

**Water Quality Field Report**  
**First State National Park**  
**Brandywine-Piedmont Watershed**  
**2015-2016**

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## **Abstract**

Several chemical, nutrient, and biological indicators can help determine water quality and ecosystem health. As a newly designated national park, students at the University of Delaware found it important to monitor, record, and analyze several parameters including temperature, pH, conductivity, dissolved oxygen, turbidity, bacteria, nutrients, and metals to determine the general health of tributaries flowing through the Brandywine-Piedmont watershed in Delaware's First State National Historic Park. Using probes and lab facilities from the City of Wilmington and the University of Delaware, data was gathered from 12 sites throughout the watershed several times over a period of nine months. Students analyzed data according to parameter, date, and statistical averages. When compared to standards, the results showed little to no nutrient and chemical impairments, but there were some indications of chemical and bacterial concern in sites adjacent to agricultural and commercialized areas, indicative of runoff pollution or other non-point sources. It is the researcher's hope that the newly designated First State National Historic Park will act as a natural water quality improvement system or that the National Park Service will proceed with further investigations in order to prevent the degradation of the water quality in the watershed as indicated by this preliminary research.

## **Chapter 1: Introduction and Purpose**

### **Background**

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. The Mt. Cuba Center provided funds to acquire the property from the Woodlawn Trustees and transferred the title to the National Park Service. In December 2014, Congress voted to create the First State National Historical Park (FSNHP) in the National Defense Authorization Act of 2015 and the President signed the bill to make it Delaware's first national park.

### **Justification**

The National Park Service is preparing a master plan for development of FSNHP as part of a foundation document with input from the Woodlawn Coalition, which is coordinated by The Nature Conservancy. During the months of June through December in 2015 and March through April in 2016, student research intern from the University of Delaware Water Resources Center (UDWRC) conducted a water quality research project that focused on 6 streams feeding into the Brandywine Creek at the FSNHP in the Beaver Valley in Delaware and Pennsylvania (Figure 1.1). The purpose of monitoring these sites is to characterize the water quality and habitat of the Piedmont streams that flow west to the Brandywine Creek. Students selected 12 water quality sampling stations along 6 streams in the Brandywine Piedmont watershed. These tributaries flow through areas impacted by agriculture, commercial, transportation, and residential neighborhoods before flowing into FSNHP. As these tributaries are connected to the sole source of Wilmington's drinking water, the Brandywine Creek, it is important to monitor water quality levels in these streams to ensure that they are healthy enough for human uses and as an overall guide for actions to be taken by the National Park Service along with the Delaware Division of Parks and Recreation.

Beaver Creek, Talley Run, and Rocky Run are listed on the 2014 Delaware Department of Natural Resources and Environmental Control Clean Water Act Section 303(d) report for impaired habitat and biology. It is important to determine the root cause of these impairments whether it be from land erosion, heavy use of agriculture or stormwater runoff. This project will help determine the current health of the tributaries flowing into the Brandywine Creek. Long term monitoring of parameters such as temperature, pH, dissolved oxygen, conductivity, and turbidity will provide the framework to assess future trends. The areas of concern for this project include the FSNHP at Woodlawn, operated by the National Park Service and adjacent Brandywine Creek State Park, owned by the Delaware Division of Parks and Recreation (Figures 1.2 and 1.3).



**Figure 1.1.** Summer research field crew 2015. From the University of Delaware and The Nature Conservancy. Left to right: Seth Olson (DWRC undergraduate intern), Erica Rossetti (DWRC undergraduate intern), Kristen Molfetta (IPA WRA graduate research fellow), Laura Askin (IPA WRA graduate research fellow), and Mika Ulmet (The Nature Conservancy GLOBE intern). Not shown: Maria Dziembowska (The Nature Conservancy), Maya Kassoff (UD undergraduate research assistant), Gerald Kauffman (UDWRC director and student advisor), and Samantha Serratore (DWRC undergraduate intern).

First State National Monument  
Boundary

**DRAFT**

National Park Service  
U.S. Department of the Interior



New Castle & Kent Counties, Delaware  
Delaware County, Pennsylvania

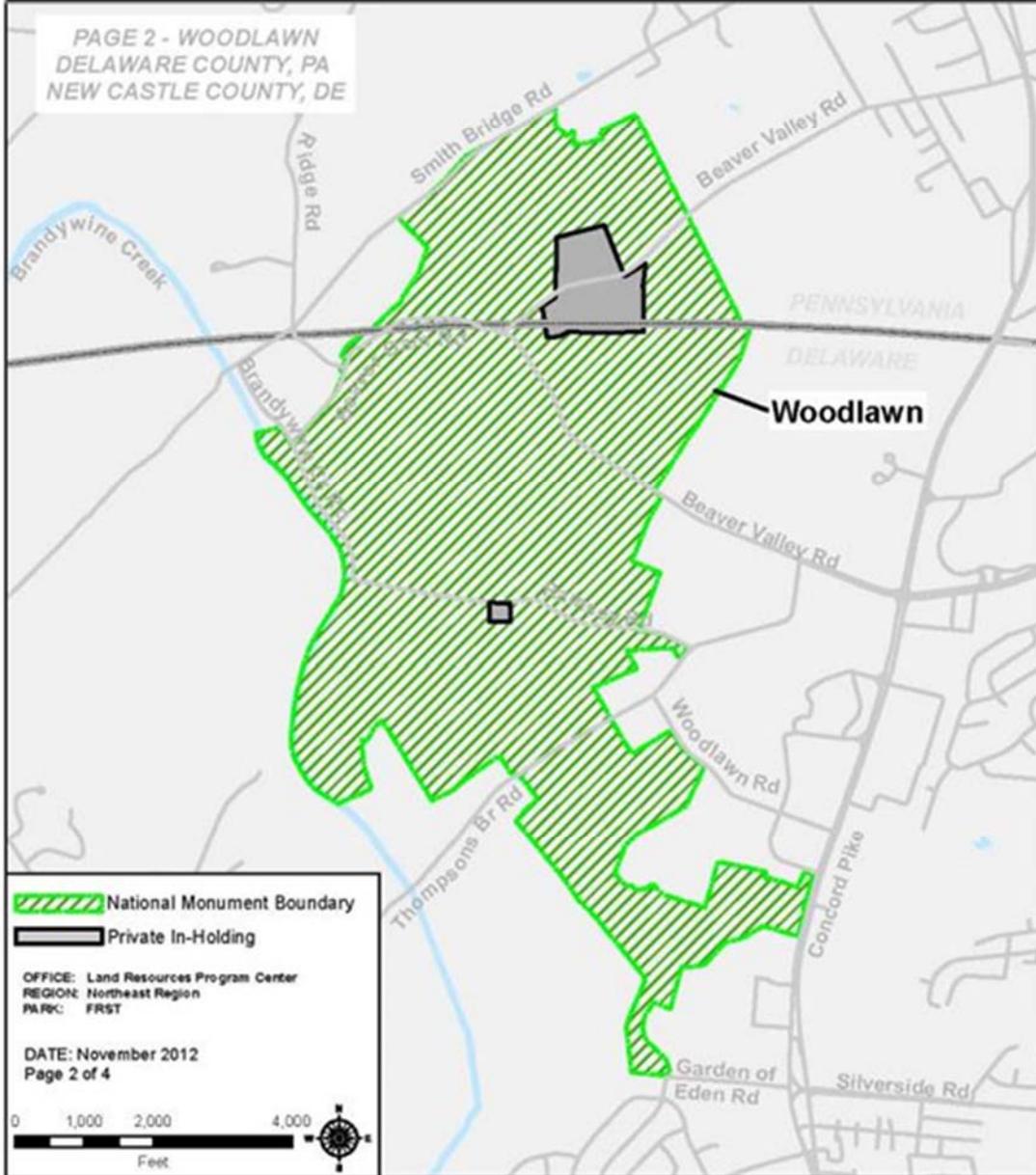
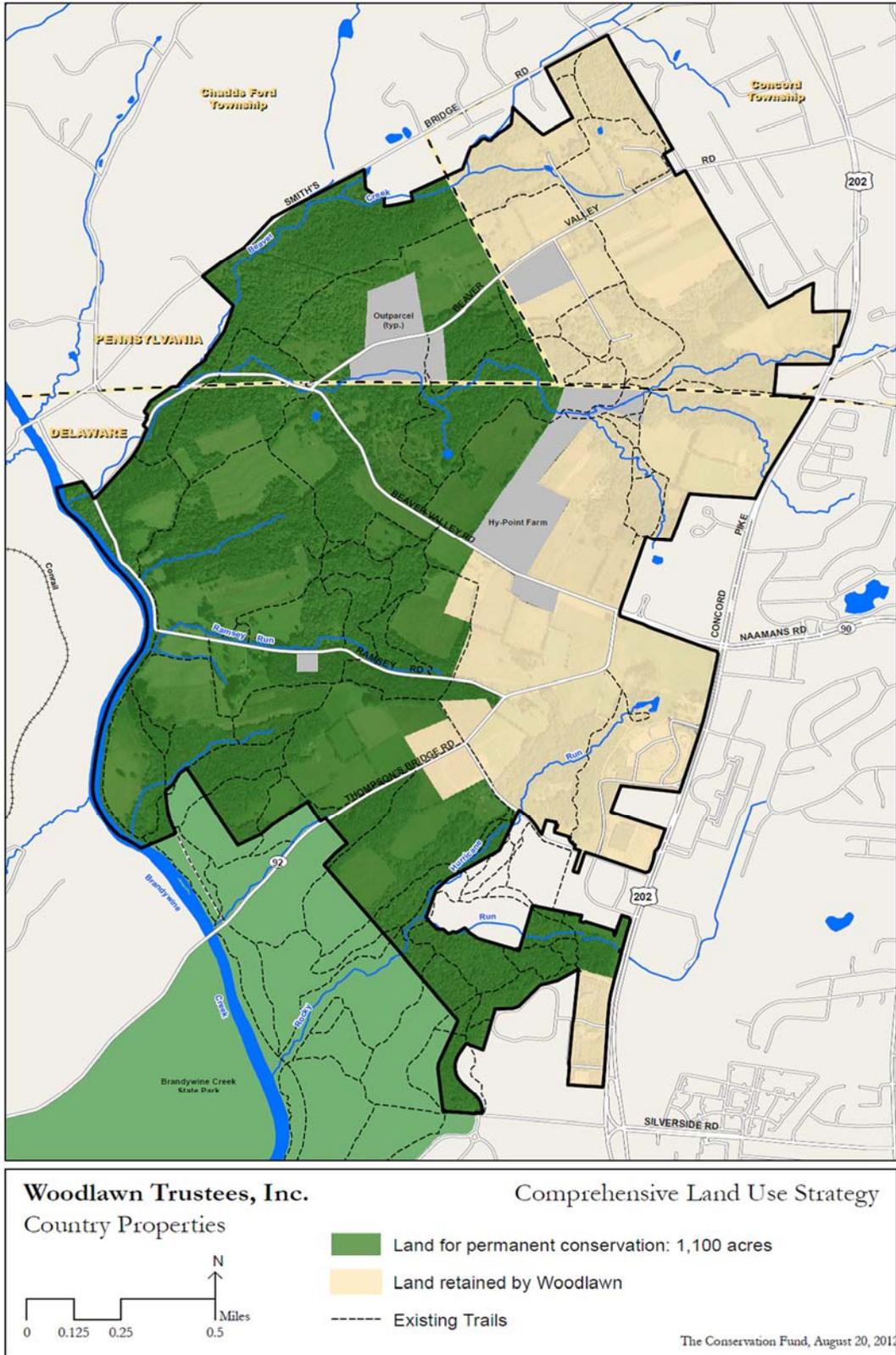


Figure 1.2. First State National Historic Park boundary



**Figure 1.3.** First State National Historical Park - Woodlawn Unit

## Chapter 2: Watershed Characterization

The Brandywine Piedmont Watershed Plan (BPWP) is designed to protect and restore the scenic watersheds that flow through the newly designated First State National Historical Park at Woodlawn operated by the National Park Service and adjacent Brandywine Creek State Park owned by the Delaware Division of Parks and Recreation. Summer 2014 field crews from the University of Delaware and The Nature Conservancy characterized these watersheds according as follows according to land use, topography, soils, and geology.

### Ridge Run

The 262-acre Ridge Run watershed borders the northerly boundary of the FSNHP, forms in the headwaters at 400 feet above sea level in Pennsylvania, and flows for 1.5 miles into Delaware to the confluence with the Brandywine Creek at Smith's Bridge (Figure 2.1). The watershed is lightly developed (0.3% impervious) and land use is 19% forest/wetlands, 5% urban/suburban, and 77% agriculture (meadow, horse farms, and corn and soybeans). The steeply sloped watershed (12% slopes) is covered by soils in all 4 hydrologic soil groups. Geology of the watershed is the Wissahickon Formation gneiss, the Wilmington Blue Rock.

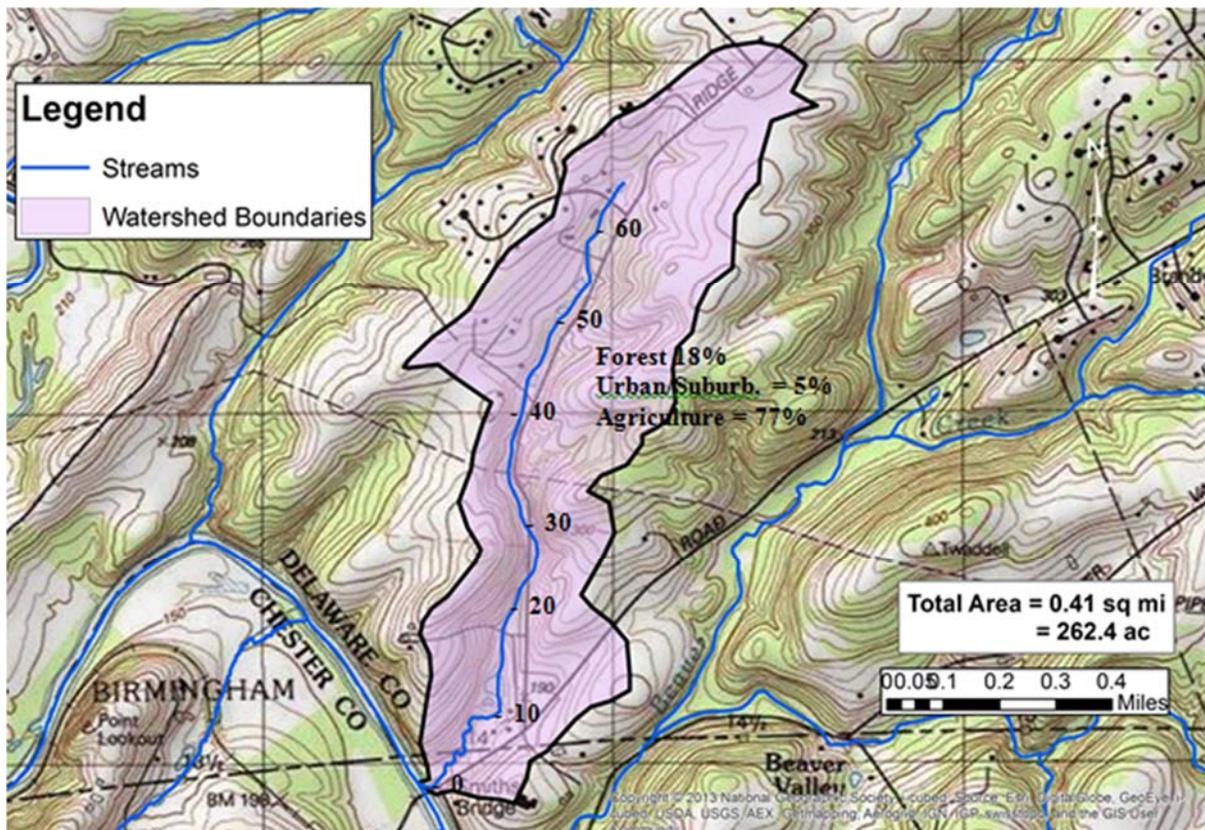


Figure 2.1. Ridge Run watershed delineation and topography

## Beaver Creek

Beaver Creek is the largest watershed surveyed, and it drains 4 square miles from the north and south forks and main stem of the stream (Figure 2.2). It covers the northerly third of the FSNHP. The north fork of Beaver Creek originates near the densely developed shopping centers and neighborhoods along Concord Pike in Pennsylvania and flows southwest for three miles through horse farms into the forested First State National Park before joining the main stem about a half mile upstream from the Brandywine Creek. The south fork forms along the Delaware/Pennsylvania state line near the Brandywine Town Center shopping mall and flows west for four miles under Concord Pike. The main stem flows for a half mile along Beaver Valley Road to the confluence with the Brandywine at a popular beach known as Peter's Rock. The watershed is moderately developed (9% impervious) in the upper third near Concord Pike and mostly undeveloped in the stream valleys down below near the Brandywine. Watershed land use is 41% forest/wetlands, 28% urban/suburban, and 31% agriculture primarily horse farms and meadow. The steeply sloped watershed (9% slopes) 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, a high water yield carbonate rock that provides buffering capacity to the stream for trout populations.

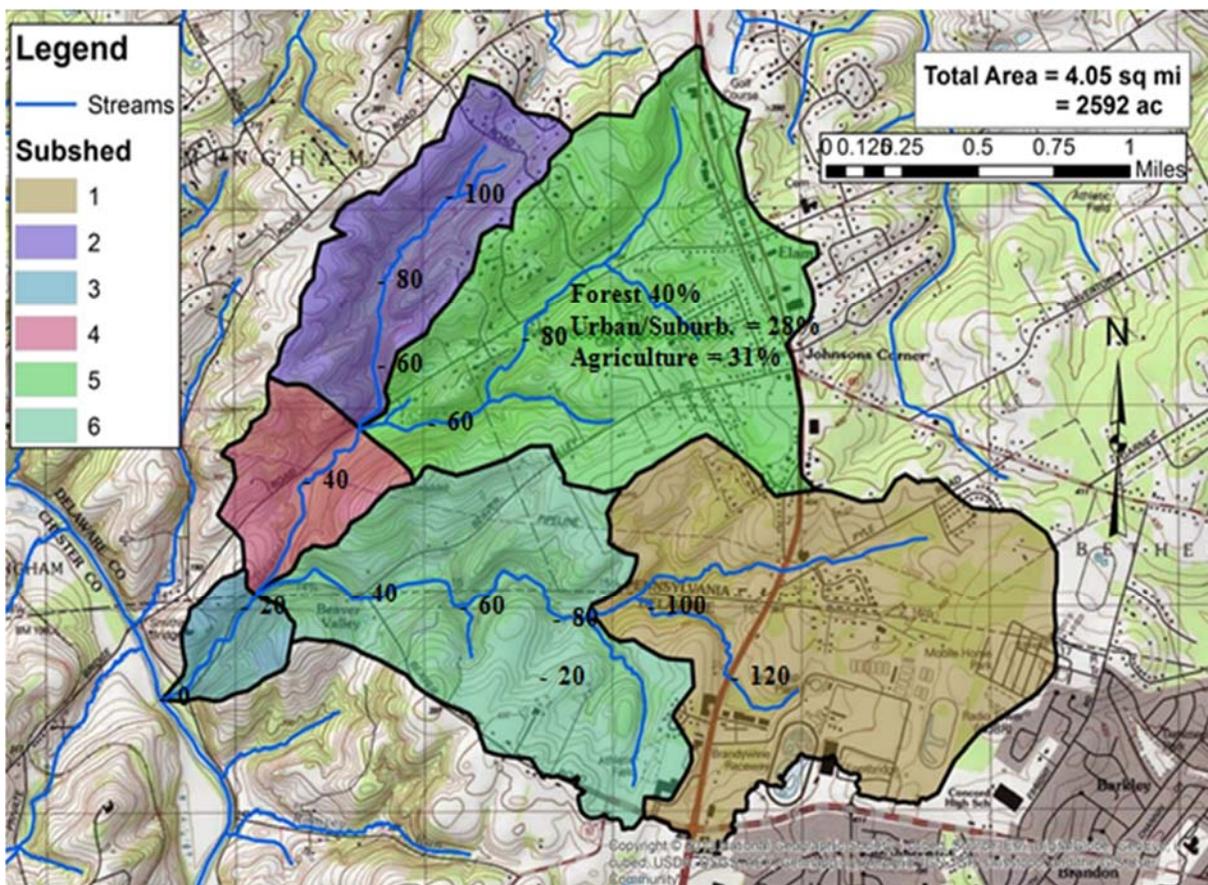


Figure 2.2. Beaver Creek watershed delineation and topography

## Talley Run

The 128-acre Talley Run watershed lies entirely within Delaware in the Woodlawn tract of FSNHP (Figure 2.3). The small creek forms on a 400 ft. high hill near Beaver Valley Road and flows for  $\frac{3}{4}$  mile through a beautiful valley cupped by trail system down to elevation 70 above mean sea level (msl) to feed the Brandywine Creek. The watershed is lightly developed (0% impervious) and land use is 54% forest/wetlands, 3% urban/suburban, and 43% agriculture (primarily horse farms, meadows, and corn/soybeans). The steeply sloped (13%) watershed is covered by soils of hydrologic soil group A and B. The geology of the watershed is the Wissahickon Formation gneiss.

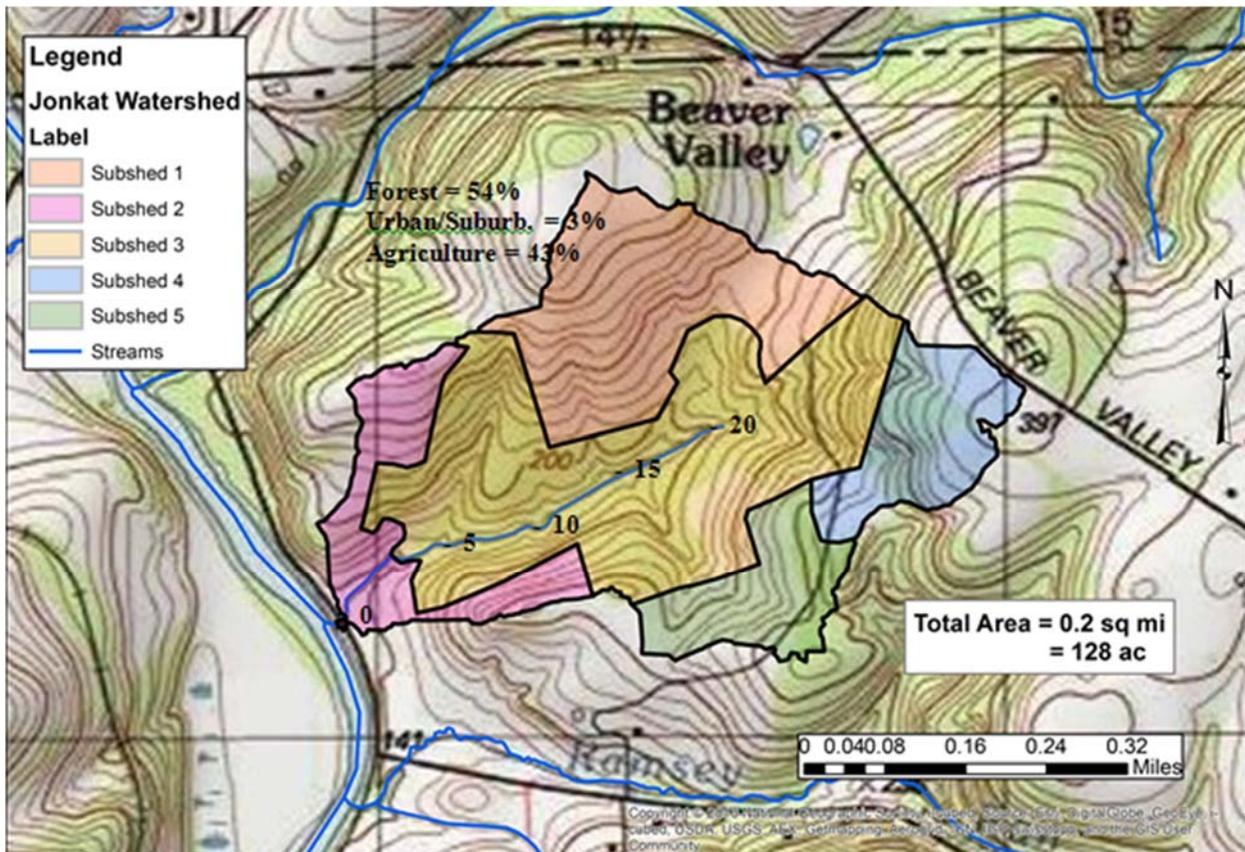
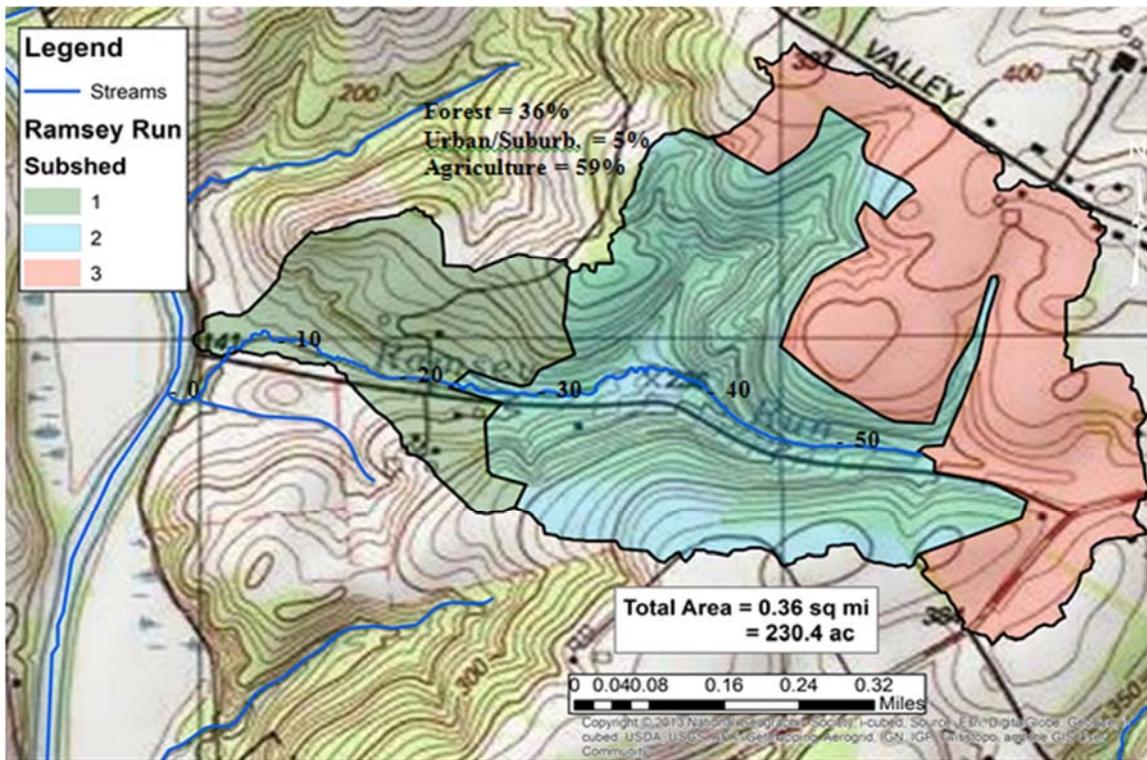


Figure 2.3. Talley Run watershed delineation and topography

## Ramsey Run

The 230-acre Ramsey Run watershed drains the Ramsey Farm and rises at 420 feet above sea level and flows for a mile along the road and then through a bridge under the foot trail along Brandywine Creek (Figure 2.4). The watershed is almost entirely undeveloped (0.2% impervious) and land use is 36% forest/wetlands, 5% urban/suburban, and 59% agriculture primarily pumpkin farm, meadow, and horse farm. The steeply sloped (11%) watershed is covered by soils are % hydrologic soil group A and. The geology of the watershed is the Wissahickon Formation gneiss with an outcrop of amphibolite downstream near the Brandywine.



**Figure 2.4.** Ramsey Run watershed delineation and topography

### Carney Run

The 122-acre Carney Run watershed originates at 400 ft. above sea level and flows for almost a mile along the road to join the Brandywine Creek just upstream from Thompson Bridge (Figure 2.5). The watershed is lightly developed (0.1% impervious) and land use is 61% forest/wetlands, 3% urban/suburban, and 36% agriculture primarily horse farm, meadow, and corn/soybeans. The steeply sloped (15%) watershed is covered by hydrologic soil group A and B. The geology of the watershed is Wissahickon Formation gneiss.



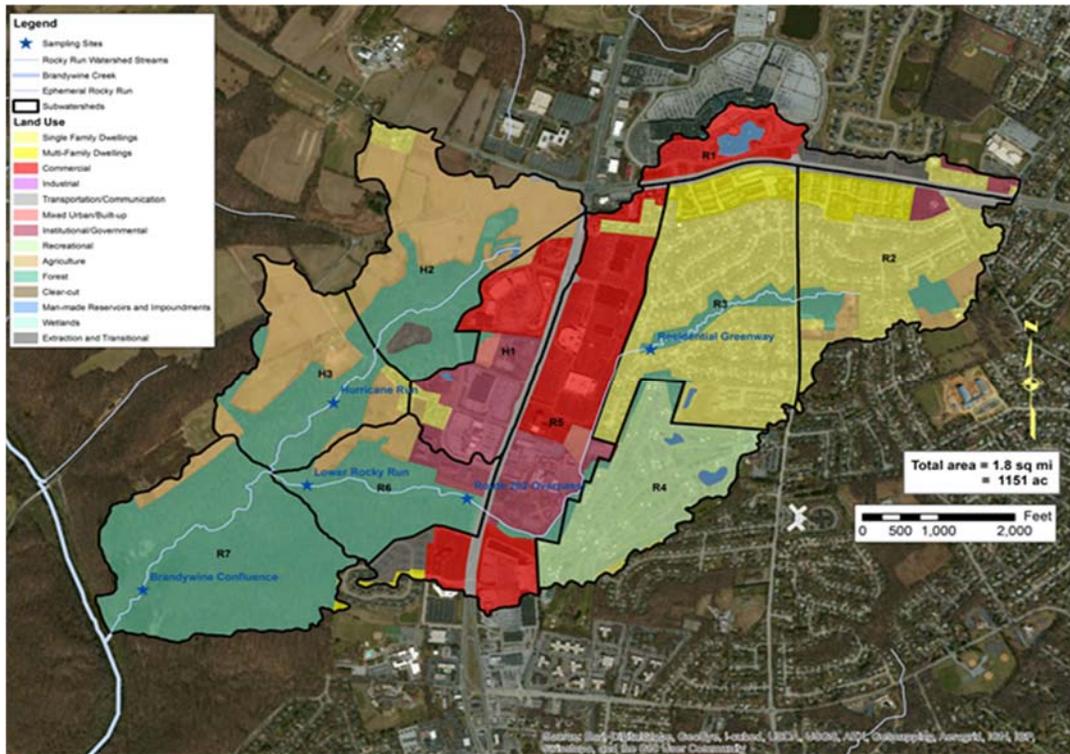


Figure 2.6. Rocky Run watershed land use map

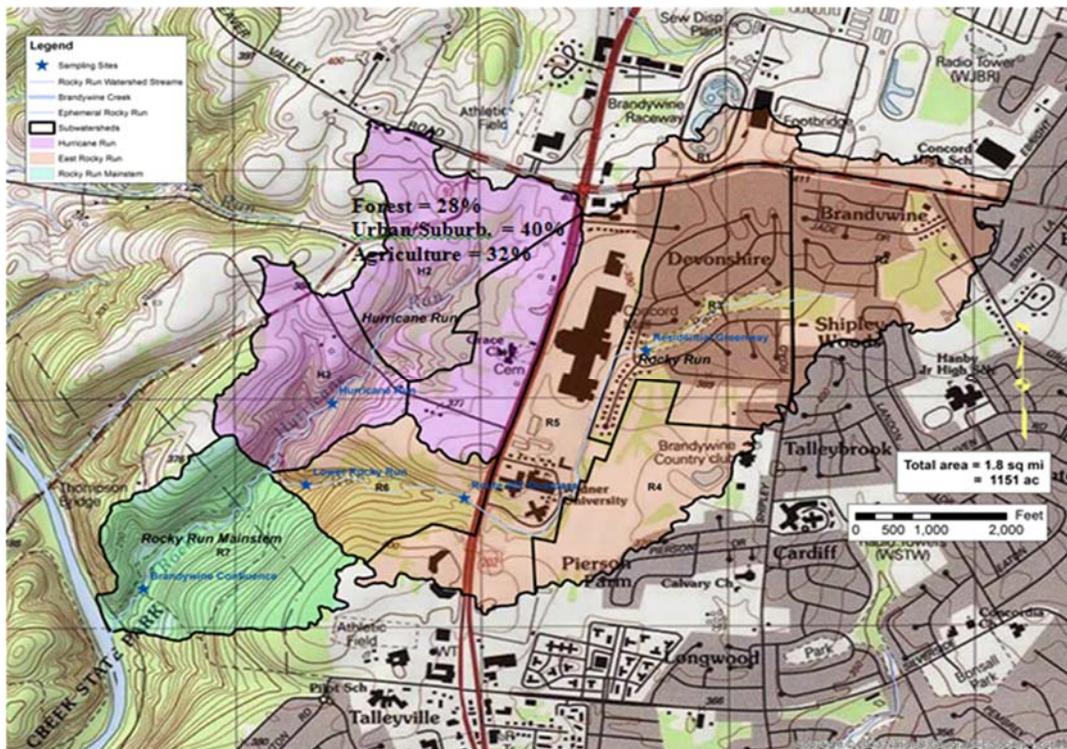


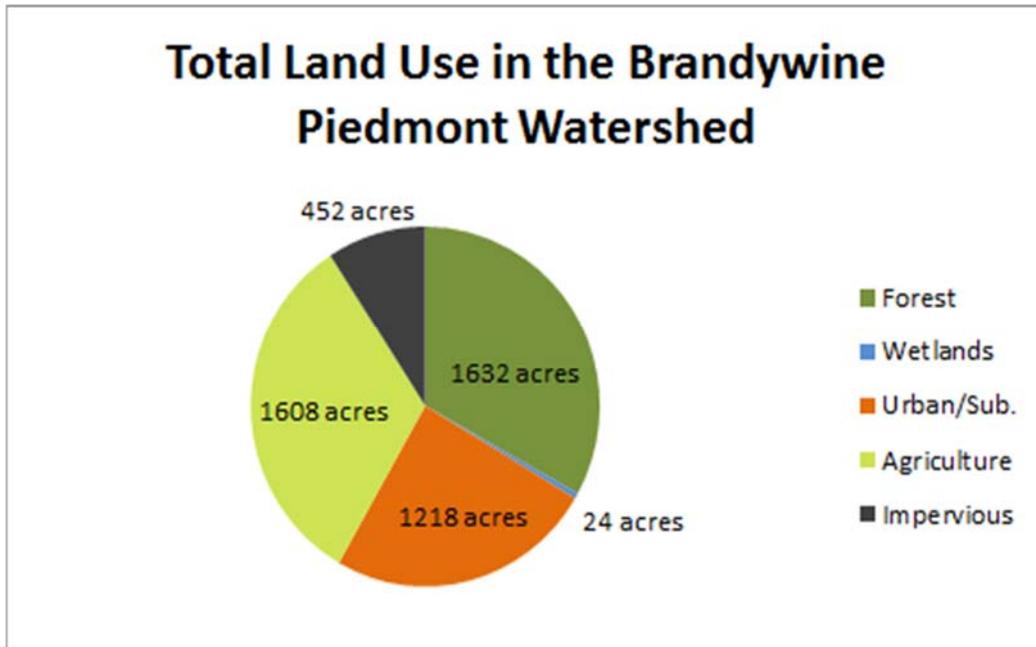
Figure 2.7. Rocky Run watershed delineation and topography

## Land Use

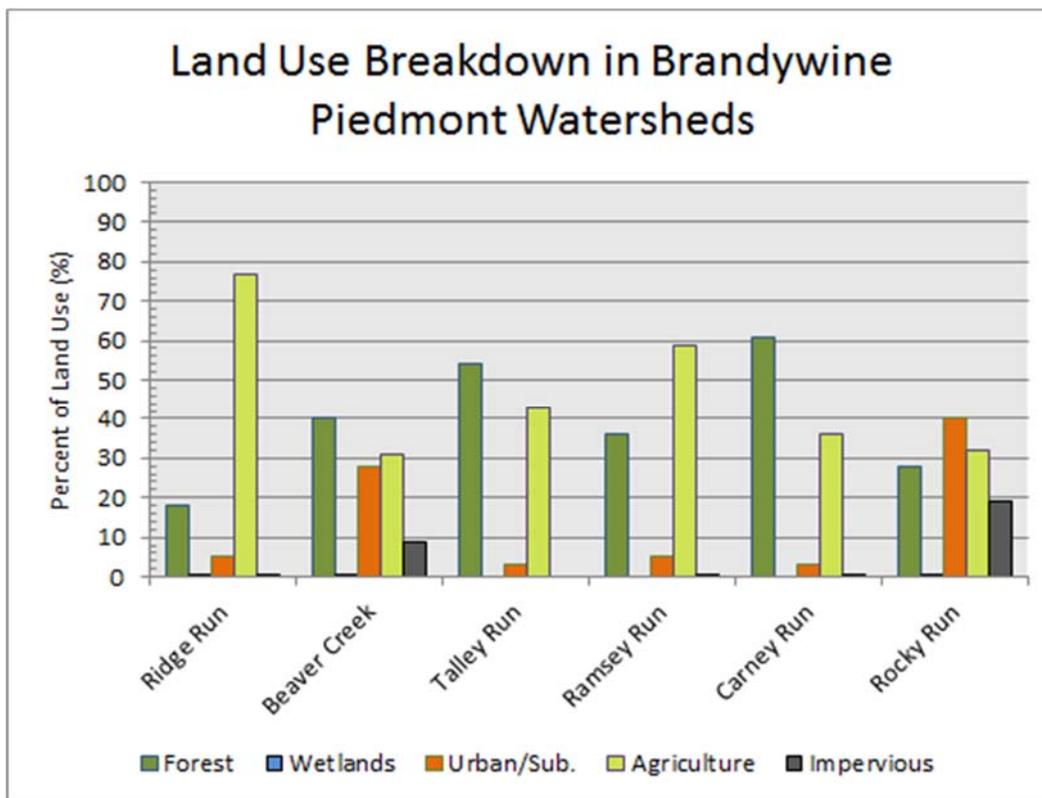
The 6 streams that flow through the First State National Historical Park capture a drainage area of 4,485 acres or 7.0 square miles. Land use in the six watersheds covers 36% forest, 1% wetlands, 27% urban/suburban, and 36% agriculture with an overall impervious coverage of 10% (Table 1.1 and Figures 2.8 and 2.9). Watershed land use is mostly urban/suburban and commercial to the east on the 400 feet heights of the Piedmont plateau along Concord Pike (Route 202) and changes to agriculture as the streams flow west and downstream over 300 feet in elevation through the steeply sloped forested valleys to the Brandywine Creek (Figure 2.10). The flat Piedmont heights 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 (< 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 (Figure 2.11).

**Table 1.1.** Land use in the Brandywine Piedmont watershed

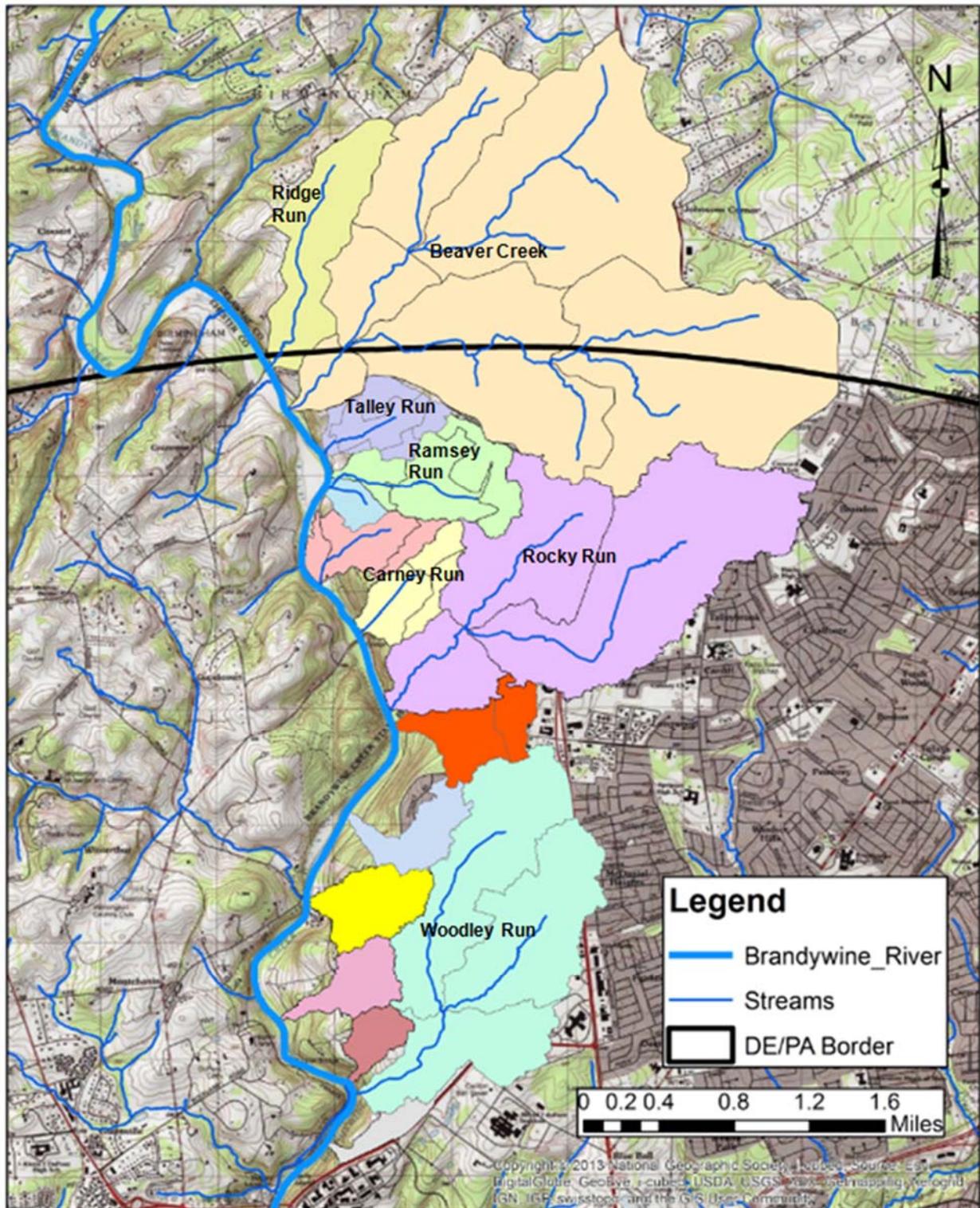
<b>Watershed</b>	<b>Area (ac)</b>	<b>Forest (ac)</b>	<b>Wetlands (ac)</b>	<b>Urban/Sub. (ac)</b>	<b>Agriculture (ac)</b>	<b>Impervious (ac)</b>
Ridge Run	262	47	1	13	202	0.8
Beaver Creek	2,592	1037	21	726	804	233
Talley Run	128	69	0	4	55	0
Ramsey Run	230	83	0	12	136	0.5
Carney Run	122	74	0	4	44	0.1
Rocky Run	1,151	322	2	460	368	218
	<b>4,485</b>	<b>1,633</b>	<b>24</b>	<b>1,218</b>	<b>1,608</b>	<b>452</b>
<b>Watershed</b>	<b>(%)</b>	<b>(%)</b>	<b>(%)</b>	<b>(%)</b>	<b>(%)</b>	<b>(%)</b>
Ridge Run	100%	18%	0.4%	5%	77%	0.3%
Beaver Creek	100%	40%	0.8%	28%	31%	9%
Talley Run	100%	54%	0.0%	3%	43%	0%
Ramsey Run	100%	36%	0.0%	5%	59%	0.2%
Carney Run	100%	61%	0.0%	3%	36%	0.1%
Rocky Run	100%	28%	0.2%	40%	32%	19%
	100%	<b>36%</b>	<b>1%</b>	<b>27%</b>	<b>36%</b>	<b>10%</b>



**Figure 2.8.** Total land use in the Brandywine Piedmont Watershed



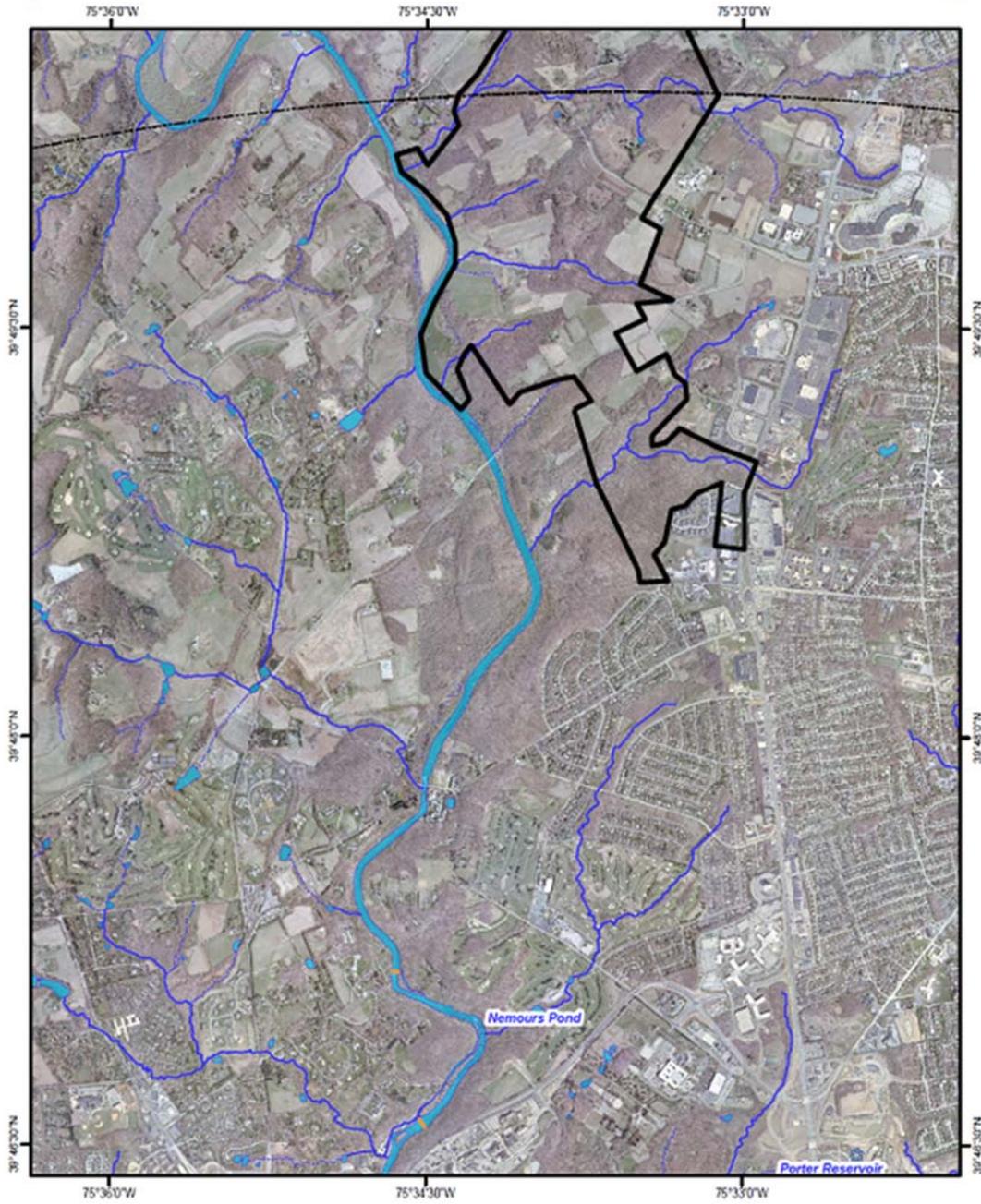
**Figure 2.9.** Land use in the Brandywine Piedmont watershed



**Figure 2.10.** Brandywine-Piedmont watersheds at First State National Historic Park



# State of Delaware



Data on map are based on Delaware framework data layers. The Delaware DataMIL is maintained by the Delaware Geological Survey (DGS) and served via the Delaware Department of Technology and Information (DTI) internet.

Scale 1:36,000

0 0.15 0.3 0.6

Kilometers

0 1000 2000 4000

Feet



Magnetic Declination  
Approx. 11 mls

DataMIL Mini Map



**Figure 2.11.** Aerial photograph of streams within FSNHP boundary

## Basin Characteristics

The USGS STREAMSTATS model (Table 2.1) indicates the watersheds are steeply sloped (6%-15% slopes), at least 15% forested (18%-61%), with minimal wetland coverage (0.2%-0.8%). The small watersheds are mostly undeveloped with impervious coverage less than 0.3% of the catchment area. The larger watersheds, Beaver Creek and Rocky Run, are covered by higher amounts of impervious cover (9% and 19%) as these watersheds form in the neighborhoods and shopping centers along the commercialized Concord Pike (Route 202) corridor (Figure 2.12).

**Table 2.1.** Characteristics of the Brandywine Piedmont watershed

<b>Watershed</b>	<b>Area (mi<sup>2</sup>)</b>	<b>Basin Slope (%)</b>	<b>Forest (%)</b>	<b>Wetlands (%)</b>	<b>Impervious (%)</b>
Ridge Run	0.4	12%	18%	0.4%	0.3%
Beaver Creek	4.2	9%	40%	0.8%	9.0%
Talley Run	0.2	13%	54%	0%	0.0%
Ramsey Run	0.4	11%	36%	0%	0.2%
Carney Run	0.2	15%	61%	0%	0.1%
Rocky Run	1.8	6%	28%	0.2%	19.0%
	<b>7.0 mi<sup>2</sup></b>				

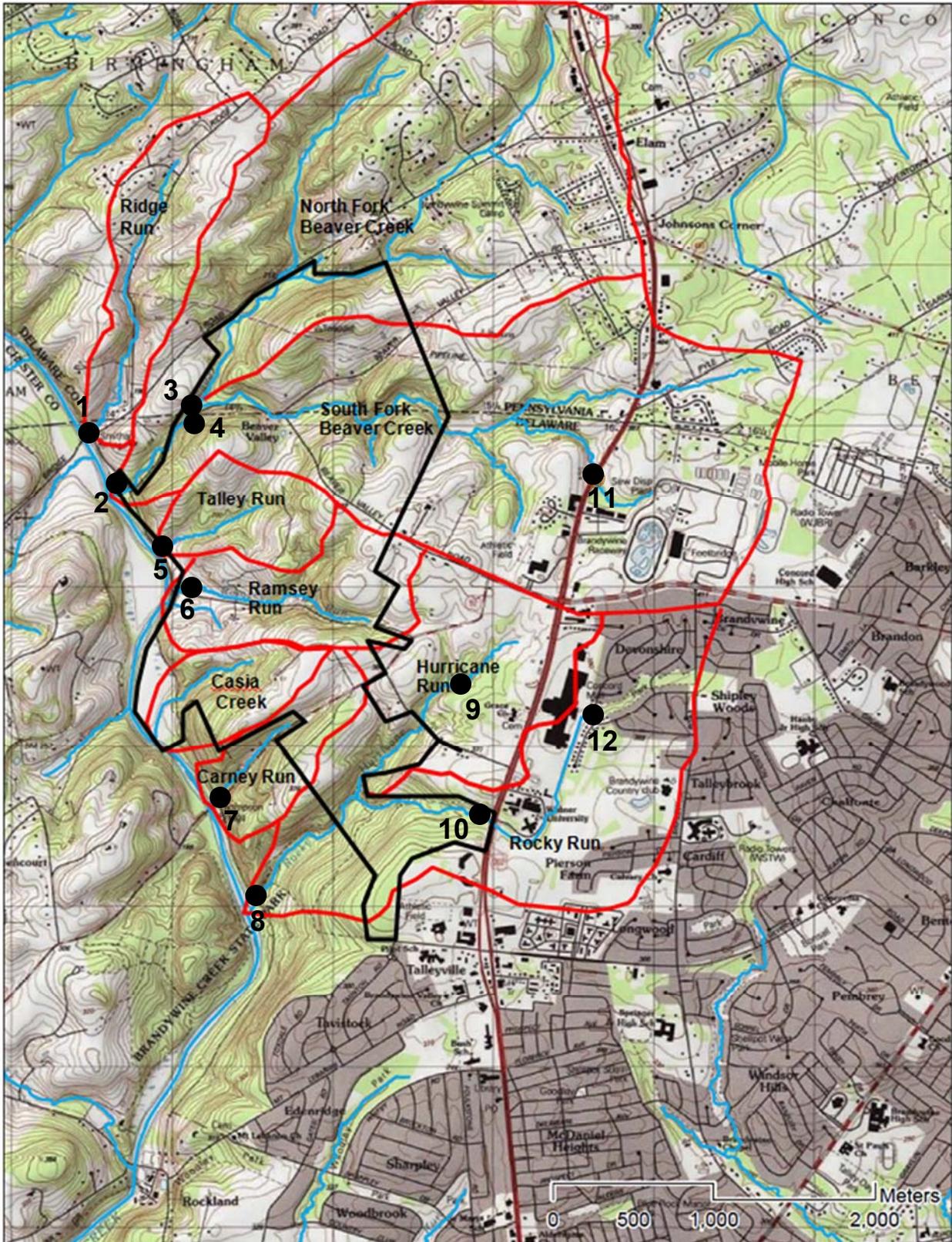


Figure 2.12. Topography of watersheds within FSNHP

## Soils

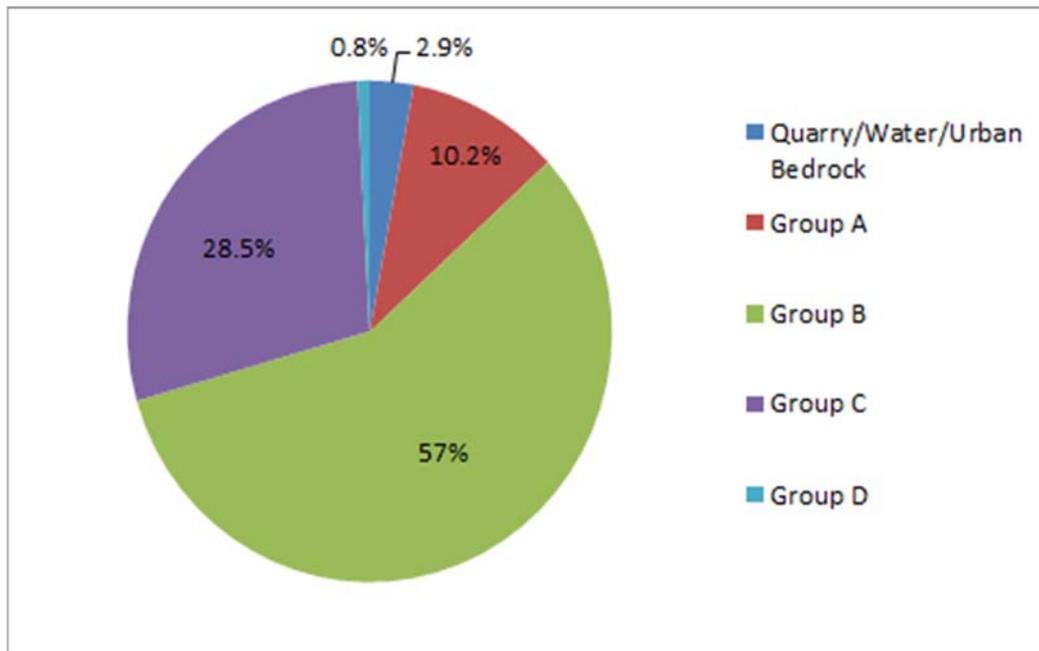
According to the USDA soil survey, 2.9% of the FSNHP watershed soils are classified as quarry/water/urban bed rock, 10.2% are hydrologic soil group A (moderate permeability), 57% are HSG B (moderately drained), 28.5% are HSG C (low permeability), and 0.8% are HSG D (poorly drained/wetlands), see Figure 2.13. The four hydrologic soil groups are:

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. These soils have a high rate of water transmission.

Group B soils have a moderate infiltration rate when thoroughly wet. These consist of moderately deep or deep, moderately well-drained or well-drained soils with moderately fine to moderately coarse texture. These soils have a moderate rate of water transmission.

Group C soils have a slow infiltration rate that impedes the downward movement of water or soils of moderately fine texture with a slow rate of water transmission.

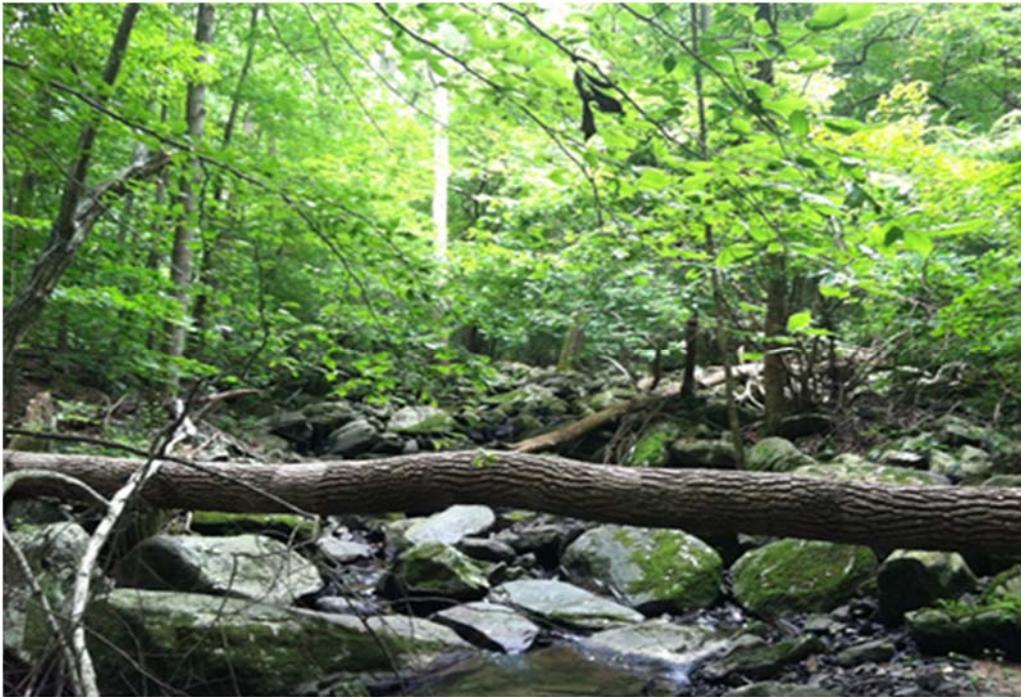
Group D soils have a very slow infiltration rate (high runoff potential) when wet and are commonly hydric or wetland soils. These soils have a very slow rate of water transmission.



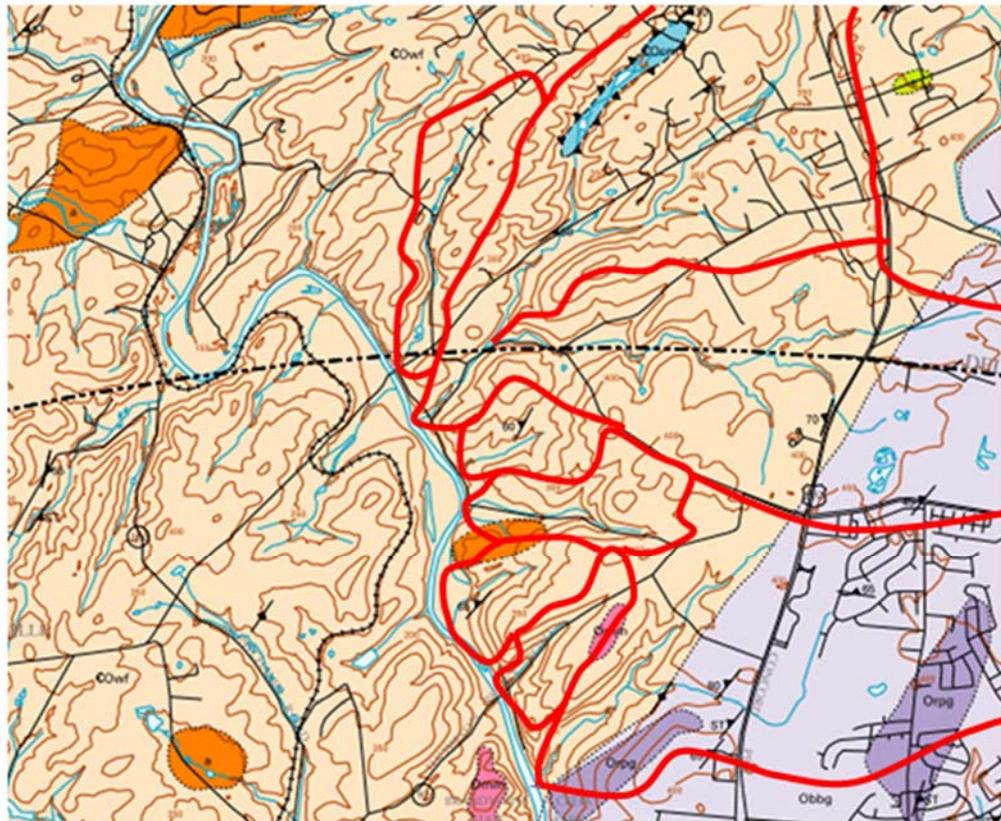
**Figure 2.13.** USDA Soil Survey - FSNHP watershed hydrologic soil group classifications

## Geology

FSNHP watersheds are underlain by outcrops of the Wissahickon Formation gneiss (Wilmington Blue Rock), blue-green in color and form large erosion resistant boulder and cobble complexes in the beds of streams that tumble through the Piedmont (Figures 2.14 and 2.15). Rock types include mostly Wissahickon, Amphibolite, and Cockeysville Marble.



**Figure 2.14.** Wilmington Blue Rock boulder complex found in Beaver Creek, FSNHP, 2014.



**Figure 2.15.** Geologic map in watersheds of First State National Park (Schenck, Planck, and Srogi 2000)

## Chapter 3: Methodology

### Schedule

Stream sample sites at the First State National Historical Park were visited and mapped out on June 15th, 2015. Sampling for the summer began on June 22 and ended on July 28, 2015. The team collected data once a week (either on Monday or Tuesday) at the 12 locations in Beaver Valley. On days of bacterial sampling, samples were delivered to the City of Wilmington Water Quality Lab. Sampling for the fall began on October 9th and ended on December 4th and was conducted every other week. Nutrient samples were sent to the Soil Testing Program at the University of Delaware College of Agriculture and Natural Resources. Sampling in the spring was conducted three times in March and April 2016. Measurements for the summer and fall of 2016 consisted of only electrical conductivity and turbidity. Sampling for the summer began on June 22, 2015.

June 8, 2015- Kick-off meeting

June 15, 2015- Mapped out and visited each site location

June 17, 2015 - Visited the City of Wilmington Water Quality Lab

June 22, 2015- Borrowed equipment from City of Wilmington

June 30, 2015 - Probe data collection, bacterial and TSS sampling

July 6, 2015 - Probe data collection

July 13, 2015 - Probe data collection

July 20, 2015 - Probe data collection, bacterial and TSS sampling

July 23, 2015 - Macroinvertebrate sampling (Water Blitz) along Beaver Creek for TNC

July 28, 2015 – WQ probe data collection

October 9, 2015 - Collected water samples for nutrient analysis by UD WQ Lab

October 23, 2015- WQ probe data collection

November 6, 2015 – WQ probe data collection

November 13, 2015 - Collected nutrient sample at site 9 for UD Soil Testing Program

December 4, 2015 - WQ probe data collection

March 4, 2016 - WQ probe data collection

March 21, 2016 - WQ probe data collection

April 8, 2016 – WQ probe data collection

June 22, 2016- WQ probe data collection

June 29th, 2016- Probe data collection

July 13, 2016- WQ probe data collection

July 20, 2016- WQ probe data collection

July 27, 2016- WQ probe data collection

August 3, 2016- WQ probe data collection

October 10, 2016- Probe data collection

## Parameters

The field crews collected water quality data for the parameters listed in Table 3.1.

**Table 3.1.** Water quality standards of tested parameters

Parameter	Unit	Water Quality Standard
Temperature	°C	No more than 27.7°C
pH	pH unit	6.5-8.5
Turbidity	NTU	Cannot exceed 10 NTUs
Dissolved Oxygen (DO)	mg/L	Cannot be <5.5 average
Electrical Conductivity (EC)	µS	Should be between 150-500µS
Enterococci Bacteria	#/100mL	925/100mL
Aluminum (Al)	mg/L	0.75 mg/L acute 0.087 mg/L chronic
Boron (B)	mg/L	0.75 mg/L
Calcium (Ca)	mg/L	*
Copper (Cu)	mg/L	0.0134 mg/L
Iron (Fe)	mg/L	1 mg/L
Potassium (K)	mg/L	*
Magnesium (Mg)	mg/L	*
Manganese (Mn)	mg/L	0.5 mg/L
Sodium (Na)	mg/L	*
Phosphorus (P)	mg/L	0.2 mg/L
Sulfur (S)	mg/L	250 mg/L
Zinc (Zn)	mg/L	0.117 mg/L acute 0.118 mg/L chronic
NH <sub>4</sub> -N (Ammonia-Nitrate)	mg/L	Usually does not exceed 0.2 mg/L
NO <sub>3</sub> (Nitrate)	mg/L	10 mg/L

## Equipment

Field crews utilized the following water quality sampling equipment.

- Monitoring probes for pH, DO, temperature, conductivity and TDScan 3 Conductivity probe, turbidity meter (Figure 3.1 and 3.2)
- 4 oz. Nasco Whirl-pak bags
- 100 ml IDEXX sterilized and sealed bottles (Figure 3.3)
- 500 ml Nalgene sample bottles
- 100 ml plastic beakers
- 3 buffer solutions (pH 4, 7, and 10) for pH probe calibration
- Ice cooler and ice
- Label tags
- Chain of Custody forms
- Field notebook, pen, and watch



**Figure 3.1.** Water quality probes.



**Figure 3.2.** Turbidity probe



**Figure 3.3.** IDEXX sterilized and sealed 100mL bottles

### Site Descriptions

Water quality sampling at the 12 locations along the six streams took place according to a method that would allow for the fastest and most effective way to collect data (Figure 3.4 and Table 3.2). The GPS coordinates of each location were recorded prior to sampling. In

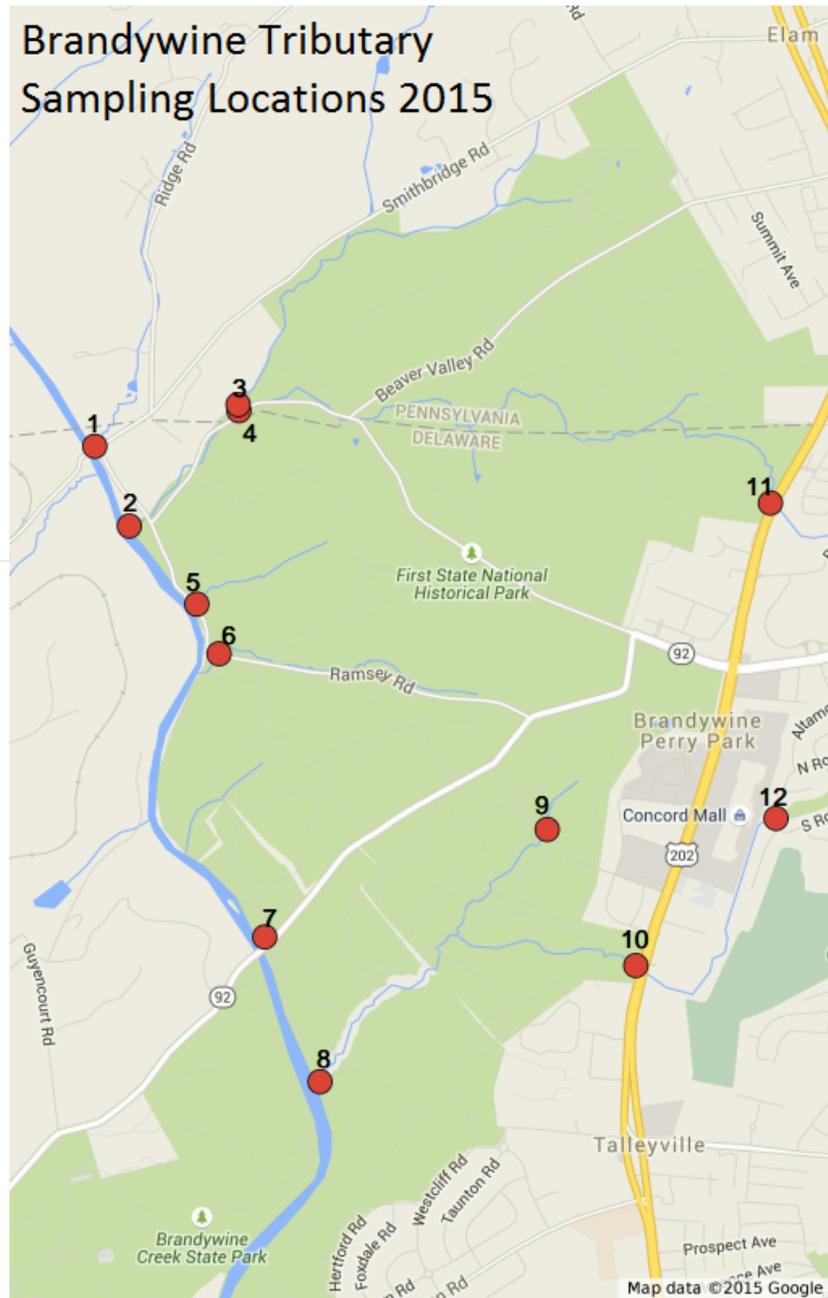
June and July 2015, stream monitoring occurred once a week in the morning between the hours of 9:30am and noon. In addition to chemical testing at each location, stream samples were collected twice during the month of July for bacterial and turbidity sampling. In October through December, stream monitoring occurred twice a month in the afternoon between the hours of 12:00pm and 3:00pm. Once during October, stream samples were collected for solution pH and nutrient analysis tests, performed by the University of Delaware Soil Testing Program. Three data collections were also taken in March and April 2016 between 2:30pm and 4:30pm for turbidity and conductivity. Depending on the location, the characteristics of the streams were variable according to the vegetation, substrate material, depth, and bank stability amongst other habitat characteristics that would define a healthy stream. Not all sampling locations had a riparian vegetative buffer zone that protected the tributaries from erosion, runoff and deposition. For example, Rocky Run upstream of the Concord Pike is heavily channelized, with little to no vegetative protection, before it flows into the FSNHP.

**Table 3.2.** Sampling site latitudinal/longitudinal coordinates

<b>Site No.</b>	<b>Monitoring Location</b>	<b>GPS Coordinates</b>
1	Ridge Run	Lat: 39°50'17" Long: 75°34'44"
2	Beaver Creek Mouth	Lat: 39°50'5" Long: 75°34'44"
3	Beaver Creek North Fork	Lat: 39°50'5" Long: 75°34'17"
4	Beaver Creek South Fork	Lat: 39°50'21" Long: 75°34'16"
5	Talley Run Mouth	Lat: 39°49'53" Long: 75°34'24"
6	Ramsey Run Mouth	Lat: 39°49'46" Long: 75°34'24"
7	Carney Run Mouth	Lat: 39°49'2" Long: 75°34'10"
8	Rocky Run Mouth	Lat: 39°48'42" Long: 75°33'58"
9	Hurricane Run	Lat: 39°49'3" Long: 75°33'33"
10	Rocky Run at Route 202	Lat: 39°48'59" Long: 75°32'58"
11	Beaver Creek at Route 202	Lat: 39°50'7" Long: 75°32'33"
12	Rocky Run Residential Area	Lat: 39°49'21" Long: 75°32'31"

Sampling Locations

- #1 Ridge Run
- #2 Beaver Creek Mouth
- #3 North Fork Beaver Run
- #4 South Fork Beaver Creek
- #5 Talley Run
- #6 Ramsey Run
- #7 Carney Run
- #8 Rocky Run Mouth
- #9 Hurricane Run
- #10 Rocky Run @ Rt 202
- #11 Beaver Creek @ Rt 202
- #12 Rocky Run Residential



**Figure 3.4.** Sampling location map

**Site 1- Ridge Run:** Located slightly south of the border of Pennsylvania and Delaware, this is the northernmost tributary flowing into the Brandywine Creek in the First State National Historical Park (Figure 3.5). 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. On one side of the stream there is evidence of a narrow strip of vegetative buffer between the road and the tributary. There is some overhanging vegetation and little to no bank erosion.



**Figure 3.5.** Site 1: Ridge Run, July 2015

**Site 2- Beaver Creek Mouth:** Water samples were taken before the confluence of Beaver Creek and the Brandywine Creek. As shown in Figure 3.6, the stream is observed to be moderate in width (10-50m), shallow, and slow moving. Boulders and cobble were the main substrates found in this location. There is moderate bank erosion taking place on the right hand-side facing upstream, whereas on the left side there is minimal erosion due to the stabilization of the banks from the trees. On most days where sampling occurred, there have been signs of an overwhelming amount of trash deposited on the banks of the tributary due to the adjacent recreational state park area.



**Figure 3.6.** Site 2: Beaver Creek Mouth, July 2015

**Site 3- Beaver Creek North Fork:** Located further upstream and to the north of Beaver Creek Mouth, the north fork originates near the Concord Pike in Pennsylvania before entering the forested areas of the First State National Historical Park (Figure 3.7). The area that was chosen for this site is located right before the confluence of Beaver Creek North and South. This study site is covered by overhanging vegetation and is characterized by deep pools, slow velocity, and no undercutting of the banks on either side. The northern fork does not run adjacent to any trails or roads, making it less susceptible to pollution from agricultural, industrial, commercial, or residential runoff.



**Figure 3.7.** Site 3: Beaver Creek North Fork, July 2015

**Site 4- Beaver Creek South Fork:** Similar to the north fork, the south fork of Beaver Creek originates in a heavily developed area and flows past the Concord Pike and into the National Park (Figure 3.8). The stream meanders along the Beaver Valley Road and becomes narrower upstream. This site has both riffle and run sections where the velocity of the stream varies. There is a five-foot-high vegetative hill between the tributary and the road at the sampling site, about 50 feet away from the north and south forks.



**Figure 3.8.** Site 4: Beaver Creek South Fork, July 2015

**Site 5- Talley Run:** This specific location of Talley Run runs alongside Brandywine Creek Road and is covered by a heavy understory growth of vegetation (Figure 3.9). There is very minimal vegetation acting as a buffer on the left side of the tributary facing upstream. This area of the stream has the characteristics of an intermittent stream such as its shallow depth, small width, but well-defined channel. There is no noticeable amount of erosion occurring at this sample site. The samples were taken near the mouth of the tributary several feet upstream of where it crosses underneath Brandywine Creek Road.



**Figure 3.9.** Site 5: Talley Run, July 2015

**Site 6- Ramsey Run:** Ramsey Run flows right underneath Ramsey Road before it converges with the Brandywine Creek (Figure 3.10). There is lots of vegetation, (tall grasses, trees, wildflowers) on either side of this narrow stream, keeping the banks stabilized. The sampling site was directly upstream from the bridge where Ramsey Run crosses the road. The result of storm water runoff entering the stream from Ramsey Road, which often had polluted puddles, should be considered as a concern for nonpoint source pollution due to its close proximity.



**Figure 3.10.** Site 6: Ramsey Road, July 2014

**Site 7- Carney Run:** The location chosen for this sampling site is situated at the mouth of the tributary and directly downstream of a pedestrian trail bridge (Figure 3.11). The stream consists of substrate such as gravel and boulder in areas that are visible and are not covered by vegetation. Both banks are overgrown with dense vegetation. Carney Run runs directly alongside Thompson’s Bridge Road and is characterized by low flow.



**Figure 3.11.** Site 7 Carney Run mouth

**Site 8- Rocky Run Mouth:** This section of the stream is located near heavily used hiking and biking recreational trails (Figure 3.12). There are big boulders scattered around in the stream with established trees lining both sides of the banks for stability. 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.



**Figure 3.12.** Site 8: Rocky Run Mouth, July 2015 (facing upstream)

**Site 9- Hurricane Run:** - At this shaded sampling site, the banks of Hurricane Run display moderate signs of erosion and drying up. Due to a recent storm, there are also dead trees lying across the stream. The substrate in this section of the stream is mostly composed of cobblestones and gravel. The sampling site is directly upstream of where the tributary crosses beneath Woodlawn Road and flows into an extensive hiking/biking trail system.

**Site 10- Rocky Run at Route 202:** This area is located between the National Park Boundary and downstream (west) of the Concord Pike (Route 202) overpass (Figure 3.13). Long grasses cover the banks on either side of the stream. 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.



**Figure 3.13.** Site 10: Rocky Run at Route 202, July 2015



**Figure 3.14.** Site 10: Rocky Run at Route 202

**Site 11- Beaver Creek at Route 202:** Beaver Creek also runs underneath the Concord Pike before it enters the National Park (Figure 3.15). At this location, the vegetation is very dense and the banks on either side are steep. There is a lot of trash (broken bottles, plastic bags) scattered on the banks. The color of the water is murky but not to the degree found at the pool of water before the tunnel at Site 12. The stream velocity was slow and there was little to no channel sinuosity. The sampling site was directly downhill and downstream from a horse farm and therefore is in danger of high nutrient levels.



**Fig. 3.15.** Site 11: Beaver Creek at Route 202

**Site 12: Rocky Run Residential:** Rocky Run originates slightly upstream of this residential 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 (Figure 3.16). The coloration of the pool is sometimes noted as copper orange, murky and opaque. The banks on either side of Rocky Run are steep and eroded. This site was chosen because it is downstream of a suburban community but directly upstream of the Concord Mall and Route 202 area, which is very developed.



**Figure 3.16.** Site 12: Rocky Run Residential

### **Chemical Analysis Methods**

The parameters tested at each of the stream sampling locations include pH, conductivity, temperature, turbidity, and dissolved oxygen that were calibrated once a week using standardized procedures to ensure quality control. For example, buffer solutions of pH 4, 7, and 10 were used to calibrate the pH probe. To prevent damage to the probes, a beaker was filled with stream water and brought to a safe location for the chemical assessment. After each use, the probes were wiped off with a Kimwipe to prevent damage.

To test for turbidity (TSS), water samples were collected, stored, and transported to the City of Wilmington Water Quality Lab in 4oz Nasco Whirl-pak bags labeled with the stream name and location number prior to sampling. Using a 100ml beaker, the Whirl-pak bags were filled with stream water to the minimum sampling volume (4 oz line). The tabs on either side of the Whirl-pak bags were then pulled to seal it tightly. The top of the bags were folded twice and flipped over once. The tabs were then folded inwards towards the bag to secure and prevent leakage. The Whirl-pak bags were placed upright in an ice-filled cooler immediately after sampling occurred. A second method of analyzing turbidity was using an MI 415 Turbidity meter borrowed from the University of Delaware. Vials of water were wiped with Kimwipes before each reading in order to ensure accuracy.

To test for nutrients, water samples were collected, stored, and transported to the University of Delaware College of Agriculture and Natural Resources Soil Testing Lab in 500 mL Nalgene bottles labeled with the stream and site number. The jars were kept in a cooler with ice and transferred to a refrigerator and transported to the UD Soil Testing Lab.

## **Pathogen Analysis Methods**

Bacterial quality was tested through enterococci analysis. The City of Wilmington Water Quality Lab provided 100 ml sterilized bottles for bacterial (enterococci) sampling and team members were taught to use the proper technique for sampling by lab staff. Stream water was collected mid-stream in a plastic beaker and poured into a sterilized bottle until filled to the 100ml line. All team members practiced a sterile technique by refraining from touching the mouth of the bottle and setting the lid down while opening, sampling, and closing the bottle. The samples were immediately stored in an ice cooler with a temperature control and transported to the City of Wilmington Water Quality Lab within no more than three hours of collection. TSS and bacterial samples were collected twice during low flow stream conditions in the month of July.

## **Quality Control**

Team members followed the City of Wilmington Water Quality Sampling guidelines, which comply with EPA's monitoring techniques. An additional resource that was used to double-check sampling techniques was EPA's Volunteer Stream Monitoring methods manual, which is a comprehensive document that is in accordance with the U.S Environmental Protection Agency policy and is designed to ensure the validity of field samples collected. To verify the temperature of the bacterial samples, a Temperature Control was used. A sterilized bottle filled with water was placed in the cooler and submitted along with the bacterial samples to the City of Wilmington lab. City of Wilmington Water Quality staff utilized the Temperature Control to monitor and record the temperature of the stream samples testing for bacteria. Additionally, members took samples and data collection from the same exact locations each field day to reduce chances of skewed data (with the exception of site 11 in which the location was moved a few feet downstream after November 6th, 2015 in response to a snake/insect infestation discovered underneath the Route 202 overpass).

## Chapter 4: Field Monitoring Results

### Chemical Results

Graphs are organized into 3 categories: (1) tributaries flowing into Brandywine Creek, (2) Beaver Creek watershed, and (3) Rocky Run watershed.

**Temperature:** Temperature is an important factor for water quality sampling as it can alter other chemical parameters, such as dissolved oxygen (high temperature reduces oxygen levels), conductivity, and pH. Temperature is crucial for maintaining the metabolism of an aquatic ecosystem. According to the EPA Delaware Freshwater Quality Standards, no human-induced increase of the true daily mean temperature above 82°F (27°C) should be allowed. Ridge Run has the highest median temperature of 22.5°C, followed by Rocky Run at Route 202 with a value of 21.5°C. The lowest median temperature of 17.7°C is recorded at Carney Run (Figure 4.1).

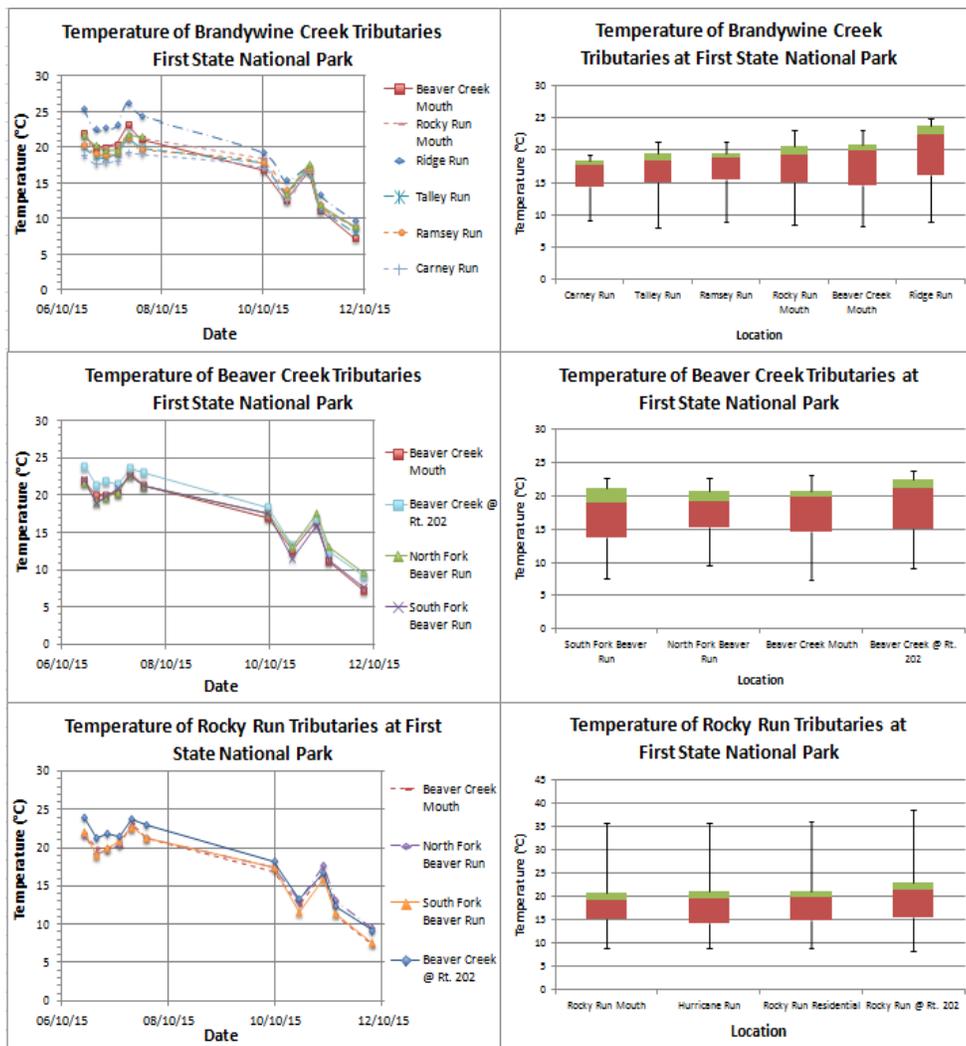


Figure 4.1. Water temperature results

**pH:** 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, hereby showing that there are no impairments in the pH levels and this can be seen in the graphs below. Rocky Run Residential has the lowest median pH value at 7 whereas Beaver Creek Mouth has the highest median pH at a value of 7.9 (Figure 4.2).

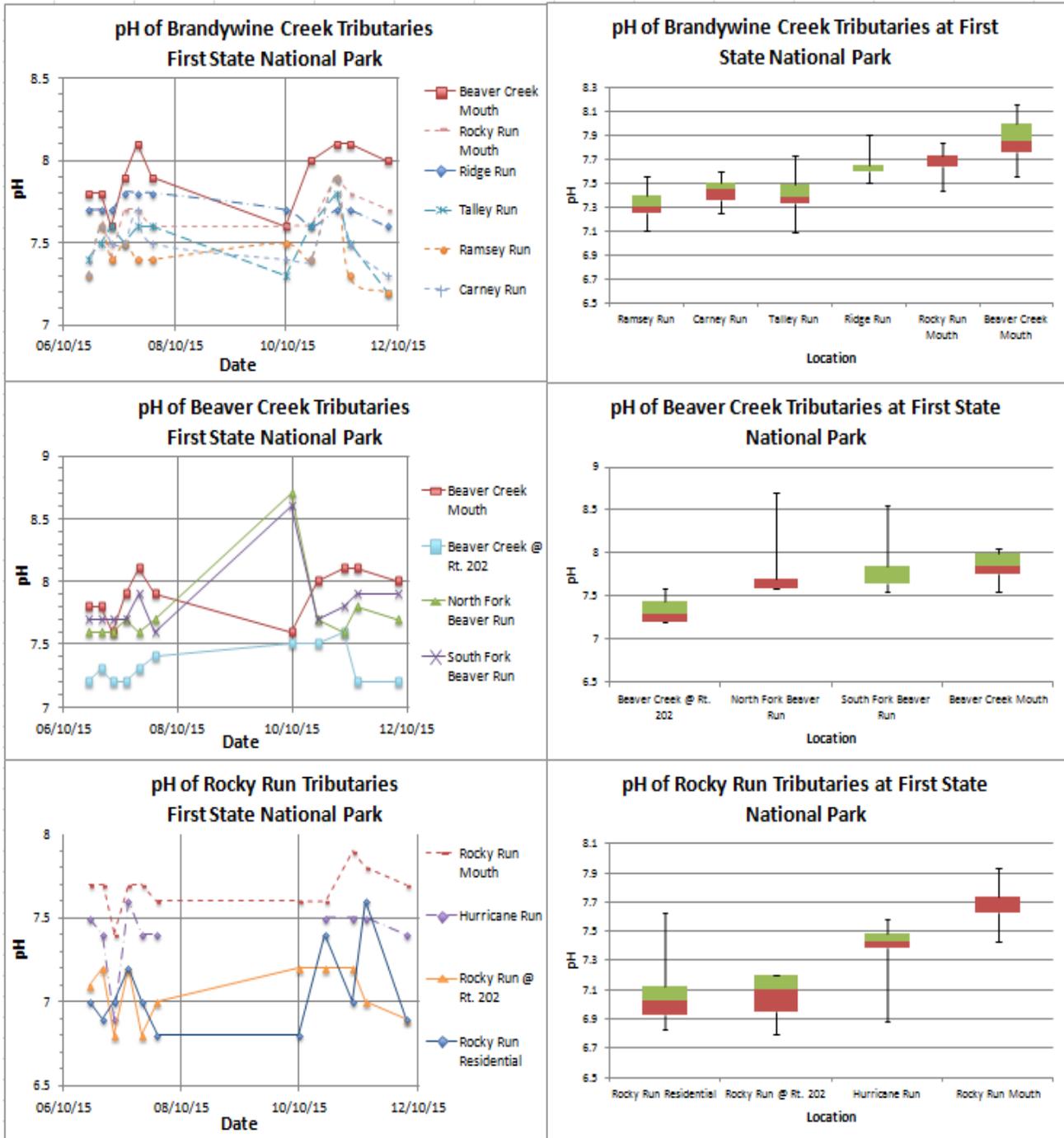


Figure 4.2. pH results

**Turbidity:** Measures both suspended and dissolved particulate matter in water, and is essentially a measure of water murkiness. The higher the turbidity, the “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 to grow. High turbidities have a variety of harmful effects on aquatic wildlife, including prevented development, modified movement and migrations, reducing food availability and growth, decreasing resistance to disease, or death. Turbidity should not exceed a level of 10 NTUs. Data was analyzed 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. 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 NTUs or FNUs (Figure 4.3). However, Rocky Run Mouth has the lowest median turbidity out of all twelve sites, so there is little concern for turbid water entering the Brandywine Creek.

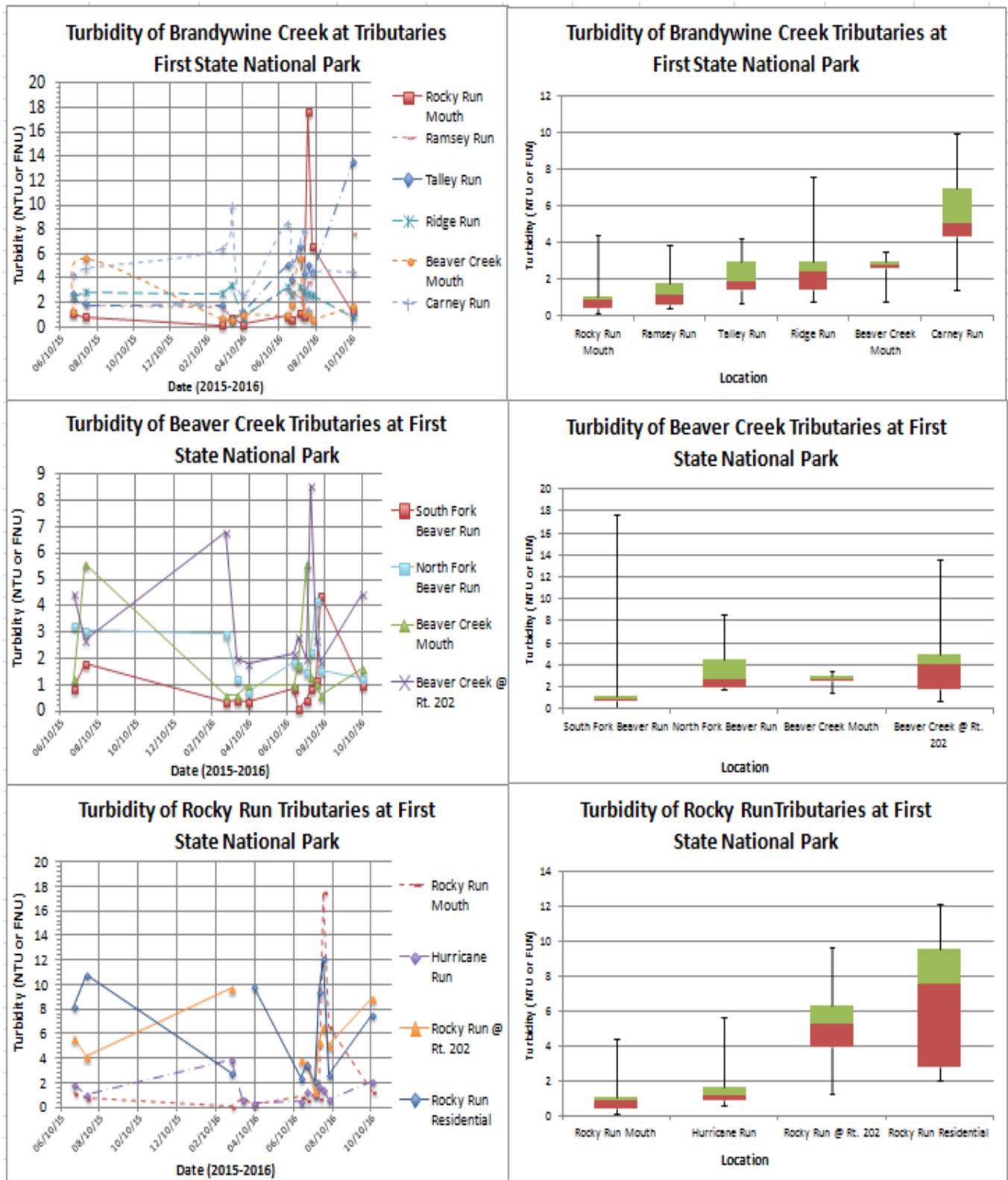


Figure 4.3. Turbidity results

**Dissolved Oxygen:** Fish, macroinvertebrates, plants and bacteria rely on dissolved oxygen to survive. A healthy stream, according to the Water Quality Standards manual, should not have a dissolved oxygen average below 5.5 mg/L. These conditions might occur in slow-moving, narrow waterways with little aquatic plant life. Fish species exposed to less than 5.5 mg/L of dissolved oxygen will have impaired functionality and lower survival rates. The tributaries in the First State National Historical Park all have median dissolved oxygen levels between 7.15 mg/L and 9.8 mg/L (Figure 4.4). The tributary with the lowest median dissolved oxygen (7.15 mg/L) is Beaver Creek at Route 202 and the tributary with the highest median dissolved oxygen (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 be an area of concern for that tributary but not for the Brandywine.

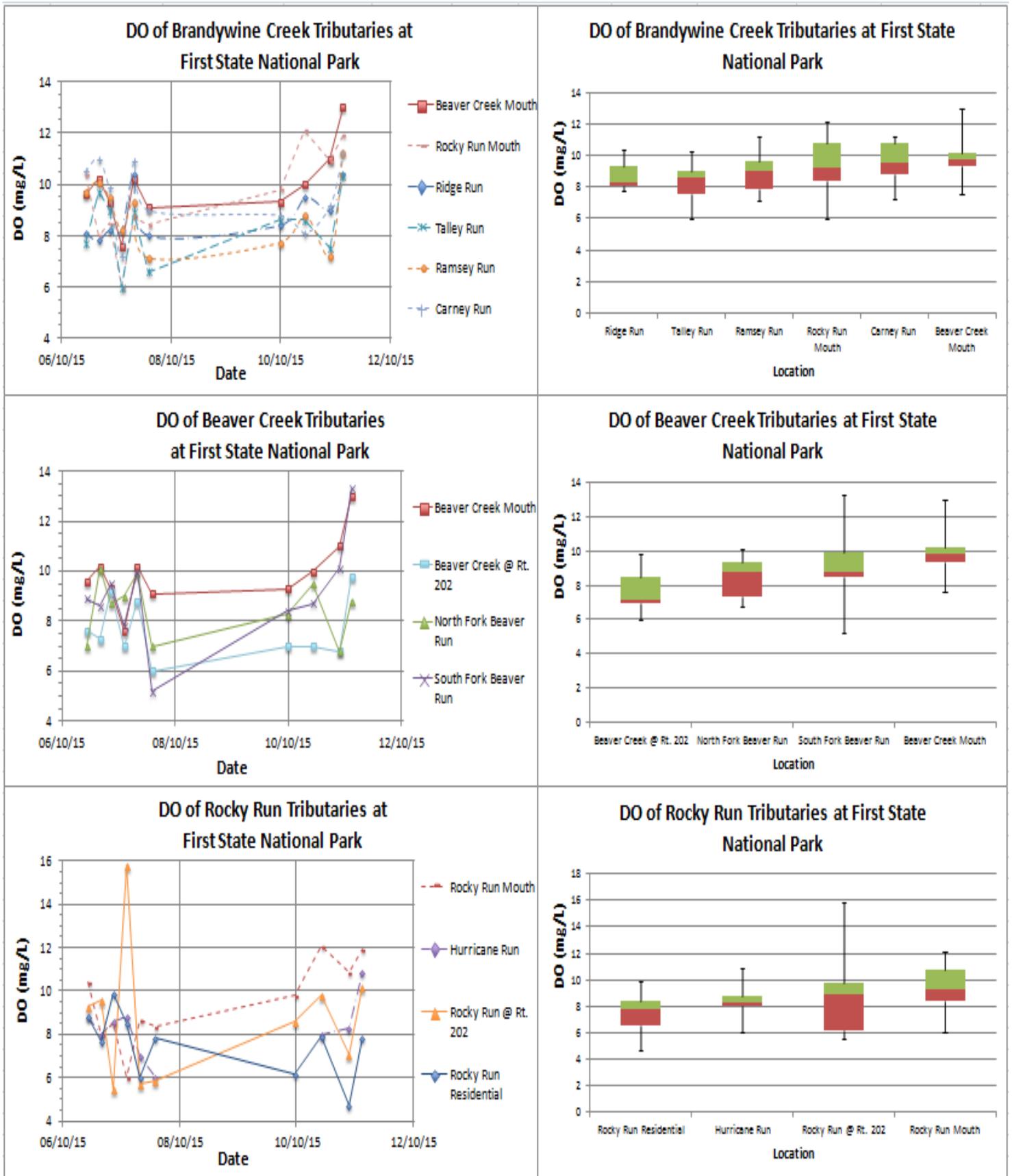


Figure 4.4. Dissolved oxygen results

**Conductivity:** A sudden change in conductivity can indicate pollution due to an increased influx of ions from an external source such as agricultural runoff or residential waste leakage. For aquatic organisms, the ideal value of conductivity is between 150 $\mu$ S and 500 $\mu$ S. However, normal conductivity levels for surface waters are expected to range from 50 $\mu$ S to 1500 $\mu$ S. The highest median conductivity is found at Beaver Creek at Route 202 with a mean of 899 $\mu$ S (Figure 4.5). 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 1720 $\mu$ S. We expect this was due to agricultural runoff from the adjacent horse farm. Talley Run has the lowest median conductivity at a value of 110 $\mu$ S, which may actually indicate low nutrient levels for aquatic life.

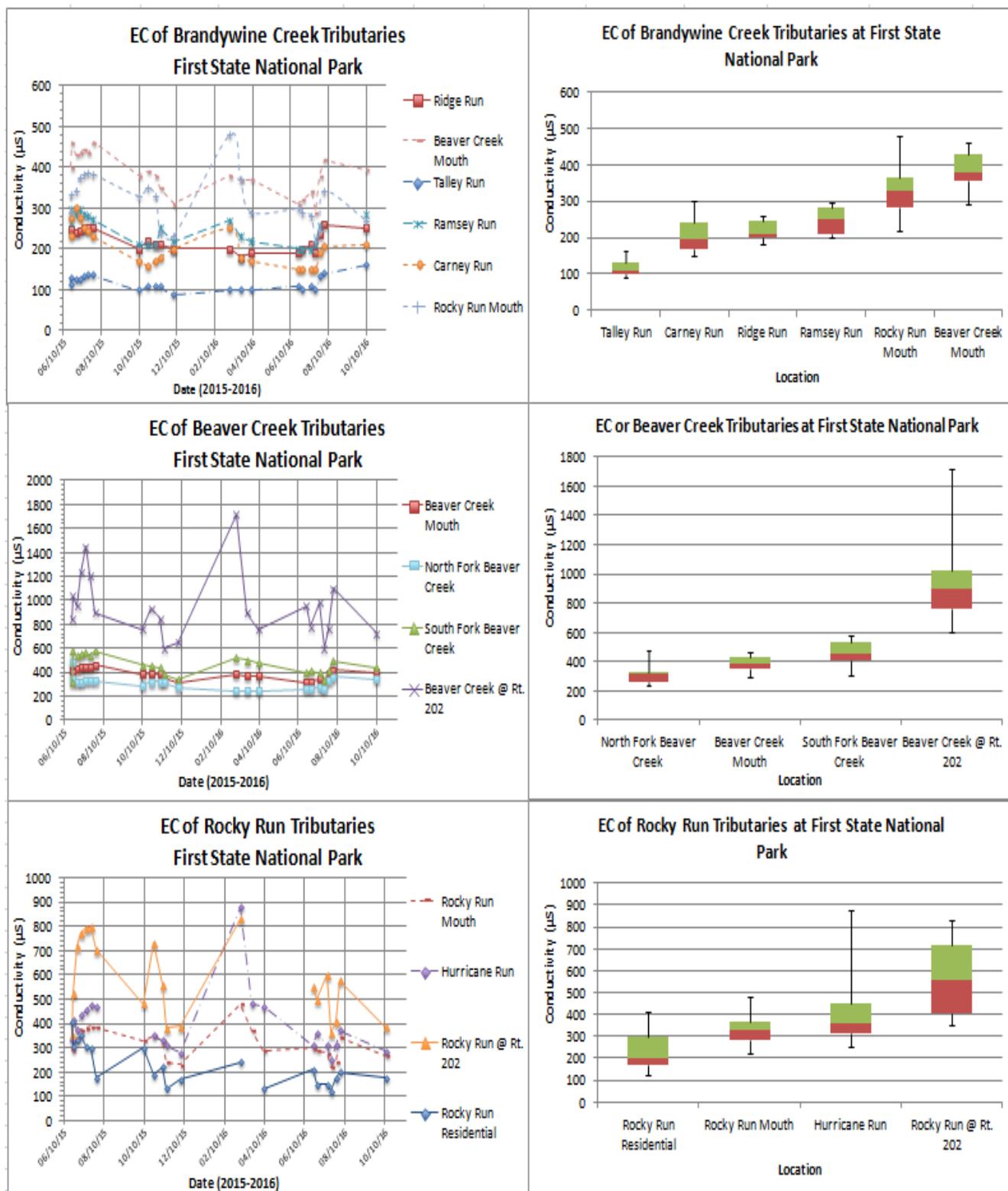


Figure 4.5. Conductivity results

**Nutrients and Metals:** The University of Delaware College of Agriculture and Natural Resources Soil Testing Program performed nutrient Analysis from samples collected on October 9th, 2015. The parameters tested were aluminum, boron, calcium, copper, iron, potassium, magnesium, manganese, sodium, phosphorus, sulfur, zinc, ammonia, and nitrate. For the purposes of our study, we will only analyze copper, iron, manganese,

phosphorus, zinc, ammonia, and nitrate as we deemed the others to be mostly inconsequential to the water quality. Overall, our results showed no problems with the results of the nutrient and metal tests. Test results for all parameters can be found in Table 4.1 below.

**Table 4.1.** Nutrient and Metal data, October 9, 2015

UDSTP Lab No.	Sample No.	Site No.	Sample ID	Al (mg/L)	B (mg/L)	Ca (mg/L)	Cu (mg/L)	Fe (mg/L)	K (mg/L)	Mg (mg/L)
24683	1	Site 1	Ridge Run	0.015	0.008	15.318	0.002	0.079	3.122	6.816
24684	2	Site 2	BC Mouth	0.007	0.010	29.819	0.003	0.116	3.200	13.621
24685	3	Site 3	BC North	0.020	0.003	6.560	0.001	0.071	0.782	3.113
24686	4	Site 4	BC South	0.039	0.009	30.447	0.003	0.065	3.621	14.182
24687	5	Site 5	Talley Run	0.028	0.006	10.127	0.000	0.084	2.702	4.865
24688	6	Site 6	Ramsey Run	0.032	0.006	13.941	0.003	0.078	2.552	7.303
24689	7	Site 7	Carney Run	0.041	0.004	11.134	0.002	0.073	1.705	5.369
24690	8	Site 8	RR Mouth	0.021	0.002	7.785	0.001	0.055	0.944	3.406
24691	9	Site 10	RR 202	0.398	0.010	32.819	0.003	0.373	2.940	12.993
24692	10	Site 11	BC 202	0.049	0.015	66.562	0.005	0.173	5.292	27.515
24693	11	Site 12	RR Residential	0.021	0.002	4.712	0.002	0.068	0.720	1.616

UDSTP Lab No.	Sample No.	Site No.	Sample ID	Mn (mg/L)	Na (mg/L)	P (mg/L)	S (mg/L)	Zn (mg/L)	NH4-N (mg/L)	NO3-N (mg/L)
24683	1	Site 1	Ridge Run	0.001	14.467	0.025	4.956	0.001	<0.01	0.64
24684	2	Site 2	BC Mouth	0.004	34.223	0.031	4.973	0.000	<0.01	1.42
24685	3	Site 3	BC North	0.006	3.561	0.011	0.821	0.000	<0.01	0.22
24686	4	Site 4	BC South	0.001	49.852	0.032	5.757	0.000	<0.01	1.89
24687	5	Site 5	Talley Run	0.000	4.950	0.012	5.280	0.000	<0.01	0.98
24688	6	Site 6	Ramsey Run	0.013	19.822	0.011	3.821	0.000	<0.01	3.79
24689	7	Site 7	Carney Run	0.000	18.546	0.017	2.285	0.000	<0.01	1.34
24690	8	Site 8	RR Mouth	0.000	10.017	0.014	1.084	0.000	<0.01	0.33
24691	9	Site 10	RR 202	0.007	53.203	0.036	4.938	0.005	0.02	0.74
24692	10	Site 11	BC 202	0.044	98.327	0.055	9.156	0.002	<0.01	0.80
24693	11	Site 12	RR Residential	0.001	8.462	0.017	1.099	0.001	<0.01	0.30

**Iron:** Pertaining to aquatic life, ferric irons are of primary concern in waterways. Iron's presence can also indicate organic or inorganic waste substances. The chronic criteria for Iron is 1 mg/L. None of the sampling sites reach this point. The site with the highest Iron levels is Rocky Run at 202 with 0.373 mg/L.

**Nitrate:** The majority of nitrates in waterways sources from fertilizers in agricultural runoff. Other sources include organic waste, domestic effluent, industrial sewage discharge, and leaching from dumps. As a nutrient, high levels of nitrate can suffocate the oxygen in a water body and lead to eutrophication, causing an unhealthy environment for humans, fish, and wildlife. High levels can also cause diseases such as Methemoglobinemia. Nitrate becomes a systemic toxin at a level of 10 mg/L. None of the sites reach this point, but the site with the highest nitrate value (3.79 mg/L) is Ramsey Run. Since Ramsey Run is downstream of farms, nitrates from manure and other fertilizers may be the cause of this relatively high number.

**Copper:** can get into waterways from things such as construction and electric equipment and agricultural use to treat certain plant diseases. While it is an essential nutrient at low levels, copper becomes toxic to both aquatic organisms and humans when it reaches higher levels, leading to health issues including alterations in the nervous, gastrointestinal, hematological, and hepatic systems as well as mortality. None of the sites have a problem

with Copper, which is not a toxin until it reaches .0134 mg/L; none of the sites exceed 0.005 mg/L.

**Ammonia:** Comes from natural sources such as forest fires, animals and human waste, and nitrogen fixation processes, but is also used in commercial fertilizers and various other industrial processes, leading to the possibility of excess in waterways. At high enough levels, the toxin builds up in the tissues and blood of aquatic organisms, sometimes leading to death. According to the World Health Organization, the levels of ammonia in groundwater and drinking water usually does not exceed 0.2mg/L. Ammonia levels were not a problem for any of the sites. They all contained less than 0.02 mg/L.

**Zinc:** Zinc enters water through both natural and human-induced processes, including mining, coal burning, and the burning and disposal of zinc wastes from metal manufacturing industries. Animals can take up zinc through eating and drinking and travels through the food chain as a toxin. The highest Zinc level seen in the tributaries in question is 0.005 mg/L and this element is not toxic until it reaches 7.4 mg/L.

**Manganese:** A naturally occurring element in water, but due to underground pollution sources and air pollution from power plants, it can reach harmful levels. Excessive exposure can lead to human health problems, such as negative impacts on the central nervous system. It also has toxic effects on a variety of aquatic organisms. The limit for Manganese is 0.50 mg/L and the highest seen in these sites is 0.044 mg/L (Beaver Creek at Route 202).

**Phosphorous:** Phosphorous can get into waterways due to runoff from agricultural fertilizers, manure, and organic wastes from sewage. Phosphates are not toxic to people or animals unless they exist at high levels, where it can lead to eutrophication, where over-fertilized aquatic plants and algae use oxygen and choke the waterway. The limit for Phosphorus is 0.2 mg/L and the highest seen in these sites is 0.055 mg/L (Beaver Creek at 202).

## **Pathogen Results**

It is necessary to monitor bacteria in surface waters because they can help detect the presence of harmful pathogens that can negatively affect the health of the people who utilize the streams and rivers both functionally and recreationally. The most common biological indicators are E. coli and enterococci as they both help indicate sewage contamination.

Healthy primary contact recreation fresh waters (swimming, fishing, drinking) should have a maximum single-sample value of 185 MPN. Secondary contact recreation fresh waters (wading, boating, rafting) can have up to 925 MPN for it to be a safe environment to be used recreationally. Results from the City of Wilmington Water Quality lab indicate that the enterococci levels are much higher in certain locations than others. Sampling sites that indicate extremely problematic 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 (Figure 4.6).

Bacterial sampling should be re-done at these sample sites as the bacterial levels seemed abnormally high. If bacteria levels are indeed verified to be this high, then further measures to enforce people from swimming in these tributaries should be taken.

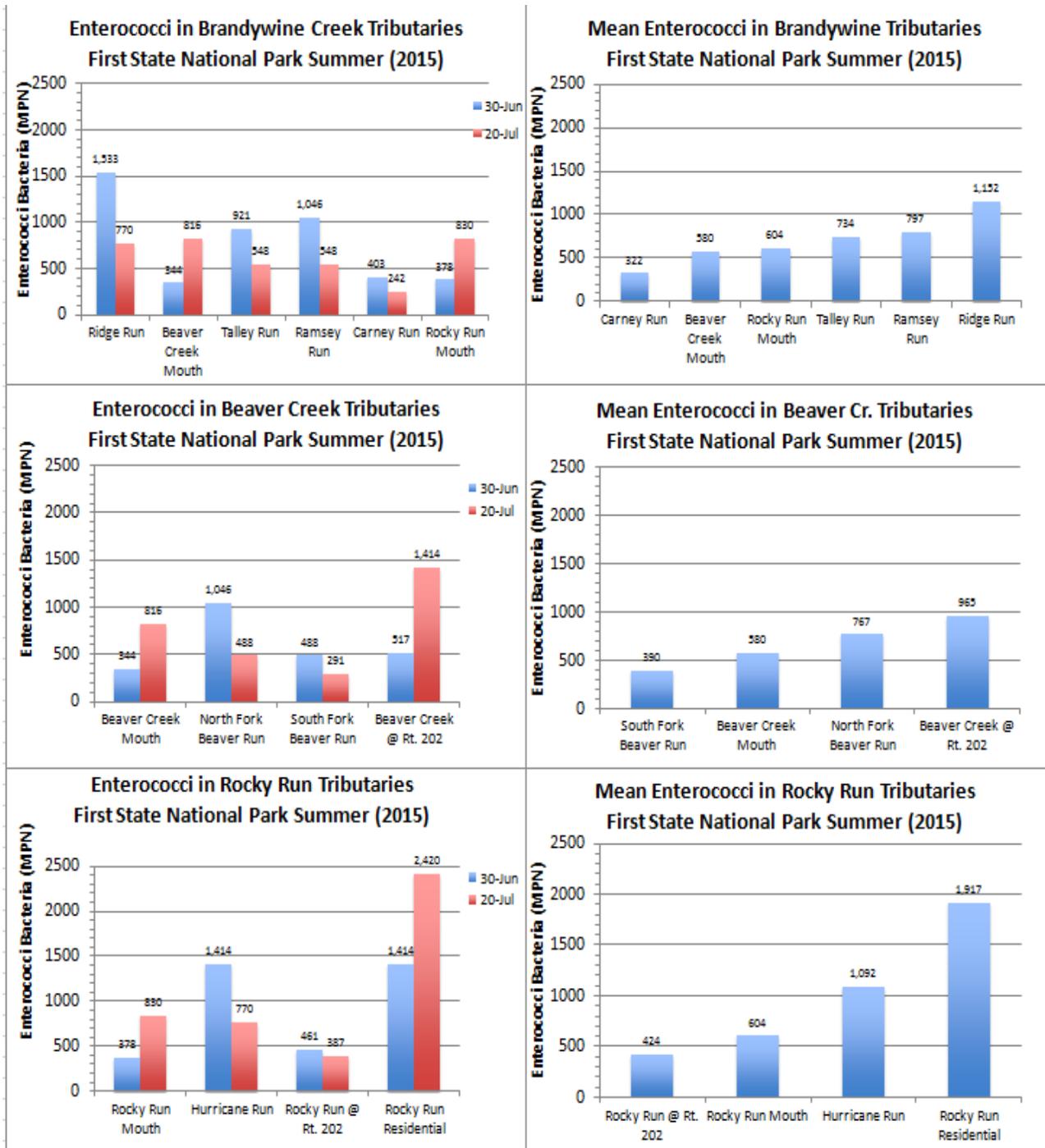


Figure 4.6. Enterococcus bacteria results

## Chapter 5: Discussion and Conclusions

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.

There are a few tributaries in which our results have shown values close to the borderline of having impaired waters. Beaver Creek at Route 202 has the lowest dissolved oxygen levels, the highest conductivity values, and sodium levels that miss the limit by less than 2mg/L. 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. This site also had high levels of bacteria, which may be an indication of farms, horse, and septic systems in the watersheds.

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 pH values and the highest turbidity values of our twelve testing sites. 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 National Historical Park may help restore the water quality of unhealthy streams.

Beaver Creek Mouth has the highest median pH value of 7.9 when compared to the other eleven sampling sites. Ridge Run also has one of the higher pH values, which may be due to its closeness to a horse ranch. The measurements may indicate increased levels of nitrogen and phosphorus from residual runoff, horse manure or other agricultural practices.

To improve the water quality of the tributaries mentioned above, native plants could be planted along roadways where there is clearly not enough of a buffer zone between the road and stream. 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 would be a method to prevent further degradation. Since the Brandywine State Park and First State National Historic Park contain many horse and agricultural farms, it is imperative that preventative measures are taken to prevent nutrient runoff and bacteria from further endangering the adjacent waterways.

In conclusion, we found no nutrient impairments in the Brandywine Creek tributaries. There are some concerns for chemical impairments, specifically conductivity, in certain sites that were adjacent to commercialized or agricultural areas. This may indicate high levels of nutrients from runoff that may impair the ecosystem. There are also concerns about bacterial contamination in many sites, although this research should be continued to add more statistical data. Hopefully these results will help the National Park Service and Delaware State Park to identify problems areas in the Brandywine-Piedmont watershed that may affect water quality and take appropriate actions to prevent further degradation.

## References

- Dowtin, A. and G. Kauffman. 2015. Field Report First State National Park Brandywine-Piedmont Watershed Plan.
- Agency for Toxic Substances and Disease Registry, 2014. Toxic Substances Portal. <<http://www.atsdr.cdc.gov/substances/index.asp>>
- Cruz-Ortiz, C., A. Dowtin, K. Miller, E. Rubino. 2015. Field Report Plan for Rocky Run Environmental Protection (PRREP).
- Delaware Department of Natural Resources and Environmental Control, 2014. Draft Determination for the State of Delaware 2014 Clean Water Act Section 303(d) List of Waters Needing TMDLs. Dover, Del.
- Delaware River Basin Commission, 2013. Water Quality Regulations. <<http://www.state.nj.us/drbc/library/documents/WQregs.pdf>>
- Department of Natural Resources and Environmental Control, 2011. State of Delaware Surface Water Quality Standards. <<http://water.epa.gov/scitech/swguidance/standards/wqslibrary/upload/dewqs.pdf>>
- Alison, K. 2010. Development and Use of Water Quality Indices (WQI) to Assess the Impact of BMP Implementation on Water Quality in the Cool Run Tributary of the White Clay Creek Watershed. University of Delaware.
- Kumar, M., A. Puri. 2012. A Review of Permissible Limits of Drinking Water. Indian J Occup Environ Med, 16(1): 40-44. Accessed 19 February 2016 through National Center for Biotechnology Information.
- Minnesota Pollution Control Agency, 2008. Turbidity: Description, Impact on Water Quality, Sources, Measures. <<https://www.pca.state.mn.us/sites/default/files/wq-iw3-21.pdf>>.
- Schenck, W.S., M. O. Planck, and L. Srogi, 2000. Bedrock Geologic Map of the Piedmont of Delaware and Adjacent Pennsylvania. Delaware Geological Survey.
- Sheffer, M., ed., 2003. Ammonia in Drinking Water. World Health Organization.
- Stream Testing Protocols. Delaware Riverkeeper Network, 8 September 2010. Web. 3 August 2015. <[http://www.delawareriverkeeper.org/pdf/gas\\_drilling\\_stream\\_watchdog\\_protocols.pdf](http://www.delawareriverkeeper.org/pdf/gas_drilling_stream_watchdog_protocols.pdf)>.

## Appendix

### Table A.1. Temperature data

Date	Sites (°C)											
	(1) Ridge Run	(2) Beaver Creek Mouth	(3) North Fork Beaver Creek	(4) South Fork Beaver Creek	(5) Talley Run	(6) Ramsey Run	(7) Carney Run	(8) Rocky Run Mouth	(9) Hurricane Run	(10) Rocky Run at Route 202	(11) Beaver Creek at Route 202	(12) Rocky Run Residential
6/23/15	25.5	21.9	21.7	22	20.1	20.4	18.8	21.8	21.7	24.8	23.9	22.2
6/30/15	22.5	19.9	19.2	19	18.7	19.1	17.7	19.3	20.3	21.5	21.2	19.8
7/6/15	22.7	20	19.8	19.9	18.5	18.9	17.8	20	19.5	22.3	21.9	20.2
7/13/15	23.1	20.4	20.4	20.9	19	19.2	18.1	20.1	19.6	22.9	21.5	20.6
7/20/15	26.3	23.1	22.7	22.7	21.3	21.4	19.2	21.9	21.7	24.3	23.7	22.3
7/28/15	24.5	21.2	21.2	21.3	19.9	19.7	19	21.3	21.5	23.1	23	21.5
10/9/15	19.4	16.9	17.5	17.5	17.8	17.9	17.1	18.4		19.6	18.3	17.8
10/23/15	15.4	12.6	13.1	11.6	13.3	14	12.5	13.2	13.3	13.1	13.3	13.3
11/6/15	17.1	16.6	17.6	15.9	17	16.9	16.4	17	17.7	18	16.7	16.5
11/13/15	13.4	11.2	13.1	11.4	11.3	11.9	11.7	11.7	12	11.4	12.4	11.9
12/4/15	9.7	7.3	9.5	7.6	8.1	8.9	9.1	8.9	8.9	8.3	9.2	8.9

**Temperature Measurements at First State National Park Testing Sites**

### Table A.2. pH data

Date	Sites (pH)											
	(1) Ridge Run	(2) Beaver Creek Mouth	(3) North Fork Beaver Creek	(4) South Fork Beaver Creek	(5) Talley Run	(6) Ramsey Run	(7) Carney Run	(8) Rocky Run Mouth	(9) Hurricane Run	(10) Rocky Run at Route 202	(11) Beaver Creek at Route 202	(12) Rocky Run Residential
6/23/15	7.7	7.8	7.6	7.7	7.4	7.3	7.3	7.7	7.5	7.1	7.2	7
6/30/15	7.7	7.8	7.6	7.7	7.5	7.6	7.6	7.7	7.4	7.2	7.3	6.9
7/6/15	7.7	7.6	7.6	7.7	7.6	7.4	7.5	7.4	6.9	6.8	7.2	7
7/13/15	7.8	7.9	7.7	7.7	7.5	7.5	7.5	7.7	7.6	7.2	7.2	7.2
7/20/15	7.8	8.1	7.6	7.9	7.6	7.4	7.7	7.7	7.4	6.8	7.3	7
7/28/15	7.8	7.9	7.7	7.6	7.6	7.4	7.5	7.6	7.4	7	7.4	6.8
10/9/15	7.7	7.6	8.7	8.6	7.3	7.5	7.4	7.6		7.2	7.5	6.8
10/23/15	7.6	8	7.7	7.7	7.6	7.4	7.4	7.6	7.5	7.2	7.5	7.4
11/6/15	7.7	8.1	7.6	7.8	7.8	7.9	7.9	7.9	7.5	7.2	7.6	7
11/13/15	7.7	8.1	7.8	7.9	7.5	7.3	7.5	7.8	7.5	7	7.2	7.6
12/4/15	7.6	8	7.7	7.9	7.2	7.2	7.3	7.7	7.4	6.9	7.2	6.9

**pH Measurements at First State National Park Testing Sites**

**Table A.3. Turbidity data**

Date	Sites (FNU/NTU)											
	(1) Ridge Run	(2) Beaver Creek Mouth	(3) North Fork Beaver Creek	(4) South Fork Beaver Creek	(5) Talley Run	(6) Ramsey Run	(7) Carney Run	(8) Rocky Run Mouth	(9) Hurricane Run	(10) Rocky Run at Route 202	(11) Beaver Creek at Route 202	(12) Rocky Run Residential
6/30/15	2.44	1.23	3.28	0.838	2.72	2.36	4.18	1.1	1.87	5.62	4.48	8.15
7/20/15	2.83	5.62	3.09	1.79	1.86	1.77	4.82	0.814	1.07	4.18	2.71	10.8
3/4/16	2.77	0.63	2.93	0.33	1.8	1.57	6.42	0.12	3.9	9.67	6.79	2.8
3/21/16	3.45	0.6	1.24	0.42	0.75	0.73	9.92	0.75	0.62		1.98	
4/8/16	0.75	1	0.72	0.36	1.17	0.82	2.64	0.19	0.39		1.78	9.8
6/22/16	3.25	0.96	1.9	0.84	5.02	3.08	8.53	0.88	0.5	3.85	2.18	2.42
6/29/16	2.63	1.77	1.77	0.09	3.81	2.9	5.34	0.57	1.23	3.59	2.8	3.48
7/13/16	3.22	5.62	1.51	0.44	6.52	2.44	6.7	1.03	1.08	1.23	1.99	2.04
7/20/16	2.85	1.3	2.25	0.84	4.43	1.27	7.82	0.81	1.71	5.39	8.56	9.43
7/27/16	2.72	1.03	4.2	1.19	5.07	3.63	1.4	17.61	1.45	6.53	2.69	12.16
8/3/16	2.64	0.6	1.55	4.37	4.48		4.35	6.62	0.6	5.1	1.9	2.7
10/10/16	0.88	1.6	1.22	0.96	13.52	7.62	4.56	1.24	2.08	8.88	4.47	7.53

**Turbidity Measurements at First State National Park Testing Sites**

**Table A.4. Dissolved oxygen data**

Date	Sites (mg/L)											
	(1) Ridge Run	(2) Beaver Creek Mouth	(3) North Fork Beaver Creek	(4) South Fork Beaver Creek	(5) Talley Run	(6) Ramsey Run	(7) Carney Run	(8) Rocky Run Mouth	(9) Hurricane Run	(10) Rocky Run at Route 202	(11) Beaver Creek at Route 202	(12) Rocky Run Residential
6/23/15	8.1	9.6	7	8.9	7.7	9.7	10.5	10.4	8.8	9.3	7.6	8.8
6/30/15	7.8	10.2	10.1	8.6	9.7	10.1	11	8	8	9.6	7.3	7.7
7/6/15	8.2	9.3	8.7	9.5	9	9.5	9.9	8.5	8.6	5.5	9.2	9.9
7/13/15	8.2	7.6	9	7.8	6	8.2	7.2	6	8.8	15.8	7	8.5
7/20/15	10.4	10.2	9.9	10	8.9	9.3	10.9	8.7	7	5.7	8.8	6
7/28/15	8	9.1	7	5.2	6.6	7.1	9	8.4	6	5.9	6	7.8
10/9/15	8.4	9.3	8.3	8.4	8.6	7.7	8.8	9.8		8.6	7	6.2
10/23/15	9.5	10	9.5	8.7	8.6	8.8	8.1	12.1	8	9.8	7	7.9
11/6/15	9	11	6.8	10.1	7.5	7.2	9.2	10.9	8.3	7.1	6.8	4.7
11/13/15	10.4	13	8.8	13.3	10.3	11.2	11.2	11.9	10.9	10.2	9.8	7.8

**DO Measurements at First State National Park Testing Sites**

**Table A.5. Conductivity data**

Date	Sites (µS)											
	(1) Ridge Run	(2) Beaver Creek Mouth	(3) North Fork Beaver Creek	(4) South Fork Beaver Creek	(5) Talley Run	(6) Ramsey Run	(7) Carney Run	(8) Rocky Run Mouth	(9) Hurricane Run	(10) Rocky Run at Route 202	(11) Beaver Creek at Route 202	(12) Rocky Run Residential
6/22/15		400	480	310	115	265	230	290	335	350	840	410
6/23/15	246	461	342	577	130	295	275	333	416	525	1032	307
6/30/15	238	432	315	535	124	283	299	342	372	717	952	330
7/6/15	245	435	311	551	127	296	275	373	434	773	1232	351
7/13/15	251	445	326	561	132	284	251	381	454	792	1444	305
7/20/15	250	435	328	545	137	280	243	387	477	796	1209	296
7/28/15	252	461	331	577	136	271	230	384	468	704	898	176
10/9/15	200	380	290	460	100	210	170	330		480	760	300
10/23/15	220	390	320	450	110	210	160	350	350	730	930	190
11/6/15	210	380	320	440	110	210	170	330	330	560	850	220
11/13/15	210	350	310	380	110	250	180	240	310	380	600	130
12/4/15	200	310	270	340	90	220	200	230	280	390	650	170
3/4/16	200	380	240	520	100	270	250	480	880	830	1720	240
3/21/16	180	370	240	500	100	230	180	370	480		900	
4/8/16	190	370	240	480	100	220	170	290	470		760	130
6/22/16	190	310	260	400	110	200	150	300	310	550	950	210
6/29/16	200	320	260	410	100	200	150	290	360	500	780	150
7/13/16	210	340	280	400	110	200	150	280	310	600	980	150
7/20/16	190	290	260	330	100	210	150	220	250	360	600	120
7/27/16	235	380	330	415	135	255	190	245	310	140	760	175
8/3/16	260	418	360	493	140		205	343	370	576	1100	200
10/10/16	250	395	343	442	162.2	286	210	270	285	386	723	176

**EC Measurements at First State National Park Testing Sites**