	9.5	10.0	9.5	8.7	8.6	8.8	8.1	12.1	8.0	9.8	7.0	7.9
11/6/15	9.0	11.0	6.8	10.1	7.5	7.2	9.2	10.9	8.3	7.1	6.8	4.7
11/13/15	10.4	13.0	8.8	13.3	10.3	11.2	11.2	11.9	10.9	10.2	9.8	7.8
Averages	8.8	9.9	8.5	9.1	8.3	8.9	9.6	9.5	7.9	8.8	7.7	7.5
Min	7.8	7.6	6.8	5.2	6.0	7.1	7.2	6.0	6.0	5.5	6.0	4.7
25th Per.	8.1	9.3	7.3	8.5	7.6	7.8	8.9	8.4	8.0	6.2	7.0	6.6
Median	8.3	9.8	8.8	8.8	8.6	9.1	9.6	9.3	8.3	9.0	7.2	7.8
75th Per.	9.4	10.2	9.4	9.9	9.0	9.7	10.8	10.8	8.8	9.8	8.5	8.4
Max	10.4	13.0	10.1	13.3	10.3	11.2	11.2	12.1	10.9	15.8	9.8	9.9

Appendix E

CONDUCTIVIY DATA IN BRANDYWINE CREEK TRIBUTARIES

Site	1	2	3	4	5	6	7	8	9	10	11	12
Date	**Ridge Run**	**Beaver Creek Mouth**	**North Fork Beaver Creek**	**South Fork Beaver Creek**	**Talley Run**	**Ramsey Run**	**Carney Run**	**Rocky Run Mouth**	**Hurricane Run**	**Rocky Run @ Rt. 202**	**Beaver Creek @ Rt. 202**	**Rocky Run Residential**
6/22/15		400	480	310	115	265	230	290	335	350	840	410
6/23/15	246	461	342	577	130	295	275	333	416	525	1032	307
6/30/15	238	432	315	535	124	283	299	342	372	717	952	330
7/6/15	245	435	311	551	127	296	275	373	434	773	1232	351
7/13/15	251	445	326	561	132	284	251	381	454	792	1444	305
7/20/15	250	435	328	545	137	280	243	387	477	796	1209	296
7/28/15	252	461	331	577	136	271	230	384	468	704	898	176
10/9/15	200	380	290	460	100	210	170	330		480	760	300
10/23/15	220	390	320	450	110	210	160	350	350	730	930	190
11/6/15	210	380	320	440	110	210	170	330	330	560	850	220
11/13/15	210	350	310	380	110	250	180	240	310	380	600	130
12/4/15	200	310	270	340	90	220	200	230	280	390	650	170
3/4/16	200	380	240	520	100	270	250	480	880	830	1720	240
3/21/16	180	370	240	500	100	230	180	370	480		900	
4/8/16	190	370	240	480	100	220	170	290	470		760	130
6/22/16	190	310	260	400	110	200	150	300	310	550	950	210
6/29/16	200	320	260	410	100	200	150	290	360	500	780	150
7/13/16	210	340	280	400	110	200	150	280	310	600	980	150
7/20/16	190	290	260	330	100	210	150	220	250	360	600	120
7/27/16	235	380	330	415	135	255	190	245	310	410	760	175
8/3/16	260	418	360	493	140		205	343	370	576	1100	200
10/10/16	250	395	343	442	162	286	210	270	285	386	723	176
Averag	220	384	307	459	117	242	204	320	392	617	939	263

es												
Min	180	290	240	310	90	200	150	220	250	350	600	120
25th Per.	200	355	262	402	100	210	170	282	310	405	760	170
Median	210	380	313	455	110	250	195	330	360	555	899	200
75th Per.	246	428	329	531	131	280	239	365	454	720	1019	300
Max	260	461	480	577	162	296	299	480	880	830	1720	410

Appendix F

ENTEROCOCCI BACTERIA DATA IN BRANDYWINE CREEK TRIBUTARIES

Site	1	2	3	4	5	6	7	8	9	10	11	12
Date	**Ridge Run**	**Beaver Creek Mouth**	**North Fork Beaver Run**	**South Fork Beaver Run**	**Talley Run**	**Ramsey Run**	**Carney Run**	**Rocky Run Mouth**	**Hurricane Run**	**Rocky Run @ Rt. 202**	**Beaver Creek @ Rt. 202**	**Rocky Run Residential**
6/30/2015	1533.1	344.1	1046.2	488.4	920.8	1046.2	403.4	378.4	1413.6	461.1	517.2	1413.6
7/20/2015	770.1	816.4	488.4	290.9	547.5	547.5	241.5	829.7	770.1	387.3	1413.6	2419.6
Average	1151.6	580.3	767.3	389.7	734.2	796.9	322.5	604.1	1091.9	424.2	965.4	1916.6