



# Status and Trends of Water Quality in the Mid-Atlantic Inventory and Monitoring Network, Water Years 2011–2023



Nathan Dammeyer sampling water quality in Plum Run, Gettysburg National Military Park  
NPS / JEB WOFFORD

# **Status and trends of water quality in the Mid-Atlantic Inventory and Monitoring Network, water years 2011–2023**

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## Abstract

The Mid-Atlantic Inventory and Monitoring Network (MIDN) monitors water quality due to the ecological, management, and policy significance of aquatic resources in MIDN parks. Specifically, water quality is monitored due to the direct effect it has on aquatic communities, the National Park Service's responsibilities for the protection and improvement of water quality, and the clear connection to state-based regulatory programs. Here we provide a summary report on the status and trends in "core" water quality parameters as defined by the National Park Service (i.e., pH, dissolved oxygen, water temperature, and specific conductivity). We include data from discrete monthly or quarterly observations for water years 2011 to 2023 at 47 sites distributed across eight MIDN parks.

Overall, the status of water quality at most sites met state standards for the parameters monitored. Where water quality observations deviated from state standards, this was often due to natural conditions in the associated watershed such as underlying acidic soils or beaver activity. Out of 141 site-parameter combinations, only 10 showed more than 10% of observations outside state standards. And, of these 10, only three are believed to be associated with anthropogenic activity. In those few locations, upstream agricultural use or development is negatively impacting water quality. In terms of trend, significant trends in water quality parameters were rare across the network, and when present, were relatively small. Even though current monitoring suggests relatively good water quality across the MIDN, these conclusions are based on discrete monthly or quarterly samples, and it is possible that field observations during other times of the day would reveal additional water quality issues given large diel changes in water quality in some streams.

Although state water quality standards were generally met for the observed "core" parameters, it is important to note that these parameters represent a small portion of the many factors necessary for healthy stream ecosystems. Traits such as quality substrate, habitat complexity, good riparian condition, and other water quality criteria (e.g., nutrients and heavy metals) are also important. A more complete understanding of stream ecosystem health must include other components such as biological and physical habitat assessments.

## List of Acronyms

**APCO:** Appomattox Courthouse National Historical Park

**BOWA:** Booker T. Washington National Monument

**EISE:** Eisenhower National Historic Site

**FRSP:** Fredericksburg and Spotsylvania National Military Park

**GETT:** Gettysburg National Military Park

**HOFU:** Hopewell Furnace National Historic Site

**I&M:** Inventory and Monitoring Program

**MIDN:** Mid-Atlantic Network

**NB:** National Battlefield

**NBP:** National Battlefield Park

**NHP:** National Historical Park

**NHS:** National Historic Site

**NM:** National Monument

**NPS:** National Park Service

**PADEP:** Pennsylvania Department of Environmental Protection

**PETE:** Petersburg National Battlefield

**RICH:** Richmond National Battlefield Park

**TMDL:** Total Maximum Daily Load

**VADEQ:** Virginia Department of Environmental Quality

**WY:** Water year

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We extend thanks to the numerous park staff and volunteers over the years that contributed to the collection of these data. This monitoring program could not be implemented without their contributions. We would especially like to recognize the efforts of J. Borgman, L. Borgman, and D. Kelso along with their dedicated cadre of volunteers at Booker T. Washington National Monument. Additionally, we would like to thank A. Birch, M. Johnson, and A. Weed for their thoughtful comments that improved this report.

# Introduction

The Mid-Atlantic Inventory and Monitoring Network (MIDN) was created as part of the National Park Service (NPS) Natural Resource Inventory and Monitoring Program (I&M) which was established in 1998. The purpose of the MIDN is to collect monitoring data to describe the status and trends of ecosystems within national parks across the Mid-Atlantic region. After the creation of the MIDN, several ecosystem components (termed “vital signs”) were selected for monitoring, including water quality (Comiskey and Callahan 2008). Water quality is monitored due to the direct effect on aquatic communities, the National Park Service’s responsibilities for the protection and improvement of water quality, and the clear connection to state-based regulatory programs. Water quality is ecologically significant as it directly affects aquatic communities (Karr et al. 1985), and the National Park Service has a legal requirement to (1) protect pristine water quality, and (2) improve impaired water quality (Rosenlieb and Long 2006). MIDN streams provide habitat for aquatic and semi-aquatic organisms, are a water source for terrestrial wildlife and local municipalities and represent a significant portion of the publicly accessible headwater streams in the surrounding communities.

Here we report on the status and trends in water quality at 47 sites distributed across eight MIDN parks for water years (i.e., October of one year through September of the following year) 2011 – 2023. We include information on NPS defined “core” water quality parameters including pH, dissolved oxygen, water temperature, and specific conductivity (Irwin 2008). The purpose of this report is to provide information on the status and trends for these site-parameter combinations relative to state-based water quality standards using discrete water quality data. Although the MIDN water quality monitoring protocol includes both discrete and continuous monitoring, this report is limited to discrete water quality data. Future reporting will provide a more complete assessment of ecosystem health by incorporating additional data (e.g., benthic macroinvertebrate monitoring, continuous water quality data) at a more focused spatial scale (e.g., park or stream).

## Study areas

In all, a total of 47 sites across eight parks are monitored for water quality in the MIDN. In Virginia, these sites include three sites at Appomattox Court House National Historical Park (APCO), five sites at Booker T. Washington National Monument (BOWA), 14 sites at Fredericksburg and Spotsylvania National Military Park (FRSP), 10 sites at Petersburg National Battlefield (PETE), and eight sites at Richmond National Battlefield Park (RICH). In Pennsylvania, these sites include two sites at Eisenhower National Historic Site (EISE), three sites at Gettysburg National Military Park (GETT), and two sites at Hopewell Furnace National Historic Site (HOFU; see Appendix A for additional site information). The target population for monitoring locations was limited to wadeable streams that had at least a 250-meter reach within or adjacent to park lands. Preference for downstream locations near park boundaries was used which achieved a near census of MIDN wadable streams greater than first order (Dammeyer and Weed 2017).

For context, it is important to note that water quality monitoring sites across the MIDN are in highly variable watersheds (see Appendix A in Dammeyer and Weed, 2017, for site watershed characteristics). Some watersheds are entirely under park management while others have very little

park ownership. Watershed size can vary widely across sites as well; site EISE\_03 (Marsh Creek) drains approximately 14,500 hectares (35,830 acres) while site RICH 02 (unnamed tributary of the Chickahominy River) drains approximately 35 hectares (86.5 acres). Land use is also highly variable across site watersheds. Some sites are in heavily forested and undeveloped watersheds, others are in watersheds that are highly developed or are dominated by agricultural land use. Extreme examples include Baptism Creek in Hopewell Furnace NHS (HOFU\_02) which drains a watershed that is 90% forested. In contrast, 68% of the FRSP\_08 (Hazel Run) watershed is developed and 59% of the GETT\_01 (Willoughby Run) watershed is in agricultural land use (Dammeyer and Weed 2017). This watershed diversity occurs not only across parks but within parks as well. This context is important and requires site level data interpretation.

# Methods

## Field procedures

Water quality observations were collected from field locations following procedures outlined in the Water Quality Monitoring Protocol for the Mid-Atlantic Network (Dammeyer and Weed 2017). Data collection was initiated at some sites in 2008 and at all sites by 2010 with various discrete sampling frequencies (monthly or quarterly). Field collection and quality assurance procedures during pilot testing of the protocol (2008-2017) were equivalent to final protocol methodologies (e.g., calibration schedule, sensor checks). After the publication of the protocol in 2017, observations were targeted to occur approximately every 30 days (i.e., monthly) at all sites year-round. Due to logistical constraints (e.g., available effort, field activity restrictions) consistency of monthly field events varied over the period of record. Attempts were made to reduce variation in the time of day of observation at individual sites, but logistical considerations could not always accommodate this (e.g., change in travel schedules to sites shifting from morning to afternoon). In the field, pH, dissolved oxygen, water temperature, and specific conductivity were observed in-situ using a calibrated multiparameter water-quality sonde. Reporting on continuous monitoring will be the focus of future work.

## Data screening

Data collection occurred as early as October 2008, but monitoring across the MIDN was not fully implemented until June 2010 making WY 2011 the first complete water year (a water year is defined as October through September of the following year). Data for this report were limited to complete water years (WY 2011 through WY 2023). Data were further screened to include only flowing water conditions. A subset of monitored streams have periods of no surface flow during certain months (i.e., intermittent status) or after prolonged drought. These monitoring locations can contain isolated pools that could be monitored for water quality parameters but are not representative of flowing stream conditions. Therefore, we excluded any water quality data collected when stream flows were recorded as “no flow”, “interstitial”, or “dry”.

## Data analysis

All data analyses were completed using R v.4.2.3 (R Core Team 2023) and the EnvStats (Millard 2013) package for R. Data are reported (i.e., rounding conventions) following USGS reporting guidelines found in the National Field Manual (USGS 2018).

## *Water-quality standards comparison*

When evaluating the status of water quality parameters, values were compared to standards published by states for relevant stream classes (Virginia 9VAC25-260-50, accessed at [law.lis.virginia.gov](http://law.lis.virginia.gov) on 09/25/2023 and Pennsylvania 25 Pa. Code § 93.7, accessed at [www.pacodeandbulletin.gov](http://www.pacodeandbulletin.gov) on 9/25/2023; Table 1). Stream classes for individual sites can be found in Appendix A. Throughout the report, we reference water quality “excursions.” Excursions are defined as observations that deviate from state standards (e.g., for a pH standard of 6–9, an “excursion” is defined as a pH observation less than 6 or greater than 9).

**Table 1.** Water quality standards relevant to streams monitored in MIDN. Specific conductance does not have a state standard in Virginia or Pennsylvania.

| State        | State stream class <sup>A</sup> | pH                     | Dissolved oxygen (mg/l)  | Water temperature (°C) |
|--------------|---------------------------------|------------------------|--------------------------|------------------------|
| Virginia     | III                             | 6.0 – 9.0              | Minimum 4.0              | Maximum 32.0           |
| Virginia     | VII                             | 3.7 – 8.0 <sup>B</sup> | N/A <sup>B</sup>         | Maximum 32.0           |
| Pennsylvania | WWF                             | 6.0 – 9.0              | Minimum 5.0              | N/A <sup>D</sup>       |
| Pennsylvania | CWF, EV                         | 6.0 – 9.0              | Minimum 5.0 <sup>C</sup> | N/A <sup>D</sup>       |

<sup>A</sup> Stream class is established by VADEQ (9VAC25-260, Sections 360-540; III = nontidal waters in coastal and piedmont zones, VII = swamp waters) and PADEP (25 Pa. Code 93.1; WWF = warm water fishery, CWF = cold water fishery, EV = exceptional value).

<sup>B</sup> No relevant standard. Virginia acknowledges that the natural qualities of Class VII waters may fluctuate outside published water quality standards, and that “the natural quality of these waters is the water quality found or expected in the absence of human-induced pollution.”

<sup>C</sup> For streams with natural trout reproduction, PADEP dissolved oxygen standard is a minimum of 8.0 mg/l for October 1 – May 31.

<sup>D</sup> No relevant standard. Maximum temperature criteria in Pennsylvania are only applied to streams with regulated waste sources and documented thermal effects on biological resources as defined in PA code (Shull and Whiteash 2021; see discussion below).

Pennsylvania only applies water quality temperature standards when a thermal impact to biological resources (e.g., fish communities) has been documented, and a waste-water source is present (Shull and Whiteash 2021). Pennsylvania’s water quality temperature criteria should not be applied to surface waters in isolation of other data (M. Lookenbill, PADEP, personal communication), and we therefore exclude temperature standards from PA sites in this analysis. Dissolved oxygen standards in Pennsylvania also vary based on site-specific biological criteria. The Baptism Creek site in Hopewell Furnace NHS has a known brook trout population (site HOFU\_02; Sharpe and Keener 2003) and therefore, Pennsylvania’s more stringent dissolved oxygen standard for natural reproducing salmonid early life stages was applied (i.e., minimum 8.0 mg/l for October 1 – May 31 and minimum 5.0 mg/l for June 1 – September 30).

Based upon state thresholds of impairment and for purposes of reporting, we define 0–2% of excursions as “few” (PADEP uses a 2% excursion threshold for determining if a water body needs closer consideration for impairment determination) and >10% of excursions as “substantial” (VA uses a relatively strict 10.5% excursion threshold for impairment determination). We define an excursion percentage between 3–9% as “moderate”.

### ***Trend analysis***

Trends were estimated using the seasonal Kendall test adjusted for serial correlation as recommended in Helsel et al. (2002). As described below, the purpose of this analysis is to detect monotonic trends in the parameters monitored while controlling for seasonal effects. The seasonal Kendall test provides a long-standing method for assessing trends in water quality data using Kendall’s tau correlation coefficient. As described in Weissinger (2022):

*“The seasonal Kendall is a non-parametric, rank-based test, meaning it scores concentrations as higher or lower than a seasonal median value but does not evaluate the magnitude of departure from the median. For this reason, the seasonal Kendall test is robust for evaluating water-quality datasets, which often contain extreme concentrations and censored values.*

*The seasonal Kendall test accounts for expected seasonal variation in water-quality parameters by comparing concentrations within user-defined seasons (e.g., monthly, quarterly, semi-annual) and then aggregating the results for each season into an overall test for trend at a site (Helsel et al. 2002). For example, if the season is set to “monthly,” then samples collected during May are always compared to other samples from May, while August samples are always compared to August samples. The trends for each defined season are then combined to determine whether there is an overall trend for that constituent. Seasons with opposite trends are cancelled out in this analysis and would result in an overall evaluation of no trend. A consistent trend across seasons would result in an overall upward or downward trend.”*

General procedures outlined in Schertz et al. (1991) were utilized to select appropriate seasonal periods for each site and to confirm that a sufficient data record was available for the trend analysis. Data records were first assessed to determine if they could be analyzed at the monthly time scale on a site-parameter basis, and if data were insufficient, site-parameter combinations were then assessed on a quarterly scale. Site-parameter combinations that had fewer than seven months of observations with at least 50% of comparisons in the first and last 20% of the data were excluded from monthly seasonal analyses. Quarterly sites with fewer than three quarters with at least 50% of comparisons in the first and last 20% of the data were excluded from quarterly analysis and therefore were not considered for trends. Additionally, sites were screened to ensure that >50% of the seasonal data record was available and that each site had a data record spanning a minimum of five years and a minimum number of observations of at least three times the designated number of seasons. Quarters were defined by water year as October – December, January – March, April – June, and July – September. The seasonal Kendall test requires one observation per seasonal period, and following Schertz et al. (1991), in seasons where more than a single observation was present, the most central observation to the seasonal period with respect to time was selected for estimating the trend. Occasionally, an individual site had two visits during a single month. These events were evaluated to establish if they represented separate seasonal events (e.g., monitoring event occurred on September 29 when the target date was October 2). If an event was determined to represent a separate season, it was assigned to the appropriate season, otherwise, the event was removed from the dataset prior to analysis. Trend analyses were evaluated at  $p \leq 0.05$  for statistical significance.

Time of day of water quality observations can be important as diel changes in some water quality parameters can be substantial, particularly in nutrient enriched streams (EPA 2000). We discuss the effect of time of observation on status determinations in site level discussions when pertinent. In addition, variation in the time of day of observations over the period of record can influence trend detection. Therefore, we used scatterplots of observation time vs. visit date to assess observation time

implications on data interpretation. Although the protocol did not have any site-specific constraints to minimize variation in the time of water quality observations, observation times were generally consistent within sites (i.e.,  $\pm$  3-hour observation window) as routes for travel between locations were specified in operating procedures. An exception was at Appomattox Courthouse where observations shifted from afternoon to morning over the period of record because of travel and logistical changes. Given that this is the only park where changes in sampling time likely impacted results, we did not alter trend modeling procedures to address observation time variability but discuss the impacts of this variability in the Appomattox site discussion. All results are included below, but we generally constrained data interpretation and textual discussion to sites where more than 10% of the observations deviated from state standards or where a significant trend was documented.

## Results and Discussion

Based on state standards for the water quality parameters monitored, most sites had water quality that met standards and was stable over the period of record (Table 2). Nevertheless, 9 sites deviated from state standards in more than 10% of the observations though many of these excursions were due to natural conditions. Out of 141 site-parameter combinations (specific conductance does not have a state standard, and temperature does not have a state standard in PA relevant to the locations monitored), 10 had more than 10% of their measurements outside of state standards and only three of these are believed to be associated with anthropogenic activity. In general, when trends were present, they were associated with relatively small changes in observed values over the period of record (Table 2). Individual national park results are discussed below.

**Table 2.** Summary of status (% of observations deviating from state standards) and trends (rate of change per year) of core parameters across all MIDN monitoring sites. Excursions (deviations from state standards) are color coded as few (green, 0–2%), moderate (yellow, 3–9%), or substantial (red, 10+%) excursions from state standards. Excursions with “N/A” indicate parameters where a state standard was not applied. Only statistically significant trends are reported. Trends with “N/A” indicate insufficient data for trend analysis for that site/parameter and a “—” represents a non-significant trend.

| Park | Site | pH    |             | Dissolved oxygen (mg/L) |             | Water temperature (°C) |             | Specific conductivity (µS/cm) |             |
|------|------|-------|-------------|-------------------------|-------------|------------------------|-------------|-------------------------------|-------------|
|      |      | Trend | Excursion % | Trend                   | Excursion % | Trend                  | Excursion % | Trend                         | Excursion % |
| APCO | 01   | –0.04 | 0–2         | –                       | 0–2         | –                      | 0–2         | –                             | N/A         |
| APCO | 02   | –0.04 | 0–2         | –                       | 0–2         | –                      | 0–2         | –                             | N/A         |
| APCO | 03   | –0.04 | 0–2         | –                       | 0–2         | –                      | 0–2         | –                             | N/A         |
| BOWA | 01   | –     | 0–2         | –                       | 0–2         | –                      | 0–2         | –                             | N/A         |
| BOWA | 02   | –     | 0–2         | –                       | 0–2         | –                      | 0–2         | 0.67                          | N/A         |
| BOWA | 03   | –     | 0–2         | –                       | 0–2         | –                      | 0–2         | 0.74                          | N/A         |
| BOWA | 04   | –     | 0–2         | –                       | 0–2         | –                      | 0–2         | –                             | N/A         |
| BOWA | 05   | –     | 0–2         | –                       | 0–2         | –                      | 0–2         | 0.97                          | N/A         |
| EISE | 03   | –     | 0–2         | –                       | 0–2         | –                      | N/A         | –                             | N/A         |
| EISE | 04   | –     | 10+         | –                       | 3–9         | –                      | N/A         | –                             | N/A         |
| FRSP | 01   | –0.01 | 0–2         | –                       | 10+         | –                      | 0–2         | –                             | N/A         |
| FRSP | 02   | –0.02 | 10+         | –                       | 10+         | –                      | 0–2         | –                             | N/A         |
| FRSP | 03   | –     | 0–2         | –                       | 0–2         | –                      | 0–2         | –                             | N/A         |
| FRSP | 04   | –     | 0–2         | –                       | 3–9         | –                      | 0–2         | –                             | N/A         |
| FRSP | 06   | –     | 10+         | –                       | 0–2         | –                      | 0–2         | –                             | N/A         |
| FRSP | 08   | –     | 0–2         | –                       | 0–2         | –                      | 0–2         | –                             | N/A         |
| FRSP | 09   | –     | 3–9         | –                       | 0–2         | –                      | 0–2         | –                             | N/A         |
| FRSP | 10   | –     | 0–2         | –                       | 3–9         | –                      | 0–2         | –                             | N/A         |
| FRSP | 11   | –     | 0–2         | –                       | 0–2         | –                      | 0–2         | –                             | N/A         |
| FRSP | 14   | –     | 0–2         | 0.09                    | 0–2         | –                      | 0–2         | –                             | N/A         |
| FRSP | 15   | –     | 0–2         | –                       | 0–2         | –                      | 0–2         | –                             | N/A         |
| FRSP | 16   | –     | 0–2         | –                       | 0–2         | –                      | 0–2         | –                             | N/A         |
| FRSP | 17   | –     | 10+         | –                       | 0–2         | –                      | 0–2         | –                             | N/A         |

**Table 2 (continued).** Summary of status (% of observations deviating from state standards) and trends (rate of change per year) of core parameters across all MIDN monitoring sites. Excursions (deviations from state standards) are color coded as few (green, 0–2%), moderate (yellow, 3–9%), or substantial (red, 10+%) excursions from state standards. Excursions with “N/A” indicate parameters where a state standard was not applied. Only statistically significant trends are reported. Trends with “N/A” indicate insufficient data for trend analysis for that site/parameter and a “—” represents a non-significant trend.

| Park | Site | pH    |             | Dissolved oxygen (mg/L) |             | Water temperature (°C) |             | Specific conductivity (µS/cm) |             |
|------|------|-------|-------------|-------------------------|-------------|------------------------|-------------|-------------------------------|-------------|
|      |      | Trend | Excursion % | Trend                   | Excursion % | Trend                  | Excursion % | Trend                         | Excursion % |
| FRSP | 18   | —     | 0–2         | —                       | 0–2         | —                      | 0–2         | —                             | N/A         |
| GETT | 01   | —     | 3–9         | —                       | 3–9         | —                      | N/A         | —                             | N/A         |
| GETT | 06   | —     | 3–9         | —                       | 0–2         | —                      | N/A         | —                             | N/A         |
| GETT | 07   | —     | 0–2         | —                       | 3–9         | —                      | N/A         | —                             | N/A         |
| HOFU | 01   | —     | 0–2         | N/A                     | 0–2         | —                      | N/A         | 1.82                          | N/A         |
| HOFU | 02   | —     | 0–2         | N/A                     | 0–2         | —                      | N/A         | —                             | N/A         |
| PETE | 01   | —     | 0–2         | —                       | 0–2         | —                      | 0–2         | —                             | N/A         |
| PETE | 02   | —     | 0–2         | —                       | 0–2         | —                      | 0–2         | —                             | N/A         |
| PETE | 03   | —     | 0–2         | —                       | 0–2         | —                      | 0–2         | —                             | N/A         |
| PETE | 04   | —     | 0–2         | —                       | 0–2         | —                      | 0–2         | —                             | N/A         |
| PETE | 05   | —     | 0–2         | —                       | 0–2         | —                      | 0–2         | —                             | N/A         |
| PETE | 06   | N/A   | 0–2         | N/A                     | 0–2         | N/A                    | 0–2         | N/A                           | N/A         |
| PETE | 07   | —     | 0–2         | —                       | 0–2         | —                      | 0–2         | —                             | N/A         |
| PETE | 08   | N/A   | 0–2         | N/A                     | 0–2         | N/A                    | 0–2         | N/A                           | N/A         |
| PETE | 09   | N/A   | 0–2         | N/A                     | 0–2         | N/A                    | 0–2         | N/A                           | N/A         |
| PETE | 10   | —     | 10+         | —                       | 3–9         | —                      | 0–2         | —                             | N/A         |
| RICH | 01   | —     | 0–2         | 0.08                    | 0–2         | —                      | 0–2         | —                             | N/A         |
| RICH | 02   | —     | 0–2         | 0.06                    | 0–2         | —                      | 0–2         | —                             | N/A         |
| RICH | 03   | 0.04  | 10+         | —                       | 3–9         | —                      | 0–2         | —                             | N/A         |
| RICH | 04   | —     | 10+         | —                       | 0–2         | —                      | 0–2         | —                             | N/A         |
| RICH | 05   | —     | 3–9         | —                       | 0–2         | —                      | 0–2         | —                             | N/A         |
| RICH | 06   | —     | 3–9         | —                       | 10+         | —                      | 0–2         | —                             | N/A         |
| RICH | 07   | —     | 3–9         | —                       | 3–9         | —                      | 0–2         | —                             | N/A         |

**Table 2 (continued).** Summary of status (% of observations deviating from state standards) and trends (rate of change per year) of core parameters across all MIDN monitoring sites. Excursions (deviations from state standards) are color coded as few (green, 0–2%), moderate (yellow, 3–9%), or substantial (red, 10+%) excursions from state standards. Excursions with “N/A” indicate parameters where a state standard was not applied. Only statistically significant trends are reported. Trends with “N/A” indicate insufficient data for trend analysis for that site/parameter and a “—” represents a non-significant trend.

| Park | Site | pH    |             | Dissolved oxygen (mg/L) |             | Water temperature (°C) |             | Specific conductivity (µS/cm) |             |
|------|------|-------|-------------|-------------------------|-------------|------------------------|-------------|-------------------------------|-------------|
|      |      | Trend | Excursion % | Trend                   | Excursion % | Trend                  | Excursion % | Trend                         | Excursion % |
| RICH | 08   | 0.01  | 0–2         | 0.14                    | 3–9         | —                      | 0–2         | –10.93                        | N/A         |

## **Virginia National Parks**

Five national parks were monitored for water quality in the Commonwealth of Virginia including Appomattox Court House NHP, Booker T. Washington NM, Fredericksburg and Spotsylvania NMP, Petersburg NBP, and Richmond NB.

### ***Appomattox Court House National Historical Park***

Three perennial stream sites were monitored for water quality at Appomattox Court House NHP (Figure 1). None of these sites had documented excursions from state water-quality standards for any parameter (Table 3).

Trend analysis revealed that three sites had statistically significant decreasing trends in pH (Table 4). At each of these sites, pH was estimated to decrease by 0.52 units over the 13-year period of record. Although these trends are statistically significant, the observations remain within standards and are likely a result of diel fluctuations and logistical shifts related to time of observation during field events. Over the period of record the monitoring sites at APCO shifted from observations typically occurring in the mid-late afternoon to early or mid-morning. This change in the timing of observations is important given known diel fluctuations in water quality parameters. In freshwater streams, pH varies through the course of the day in large part due to photosynthesis (which increases pH during the day) and respiration (which decreases pH overnight) — morning observations will generally have a lower pH than afternoon observations (EPA 2000, Valenti et al. 2011). pH is known to fluctuate in APCO streams from as little as 0.2 to as much as 2 pH units over the course of a single day (NPS unpublished data). The trends observed in APCO are likely an outcome of the shift in the time of day of field visits.

In accordance with the Clean Water Act, the Commonwealth of Virginia Department of Environmental Quality (VADEQ) also monitors water quality, and the most recent summary of results are included in the Virginia 2022 305(b)/303(d) Integrated Report (VADEQ 2022). This report provides a list of Virginia waters that fail to meet standards for a variety of water quality parameters – not only pH, dissolved oxygen, and water temperature, but also other parameters like bacterial levels and fish tissue contaminants. Of importance to APCO, the Appomattox River is currently listed as impaired for recreation use due to high levels of *E. coli* bacteria (VADEQ 2022).

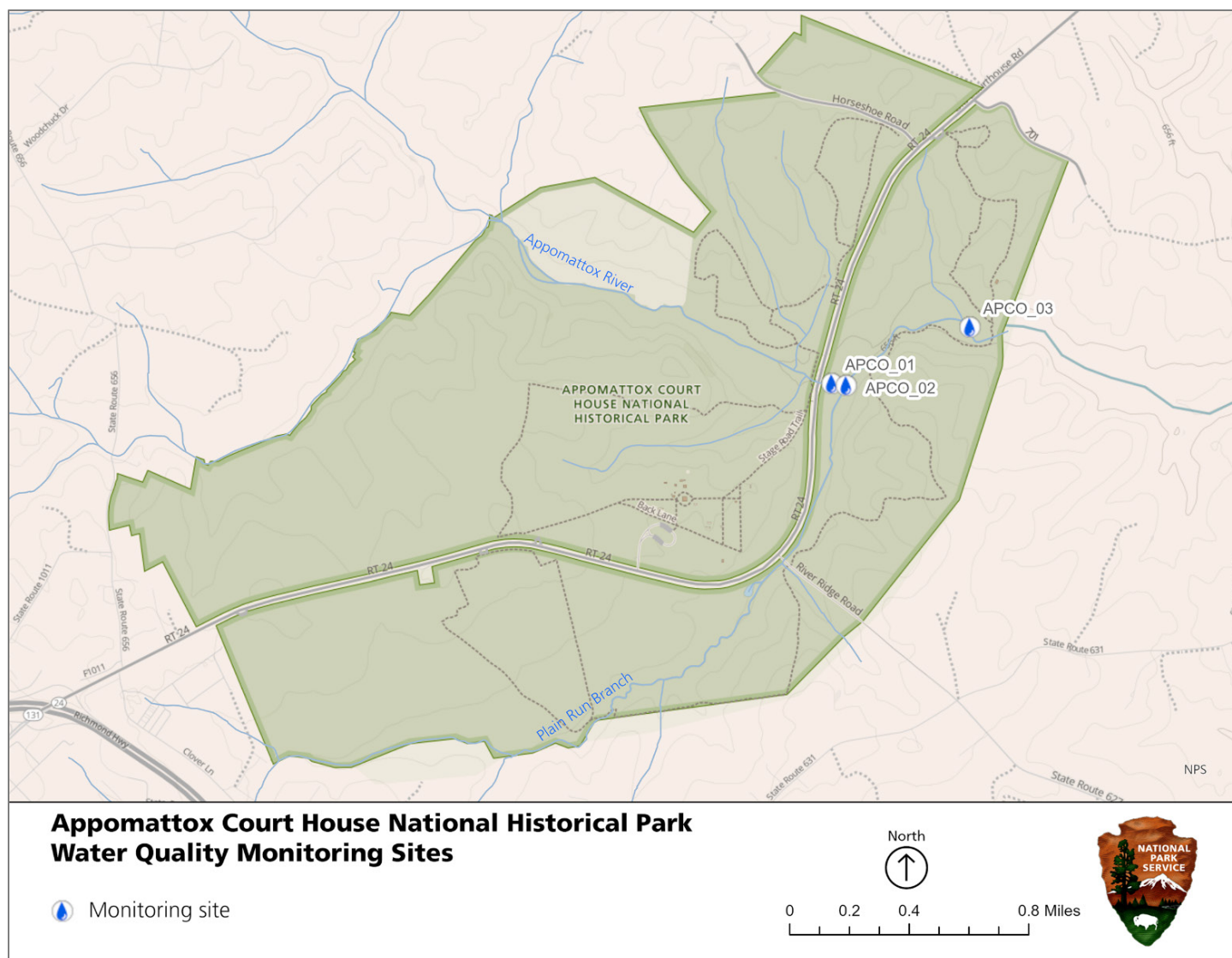


**Figure 1.** Map of three water quality monitoring sites at Appomattox Court House National Historical Park. NPS proclaimed boundaries (green outline) and NPS park lands (green fill) are based on NPS Park Tiles basemap products (<https://www.nps.gov/subjects/gisandmapping/npmap.htm>).

**Table 3.** Summary statistics for core parameters at Appomattox Court House National Historical Park. Statistics include sample period, total number of samples (N), percentiles 10, 50 (median), and 90 of the dataset, and the percent of samples that did not meet state water-quality standards.

| Site (Stream name)         | Parameter <sup>A</sup> | Start      | End        | Period of record | N   | Percentile |      |      | Excursion % <sup>B</sup> |
|----------------------------|------------------------|------------|------------|------------------|-----|------------|------|------|--------------------------|
|                            |                        |            |            |                  |     | 10         | 50   | 90   |                          |
| APCO_01 (Appomattox River) | pH                     | 2010-11-03 | 2023-09-21 | 13               | 106 | 6.94       | 7.33 | 7.68 | 0                        |
|                            | Dissolved oxygen       | 2010-11-03 | 2023-09-21 | 13               | 106 | 8.1        | 9.8  | 13.0 | 0                        |
|                            | Water temperature      | 2010-11-03 | 2023-09-21 | 13               | 107 | 5.2        | 13.9 | 22.3 | 0                        |
|                            | Specific conductance   | 2010-11-03 | 2023-09-21 | 13               | 107 | 73         | 85   | 94   | N/A                      |
| APCO_02 (Plain Run)        | pH                     | 2010-11-03 | 2023-09-21 | 13               | 113 | 7.01       | 7.38 | 7.67 | 0                        |
|                            | Dissolved oxygen       | 2010-11-03 | 2023-09-21 | 13               | 113 | 8.1        | 9.7  | 13.1 | 0                        |
|                            | Water temperature      | 2010-11-03 | 2023-09-21 | 13               | 114 | 4.9        | 13.6 | 21.7 | 0                        |
|                            | Specific conductance   | 2010-11-03 | 2023-09-21 | 13               | 114 | 92         | 111  | 120  | N/A                      |
| APCO_03 (Appomattox River) | pH                     | 2010-11-03 | 2023-09-21 | 13               | 114 | 7.01       | 7.36 | 7.67 | 0                        |
|                            | Dissolved oxygen       | 2010-11-03 | 2023-09-21 | 13               | 113 | 8.1        | 9.9  | 13.0 | 0                        |
|                            | Water temperature      | 2010-11-03 | 2023-09-21 | 13               | 115 | 4.6        | 13.2 | 22.2 | 0                        |
|                            | Specific conductance   | 2010-11-03 | 2023-09-21 | 13               | 115 | 81         | 93   | 101  | N/A                      |

<sup>A</sup> Units: pH = dimensionless, dissolved oxygen = mg/L, water temperature = °C, specific conductance = µS/cm, period of record = years.

<sup>B</sup> Virginia does not have a state standard for specific conductance.

**Table 4.** Trend analysis results for Appomattox Court House National Historical Park. The table includes test results, trend (rate of change per year), median value, ambient change over the period of record, and magnitude of change (ambient change compared to median).

| Site (Stream name)         | Parameter <sup>A</sup> | Period of record <sup>A</sup> | Season    | Tau   | p-value | Trend | Median <sup>B</sup> | Ambient change | Magnitude of change (%) |
|----------------------------|------------------------|-------------------------------|-----------|-------|---------|-------|---------------------|----------------|-------------------------|
| APCO_01 (Appomattox River) | pH                     | 13                            | Quarterly | −0.46 | 0.01    | −0.04 | 7.39                | −0.52          | −7                      |
|                            | Dissolved oxygen       | 13                            | Quarterly | 0.07  | 0.53    | None  | 10.6                | –              | –                       |
|                            | Water temperature      | 13                            | Quarterly | −0.18 | 0.09    | None  | 12.3                | –              | –                       |
|                            | Specific conductance   | 13                            | Quarterly | 0.11  | 0.42    | None  | 82                  | –              | –                       |
| APCO_02 (Plain Run)        | pH                     | 13                            | Quarterly | −0.43 | 0.01    | −0.04 | 7.44                | −0.52          | −7                      |
|                            | Dissolved oxygen       | 13                            | Quarterly | 0.01  | 0.93    | None  | 10.6                | –              | –                       |
|                            | Water temperature      | 13                            | Quarterly | −0.06 | 0.39    | None  | 12.2                | –              | –                       |
|                            | Specific conductance   | 13                            | Quarterly | 0.04  | 0.86    | None  | 110                 | –              | –                       |
| APCO_03 (Appomattox River) | pH                     | 13                            | Quarterly | −0.41 | 0.00    | −0.04 | 7.36                | −0.52          | −7                      |
|                            | Dissolved oxygen       | 13                            | Quarterly | −0.06 | 0.59    | None  | 10.4                | –              | –                       |
|                            | Water temperature      | 13                            | Quarterly | −0.09 | 0.22    | None  | 12.1                | –              | –                       |
|                            | Specific conductance   | 13                            | Quarterly | 0.20  | 0.22    | None  | 90                  | –              | –                       |

<sup>A</sup> Units: pH = dimensionless, dissolved oxygen = mg/L, water temperature = °C, specific conductance = μS/cm, period of record = years.

<sup>B</sup> This value represents the seasonal median not the full dataset median as in Table 3.

**Booker T. Washington National Monument**

Five perennial stream sites were monitored for water quality at Booker T. Washington NM (Figure 2). Three of these sites are located on Jack-O-Lantern Branch (BOWA\_01, 02, and 03), one site is on Gills Creek (BOWA\_04), and one site is on an unnamed tributary to Gill's Creek (BOWA\_05). Only BOWA\_01 had deviations from a state water-quality standard and excursions only occurred during 1% of pH observations at the site (Table 5). All other parameters monitored by MIDN met state water quality standards during all site visits. Even so, it is important to note that Gills Creek is listed by Virginia as impaired for recreational use due to high levels of *E. coli* bacterial contamination (VADEQ 2022).

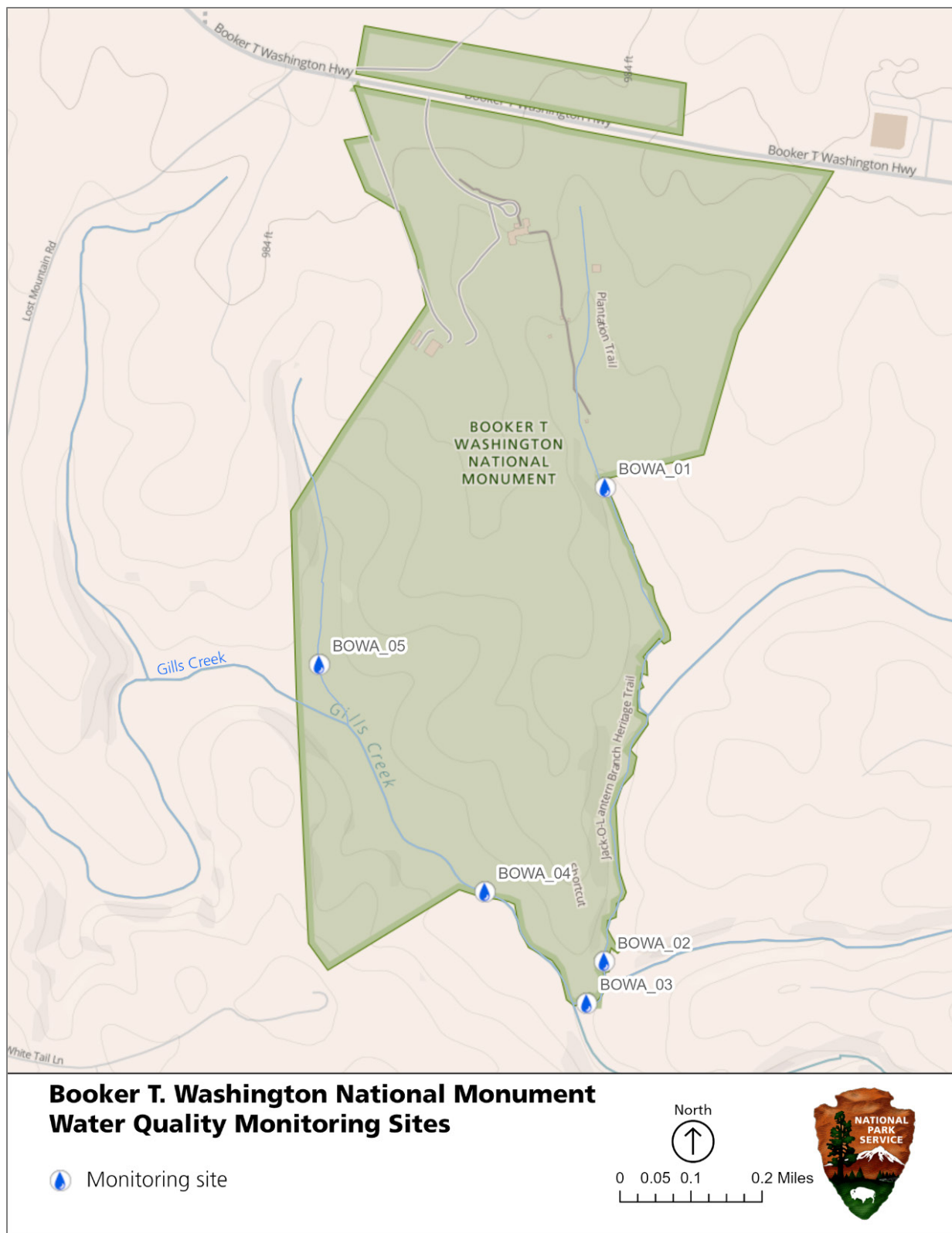


**Figure 2.** Map of five water quality monitoring sites at Booker T. Washington National Monument. NPS proclaimed boundaries (green outline) and NPS park lands (green fill) are based on NPS Park Tiles basemap products (<https://www.nps.gov/subjects/gisandmapping/npsmap.htm>).

**Table 5.** Summary statistics for core parameters at Booker T. Washington National Monument. Statistics include sample period, total number of samples (N), percentiles 10, 50 (median), and 90 of the dataset, and the percent of samples that did not meet state water-quality standards.

| Site (Stream name)                 | Parameter <sup>A</sup> | Start      | End        | Period of record <sup>A</sup> | N   | Percentile |      |      | Excursion % <sup>B</sup> |
|------------------------------------|------------------------|------------|------------|-------------------------------|-----|------------|------|------|--------------------------|
|                                    |                        |            |            |                               |     | 10         | 50   | 90   |                          |
| BOWA_01 (Jack-O-Lantern Branch)    | pH                     | 2010-10-06 | 2023-09-11 | 13                            | 119 | 6.55       | 6.90 | 7.34 | 1                        |
|                                    | Dissolved oxygen       | 2010-10-06 | 2023-09-11 | 13                            | 140 | 8.1        | 9.3  | 11.8 | 0                        |
|                                    | Water temperature      | 2010-10-06 | 2023-09-11 | 13                            | 147 | 6.4        | 13.0 | 18.4 | 0                        |
|                                    | Specific conductance   | 2010-10-06 | 2023-09-11 | 13                            | 145 | 78         | 85   | 93   | N/A                      |
| BOWA_02 (Jack-O-Lantern Branch)    | pH                     | 2010-10-06 | 2023-09-11 | 13                            | 119 | 7.09       | 7.40 | 7.60 | 0                        |
|                                    | Dissolved oxygen       | 2010-10-06 | 2023-09-11 | 13                            | 140 | 8.4        | 10.2 | 13.3 | 0                        |
|                                    | Water temperature      | 2010-10-06 | 2023-09-11 | 13                            | 147 | 4.8        | 13.1 | 19.8 | 0                        |
|                                    | Specific conductance   | 2010-10-06 | 2023-09-11 | 13                            | 145 | 92         | 101  | 110  | N/A                      |
| BOWA_03 (Jack-O-Lantern Branch)    | pH                     | 2010-10-06 | 2023-09-11 | 13                            | 119 | 7.25       | 7.44 | 7.62 | 0                        |
|                                    | Dissolved oxygen       | 2010-10-06 | 2023-09-11 | 13                            | 140 | 8.2        | 9.9  | 13.0 | 0                        |
|                                    | Water temperature      | 2010-10-06 | 2023-09-11 | 13                            | 147 | 4.7        | 13.3 | 20.0 | 0                        |
|                                    | Specific conductance   | 2010-10-06 | 2023-09-11 | 13                            | 145 | 90         | 100  | 108  | N/A                      |
| BOWA_04 (Gills Creek)              | pH                     | 2010-10-06 | 2023-09-11 | 13                            | 117 | 7.07       | 7.41 | 7.61 | 0                        |
|                                    | Dissolved oxygen       | 2010-10-06 | 2023-09-11 | 13                            | 138 | 8.2        | 10.1 | 13.6 | 0                        |
|                                    | Water temperature      | 2010-10-06 | 2023-09-11 | 13                            | 145 | 4.3        | 13.7 | 21.8 | 0                        |
|                                    | Specific conductance   | 2010-10-06 | 2023-09-11 | 13                            | 143 | 67         | 77   | 87   | N/A                      |
| BOWA_05 (Tributary of Gills Creek) | pH                     | 2010-10-06 | 2023-09-11 | 13                            | 117 | 7.08       | 7.33 | 7.57 | 0                        |
|                                    | Dissolved oxygen       | 2010-10-06 | 2023-09-11 | 13                            | 138 | 8.0        | 9.6  | 12.5 | 0                        |
|                                    | Water temperature      | 2010-10-06 | 2023-09-11 | 13                            | 145 | 5.3        | 13.4 | 19.6 | 0                        |
|                                    | Specific conductance   | 2010-10-06 | 2023-09-11 | 13                            | 143 | 77         | 89   | 104  | N/A                      |

<sup>A</sup> Units: pH = dimensionless, dissolved oxygen = mg/L, water temperature = °C, specific conductance = µS/cm, period of record = years.

<sup>B</sup> Virginia does not have a state standard for specific conductance.

Trend analysis revealed that three sites had increasing trends in specific conductance (BOWA\_02, BOWA\_03, and BOWA\_05; Table 6). Total estimated increases over the 13-year period of record were small, ranging from 9–13  $\mu\text{S}/\text{cm}$ . For context, the MIDN daily sensor check error limit for specific conductance is  $\pm 5.0 \mu\text{S}/\text{cm}$ . In addition, median values ranged from 89 – 101  $\mu\text{S}/\text{cm}$ , well below levels expected to indicate stressful conditions for biota in Virginia’s piedmont streams (i.e., > 250  $\mu\text{S}/\text{cm}$ , VADEQ 2017). However, increasing salination of freshwater streams due to increased development (i.e., roads and impervious surfaces) and deicers is a concern in the Mid-Atlantic region (Kaushal et al. 2005).

**Table 6.** Trend analysis results for Booker T. Washington National Monument. The table includes test results, trend (rate of change per year), median value, ambient change over the period of record, and magnitude of change (ambient change compared to median).

| Site (Stream name)                 | Parameter <sup>A</sup> | Period of record <sup>A</sup> | Season  | Tau   | p-value | Trend | Median <sup>B</sup> | Ambient change | Magnitude of change (%) |
|------------------------------------|------------------------|-------------------------------|---------|-------|---------|-------|---------------------|----------------|-------------------------|
| BOWA_01 (Jack-O-Lantern Branch)    | pH                     | 13                            | Monthly | 0.46  | 0.10    | None  | 6.90                | –              | –                       |
|                                    | Dissolved oxygen       | 13                            | Monthly | 0.07  | 0.39    | None  | 9.3                 | –              | –                       |
|                                    | Water temperature      | 13                            | Monthly | 0.03  | 0.78    | None  | 13.0                | –              | –                       |
|                                    | Specific conductance   | 13                            | Monthly | 0.24  | 0.07    | None  | 85                  | –              | –                       |
| BOWA_02 (Jack-O-Lantern Branch)    | pH                     | 13                            | Monthly | 0.22  | 0.37    | None  | 7.40                | –              | –                       |
|                                    | Dissolved oxygen       | 13                            | Monthly | –0.03 | 0.76    | None  | 10.2                | –              | –                       |
|                                    | Water temperature      | 13                            | Monthly | 0.01  | 1.00    | None  | 13.1                | –              | –                       |
|                                    | Specific conductance   | 13                            | Monthly | 0.29  | 0.05    | 0.67  | 101                 | 9              | 9                       |
| BOWA_03 (Jack-O-Lantern Branch)    | pH                     | 13                            | Monthly | 0.04  | 0.91    | None  | 7.44                | –              | –                       |
|                                    | Dissolved oxygen       | 13                            | Monthly | 0.06  | 0.44    | None  | 9.9                 | –              | –                       |
|                                    | Water temperature      | 13                            | Monthly | –0.01 | 0.88    | None  | 13.3                | –              | –                       |
|                                    | Specific conductance   | 13                            | Monthly | 0.32  | 0.03    | 0.74  | 100                 | 10             | 10                      |
| BOWA_04 (Gills Creek)              | pH                     | 13                            | Monthly | –0.12 | 0.60    | None  | 7.41                | –              | –                       |
|                                    | Dissolved oxygen       | 13                            | Monthly | 0.02  | 0.60    | None  | 10.1                | –              | –                       |
|                                    | Water temperature      | 13                            | Monthly | 0.06  | 0.61    | None  | 13.7                | –              | –                       |
|                                    | Specific conductance   | 13                            | Monthly | 0.21  | 0.06    | None  | 77                  | –              | –                       |
| BOWA_05 (Tributary of Gills Creek) | pH                     | 13                            | Monthly | –0.02 | 0.93    | None  | 7.33                | –              | –                       |
|                                    | Dissolved oxygen       | 13                            | Monthly | 0.14  | 0.07    | None  | 9.6                 | –              | –                       |
|                                    | Water temperature      | 13                            | Monthly | –0.05 | 0.49    | None  | 13.4                | –              | –                       |
|                                    | Specific conductance   | 13                            | Monthly | 0.44  | 0.00    | 0.97  | 89                  | 13             | 14                      |

<sup>A</sup> Units: pH = dimensionless, dissolved oxygen = mg/L, water temperature = °C, specific conductance = µS/cm, period of record = years.

<sup>B</sup> This value represents the seasonal median not the full dataset median as in Table 5.

***Fredericksburg and Spotsylvania National Military Park.***

Fourteen sites were monitored for water quality at Fredericksburg and Spotsylvania NMP (Figure 3). Nine of these sites had at least one excursion from pH standards, with sites FRSP\_02 (tributary to Lewis Run), FRSP\_17 (Brock Run), and FRSP\_06 (N. Branch of Deep Run) deviating from the VA pH standard in 17%, 29%, and 37% of observations, respectively (Table 7). All these sites are located on acidic soils and likely have naturally derived low pH. FRSP\_02 and FRSP\_17 are located on Toddstav silt loam soils which are characterized as “extremely acid through strongly acid” (NPS 2012, Elder 1985). Site FRSP\_06, on the N. Branch of Deep Run, is on soils of the Udorthents-Udifluvents complex which is “strongly acid or very strongly acid throughout” (NPS 2012, Elder 1985). VADEQ (2022) listed Deep Run (FRSP\_06) in the state’s integrated report as category 5C (impaired due to suspected natural conditions) for aquatic life due to pH and Brock Run (FRSP\_17) is listed as category 5A (impaired requiring a TMDL) for aquatic life due to pH. However, it is likely that the Brock Run stream segment would be moved to either 5C or 4C (impaired due to natural conditions and not requiring a TMDL) following a use attainability analysis by the state.



**Figure 3.** Map of 14 water quality monitoring sites at Fredericksburg and Spotsylvania National Military Park. NPS proclaimed boundaries (green outline) and NPS park lands (green fill) are based on NPS Park Tiles basemap products (<https://www.nps.gov/subjects/gisandmapping/npmap.htm>).

**Table 7.** Summary statistics for core parameters at Fredericksburg and Spotsylvania National Military Park. Statistics include sample period, total number of samples (N), percentiles 10, 50 (median), and 90 of the dataset, and the percent of samples that did not meet state water-quality standards.

| Site (Stream name)                       | Parameter <sup>A</sup> | Start      | End        | Period of record | N   | Percentile |      |      | Excursion % <sup>B</sup> |
|------------------------------------------|------------------------|------------|------------|------------------|-----|------------|------|------|--------------------------|
|                                          |                        |            |            |                  |     | 10         | 50   | 90   |                          |
| FRSP_01 (Lewis Run)                      | pH                     | 2010-10-04 | 2023-09-15 | 13               | 135 | 6.31       | 6.57 | 6.86 | 2                        |
|                                          | Dissolved oxygen       | 2010-10-04 | 2023-09-15 | 13               | 134 | 3.6        | 8.3  | 12.4 | 13                       |
|                                          | Water temperature      | 2010-10-04 | 2023-09-15 | 13               | 135 | 5.5        | 16.9 | 23.6 | 0                        |
|                                          | Specific conductance   | 2010-10-04 | 2023-09-15 | 13               | 134 | 56         | 73   | 117  | N/A                      |
| FRSP_02 (Unnamed tributary of Lewis Run) | pH                     | 2010-10-04 | 2023-08-15 | 13               | 135 | 5.91       | 6.26 | 6.68 | 17                       |
|                                          | Dissolved oxygen       | 2010-10-04 | 2023-08-15 | 13               | 134 | 3.1        | 8.6  | 11.8 | 12                       |
|                                          | Water temperature      | 2010-10-04 | 2023-08-15 | 13               | 135 | 4.9        | 13.1 | 22.5 | 0                        |
|                                          | Specific conductance   | 2010-10-04 | 2023-08-15 | 13               | 134 | 40         | 56   | 79   | N/A                      |
| FRSP_03 (Lewis Run)                      | pH                     | 2010-10-04 | 2023-09-15 | 13               | 136 | 6.33       | 6.70 | 6.91 | 1                        |
|                                          | Dissolved oxygen       | 2010-10-04 | 2023-09-15 | 13               | 135 | 5.6        | 8.4  | 12.2 | 1                        |
|                                          | Water temperature      | 2010-10-04 | 2023-09-15 | 13               | 136 | 5.0        | 15.4 | 23.4 | 0                        |
|                                          | Specific conductance   | 2010-10-04 | 2023-09-15 | 13               | 135 | 59         | 76   | 97   | N/A                      |
| FRSP_04 (Brock Run)                      | pH                     | 2010-10-04 | 2023-09-15 | 13               | 134 | 6.29       | 6.65 | 6.86 | 2                        |
|                                          | Dissolved oxygen       | 2010-10-04 | 2023-09-15 | 13               | 133 | 4.5        | 9.1  | 12.8 | 8                        |
|                                          | Water temperature      | 2010-10-04 | 2023-09-15 | 13               | 134 | 3.9        | 14.0 | 22.4 | 0                        |
|                                          | Specific conductance   | 2010-10-04 | 2023-09-15 | 13               | 133 | 43         | 51   | 64   | N/A                      |
| FRSP_06 (North Branch of Deep Run)       | pH                     | 2010-10-04 | 2023-09-15 | 13               | 134 | 5.64       | 6.14 | 6.53 | 37                       |
|                                          | Dissolved oxygen       | 2010-10-04 | 2023-09-15 | 13               | 133 | 7.1        | 9.4  | 12.1 | 1                        |
|                                          | Water temperature      | 2010-10-04 | 2023-09-15 | 13               | 134 | 4.4        | 13.0 | 21.9 | 0                        |
|                                          | Specific conductance   | 2010-10-04 | 2023-09-15 | 13               | 133 | 89         | 107  | 143  | N/A                      |
| FRSP_08 (Hazel Run)                      | pH                     | 2010-10-04 | 2023-09-15 | 13               | 136 | 6.56       | 6.96 | 7.30 | 0                        |
|                                          | Dissolved oxygen       | 2010-10-04 | 2023-09-15 | 13               | 135 | 7.9        | 10.2 | 13.3 | 0                        |

<sup>A</sup> Units: pH = dimensionless, dissolved oxygen = mg/L, water temperature = °C, specific conductance = µS/cm, period of record = years.

<sup>B</sup> Virginia does not have a state standard for specific conductance

**Table 7 (continued).** Summary statistics for core parameters at Fredericksburg and Spotsylvania National Military Park. Statistics include sample period, total number of samples (N), percentiles 10, 50 (median), and 90 of the dataset, and the percent of samples that did not meet state water-quality standards.

| Site (Stream name)                             | Parameter <sup>A</sup> | Start      | End        | Period of record | N   | Percentile |      |      | Excursion % <sup>B</sup> |
|------------------------------------------------|------------------------|------------|------------|------------------|-----|------------|------|------|--------------------------|
|                                                |                        |            |            |                  |     | 10         | 50   | 90   |                          |
| FRSP_08 (Hazel Run)<br>(continued)             | Water temperature      | 2010-10-04 | 2023-09-15 | 13               | 136 | 4.0        | 14.3 | 24.0 | 0                        |
|                                                | Specific conductance   | 2010-10-04 | 2023-09-15 | 13               | 135 | 133        | 181  | 256  | N/A                      |
| FRSP_09 (Unnamed tributary of Ni River)        | pH                     | 2010-10-04 | 2023-07-17 | 13               | 134 | 6.18       | 6.62 | 6.80 | 4                        |
|                                                | Dissolved oxygen       | 2010-10-04 | 2023-07-17 | 13               | 133 | 7.4        | 8.8  | 11.4 | 0                        |
|                                                | Water temperature      | 2010-10-04 | 2023-07-17 | 13               | 134 | 6.4        | 14.2 | 21.7 | 0                        |
|                                                | Specific conductance   | 2010-10-04 | 2023-07-17 | 13               | 133 | 47         | 65   | 79   | N/A                      |
| FRSP_10 (North Branch of Burnside Drive Creek) | pH                     | 2010-10-04 | 2023-09-15 | 13               | 136 | 6.34       | 6.69 | 6.93 | 0                        |
|                                                | Dissolved oxygen       | 2010-10-04 | 2023-09-15 | 13               | 135 | 6.8        | 8.9  | 11.7 | 4                        |
|                                                | Water temperature      | 2010-10-04 | 2023-09-15 | 13               | 136 | 5.2        | 14.7 | 24.2 | 0                        |
|                                                | Specific conductance   | 2010-10-04 | 2023-09-15 | 13               | 135 | 38         | 49   | 56   | N/A                      |
| FRSP_11 (South Branch of Burnside Drive Creek) | pH                     | 2010-10-04 | 2023-08-17 | 13               | 133 | 6.48       | 6.82 | 7.03 | 0                        |
|                                                | Dissolved oxygen       | 2010-10-04 | 2023-08-17 | 13               | 132 | 7.0        | 9.3  | 12.2 | 1                        |
|                                                | Water temperature      | 2010-10-04 | 2023-08-17 | 13               | 133 | 5.7        | 13.9 | 22.4 | 0                        |
|                                                | Specific conductance   | 2010-10-04 | 2023-08-17 | 13               | 132 | 92         | 123  | 175  | N/A                      |
| FRSP_14 (North Wilderness Run)                 | pH                     | 2010-10-04 | 2023-09-15 | 13               | 134 | 6.67       | 7.06 | 7.38 | 1                        |
|                                                | Dissolved oxygen       | 2010-10-04 | 2023-09-15 | 13               | 131 | 7.2        | 9.6  | 13.1 | 0                        |
|                                                | Water temperature      | 2010-10-04 | 2023-09-15 | 13               | 134 | 3.5        | 13.6 | 22.4 | 0                        |
|                                                | Specific conductance   | 2010-10-04 | 2023-09-15 | 13               | 133 | 60         | 88   | 110  | N/A                      |
| FRSP_15 (Wilderness Run)                       | pH                     | 2010-10-04 | 2023-09-15 | 13               | 135 | 6.62       | 7.02 | 7.33 | 1                        |
|                                                | Dissolved oxygen       | 2010-10-04 | 2023-09-15 | 13               | 134 | 7.0        | 9.5  | 13.0 | 2                        |
|                                                | Water temperature      | 2010-10-04 | 2023-09-15 | 13               | 135 | 4.1        | 14.3 | 24.1 | 0                        |
|                                                | Specific conductance   | 2010-10-04 | 2023-09-15 | 13               | 134 | 67         | 75   | 89   | N/A                      |

<sup>A</sup> Units: pH = dimensionless, dissolved oxygen = mg/L, water temperature = °C, specific conductance = µS/cm, period of record = years.

<sup>B</sup> Virginia does not have a state standard for specific conductance

**Table 7 (continued).** Summary statistics for core parameters at Fredericksburg and Spotsylvania National Military Park. Statistics include sample period, total number of samples (N), percentiles 10, 50 (median), and 90 of the dataset, and the percent of samples that did not meet state water-quality standards.

| Site (Stream name)                            | Parameter <sup>A</sup> | Start      | End        | Period of record | N   | Percentile |      |      | Excursion % <sup>B</sup> |
|-----------------------------------------------|------------------------|------------|------------|------------------|-----|------------|------|------|--------------------------|
|                                               |                        |            |            |                  |     | 10         | 50   | 90   |                          |
| FRSP_16 (Unnamed tributary of Wilderness Run) | pH                     | 2010-10-04 | 2023-09-15 | 13               | 134 | 6.63       | 7.05 | 7.32 | 0                        |
|                                               | Dissolved oxygen       | 2010-10-04 | 2023-09-15 | 13               | 134 | 6.8        | 9.4  | 12.7 | 0                        |
|                                               | Water temperature      | 2010-10-04 | 2023-09-15 | 13               | 135 | 4.2        | 14.3 | 23.5 | 0                        |
|                                               | Specific conductance   | 2010-10-04 | 2023-09-15 | 13               | 134 | 111        | 158  | 202  | N/A                      |
| FRSP_17 (Brock Run)                           | pH                     | 2010-11-01 | 2023-07-17 | 13               | 87  | 5.64       | 6.20 | 6.62 | 29                       |
|                                               | Dissolved oxygen       | 2010-11-01 | 2023-07-17 | 13               | 87  | 5.4        | 9.2  | 12.6 | 0                        |
|                                               | Water temperature      | 2010-11-01 | 2023-07-17 | 13               | 87  | 4.2        | 11.2 | 21.8 | 0                        |
|                                               | Specific conductance   | 2010-11-01 | 2023-07-17 | 13               | 86  | 29         | 34   | 45   | N/A                      |
| FRSP_18 (Burnside Drive Creek)                | pH                     | 2010-10-04 | 2023-09-15 | 13               | 135 | 6.58       | 6.92 | 7.15 | 0                        |
|                                               | Dissolved oxygen       | 2010-10-04 | 2023-09-15 | 13               | 134 | 7.0        | 9.5  | 12.8 | 0                        |
|                                               | Water temperature      | 2010-10-04 | 2023-09-15 | 13               | 135 | 4.2        | 15.5 | 24.6 | 0                        |
|                                               | Specific conductance   | 2010-10-04 | 2023-09-15 | 13               | 134 | 73         | 95   | 133  | N/A                      |

<sup>A</sup> Units: pH = dimensionless, dissolved oxygen = mg/L, water temperature = °C, specific conductance = µS/cm, period of record = years.

<sup>B</sup> Virginia does not have a state standard for specific conductance.

Eight sites had at least one excursion from state water-quality standards for dissolved oxygen concentrations (Table 7), but only FRSP\_01 and FRSP\_02 had a substantial number of excursions (i.e., >10%). Site FRSP\_01 is located on Lewis Run, approximately 100m downstream of Cool Spring Lake and its overflow spillway dam. During periods of low flows or drought, discharge over the dam is greatly reduced or eliminated. Under these conditions, surface flows in Lewis Run are supported primarily by groundwater inputs likely through the earthen dam resulting in low dissolved oxygen conditions.

Site FRSP\_02 departed from dissolved oxygen standards in 12% of observations. This monitoring site is located on a backwater of Cool Spring Lake where an unnamed tributary enters the reservoir. Unlike a flowing stream, it is similar to a beaver pond with more stagnant lake-like conditions where lower dissolved oxygen levels are expected. Dissolved oxygen levels at FRSP\_04, located on lower Brock Run, were less than the 4.0 mg/L standard for aquatic life for 8% of observations. And lower Brock Run is currently listed as impaired for aquatic life due to low dissolved oxygen levels (VADEQ 2022). These low dissolved oxygen conditions occurred between July and October, likely due to summer low flow during drier years.

In addition to the water quality conditions noted above, VADEQ has listed several streams within FRSP for other water quality impairments (VADEQ 2022). Lower Brock Run (FRSP\_04), Hazel Run (FRSP\_08), and Wilderness Run (FRSP\_15) are all listed as impaired for recreational use due to *E. coli* bacterial contamination. Hazel Run (FRSP\_08) is also impaired for fish consumption due to high levels of polychlorinated biphenyls (PCBs) in fish tissue.

Trend analysis revealed that two sites had declining trends in pH (FRSP\_01 on Lewis Run and FRSP\_02 on a tributary to Lewis Run; Table 8) and one site had an increasing trend in dissolved oxygen (FRSP\_14 on North Wilderness Run). The causes of these trends are currently unknown. Declines in pH were small, ranging from 0.13 (FRSP\_01) to 0.26 units (FRSP\_02) over the 13-year period of record. For context, the MIDN daily sensor check error limit for pH is 0.2 units. Increases in dissolved oxygen concentrations in North Wilderness Run (FRSP\_14) are within healthy conditions, and do not currently constitute any reason for concern.

**Table 8.** Trend analysis results for Fredericksburg and Spotsylvania National Military Park. The table includes test results, trend (rate of change per year), median value, ambient change over the period of record, and magnitude of change (ambient change compared to median).

| Site (Stream name)                       | Parameter <sup>A</sup> | Period of record <sup>A</sup> | Season  | Tau   | p-value | Trend | Median <sup>B</sup> | Ambient change | Magnitude of change (%) |
|------------------------------------------|------------------------|-------------------------------|---------|-------|---------|-------|---------------------|----------------|-------------------------|
| FRSP_01 (Lewis Run)                      | pH                     | 13                            | Monthly | −0.25 | 0.04    | −0.01 | 6.57                | −0.13          | −2                      |
|                                          | Dissolved oxygen       | 13                            | Monthly | −0.14 | 0.14    | None  | 8.2                 | —              | —                       |
|                                          | Water temperature      | 13                            | Monthly | 0.10  | 0.27    | None  | 17.1                | —              | —                       |
|                                          | Specific conductance   | 13                            | Monthly | 0.07  | 0.70    | None  | 73                  | —              | —                       |
| FRSP_02 (Unnamed tributary of Lewis Run) | pH                     | 13                            | Monthly | −0.24 | 0.02    | −0.02 | 6.26                | −0.26          | −4                      |
|                                          | Dissolved oxygen       | 13                            | Monthly | −0.07 | 0.57    | None  | 7.9                 | —              | —                       |
|                                          | Water temperature      | 13                            | Monthly | 0.05  | 0.48    | None  | 13.5                | —              | —                       |
|                                          | Specific conductance   | 13                            | Monthly | 0.01  | 0.96    | None  | 58                  | —              | —                       |
| FRSP_03 (Lewis Run)                      | pH                     | 13                            | Monthly | −0.05 | 0.67    | None  | 6.70                | —              | —                       |
|                                          | Dissolved oxygen       | 13                            | Monthly | 0.03  | 0.56    | None  | 8.2                 | —              | —                       |
|                                          | Water temperature      | 13                            | Monthly | 0.00  | 0.99    | None  | 15.6                | —              | —                       |
|                                          | Specific conductance   | 13                            | Monthly | 0.09  | 0.62    | None  | 76                  | —              | —                       |
| FRSP_04 (Brock Run)                      | pH                     | 13                            | Monthly | −0.16 | 0.17    | None  | 6.66                | —              | —                       |
|                                          | Dissolved oxygen       | 13                            | Monthly | −0.05 | 0.66    | None  | 9.0                 | —              | —                       |
|                                          | Water temperature      | 13                            | Monthly | 0.01  | 0.80    | None  | 14.3                | —              | —                       |
|                                          | Specific conductance   | 13                            | Monthly | −0.02 | 0.81    | None  | 51                  | —              | —                       |
| FRSP_06 (North Branch of Deep Run)       | pH                     | 13                            | Monthly | 0.24  | 0.07    | None  | 6.15                | —              | —                       |
|                                          | Dissolved oxygen       | 13                            | Monthly | −0.01 | 0.93    | None  | 9.4                 | —              | —                       |
|                                          | Water temperature      | 13                            | Monthly | 0.00  | 0.92    | None  | 13.5                | —              | —                       |
|                                          | Specific conductance   | 13                            | Monthly | 0.12  | 0.43    | None  | 107                 | —              | —                       |
| FRSP_08 (Hazel Run)                      | pH                     | 13                            | Monthly | 0.06  | 0.63    | None  | 6.96                | —              | —                       |
|                                          | Dissolved oxygen       | 13                            | Monthly | −0.06 | 0.58    | None  | 10.2                | —              | —                       |

<sup>A</sup> Units: pH = dimensionless, dissolved oxygen = mg/L, water temperature = °C, specific conductance = μS/cm, period of record = years.

<sup>B</sup> This value represents the seasonal median not the full dataset median as in Table 7.

**Table 8 (continued).** Trend analysis results for Fredericksburg and Spotsylvania National Military Park. The table includes test results, trend (rate of change per year), median value, ambient change over the period of record, and magnitude of change (ambient change compared to median).

| Site (Stream name)                             | Parameter <sup>A</sup> | Period of record <sup>A</sup> | Season  | Tau   | p-value | Trend | Median <sup>B</sup> | Ambient change | Magnitude of change (%) |
|------------------------------------------------|------------------------|-------------------------------|---------|-------|---------|-------|---------------------|----------------|-------------------------|
| FRSP_08 (Hazel Run)<br>(continued)             | Water temperature      | 13                            | Monthly | -0.03 | 0.70    | None  | 14.4                | —              | —                       |
|                                                | Specific conductance   | 13                            | Monthly | 0.06  | 0.54    | None  | 181                 | —              | —                       |
| FRSP_09 (Unnamed tributary of Ni River)        | pH                     | 13                            | Monthly | -0.17 | 0.23    | None  | 6.62                | —              | —                       |
|                                                | Dissolved oxygen       | 13                            | Monthly | 0.06  | 0.45    | None  | 8.7                 | —              | —                       |
|                                                | Water temperature      | 13                            | Monthly | 0.05  | 0.51    | None  | 14.3                | —              | —                       |
|                                                | Specific conductance   | 13                            | Monthly | 0.03  | 0.85    | None  | 65                  | —              | —                       |
| FRSP_10 (North Branch of Burnside Drive Creek) | pH                     | 13                            | Monthly | -0.11 | 0.49    | None  | 6.70                | —              | —                       |
|                                                | Dissolved oxygen       | 13                            | Monthly | 0.21  | 0.06    | None  | 8.9                 | —              | —                       |
|                                                | Water temperature      | 13                            | Monthly | 0.06  | 0.51    | None  | 14.9                | —              | —                       |
|                                                | Specific conductance   | 13                            | Monthly | -0.07 | 0.55    | None  | 50                  | —              | —                       |
| FRSP_11 (South Branch of Burnside Drive Creek) | pH                     | 13                            | Monthly | -0.08 | 0.50    | None  | 6.82                | —              | —                       |
|                                                | Dissolved oxygen       | 13                            | Monthly | 0.03  | 0.57    | None  | 9.2                 | —              | —                       |
|                                                | Water temperature      | 13                            | Monthly | 0.02  | 0.76    | None  | 14.2                | —              | —                       |
|                                                | Specific conductance   | 13                            | Monthly | -0.01 | 0.99    | None  | 123                 | —              | —                       |
| FRSP_14 (North Wilderness Run)                 | pH                     | 13                            | Monthly | 0.04  | 0.69    | None  | 7.06                | —              | —                       |
|                                                | Dissolved oxygen       | 13                            | Monthly | 0.17  | 0.05    | 0.09  | 9.4                 | 1.2            | 12                      |
|                                                | Water temperature      | 13                            | Monthly | -0.13 | 0.12    | None  | 13.6                | —              | —                       |
|                                                | Specific conductance   | 13                            | Monthly | 0.03  | 0.85    | None  | 88                  | —              | —                       |
| FRSP_15 (Wilderness Run)                       | pH                     | 13                            | Monthly | -0.19 | 0.11    | None  | 7.04                | —              | —                       |
|                                                | Dissolved oxygen       | 13                            | Monthly | -0.06 | 0.51    | None  | 9.3                 | —              | —                       |
|                                                | Water temperature      | 13                            | Monthly | -0.06 | 0.50    | None  | 14.7                | —              | —                       |
|                                                | Specific conductance   | 13                            | Monthly | 0.12  | 0.29    | None  | 75                  | —              | —                       |

<sup>A</sup> Units: pH = dimensionless, dissolved oxygen = mg/L, water temperature = °C, specific conductance = μS/cm, period of record = years.

<sup>B</sup> This value represents the seasonal median not the full dataset median as in Table 7.

**Table 8 (continued).** Trend analysis results for Fredericksburg and Spotsylvania National Military Park. The table includes test results, trend (rate of change per year), median value, ambient change over the period of record, and magnitude of change (ambient change compared to median).

| Site (Stream name)                            | Parameter <sup>A</sup> | Period of record <sup>A</sup> | Season    | Tau   | p-value | Trend | Median <sup>B</sup> | Ambient change | Magnitude of change (%) |
|-----------------------------------------------|------------------------|-------------------------------|-----------|-------|---------|-------|---------------------|----------------|-------------------------|
| FRSP_16 (Unnamed tributary of Wilderness Run) | pH                     | 13                            | Monthly   | −0.01 | 0.96    | None  | 7.05                | –              | –                       |
|                                               | Dissolved oxygen       | 13                            | Monthly   | 0.00  | 0.83    | None  | 9.2                 | –              | –                       |
|                                               | Water temperature      | 13                            | Monthly   | −0.10 | 0.22    | None  | 14.6                | –              | –                       |
|                                               | Specific conductance   | 13                            | Monthly   | −0.16 | 0.11    | None  | 158                 | –              | –                       |
| FRSP_17 (Brock Run)                           | pH                     | 13                            | Quarterly | −0.13 | 0.25    | None  | 6.21                | –              | –                       |
|                                               | Dissolved oxygen       | 13                            | Quarterly | 0.00  | 0.91    | None  | 8.1                 | –              | –                       |
|                                               | Water temperature      | 13                            | Quarterly | −0.01 | 0.84    | None  | 11.7                | –              | –                       |
|                                               | Specific conductance   | 13                            | Quarterly | −0.06 | 0.46    | None  | 35                  | –              | –                       |
| FRSP_18 (Burnside Drive Creek)                | pH                     | 13                            | Monthly   | −0.18 | 0.13    | None  | 6.92                | –              | –                       |
|                                               | Dissolved oxygen       | 13                            | Monthly   | 0.05  | 0.55    | None  | 9.4                 | –              | –                       |
|                                               | Water temperature      | 13                            | Monthly   | 0.00  | 1.00    | None  | 15.7                | –              | –                       |
|                                               | Specific conductance   | 13                            | Monthly   | −0.09 | 0.50    | None  | 95                  | –              | –                       |

<sup>A</sup> Units: pH = dimensionless, dissolved oxygen = mg/L, water temperature = °C, specific conductance = μS/cm, period of record = years.

<sup>B</sup> This value represents the seasonal median not the full dataset median as in Table 7.

***Petersburg National Battlefield Park***

Ten sites were monitored for water quality at Petersburg NBP (Figure 4). Four of the sites deviated from pH standards, and two sites deviated from dissolved oxygen standards (Table 9). Even so, the only site with a substantial number of excursions (i.e., >10%) is located on Gravelly Brook (PETE\_10; 98% excursion from pH standard). Although PETE\_10 is currently identified by VADEQ as a Class III stream (i.e., nontidal waters), a review of this classification would likely result in a Class VII determination (i.e., swamp waters). Gravelly Brook meets several qualifications of a Class VII stream, including nearby wetlands, low pH due to organic acids (i.e., tannins), and a brownish color due to high concentrations of dissolved organic matter. Additionally, all other stream segments in the Five Forks unit are currently classified as Class VII. These ecological conditions result in naturally derived low pH and low dissolved oxygen levels (the site also deviated from dissolved oxygen standards 8% of the time) and should not be of management concern. Under the Class VII swamp water classification, PETE\_10 would meet state water quality standards for pH and dissolved oxygen.

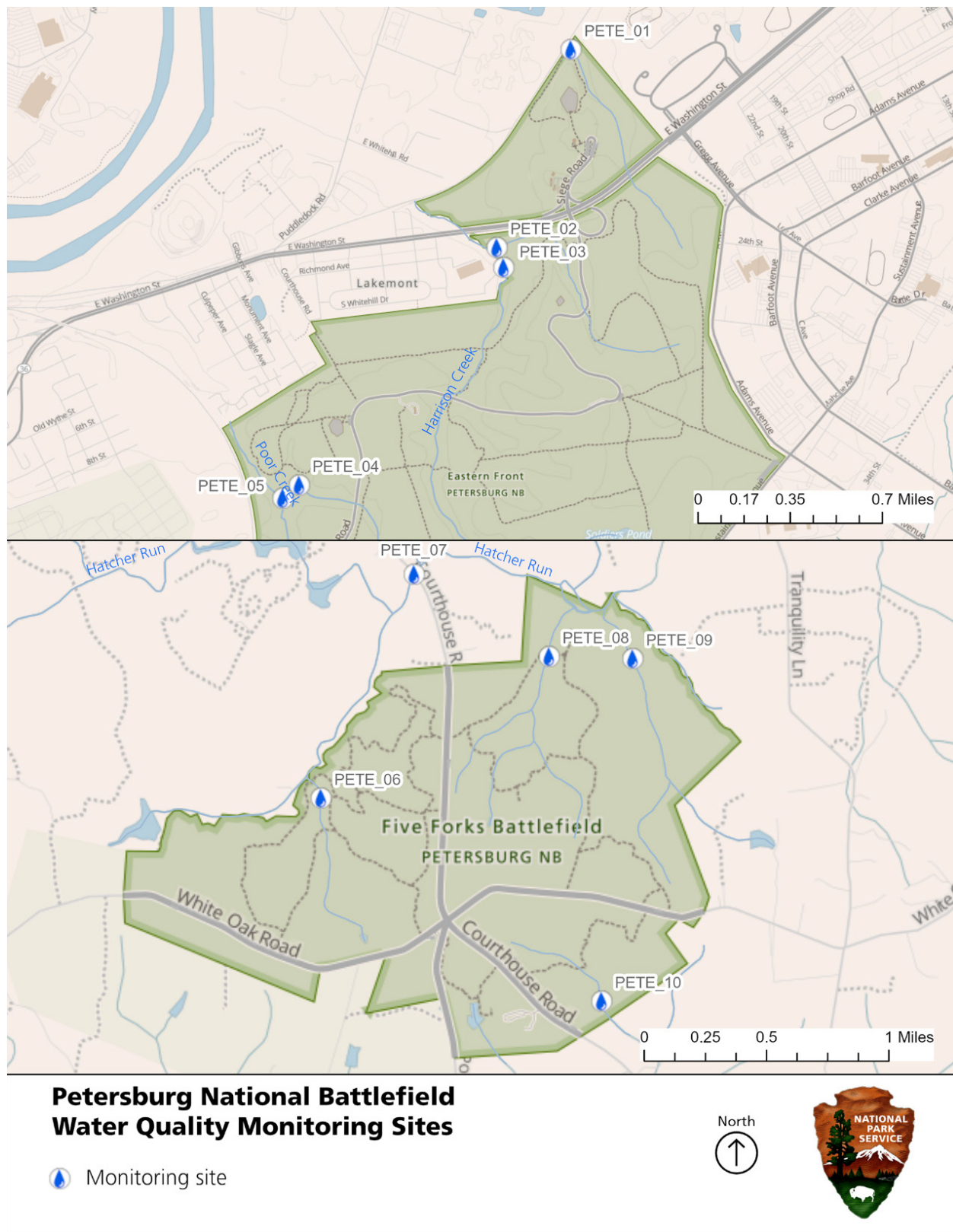


**Figure 4.** Map of 10 water quality monitoring sites at Petersburg National Battlefield. NPS proclaimed boundaries (green outline) and NPS park lands (green fill) are based on NPS Park Tiles basemap products (<https://www.nps.gov/subjects/gisandmapping/npmmap.htm>).

**Table 9.** Summary statistics for core parameters at Petersburg National Military Park. Statistics include sample period, total number of samples (N), percentiles 10, 50 (median), and 90 of the dataset, and the percent of samples that did not meet state water-quality standards.

| Site (Stream name)                              | Parameter <sup>A</sup> | Start      | End        | Period of record | N  | Percentile |      |      | Excursion % <sup>B</sup> |
|-------------------------------------------------|------------------------|------------|------------|------------------|----|------------|------|------|--------------------------|
|                                                 |                        |            |            |                  |    | 10         | 50   | 90   |                          |
| PETE_01 (Unnamed tributary of Appomattox River) | pH                     | 2010-11-10 | 2023-09-27 | 13               | 62 | 6.21       | 6.40 | 6.79 | 2                        |
|                                                 | Dissolved oxygen       | 2010-11-10 | 2023-09-27 | 13               | 60 | 7.4        | 8.7  | 11.8 | 0                        |
|                                                 | Water temperature      | 2010-11-10 | 2023-09-27 | 13               | 62 | 7.7        | 14.4 | 22.3 | 0                        |
|                                                 | Specific conductance   | 2010-11-10 | 2023-09-27 | 13               | 62 | 74         | 88   | 96   | N/A                      |
| PETE_02 (Branch Creek)                          | pH                     | 2010-10-19 | 2023-09-27 | 13               | 89 | 6.47       | 6.82 | 7.23 | 0                        |
|                                                 | Dissolved oxygen       | 2010-10-19 | 2023-09-27 | 13               | 85 | 7.7        | 10.0 | 12.6 | 0                        |
|                                                 | Water temperature      | 2010-10-19 | 2023-09-27 | 13               | 89 | 6.3        | 14.8 | 22.3 | 0                        |
|                                                 | Specific conductance   | 2010-10-19 | 2023-09-27 | 13               | 89 | 50         | 56   | 63   | N/A                      |
| PETE_03 (Harrison Creek)                        | pH                     | 2010-10-19 | 2023-07-26 | 13               | 85 | 6.79       | 7.07 | 7.33 | 1                        |
|                                                 | Dissolved oxygen       | 2010-10-19 | 2023-07-26 | 13               | 81 | 7.5        | 9.9  | 13.2 | 0                        |
|                                                 | Water temperature      | 2010-10-19 | 2023-07-26 | 13               | 85 | 5.6        | 13.5 | 22.9 | 0                        |
|                                                 | Specific conductance   | 2010-10-19 | 2023-07-26 | 13               | 85 | 83         | 132  | 162  | N/A                      |
| PETE_04 (Taylor Creek)                          | pH                     | 2010-10-19 | 2023-09-27 | 13               | 85 | 6.45       | 6.72 | 7.12 | 2                        |
|                                                 | Dissolved oxygen       | 2010-10-19 | 2023-09-27 | 13               | 83 | 5.9        | 8.9  | 13.1 | 2                        |
|                                                 | Water temperature      | 2010-10-19 | 2023-09-27 | 13               | 87 | 5.4        | 15.2 | 23.1 | 0                        |
|                                                 | Specific conductance   | 2010-10-19 | 2023-09-27 | 13               | 87 | 59         | 100  | 200  | N/A                      |
| PETE_05 (Poor Creek)                            | pH                     | 2010-10-19 | 2023-09-27 | 13               | 86 | 6.95       | 7.24 | 7.51 | 0                        |
|                                                 | Dissolved oxygen       | 2010-10-19 | 2023-09-27 | 13               | 84 | 7.5        | 9.8  | 12.8 | 0                        |
|                                                 | Water temperature      | 2010-10-19 | 2023-09-27 | 13               | 88 | 5.5        | 14.7 | 23.4 | 0                        |
|                                                 | Specific conductance   | 2010-10-19 | 2023-09-27 | 13               | 88 | 129        | 203  | 268  | N/A                      |
| PETE_06 (Unnamed tributary of Hatcher Run)      | pH                     | 2011-02-04 | 2023-06-26 | 12               | 36 | 5.29       | 5.71 | 6.14 | 0                        |
|                                                 | Dissolved oxygen       | 2011-02-04 | 2023-06-26 | 12               | 34 | 3.9        | 8.9  | 10.6 | 0                        |

<sup>A</sup> Units: pH = dimensionless, dissolved oxygen = mg/L, water temperature = °C, specific conductance = µS/cm, period of record = years.

<sup>B</sup> Virginia does not have a state standard for specific conductance.

**Table 9 (continued).** Summary statistics for core parameters at Petersburg National Military Park. Statistics include sample period, total number of samples (N), percentiles 10, 50 (median), and 90 of the dataset, and the percent of samples that did not meet state water-quality standards.

| Site (Stream name)                                     | Parameter <sup>A</sup> | Start      | End        | Period of record | N  | Percentile |      |      | Excursion % <sup>B</sup> |
|--------------------------------------------------------|------------------------|------------|------------|------------------|----|------------|------|------|--------------------------|
|                                                        |                        |            |            |                  |    | 10         | 50   | 90   |                          |
| PETE_06 (Unnamed tributary of Hatcher Run) (continued) | Water temperature      | 2011-02-04 | 2023-06-26 | 12               | 36 | 6.3        | 11.5 | 18.9 | 0                        |
|                                                        | Specific conductance   | 2011-02-04 | 2023-06-26 | 12               | 36 | 29         | 34   | 52   | N/A                      |
| PETE_07 (Hatcher Run)                                  | pH                     | 2010-10-19 | 2023-09-27 | 13               | 84 | 5.67       | 6.05 | 6.36 | 0                        |
|                                                        | Dissolved oxygen       | 2010-10-19 | 2023-09-27 | 13               | 82 | 0.6        | 2.8  | 9.2  | 0                        |
|                                                        | Water temperature      | 2010-10-19 | 2023-09-27 | 13               | 85 | 6.1        | 15.2 | 25.3 | 0                        |
|                                                        | Specific conductance   | 2010-10-19 | 2023-09-27 | 13               | 84 | 46         | 54   | 74   | N/A                      |
| PETE_08 (Beaverdam Creek)                              | pH                     | 2011-02-04 | 2023-06-26 | 12               | 37 | 5.67       | 5.96 | 6.50 | 0                        |
|                                                        | Dissolved oxygen       | 2011-02-04 | 2023-06-26 | 12               | 35 | 6.3        | 9.6  | 11.2 | 0                        |
|                                                        | Water temperature      | 2011-02-04 | 2023-06-26 | 12               | 37 | 6.3        | 11.5 | 20.1 | 0                        |
|                                                        | Specific conductance   | 2011-02-04 | 2023-06-26 | 12               | 37 | 30         | 35   | 51   | N/A                      |
| PETE_09 (Boulder Creek)                                | pH                     | 2010-11-10 | 2023-06-26 | 13               | 39 | 5.66       | 6.07 | 6.42 | 0                        |
|                                                        | Dissolved oxygen       | 2010-11-10 | 2023-06-26 | 13               | 35 | 5.9        | 9.7  | 11.4 | 0                        |
|                                                        | Water temperature      | 2010-11-10 | 2023-06-26 | 13               | 38 | 5.4        | 11.1 | 18.1 | 0                        |
|                                                        | Specific conductance   | 2010-11-10 | 2023-06-26 | 13               | 38 | 38         | 46   | 54   | N/A                      |
| PETE_10 (Gravelly Brook)                               | pH                     | 2011-02-04 | 2023-06-26 | 12               | 53 | 4.49       | 4.72 | 5.20 | 98                       |
|                                                        | Dissolved oxygen       | 2011-02-04 | 2023-06-26 | 12               | 50 | 4.5        | 8.5  | 11.2 | 8                        |
|                                                        | Water temperature      | 2011-02-04 | 2023-06-26 | 12               | 53 | 5.5        | 10.7 | 19.7 | 0                        |
|                                                        | Specific conductance   | 2011-02-04 | 2023-06-26 | 12               | 53 | 37         | 47   | 63   | N/A                      |

<sup>A</sup> Units: pH = dimensionless, dissolved oxygen = mg/L, water temperature = °C, specific conductance = µS/cm, period of record = years.

<sup>B</sup> Virginia does not have a state standard for specific conductance.

Virginia has listed several streams in PETE for impairments not associated with NPS core water quality parameters. Though bacterial levels are not monitored by MIDN, high levels of *E. coli* bacteria in stream water samples have been documented in Poor Creek (PETE\_05) and Harrison Creek (PETE\_03), and both are currently listed as impaired for recreational use (VADEQ 2022). In addition, Hatcher Run (PETE\_07) is listed as impaired for fish consumption due to high concentrations of mercury in fish tissue (VADEQ 2022).

Data was insufficient for trend analysis in PETE\_06 (Unnamed tributary of Hatcher Run), PETE\_08 (Beaverdam Creek), and PETE\_09 (Boulder Creek). At sites where trend analysis was possible, no significant trends were observed (Table 10).

**Table 10.** Trend analysis results for Petersburg National Military Park. The table includes test results, trend (rate of change per year), median value, ambient change over the period of record, and magnitude of change (ambient change compared to median).

| Site (Stream name)                              | Parameter <sup>A</sup> | Period of record <sup>A</sup> | Season    | Tau   | p-value | Trend | Median <sup>B</sup> | Ambient change | Magnitude of change (%) |
|-------------------------------------------------|------------------------|-------------------------------|-----------|-------|---------|-------|---------------------|----------------|-------------------------|
| PETE_01 (Unnamed tributary of Appomattox River) | pH                     | 13                            | Quarterly | 0.00  | 0.90    | None  | 6.38                | –              | –                       |
|                                                 | Dissolved oxygen       | 13                            | Quarterly | –0.23 | 0.43    | None  | 8.8                 | –              | –                       |
|                                                 | Water temperature      | 13                            | Quarterly | 0.39  | 0.20    | None  | 14.1                | –              | –                       |
|                                                 | Specific conductance   | 13                            | Quarterly | –0.05 | 0.82    | None  | 88                  | –              | –                       |
| PETE_02 (Branch Creek)                          | pH                     | 13                            | Monthly   | 0.00  | 0.99    | None  | 6.82                | –              | –                       |
|                                                 | Dissolved oxygen       | 13                            | Monthly   | 0.06  | 0.88    | None  | 10.0                | –              | –                       |
|                                                 | Water temperature      | 13                            | Monthly   | 0.21  | 0.56    | None  | 14.8                | –              | –                       |
|                                                 | Specific conductance   | 13                            | Monthly   | –0.17 | 0.66    | None  | 56                  | –              | –                       |
| PETE_03 (Harrison Creek)                        | pH                     | 13                            | Monthly   | –0.08 | 0.87    | None  | 7.07                | –              | –                       |
|                                                 | Dissolved oxygen       | 13                            | Monthly   | –0.14 | 0.69    | None  | 9.8                 | –              | –                       |
|                                                 | Water temperature      | 13                            | Monthly   | 0.22  | 0.55    | None  | 13.7                | –              | –                       |
|                                                 | Specific conductance   | 13                            | Monthly   | –0.22 | 0.56    | None  | 132                 | –              | –                       |
| PETE_04 (Taylor Creek)                          | pH                     | 13                            | Monthly   | 0.00  | 0.98    | None  | 6.72                | –              | –                       |
|                                                 | Dissolved oxygen       | 13                            | Monthly   | 0.16  | 0.69    | None  | 8.9                 | –              | –                       |
|                                                 | Water temperature      | 13                            | Monthly   | 0.15  | 0.70    | None  | 15.2                | –              | –                       |
|                                                 | Specific conductance   | 13                            | Monthly   | –0.04 | 0.90    | None  | 101                 | –              | –                       |
| PETE_05 (Poor Creek)                            | pH                     | 13                            | Monthly   | 0.01  | 1.00    | None  | 7.24                | –              | –                       |
|                                                 | Dissolved oxygen       | 13                            | Monthly   | –0.12 | 0.72    | None  | 9.8                 | –              | –                       |
|                                                 | Water temperature      | 13                            | Monthly   | 0.18  | 0.64    | None  | 14.6                | –              | –                       |
|                                                 | Specific conductance   | 13                            | Monthly   | –0.33 | 0.40    | None  | 204                 | –              | –                       |
| PETE_07 (Hatcher Run)                           | pH                     | 13                            | Monthly   | –0.34 | 0.41    | None  | 6.05                | –              | –                       |
|                                                 | Dissolved oxygen       | 13                            | Monthly   | 0.14  | 0.71    | None  | 2.8                 | –              | –                       |

<sup>A</sup> Units: pH = dimensionless, dissolved oxygen = mg/L, water temperature = °C, specific conductance = μS/cm, period of record = years.

<sup>B</sup> This value represents the seasonal median not the full dataset median as in Table 9.

**Table 10 (continued).** Trend analysis results for Petersburg National Military Park. The table includes test results, trend (rate of change per year), median value, ambient change over the period of record, and magnitude of change (ambient change compared to median).

| Site (Stream name)                   | Parameter <sup>A</sup> | Period of record <sup>A</sup> | Season    | Tau   | p-value | Trend | Median <sup>B</sup> | Ambient change | Magnitude of change (%) |
|--------------------------------------|------------------------|-------------------------------|-----------|-------|---------|-------|---------------------|----------------|-------------------------|
| PETE_07 (Hatcher Run)<br>(continued) | Water temperature      | 13                            | Monthly   | 0.11  | 0.78    | None  | 15.2                | –              | –                       |
|                                      | Specific conductance   | 13                            | Monthly   | –0.34 | 0.38    | None  | 54                  | –              | –                       |
| PETE_10 (Gravelly Brook)             | pH                     | 13                            | Quarterly | –0.46 | 0.31    | None  | 4.83                | –              | –                       |
|                                      | Dissolved oxygen       | 13                            | Quarterly | 0.22  | 0.74    | None  | 7.5                 | –              | –                       |
|                                      | Water temperature      | 13                            | Quarterly | –0.04 | 0.87    | None  | 10.2                | –              | –                       |
|                                      | Specific conductance   | 13                            | Quarterly | –0.07 | 1.00    | None  | 49                  | –              | –                       |

<sup>A</sup> Units: pH = dimensionless, dissolved oxygen = mg/L, water temperature = °C, specific conductance = µS/cm, period of record = years.

<sup>B</sup> This value represents the seasonal median not the full dataset median as in Table 9.

***Richmond National Battlefield***

Eight sites were monitored for water quality at Richmond NB (Figure 5), and seven of those sites had at least one excursion from state water-quality standards for pH (Table 11). Five sites had at least one excursion from dissolved oxygen standards. A single site deviated from state water temperature standards, though only for 1% of measurements (in this case, a single site visit at RICH\_06 on Crewe's Channel).

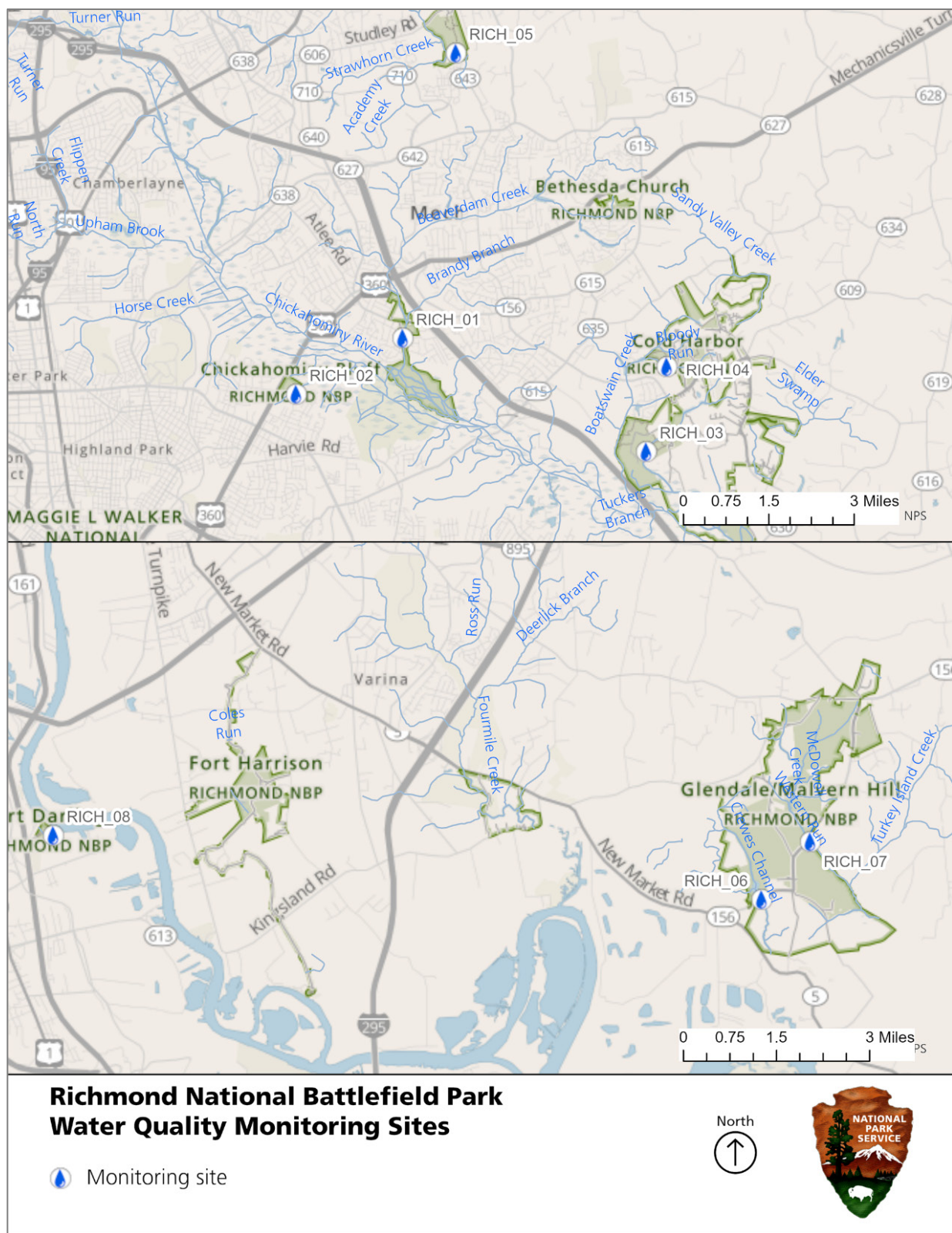


**Figure 5.** Map of eight water quality monitoring sites at Richmond National Battlefield. NPS proclaimed boundaries (green outline) and NPS park lands (green fill) are based on NPS Park Tiles basemap products (<https://www.nps.gov/subjects/gisandmapping/npsmap.htm>).

**Table 11.** Summary statistics for core parameters at Richmond National Battlefield. Statistics include sample period, total number of samples (N), percentiles 10, 50 (median), and 90 of the dataset, and the percent of samples that did not meet state water-quality standards.

| Site (Stream name)                                | Parameter <sup>A</sup> | Start      | End        | Period of record | N   | Percentile |      |      | Excursion % <sup>B</sup> |
|---------------------------------------------------|------------------------|------------|------------|------------------|-----|------------|------|------|--------------------------|
|                                                   |                        |            |            |                  |     | 10         | 50   | 90   |                          |
| RICH_01 (Beaverdam Creek)                         | pH                     | 2010-10-05 | 2023-09-22 | 13               | 126 | 6.42       | 6.64 | 6.92 | 2                        |
|                                                   | Dissolved oxygen       | 2010-10-05 | 2023-09-22 | 13               | 124 | 6.9        | 8.9  | 12.1 | 0                        |
|                                                   | Water temperature      | 2010-10-05 | 2023-09-22 | 13               | 127 | 6.8        | 16.3 | 24.8 | 0                        |
|                                                   | Specific conductance   | 2010-10-05 | 2023-09-22 | 13               | 126 | 93         | 112  | 136  | N/A                      |
| RICH_02 (Unnamed tributary of Chickahominy River) | pH                     | 2010-10-05 | 2023-09-22 | 13               | 125 | 6.36       | 6.64 | 6.94 | 0                        |
|                                                   | Dissolved oxygen       | 2010-10-05 | 2023-09-22 | 13               | 123 | 7.3        | 9.1  | 11.8 | 0                        |
|                                                   | Water temperature      | 2010-10-05 | 2023-09-22 | 13               | 126 | 7.0        | 15.5 | 23.7 | 0                        |
|                                                   | Specific conductance   | 2010-10-05 | 2023-09-22 | 13               | 124 | 128        | 156  | 199  | N/A                      |
| RICH_03 (Boatswain Creek)                         | pH                     | 2010-10-05 | 2023-09-22 | 13               | 125 | 5.89       | 6.28 | 6.70 | 15                       |
|                                                   | Dissolved oxygen       | 2010-10-05 | 2023-09-22 | 13               | 123 | 5.4        | 8.7  | 12.0 | 5                        |
|                                                   | Water temperature      | 2010-10-05 | 2023-09-22 | 13               | 126 | 5.5        | 14.4 | 23.3 | 0                        |
|                                                   | Specific conductance   | 2010-10-05 | 2023-09-22 | 13               | 125 | 59         | 72   | 108  | N/A                      |
| RICH_04 (Bloody Run)                              | pH                     | 2010-10-05 | 2023-09-22 | 13               | 126 | 5.45       | 5.86 | 6.22 | 69                       |
|                                                   | Dissolved oxygen       | 2010-10-05 | 2023-09-22 | 13               | 124 | 6.9        | 8.9  | 11.4 | 0                        |
|                                                   | Water temperature      | 2010-10-05 | 2023-09-22 | 13               | 127 | 7.1        | 14.1 | 20.6 | 0                        |
|                                                   | Specific conductance   | 2010-10-05 | 2023-09-22 | 13               | 126 | 49         | 59   | 69   | N/A                      |
| RICH_05 (Totopotomoy Creek)                       | pH                     | 2010-11-03 | 2023-09-22 | 13               | 69  | 6.44       | 6.68 | 6.89 | 3                        |
|                                                   | Dissolved oxygen       | 2010-11-03 | 2023-09-22 | 13               | 68  | 6.4        | 8.7  | 12.0 | 1                        |
|                                                   | Water temperature      | 2010-11-03 | 2023-09-22 | 13               | 70  | 6.2        | 15.6 | 25.1 | 0                        |
|                                                   | Specific conductance   | 2010-11-03 | 2023-09-22 | 13               | 70  | 89         | 102  | 114  | N/A                      |
| RICH_06 (Crewes Channel)                          | pH                     | 2010-10-05 | 2023-07-19 | 13               | 81  | 6.19       | 6.62 | 7.06 | 6                        |
|                                                   | Dissolved oxygen       | 2010-10-05 | 2023-07-19 | 13               | 77  | 2.9        | 7.7  | 11.8 | 14                       |

<sup>A</sup> Units: pH = dimensionless, dissolved oxygen = mg/L, water temperature = °C, specific conductance = µS/cm, period of record = years.

<sup>B</sup> Virginia does not have a state standard for specific conductance.

**Table 11 (continued).** Summary statistics for core parameters at Richmond National Battlefield. Statistics include sample period, total number of samples (N), percentiles 10, 50 (median), and 90 of the dataset, and the percent of samples that did not meet state water-quality standards.

| Site (Stream name)                         | Parameter <sup>A</sup> | Start      | End        | Period of record | N   | Percentile |      |      | Excursion % <sup>B</sup> |
|--------------------------------------------|------------------------|------------|------------|------------------|-----|------------|------|------|--------------------------|
|                                            |                        |            |            |                  |     | 10         | 50   | 90   |                          |
| RICH_06 (Crewes Channel)<br>(continued)    | Water temperature      | 2010-10-05 | 2023-07-19 | 13               | 81  | 5.4        | 15.8 | 27.1 | 1                        |
|                                            | Specific conductance   | 2010-10-05 | 2023-07-19 | 13               | 81  | 49         | 86   | 241  | N/A                      |
| RICH_07 (Western Run)                      | pH                     | 2010-10-05 | 2023-09-22 | 13               | 126 | 6.10       | 6.53 | 6.95 | 7                        |
|                                            | Dissolved oxygen       | 2010-10-05 | 2023-09-22 | 13               | 124 | 5.5        | 8.1  | 12.2 | 6                        |
|                                            | Water temperature      | 2010-10-05 | 2023-09-22 | 13               | 127 | 4.8        | 13.8 | 23.3 | 0                        |
|                                            | Specific conductance   | 2010-10-05 | 2023-09-22 | 13               | 126 | 58         | 66   | 84   | N/A                      |
| RICH_08 (Unnamed tributary of James River) | pH                     | 2011-02-01 | 2023-09-22 | 13               | 70  | 6.23       | 6.42 | 6.63 | 1                        |
|                                            | Dissolved oxygen       | 2011-02-01 | 2023-09-22 | 13               | 68  | 6.0        | 7.9  | 10.2 | 3                        |
|                                            | Water temperature      | 2011-02-01 | 2023-09-22 | 13               | 69  | 6.5        | 12.9 | 20.6 | 0                        |
|                                            | Specific conductance   | 2011-02-01 | 2023-09-22 | 13               | 70  | 176        | 296  | 365  | N/A                      |

<sup>A</sup> Units: pH = dimensionless, dissolved oxygen = mg/L, water temperature = °C, specific conductance = µS/cm, period of record = years.

<sup>B</sup> Virginia does not have a state standard for specific conductance.

For pH, RICH\_03 (Boatswain Creek) and RICH\_04 (Bloody Run) had a substantial number of excursions (i.e., >10%). These sites deviated from the state standard during 15% and 69% of observations, respectively. Both sites are listed by VADEQ as impaired for aquatic life due to pH violations. Boatswain Creek (RICH\_03) is listed as 5D (needing TMDL development) while Bloody Run (RICH\_04) is listed as 5C (impaired likely due to natural conditions). The sites on Boatswain Creek and Bloody Run are both located on Udults-Ochrepts complex soils which are described as “strongly acid to extremely acid” by Hodges et al. (1980) which potentially explains the high number of pH excursions.

For dissolved oxygen, only RICH\_06 had a substantial number of excursions. RICH\_06 is located on Crewe’s Channel, downstream of large beaver-maintained wetland complex, and the site deviated from dissolved oxygen standards during 14% of observations. Over the period of record the site cycled through periods of beaver pond outflow and free flowing stream. The low dissolved oxygen concentrations were likely a result of natural conditions due to this beaver activity.

In addition to the pH impairments noted above, VADEQ (2022) has also listed many of the sites at RICH as impaired for recreational use due to *E. coli* bacterial contamination, including Beaverdam Creek (RICH\_01), Boatswain Creek (RICH\_03), Totopotomoy Creek (RICH\_05), Crewe’s Channel (RICH\_06), and Western Run (RICH\_07).

Trend analysis at Richmond NB indicated that three sites had increasing trends in dissolved oxygen (RICH\_01 on Beaverdam Creek, RICH\_02 on an unnamed tributary to the Chickahominy River, and RICH\_08 on an unnamed tributary to the James River at Drewy’s Bluff), two sites had increasing trends in pH (RICH\_03 on Boatswain Creek and RICH\_08) and one site (RICH\_08) had a decreasing trend in specific conductance (Table 12). The causes of these trends are currently unknown. Over the period of record, RICH\_03 has been inundated by beaver activity at various times (beavers abandoned the site around 2016) which might have affected pH at the site. RICH\_08 is known to be impacted by leachate from a closed and capped landfill (Nimmo et al. 1994), and trends observed at this site might be a result of changing stream conditions related to this leachate. Increasing trends in dissolved oxygen do not currently constitute any reason for concern and are within normal, healthy conditions for these stream types.

**Table 12.** Trend analysis results for Richmond National Battlefield. The table includes test results, trend (rate of change per year), median value, ambient change over the period of record, and magnitude of change (ambient change compared to median).

| Site (Stream name)                                | Parameter <sup>A</sup> | Period of record <sup>A</sup> | Season    | Tau   | p-value | Trend | Median <sup>B</sup> | Ambient change | Magnitude of change (%) |
|---------------------------------------------------|------------------------|-------------------------------|-----------|-------|---------|-------|---------------------|----------------|-------------------------|
| RICH_01 (Beaverdam Creek)                         | pH                     | 13                            | Monthly   | 0.24  | 0.08    | None  | 6.64                | –              | –                       |
|                                                   | Dissolved oxygen       | 13                            | Monthly   | 0.22  | 0.03    | 0.08  | 9.0                 | 1.0            | 12                      |
|                                                   | Water temperature      | 13                            | Monthly   | 0.03  | 0.78    | None  | 16.3                | –              | –                       |
|                                                   | Specific conductance   | 13                            | Monthly   | 0.02  | 0.88    | None  | 112                 | –              | –                       |
| RICH_02 (Unnamed tributary of Chickahominy River) | pH                     | 13                            | Monthly   | 0.22  | 0.16    | None  | 6.64                | –              | –                       |
|                                                   | Dissolved oxygen       | 13                            | Monthly   | 0.21  | 0.03    | 0.06  | 9.1                 | 0.8            | 9                       |
|                                                   | Water temperature      | 13                            | Monthly   | 0.05  | 0.74    | None  | 15.5                | –              | –                       |
|                                                   | Specific conductance   | 13                            | Monthly   | 0.07  | 0.64    | None  | 156                 | –              | –                       |
| RICH_03 (Boatswain Creek)                         | pH                     | 13                            | Monthly   | 0.31  | 0.02    | 0.04  | 6.28                | 0.52           | 8                       |
|                                                   | Dissolved oxygen       | 13                            | Monthly   | 0.19  | 0.12    | None  | 8.7                 | –              | –                       |
|                                                   | Water temperature      | 13                            | Monthly   | 0.01  | 0.83    | None  | 14.5                | –              | –                       |
|                                                   | Specific conductance   | 13                            | Monthly   | 0.24  | 0.07    | None  | 75                  | –              | –                       |
| RICH_04 (Bloody Run)                              | pH                     | 13                            | Monthly   | 0.08  | 0.40    | None  | 5.86                | –              | –                       |
|                                                   | Dissolved oxygen       | 13                            | Monthly   | 0.07  | 0.48    | None  | 8.9                 | –              | –                       |
|                                                   | Water temperature      | 13                            | Monthly   | 0.02  | 0.98    | None  | 14.1                | –              | –                       |
|                                                   | Specific conductance   | 13                            | Monthly   | 0.25  | 0.07    | None  | 59                  | –              | –                       |
| RICH_05 (Totopotomoy Creek)                       | pH                     | 13                            | Quarterly | 0.13  | 0.52    | None  | 6.69                | –              | –                       |
|                                                   | Dissolved oxygen       | 13                            | Quarterly | 0.05  | 0.65    | None  | 9.0                 | –              | –                       |
|                                                   | Water temperature      | 13                            | Quarterly | –0.01 | 0.92    | None  | 14.1                | –              | –                       |
|                                                   | Specific conductance   | 13                            | Quarterly | 0.06  | 0.82    | None  | 103                 | –              | –                       |
| RICH_06 (Crewes Channel)                          | pH                     | 13                            | Quarterly | –0.06 | 0.53    | None  | 6.64                | –              | –                       |
|                                                   | Dissolved oxygen       | 13                            | Quarterly | 0.00  | 1.00    | None  | 7.4                 | –              | –                       |

<sup>A</sup> Units: pH = dimensionless, dissolved oxygen = mg/L, water temperature = °C, specific conductance = μS/cm, period of record = years.

<sup>B</sup> This value represents the seasonal median not the full dataset median as in Table 11.

**Table 12 (continued).** Trend analysis results for Richmond National Battlefield. The table includes test results, trend (rate of change per year), median value, ambient change over the period of record, and magnitude of change (ambient change compared to median).

| Site (Stream name)                         | Parameter <sup>A</sup> | Period of record <sup>A</sup> | Season    | Tau   | p-value | Trend  | Median <sup>B</sup> | Ambient change | Magnitude of change (%) |
|--------------------------------------------|------------------------|-------------------------------|-----------|-------|---------|--------|---------------------|----------------|-------------------------|
| RICH_06 (Crewes Channel)<br>(continued)    | Water temperature      | 13                            | Quarterly | -0.04 | 0.77    | None   | 15.7                | -              | -                       |
|                                            | Specific conductance   | 13                            | Quarterly | 0.10  | 0.45    | None   | 94                  | -              | -                       |
| RICH_07 (Western Run)                      | pH                     | 13                            | Monthly   | 0.06  | 0.59    | None   | 6.53                | -              | -                       |
|                                            | Dissolved oxygen       | 13                            | Monthly   | -0.11 | 0.40    | None   | 8.1                 | -              | -                       |
|                                            | Water temperature      | 13                            | Monthly   | 0.00  | 0.83    | None   | 14.1                | -              | -                       |
|                                            | Specific conductance   | 13                            | Monthly   | 0.10  | 0.47    | None   | 67                  | -              | -                       |
| RICH_08 (Unnamed tributary of James River) | pH                     | 13                            | Quarterly | 0.25  | 0.05    | 0.01   | 6.40                | 0.13           | 2                       |
|                                            | Dissolved oxygen       | 13                            | Quarterly | 0.37  | 0.02    | 0.14   | 7.7                 | 1.8            | 24                      |
|                                            | Water temperature      | 13                            | Quarterly | 0.03  | 0.97    | None   | 12.2                | -              | -                       |
|                                            | Specific conductance   | 13                            | Quarterly | -0.47 | 0.00    | -10.93 | 313                 | -142           | -45                     |

<sup>A</sup> Units: pH = dimensionless, dissolved oxygen = mg/L, water temperature = °C, specific conductance = µS/cm, period of record = years.

<sup>B</sup> This value represents the seasonal median not the full dataset median as in Table 11.

**Pennsylvania National Parks**

MIDN monitors three national parks for water quality in the commonwealth of Pennsylvania including Eisenhower NHS, Gettysburg NMP, and Hopewell Furnace NHS.

***Eisenhower National Historic Site***

Two sites were monitored for water quality at Eisenhower NHS (Figure 6); a site on Marsh Creek (EISE\_03) and a site on lower Willoughby Run (EISE\_04).

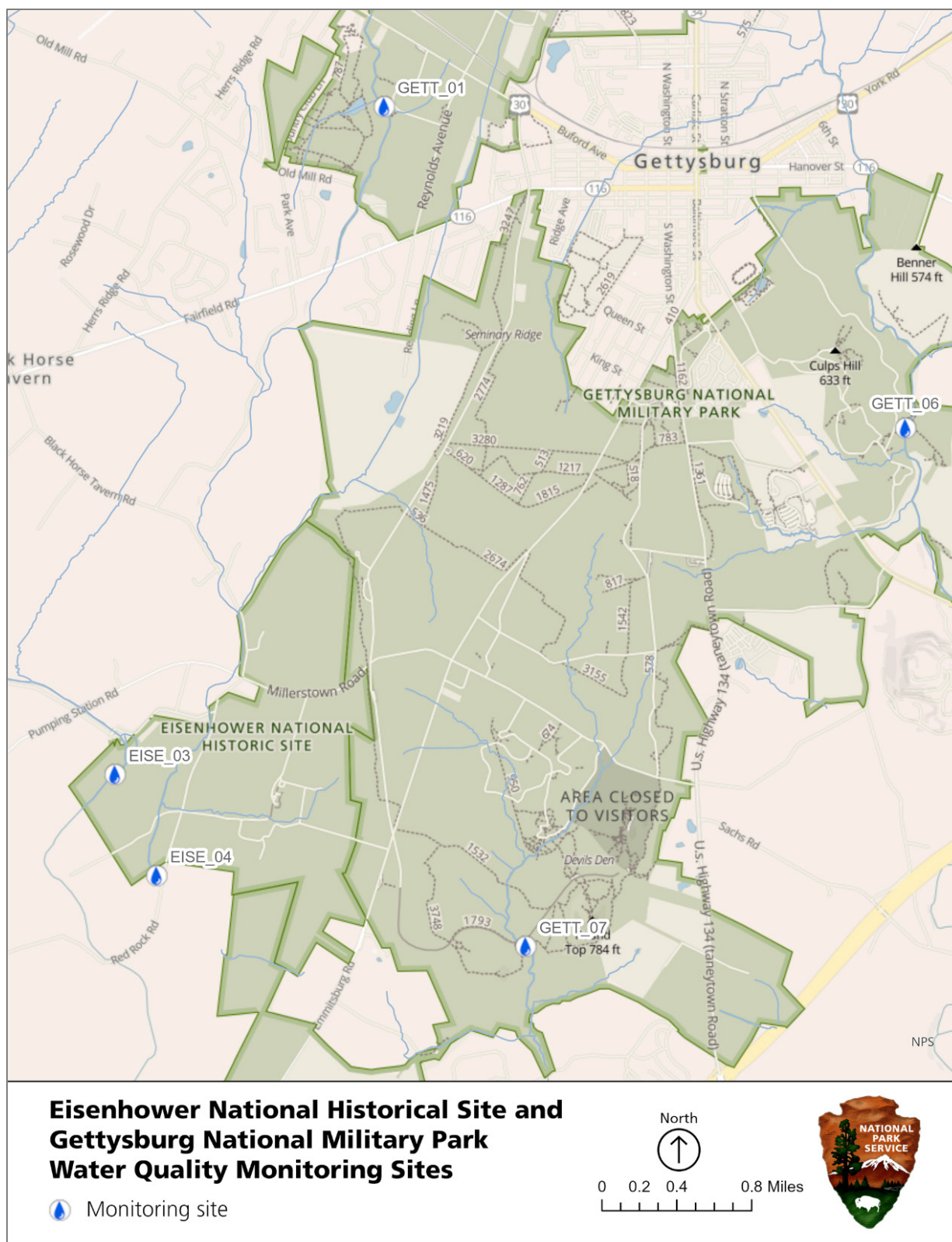


**Figure 6.** Map of five water quality monitoring sites at Eisenhower National Historic Site and Gettysburg National Military Park. NPS proclaimed boundaries (green outline) and NPS park lands (green fill) are based on NPS Park Tiles basemap products (<https://www.nps.gov/subjects/gisandmapping/npmmap.htm>).

The lower Willoughby Run site deviated from water quality standards in 11% of the measurements for pH and 3% of the measurements for dissolved oxygen (Table 13). The pH excursions (higher than standards) and dissolved oxygen excursions (lower than standards) in Willoughby Run are likely driven by upstream nutrient enrichment and associated algal growth. Large portions of the Willoughby Run watershed are intensively utilized for agriculture, and this stream segment is currently listed as impaired for aquatic life due to “agriculture – siltation, agriculture - organic enrichment, and agriculture – habitat alterations” (PADEP 2022). The agricultural impairments create an ideal nutrient environment for algal growth which can create large diel fluctuations in dissolved oxygen and pH as these abundant organisms shift from daytime photosynthesis to nighttime respiration (EPA 2000). Indeed, more targeted water quality sampling late in the day (when high pH would be expected) or early in the morning (when low dissolved oxygen would be expected) would have likely led to more excursions in Willoughby Run for these parameters. In terms of trend, no significant trends were observed at EISE for any water quality parameters (Table 14).

**Table 13.** Summary statistics for core parameters at Eisenhower National Historic Site. Statistics include sample period, total number of samples (N), percentiles 10, 50 (median), and 90 of the dataset, and the percent of samples that did not meet state water-quality standards.

| Site (Stream name)       | Parameter <sup>A</sup> | Start      | End        | Period of record | N   | Percentile |      |      | Excursion % <sup>B</sup> |
|--------------------------|------------------------|------------|------------|------------------|-----|------------|------|------|--------------------------|
|                          |                        |            |            |                  |     | 10         | 50   | 90   |                          |
| EISE_03 (Marsh Creek)    | pH                     | 2010-10-06 | 2023-09-19 | 13               | 100 | 7.49       | 7.90 | 8.37 | 0                        |
|                          | Dissolved oxygen       | 2010-10-06 | 2023-09-19 | 13               | 99  | 7.9        | 10.7 | 14.5 | 0                        |
|                          | Water temperature      | 2010-10-06 | 2023-09-19 | 13               | 102 | 2.5        | 13.1 | 24.4 | N/A                      |
|                          | Specific conductance   | 2010-10-06 | 2023-09-19 | 13               | 102 | 153        | 201  | 484  | N/A                      |
| EISE_04 (Willoughby Run) | pH                     | 2010-10-06 | 2023-09-19 | 13               | 103 | 7.54       | 8.30 | 9.02 | 11                       |
|                          | Dissolved oxygen       | 2010-10-06 | 2023-09-19 | 13               | 102 | 7.6        | 13.1 | 17.4 | 3                        |
|                          | Water temperature      | 2010-10-06 | 2023-09-19 | 13               | 105 | 2.5        | 13.3 | 25.3 | N/A                      |
|                          | Specific conductance   | 2010-10-06 | 2023-09-19 | 13               | 105 | 251        | 415  | 810  | N/A                      |

<sup>A</sup> Units: pH = dimensionless, dissolved oxygen = mg/L, water temperature = °C, specific conductance = µS/cm, period of record = years.

<sup>B</sup> Pennsylvania does not have a state standard for specific conductance (uS/cm).

**Table 14.** Trend analysis results for Eisenhower National Historic Site. The table includes test results, trend (rate of change per year), median value, ambient change over the period of record, and magnitude of change (ambient change compared to median).

| Site (Stream name)       | Parameter <sup>A</sup> | Period of record <sup>A</sup> | Season    | Tau   | p-value | Trend | Median <sup>B</sup> | Ambient change | Magnitude of change (%) |
|--------------------------|------------------------|-------------------------------|-----------|-------|---------|-------|---------------------|----------------|-------------------------|
| EISE_03 (Marsh Creek)    | pH                     | 13                            | Quarterly | 0.11  | 0.40    | None  | 7.91                | –              | –                       |
|                          | Dissolved oxygen       | 13                            | Quarterly | –0.02 | 0.89    | None  | 11.3                | –              | –                       |
|                          | Water temperature      | 13                            | Quarterly | 0.09  | 0.47    | None  | 10.7                | –              | –                       |
|                          | Specific conductance   | 13                            | Quarterly | 0.20  | 0.09    | None  | 194                 | –              | –                       |
| EISE_04 (Willoughby Run) | pH                     | 13                            | Quarterly | 0.20  | 0.07    | None  | 8.21                | –              | –                       |
|                          | Dissolved oxygen       | 13                            | Quarterly | 0.06  | 0.63    | None  | 13.6                | –              | –                       |
|                          | Water temperature      | 13                            | Quarterly | 0.06  | 0.72    | None  | 10.8                | –              | –                       |
|                          | Specific conductance   | 13                            | Quarterly | 0.06  | 0.65    | None  | 415                 | –              | –                       |

<sup>A</sup> Units: pH = dimensionless, dissolved oxygen = mg/L, water temperature = °C, specific conductance = µS/cm, period of record = years.

<sup>B</sup> This value represents the seasonal median not the full dataset median as in Table 13.

**Gettysburg National Military Park**

At Gettysburg NMP, water quality monitoring sites are located on upper Willoughby Run (GETT\_01), Rock Creek (GETT\_06), and Plum Run (GETT\_07; Figure 6). The upper Willoughby Run site deviated from water quality standards in 3% of observations for pH and 5% of the measurements for dissolved oxygen (Table 15). As noted for EISE, Willoughby Run is in an intensively farmed agricultural watershed and the downstream reach at EISE\_04 is listed as impaired on the state 303 list of non-attaining streams (PADEP 2022). Rock Creek is also listed as non-attaining for aquatic life due to nutrient enrichment from agricultural and municipal sources. Rock Creek (GETT\_06) deviated from the pH standard on 5% of observations. As indicated with EISE\_04, it is likely that more excursions from water quality standards would be observed if observations occurred early or late in the day at GETT\_06 and GETT\_01 (e.g., low dissolved oxygen at dawn during the growing season). Plum Run (GETT\_07) had low dissolved oxygen concentrations on 4% of observations but unlike Rock Creek and Willoughby Run, these events were driven by summer low flow conditions and not large diel swings due to photosynthesis and respiration within the stream. No significant trends were observed for any water quality parameters at GETT (Table 16).

**Table 15.** Summary statistics for core parameters at Gettysburg National Military Park. Statistics include sample period, total number of samples (N), percentiles 10, 50 (median), and 90 of the dataset, and the percent of samples that did not meet state water-quality standards.

| Site (Stream name)       | Parameter <sup>A</sup> | Start      | End        | Period of record | N   | Percentile |      |      | Excursion % <sup>B</sup> |
|--------------------------|------------------------|------------|------------|------------------|-----|------------|------|------|--------------------------|
|                          |                        |            |            |                  |     | 10         | 50   | 90   |                          |
| GETT_01 (Willoughby Run) | pH                     | 2010-10-05 | 2023-09-19 | 13               | 103 | 7.39       | 7.72 | 8.42 | 3                        |
|                          | Dissolved oxygen       | 2010-10-05 | 2023-09-19 | 13               | 101 | 6.2        | 11.2 | 15.9 | 5                        |
|                          | Water temperature      | 2010-10-05 | 2023-09-19 | 13               | 105 | 1.4        | 12.8 | 22.9 | N/A                      |
|                          | Specific conductance   | 2010-10-05 | 2023-09-19 | 13               | 105 | 246        | 410  | 724  | N/A                      |
| GETT_06 (Rock Creek)     | pH                     | 2010-10-06 | 2023-09-19 | 13               | 104 | 7.44       | 8.10 | 8.80 | 5                        |
|                          | Dissolved oxygen       | 2010-10-06 | 2023-09-19 | 13               | 103 | 8.2        | 11.9 | 17.7 | 0                        |
|                          | Water temperature      | 2010-10-06 | 2023-09-19 | 13               | 106 | 3.8        | 14.2 | 25.8 | N/A                      |
|                          | Specific conductance   | 2010-10-06 | 2023-09-19 | 13               | 106 | 308        | 468  | 737  | N/A                      |
| GETT_07 (Plum Run)       | pH                     | 2010-10-05 | 2023-09-19 | 13               | 103 | 7.37       | 7.68 | 8.02 | 0                        |
|                          | Dissolved oxygen       | 2010-10-05 | 2023-09-19 | 13               | 102 | 6.6        | 10.7 | 14.6 | 4                        |
|                          | Water temperature      | 2010-10-05 | 2023-09-19 | 13               | 105 | 1.8        | 10.9 | 21.0 | N/A                      |
|                          | Specific conductance   | 2010-10-05 | 2023-09-19 | 13               | 105 | 146        | 201  | 257  | N/A                      |

<sup>A</sup> Units: pH = dimensionless, dissolved oxygen = mg/L, water temperature = °C, specific conductance = µS/cm, period of record = years.

<sup>B</sup> Pennsylvania does not have a state standard for specific conductance.

**Table 16.** Trend analysis results for Gettysburg National Military Park. The table includes test results, trend, median value, ambient change over the period of record, and magnitude of change (ambient change compared to median).

| Site (Stream name)       | Parameter <sup>A</sup> | Period of record <sup>A</sup> | Season    | Tau   | p-value | Trend | Median <sup>B</sup> | Ambient change | Magnitude of change (%) |
|--------------------------|------------------------|-------------------------------|-----------|-------|---------|-------|---------------------|----------------|-------------------------|
| GETT_01 (Willoughby Run) | pH                     | 13                            | Quarterly | 0.09  | 0.35    | None  | 7.76                | –              | –                       |
|                          | Dissolved oxygen       | 13                            | Quarterly | 0.09  | 0.37    | None  | 12.6                | –              | –                       |
|                          | Water temperature      | 13                            | Quarterly | –0.01 | 0.95    | None  | 10.7                | –              | –                       |
|                          | Specific conductance   | 13                            | Quarterly | 0.01  | 0.92    | None  | 390                 | –              | –                       |

<sup>A</sup> Units: pH = dimensionless, dissolved oxygen = mg/L, water temperature = °C, specific conductance = µS/cm, period of record = years.

<sup>B</sup> This value represents the seasonal median not the full dataset median as in Table 15.

**Table 16 (continued).** Trend analysis results for Gettysburg National Military Park. The table includes test results, trend, median value, ambient change over the period of record, and magnitude of change (ambient change compared to median).

| Site (Stream name)   | Parameter <sup>A</sup> | Period of record <sup>A</sup> | Season    | Tau   | p-value | Trend | Median <sup>B</sup> | Ambient change | Magnitude of change (%) |
|----------------------|------------------------|-------------------------------|-----------|-------|---------|-------|---------------------|----------------|-------------------------|
| GETT_06 (Rock Creek) | pH                     | 13                            | Quarterly | 0.24  | 0.07    | None  | 7.97                | –              | –                       |
|                      | Dissolved oxygen       | 13                            | Quarterly | 0.05  | 0.75    | None  | 13.0                | –              | –                       |
|                      | Water temperature      | 13                            | Quarterly | 0.12  | 0.37    | None  | 12.7                | –              | –                       |
|                      | Specific conductance   | 13                            | Quarterly | 0.11  | 0.38    | None  | 455                 | –              | –                       |
| GETT_07 (Plum Run)   | pH                     | 13                            | Quarterly | 0.07  | 0.42    | None  | 7.65                | –              | –                       |
|                      | Dissolved oxygen       | 13                            | Quarterly | 0.07  | 0.63    | None  | 11.2                | –              | –                       |
|                      | Water temperature      | 13                            | Quarterly | –0.07 | 0.56    | None  | 9.7                 | –              | –                       |
|                      | Specific conductance   | 13                            | Quarterly | –0.13 | 0.25    | None  | 198                 | –              | –                       |

<sup>A</sup> Units: pH = dimensionless, dissolved oxygen = mg/L, water temperature = °C, specific conductance = µS/cm, period of record = years.

<sup>B</sup> This value represents the seasonal median not the full dataset median as in Table 15.

### ***Hopewell Furnace National Historic Site***

Water quality monitoring in Hopewell Furnace National Historic Site occurs on French Creek (HOFU\_01) and on Baptism Creek (HOFU\_02; Figure 7). No deviations from water quality standards were observed in French Creek or Baptism Creek (Table 17). Both streams are designated as “exceptional value” waters by the Pennsylvania Department of Environmental Protection. Exceptional value streams are to be protected at their existing water quality, meaning that no declines in water quality should be permitted.

In terms of trend, analysis indicated an increasing trend in specific conductance at the French Creek site (HOFU\_01; Table 18). Over the 13-year period of record the estimated increase was relatively small (18  $\mu\text{S}/\text{cm}$ ), and observed values are well below levels expected to indicate stressful conditions for biota due to dissolved ions. However, increasing salination of freshwater systems due to increasing development (i.e., roads and impervious surfaces) and deicers is a concern across the Mid-Atlantic region (Kaushal et al. 2005). Even where much of the land in the watershed is in conservation, as is the case with the HOFU\_01 site, recent studies suggest even small changes in impervious surface cover can increase surface water ion concentrations (i.e., chloride; Rossi et al. 2022).

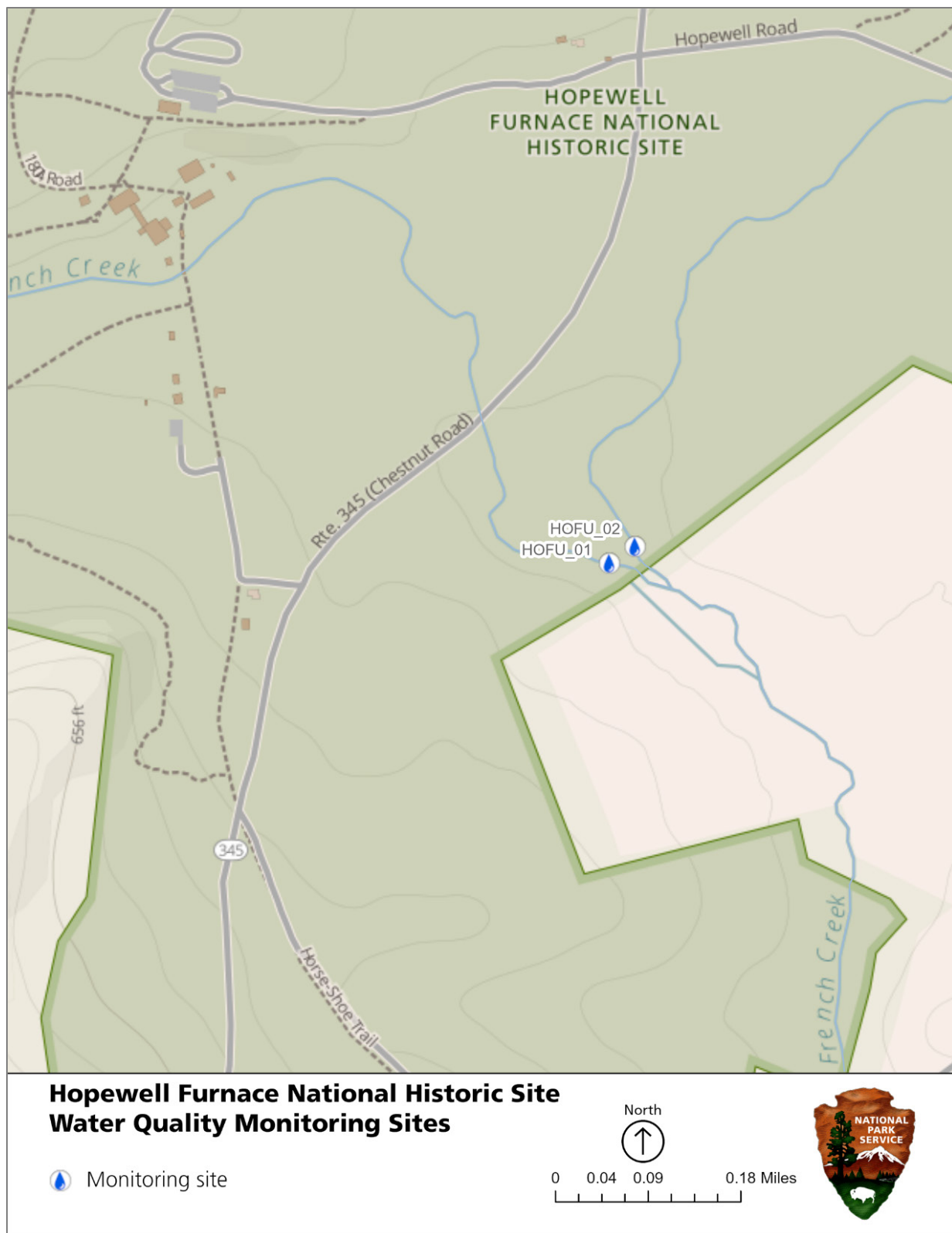


**Figure 7.** Map of two water quality monitoring sites at Hopewell Furnace National Historic Site. NPS proclaimed boundaries (green outline) and NPS park lands (green fill) are based on NPS Park Tiles basemap products (<https://www.nps.gov/subjects/gisandmapping/npsmap.htm>).

**Table 17.** Summary statistics for core parameters at Hopewell National Historic Site. Statistics include sample period, total number of samples (N), percentiles 10, 50 (median), and 90 of the dataset, and the percent of samples that did not meet state water-quality standards.

| Site (Stream name)      | Parameter <sup>A</sup> | Start      | End        | Period of record | N   | Percentile |      |      | Excursion % <sup>B</sup> |
|-------------------------|------------------------|------------|------------|------------------|-----|------------|------|------|--------------------------|
|                         |                        |            |            |                  |     | 10         | 50   | 90   |                          |
| HOFU_01 (French Creek)  | pH                     | 2010-10-13 | 2023-09-18 | 13               | 98  | 6.81       | 7.04 | 7.30 | 0                        |
|                         | Dissolved oxygen       | 2010-10-13 | 2023-09-18 | 13               | 95  | 7.2        | 9.3  | 12.9 | 0                        |
|                         | Water temperature      | 2010-10-13 | 2023-09-18 | 13               | 101 | 4.4        | 15.3 | 25.6 | N/A                      |
|                         | Specific conductance   | 2010-10-13 | 2023-09-18 | 13               | 99  | 67         | 79   | 96   | N/A                      |
| HOFU_02 (Baptism Creek) | pH                     | 2010-10-13 | 2023-09-18 | 13               | 88  | 6.77       | 7.08 | 7.38 | 0                        |
|                         | Dissolved oxygen       | 2010-10-13 | 2023-09-18 | 13               | 85  | 8.4        | 9.8  | 12.4 | 0                        |
|                         | Water temperature      | 2010-10-13 | 2023-09-18 | 13               | 91  | 5.7        | 13.2 | 20.3 | N/A                      |
|                         | Specific conductance   | 2010-10-13 | 2023-09-18 | 13               | 89  | 67         | 80   | 98   | N/A                      |

<sup>A</sup> Units: pH = dimensionless, dissolved oxygen = mg/L, water temperature = °C, specific conductance = µS/cm, period of record = years.

<sup>B</sup> Pennsylvania does not have a state standard for specific conductance.

**Table 18.** Trend analysis results for Hopewell Furnace National Historic Site. The table includes test results, trend (rate of change per year), median value, ambient change over the period of record, and magnitude of change (ambient change compared to median).

| Site (Stream name)      | Parameter <sup>A</sup> | Period of record <sup>A</sup> | Season  | Tau  | p-value | Trend | Median <sup>B</sup> | Ambient change | Magnitude of change (%) |
|-------------------------|------------------------|-------------------------------|---------|------|---------|-------|---------------------|----------------|-------------------------|
| HOFU_01 (French Creek)  | pH                     | 10                            | Monthly | 0.28 | 0.15    | None  | 7.04                | –              | –                       |
|                         | Water temperature      | 10                            | Monthly | 0.04 | 0.95    | None  | 15.0                | –              | –                       |
|                         | Specific conductance   | 10                            | Monthly | 0.37 | 0.02    | 1.82  | 77                  | 18             | 24                      |
| HOFU_02 (Baptism Creek) | pH                     | 10                            | Monthly | 0.23 | 0.38    | None  | 7.08                | –              | –                       |
|                         | Water temperature      | 10                            | Monthly | 0.08 | 0.42    | None  | 13.2                | –              | –                       |
|                         | Specific conductance   | 10                            | Monthly | 0.21 | 0.18    | None  | 80                  | –              | –                       |

<sup>A</sup> Units: pH = dimensionless, water temperature = °C, specific conductance = µS/cm, period of record = years.

<sup>B</sup> This value represents the seasonal median not the full dataset median as in Table 17.

## Conclusions

This report is focused on the status and trends of “core” water quality parameters as defined by the NPS’s Water Resources Division. Overall, the status of water quality at most sites met state standards for the parameters monitored. Where water quality observations deviated from state standards, this was often attributable to natural conditions in the associated watershed such as underlying acidic soils or beaver activity. Out of 141 site-parameter combinations, only 10 showed more than 10% of observations outside state standards. And, of these 10, only three are likely associated with anthropogenic activity. These three sites include EISE\_04 on lower Willoughby Run, FRSP\_01 on Lewis Run, and FRSP\_02 on a tributary to Lewis Run. Site EISE\_04 had 11% excursions of high pH and is likely impacted by agricultural nutrient pollution. Site FRSP\_01 (13% low dissolved oxygen excursions) and FRSP\_02 (17% low pH and 12% low dissolved oxygen excursions) are both on streams affected by human impoundments. In terms of trend, significant trends in water quality parameters were rare across the network, and when present, were relatively small.

These core water quality parameters and associated state-based standards represent some of the basic physical requirements necessary to maintain healthy and functioning aquatic ecosystems. Sufficient dissolved oxygen for respiration, pH conditions that allow for reproduction, temperature ranges that are adequate for the persistence of populations, and limited exposure to pollutants are all critical. However, these parameters cannot, on their own, provide insight into the full condition of these ecosystems. Insights into stream ecosystem health must include other components such as biological and physical habitat assessments. These additional components are monitored by the MIDN through the Benthic Macroinvertebrate Monitoring Protocol (Dammeyer 2018). Future reporting will incorporate these data for a more complete assessment of ecosystem health. Additionally, even though most sites currently meet state standards, future targeting of observations to capture high-stress conditions such as low dissolved oxygen (at dawn) or high pH values (in the late afternoon) in nutrient enriched streams could lead to a better assessment and understanding of stream ecosystem status and stressors (Shull and Whiteash 2021). Trend detection could be improved by reducing the variation in the time of day of water quality observations and limiting the effect of diel fluctuations on monitoring results. Despite these potential improvements, data included herein are informative on baseline conditions and estimates of trends in these freshwater streams.

This protocol was designed to monitor water quality in targeted streams. Therefore, it is inappropriate to draw inferences about status and trends across sites or national park lands at larger spatial scales. A targeted design was implemented due to the diversity of watershed characteristics, stream types, and aquatic stressors present in the MIDN. Although large-scale drivers of ecosystem function are certainly relevant (e.g., weather and climate), local factors (e.g., urban/suburban development, agricultural use) also have a strong impact on the current condition of MIDN streams. It is therefore likely that site-specific management planning is necessary.

Streams in Mid-Atlantic national parks face a wide variety of stressors but also opportunities for improvement. Although providing specific recommendations at the site scale is beyond the scope of this report, there are general practices in watershed management that are applicable. Both within and

outside of park boundaries, improving riparian buffers, developing filter strips around agricultural fields, and continuing best management practices for stormwater management can improve conditions within park streams. Providing park-specific recommendations for individual streams will be the focus of future work.

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## Appendix A.

**Table 19.** Virginia water quality monitoring site information.

| Park | Site                 | Stream name                          | Stream type <sup>A</sup> | Stream class <sup>B</sup> | NHD reach code | Latitude    | Longitude    |
|------|----------------------|--------------------------------------|--------------------------|---------------------------|----------------|-------------|--------------|
| APCO | APCO_01              | Appomattox River                     | P                        | III                       | 02080207001211 | 37.38197199 | -78.78891919 |
| APCO | APCO_02              | Plain Run                            | P                        | III                       | 02080207001219 | 37.38184987 | -78.78816024 |
| APCO | APCO_03              | Appomattox River                     | P                        | III                       | 02080207001210 | 37.38414691 | -78.78215730 |
| BOWA | BOWA_01              | Jack-O-Lantern Branch                | P                        | III                       | 03010101006176 | 37.11527724 | -79.72991607 |
| BOWA | BOWA_02              | Jack-O-Lantern Branch                | P                        | III                       | 03010101001881 | 37.10755109 | -79.72990510 |
| BOWA | BOWA_03              | Jack-O-Lantern Branch                | P                        | III                       | 03010101001881 | 37.10686377 | -79.73032299 |
| BOWA | BOWA_04              | Gills Creek                          | P                        | III                       | 03010101000446 | 37.10869750 | -79.73238879 |
| BOWA | BOWA_05              | Tributary of Gills Creek             | P                        | III                       | 03010101006190 | 37.11237806 | -79.73580297 |
| FRSP | FRSP_01              | Lewis Run                            | P                        | III                       | 02080105000217 | 38.29567540 | -77.64840348 |
| FRSP | FRSP_02              | Unnamed tributary of Lewis Run       | B                        | III                       | 02080105000800 | 38.30165440 | -77.64928157 |
| FRSP | FRSP_03              | Lewis Run                            | P                        | III                       | 02080105000216 | 38.28928309 | -77.64613241 |
| FRSP | FRSP_04              | Brock Run                            | P                        | III                       | 02080105000370 | 38.28194123 | -77.64693116 |
| FRSP | FRSP_06              | North Branch of Deep Run             | P                        | III                       | 02080104000796 | 38.26549606 | -77.47438639 |
| FRSP | FRSP_08              | Hazel Run                            | P                        | III                       | 02080104000321 | 38.29139153 | -77.47046622 |
| FRSP | FRSP_09              | Unnamed tributary of Ni River        | P                        | III                       | 02080105000805 | 38.22342177 | -77.61082677 |
| FRSP | FRSP_10              | North Branch of Burnside Drive Creek | P                        | III                       | 02080105000807 | 38.21677097 | -77.59135921 |
| FRSP | FRSP_11              | South Branch of Burnside Drive Creek | P                        | III                       | 02080105001995 | 38.21499916 | -77.59084411 |
| FRSP | FRSP_14 <sup>C</sup> | North Wilderness Run                 | P                        | III                       | 02080103000736 | 38.31040015 | -77.74912610 |
| FRSP | FRSP_15              | Wilderness Run                       | P                        | III                       | 02080103008906 | 38.32470333 | -77.72649362 |
| FRSP | FRSP_16              | Unnamed tributary of Wilderness Run  | P                        | III                       | 02080103000726 | 38.32524490 | -77.72687697 |
| FRSP | FRSP_17              | Brock Run                            | P                        | III                       | 02080105007455 | 38.28351870 | -77.70176020 |

<sup>A</sup> Stream type is noted as perennial (P), intermittent (I), or backwatered (B) as determined by the MIDN ecologist.

<sup>B</sup> Stream class is established by VADEQ (9VAC25-260, Sections 360-540; III = nontidal waters in coastal and piedmont zones, VII = swamp waters).

<sup>C</sup> Data from FRSP\_14a and FRSP\_14 were combined as FRSP\_14 for analysis due to spatial proximity (approximately 100 – 150 m between sites with no tributaries).

**Table 19 (continued).** Virginia water quality monitoring site information.

| Park | Site    | Stream name                             | Stream type <sup>A</sup> | Stream class <sup>B</sup> | NHD reach code | Latitude    | Longitude    |
|------|---------|-----------------------------------------|--------------------------|---------------------------|----------------|-------------|--------------|
| FRSP | FRSP_18 | Burnside Drive Creek                    | P                        | III                       | 02080105000807 | 38.21621328 | -77.58218697 |
| PETE | PETE_01 | Unnamed tributary of Appomattox River   | P                        | III                       | 02080207004856 | 37.24778528 | -77.35719596 |
| PETE | PETE_02 | Branch Creek                            | P                        | III                       | 02080207004917 | 37.23916707 | -77.36118053 |
| PETE | PETE_03 | Harrison Creek                          | P                        | III                       | 02080207000863 | 37.23828185 | -77.36087461 |
| PETE | PETE_04 | Taylor Creek                            | P                        | III                       | 02080207005047 | 37.22863229 | -77.37215880 |
| PETE | PETE_05 | Poor Creek                              | P                        | III                       | 02080207000855 | 37.22851504 | -77.37239457 |
| PETE | PETE_06 | Unnamed tributary of Hatcher Run        | I                        | VII                       | 03010201010641 | 37.14525670 | -77.63058530 |
| PETE | PETE_07 | Hatcher Run                             | B                        | VII                       | 03010201000158 | 37.15591773 | -77.62523929 |
| PETE | PETE_08 | Beaverdam Creek                         | I                        | VII                       | 03010201013641 | 37.15192741 | -77.61718541 |
| PETE | PETE_09 | Boulder Creek                           | I                        | VII                       | 03010201013648 | 37.15188851 | -77.61199004 |
| PETE | PETE_10 | Gravelly Brook                          | I                        | III                       | 03010201001171 | 37.13565442 | -77.61417594 |
| RICH | RICH_01 | Beaverdam Creek                         | P                        | III                       | 02080206001170 | 37.59519980 | -77.35918617 |
| RICH | RICH_02 | Unnamed tributary of Chickahominy River | P                        | III                       | 02080206001332 | 37.58370296 | -77.38605946 |
| RICH | RICH_03 | Boatswain Creek                         | P                        | III                       | 02080206001163 | 37.57231272 | -77.29721579 |
| RICH | RICH_04 | Bloody Run                              | P                        | III                       | 02080206001167 | 37.58913737 | -77.29192274 |
| RICH | RICH_05 | Totopotomoy Creek                       | P                        | III                       | 02080106000447 | 37.65247007 | -77.34551579 |
| RICH | RICH_06 | Crewes Channel                          | P                        | III                       | 02080206016368 | 37.40869103 | -77.25590235 |
| RICH | RICH_07 | Western Run                             | P                        | III                       | 02080206013920 | 37.41942319 | -77.24505863 |
| RICH | RICH_08 | Unnamed tributary of James River        | P                        | III                       | 02080206017186 | 37.42045810 | -77.42117605 |

<sup>A</sup> Stream type is noted as perennial (P), intermittent (I), or backwatered (B) as determined by the MIDN ecologist.

<sup>B</sup> Stream class is established by VADEQ (9VAC25-260, Sections 360-540; III = nontidal waters in coastal and piedmont zones, VII = swamp waters).

<sup>C</sup> Data from FRSP\_14a and FRSP\_14 were combined as FRSP\_14 for analysis due to spatial proximity (approximately 100 – 150 m between sites with no tributaries).

**Table 20.** Pennsylvania water quality monitoring site information.

| Park | Site    | Stream name    | Stream type <sup>A</sup> | Stream class <sup>B</sup> | NHD reach code | Latitude    | Longitude    |
|------|---------|----------------|--------------------------|---------------------------|----------------|-------------|--------------|
| EISE | EISE_03 | Marsh Creek    | P                        | WWF <sup>C</sup>          | 02070009000243 | 39.79485537 | -77.27606740 |
| EISE | EISE_04 | Willoughby Run | P                        | WWF                       | 02070009000816 | 39.7888438  | -77.27284096 |
| GETT | GETT_01 | Willoughby Run | P                        | WWF                       | 02070009000819 | 39.83452235 | -77.25527418 |
| GETT | GETT_06 | Rock Creek     | P                        | WWF                       | 02070009000232 | 39.81542065 | -77.21504826 |
| GETT | GETT_07 | Plum Run       | P                        | WWF                       | 02070009000814 | 39.78462758 | -77.24434376 |
| HOFU | HOFU_01 | French Creek   | P                        | EV                        | 02040203000268 | 40.20160847 | -75.76769333 |
| HOFU | HOFU_02 | Baptism Creek  | P                        | EV                        | 02040203000679 | 40.20205648 | -75.76712327 |

<sup>A</sup> Stream type is noted as perennial (P), intermittent (I), or backwatered (B) as determined by the MIDN ecologist.

<sup>B</sup> Stream class is established by PADEP (25 Pa. Code 93.1; CWF = cold water fishery, WWF = warm water fishery, EV = exceptional value).

<sup>C</sup> Though currently classified as a CWF by PADEP, recent fish inventories (Atkinson 2008) indicate Marsh Creek is definitively a WWF.



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