# 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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## ABSTRACT

The United States National Park Service is required to manage the parks water resources in accordance to all applicable federal and state laws and regulations, and many programs 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 The First State National Historical Park will be compared to Valley Forge, Minute Man, and Harpers Ferry National Historical Parks. The policies, approaches to water resources management, and how complex scientific information on water resources is conveyed in Natural Resource Condition Assessments and State of the Park Reports differs among First State and the 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 resources. In Minute Man and Valley Forge, the condition status/trend of water resources were displayed pictorially using traffic-like symbols, that were colored either red, yellow, or green, and included either a up, down or sideways arrow. Harpers Ferry did not use traffic-like symbols to illustrate their results, but used a similar color scheme to communicate the water resources condition.

# Chapter 1

# INTRODUCTION

## 1.1 Research objectives, scope, and limitation

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 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) (Figure 1.1). The research will identify 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 based on their designation as a national historical park, size, and location. These three parks are similar in size to First State and are located in the Northeastern United States.

The focus area for this research is the First State National Historical Park (First State), geographically situated along the Brandywine River in Delaware and Pennsylvania. First State is Delaware's first and only national historical park. First State was designated a national monument in 2013 and later designated a national historical park in 2015. Therefore, the historical park is very new and classified as a starter park. The main focus of the historical park is planning and progress, establishing a general management plan for the park, which will provide foresight for how to strategically manage the parks resources, engaging the community and youth, and building partnerships. As the First State is in its infancy, this research will hopefully provide meaningful information on monitoring, reporting and conveying complex information on water resources to the public to managers and employees of First State.

Despite the contributions this research hopes to address, there a several limitations that must be addressed. Due to time and resource constraints, an exhaustive investigation of water resources policies and management in all of the national historical parks and/or sites of the national park system has not been conducted. Thus, the findings of this research are not representative of all of the national historical park sites or sites in the national park system. In addition, the discussion of monitoring and reporting of the national historical parks sites discussed in this research is limited to what is readily available online.

## 1.2 Research Questions

The monitoring, reporting, policies, and management of water resources vary among sites managed by the National Park Service (NPS) due to their location, size, status, and condition. Water quality standards are provisions of state or federal law approved by Environmental Protection Agency (EPA) 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 NPS is required to meet the state requirements where the park is located. Therefore, the approach to managing water resources might 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 does water resources policies and management vary among Valley Forge, Harpers Ferry, and Minute Man National Historical Parks as compared to First State?

The objective of this paper is to compare the programs, monitoring, reporting, standards, policies, and approaches to water resources management of the First State to Valley Forge, Harpers Ferry, and Minute Man. These parks, Valley Forge, Harpers Ferry, and Minute Man, were chosen based on their designation as a national historical park, size, and location.

## 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 NPS.

**Chapter 3:** Briefly discusses the history and physical characteristics of First State.

**Chapter 4:** Discusses the University of Delaware (UD) Water Resources Center water quality monitoring report of First State.

**Chapter 5:** Examines the water-related laws, standards, programs, monitoring networks, and reports of Valley Forge, Harpers Ferry, Minute Man, and First State National Historical Parks.

**Chapter 6:** Provides conclusions and recommendations for future research.

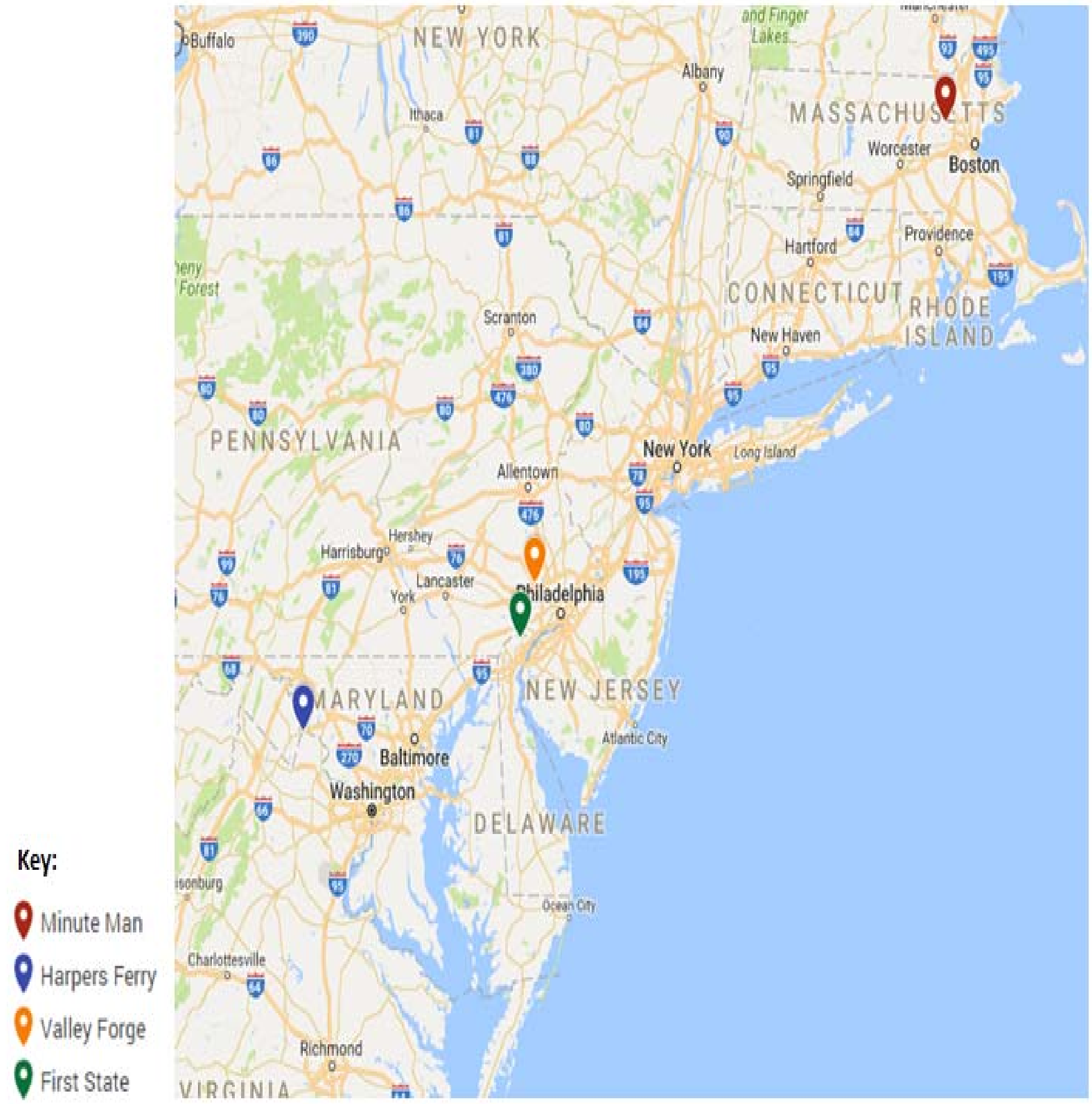



Figure 1.1 Map of National Historical Parks

# Chapter 2

# NATIONAL PARK SERVICE

## 2.1 Introduction

This chapter provides an overview of what the United States NPS is and what it does. This chapter also describes the purpose, mission, and history of the NPS, the organizational structure of the NPS, laws and policies the NPS is required to follow, and how the NPS manages its water resources.

## 2.2 Mission

On August 25, 1916, President Woodrow Wilson signed the Organic Act which established the NPS to protect and conserve unimpaired many of the country's most spectacular places. The mission of The NPS 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, 2017).

## 2.3 Organization

Located in the United States Department of the Interior, The NPS is responsible for managing over 400 areas covering more than 84 million acres in 50 states, the District of Colombia, American Samoa, Guam, Puerto Rico, Saipan, and the Virgin Islands (NPS History, n.d.). The NPS is comprised of 417 sites with at least 19 different designations (NPS Overview, 2017). 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 (NPS, 2017).

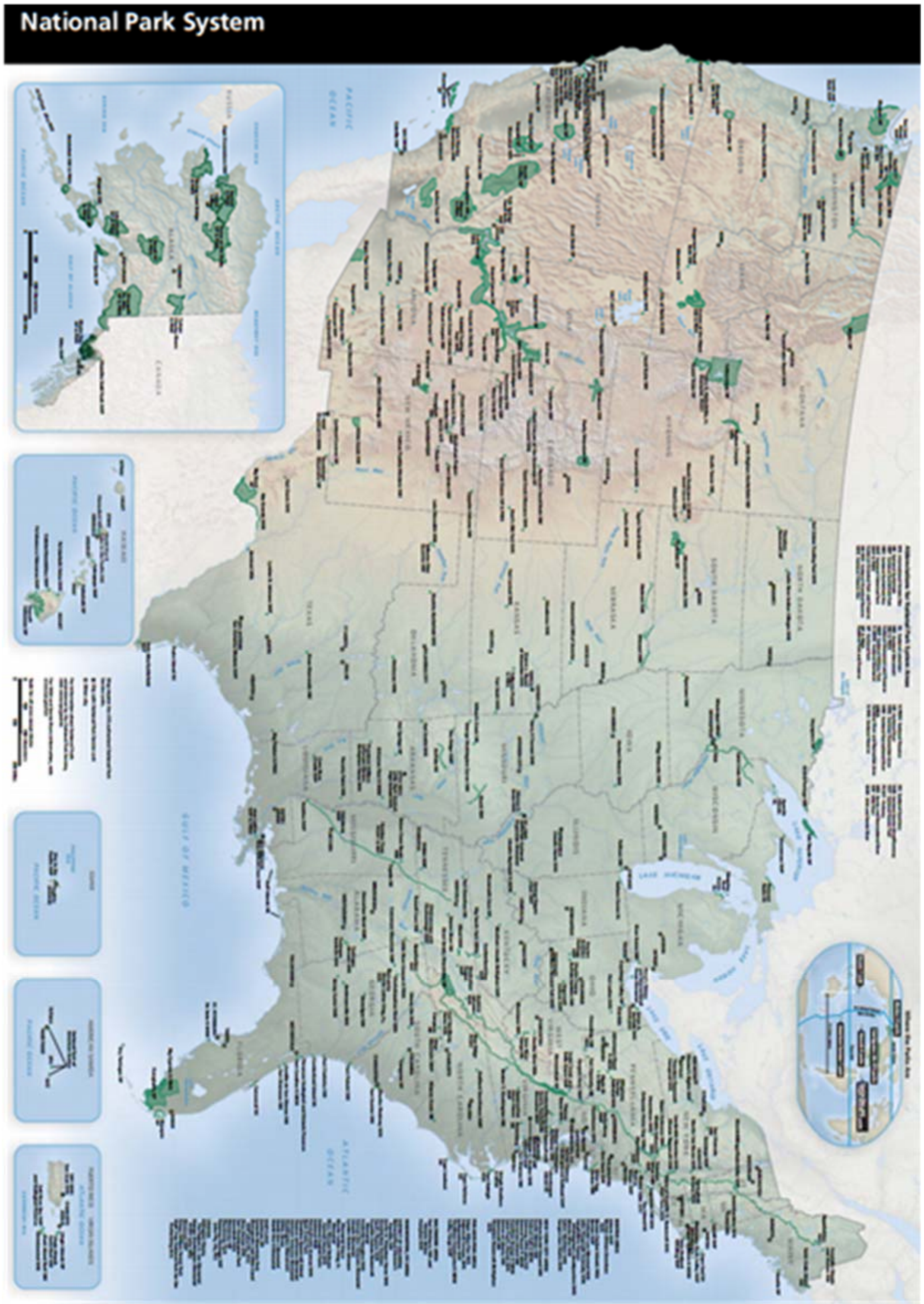



Figure 2.1 Map of the National Park System (National Park System Brochure, 2016)

The NPS employs over 20,000 individuals whom are responsible for preserving these lands designated by the nation for their cultural, historical, and environmental worth (NPS Overview, 2017). The NPS employees are assisted by 440,000 Volunteers-In-Parks (VIPs) who donate more than 7 million hours every year (NPS Overview, 2017). 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 (NPS Overview, 2017). They also fill roles such as environmental advocate, partner in community revitalization and leader in the drive to protect America's open spaces (NPS Overview, 2017).

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 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, the Yellowstone National Park Act was signed into law, by President Ulysses S. Grant, establishing Yellowstone as the country's first national park (and the world's) (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" (NPS, 2000). The public park was placed under the exclusive control of the Secretary of Interior (NPS, 2000). 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 (NPS History: National Park System Timeline, n.d.).This new idea of a national park started a worldwide movement that quickly spread to over one hundred countries (NPS History: National Park System Timeline, n.d.). 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 the prehistoric cliff dwellings, pueblo ruins and early missions in the Southwestern United States (American Antiquities Act of 1906, n.d.) (Table 2.1). It 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 (American Antiquities Act of 1906, n.d.). 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.).

**NPS 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 (NPS History: National Park System Timeline, n.d.) (Table 2.1). However, there was no organization to operate them at the time and this left the parks and monuments vulnerable to competing interests (NPS History: National Park System Timeline, n.d.). 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 (NPS History: National Park System Timeline, n.d.). On August 25, 1916, President Woodrow Wilson signed the act, often known as the Organic Act, which established the NPS (NPS History: National Park System Timeline, n.d.) (Table 2.1). All of the existing and future parks were placed under its management. 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)

**Reorganization:** The number and diversity of parks within the organization continued to grow as a result of a significant reorganization in 1933, following World War 2, and during the 1960s (NPS History: National Park System Timeline, n.d.). An executive order, within President Franklin Roosevelt's executive branch in 1933, transferred 56 national monuments and military sites from the Forest Service and the War Department to the NPS (NPS History: National Park System Timeline, n.d.). This reorganization was a significant event in the evolution of the NPS, as it was a major step in the development of today's national system of parks (NPS History: National

Park System Timeline, n.d.). 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 NPS (NPS History: National Park System Timeline, n.d.). 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…" (NPS General Authorities Act 1970, n.d.).

**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, 26 new parks were added 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.

**NPS Centennial:** The NPS turned 100 years old on August 25, 2016, and the NPS celebrated throughout the year with partners and visitors across the country. To celebrate the Centennial, the NPS kicked off a campaign called Find Your Park, to raise awareness of the spectacular places managed by the NPS, 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 Find Your Park, 2017). 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 (NPS Find Your Park, 2017).

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 | Allowed for the protection of 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 100$^{th}$ 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, CO 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 (NPS Water Resources Division, n.d.). 100,000 miles of perennial streams is approximately four times the distance of the circumference of the Earth. The NPS is required to manage all National Park System units according to the NPS 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” (NPS, 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 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 Clean Water Act, 2017). All federal agencies are required to follow the requirements of state law for water quality management, regardless of other jurisdictional status or landownership (NPS Clean Water Act, 2017). 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 Clean Water Act, 2017).

A state's anti-degradation policy is a three-tiered approach to maintaining and protecting various levels of water quality. The first level is that, minimally, the existing uses of a water segment and the level of quality necessary to protect the uses must be maintained (NPS Clean Water Act, 2017). 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 Clean Water Act, 2017). 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 to that of ONRW 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 Clean Water Act, 2017). 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. (NPS Clean Water Act, 2017).

**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 NEPA Policy, n.d.). To further this policy, NEPA requires federal agencies, such as the NPS, to evaluate the environmental impacts of its actions and to involve the public in the decision-making process. Within the NPS, the NEPA process is a crucial tool for making certain informed decisions that conserve park resources and values. The NPS uses four pathways, or levels of analysis and documentation, to comply with NEPA (NPS, 2015). A brief description of each of these pathways 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 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 (NPS, 2016). 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 Map of National Park Service Inventory and Monitoring Program Networks (NPS I&M, 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. Valley Forge is one of 10 parks in the Mid-Atlantic Network (NPS, 2016). The First State 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.

The majority of park's in the MIDN network was established for their historical or cultural interest, but 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. (NPS, 2016)

**National Capital Region Network:** The National Capital Region Network (NCRN) is also one of 32 I&M networks nationwide. Harpers Ferry 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 NPS to monitor ecological conditions in 13 parks, including Minute Man, located in seven northeastern states as well as six additional states through which the Appalachian National Scenic Trail passes. 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 MIDN, NCRN, and NETN 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 parks (NPS, 2014). 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 (NPS, 2014). Funding to conduct a similar assessment at approximately 110 other parks with significant natural resources over the next few years have been recommended (NPS, 2014). 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 (NPS 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 (NPS State of the Parks, n.d.). 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 NPS is an agency of the United States federal government that manages 417 areas of lands designated by the nation for their cultural, historical, and environmental worth. The Water Resources Division of the NPS's Natural Resource Stewardship and Science Directorate in Fort Collins, CO is authorized to manage water resources contained in the 417 units of the National Park System. The NPS is required to manage its units in accordance to all applicable federal and state laws and regulations, including the Clean Water Act and NEPA. Also located in the Natural Resource Stewardship and Science Directorate, the NPS'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 in this thesis describes the history and physical characteristics of the unit of the National Park System that is the focus of this research; The First State National Historical Park.

# Chapter 3

# FIRST STATE NATIONAL HISTORICAL PARK

## 3.1 Overview

In 2013, under the authority of the NPS Organic Act, President Obama signed the act that established First State National Monument. Later approved by Congress in 2015, the First State became designated as a national historical park. The First State 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 discussion of the First State National Historical Park in the following chapters of this thesis is on the Beaver Valley unit. 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). I chose to analyze the Beaver Valley unit because it is the largest unit and only unit that contain streams. The other 6 units only consist of historic buildings and structures. In this chapter, the history, climate, soils, geology, hydrology, and land use of the Beaver Valley Unit is discussed.

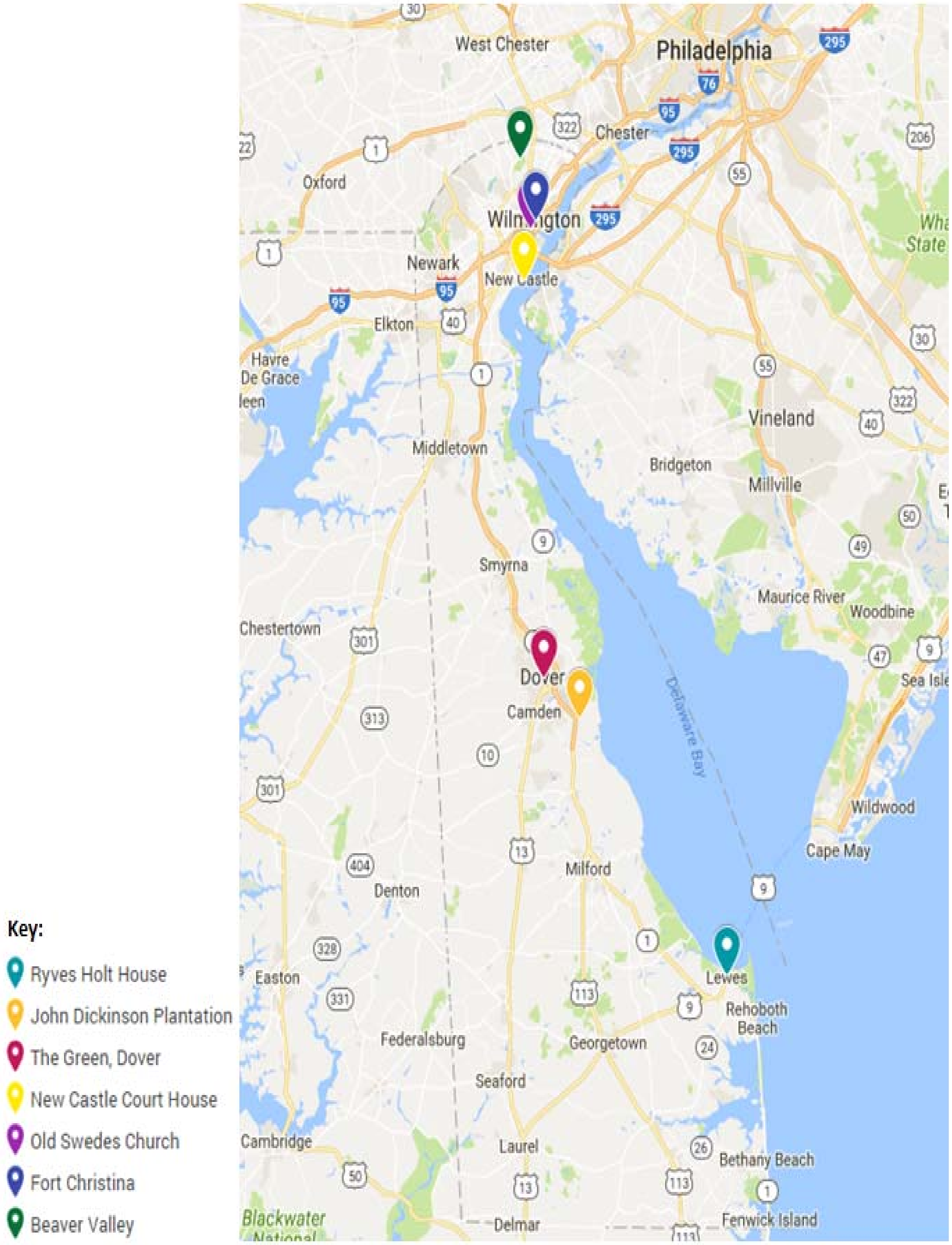



Figure 3.1 Map of First State National Historical Park (NPS First State National Historical Park Maps, n.d.)

## 3.2 History

Located three miles north of Wilmington, 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 (The Conservation Fund, n.d.) (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 (The Conservation Fund, n.d.). 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 (The Conservation Fund, n.d.). Recognizing the historical significance and value of the property, elected officials, including the Governor of Delaware, 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 Conservation Fund, n.d.).

The Woodlawn Trustees long kept the Woodlawn property unspoiled for the community and visitors to enjoy, with land preservation a top goal, but knew it was time to sell the property (The Conservation Fund, n.d.). In 2012, the Conservation Fund quickly purchased the historic 1,100-acre Woodlawn property to keep it protected for the public (The Conservation Fund, n.d.). The acquisition of the Woodlawn property was made possible by a generous gift from Mt. Cuba Center, a non-profit botanical garden located in Hockessin, Delaware, as well as the desire of the property's trustees to see the land protected (The Conservation Fund, n.d.). 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 (The Conservation Fund, n.d.). Hundreds of people attended a public hearing, 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 Conservation Fund, n.d.). When the NPS evaluated the land's historic significance, it knew this place was special and belonged to all Americans (The Conservation Fund, n.d.). The Conservation Fund donated the land to the NPS as a gift for future generations to enjoy (The Conservation Fund, n.d.). 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, The First State was re-designated from a national monument to a historical park.

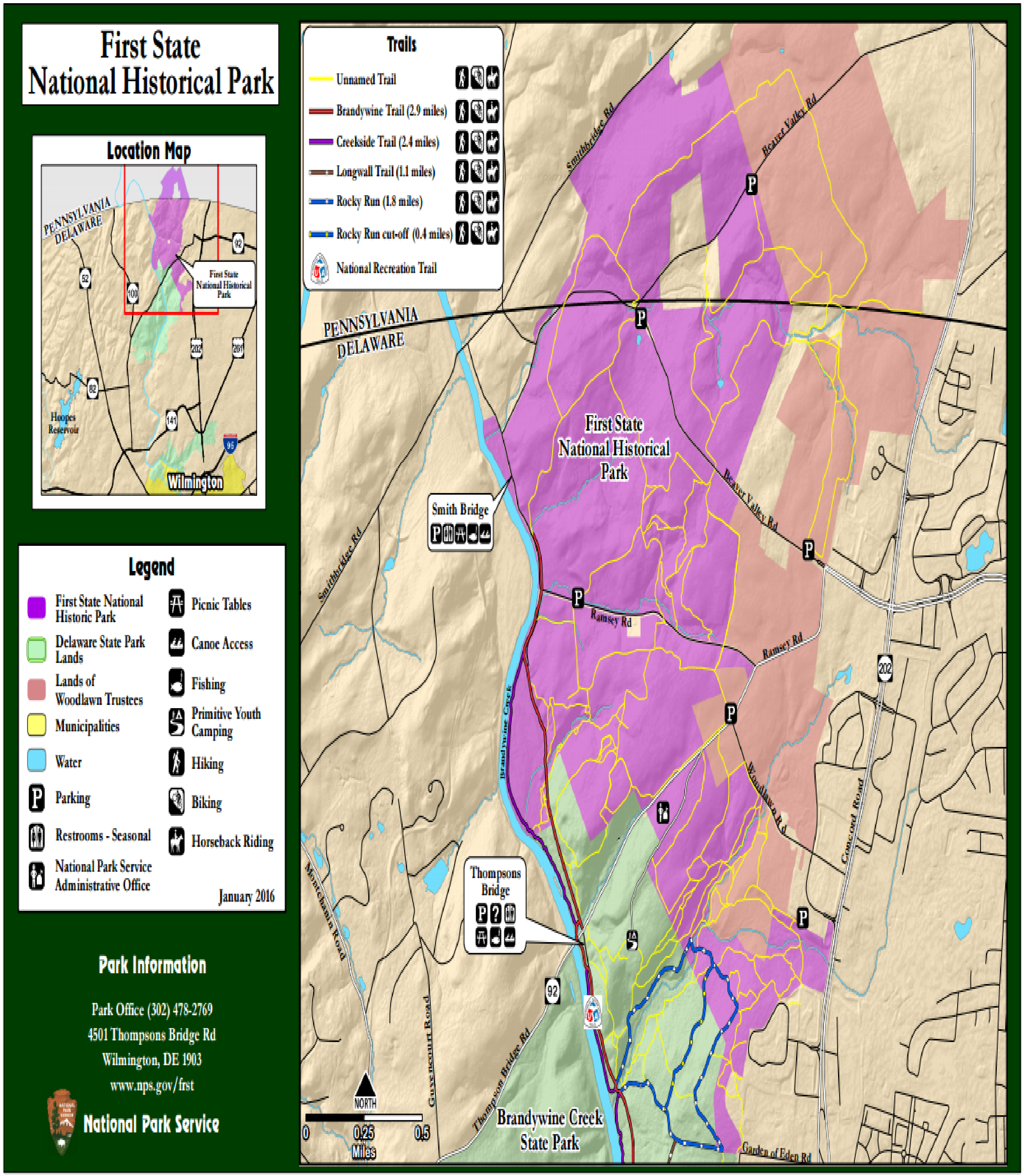



Figure 3.2 Map of Beaver Valley Unit (NPS Beaver Valley, n.d.)

## 3.3 Climate

Situated in Northern Delaware and Pennsylvania, The First State experiences a humid continental climate with cold winters, hot summers, and no dry/rainy season. 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 (Office of the Delaware State Climatologist, n.d.). 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 (Office of the Delaware State Climatologist, n.d.). 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 (Office of the Delaware State Climatologist, n.d.).

## 3.4 Soils

According to the United States Department of Agriculture soil survey, 2.9% of the First State watershed soils are classified as quarry/water/urban bedrock, 10.2% are hydrologic soil group A, 57% are hydrologic soil group B, 28.5% are hydrologic soil group C, and 0.8% is hydrologic soil group D. This data is summarized and represented graphically in Figures 3.3 and 3.4 below.

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 (U.S. Department of Agriculture, 2005). They typically contain less than 10 percent clay and more than 90 percent sand or gravel and have gravel or sand textures (United States Department of Agriculture, 2007).

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 (United States Department of Agriculture, 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 (United States Department of Agriculture, 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 (U.S. Department of Agriculture, 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 (United States Department of Agriculture, 2007).

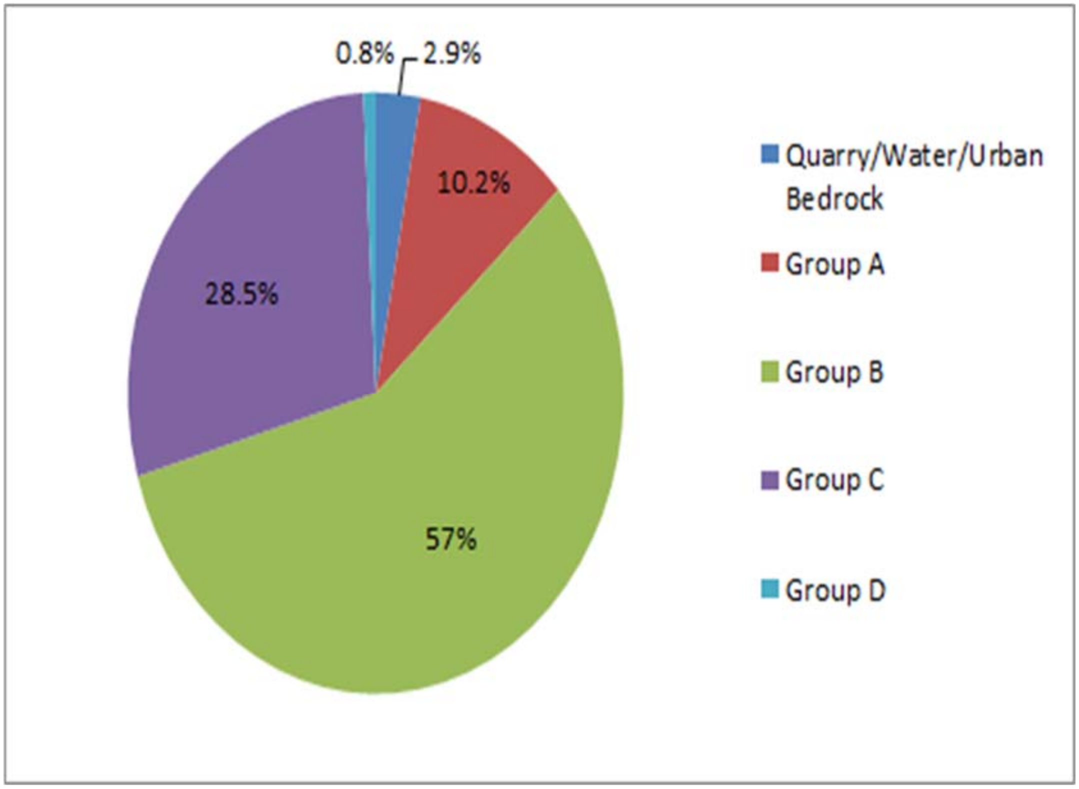



Figure 3.3 First State National Historical Park Watershed Soils (UD Water Resources Center, 2017)

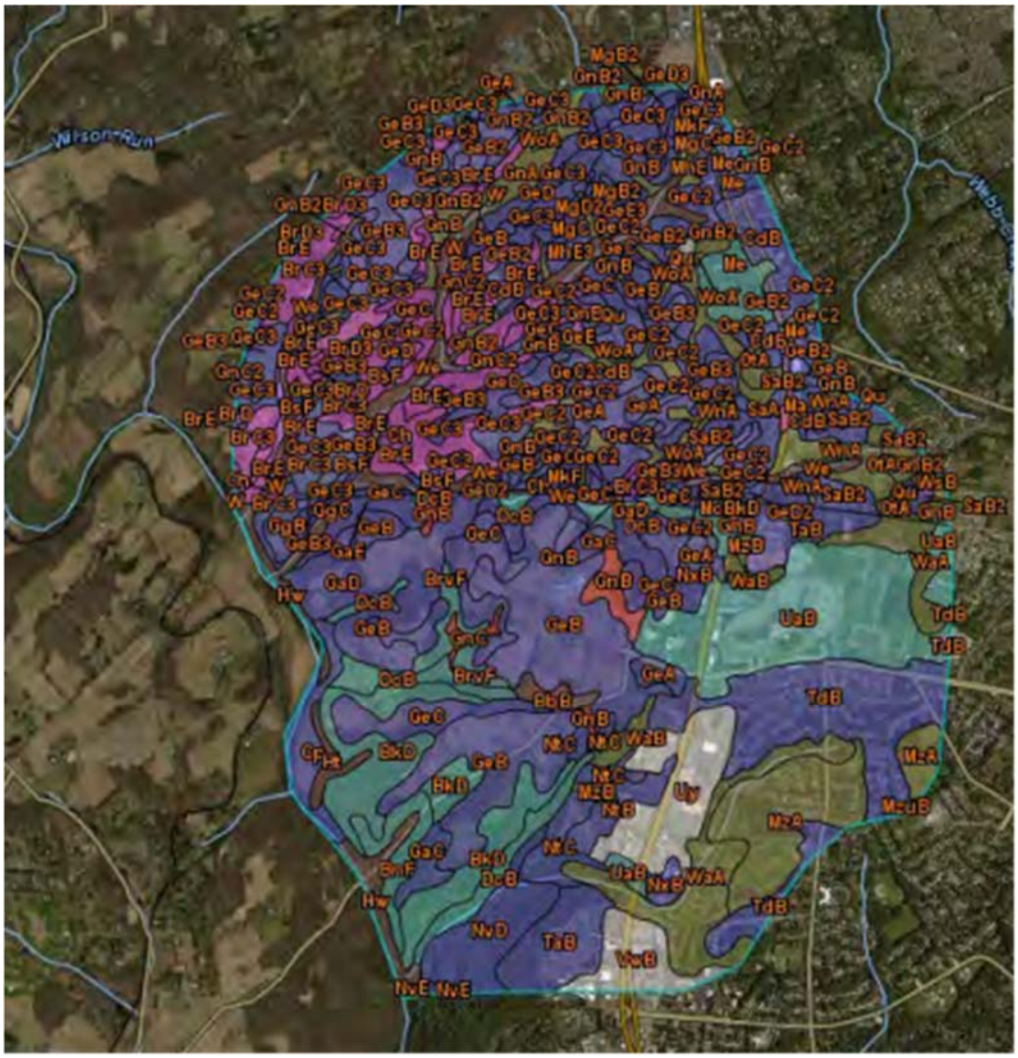



Figure 3.4 Hydrologic Soil Groups in First State National Historical Park (UD Water Resources Center, 2014)

## 3.5 Geology

Watersheds in the First State are underlain by outcrops of the Wissahickon Formation gneiss (UD Water Resources Center, 2017). 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 (The Delaware Geological Survey, n.d.) (Figure 3.5). The rock types in the First State include mainly Wissahickon Formation and Cockeysville Marble (UD Water Resources Center, 2017). 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 (The Delaware Geological Survey, n.d.) (Figure 3.6).

Figure 3.5 Geology of First State National Historical Park (UD Water Resources Center, 2017).

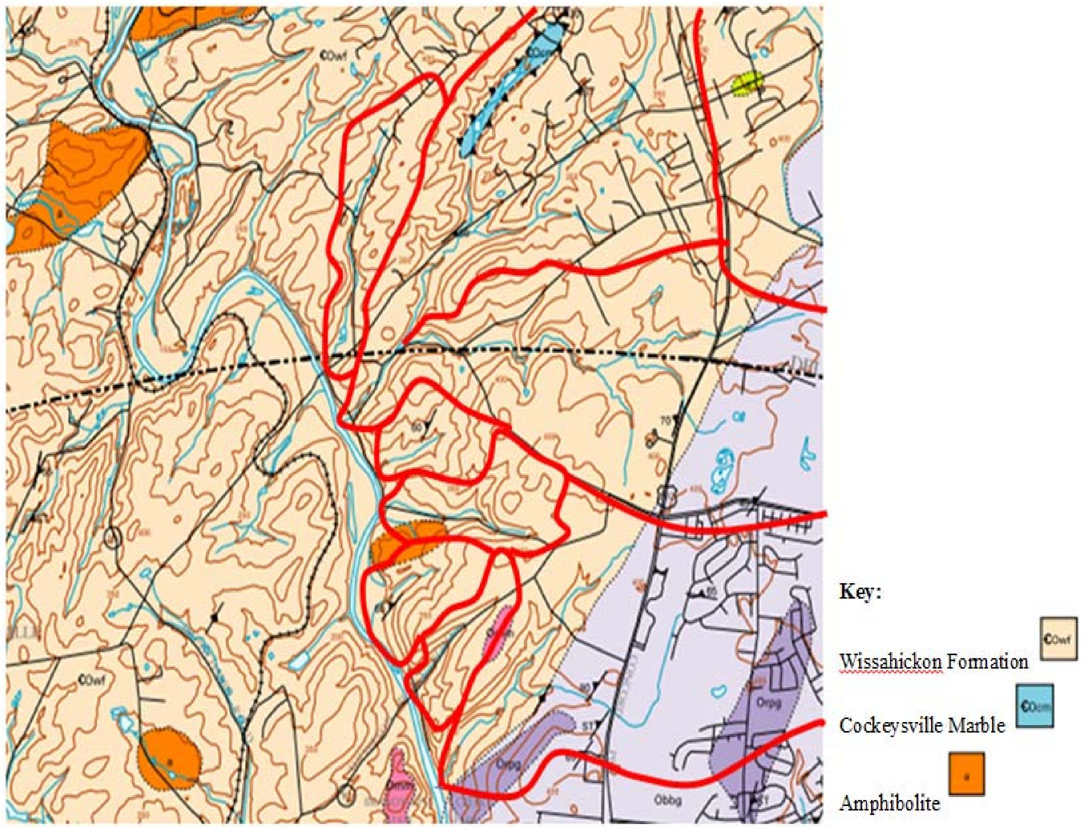



Figure 3.6 Geology of First State National Historical Park Watersheds (UD Water Resources Center, 2014)

### 3.6 Hydrology

There are six streams that flow through the First State. These six sub-watersheds of the Brandywine Piedmont Watershed that flow through the First State capture a drainage area of 4,485 acres or 7.0 mi$^2$ (Figure 3.7). The Beaver Creek watershed is the largest watershed, followed by Rocky Run, Ridge Run, Ramsey Run, Talley Run, and Carney Run.

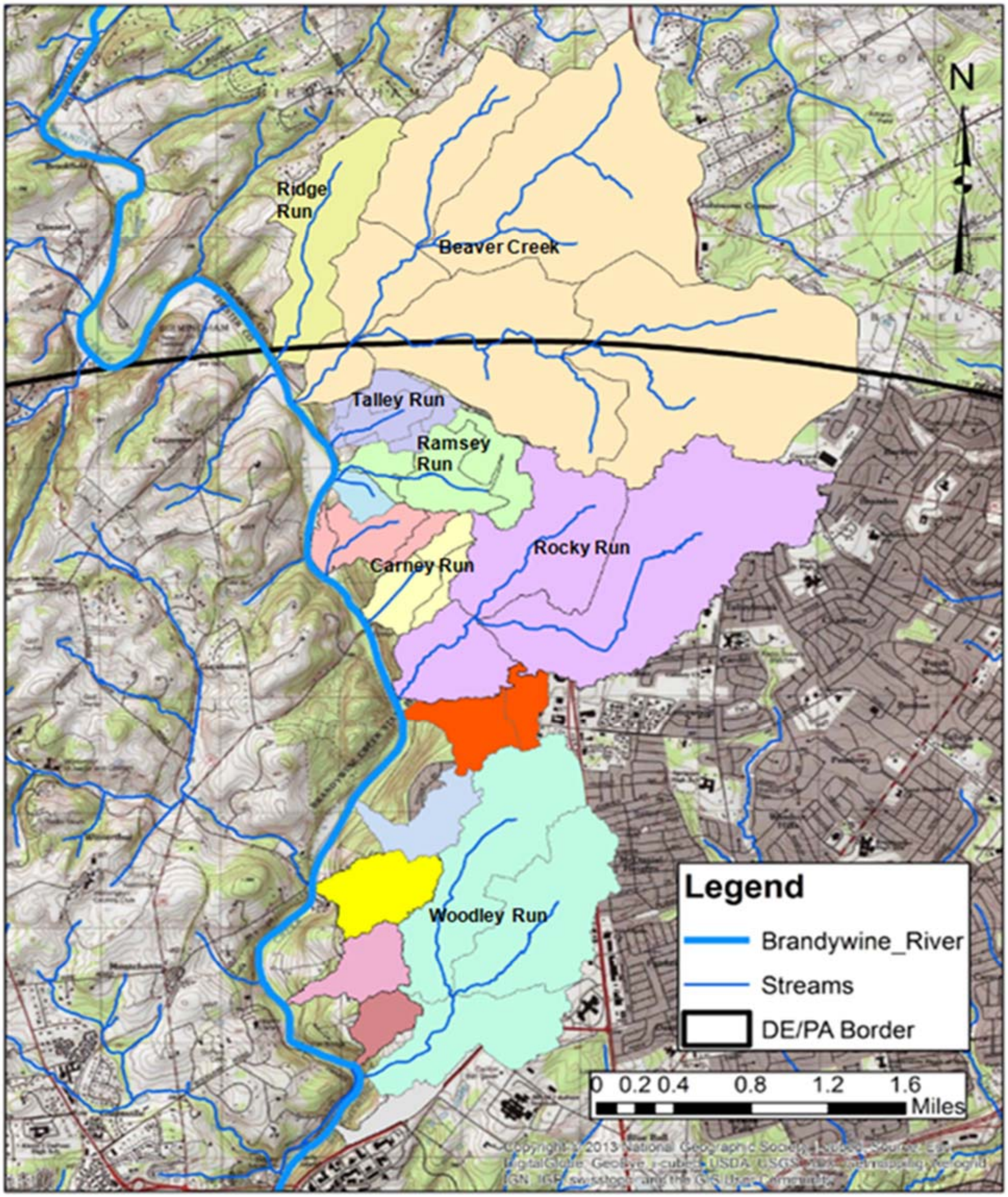



Figure 3.7 Watersheds of First State National Historical Park (UD Water Resources Center, 2017).

**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), is covered by soils in all four hydrologic soil groups, and the geology is the Wissahickon Formation gneiss. (UD Water Resources Center, 2017)

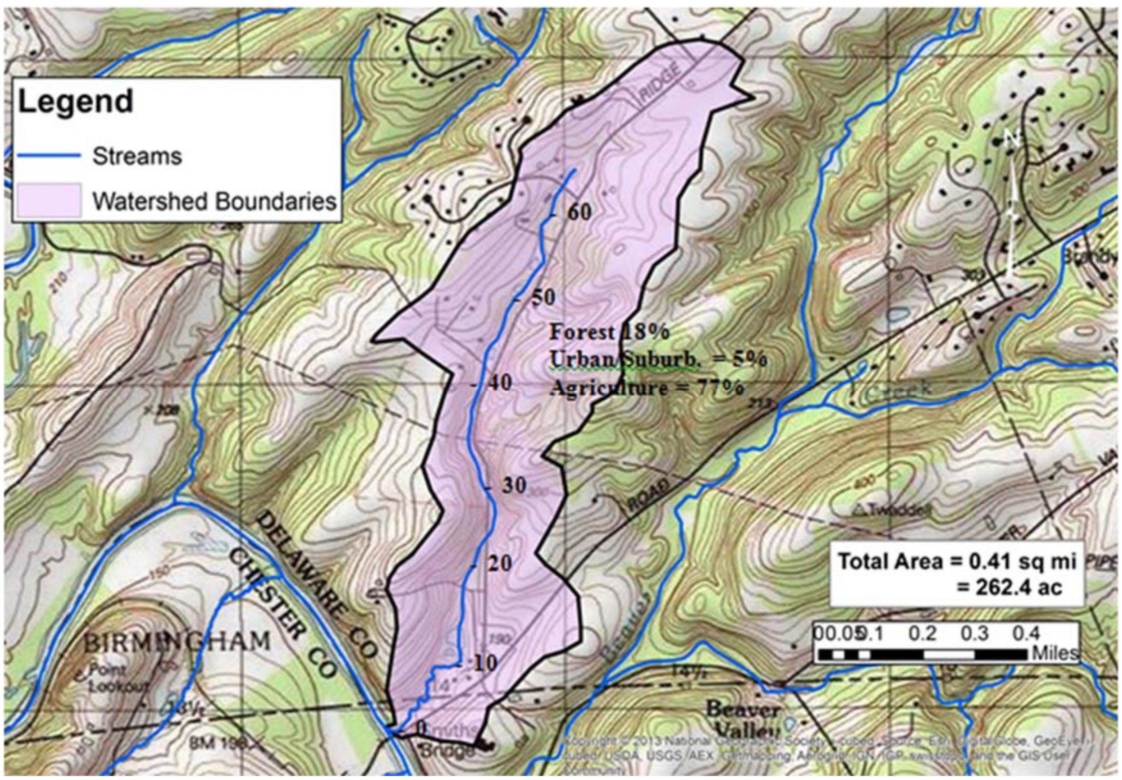



Figure 3.8 Ridge Run Watershed (UD Water Resources Center, 2017)

**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 (UD Water Resources Center, 2017) (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 (UD Water Resources Center, 2017). The south fork forms along the Delaware/Pennsylvania state line near the Brandywine Town Center and flows west for four miles under Concord Pike (UD Water Resources Center, 2017). It then flows through horse farms and forested sections of the First State before combining with the north fork near Beaver Valley Road (UD Water Resources Center, 2017). 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 (UD Water Resources Center, 2017). 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 (UD Water Resources Center, 2017). Watershed land use is 41% forest/wetlands, 28% urban/suburban, and 31% agriculture (UD Water Resources Center, 2017). 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.

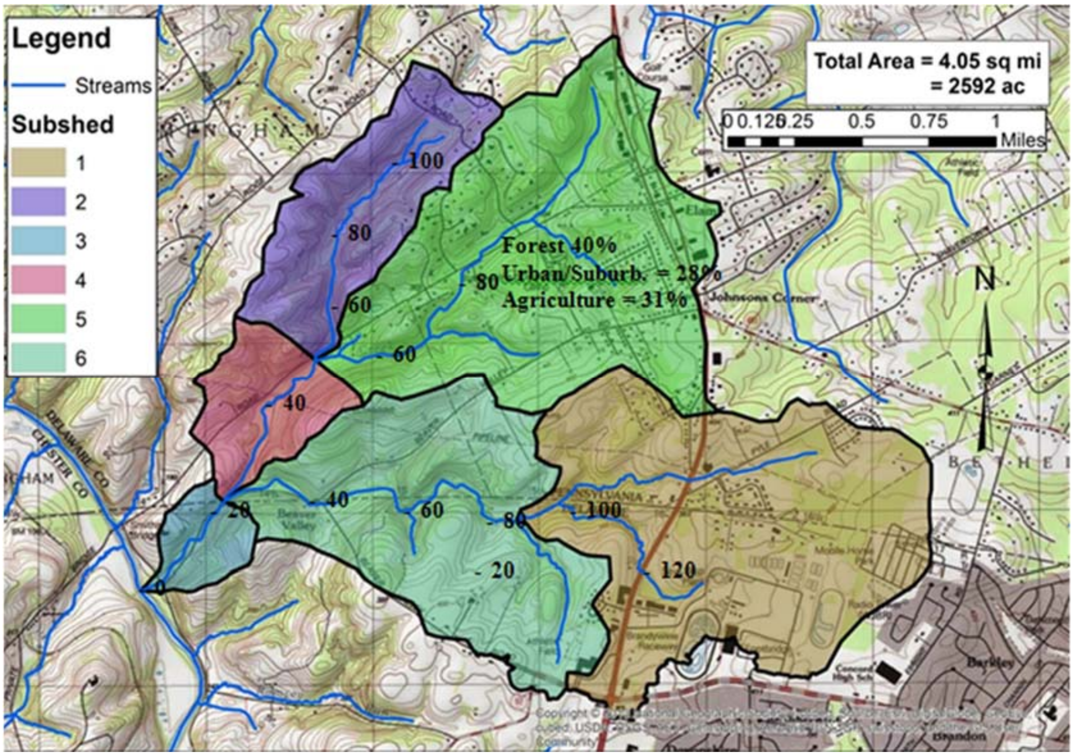



Figure 3.9 Beaver Creek Watershed (UD Water Resources Center, 2017)

**Talley Run:** The 128-acre Talley Run watershed lies entirely within the First State. The small creek forms on a 400 ft. high hill near Beaver Valley Road and flows less than a mile to then 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. (UD Water Resources Center, 2017)

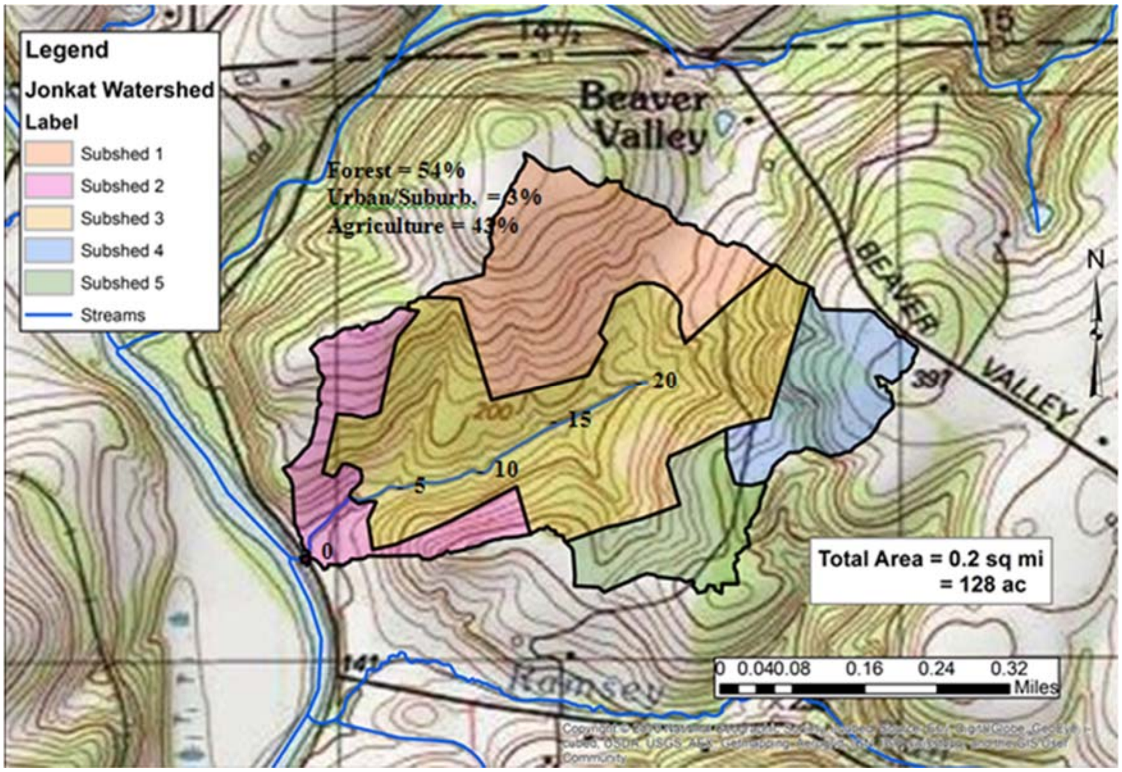



Figure 3.10 Talley Run Watershed (UD Water Resources Center, 2017)

**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. (UD Water Resources Center, 2017)

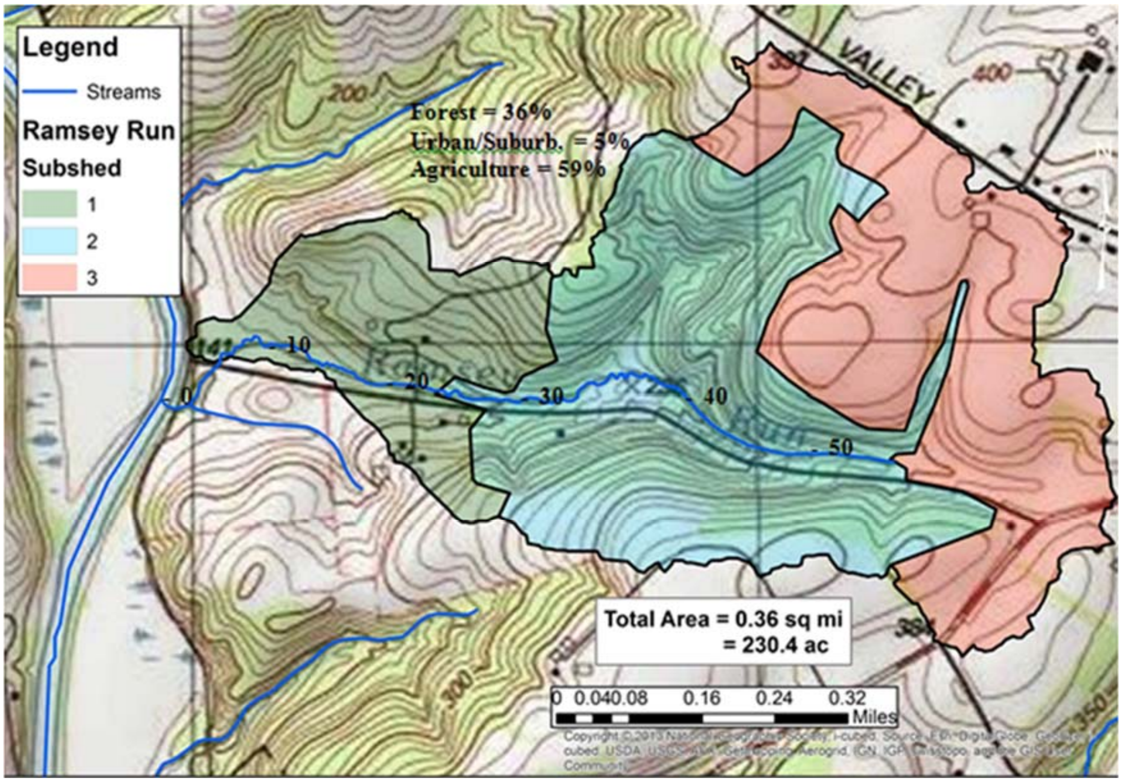



Figure 3.11 Ramsey Run Watershed (UD Water Resources Center, 2017)

**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. (UD Water Resources Center, 2017)

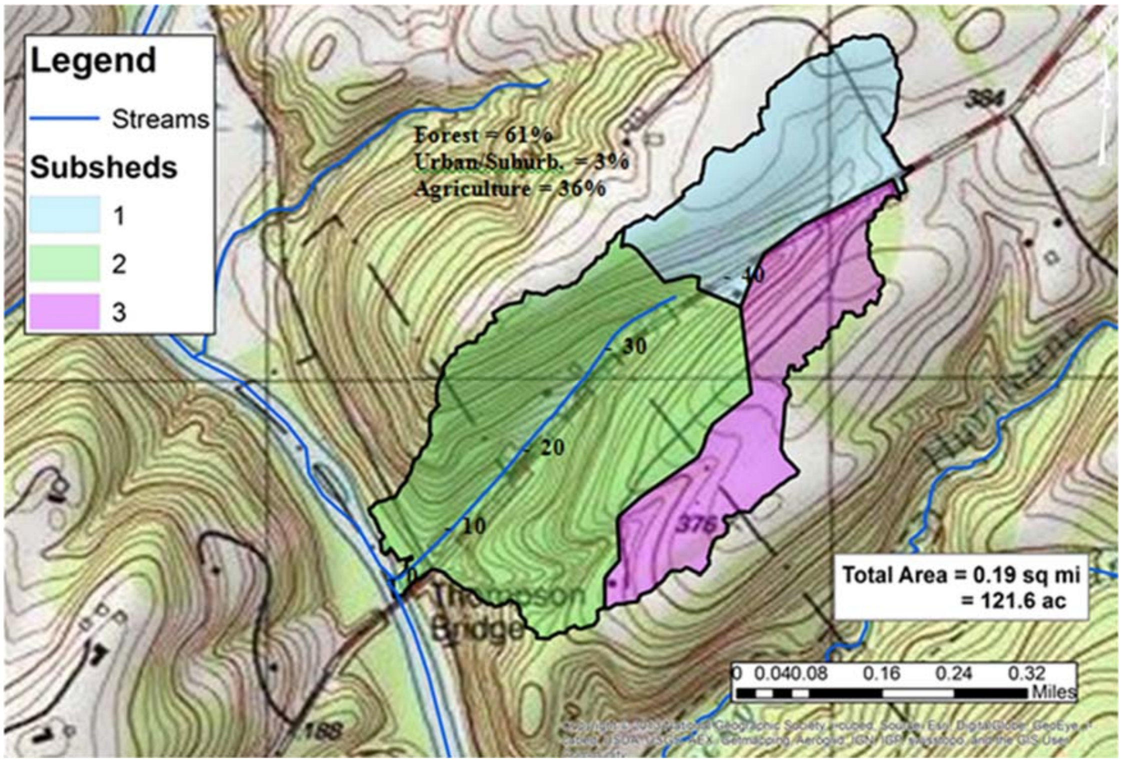



Figure 3.12 Carney Run Watershed (UD Water Resources Center, 2017)

**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 (UD Water Resources Center, 2017) (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 (UD Water Resources Center, 2017). 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 (UD Water Resources Center, 2017). The main stem flows for a half mile to the confluence with the Brandywine about a half-mile south of Thompson's Bridge (UD Water Resources Center, 2017). 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 (UD Water Resources Center, 2017). Watershed land use is 28% forest/wetlands, 40% urban/suburban, and 32% agriculture (UD Water Resources Center, 2017). The watershed is steeply sloped (10% slopes), is covered by soils from hydrologic soil group A, and geology is mostly formed by Wissahickon Formation gneiss (UD Water Resources Center, 2017). However, the north fork is underlain by an outcrop of the Cockeysville marble. (UD Water Resources Center, 2017)

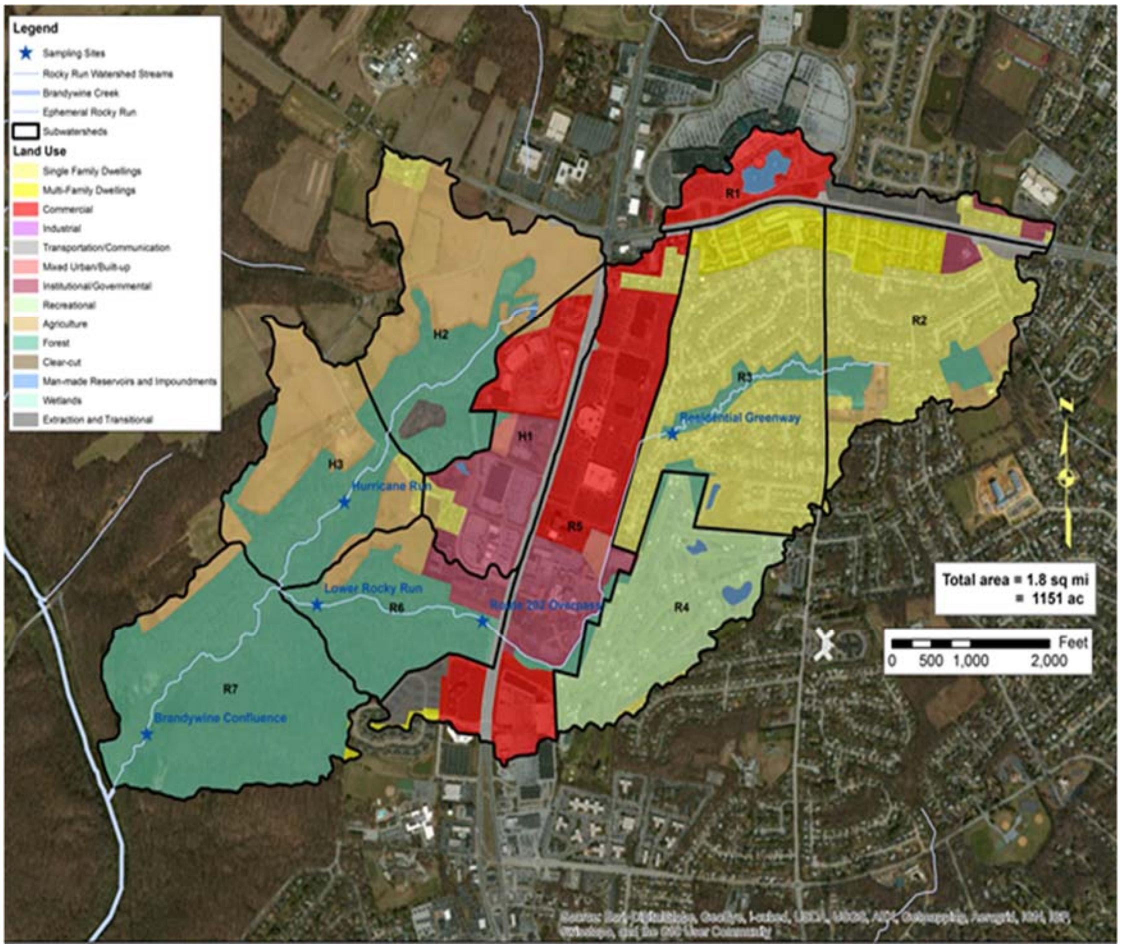



Figure 3.13 Rocky Run Watershed (UD Water Resources Center, 2017)

## 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). The 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 (UD Water Resources Center, 2017). 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). (UD Water Resources Center, 2017)

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%** |

(UD Water Resources Center, 2017)

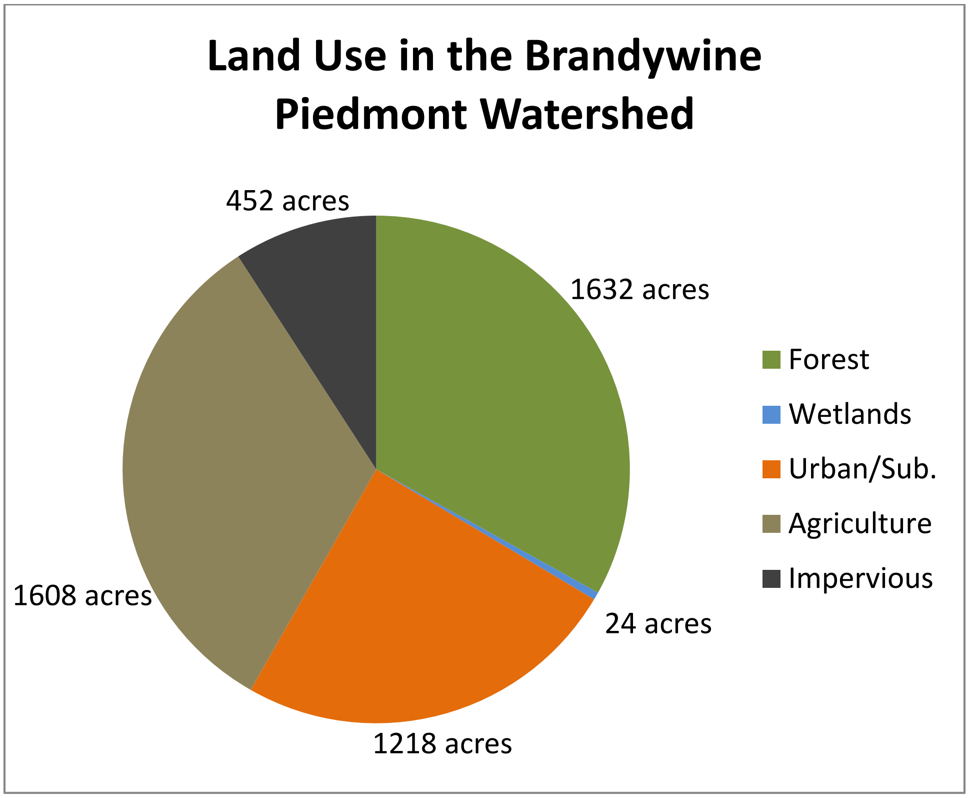



Figure 3.14 Land Use in the Brandywine Piedmont Watersheds (UD Water Resources Center, 2017)

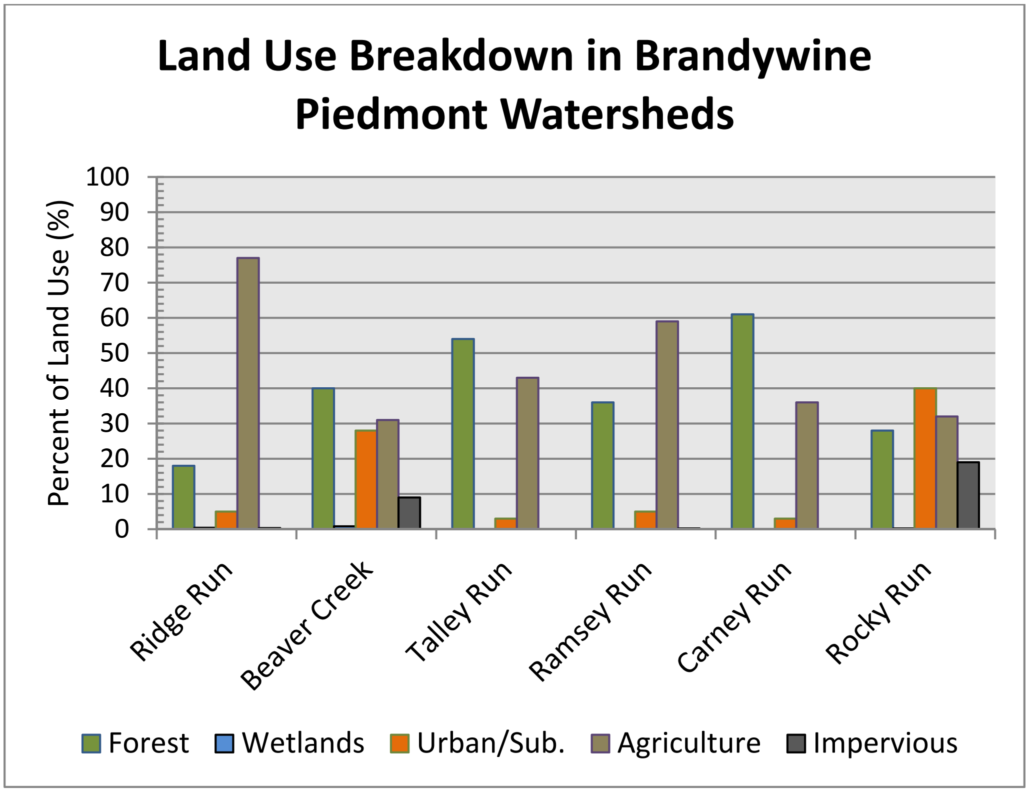



Figure 3.15 Land Use by Sub-watershed in the Brandywine Piedmont (UD Water Resources Center, 2017)

## 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%. It experiences a humid continental climate, its soil type consists primarily of Group B and Group C, and its geology is made up of Wissahickon Formation and Cockeysville Marble. The following chapter of this thesis discusses the water quality condition of the six sub-watersheds.

# Chapter 4

# WATER QUALITY IN FIRST STATE NATIONAL HISTORICAL PARK

## 4.1 Introduction

In this chapter, an analysis of the water quality condition in First State is discussed. The water quality was assessed by UD Water Resources Center students and staff, and the results were written up in several reports and documents. This chapter summarizes the findings and conclusions of UD Water Resources Center reports.

## 4.2 Overview

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 six streams feeding into the Brandywine Creek at the First State National Historical Park in Beaver Valley, Delaware. The purpose of this project was to further characterize Piedmont streams that flow west to the Brandywine Creek. Water quality sampling was conducted at twelve sites located in six sub-watersheds of the Brandywine Piedmont watershed (Figure 4.1).

## 4.3 Site Descriptions

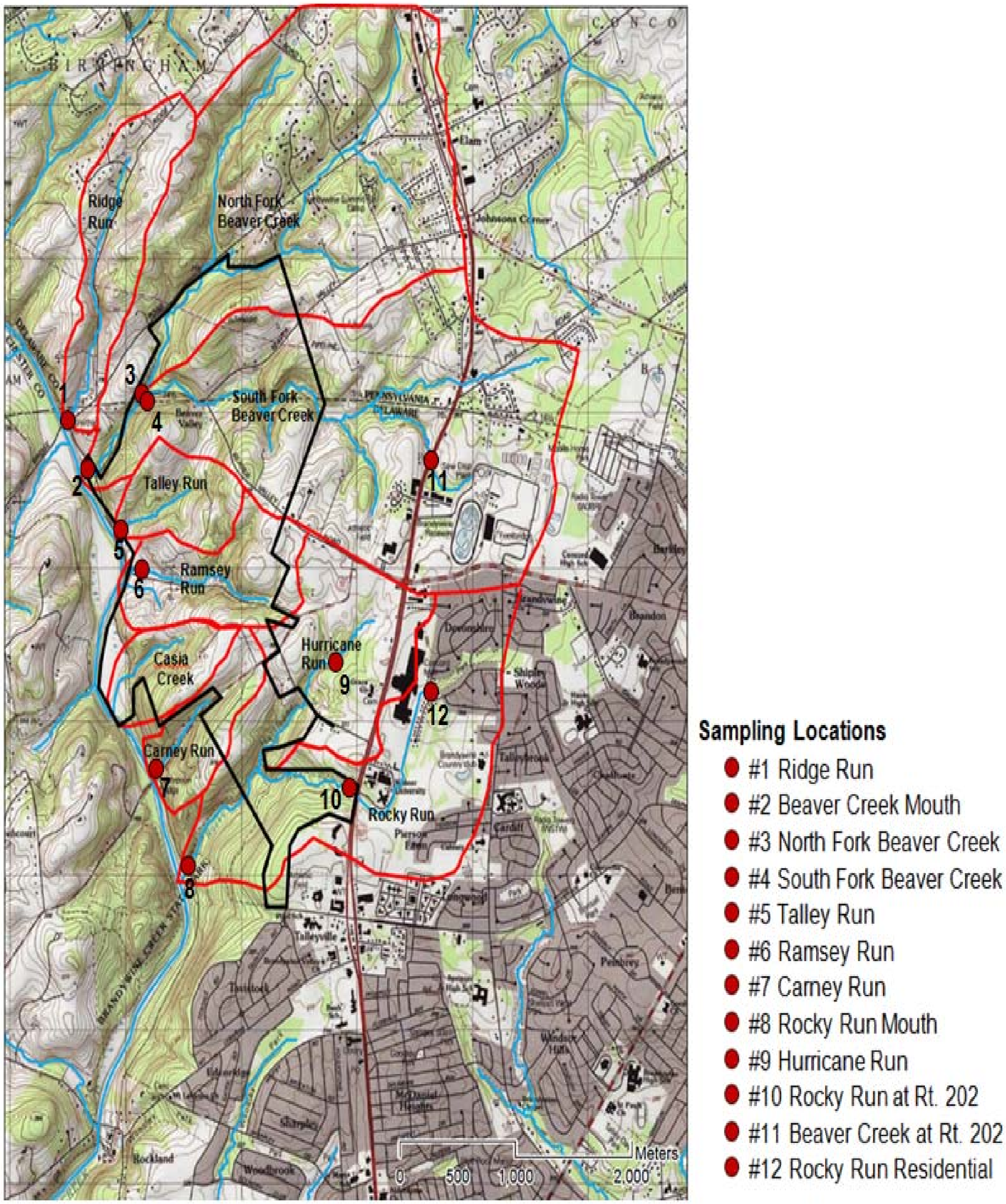



Figure 4.1 Water Quality Sampling Site Locations (UD Water Resources Center, 2017)

**Site 1:** The first site (Ridge Run) is located slightly south of the border of Pennsylvania and Delaware. This stream meanders into a private parcel of land containing a horse farm, grassy lawns, and housing areas along Smithbridge Road. The sampling site was downstream from these areas near the mouth of the tributary.

**Site 2:** Water samples at the second site (Beaver Creek Mouth) were taken before the confluence of Beaver Creek and the Brandywine Creek.

**Site 3:** The third site (Beaver Creek North Fork) is located further upstream and to the north of Beaver Creek Mouth. The area that was chosen for this site is located right before the confluence of Beaver Creek North and South.

**Site 4:** The fourth site (Beaver Creek South Fork) is similar to the north fork in that it originates in a heavily developed area and flows past the Concord Pike and into the National Park. The stream meanders along the Beaver Valley Road and becomes narrower upstream. There is an approximately five-foot-high vegetative hill between the tributary and the road at the sampling site, which is about 50 feet away from the intersection of the north and south forks.

**Site 5:** Samples at the fifth site (Talley Run) were taken near the mouth of the tributary several feet upstream of where it crosses underneath Brandywine Creek Road.

**Site 6:** This site (Ramsey Run) flows right underneath Ramsey Road before it converges with the Brandywine Creek. The sampling site was directly upstream from the bridge where Ramsey Run crosses the road. It was noted in the report that the result of stormwater runoff entering the stream from Ramsey Road, which often had polluted puddles, should be considered a concern for nonpoint source pollution due to its close proximity (UD Water Resources Center, 2017).

**Site 7:** This site (Carney Run) runs 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:** This site (Rocky Run Mouth) stream sampling occurred between the mouth at the Brandywine Creek and a temporary pedestrian trail bridge that was built after the permanent bridge was wiped out in a large storm. Construction on the new bridge began in August 2015 and was completed that winter, which may have influenced our fall samples since our sampling site was directly downstream of the construction area. This section is located downstream of Hurricane Run and Rocky Run's confluence, so the water quality is a combination of all six of Rocky Run's sub-sheds after it flows through the protected areas of First State.

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

**Site 10:** This site (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 as it passes 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:** This site (Beaver Creek) runs underneath the Concord Pike before it enters the National Park. Site 11 (Beaver Creek at Route 202) was located directly downhill and downstream from a horse farm and therefore is in danger of high nutrient levels.

**Site 12:** This site (Rocky Run Residential) 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.

## 4.4 Methodology

Sampling for the summer of 2015 began on June 22, 2015 and ended on July 28, 2015. Data was collected once a week (either on Monday or Tuesday) at the 12 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$^{th}$ and July 20$^{th}$ and sent to the City of Wilmington Water Quality lab to test for Enterococci bacteria and turbidity (total suspended solids). Water samples were tested and analyzed for turbidity twice in NTUs at the Wilmington lab in the summer and three times in FNUs, a similar measurement, in the fall with a turbidity meter on site. Sampling for the fall of 2015 began on October 9$^{th}$ and ended on December 4$^{th}$ and was conducted every other week. On October 9$^{th}$, nutrient samples taken from each of the sampling locations were sent to the Soil Testing Program at the University of Delaware College of Agriculture and Natural Resources. In 2016, sampling in the spring was conducted three times in March and April. Measurements for the summer and fall of 2016 consisted of only electrical conductivity and turbidity. Sampling for the summer began on June 22$^{nd}$. (UD Water Resources Center, 2017)

## 4.5 Results

The results from the chemical assessments that were conducted at each location are displayed as graphs. The graphs are organized into three categories: (1) mouth of tributaries flowing directly into Brandywine Creek, (2) tributaries of Beaver Creek Watershed, and (3) tributaries of Rocky Run Watershed. Categories are divided into the fluctuations of temperature, pH, turbidity, DO, conductivity, and enterococci bacteria over time as well as the median and interquartile ranges of these parameters over the entire testing period in order to better analyze the overall conditions at each of the 12 locations. (UD Water Resources Center, 2017)

Temperature is an important factor for addressing water quality as it can influence other parameters, such as DO, 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. As stated in the EPA Delaware Freshwater Quality Standards manual, no human-induced increase of the true daily mean temperature above 82.0°F (27°C) should be allowed. Our results show that Ridge Run has the highest median temperature at a value of 22.5°C (72.5°F), followed by Rocky Run at Route 202 with a value of 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 the temperature observations at each sampling site meet the standards for temperature. (UD Water Resources Center, 2017).

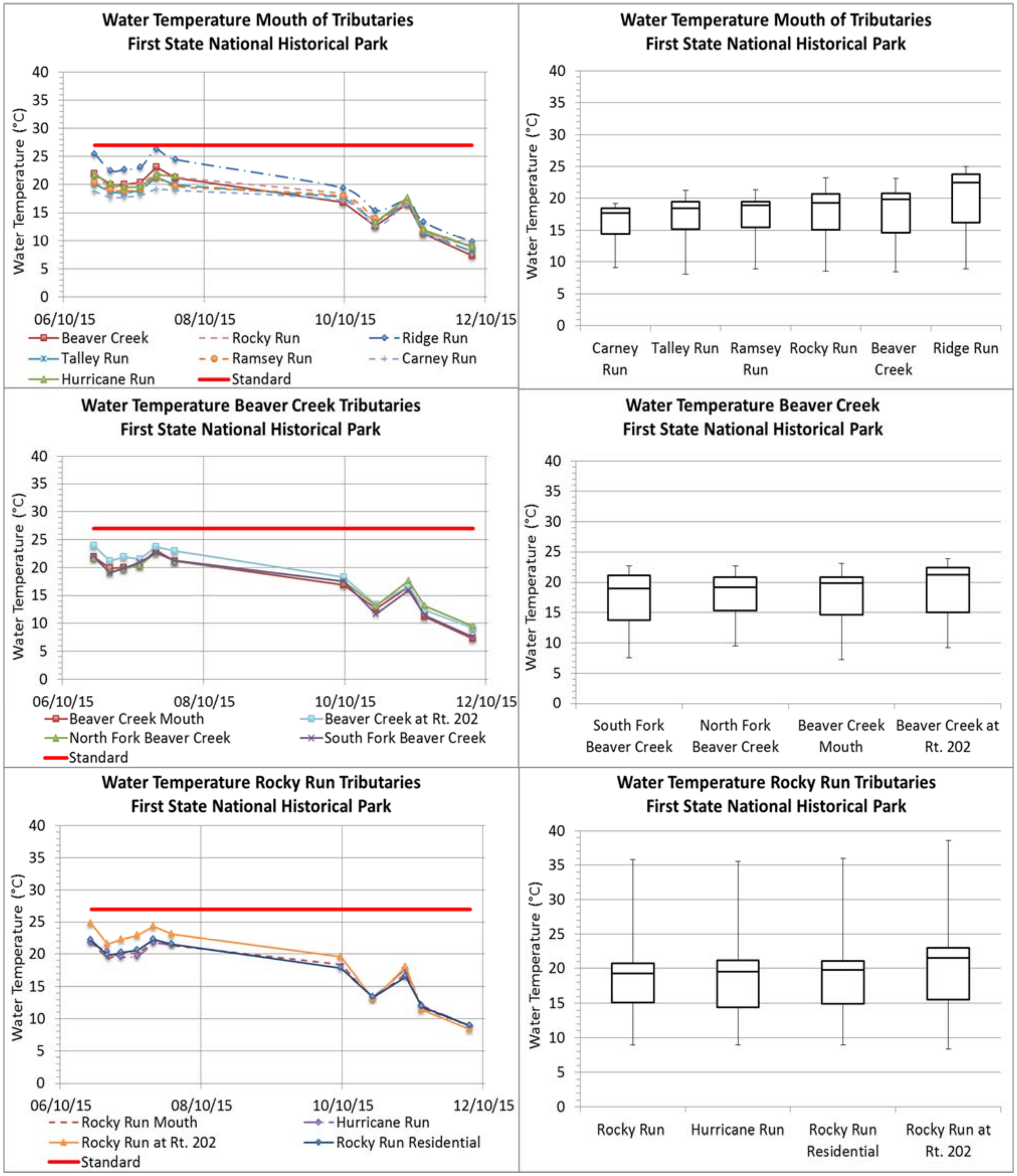



Figure 4.2 Water Temperatures in First State National Historical Park Tributaries (UD Water Resources Center, 2017)

The pH is the measure of the acidity of water. The pH will affect the types of organisms that live in the stream. If the 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 the EPA Delaware Freshwater Quality Standards manual, all waters in the state of Delaware should have a pH in the range of 6.5 and 8.5 units in its unaltered state. 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. (UD Water Resources Center, 2017)

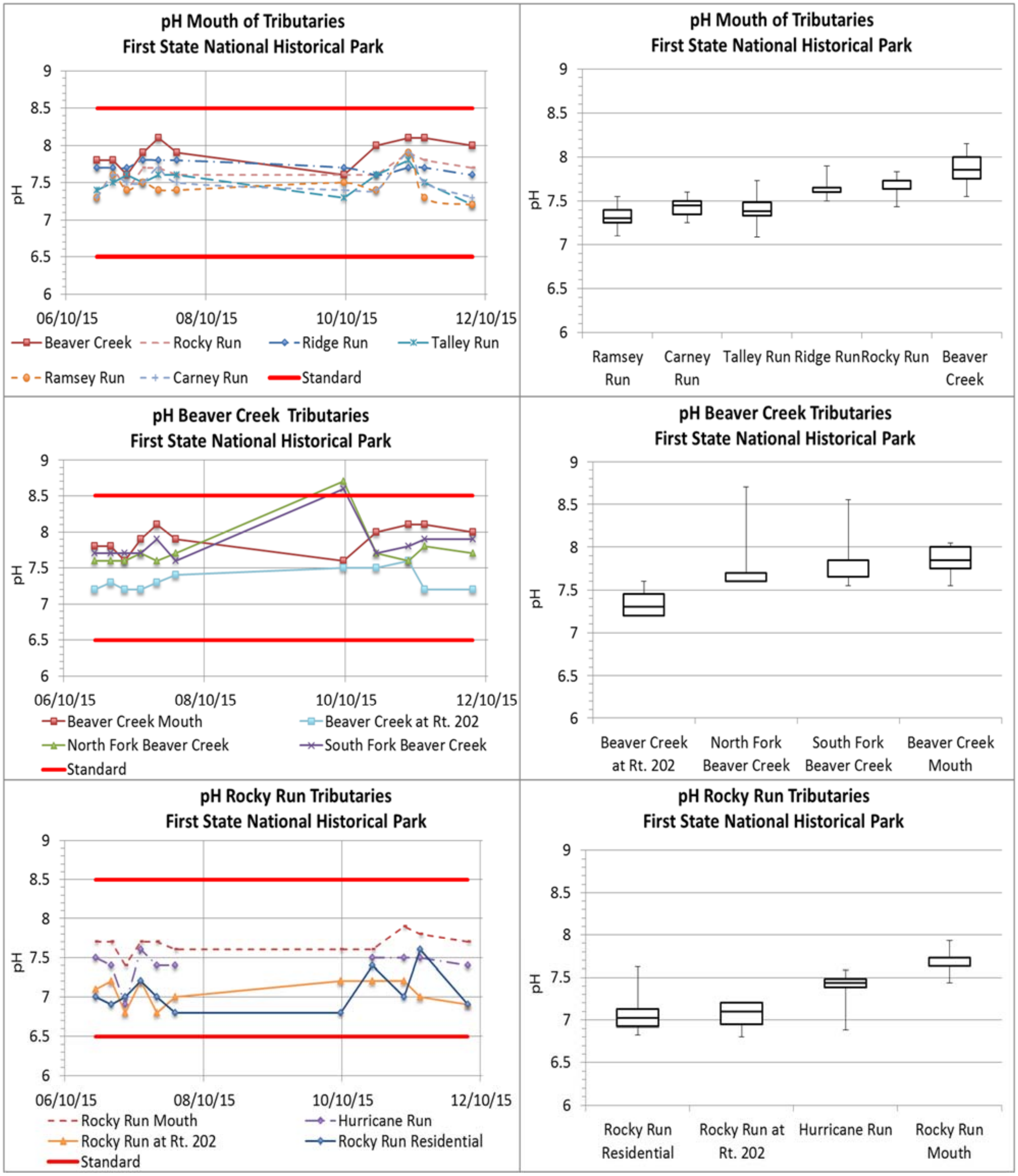



Figure 4.3 pH of First State National Historical Park Tributaries (UD Water Resources Center, 2017)

Turbidity measures both suspended and dissolved particulate matter in water, and is 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. According to the graphs shown below, 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/surburban 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. (UD Water Resources Center, 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.

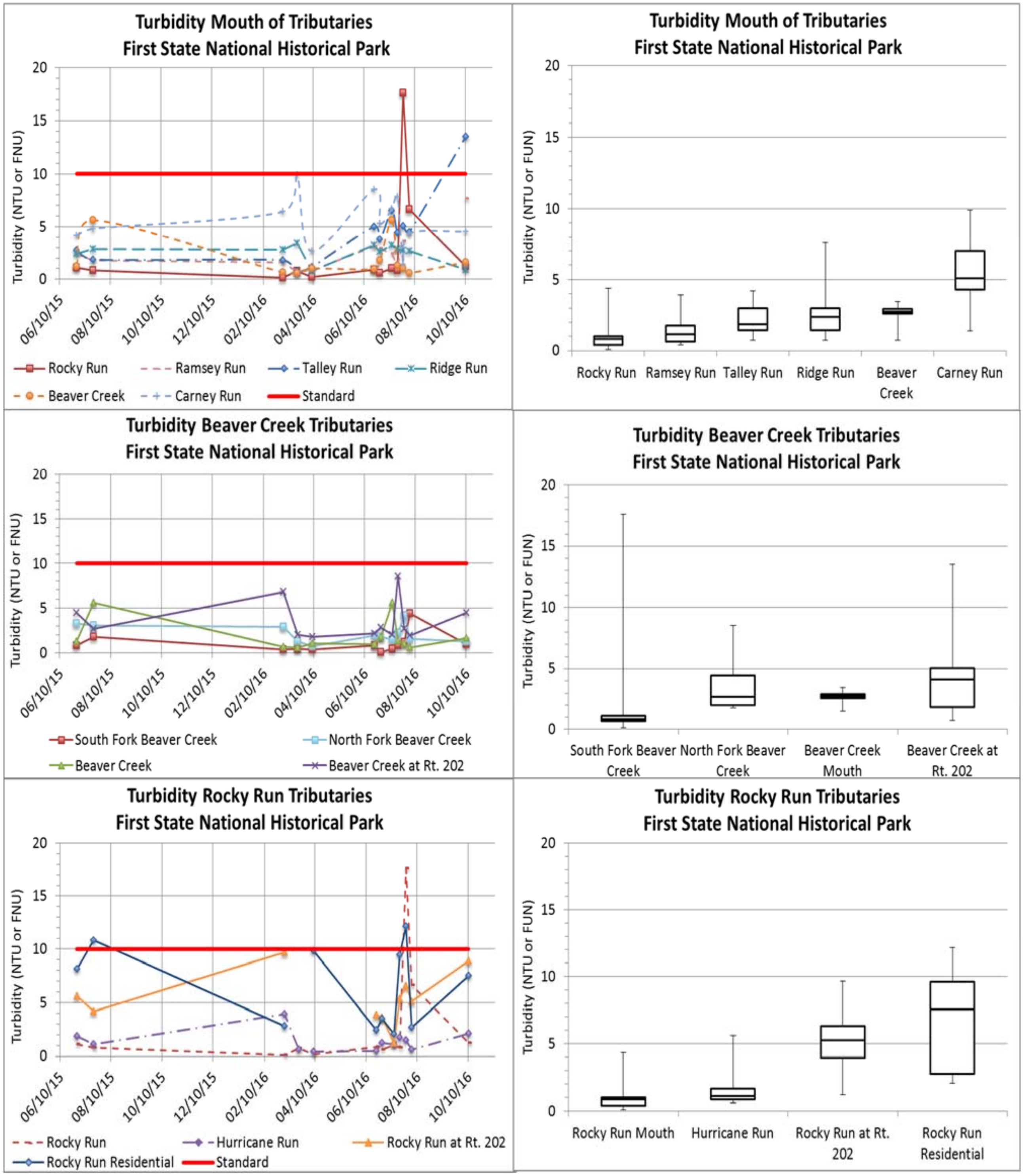



Figure 4.4 Turbidity of First State National Historical Park Tributaries (UD Water Resources Center, 2017)

Fish, macroinvertebrates, plants and bacteria all rely on DO to survive. According to the Water Quality Standards manual, 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. (UD Water Resources Center, 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, it can be recommended that establishing forested buffers in the upper parts of the watershed could help increase DO.

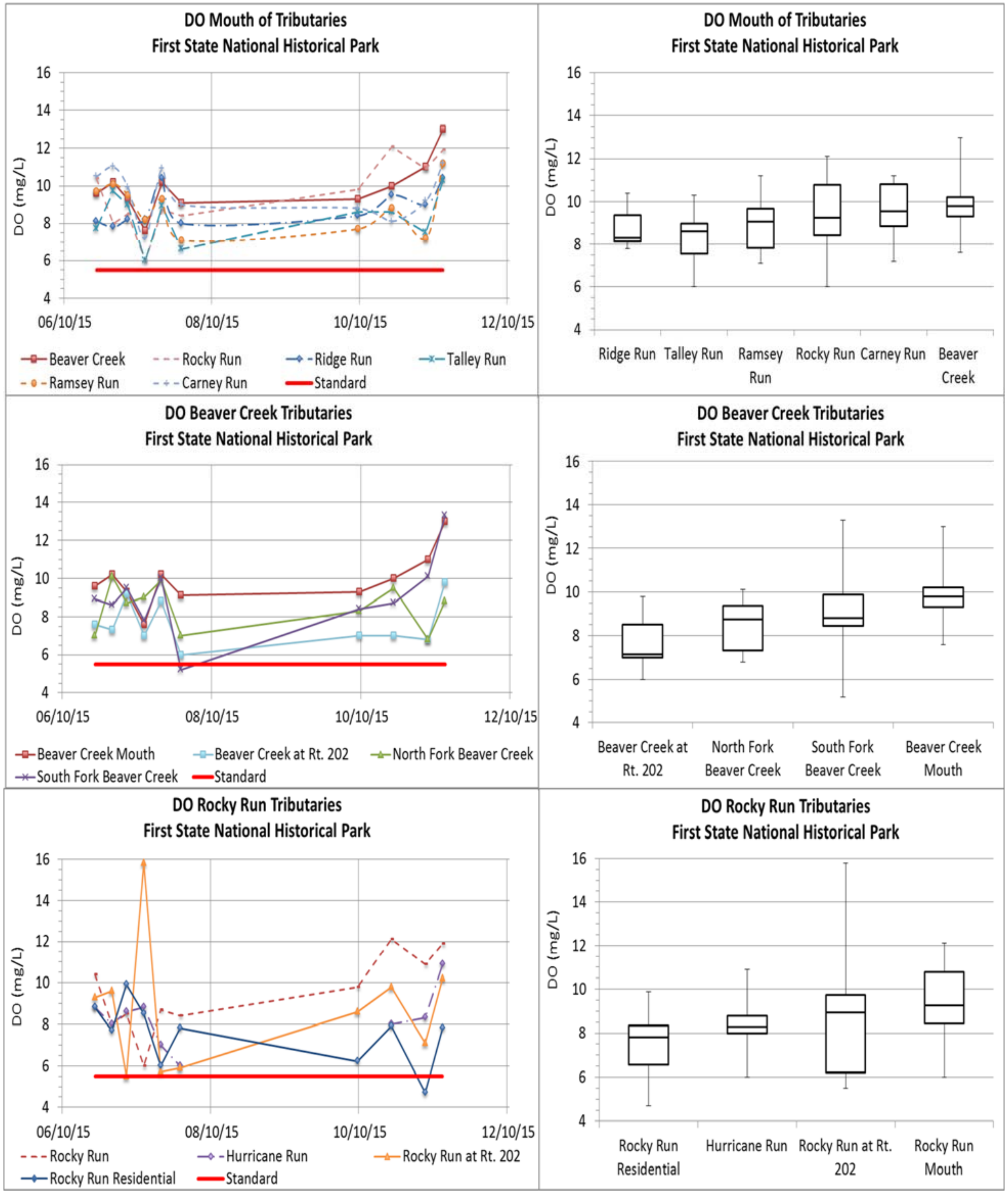



Figure 4.5 Dissolved Oxygen of First State National Historical Park Tributaries (UD Water Resources Center, 2017)

Conductivity is a measure of the ability of water to pass an electrical current and in water is affected by the presence of dissolved solids such as phosphate, nitrate, and sulfate (Conductivity, Salinity, and Total Dissolved Solids, 2014). A sudden 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. The ideal value of conductivity for aquatic organisms is between 150µS and 500µS. However, normal conductivity levels for surface waters are expected to range from 50µS to 1500µS. Shown in Figure 4.6 below, 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 4th, 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. (UD Water Resources Center, 2017) 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 which act as a buffer to pollutants.

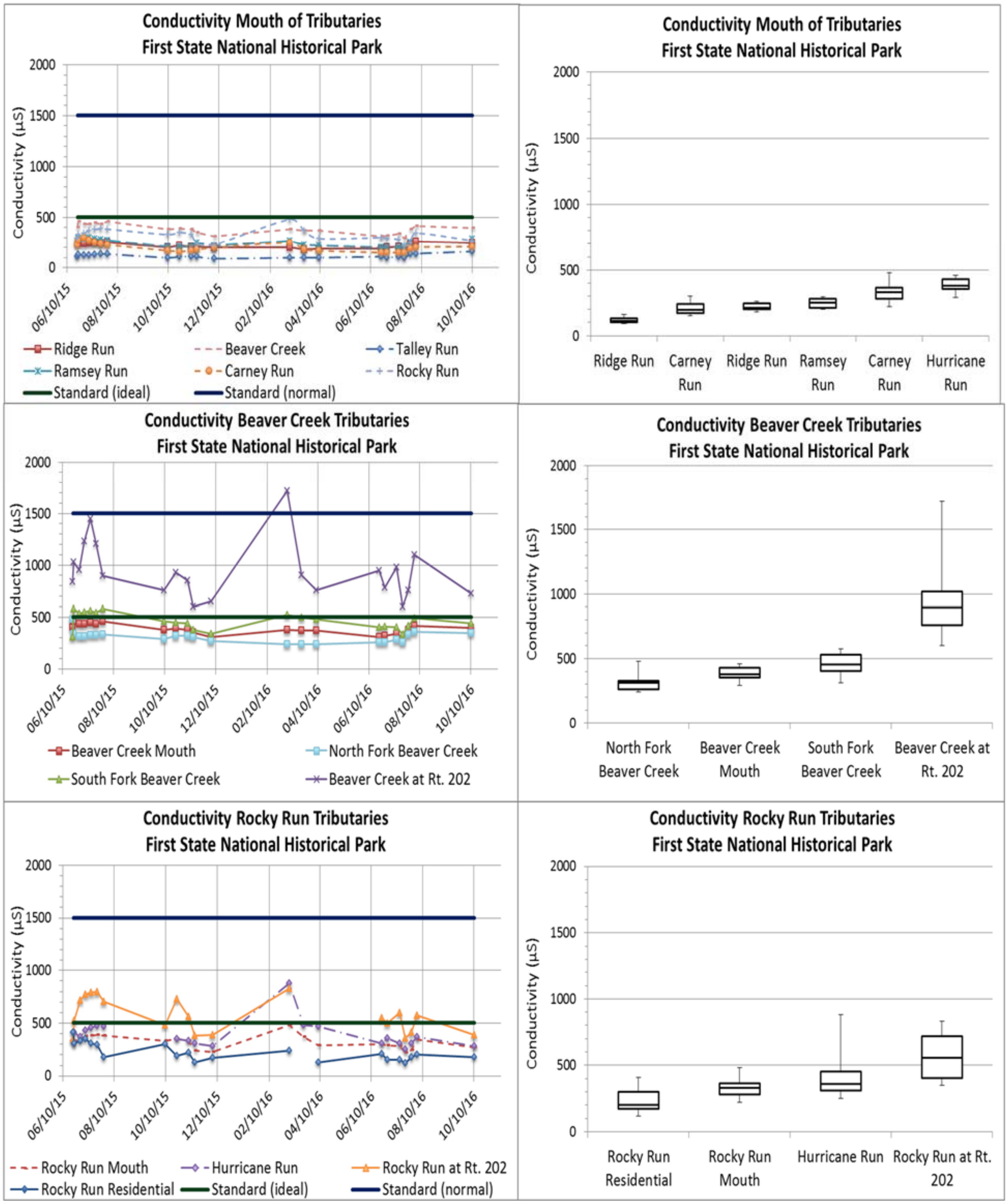



Figure 4.6 Conductivity of First State National Historical Park Tributaries (UD Water Resources Center, 2017)

Monitoring for bacteria is important because it can help detect the presence of harmful pathogens that can negatively affect human health. The most common biological indicators are E. coli and enterococci as they both help indicate sewage contamination (UD Water Resources Center, 2017). 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 (UD Water Resources Center, 2017). Results from the City of Wilmington Water Quality lab 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 this high, it is recommended that further measures to enforce people from swimming in these tributaries should be taken. (UD Water Resources Center, 2017)

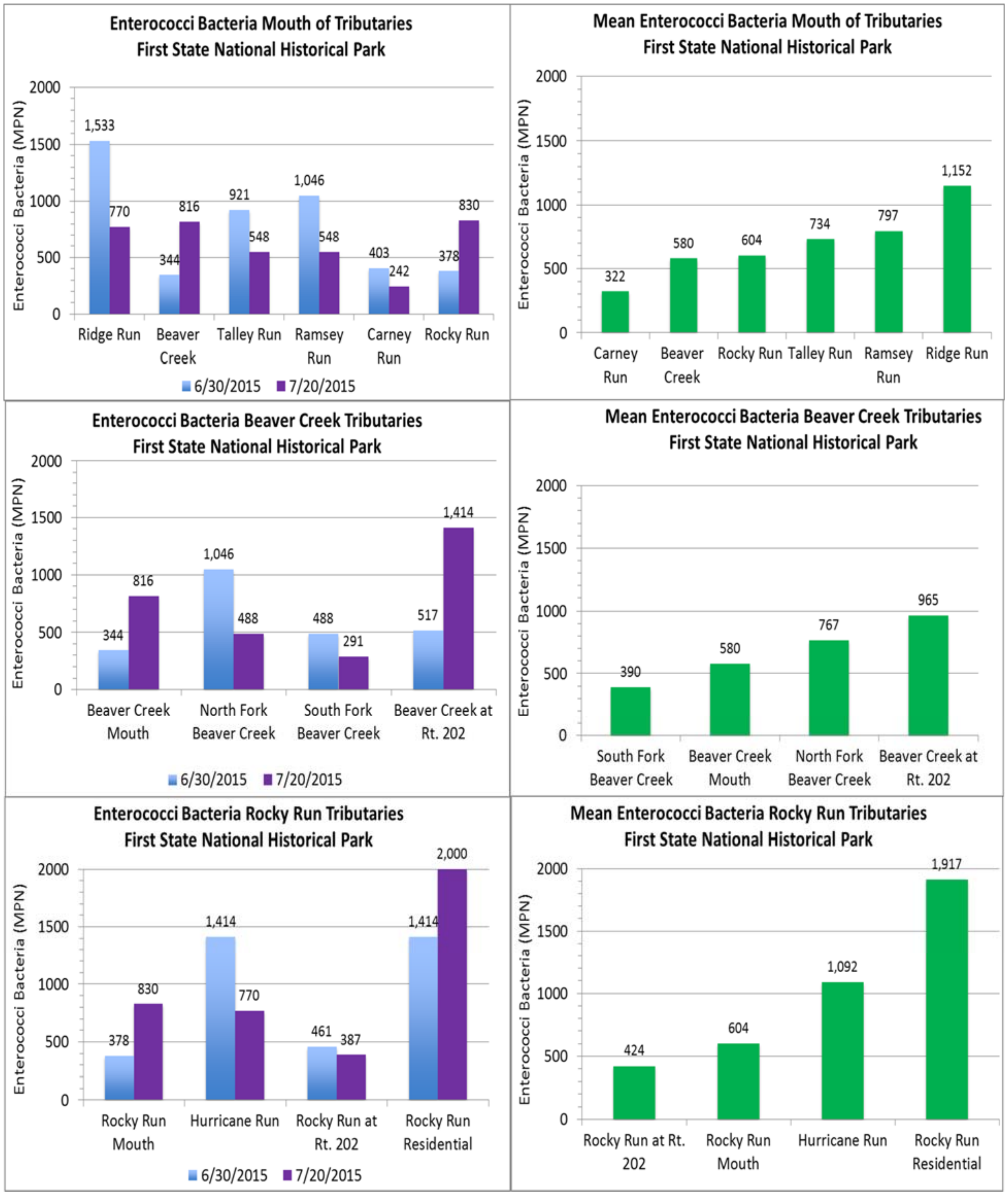



Figure 4.7 Enterococci of First State National Historical Park Tributaries (UD Water Resources Center, 2017)

## 4.6 Summary

Water quality sampling was conducted at twelve sites located in six sub-watersheds of the Brandywine Piedmont watershed by UD Water Resources Center students and staff. 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, due to several high recorded turbidity and conductivity readings. The heavily forested and less-developed parts of the watershed, at/near the mouth of the tributaries near the Brandywine River, have excellent water quality. Therefore, from these results, 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 following chapter of this thesis discusses the water quality condition 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.

# Chapter 5

# WATER RESOURCES MANAGEMENT AND POLICIES OF THE NATIONAL PARK SERVICE

## 5.1 Introduction

The following chapter of this thesis describes the water quality condition discussed in State of the Park Reports and Natural Resource Condition Assessments of Valley Forge, Harpers Ferry, and Minute Man National Historical Parks. Differences in reporting, policies, and approaches to water resources management among First State, Valley Forge, Harpers Ferry, and Minute Man are discussed.

## 5.2 Valley Forge National Historical Park

**Overview:** Valley Forge National Historical Park is a 3465.6 acres/5.4 $mi^2$ historical park located approximately 20 miles northwest of Philadelphia in Pennsylvania. Valley Forge is approximately 3 times the size of First State. Valley Forge is nationally significant as it was the site of the 1777-78 winter encampment of the Continental Army under General George Washington (Valley Forge State of the Park Report, 2015). 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 (Valley Forge State of the Park Report, 2015).

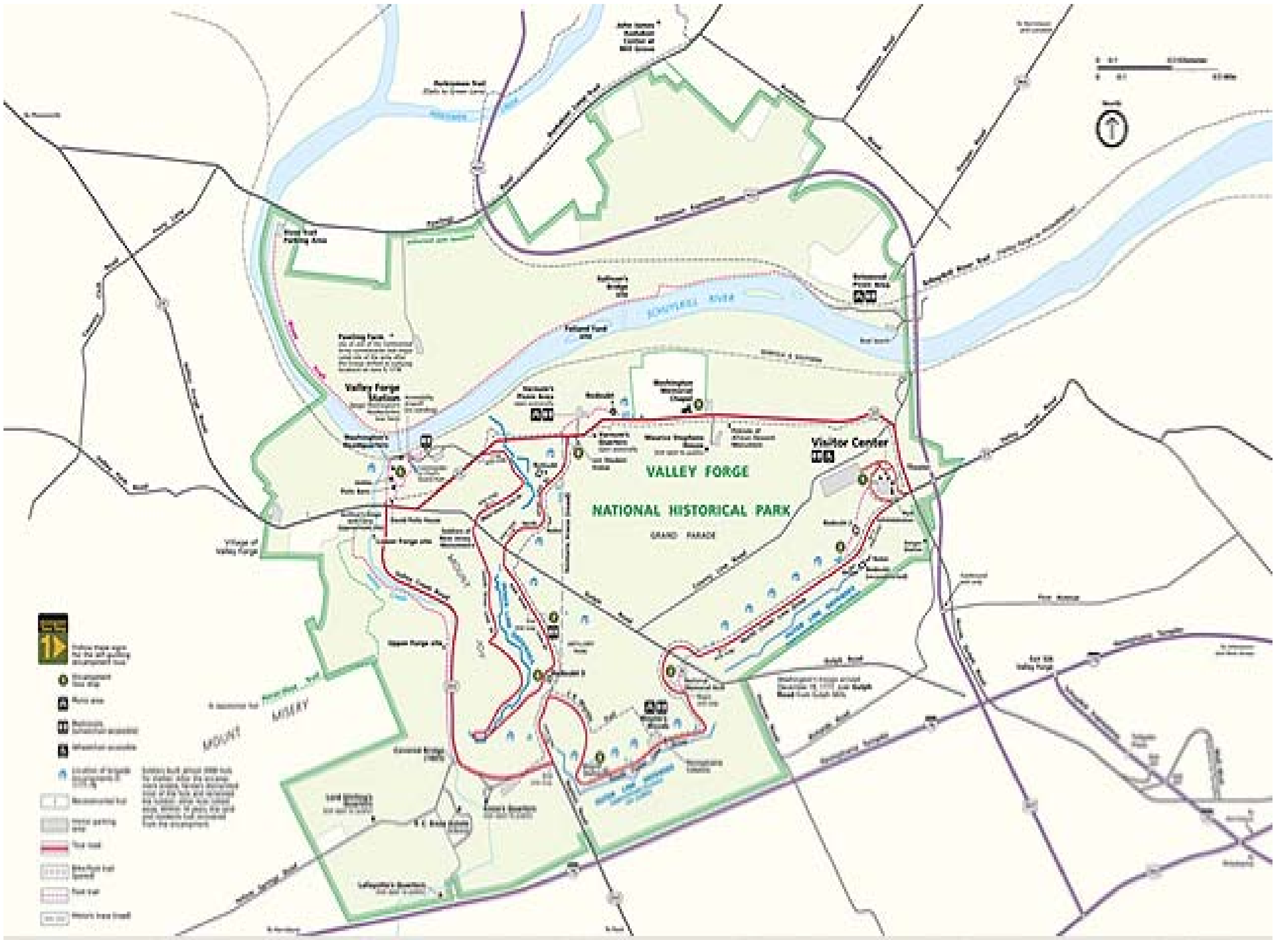



Figure 5.2 Map of Valley Forge National Historical Park (NPS, Valley Forge Maps and Brochures)

**State of the Park Report:** Valley Forge published a State of the Park Report in 2015. In the report it describes the condition of the two streams that flow through the park, Valley Creek and Schuylkill River. The State of the Park Report summarizes the park's Natural Resource Condition Assessment, as well as other inventories and assessments to determine the condition and trend of the park's water resources (State of the Park Report, 2015).

Valley Creek is a designated Pennsylvania "Exceptional Value" waterway, which provides it the highest level of protection from the Pennsylvania Department of Environmental Protection. It is also a spring-fed, cold-water fishery and a Class A Wild Trout Stream (State of the Park Report, 2015). 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" (PA Code Title 25, Chapter 93 Water Quality Standards). It flows through a 23 square mile watershed, with only the last two miles of the creek flowing within the park (State of the Park Report, 2015).

In the park's Natural Resource Condition Assessment, Sherwin et al. 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 (State of the Park Report, 2015). 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 (State of the Park Report, 2015). 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 (State of the Park Report, 2015).

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" (PA Code Title 25, Chapter 93 Water Quality Standards). The Schuylkill River was the first waterway to be designated as a

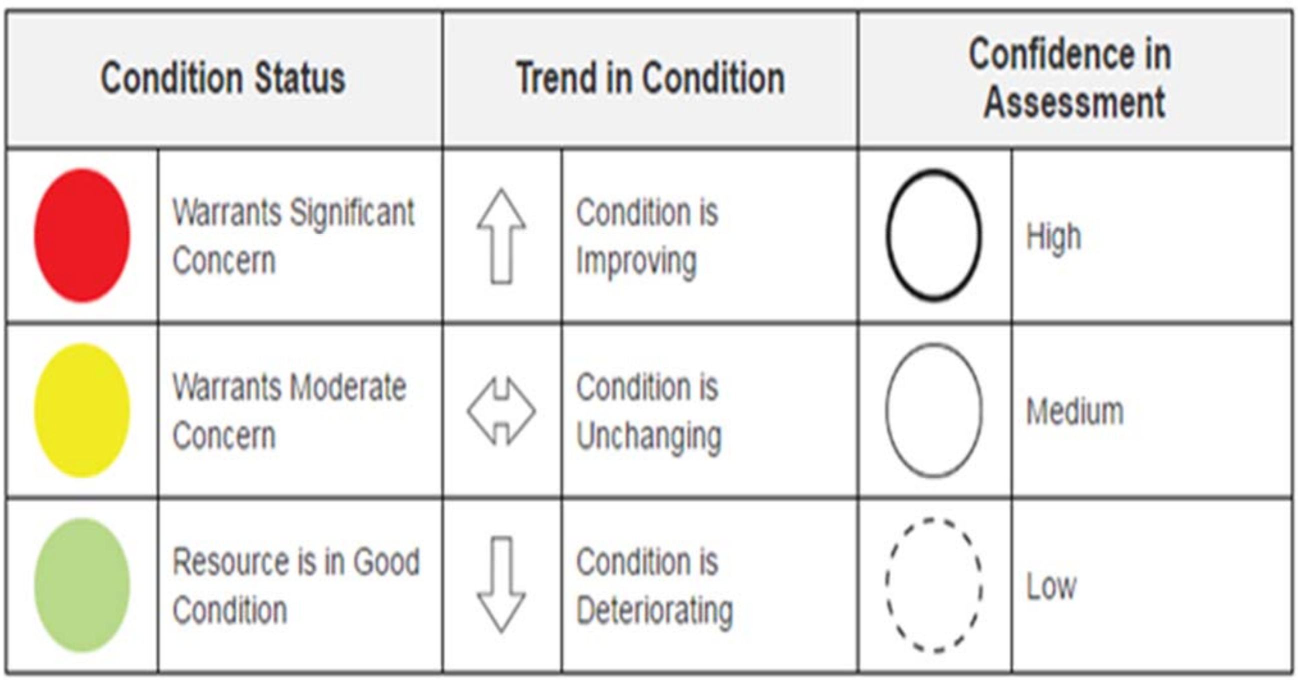
Pennsylvania Scenic River and is a nationally designated heritage area (State of the Park Report, 2015). It is also designated as a Migratory Fishes water body, meaning it is also regulated for the protection of "passage, maintenance and propagation of anadromous and catadromous fishes and other fishes which move to or from flowing waters to complete their life cycle in other waters" (PA Code Title 25, Chapter 93 Water Quality Standards). Three miles of the 1,916 square mile 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 NPS. 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 the 3 miles that flow through the park, have been designated impaired by the Pennsylvania Department of Environmental Protection. It is considered impaired and listed on the 303d list under the federal Clean Water Act from industrial runoff including polychlorinated biphenyl and chlordane contamination (State of the Park Report, 2015). About one-third of the Schuylkill River watershed is listed as impaired for aquatic life use (Environmental Protection Agency, 2010).

According to an assessment conducted by Sherwin et al., 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)



| Condition Status | | Trend in Condition | | Confidence in Assessment | |
|---|---|---|---|---|---|
| | Warrants Significant Concern | | Condition is Improving | | High |
| | Warrants Moderate Concern | | Condition is Unchanging | | Medium |
| | Resource is in Good Condition | | Condition is Deteriorating | | Low |

Figure 5.3 The Status and trend symbols in the State of the Park Report (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 fisheries) | PA Code, 2001 | 6.0-9.0 (warm water fisheries) | PA Code, 2001 |
| DO (mg/L) | Min. 7.0 mg/L (cold water fisheries and exceptional value waters) | PA Code, 2001 | Min. daily avg. 5.0 mg/L Min. 4.0 mg/L (warm water fisheries) | PA Code, 2001 |
| Water Temp. (°C) | Max: 3.0 ≤ °C ≤ 19.0 (37.4 ≤ °F ≤ 66.2)-cold water fisheries | PA Code, 2001 | Max: 3.0 ≤ °C ≤ 19.0 (37.4 ≤ °F ≤ 66.2)- warm water fisheries | PA Code, 2001 |
| Alkalinity (mg/L) | 140 mg/L[3]<br><br>Min. 20 mg/L as CaCO3 (cold water fisheries)[4] | Botts, 2005<br><br>PA Code, 2001 | No data recorded<br><br>Min. 20 mg/L as CaCO3 (warm water fisheries)[4] | PA Code, 2001 |
| Specific conductivity (µS/cm) | No data recorded<br><br>150-500 µS/cm (cold water fisheries)[4] | EPA, 2009 | No data recorded<br><br>No standard (warm water fisheries) | |
| Nitrate+Nitrite (mg/L) | Max. 10 mg/L (cold water fisheries) | PA Code, 2001 | Max. 10 mg/L (warm water fisheries) | PA Code, 2001 |
| Phosphorus (mg/L) | < 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<br><br>17 mg TAN/L<br>1.9 mg TAN/L at pH 7 and 20°C,<br>Max. 4.8 mg TAN/L as a 4-day average<br>(TAN stands for Total Ammonia Nitrogen) (warm water fisheries). | EPA, 2009 |
| Chloride (mg/L) | Max. 250 mg/L (cold water fisheries) | PA Code, 2001 | Max. 250 mg/L(warm water fisheries) | PA Code, 2001 |
| Total Dissolved Solids (TDS) | No data recorded<br><br>750 mg/L and/or 500 mg/l as a monthly average value (cold water fisheries)[4] | PA Code, 2001 | Min. median monthly value of 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)

### 5.3 Harpers Ferry National Historical Park

**Overview:** Harpers Ferry is a 3660.8 acres/5.7 $mi^2$ park located at the confluence of the Potomac and Shenandoah Rivers in the state of West Virginia, Virginia, and Maryland. Harpers Ferry is similar in size to Valley Forge and approximately 3 times the size of First State. Harpers Ferry was established in 1944 to be a public national memorial commemorating a diverse number of historic people and events that influenced the course of our nation's history at or near Harpers Ferry (Harpers Ferry Natural Resource Condition Assessment, 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 (Harpers Ferry Natural Resource Condition Assessment, 2013).

Although the Potomac and Shenandoah Rivers flow through the park boundaries, they are not considered part of Harpers Ferry. However, there are a few small tributaries that cross the park. A 500-foot section of Elk Run flows through the park before it empties into the Potomac River and is the 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.


1. Lower Town  2. Virginius Island  3. Camp Hill  4. Murphy Farm  5. Bolivar Heights

6. Schoolhouse Ridge North  7. Schoolhouse Ridge South  8. Maryland Heights  9. Loudoun Heights

Figure 5.4 Map of Harpers Ferry National Historical Park (NPS, 2008)

**Natural Resource Condition Assessment:** Every few years, Harpers Ferry assesses the condition of its natural resources and releases a natural resource condition assessment. The most recent report, published in 2013, includes the condition of its water resources. Harpers Ferry has not released a State of the Park report. As of 2013, water resources within Harpers Ferry meet federal and state water quality standards. Studies were conducted during 2004-2011 to determine the overall status of water resources within the park (Thomas et al., 2013). Nine metrics, pH, DO, water temperature, acid neutralizing capacity (ANC), salinity/specific conductance, nitrate, total phosphorus, Benthic Index of Biotic Integrity (BIBI), and Physical Habitat Index

(PHI), were chosen to assess the overall quality of water resources within Harpers Ferry. Data was collected in Flowing Springs Creek by I&M staff. Data was collected during the period of 2005-2011 for pH, DO, water temperature, ANC, specific conductance, and nitrate. Data on total phosphorus was collected during the period of 2007-2011, and data on BIBI and PHI was collected during 2004. (Thomas et al., 2013)

Reference conditions were established for each of the nine 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 5.5). HAFE scored "very good" for pH, water temperature, ANC (100% attainment), and DO (96% attainment). BIBI scored "degraded" (45% attainment), PHI 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, DO, 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 ANC, nitrate, BIBI, and PHI 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. EPA 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 (°C) | ≤30.56°C (87.0°F) May-Nov; ≤22.78 (73°F) Dec-Apr[6] | State of West Virginia, 2008 | 19.1 May-Nov; 7.4 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 |
| Benthic Index of Biotic Integrity (BIBI) | 1.0-1.9; 2.0-2.9; 3.0-3.9; 4.0-5.0 | MBSS interpretation of the BIBI | 2.8 | 45 | Poor |
| Physical Habitat Index | 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 | Fair |
| 2.0–2.9 | linearly ↓ | 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 5.5 Reference conditions for the Natural Resource Condition Assessment Report (Thomas et al., 2013)

## 5.4 Minute Man National Historical Park

**Overview:** Minute Man is a 967.0 acre/1.5 mi² historical park located approximately 22 miles outside of Boston within the towns of Lexington, Lincoln, and Concord, Massachusetts. Out of the 3 historical parks described in this chapter, Minute Man is the closest in size to First State. First State is 0.2 square miles larger than Minute Man. 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. (United States. NPS "Plan Your Visit"). The 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).

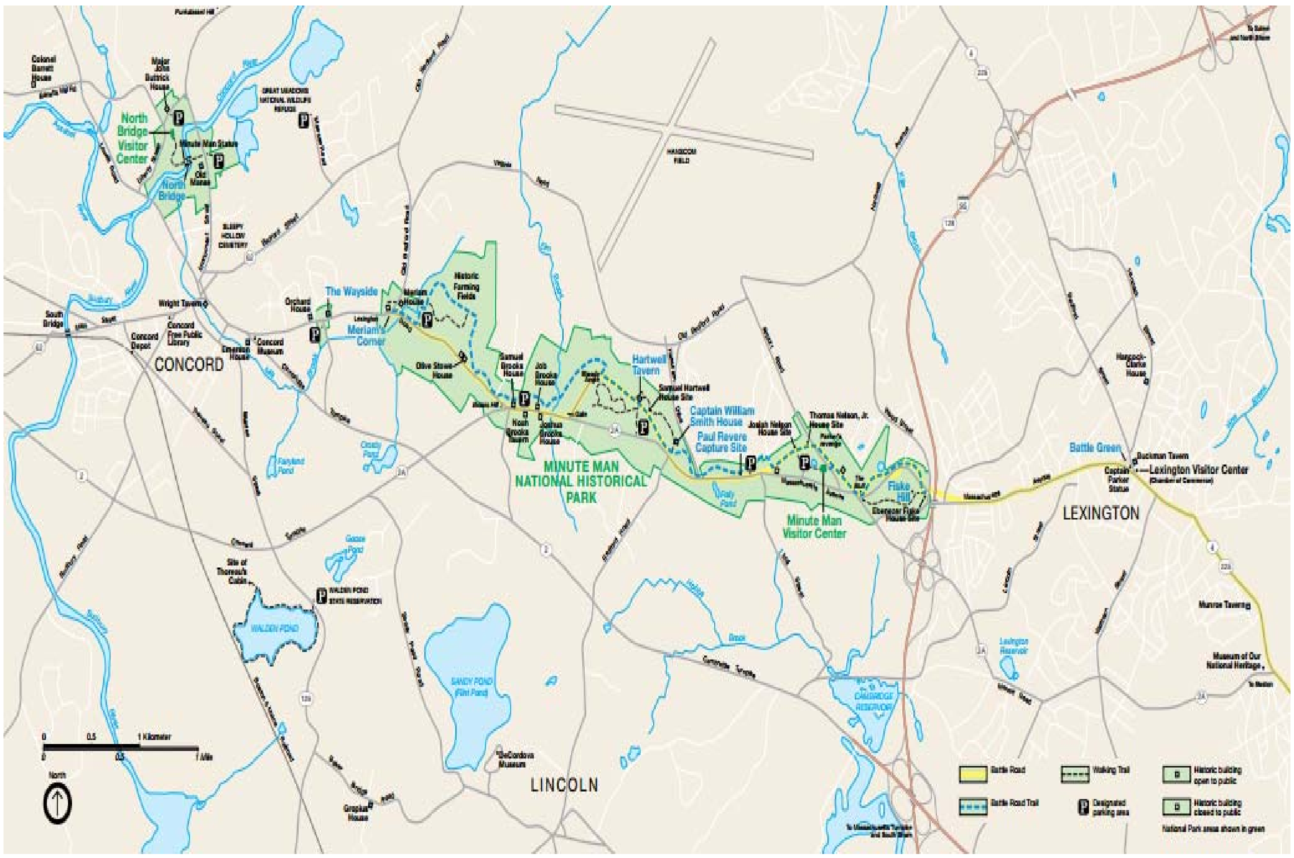



Figure 5.6 Map of Minute Man National Historical Park (NPS, Minute Man National Historical Park Maps)

**Natural Resource Condition Assessment:** Every few years, Minute Man 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 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 MIMA 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" (Figure 5.7). NETN threshold values for assessments from established monitoring programs (water quality monitoring) were used to estimate the condition of Minute Man'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 (Figure 5.7). The reliability and quality of data used to assess the condition were rated using three rating categories: "good," "satisfactory," and "limited" (Figure 5.7). 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 (Figure 5.8).

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) (Pirri, 2009).

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 1. Rating categories and numerical scores used in the assessment of condition, trend, and data reliability.

| 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) |

Figure 5.7 Assessment of Natural Resources in Minute Man National Historical Park (Pirri, 2009)

| | | | |
|---|---|---|---|
| **Current Condition:** | Water quality – Concord River, Elm Brook, Mill Brook | ● Significant concern | 0.16 |
| **Trend:** | Water quality | ↓ Declining trend | 0.16 |
| **Reliability:** | US EPA water quality assessment data | ● Good | 0.84 |

Figure 5.8 Condition Assessment Scores for Water Resources

**Northeast Temperate Network Summary Report:** The most recent water quality monitoring was conducted in 2013 at Minute Man 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 (Table 5.4). 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 5.4 Summary of Water Resources Condition Assessment in Minute Man National Historical Park

| **Water Quality Parameter** | **Reference Condition** | **Source** | **Results** |
|---|---|---|---|
| pH | 6.5-8.3 | MADEP, 2007 | All values were between the upper and lower Massachusetts water quality standards |
| DO | Min. 6 mg/L | MADEP, 2007 | Most measurements were above the standard except the June and July measurements from Mill Brook and July measurement from Concord River |
| Water Temperature | Max. 28.3°C (82.9°F)-warm water; 20°C (68°F)-cold water | MADEP, 2007 | Most measurements were within the standards except in July at Mill Brook and Elm Brook |
| ANC | >100 µeq/L= well-buffered < 0 µeq/L= acidic waters | Stoddard et al. 2003 | All values exceeded the standard |
| Turbidity | 0-10 NTU | EPA, 1999 | All values fall within this range |
| Nitrogen | 0.71 mg/L | EPA, 2000 | All but 1 value were above the criterion of 0.71 mg/L |
| Total phosphorus | 31.25 µg/L | EPA, 2000 | All values were above the criterion of 31.25µg/L |

Adapted from (Gawley et al., 2014))

## 5.5 First State National Historical Park

**Impaired Waters:** Beaver Creek, Talley Run, and Rocky Run are listed on the Draft Delaware Department of Natural Resources and Environmental Control (DNREC) 2014 Clean Water Act Section 303(d) for impaired habitat and biology (Figure 5.9). As a result, it is important to determine the root cause of these impairments, whether it is from land erosion, and heavy use of 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 305(b) Assessment and Methodology | 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 5.9 Draft Delaware Section 303d list of Impaired Streams (DNREC, 2014)

**Water Quality Standards Attainment:** The data (described in Chapter 4 of this paper) was compared with water quality standards for each of the 20 metrics (Table 5.1) to obtain the percent attainment and converted to the condition assessment for that metric. This was done using the methods described in 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. First State 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 Summary of Water Resources Condition 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 |
| Electrical Conductivity (EC) | µS | 150-500 | 84.1% | Very Good |
| Enterococci Bacteria | #/100mL | 925/100 | 71% | Good |

Adapted from (UD Water Resources Center, 2017)

Based on the chemical parameters monitored over the course of the testing period and the water quality standards found for each parameter, the overall results from this study indicate that there are little chemical impairments, no nutrient impairments, and possible bacterial impairments in the tributaries flowing into the Brandywine Creek (UD Water Resources Center, 2017).

There are a few tributaries in which our results have shown values close to the borderline of impaired waters. Beaver Creek at Route 202 has the highest conductivity values. It had an attainment of 0% for conductivity because all of the recorded observations fell above the (150-500µS) standard. The water quality of this stream may be affected due to its proximity to the 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. (UD Water Resources Center, 2017)

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 may help restore the water quality of unhealthy streams. (UD Water Resources Center, 2017)

Beaver Creek Mouth has the highest median pH value of 7.9 when compared to the other eleven sampling sites. Considering that both Beaver Creek North and South Forks also have higher mean pH values and that they converge into Beaver

Creek, the highest pH value may be a result of these two streams combining (UD Water Resources Center, 2017)

Talley Run had an attainment of 100% for all of the parameters except for turbidity. Talley Run had the second highest recorded turbidity reading out of the twelve sites. It 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 mentioned above, it has been suggested to plant native vegetation along roadways where there is little to no vegetation between the road and stream (UD Water Resources Center, 2017). Furthermore, as Beaver Creek, Talley Run and Rocky Run are currently listed as impaired for habitat and biology, implementing reforestation techniques along heavily eroded banks is recommended to prevent further degradation (UD Water Resources Center, 2017). Since the Brandywine State Park and First State National Historic Park contain many horse and agricultural farms, it is important that preventative measures are taken to prevent nutrient runoff and bacteria from further endangering the adjacent waterways. (UD Water Resources Center, 2017)

## 5.6 Comparative Analysis of Water Resources Management of Units in the National Park System

**Impaired Waterways:** All of the national historical parks, except Harpers Ferry, have waterways that are impaired. One of the two rivers that flow through Valley Forge is considered impaired by the state of Massachusetts. The Schuylkill River in Valley Forge is on the 303d list under the Clean Water Act and fails to meet water quality standards of the Pennsylvania Department of Environmental Protection. The water quality of rivers and creeks in Minute Man 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 the First State, Beaver Creek, Talley Run, and Rocky Run are listed on the Draft Delaware Department of Natural Resources and Environmental Control 2014 Clean Water Act Section 303(d) for impaired habitat and biology. The water quality of rivers and creeks in Harpers Ferry meet or exceed all applicable water quality standards.

**Water Quality Standards:** The 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. Valley Forge is required to follow federal and Pennsylvania state water quality regulations and Minute Man is required to follow federal and Massachusetts state water quality regulations. First State is required to follow federal and Delaware state water quality regulations. Harpers Ferry is required to follow federal and West Virginia state water quality regulations.

All four national historical parks follow similar standards for pH and DO. Valley Forge and Harpers Ferry follow the same standard for pH, and Harpers Ferry and Valley Forge follow similar standards for DO. All four national parks follow similar standards for water temperature; however, Harpers Ferry has the highest standard for temperature and Valley Forge has the lowest standard for temperature. Valley Forge and First State follow the same standard for alkalinity, while Minute Man and Harpers Ferry do not have a standard they are required to follow. Harpers Ferry, Valley Forge, and First State are required to meet nitrogen standard for domestic water supply (human health). Minute Man does not have water sources used for public water supply so it is not required to follow the same standard. All of the national historical parks are not required to follow the EPA Region Criteria for nitrogen, phosphorus, and turbidity as these are only suggested criterions and are non-regulatory. Harper's Ferry had the lowest recommended maximum value for nitrogen, followed by Valley Forge and First State and Minute Man. Harper's Ferry had the lowest recommended maximum value for phosphorus and turbidity, followed by Minute Man and Valley Forge and First State. Harpers Ferry, Valley Forge, and First State all follow similar standards for bacteria, while Minute Man does not follow a standard. Minute Man, Harpers Ferry and Valley Forge follow the same standard for TDS, while First State has a much lower standard it is required to meet. Minute Man, Harpers Ferry and Valley Forge follow the same standards for chloride, while First State does not follow a standard. Valley Forge and First State follow the same standard for alkalinity, while Minute Man and Harpers Ferry do not follow a standard.

**Water Quality Monitoring and Reporting:** Water quality monitoring and reporting is varied among the four national parks. Valley Forge is the only park to have released a State of the Park Report. This report is the most recent published report on the condition of water resources in the park. Valley Forge, Harpers Ferry, and Minute Man have released a Natural Resource Condition Assessment Report. Valley Forge and Harpers Ferry both released a Natural Resource Condition Assessment Report in 2013, which is the most recent Natural Resource Condition Assessment Report released by both parks. The most recent Natural Resource Condition Assessment Report for Minute Man was released in 2009. First State 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, twelve water quality parameters have been tested/sampled at all of the streams found in the park (Table 5.7). At Valley Forge, thirteen water quality parameters have been tested/sampled at all of streams found in the park (Table 5.7). At Harpers Ferry, nine water quality parameters have been tested/sampled at all of streams found in the park (Table 5.7). At First State 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-like 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 (Figures 5.3 and 5.7). Harpers Ferry, however, uses a slightly different method to evaluate the condition of its water resources. Harpers Ferry did not determine the trend and data reliability of the parks water resources. However, Harpers Ferry found the percent attainment, which was then converted to the condition assessment for each of the metrics (Figure 5.5). Although Harpers Ferry did not use traffic-like symbols to illustrate their results, a similar color scheme of red, yellow, and green was used to communicate the water resources condition (Figure 5.5).

Table 5.6 Water Quality Standards in Natural Park Units

| | **Minute Man National Historical Park** | **Harpers Ferry National Historical Park** | **Valley Forge National Historical Park** | **First State National Historical Park** |
|---|---|---|---|---|
| **Water Quality Parameter** | **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).<br>≥ 7.0 mg/L (Cold Water Fisheries and Exceptional Value Waters)[7] | Avg. ≥ 5.5 mg/L[9] |
| Water Temperature | ≤ 28.3°C (82.9°F)- warm water; ≤20°C (68°F)- cold water[1] | ≤ 30.56°C (87.0°F) May-Nov; ≤22.78 (73°F) Dec-Apr[6] | Max: 3.0 ≤ °C ≤ 19.0 (37.4 ≤ °F ≤ 66.2) [7] | Max. 82°F (27°C)[9] |
| Total Nitrogen | ≤ 0.71 mg/L[2] | ≤ 0.31 mg/L[4]<br>≤ 2 mg/L[13]<br>≤ 10 mg/L[5] | ≤ 0.69 mg/L[8]<br><br>≤ 10 mg/L[5] | ≤ 0.69 mg/L [10]<br><br>≤ 10 mg/L[5] |
| Total phosphorus | ≤ 31.25 µg/L[2] | ≤ 0.01mg/L[4] | ≤ 36.56 µg/L[8]<br>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]<br><br>≤10 NTU's[6] | ≤ 5.7 FTU[8]<br><br>≤10 NTU[7] | ≤ 5.7 FTU[11]<br><br>≤ 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]<br>Min. 140 mg/L[12] | ≥ 20 mg/L as CaCO3. [9] |

[1] Massachusetts Department of Environmental Protection (2007),[2] EPA (2000), [3] State of West Virginia (2011), [4] EPA Region XI Nutrient Criteria, [5] EPA Criteria for Human Health Protection, [6] State of West Virginia (2008) [7] PA Code (2001), [8] EPA Region IX Nutrient Criteria, [9]EPA State of Delaware Surface Water Quality Standards, [10] EPA Region IX Nutrient Criteria, [11]Abrams and Jarrell (1995), Correll (1998), [12]Botts (2005), [13]MBSS

Table 5.7 Reporting and Water Quality Parameters of NPS 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., specific conductance, alkalinity, TDS, ammonia, chloride, nitrite/nitrate, phosphorus, pH, DO, boron, and macroinvertebrate and fish sampling |
| Minute Man | | ✓ | Specific conductance, DOC, bacteria, turbidity, total nitrogen, total phosphorus, water temp., DO, pH, and ANC, chloride, and sulfate |
| Harpers Ferry | | ✓ | pH, DO, water temperature, ANC, salinity/specific conductance, nitrate, total phosphorus, Benthic Index of Biotic Integrity, and Physical Habitat Index |

**Approaches to Water Resources Management:** 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'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 embraces the belief that their mission and message is strengthened through the collaborative efforts of many park partners (NPS, 2007). In Valley Forge, 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 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 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 states that river banks will be stabilized and degraded sections of the streams restored within the national historical park (NPS, 2008).

At Minute Man, staff and employees have partnerships 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.

The First State 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 UD Water Resources Center, Mt. Cuba Center, The Conservation Fund, and The Nature Conservancy.

### 5.7 Summary

This chapter has provided an overview of water resources information contained in 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 the condition of water resources, methods of reporting, water quality standards, approaches to water resources management 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

The previous chapters in this thesis successively describe the policies and management of water resources of the NPS, focusing specifically on First State. This thesis begins with an overview of the NPS, which describes the NPS's mission, history, organizational structure, and laws and policies of managing water resources. An overview of the First State and its history and physical characteristics are explained. Water resources information contained in the UD Water Resources Center water quality monitoring report of First State are also discussed. Lastly, this research compares the structures, programs, monitoring, water quality standards, reporting, and approach to water resources management of First State to Valley Forge, Harpers Ferry, and Minute Man National Historical Parks. Valley Forge, Harpers Ferry, and Minute Man were chosen based on their classification as a historical park, they are similar in size to First State, and are located in the Northeastern United States. Overall, this research sought to understand the policies and management of water resources within the NPS, specifically that of the First State and other similar national historical parks.

## 6.2 Conclusions

It must be explicitly stated that the findings from this research may not be representative of all of the sites managed by the NPS, other national historical park sites, or other national park sites located same states as the national historical parks discussed in this research. The policies and approaches to water resources management often vary among national park sites due to location, size, status, and history.

This research of the NPS and First State, Valley Forge, Harpers Ferry, and Minute Man National Historical Parks offers the following conclusions:

**1. NPS:** Established in 1916, the NPS, located in the United States Department of the Interior, is responsible for managing over 400 areas covering more than 84 million acres that contain 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 NPS 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 NPS Inventory and Monitoring Program that are responsible for the inventory of natural resources under NPS 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. The Natural Resource Condition Assessment will assist 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 400$^{th}$ unit of the National Park System and first unit of the National Park System in the state of

Delaware, First State contains 7 units that tell the story of Delaware's early settlement and role of being the first state to ratify the constitution. The Beaver Valley unit of First State contains 6 sub-watersheds of the Brandywine Piedmont Watershed that capture a drainage area of 4,485 acres/7.0 $mi^2$. 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, UD Water Resources Center students and interns conducted a water sampling project at tributaries of Brandywine Piedmont Watershed in First State. Water quality sampling was conducted at twelve sites located in six sub-watersheds 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 only tested for conductivity and turbidity. Water quality testing in First State National Historical Park indicates that standards are met for pH, temperature, and DO, but there are concerns for high turbidity, conductivity, and Enterococci bacteria levels in headwater streams.

**4. Water Resources Management and Policies of the NPS:** How the results and findings are communicated in 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 was displayed pictorially using traffic 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. Harpers Ferry, however, used a slightly different method to evaluate the condition of its water resources. Harpers Ferry found the percent attainment, which was then converted to the condition assessment for each of the water quality metrics. Harpers Ferry did not use traffic-like symbols to illustrate their results, although a similar color scheme of red, yellow, and green was used to communicate the water resources condition. The 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 historical parks. Valley Forge is required to follow federal and Pennsylvania state water quality regulations, Minute Man is required to follow federal and Massachusetts state water quality regulations, First State is required to follow federal and Delaware state water quality regulations, and Harpers Ferry is required to follow federal and West Virginia state water quality regulations.

### 6.3 Recommendations for Future Research

Data collection and conclusions acquired through this research yield the following recommendations for future studies in the areas of governance and policy of units in the National Park System:

**1. Water Quality Criteria:** First State has yet to complete a general management plan and natural resource condition assessment. First State should manage its water resources similarly to Valley Forge, Minute Man and Harpers Ferry National Historical Parks. These historical parks have the same designation as a historical park to First State, and are similar in size and physiographic province, so they provide an excellent point of reference of how First State should manage its water resources.

**2. Condition Assessments:** First State 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, 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. 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:** I suggest that First State 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 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:** I suggest providing recommendations for Best Management Practices in First State. From my analysis in Chapter 3, sampling sites located at the mouths of the tributaries have better water quality compared to sampling sites located at the headwaters of the tributaries. This is due to increased forested areas, which act as a buffer to filter out pollutants from entering the stream. Therefore, Best Management Practices should include reforestation throughout the watershed, and establishing stream buffers in the headwaters of the tributaries, near residential and urban areas outside the historical park's boundaries.

**5. Streamline NPS Reporting Framework:** The framework of reporting water resources information varies among the historical parks discussed in this thesis. The methods of determining water quality condition and how water quality condition is displayed in State of the Park Reports and Natural Resource Condition Assessments vary among the historical parks. It would be beneficial for the NPS 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 NPS units. This would be valuable to future researchers carrying out any analyses of similar in nature within units of the NPS.

**6. Revise NPS Waterbody Designation/Water Quality Standards:** The National Park Service is required to follow state water quality standards under the Clean Water Act. There are various levels of designated uses for aquatic life and these designations 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 Fishes streams require the minimum amount of protection in order to sustain their designated use, and Exceptional Value streams require the maximum amount of protection to sustain their designated use (Clark, 2011). In both 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 partly based on the designated uses of a water body. The designated uses of streams in the historical parks discussed in this thesis vary. Valley Forge has one stream designated an exceptional value waterway, and one stream designated a migratory fishes waterbody. The other historical parks discussed in this thesis include waterbodies designated as warm water fishes and cold water fishes. I believe that waterbodies contained in areas managed by the NPS should hold a higher than minimum designation. Lands managed by the NPS represent the most spectacular places of high cultural, historical, and environmental worth. Therefore, I believe that they should have higher designations and in turn, follow stricter water quality standards. I suggest that park units apply for 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 NPS unit boundaries, they are affected by activities and development occurring outside of NPS lands. Although higher designations and stricter water quality standards would allow for increased long term protection of water resources in NPS units, it would require stricter water quality standards and regulations that many people would not support. Therefore, realistically, the NPS 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. How the Interior secretary would distribute the 12 percent 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 NPS managers and employees to maintain park facilities and operations. It could also reduce the monitoring of natural resources and delay restoration projects in units of the National Park System. Therefore, it is recommended that First State 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. Augment the Study Area:** 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 and complete understanding of differences in water resources management of NPS units throughout the United States.

**9. Expand Analysis of Water Resources Policies and Management in National Historical Parks:**

The comparison of water resources policies and management in Chapter 5 is focused on water quality. It could be beneficial to expand the topic of water resources to include water quantity/stream flow, wetlands, groundwater, and stream restoration. Information on stream restoration projects that have been completed at the national historical parks discussed in this research and if/why these projects were successful could be researched in the future. This information could be particularly useful to park managers and employees at First State as they continue the planning process and begin to write a general management plan. It could also provide information to managers and employees on strategies to effectively improve the health of streams in First State.

**10. Interview Park Managers, Employees, and Visitors of National Historical Parks**

The information contained in this paper is limited to what is available online. Due to time and resource constraints, visiting each of the national historical parks discussed in this research and meeting with managers and employees at each of these historical parks was not possible. In order to get a more accurate understanding of the approaches to water resources management in these 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 park's 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 graphs and figures in the 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 DATA OF BRANDYWINE CREEK TRIBUTARIES

| | Site 1 | Site 2 | Site 3 | Site 4 | Site 5 | Site 6 | Site 7 | Site 8 | Site 9 | Site 10 | Site 11 | Site 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** |
| 23-Jun | 25.5 | 21.9 | 21.7 | 22.0 | 20.1 | 20.4 | 18.8 | 21.8 | 21.7 | 24.8 | 23.9 | 22.2 |
| 30-Jun | 22.5 | 19.9 | 19.2 | 19.0 | 18.7 | 19.1 | 17.7 | 19.3 | 20.3 | 21.5 | 21.2 | 19.8 |
| 6-Jul | 22.7 | 20.0 | 19.8 | 19.9 | 18.5 | 18.9 | 17.8 | 20.0 | 19.5 | 22.3 | 21.9 | 20.2 |
| 13-Jul | 23.1 | 20.4 | 20.4 | 20.9 | 19.0 | 19.2 | 18.1 | 20.1 | 19.6 | 22.9 | 21.5 | 20.6 |
| 20-Jul | 26.3 | 23.1 | 22.7 | 22.7 | 21.3 | 21.4 | 19.2 | 21.9 | 21.7 | 24.3 | 23.7 | 22.3 |
| 28-Jul | 24.5 | 21.2 | 21.2 | 21.3 | 19.9 | 19.7 | 19.0 | 21.3 | 21.5 | 23.1 | 23.0 | 21.5 |
| 9-Oct | 19.4 | 16.9 | 17.5 | 17.5 | 17.8 | 17.9 | 17.1 | 18.4 | | 19.6 | 18.3 | 17.8 |
| 23-Oct | 15.4 | 12.6 | 13.1 | 11.6 | 13.3 | 14.0 | 12.5 | 13.2 | 13.3 | 13.1 | 13.3 | 13.3 |
| 6-Nov | 17.1 | 16.6 | 17.6 | 15.9 | 17.0 | 16.9 | 16.4 | 17.0 | 17.7 | 18.0 | 16.7 | 16.5 |
| 13-Nov | 13.4 | 11.2 | 13.1 | 11.4 | 11.3 | 11.9 | 11.7 | 11.7 | 12.0 | 11.4 | 12.4 | 11.9 |
| 4-Dec | 9.7 | 7.3 | 9.5 | 7.6 | 8.1 | 8.9 | 9.1 | 8.9 | 8.9 | 8.3 | 9.2 | 8.9 |
| | | | | | | | | | | | | |
| | **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** |
| **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 |
| | | | | | | | | | | | | |
| **Q1-Min** | 6.55 | 7.3 | 5.8 | 6.15 | 7.05 | 6.55 | 5.35 | 6.2 | 5.5 | 7.25 | 5.8 | 6 |
| | **Ridge Run** | **Beaver Creek Mout** | **North Fork Beaver Run** | **South Fork Beav** | **Talley Run** | **Ramsey Run** | **Carney Run** | **Rocky Run Mouth** | **Hurricane Run** | **Rocky Run @** | **Beaver Creek @ Rt. 202** | **Rocky Run Residential** |

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | h | | er Run | | | | | | Rt. 202 | | |
| **Q1** | 16.3 | 14.6 | 15.3 | 13.8 | 15.2 | 15.5 | 14.5 | 15.1 | 14.4 | 15.6 | 15.0 | 14.9 |
| **Med-Q1** | 6.3 | 5.3 | 3.9 | 5.3 | 3.4 | 3.5 | 3.3 | 4.2 | 5.2 | 6.0 | 6.2 | 4.9 |
| **Q3-Med** | 1.3 | 0.9 | 1.6 | 2.1 | 0.9 | 0.6 | 0.8 | 1.4 | 1.7 | 1.5 | 1.3 | 1.3 |
| **Max-Q3** | 2.5 | 2.3 | 1.9 | 1.6 | 1.9 | 2.0 | 0.7 | 1.2 | 0.5 | 1.8 | 1.5 | 1.3 |
| | | | | | | | | | | | | |
| | **Carney Run** | **Talley Run** | **Rams ey Run** | **Sout h Fork Beav er Run** | **Nort h Fork Beav er Run** | **Rocky Run Mouth** | **Hurrica ne Run** | **Rocky Run Resident ial** | **Beaver Creek Mouth** | **Beav er Cree k @ Rt. 202** | **Rocky Run @ Rt. 202** | **Ridge Run** |
| **Min** | 9.1 | 8.1 | 8.9 | 7.6 | 9.5 | 8.9 | 8.9 | 8.9 | 7.3 | 9.2 | 8.3 | 9.7 |
| **25th Per.** | 14.5 | 15.2 | 15.5 | 13.8 | 15.3 | 15.1 | 14.4 | 14.9 | 14.6 | 15.0 | 15.6 | 16.3 |
| **Median** | 17.7 | 18.5 | 18.9 | 19.0 | 19.2 | 19.3 | 19.6 | 19.8 | 19.9 | 21.2 | 21.5 | 22.5 |
| **75th Per.** | 18.5 | 19.5 | 19.5 | 21.1 | 20.8 | 20.7 | 21.2 | 21.1 | 20.8 | 22.5 | 23.0 | 23.8 |
| **Max** | 19.2 | 21.3 | 21.4 | 22.7 | 22.7 | 21.9 | 21.7 | 22.3 | 23.1 | 23.9 | 24.8 | 26.3 |
| | | | | | | | | | | | | |
| **Q1-Min** | 5.35 | 7.05 | 6.55 | 6.15 | 5.8 | 6.2 | 5.5 | 6 | 7.3 | 5.8 | 7.25 | 6.55 |
| | **Carney Run** | **Talley Run** | **Rams ey Run** | **Sout h Fork Beav er Run** | **Nort h Fork Beav er Run** | **Rocky Run Mouth** | **Hurrica ne Run** | **Rocky Run Resident ial** | **Beaver Creek Mouth** | **Beav er Cree k @ Rt. 202** | **Rocky Run @ Rt. 202** | **Ridge Run** |
| **Q1** | 14.5 | 15.2 | 15.5 | 13.8 | 15.3 | 15.1 | 14.4 | 14.9 | 14.6 | 15.0 | 15.6 | 16.3 |
| **Med-Q1** | 3.3 | 3.4 | 3.5 | 5.3 | 3.9 | 4.2 | 5.2 | 4.9 | 5.3 | 6.2 | 6.0 | 6.3 |
| **Q3-Med** | 0.8 | 0.9 | 0.6 | 2.1 | 1.6 | 1.4 | 1.7 | 1.3 | 0.9 | 1.3 | 1.5 | 1.3 |
| **Max-Q3** | 0.7 | 1.9 | 2.0 | 1.6 | 1.9 | 1.2 | 0.5 | 1.3 | 2.3 | 1.5 | 1.8 | 2.5 |
| | | | | | | | | | | | | |
| **Site 7** | **Site 5** | **Site 6** | **Site 4** | **Site 2** | **Site 8** | **Site 12** | **Site 3** | **Site 11** | **Site 10** | **Site 1** | **Site 9** | |
| **Carney Run** | **Talley Run** | **Rams ey Run** | **South Fork Beave r Run** | **Beav er Cree k Mout h** | **Rock y Run Mout h** | **Rocky Run Resident ial** | **North Fork Beaver Run** | **Beaver Creek @ Rt. 202** | **Rocky Run @ Rt. 202** | **Ridg e Run** | **Hurrica ne Run** | **DATE** |
| 16.1 | 16.8 | 17.1 | 17.3 | 17.4 | 17.6 | 17.7 | 17.8 | 18.6 | 19.0 | 20.0 | 20.7 | AVERAG ES |

## Appendix B

## PH DATA OF BRANDYWINE CREEK TRIBUTARIES

| | **Site 1** | **Site 2** | **Site 3** | **Site 4** | **Site 5** | **Site 6** | **Site 7** | **Site 8** | **Site 9** | **Site 10** | **Site 11** | **Site 12** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **DATE** | **Ridge Run** | **Beave r Creek Mouth** | **North Fork Beaver Run** | **South Fork Beave r Run** | **Talley Run** | **Ramse y Run** | **Carne y Run** | **Rocky Run Mouth** | **Hurrica ne Run** | **Rocky Run @ Rt. 202** | **Beave r Creek @ Rt. 202** | **Rocky Run Residentia l** |
| 23-Jun | 7.7 | 7.8 | 7.6 | 7.7 | 7.4 | 7.3 | 7.3 | 7.7 | 7.5 | 7.1 | 7.2 | 7 |
| 30-Jun | 7.7 | 7.8 | 7.6 | 7.7 | 7.5 | 7.6 | 7.6 | 7.7 | 7.4 | 7.2 | 7.3 | 6.9 |
| 6-Jul | 7.7 | 7.6 | 7.6 | 7.7 | 7.6 | 7.4 | 7.5 | 7.4 | 6.9 | 6.8 | 7.2 | 7 |
| 13-Jul | 7.8 | 7.9 | 7.7 | 7.7 | 7.5 | 7.5 | 7.5 | 7.7 | 7.6 | 7.2 | 7.2 | 7.2 |
| 20-Jul | 7.8 | 8.1 | 7.6 | 7.9 | 7.6 | 7.4 | 7.7 | 7.7 | 7.4 | 6.8 | 7.3 | 7 |
| 28-Jul | 7.8 | 7.9 | 7.7 | 7.6 | 7.6 | 7.4 | 7.5 | 7.6 | 7.4 | 7 | 7.4 | 6.8 |
| 9-Oct | 7.7 | 7.6 | 8.7 | 8.6 | 7.3 | 7.5 | 7.4 | 7.6 | | 7.2 | 7.5 | 6.8 |
| 23-Oct | 7.6 | 8 | 7.7 | 7.7 | 7.6 | 7.4 | 7.4 | 7.6 | 7.5 | 7.2 | 7.5 | 7.4 |
| 6-Nov | 7.7 | 8.1 | 7.6 | 7.8 | 7.8 | 7.9 | 7.9 | 7.9 | 7.5 | 7.2 | 7.6 | 7 |
| 13-Nov | 7.7 | 8.1 | 7.8 | 7.9 | 7.5 | 7.3 | 7.5 | 7.8 | 7.5 | 7 | 7.2 | 7.6 |
| 4-Dec | 7.6 | 8 | 7.7 | 7.9 | 7.2 | 7.2 | 7.3 | 7.7 | 7.4 | 6.9 | 7.2 | 6.9 |
| **AVERAG ES** | 7.7 | 7.9 | 7.7 | 7.8 | 7.5 | 7.4 | 7.5 | 7.6 | 7.3 | 7.0 | 7.3 | 7.0 |
| | | | | | | | | | | | | |
| **Site 10** | **Site 12** | **Site 11** | **Site 9** | **Site 6** | **Site 7** | **Site 5** | **Site 8** | **Site 1** | **Site 3** | **Site 4** | **Site 2** | |
| **Rocky Run @ Rt. 202** | **Rocky Run Residenti al** | **Beave r Creek @ Rt. 202** | **Hurrica ne Run** | **Ramse y Run** | **Carney Run** | **Talley Run** | **Rocky Run Mouth** | **Ridge Run** | **North Fork Beaver Run** | **South Fork Beave r Run** | **Beave r Creek Mouth** | **DATE** |
| 7.04166667 | 7.0 | 7.3 | 7.3 | 7.4 | 7.4 | 7.4 | 7.6 | 7.6 | 7.7 | 7.7 | 7.8 | AVERAG ES |
| | | | | | | | | | | | | |
| **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 |
| | | | | | | | | | | | | |

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Q1-Min** | 0.1 | 0.2 | 0 | 0.1 | 0.25 | 0.15 | 0.1 | 0.2 | 0.5 | 0.15 | 0 | 0.1 |
| | **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** |
| **Q1** | 7.6 | 7.7 | 7.6 | 7.6 | 7.3 | 7.2 | 7.3 | 7.6 | 7.38 | 6.9 | 7.2 | 6.9 |
| **Med-Q1** | 0 | 0.1 | 0.1 | 0 | 0.05 | 0.05 | 0.1 | 0.1 | 0.05 | 0.15 | 0.1 | 0.1 |
| **Q3-Med** | 0.05 | 0.15 | 0 | 0.2 | 0.1 | 0.1 | 0.05 | 0 | 0.05 | 0.1 | 0.15 | 0.1 |
| **Max-Q3** | 0.05 | 0.05 | 1 | 0.7 | 0.2 | 0.4 | 0.3 | 0.2 | 0.1 | 0 | 0.15 | 0.5 |
| | | | | | | | | | | | | |
| | **Rocky Run Residential** | **Rocky Run @ Rt. 202** | **Beaver Creek @ Rt. 202** | **Ramsey Run** | **Hurricane Run** | **Carney Run** | **Talley Run** | **Ridge Run** | **North Fork Beaver Run** | **South Fork Beaver Run** | **Rocky Run Mouth** | **Beaver Creek Mouth** |
| **Min** | 6.8 | 6.8 | 7.2 | 7.2 | 6.9 | 7.3 | 7.2 | 7.6 | 7.6 | 7.6 | 7.4 | 7.6 |
| **25th Per.** | 6.9 | 6.95 | 7.2 | 7.35 | 7.4 | 7.4 | 7.45 | 7.7 | 7.6 | 7.7 | 7.6 | 7.8 |
| **Median** | 7 | 7.1 | 7.3 | 7.4 | 7.45 | 7.5 | 7.5 | 7.7 | 7.7 | 7.7 | 7.7 | 7.9 |
| **75th Per.** | 7.1 | 7.2 | 7.45 | 7.5 | 7.5 | 7.55 | 7.6 | 7.75 | 7.7 | 7.9 | 7.7 | 8.05 |
| **Max** | 7.6 | 7.2 | 7.6 | 7.9 | 7.6 | 7.9 | 7.8 | 7.8 | 8.7 | 8.6 | 7.9 | 8.1 |
| | | | | | | | | | | | | |
| **Q1-Min** | 0.1 | 0.1 | 0 | 0.1 | 0.5 | 0.1 | 0.2 | 0.1 | 0 | 0.1 | 0.2 | 0.2 |
| | **Rocky Run Residential** | **Rocky Run @ Rt. 202** | **Beaver Creek @ Rt. 202** | **Ramsey Run** | **Hurricane Run** | **Carney Run** | **Talley Run** | **Ridge Run** | **North Fork Beaver Run** | **South Fork Beaver Run** | **Rocky Run Mouth** | **Beaver Creek Mouth** |
| **Q1** | 6.9 | 6.9 | 7.2 | 7.2 | 7.3 | 7.3 | 7.3 | 7.6 | 7.6 | 7.6 | 7.6 | 7.7 |
| **Med-Q1** | 0.1 | 0.15 | 0.1 | 0.05 | 0.05 | 0.1 | 0.05 | 0 | 0.1 | 0 | 0.1 | 0.1 |
| **Q3-Med** | 0.1 | 0.1 | 0.1 | 0.1 | 0.05 | 0.05 | 0.1 | 0.05 | 0 | 0.2 | 0 | 0.1 |
| **Max-Q3** | 0.5 | 0 | 0.1 | 0.4 | 0.1 | 0.35 | 0.2 | 0.05 | 1 | 0.7 | 0.2 | 0.05 |

# Appendix C

## TURBIDITY DATA OF BRANDYWINE CREEK TRIBUTARIES

| | **Site 8** | **Site 4** | **Site 9** | **Site 6** | **Site 5** | **Site 1** | **Site 3** | **Site 2** | **Site 11** | **Site 7** | **site 10** | **Site 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** |
| 30-Jun-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 |
| 20-Jul-15 | 0.814 | 1.79 | 1.07 | 1.77 | 1.86 | 2.83 | 3.09 | 5.62 | 2.71 | 4.82 | 4.18 | 10.8 |
| 4-Mar-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 |
| 21-Mar-16 | 0.75 | 0.42 | 0.62 | 0.73 | 0.75 | 3.45 | 1.24 | 0.6 | 1.98 | 9.92 | | |
| 8-Apr-16 | 0.19 | 0.36 | 0.39 | 0.82 | 1.17 | 0.75 | 0.72 | 1 | 1.78 | 2.64 | | 9.8 |
| 22-Jun-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 |
| 29-Jun-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 |
| 13-Jul-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 |
| 20-Jul-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 |
| 27-Jul-16 | 17.61 | 1.19 | 1.45 | 3.63 | 5.07 | 2.72 | 4.2 | 1.03 | 2.69 | 1.4 | 6.53 | 12.16 |
| 3-Aug-16 | 6.62 | 4.37 | 0.6 | | 4.48 | 2.64 | 1.55 | 0.6 | 1.9 | 4.35 | 5.1 | 2.7 |
| 10-Oct-16 | 1.24 | 0.96 | 2.08 | 7.62 | 13.52 | 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.** | 0.705 | 0.405 | 0.615 | 1.42 | 1.845 | 2.5825 | 1.4425 | 0.8775 | 1.9875 | 4.3075 | 3.9325 | 2.75 |
| **Median** | 0.847 | 0.839 | 1.155 | 2.36 | 4.12 | 2.745 | 1.835 | 1.13 | 2.7 | 5.08 | 5.245 | 7.53 |
| **75th** | 1.135 | 1.0175 | 1.75 | 2.99 | 5.0 | 2.9 | 2.97 | 1.6425 | 4.4725 | 6.98 | 6.3025 | 9.615 |

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Per.** | | | | | 325 | 425 | | | | | | |
| **Max** | 17.61 | 4.37 | 3.9 | 7.62 | 13.52 | 3.45 | 4.2 | 5.62 | 8.56 | 9.92 | 9.67 | 12.16 |
| | | | | | | | | | | | | |
| **Q1-Min** | 0.585 | 0.315 | 0.225 | 0.69 | 1.095 | 1.8325 | 0.7225 | 0.2775 | 0.2075 | 2.9075 | 2.7025 | 0.71 |
| | | | | | | | | | | | | |
| **Q1** | 0.705 | 0.405 | 0.615 | 1.42 | 1.845 | 2.5825 | 1.4425 | 0.8775 | 1.9875 | 4.3075 | 3.9325 | 2.75 |
| **Med-Q1** | 0.142 | 0.434 | 0.54 | 0.94 | 2.275 | 0.1625 | 0.3925 | 0.2525 | 0.7125 | 0.7725 | 1.3125 | 4.78 |
| **Q3-Med** | 0.288 | 0.1785 | 0.595 | 0.63 | 0.9125 | 0.1975 | 1.135 | 0.5125 | 1.7725 | 1.9 | 1.0575 | 2.085 |
| **Max-Q3** | 16.475 | 3.3525 | 2.15 | 4.63 | 8.4875 | 0.5075 | 1.23 | 3.9775 | 4.0875 | 2.94 | 3.3675 | 2.545 |
| | | | | | | | | | | | | |
| | | | | | | | | | | | | |
| **Min** | 0.09 | 0.12 | 0.6 | 0.39 | 0.72 | 0.73 | 1.78 | 0.75 | 0.75 | 1.4 | 1.23 | 2.04 |
| **25th Per.** | 0.405 | 0.705 | 0.8775 | 0.615 | 1.4425 | 1.42 | 1.9875 | 2.5825 | 1.845 | 4.3075 | 3.9325 | 2.75 |
| **Median** | 0.839 | 0.847 | 1.13 | 1.155 | 1.835 | 2.36 | 2.7 | 2.745 | 4.12 | 5.08 | 5.245 | 7.53 |
| **75th Per.** | 1.0175 | 1.135 | 1.6425 | 1.75 | 2.97 | 2.99 | 4.4725 | 2.9425 | 5.0325 | 6.98 | 6.3025 | 9.615 |
| **Max** | 4.37 | 17.61 | 5.62 | 3.9 | 4.2 | 7.62 | 8.56 | 3.45 | 13.52 | 9.92 | 9.67 | 12.16 |
| | | | | | | | | | | | | |
| **Q1-Min** | 0.315 | 0.585 | 0.2775 | 0.225 | 0.7225 | 0.69 | 0.2075 | 1.8325 | 1.095 | 2.9075 | 2.7025 | 0.71 |
| | **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** |
| **Q1** | 0.405 | 0.705 | 0.8775 | 0.615 | 1.4425 | 1.42 | 1.9875 | 2.5825 | 1.845 | 4.3075 | 3.9325 | 2.75 |
| **Med-Q1** | 0.434 | 0.142 | 0.2525 | 0.54 | 0.3925 | 0.94 | 0.7125 | 0.1625 | 2.275 | 0.7725 | 1.3125 | 4.78 |
| **Q3-Med** | 0.1785 | 0.288 | 0.5125 | 0.595 | 1.135 | 0.63 | 1.7725 | 0.1975 | 0.9125 | 1.9 | 1.0575 | 2.085 |
| **Max-Q3** | 3.3525 | 16.475 | 3.9775 | 2.15 | 1.23 | 4.63 | 4.0875 | 0.5075 | 8.4875 | 2.94 | 3.3675 | 2.545 |

# Appendix D

## DISSOLVED OXYGEN OF BRANDYWINE CREEK TRIBUTARIES

| | **Site 1** | **Site 2** | **Site 3** | **Site 4** | **Site 5** | **Site 6** | **Site 7** | **Site 8** | **Site 9** | **Site 10** | **Site 11** | **Site 12** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **DATE** | **Ridge Run** | **Beaver Creek Mouth** | **North Fork Beaver Run** | **South Fork Beave r Run** | **Talle y Run** | **Ramse y Run** | **Carne y Run** | **Rocky Run Mout h** | **Hurrican e Run** | **Rocky Run @ Rt. 202** | **Beave r Creek @ Rt. 202** | **Rocky Run Residential** |
| 23-Jun | 8.1 | 9.6 | 7.0 | 8.9 | 7.7 | 9.7 | 10.5 | 10.4 | 8.8 | 9.3 | 7.6 | 8.8 |
| 30-Jun | 7.8 | 10.2 | 10.1 | 8.6 | 9.7 | 10.1 | 11.0 | 8.0 | 8.0 | 9.6 | 7.3 | 7.7 |
| 6-Jul | 8.2 | 9.3 | 8.7 | 9.5 | 9.0 | 9.5 | 9.9 | 8.5 | 8.6 | 5.5 | 9.2 | 9.9 |
| 13-Jul | 8.2 | 7.6 | 9.0 | 7.8 | 6.0 | 8.2 | 7.2 | 6.0 | 8.8 | 15.8 | 7.0 | 8.5 |
| 20-Jul | 10.4 | 10.2 | 9.9 | 10.0 | 8.9 | 9.3 | 10.9 | 8.7 | 7.0 | 5.7 | 8.8 | 6.0 |
| 28-Jul | 8.0 | 9.1 | 7.0 | 5.2 | 6.6 | 7.1 | 9.0 | 8.4 | 6.0 | 5.9 | 6.0 | 7.8 |
| 9-Oct | 8.4 | 9.3 | 8.3 | 8.4 | 8.6 | 7.7 | 8.8 | 9.8 | | 8.6 | 7.0 | 6.2 |
| 23-Oct | 9.5 | 10.0 | 9.5 | 8.7 | 8.6 | 8.8 | 8.1 | 12.1 | 8.0 | 9.8 | 7.0 | 7.9 |
| 6-Nov | 9.0 | 11.0 | 6.8 | 10.1 | 7.5 | 7.2 | 9.2 | 10.9 | 8.3 | 7.1 | 6.8 | 4.7 |
| 13-Nov | 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 |
| | | | | | | | | | | | | |
| **Site 12** | **Site 11** | **Site 9** | **Site 5** | **Site 3** | **Site 10** | **Site 1** | **Site 6** | **Site 4** | **Site 8** | **Site 7** | **Site 2** | |
| **Rocky Run Residential** | **Beave r Creek @ Rt. 202** | **Hurrican e Run** | **Talley Run** | **North Fork Beave r Run** | **Rock y Run @ Rt. 202** | **Ridge Run** | **Ramse y Run** | **South Fork Beave r Run** | **Rocky Run Mouth** | **Carne y Run** | **Beave r Creek Mouth** | **DATE** |
| 7.5 | 7.7 | 7.9 | 8.3 | 8.5 | 8.8 | 8.8 | 8.9 | 9.1 | 9.5 | 9.6 | 9.9 | AVERAGES |
| | | | | | | | | | | | | |
| **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 |

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Q1-Min** | 0.3 | 1.7 | 0.5 | 3.3 | 1.6 | 0.7 | 1.7 | 2.4 | 2.0 | 0.7 | 1.0 | 1.9 |
| | **Ridge Run** | **Beaver Creek Mouth** | **North Fork Beaver Run** | **South Fork Beave r Run** | **Talle y Run** | **Ramse y Run** | **Carne y Run** | **Rocky Run Mout h** | **Hurrican e Run** | **Rocky Run @ Rt. 202** | **Beave r Creek @ Rt. 202** | **Rocky Run Residential** |
| **Q1** | 8.1 | 9.3 | 7.3 | 8.5 | 7.6 | 7.8 | 8.9 | 8.4 | 8.0 | 6.2 | 7.0 | 6.6 |
| **Med-Q1** | 0.2 | 0.5 | 1.4 | 0.4 | 1.1 | 1.2 | 0.7 | 0.8 | 0.3 | 2.8 | 0.2 | 1.2 |
| **Q3-Med** | 1.1 | 0.4 | 0.6 | 1.1 | 0.4 | 0.6 | 1.3 | 1.5 | 0.5 | 0.8 | 1.4 | 0.6 |
| **Max-Q3** | 1.0 | 2.8 | 0.7 | 3.4 | 1.3 | 1.6 | 0.4 | 1.3 | 2.1 | 6.1 | 1.3 | 1.6 |
| | | | | | | | | | | | | |
| | | | | | | | | | | | | |
| **Min** | 6.0 | 4.7 | 6.0 | 7.8 | 6.0 | 6.8 | 5.2 | 5.5 | 7.1 | 6.0 | 7.2 | 7.6 |
| **25th Per.** | 7.0 | 6.6 | 8.0 | 8.1 | 7.6 | 7.3 | 8.5 | 6.2 | 7.8 | 8.4 | 8.9 | 9.3 |
| **Median** | 7.2 | 7.8 | 8.3 | 8.3 | 8.6 | 8.8 | 8.8 | 9.0 | 9.1 | 9.3 | 9.6 | 9.8 |
| **75th Per.** | 8.5 | 8.4 | 8.8 | 9.4 | 9.0 | 9.4 | 9.9 | 9.8 | 9.7 | 10.8 | 10.8 | 10.2 |
| **Max** | 9.8 | 9.9 | 10.9 | 10.4 | 10.3 | 10.1 | 13.3 | 15.8 | 11.2 | 12.1 | 11.2 | 13.0 |
| | | | | | | | | | | | | |
| **Q1-Min** | 1.0 | 1.9 | 2.0 | 0.3 | 1.6 | 0.5 | 3.3 | 0.7 | 0.7 | 2.4 | 1.7 | 1.7 |
| | **Beave r Creek @ Rt. 202** | **Rocky Run Residenti al** | **Hurrican e Run** | **Ridge Run** | **Talle y Run** | **North Fork Beaver Run** | **South Fork Beaver Run** | **Rocky Run @ Rt. 202** | **Ramsey Run** | **Rocky Run Mouth** | **Carne y Run** | **Beaver Creek Mouth** |
| **Q1** | 7.0 | 6.6 | 8.0 | 8.1 | 7.6 | 7.3 | 8.5 | 6.2 | 7.8 | 8.4 | 8.9 | 9.3 |
| **Med-Q1** | 0.2 | 1.2 | 0.3 | 0.2 | 1.1 | 1.4 | 0.4 | 2.8 | 1.2 | 0.8 | 0.7 | 0.5 |
| **Q3-Med** | 1.4 | 0.6 | 0.5 | 1.1 | 0.4 | 0.6 | 1.1 | 0.8 | 0.6 | 1.5 | 1.3 | 0.4 |
| **Max-Q3** | 1.3 | 1.6 | 2.1 | 1.0 | 1.3 | 0.7 | 3.4 | 6.1 | 1.6 | 1.3 | 0.4 | 2.8 |

## Appendix E

## CONDUCTIVIY DATA OF BRANDYWINE CREEK TRIBUTARIES

| | Site 1 | Site 2 | Site 3 | Site 4 | Site 5 | Site 6 | Site 7 | Site 8 | Site 9 | Site 10 | Site 11 | Site 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** |
| 22-Jun | | 400 | 480 | 310 | 115 | 265 | 230 | 290 | 335 | 350 | 840 | 410 |
| 23-Jun | 246 | 461 | 342 | 577 | 130 | 295 | 275 | 333 | 416 | 525 | 1032 | 307 |
| 30-Jun | 238 | 432 | 315 | 535 | 124 | 283 | 299 | 342 | 372 | 717 | 952 | 330 |
| 6-Jul | 245 | 435 | 311 | 551 | 127 | 296 | 275 | 373 | 434 | 773 | 1232 | 351 |
| 13-Jul | 251 | 445 | 326 | 561 | 132 | 284 | 251 | 381 | 454 | 792 | 1444 | 305 |
| 20-Jul | 250 | 435 | 328 | 545 | 137 | 280 | 243 | 387 | 477 | 796 | 1209 | 296 |
| 28-Jul | 252 | 461 | 331 | 577 | 136 | 271 | 230 | 384 | 468 | 704 | 898 | 176 |
| 9-Oct | 200 | 380 | 290 | 460 | 100 | 210 | 170 | 330 | | 480 | 760 | 300 |
| 23-Oct | 220 | 390 | 320 | 450 | 110 | 210 | 160 | 350 | 350 | 730 | 930 | 190 |
| 6-Nov | 210 | 380 | 320 | 440 | 110 | 210 | 170 | 330 | 330 | 560 | 850 | 220 |
| 13-Nov | 210 | 350 | 310 | 380 | 110 | 250 | 180 | 240 | 310 | 380 | 600 | 130 |
| 4-Dec | 200 | 310 | 270 | 340 | 90 | 220 | 200 | 230 | 280 | 390 | 650 | 170 |
| 3/4/2016 | 200 | 380 | 240 | 520 | 100 | 270 | 250 | 480 | 880 | 830 | 1720 | 240 |
| 3/21/2016 | 180 | 370 | 240 | 500 | 100 | 230 | 180 | 370 | 480 | | 900 | |
| 4/8/2016 | 190 | 370 | 240 | 480 | 100 | 220 | 170 | 290 | 470 | | 760 | 130 |
| 6/22/2016 | 190 | 310 | 260 | 400 | 110 | 200 | 150 | 300 | 310 | 550 | 950 | 210 |
| 6/29/2016 | 200 | 320 | 260 | 410 | 100 | 200 | 150 | 290 | 360 | 500 | 780 | 150 |
| 7/13/2016 | 210 | 340 | 280 | 400 | 110 | 200 | 150 | 280 | 310 | 600 | 980 | 150 |
| 7/20/2016 | 190 | 290 | 260 | 330 | 100 | 210 | 150 | 220 | 250 | 360 | 600 | 120 |
| 7/27/2016 | 235 | 380 | 330 | 415 | 135 | 255 | 190 | 245 | 310 | 410 | 760 | 175 |
| 8/3/2016 | 260 | 418 | 360 | 493 | 140 | | 205 | 343 | 370 | 576 | 1100 | 200 |
| 10/10/2016 | 250 | 395 | 343 | 442 | 162.2 | 286 | 210 | 270 | 285 | 386 | 723 | 176 |
| | | | | | | | | | | | | |

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| AVERAGE | 220.333333 | 384.1818182 | 307.0909091 | 459.818182 | 117.190909 | 242.95 | 204 | 320.8181818 | 392.9047619 | 617.4615385 | 939.5454545 | 263.4615385 |
| | | | | | | | | | | | | |
| **Site 5** | **Site 7** | **Site 1** | **Site 6** | **Site 12** | **Site 8** | **Site 9** | **Site 3** | **Site 2** | **Site 4** | **Site 10** | **Site 11** | |
| **Talley Run** | **Carney Run** | **Ridge Run** | **Ramsey Run** | **Rocky Run Residential** | **Rocky Run Mouth** | **Hurricane Run** | **North Fork Beaver Run** | **Beaver Creek Mouth** | **South Fork Beaver Run** | **Rocky Run @ Rt. 202** | **Beaver Creek @ Rt. 202** | **DATE** |
| 114.733 | 218.867 | 220.857 | 252.933 | 263.462 | 340.667 | 432.571 | 310.867 | 399.933 | 481.733 | 617.462 | 985.133 | AVERAGE |
| | | | | | | | | | | | | |
| **Min** | 180 | 290 | 240 | 310 | 90 | 200 | 150 | 220 | 250 | 350 | 600 | 120 |
| **25th Per.** | 200 | 355 | 262.5 | 402.5 | 100 | 210 | 170 | 282.5 | 310 | 405 | 760 | 170 |
| **Median** | 210 | 380 | 313 | 455 | 110 | 250 | 195 | 330 | 360 | 555 | 899 | 200 |
| **75th Per.** | 246 | 428.5 | 329.5 | 531.25 | 131.5 | 280 | 239.75 | 365 | 454 | 720.25 | 1019 | 300 |
| **Max** | 260 | 461 | 480 | 577 | 162.2 | 296 | 299 | 480 | 880 | 830 | 1720 | 410 |
| | | | | | | | | | | | | |
| **Q1-Min** | 20 | 65 | 22.5 | 92.5 | 10 | 10 | 20 | 62.5 | 60 | 55 | 160 | 50 |
| | **Ridge Run** | **Beaver Creek Mouth** | **North Fork Beaver Creei** | **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** |
| **Q1** | 200 | 355 | 262.5 | 402.5 | 100 | 210 | 170 | 282.5 | 310 | 405 | 760 | 170 |
| **Med-Q1** | 10 | 25 | 50.5 | 52.5 | 10 | 40 | 25 | 47.5 | 50 | 150 | 139 | 30 |
| **Q3-Med** | 36 | 48.5 | 16.5 | 76.25 | 21.5 | 30 | 44.75 | 35 | 94 | 165.25 | 120 | 100 |
| **Max-Q3** | 14 | 32.5 | 150.5 | 45.75 | 30.7 | 16 | 59.25 | 115 | 426 | 109.75 | 701 | 110 |
| | | | | | | | | | | | | |
| | | | | | | | | | | | | |
| **Min** | 90 | 150 | 120 | 180 | 200 | 240 | 220 | 250 | 290 | 310 | 350 | 600 |
| **25th Per.** | 100 | 170 | 170 | 200 | 210 | 262.5 | 282.5 | 310 | 355 | 402.5 | 405 | 760 |
| **Median** | 110 | 195 | 200 | 210 | 250 | 313 | 330 | 360 | 380 | 455 | 555 | 899 |
| **75th Per.** | 131.5 | 239.75 | 300 | 246 | 280 | 329.5 | 365 | 454 | 428.5 | 531.25 | 720.25 | 1019 |
| **Max** | 162.2 | 299 | 410 | 260 | 296 | 480 | 480 | 880 | 461 | 577 | 830 | 1720 |
| | | | | | | | | | | | | |
| **Q1-Min** | 10 | 20 | 50 | 20 | 10 | 22.5 | 62.5 | 60 | 65 | 92.5 | 55 | 160 |
| | **Talley Run** | **Carney Run** | **Rocky Run Residential** | **Ridge Run** | **Ramsey Run** | **North Fork Beaver Creek** | **Rocky Run Mout** | **Hurricane Run** | **Beaver Creek Mouth** | **South Fork Beaver Creek** | **Rocky Run @ Rt. 202** | **Beaver Creek @ Rt. 202** |

| | | | | | | | h | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Q1** | 100 | 170 | 170 | 200 | 210 | 262.5 | 282.5 | 310 | 355 | 402.5 | 405 | 760 |
| **Med-Q1** | 10 | 25 | 30 | 10 | 40 | 50.5 | 47.5 | 50 | 25 | 52.5 | 150 | 139 |
| **Q3-Med** | 21.5 | 44.75 | 100 | 36 | 30 | 16.5 | 35 | 94 | 48.5 | 76.25 | 165.25 | 120 |
| **Max-Q3** | 30.7 | 59.25 | 110 | 14 | 16 | 150.5 | 115 | 426 | 32.5 | 45.75 | 109.75 | 701 |

# Appendix F

## ENTEROCOCCI DATA OF BRANDYWINE CREEK TRIBUTARIES

| | Site 1 | Site 2 | Site 3 | Site 4 | Site 5 | Site 6 | Site 7 | Site 8 | Site 9 | Site 10 | Site 11 | Site 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** |
| 30-Jun | 1533.1 | 344.1 | 1046.2 | 488.4 | 920.8 | 1046.2 | 403.4 | 378.4 | 1413.6 | 461.1 | 517.2 | 1413.6 |
| 20-Jul | 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 |