



Water Quality Monitoring Protocol for the Mid-Atlantic Network

Natural Resource Report NPS/MIDN/NRR—2017/1388





ON THIS PAGE

Photograph of water quality monitoring in Brock Run at Fredericksburg and Spotsylvania National Military Park.
Photograph by Mark J. Johnson.

ON THE COVER

Photograph of Plum Run at Gettysburg National Military Park.
Photograph by Mark J. Johnson

Water Quality Monitoring Protocol for the Mid-Atlantic Network

Natural Resource Report NPS/MIDN/NRR—2017/1388

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Executive Summary

The Mid-Atlantic Inventory and Monitoring Network (MIDN) selected water quality as a priority vital sign for long-term monitoring due to the ecological, management, and policy significance of aquatic resources in MIDN parks. Specifically, water quality was selected for monitoring 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. The MIDN Water Quality Monitoring protocol was developed and pilot tested in nine parks across the Piedmont and Coastal Plain of Pennsylvania and Virginia. Within these parks, wadeable streams are the most prevalent aquatic resource and were chosen as the focus for water quality monitoring. The primary objectives of this protocol are to monitor the status of core, in-situ water quality parameters in targeted streams, detect trends in these parameters over time, and to relate these data to other information regarding aquatic resources (see section 1.4 below for definition of core parameters).

The sampling design was developed to address priorities within each of the MIDN parks through consultation with park natural resource managers and engagement with subject matter experts. Sampling sites were selected in streams of significant value to parks and the number of sites sampled within each park was determined by the spatial extent and number of streams. Fifty core sites across the MIDN have been established for monitoring water quality. At each core sampling site water quality is monitored during discrete events on a monthly basis. In each network park, stream reaches of particular importance to park management were identified from within these established core sites for enhanced monitoring by integrating continuous monitoring of water quality. The combination of these sampling methods will provide robust data to both address the status of water quality in wadeable streams across the MIDN as well as assess trends in these data over time.

This protocol, along with the associated standard operating procedures (SOPs), provides the framework and guidance for monitoring water quality at MIDN parks. Data collected as part of this protocol are stored locally in databases developed or supported by the Water Resources Division (WRD) of the National Park Service (NPS) and uploaded to national databases maintained by WRD on an annual basis. Reporting on these data occurs at regular intervals so that the data are available to park-staff and can be incorporated into park management.

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List of Terms Acronyms

APCO: Appomattox Courthouse National Historical Park

BMI: Benthic Macroinvertebrate

BOWA: Booker T. Washington National Monument

CBW: Chesapeake Bay Watershed

EISE: Eisenhower National Historic Site

EOD: Entrance on duty

FRSP: Fredericksburg and Spotsylvania National Military Park

GETT: Gettysburg National Military Park

GPS: Global Positioning System

HOFU: Hopewell Furnace National Historic Site

I&M: Inventory and Monitoring Program

IRMA: Integrated Resource Management Applications

MIDN: Mid-Atlantic Network

NPS: National Park Service

PADEP: Pennsylvania Department of Environmental Protection

PETE: Petersburg National Battlefield

QA/QC: Quality Assurance/Quality Control

RICH: Richmond National Battlefield Park

SAC: Science Advisory Committee

SOP: Standard Operating Procedure

USGS: United States Geological Survey

VADEQ: Virginia Department of Environmental Quality

WASO: Washington-Area Service Office

WRD: Water Resource Division

1. Background and Objectives

1.1 Background

In an effort to provide a broad understanding of baseline conditions as well as the status and trends of ecosystems within national parks, the Natural Resource Inventory and Monitoring Program (I&M) was established by congressional mandate in 1998 through the Natural Resource Challenge. This program was initiated, in part, to help National Park Service (NPS) managers gain a better understanding of the status and trends in natural resources they are charged with protecting and conserving now and into the future. The Mid-Atlantic Network (MIDN) serves 10 Park Service units spanning the Blue Ridge, Piedmont, and Coastal Plain of the mid-Atlantic region.

This protocol provides a description of the objectives and strategy for monitoring water quality in wadeable streams (Strahler stream order 1st -5th) across the Piedmont and Coastal Plain parks of the MIDN (Strahler 1952). Additionally, a series of standard operating procedures (SOPs) provide detailed steps to carry out the protocol. The national parks (9 of 10 total) monitored within the MIDN as part of this protocol include: Appomattox Court House National Historical Park (APCO), Booker T. Washington National Monument (BOWA), Eisenhower National Historic Site (EISE), Fredericksburg and Spotsylvania National Military Park (FRSP), Gettysburg National Military Park (GETT), Hopewell Furnace National Historic Site (HOFU), Petersburg National Battlefield (PETE), Richmond National Battlefield Park (RICH), and Valley Forge National Historical Park (VAFO; Figure 1). Monitoring of NPS resources in the Blue Ridge ecoregion (Shenandoah National Park) are addressed in alternative monitoring protocols and therefore not included in this document.

1.2 Vital Signs Selection

Baseline water quality was identified at the national level as one of the 12 basic inventories intended to provide park staff with information needed to effectively manage national parks. Beyond these initial inventories, I&M Program networks defined a series of “vital signs” which are outlined in network monitoring plans (Fancy and Bennetts 2012). These vital signs are expected to continuously provide relevant information about natural resources to park managers, as well as the public, and are defined as “...a subset of physical, chemical, and biological elements and processes of park ecosystems that are selected to represent the overall health or conditions of park resources...” (<http://science.nature.nps.gov/im/monitor/>). A Science Advisory Committee (SAC) was created by the MIDN to guide the process of defining and selecting vital signs relevant to the network park resources that could be monitored effectively within logistical and budgetary constraints. A candidate list of vital signs was developed and prioritized through engagement with nearly 100 subject matter experts representing park managers, academia, non-governmental organizations, and other federal and state agencies from the mid-Atlantic region (Comiskey et al. 2006). Of the 43 candidate vital signs, water quality monitoring was ranked highest for ecological, management, and policy significance within the MIDN (Comiskey and Callahan 2008).

1.3 Landscape Setting

Mid-Atlantic Network parks are located in the Eastern Temperate Forest Ecoregion (CEC 1997), which is characterized as having high rainfall, warm summers, and cold winters with temperatures falling below freezing (Cox and Moore 2005). MIDN parks are located within two major geologic divisions, the Appalachian Highlands and the Atlantic Plain (USGS 2005). The Appalachian Highlands includes two physiographic provinces, Blue Ridge and Piedmont, while the Atlantic Plain geologic division contains the Coastal Plain province (Isphording and Fitzpatrick Jr. 1992). Most of the parks are located primarily in the Piedmont, with Richmond National Battlefield Park (NBP) and Petersburg National Battlefield (NB) located in the Coastal Plain. The network's Pennsylvania parks are located in what is considered to be the Northern Piedmont (Woods et al. 1999). The Piedmont is composed of rolling uplands that are underlain by deeply weathered and deformed metamorphic rocks, intruded by igneous material, and ranging in age from Precambrian to late Paleozoic (Hack 1989, Woods et al. 1999). The Coastal Plain is composed of unconsolidated tertiary sands, silts, and clays, overlain by sedimentary material that contrasts with the older rocks of the Piedmont (Isphording and Fitzpatrick Jr. 1992). The primary vegetation type in the Mid-Atlantic Network is the Oak-Hickory-Pine Forest (Röhrig and Ulrich 1991, Barbour and Billings 2000). Oak-Hickory-Pine Forest occurs along the Piedmont Plateau, with early-successional forests dominated by pines that are eventually replaced by deciduous species (Braun 1950). The Oak-Hickory-Pine Forest corresponds with Southeastern Mixed Forest (*sensu* Bailey 1995).

Wadeable streams are the most prevalent aquatic resource within the MIDN parks and therefore have been chosen as the focus for water quality monitoring. MIDN park streams are predominately (>85%) headwater reaches and range from first to fifth order. Headwater streams (stream order 1-3) are typically dominated by allochthonous inputs. Headwater streams are shaded by riparian vegetation reducing primary production and much of the organic matter comes from terrestrial sources. As streams increase in size (stream order 3-5), there is a shift towards autochthonous resources, primary production increases and shifts in the composition of the biological community occur (Vannote et al. 1980). MIDN streams are part of the headwaters for the large river systems of the region (e.g., Schuylkill, Rappahannock, James, Chowan) which deliver water, nutrients, and sediments to the Delaware Bay, Chesapeake Bay and Albemarle-Pamlico Sound (Figure 1). Many of these estuaries have been affected by eutrophication which can lead to hypoxic conditions (e.g., Chesapeake Bay; Kemp and Boynton 2005). Headwater streams, like those found in the MIDN, play a primary role in the nutrient flux and flow in receiving waters and are important for nutrient cycling. These benefits can be diminished in streams where peak discharge and flashiness have been increased (i.e., urbanized streams) as a result of less contact with the hyporheic zone (e.g., less opportunity for denitrification to take place; Alexander and Boyer 2007) or where excessive nutrient and sediment loads are produced in the contributing watershed (e.g., agricultural lands).

1.4 Rationale for Monitoring Water Quality in the Mid-Atlantic Network

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 large portion of the publically accessible headwater streams in the surrounding communities. Along with these streams, forested floodplains and riparian zones provide a series of ecological benefits such as nutrient capture, uptake, and cycling, mitigating flood risk and increasing sustained baseflows (maintaining multiple flowpaths for stream recharge: overland, infiltration into soils, aquifer recharge, etc.), which can provide resiliency to disturbance events (Coles et al. 2012).

Several major drivers of these aquatic systems have been identified by the MIDN: climate, atmospheric conditions, natural disturbance, and anthropogenic activities (Comiskey and Callahan 2008). Land use, for example, plays an integral role in the biotic and abiotic properties of MIDN streams (Jacobson 2001, Tong and Chen 2002). Conversion to agricultural and urban uses has been related to declines in water quality and aquatic biota of streams; habitat quality and biotic integrity have been positively correlated with the amount of forested land in a watershed (Wang et al. 1997, Allan 2004, Brown et al. 2009). Riparian zones also play an important role in stream condition (Dosskey et al. 2010). Where forested buffers have been removed from headwater streams (e.g., conversion to agriculture), water temperature and primary production increases from natural, forested conditions with cascading effects on all aspects of water quality (e.g., as water temperature increases dissolved oxygen concentrations decrease).

Since the mid-1600s the eastern United States has undergone extensive land cover change. The region was once dominated by forests which were subsequently harvested and replaced by extensive urban development and agriculture (row crop and pastureland). While most abandoned agricultural lands are becoming reforested (Steyaert and Knox 2008), many of the area's early- to mid-successional plant communities are becoming dominated by non-native species. These land cover changes have fundamentally altered stream flow patterns and persistent changes in the biogeochemistry may be anticipated if novel forest communities develop as a result of the colonization and dominance by non-native species. Expansion of impervious surfaces in the region has led to increased flood risk, decreased baseflows between precipitation events, increased erosion, and other associated effects from storm events in urbanized watersheds (Leopold 1968). Additional stressors affecting water quality in these systems include, but are not limited to, acid deposition (Webb 2004, Cosby et al. 2006), habitat and thermal alteration (Allan 2004, Kaushal and Likens 2010), and sedimentation and nutrient enrichment (Brown and Froemke 2012).

Many streams within MIDN parks meander through early successional forests, are adjacent to agricultural lands, or are drainages of metropolitan areas. The variety of land uses in the Mid-Atlantic region presents many challenges to the integrity and resilience of MIDN streams. For a full description of the stream resources and land cover patterns affecting each park refer to Appendix A. All of these stressors have important consequences for core water quality parameters as well as the cultural and natural resources protected by MIDN parks.

Water temperature, dissolved oxygen, pH, and specific conductance provide critical information about the status of biotic and abiotic conditions found in streams. As such, national guidance from the WRD of the National Park Service has adopted these as "core" water quality parameters and requires their collection in any baseline monitoring program (Irwin 2008). These parameters play a

critical role, and are widely used in determining the health of aquatic ecosystems. As part of the Clean Water Act (40 CFR 130) the states in which MIDN parks are located (Pennsylvania and Virginia) have established water quality standards for water temperature, dissolved oxygen, and pH in their surface waters and have a program in place to assess surface waters for adherence to these standards. Every two years these states produce a 305(b)/303(d) report to communicate, track, and plan the water quality assessment as required by the Clean Water Act. Additionally, these states have created a process to restore impaired surface waterways if they do not meet the minimum water quality standards. The MIDN has selected these parameters to monitor because of their clear connection to stream conditions and the published state standards that have established procedures for mitigating impaired conditions in areas where the NPS cannot manage the sources of impairment directly. Data concerning wadeable streams in many of MIDN parks has been lacking or collected intermittently based on specific projects. Beyond the water quality parameter monitoring presented here, the MIDN has established a monitoring program of the benthic macroinvertebrate (BMI) fauna, which also includes an assessment of the physical habitat (in review). Because benthic macroinvertebrates are vital to the ecological function of streams, they are often used as indicators of ecological integrity. By monitoring physical and biological aspects of these streams we are able to better understand and interpret the ecological condition of these systems.

1.5 Objectives

To be relevant for management purposes, monitoring programs must be scientifically credible and produce high quality data. Explicit goals and objectives must be established to accomplish these purposes. The primary goal of this protocol is to monitor the status and trends of water quality parameters in wadeable streams which can inform management decisions within MIDN parks. The sampling design was developed in conjunction with the benthic macroinvertebrate monitoring protocol to provide a comprehensive assessment of the physical, chemical and biological attributes of MIDN streams. Therefore, site selection is closely linked in both protocols.

Monitoring objectives include:

1. Determine status of core water quality parameters (temperature, pH, dissolved oxygen, specific conductance) in selected wadeable streams (1st-5th order) and report to State-based regulatory agencies for assessment of adherence to Clean Water Act standards.
2. Determine seasonal and long-term trends in core water quality parameters in MIDN wadeable streams.
3. Relate water quality status and trends to physical habitat and benthic macroinvertebrate data to gain a broad understanding of ecological conditions in MIDN wadeable streams.

2. Sampling Design

2.1 Sampling Design Rationale

The water quality sampling design was developed through a process that involved consultation with park resource managers to determine information and management needs, review of available data, site visits, pilot data collection and analysis, and consideration of logistics and budget. A targeted sample design was developed due to the landscape attributes (e.g., land use) associated with contributing watersheds (within and beyond park boundaries) as well as the distribution of Wadeable streams within MIDN parks. Although this targeted sampling design precludes statistical inference to unsampled areas, other designs (i.e., probability-based) were inappropriate due to park boundary and stream characteristics. Given the large-scale habitat heterogeneity and varied land cover within and surrounding MIDN parks, our goal in developing the protocol was to assess the status and trends at the reach-level not park-wide (i.e., all stream segments that occur within the park). The design is tailored to monitor the water resources identified as priorities by park resource managers in the MIDN. These priorities range from concentrated sampling of the main water resource in the park (e.g., Appomattox River at APCO) to sampling across a series of disjunct stream reaches distributed across several park units (e.g., Wadeable streams at FRSP, RICH or GETT). This targeted approach provides robust data to address trends in water quality parameters over time, and when appropriate, to address land management issues unique to each park. Moreover, by conducting a near census of Wadeable streams greater than first order, this design will allow the MIDN to obtain detailed information on streams of significant value to the parks and acquire a strong baseline understanding representative of the overall condition of Wadeable streams across NPS units.

2.2 Target Population

The target population is restricted to Wadeable streams (Strahler stream order ≤ 5) within or adjacent to MIDN parks. The sampling frame for this population was established using the high resolution (1:24000 or 12000) NHDflowline feature class from the National Hydrography Dataset (USGS 2014) and the associated attribute data (e.g., hydrographic category). Any known discrepancies between the National Hydrography Dataset and conditions within streams (e.g., attribute is coded as intermittent but should be perennial) was corrected prior to site selection. Strahler stream order was appended to the attribute table of the NHDflowline feature class for all streams found in MIDN parks. Additionally, the target population was restricted to streams which have a minimum of a 250 meter reach within or adjacent to MIDN park boundaries.

2.3 Site Selection

Sampling sites were selected in streams of significant value to park managers. The number of sites sampled was determined by the spatial extent and number of streams in each park. We established 50 core sites distributed across the 9 Piedmont and Coastal Plain parks (Appendix A; Table 1). To achieve a near census of Wadeable streams (greater than first order) preference for downstream locations within a drainage system near park boundaries was used. Discrete core water quality measurements are recorded monthly at each core sampling site. In each network park, stream reaches of particular importance to park management were identified from within these established core sampling sites for enhanced monitoring by integrating continuous monitoring of water quality

parameters (see Appendix A for detailed site descriptions in each park) and benthic macroinvertebrate monitoring. Continuous monitoring will allow for a more detailed temporal analysis of water quality parameters at streams of significant interest.

2.4 Sampling Frequency

Water quality is monitored at two temporal scales: (1) discrete, monthly sampling events at all core sites and (2) continuous monitoring at a subset of these sites (Appendix A; Table 1). Discrete, monthly sampling events will provide an adequate frequency of observations to assess long-term trends in water quality as well as meet data requirements by the Commonwealths of Virginia and Pennsylvania (VADEQ 2011, PADEP 2013) for inclusion in each state's Clean Water Act programs. Continuous monitoring data will be captured on a much finer temporal scale (minutes/hours vs weeks/months) allowing for the analysis based on diel patterns (e.g., daily mean/median), extreme values (e.g., daily max/min) and provide insight into rare discharge events (i.e., core water quality parameter changes associated with flood and low-flow conditions). A two-panel sampling design is used at continuous monitoring sites, where each panel consists of four sites and data is collected every other year for each panel (i.e., Panel A: 2016, 2018; Panel B: 2017, 2019). The panel design for continuous monitoring was selected in a response to logistical concerns, available effort, and budgetary limitations after a period of pilot testing and external review. Discrete water quality sites are not split into panels and data is captured at each site on a monthly basis in every year. Specific guidance for sampling frequency and scheduling for both discrete and continuous monitoring is maintained by the MIDN (SOP 1.3).

Table 1. Summary table of sampling sites for discrete and continuous monitoring at each of the MIDN parks.

Park	# of Discrete Water Quality Sites	# of Continuous Monitoring Sites (Panel)
APCO	3	1 (B)
BOWA	5	1 (B)
FRSP	15	1 (A)
GETT/EISE	5	1 (A)
HOFU	2	1 (A)
PETE	11	1 (B)
RICH	8	1 (B)
VAFO	1	1 (A)
Total	50	8

2.5 Power Analysis

Analyses were conducted to assess the power of our sampling design to detect linear increases of monthly observations and annual extreme core water quality parameters (temperature, dissolved oxygen, specific conductance, and pH) over three sampling periods (4, 8, and 12 years) in each stream. For each of the sampling periods, we ran separate power analyses to detect a 10%, 20%, and

50% change in the monthly and annual extreme values of each core parameter at a significance level of $\alpha = 0.05$. For monthly data, independent power analyses were conducted for each month in all streams. For extreme data, power was estimated separately in each stream for the annual maximum and minimum values of each core parameter. Inputs into the power analyses (mean and variance among sampling dates) were estimated from pilot data collected during discrete, monthly samples (*in situ*) from park streams (2010-2014). Power analyses were performed on discrete data to provide a conservative estimate of the power to detect trends in water quality parameters.

2.5.1 Change in the core monthly parameters over time

Although there was modest variation in power for the core parameters by site and month, the power to detect the smallest increase (10%) over the shortest time frame (4 years) averaged over 0.90 among sites for all core parameters (Appendix B). Despite low power to detect a change in January and December temperatures the power quickly increases to over 0.80 after 8 years of sampling (Appendix B). In sum, the current sampling design has very strong power to detect a 50% increase over a 4-yr sampling period in monthly parameter; power to detect a 10% linear increase improves substantially over an 8-year time period (Table 1).

2.5.2 Change in extremes

Power curves were also constructed to assess our ability to detect trends in extreme values of selected parameters (e.g., minimum and maximum annual temperature, DO, etc.). Overall, the power to detect a linear trend in the extreme annual values of all core parameters differed slightly by site and metric (maximum vs. minimum). Estimates of power were generally higher for maximum than minimum values of temperature and DO (Appendix B). The current sampling design has a very strong power to detect a 10% increase in the annual maximum extreme values of all parameters even for a 4-year sampling period. Power to detect a linear increase in the minimum values is generally lower than the maximum values, but this will improve after 8 years.

2.5.3 Power analysis results in relation to continuous monitoring methods

The results of our above power analyses, based on data collected at monthly intervals, are quite conservative in relation to the expected power to detect changes in core parameters collected more frequently with sondes. Continuous monitoring data will also greatly increase the sample size of water quality parameters (daily/monthly vs annual) over similar periods of observation and therefore power to detect changes in the temporal slope estimate. Continuously monitored water quality parameters will also permit better estimation of extreme values (e.g., annual or monthly minimum/maximum) and hence provide more robust estimates of the trend.

3. Field and Laboratory Methods

Detailed methods and procedures are outlined in the Standard Operating Procedures (SOPs) for the protocol (Table 2). Field and laboratory methods are divided into two categories based on the temporal scale: (1) discrete, monthly sampling events and (2) continuous water quality monitoring. Although many procedures are similar, significant differences require that some procedures are presented separately for each category. Monitoring of water quality parameters is conducted year round at all active sites (SOP 1.3) unless logistical or safety concerns preclude access to sampling locations (e.g., ice conditions, hurricanes, equipment failure). Generally, both discrete and continuous monitoring procedures follow a sequence of three basic events: field preparation, field data acquisition, and post-field activities.

Table 2. List of Standard Operating Procedures associated with the field and laboratory methods for monitoring water quality in the MIDN.

SOP Title	SOP #
Aquatic Safety Procedures	1.0
Site Establishment and Documentation	1.1
Acquisition of Supplies, Repair Services, and Maintenance	1.2
Site Visit Schedule, Tracking of Events, and Communication	1.3
Use of YSI ProPlus: Calibration, Sensor Checks, and Maintenance	1.4
Use of YSI 6920 V2 Sonde: Communication, Calibration, Sensor Checks, and Operation	1.5
Use of Hydrolab DS5X Sonde: Communication, Calibration, Sensor Checks, and Operation	1.6
Use of GPS	1.7
Required Field Supplies Checklist	1.8
Field Site Visit Procedures: Discrete WQ Monitoring	1.9
Field Site Visit Procedures: Continuous WQ Monitoring	1.10
Decontamination of Equipment	1.11

3.1 Safety

The MIDN considers the occupational health and safety of their employees, cooperators, and volunteers to be of utmost importance, and is committed to ensuring that all receive adequate training on NPS safety procedures, incident reporting, and emergency response prior to field work. Emergency procedures and contacts, incident reporting, field preparations, safe field procedures, vehicle safety, and workers' compensation procedures are outlined in SOP 1.0 (Aquatic Safety Procedures).

3.2 Field Preparations

Several tasks must be accomplished prior to collecting field data for this protocol. These tasks can be split into two categories: episodic events (occur quarterly or less frequently) or procedures completed prior to each field visit. Episodic events include establishing field sites (SOP 1.1), acquisition of supplies (SOP 1.2), and scheduling and communication with MIDN parks (SOP 1.3). For each

discrete, monthly sampling event, several procedures must be carried out prior to deploying to field sites including calibrating and performing sensor checks on field meters (SOP 1.4), reviewing field supplies checklist (SOP 1.8), and reviewing field site visit procedures (1.9). Additionally, prior to maintaining continuous monitoring equipment several procedures must be accomplished: (1) calibration of sondes (SOP 1.5 and 1.6), (2) review field supplies checklist (SOP 1.8), and (3) review field site procedures (SOP 1.10). MIDN follows guidance from Wagner et al. (2006) for placement of sensors in the aquatic environment as well as operation and record computation of all continuous monitoring equipment. If personnel conducting the sampling are not familiar with all field sites, guidance for navigation as well as the use of MIDN GPS equipment is available (NPSTORET station reports and SOP 1.7).

3.3 Field Data Acquisition

Procedures for capturing discrete, monthly and continuous monitoring water quality parameter data require different techniques and are therefore described in separate SOPs. For discrete, monthly data acquisition, guidance is provided for calibrating and operating field meters (SOP 1.4), navigation to the field site (SOP 1.7 and station reports), capturing water quality data in the field (SOP 1.9), and decontamination of equipment (SOP 1.11). For maintaining continuous monitoring equipment, guidance is provided for navigation to the field site (SOP 1.7 and station reports), use and operation of continuous monitoring equipment (SOP 1.5 and 1.6), procedures for capturing continuous monitoring field data (SOP 1.10), and decontamination of equipment (SOP 1.11).

3.4 Post-Field Activities

Post-field activities can be separated into two categories: completion of the field data record (e.g., post-deployment sensor calibration checks) and data management. Procedures related to data management and quality assurance are addressed in section four of this protocol. Procedures for completion of the field data record are included in the appropriate field site visit and operation SOPs (1.4, 1.5, 1.6, 1.9 and 1.10).

4. Data Handling, Analysis, and Reporting

Data obtained as a result of water quality parameter monitoring activities are ultimately maintained in one of two databases supported by the WRD of the NPS. Procedures for handling, formatting, importing, exporting, and accepting data are provided through a series of SOPs (Table 3) as well as guidance from the WRD.

Table 3. List of Standard Operating Procedures associated with the data handling methods for monitoring water quality in the MIDN.

SOP Title	SOP #
Management of Discrete, Monthly Water Quality Data	2.1
Management of Continuous Monitoring Water Quality Data	2.2
Continuous Monitoring Record Computation and Data Quality Evaluation	2.3
Quality Assurance and Control Procedures	2.4
Annual Reporting	2.5

4.1 Metadata

Metadata are captured throughout the process of collecting data for this protocol. Initially, metadata attributes regarding field sites are captured for all sites (both continuous and discrete sites) during establishment and are updated as needed (SOP 1.1). These data along with metadata regarding sampling equipment and procedures for discrete sampling data are maintained in the NPSTORET database (see Database design below). In addition to site establishment procedures, metadata for both discrete sampling and continuous monitoring data are captured during each sampling event. These metadata concern data quality, sampling equipment, and personnel and are captured throughout the process of obtaining field data.

4.2 Overview of Databases

The MIDN uses separate databases to maintain water quality data for discrete and continuous monitoring. These databases are supported at the national level which ensures adherence to current standards and guidelines promulgated by the agency and department. Separate databases are required for the maintenance of the two data sets due to the methods and procedures required to maintain, review, process, and accept each dataset. Discrete data are maintained in NPSTORET, a database developed by the WRD of the NPS. The WRD maintains current guidance and updates to this database through internet based outreach as well as through the staff which are responsible for the database at WRD. Continuous monitoring data is maintained in a database (Aquarius) developed by Aquatic Informatics and supported by the WRD. This software package has specific tools and procedures which allow for management and record processing of these data which are unavailable in the NPSTORET environment. Included within the functionality of the Aquarius package is the ability to track and annotate all data editing within the database including censoring, data corrections, and accuracy ratings as well as the ability to produce reports regarding all data editing activities. The

MIDN participates in the use of a concurrent license for the Aquarius software to maintain continuous monitoring data.

4.3 Data Entry and Editing

Discrete and continuous data require different data handling procedures. Data are obtained and recorded on paper data sheets for both discrete and continuous data; however, continuous monitoring equipment also produces data log files containing many observations ($n > 700/\text{month}/\text{parameter}$) and metadata. The paper sheets contain field notes, metadata, and quality control data. Data management procedures guide the work flow of formatting and importing data from paper data sheets into the appropriate database. Digital data templates are used to import discrete data into NPSTORET as well as maintain quality control data for both discrete and continuous activities (SOP 2.1). Continuous monitoring log files are formatted for import into Aquarius (SOP 2.2). Specific guidance for working within each database environment is provided by WRD (or software developers) as these systems are updated regularly and functionality changes.

4.4 Verification, Record Computation, and Data Finalization

Quality assurance of water quality data is a top priority within the implementation of this protocol. As such, activities related to quality assurance are distributed throughout the field preparation, acquisition, and management of these data. Sensor maintenance schedules are established so that all sensors in service remain within their useful life cycle and are functioning correctly. Strict adherence to calibration schedules and sensor error checks prior to and after all field observations ensures high quality, accurate data is collected in the field.

Discrete data which does not meet calibration or sensor check error limits are censored from the record prior to entry into NPSTORET and appropriate notes are recorded in the database. All continuous monitoring log files are imported into Aquarius and quality control data are used to censor, apply corrections, or verify adherence to sensor error limits. All continuous monitoring data are rated for accuracy based on sensor fouling and calibration drift quality control data. Guidance for error limits, applying corrections to biased data (i.e., record computation), and rating the accuracy of the data are based on USGS published methods (Wagner et al. 2006). A conceptual overview of this process is presented in the continuous Monitoring Record Computation and Data Quality Evaluation procedures associated with this protocol (SOP 2.3). Automated methods within digital templates for data entry are used to reduce data entry errors (e.g., pick lists, data validation tools, etc.) and all data collected on paper data forms are subject to 100% verification when entered into templates. Once all quality assurance procedures are complete and data has been entered and verified, data are considered provisional.

Data is converted from provisional status to accepted on an ongoing basis throughout the year as quality control procedures are completed (SOPs 2.1 and 2.3). Accepted data are archived annually after the preparation of annual reports where it is reviewed ensuring that all data has been verified and QA/QC procedures were completed (SOP 2.4). The Quality Assurance and Control Procedures provide a description of the methods distributed throughout the data collection and handling process as well as the final steps to accept and archive the data on an annual basis (SOP 2.4).

4.5 Data Archiving

The MIDN digitally archives data and metadata collected as part of this protocol. Digital records are stored on the MIDN server in multiple formats depending on the type of data. All log files generated by monitoring equipment are stored on the MIDN server in their raw state as well as formatted for import into the database. Additionally, digital data entry templates (discrete data import template, QW_Ultimate spreadsheet, etc.) and the scanned paper data sheets, which they are derived from, are stored on the MIDN server (SOP 2.1 and 2.2). The MIDN sever is subject to routine backup procedures as outlined in the MIDN's Data Management Plan (Callahan and Wakamiya 2009). All data associated with this protocol are digitally archived as static products on an annual basis after the full year of data has been accepted and all associated reports have been produced. These archives are in the form of local (MIDN) NPSTORET database files (Front End and Back End), flat files of accepted data (.csv format), raw log files and data entry templates, and formatted log files and data entry templates. Along with accepted continuous monitoring data, a log report of all data editing is archived annually. These products are maintained on the MIDN server; additionally these products can be archived and stored through other methods such as on IRMA to facilitate access to end users. Once per year discrete data maintained in the NPSTORET database will be exported from the MIDN server following WRD guidance for inclusion in WRD's EarthSoft EQuIS database which is then uploaded into the U.S. Environmental Protection Agency's STORET Data Warehouse. In addition, data will be automatically transferred from the STORET Data Warehouse to the interagency Water Quality Portal. By archiving each step in the process of accepting the data from pre-field activities (i.e., calibration logs) through QA/QC procedures, the MIDN provides a tracking mechanism so that data quality can be objectively assessed.

4.6 Reporting and Data Analysis

The MIDN will produce data summary reports for both discrete and continuous monitoring for each park on an annual basis (SOP 2.5) and more detailed reports approximately every five years. The annual reporting period (October-September) is based on the general discharge patterns found across the mid-Atlantic region which is characterized by three seasons starting in the fall with increasing stream discharge and continuing through baseflows in late summer (Rising Limb: October-March; Falling Limb: April-June; Baseflows: July-September). These reports will be presented as concise products with summary statistics (continuous) and individual observations (discrete) as appropriate and function as the final step of the quality assurance and quality control procedures. A combination of data tables and visual graphics (figures and maps) will be used to present these data in the annual reporting (see Appendix A for examples) along with limited text to provide context. For discrete monitoring, annual reports will include all individual monthly values along with annual minimum, maximum, and mean (or median) values for each sampling location. For continuous monitoring, annual reports will include daily, monthly, and annual minimum, maximum, and mean (or median) values presented as data tables following the guidance from Wagner et al. (2006) along with associated graphics. These data will be compared with state-based water quality standards for evaluation of adherence to Clean Water Act requirements. In lieu of annual reports as static documents, web based outreach through data visualizers and delivery portals may be implemented. Trend reports will be completed at approximately five year intervals and will present a more thorough interpretation of water quality conditions along with trend assessments (see Appendix B for

examples). Trend analyses for water quality parameters will be assessed using methods described above (Section 2.5 Power Analysis) and in Appendix B (parametric tests: regression analysis, non-parametric tests: seasonal Mann-Kendall) new statistical techniques will be adopted as appropriate. Trend analyses will be completed for each water quality parameter for both discrete and continuous data on a site-by-site basis to best address the objectives stated in this protocol and the sample design. As appropriate trends in water quality will be assessed on a broader scale across sites within a park unit and covariates (e.g., stage) will be used to enhance precision of trend slope estimates.

5. Personnel Requirements and Training

5.1 Roles, Responsibilities, and Qualifications

The water quality monitoring protocol is primarily implemented by the Aquatic Ecologist with the Network Ecologist and Data Manager fulfilling specified tasks, providing support, and acting as a back-up for the Aquatic Ecologist. Portions of the protocol (some of the discrete, monthly sampling) are implemented by distributed park staff or volunteers organized at the parks.

5.1.1 Aquatic Ecologist

The Aquatic Ecologist serves as the project manager and is responsible for the overall implementation of the water quality monitoring protocol. This includes a wide variety of tasks ranging from administrative tasks and conducting field work to data management. Specifically, duties include purchasing, maintaining the protocol and SOPs, logistics (communications, scheduling, park support), maintaining field equipment, maintaining associated databases, and data analysis and reporting related to the protocol.

Some of the skills required to successfully carry out this protocol are specialized and candidates might not have direct experience with certain aspects of protocol activities. Continuous monitoring of water quality requires specific software and tools which are not commonly taught and new staff might need additional training prior to fully implementing all procedures. As soon as is practicable following the start date of any new staff, training opportunities should be pursued including:

- USGS-HIF-QW1638: Water Quality Probes: Installation, Operation, Calibration, and Maintenance
- USGS-OED-QW2298: Guidelines for the Operation and Computation of Records of Continuous Water-Quality Monitors
- NPS-WRD Training regarding working within the NPS implementation of the Aquarius Database
- NPS-I&M training regarding water quality field methods as adapted from USGS

Opportunities for training might not be immediately available following the EOD of new staff. If formal training is not available, cross training with alternate NPS I&M programs should be arranged. A number of I&M programs throughout the region and country have implemented continuous monitoring with aquatic protocols and can provide insights into monitoring procedures. Cross training can be coordinated through the regional program manager for the I&M program.

5.1.2 Network Ecologist

The principal duties of the Network Ecologist regarding this protocol are related to providing support to the Aquatic Ecologist. This person serves as the senior ecologist for the MIDN and is responsible for providing guidance for the design, implementation, analysis, and interpretation of all scientific work. These responsibilities include, but are not limited to, assisting with quantitative analyses such

as time series model development and providing editorial oversight. Additionally, the Network Ecologist participates in field work as needed.

5.1.3 Data Manager

The Data Manager is primarily responsible for supporting the Aquatic Ecologist and ensuring the data management practices of the MIDN meet agency standards. The Data Manager is responsible for maintaining MIDN servers where data for this protocol is stored including all data backup and archiving procedures. The Data Manager is responsible for ensuring all products of this protocol meet I&M, WRD, and WASO standards as well as preparing these products for publication through NPS portals (e.g., IRMA, web based visualizers, etc.). Additionally, the Data Manager participates in field work as needed and responds to data requests from outside of the MIDN parks.

5.1.4 Park Staff and Volunteers

At some parks within the MIDN, park staff and volunteers are responsible for all of the procedures related to the collection of discrete, monthly water quality data for this protocol. Park staff are responsible for following SOPs to collect high quality, accurate data in the field and transfer those data to MIDN staff. If volunteers are used to execute procedures as part of this protocol then the park staff are responsible for the coordination and communication between the park, the volunteers, and MIDN staff. All personnel must be adequately trained on the SOPs of this protocol by either MIDN staff or someone with extensive prior experience before participation in collecting data related to this protocol.

5.2 Training

All personnel that participate in the collection of water quality data related to this protocol must receive training on the specific SOPs involved. MIDN staff will provide initial and periodic refresher training for all park-based collection of data. In the event of personnel turnover, MIDN staff will provide training on the implementation of this protocol and the associated standard operating procedures. If new personnel join an existing group of park staff/volunteers that have previously gone through training and have extensive experience in implementing this protocol, that individual can obtain “on-the-job” training while assisting more experienced staff. Specialized training regarding continuous monitoring records should be pursued by MIDN staff as it is available from the WRD as well as USGS training courses. Specific training requirements are outlined in the roles and responsibilities described above.

6. Operational Requirements

6.1 Annual Workload and Field Schedule

Field work related to this protocol is conducted year-round unless logistical or safety concerns preclude access to field sites (SOP 1.3). Water quality data are processed immediately after it is collected and QA/QC procedures are implemented on a monthly basis so that data are available in a timely manner. The MIDN Aquatic Ecologist is responsible for all continuous monitoring activities and therefore travels to each of the active continuous monitoring sites on a monthly basis to maintain equipment. Annual data finalization procedures and reporting occur during fall and winter months following the conclusion of the water year which ends in September in the mid-Atlantic region.

6.2 Facility and Equipment Needs

MIDN facilities must have sufficient storage and bench space, in climate controlled areas, so that water quality equipment can be efficiently stored and maintained. Park facilities where water quality monitoring is conducted by park staff need a limited amount of space where calibrations can be carried out and a limited amount of supplies (e.g., pH buffers) can be stored in a climate controlled area. Access to a MIDN vehicle is required on a year-round basis for maintenance site visits to each of the MIDN parks monitored. Monitoring as part of this protocol requires specialized equipment which must be maintained and replaced over time including water quality meters and sondes as well as consumable supplies.

6.3 Operational Costs

This protocol is supported through base funding from the MIDN as well as water quality monitoring funds supplied by the WRD of the NPS. Table 4 summarizes estimated annual operational costs associated with this protocol.

Table 4. Estimated annual operational costs associated with the implementation of the MIDN Water Quality Monitoring Protocol.

Item	Base Salary*	Time (%)	Cost (\$)	Notes
Aquatic Ecologist	\$59,689	85	50,736	GS-9
Data manager	\$72,219	5	3,611	GS-11
Network Ecologist	\$86,564	5	4,328	GS-12
Travel - Monitoring			4,500	
Travel - Training			1,500	
Vehicle			2,500	
Equipment Replacement			12,000	
Maintenance and Supplies			8,000	
TOTAL			87,175	

*based on step 5 of GS Locality Pay Tables (2016) for northern VA, cost of benefits not included

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Appendix A. Descriptions of MIDN parks, aquatic resources, and long-term monitoring locations.

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1. Introduction

Given the large scale heterogeneity of habitat and land use within and surrounding MIDN parks, our goal in developing the both the water quality and benthic macroinvertebrate protocols was to assess status and trends at the reach-level not park-wide (i.e., all stream segments that occur within the park). The design is tailored to monitor the water resources identified as priorities by park resource managers in the MIDN. These priorities range from concentrated sampling of the main water resource in the park (e.g., Appomattox River at APCO) or sampling across a series of disjunct stream reaches distributed across several units of the park (e.g., wadeable streams at FRSP). The targeted approach provides robust data to address trends in water quality parameters and benthic macroinvertebrate communities over time and, when appropriate, to address land management issues unique to each park. Moreover, targeted sampling will allow the MIDN to acquire a strong baseline understanding of the overall condition of wadeable streams across NPS units and obtain detailed information on streams of significant value to the park. A background investigation into the aquatic resources at each of the MIDN parks was conducted to achieve the appropriate spatial coverage and identify those streams which are important to resource managers. This informed the decision making process for selecting long-term monitoring sites and is compiled in this appendix along with a brief description of each of the selected long-term monitoring locations.

1.1 Sites Selected for Long-term Monitoring

Across the MIDN, 50 sites were selected to conduct long-term monitoring of aquatic resources. Discrete (D), in-situ water quality monitoring data are collected monthly at each site. Benthic macroinvertebrate monitoring (BMI) and continuous water quality monitoring (Con) are conducted at two subsets of these sampling sites (Table A-1).

Table A-1. List of aquatic monitoring locations in the MIDN.

Site ID	Stream Name	USGS HUC-14	Latitude	Longitude	Physiographic Province	Type of Site (D, BMI, Con)*
APCO_01	Appomattox River	02080207001211	37.38192	-78.78909	Piedmont	D
APCO_02	Plain Run	02080207001219	37.38191	-78.78817	Piedmont	D, BMI
APCO_03	Appomattox River	02080207001210	37.38347	-78.78149	Piedmont	D, BMI, Con
BOWA_01	Jack-O-Lantern Branch	03010101006176	37.11521	-79.7299	Piedmont	D
BOWA_02	Jack-O-Lantern Branch	03010101001881	37.10757	-79.72993	Piedmont	D, BMI, Con
BOWA_03	Jack-O-Lantern Branch	03010101001881	37.10692	-79.73014	Piedmont	D
BOWA_04	Gills Creek	03010101000446	37.10817	-79.73154	Piedmont	D, BMI
BOWA_05	tributary of Gills Creek	03010101006190	37.11239	-79.73579	Piedmont	D
FRSP_01	Lewis Run	02080105000217	38.29559	-77.64842	Piedmont	D, BMI,
FRSP_02	tributary to Lewis Run	02080105000800	38.30171	-77.64934	Piedmont	D
FRSP_03	Lewis Run	02080105000216	38.28919	-77.64619	Piedmont	D
FRSP_04	Lower Brock Run	02080105000370	38.28189	-77.6469	Piedmont	D
FRSP_06	Deep Run	02080104000796	38.26545	-77.4744	Piedmont	D
FRSP_08	Hazel Run	02080104000321	38.29135	-77.4704	Piedmont	D, BMI
FRSP_09	tributary to Ni River	02080105000805	38.2234	-77.61086	Piedmont	D
FRSP_10	North Branch Burnside Creek	02080105000807	38.21676	-77.59143	Piedmont	D
FRSP_11	South Branch Burnside Creek	02080105001995	38.21504	-77.59084	Piedmont	D
FRSP_14	North Wilderness Run	02080103000736	38.31017	-77.75092	Piedmont	D, BMI, Con
FRSP_15	Wilderness Run	02080103008906	38.32463	-77.72655	Piedmont	D
FRSP_16	tributary to Wilderness Run	02080103000726	38.32522	-77.72694	Piedmont	D
FRSP_17	Brock Run	02080105007455	38.28349	-77.70177	Piedmont	D, BMI
FRSP_18	Burnside Creek	02080105000807	38.21617	-77.58217	Piedmont	D, BMI
FRSP_19	Lewis Run	02080105000799	38.30652	-77.68146	Piedmont	D
GETT_01	Upper Willoughby Run	02070009000819	39.83426	-77.25502	Northern Piedmont	D, BMI

* D = Discrete Water Quality, BMI = Benthic Macroinvertebrate, Con = Continuous Water Quality Monitoring

Site ID	Stream Name	USGS HUC-14	Latitude	Longitude	Physiographic Province	Type of Site (D,BMI,Con)*
EISE_03	Marsh Creek	02070009000243	39.7929	-77.27814	Northern Piedmont	D
EISE_04	Lower Willoughby Run	02070009000816	39.7893	-77.27327	Northern Piedmont	D, BMI
GETT_06	Rock Creek	02070009000232	39.81544	-77.21507	Northern Piedmont	D, BMI
GETT_07	Plum Run	02070009000814	39.78465	-77.24446	Northern Piedmont	D, BMI, Con
HOFU_01	French Creek	02040203000268	40.2017	-75.76757	Northern Piedmont	D, BMI, Con
HOFU_02	Baptism Creek	02040203000679	40.202053	-75.76715	Northern Piedmont	D, BMI
PETE_01	tributary to Appomattox River	02080207004856	37.24769	-77.35696	Coastal Plain	D
PETE_02	Branch Creek	02080207004917	37.23926	-77.36127	Coastal Plain	D
PETE_03	Harrison Creek	02080207000863	37.23846	-77.36091	Coastal Plain	D, BMI, Con
PETE_04	Taylor Creek	02080207005047	37.22871	-77.37199	Coastal Plain	D
PETE_05	Poor Creek	02080207000855	37.22841	-77.37243	Coastal Plain	D
PETE_06	tributary to Hatcher Run	03010201010641	37.14602	-77.63109	Coastal Plain	D
PETE_07	Hatcher Run	03010201000158	37.15575	-77.62536	Coastal Plain	D
PETE_08	Beaverdam Creek	03010201013641	37.15169	-77.61715	Coastal Plain	D
PETE_09	Boulder Creek	03010201013648	37.15189	-77.612	Coastal Plain	D
PETE_10	Gravelly Brook	03010201001171	37.13572	-77.61411	Coastal Plain	D, BMI
PETE_11	Harrison Creek	02080207004917	37.23646	-77.35637	Coastal Plain	D
RICH_01	Beaverdam Creek	02080206001170	37.59513	-77.35908	Coastal Plain	D
RICH_02	tributary to Chickahominy River	02080206001332	37.58375	-77.3862	Coastal Plain	D, BMI
RICH_03	Boatswain Creek	02080206001163	37.57236	-77.29733	Coastal Plain	D
RICH_04	Bloody Run	02080206001167	37.5892	-77.29192	Coastal Plain	D, BMI
RICH_05	Totopotomoy Creek	02080106000447	37.65249	-77.34549	Coastal Plain	D
RICH_06	Crews Channel	02080206016368	37.4087	-77.25588	Coastal Plain	D
RICH_07	Western Run	02080206013920	37.41948	-77.24512	Coastal Plain	D, BMI, Con
RICH_08	tributary to James River	02080206-----	37.42057	-77.42125	Coastal Plain	D
VAFO_01	Valley Creek	02040203000511	40.07925	-75.4609	Northern Piedmont	D, Con

* D = Discrete Water Quality, BMI = Benthic Macroinvertebrate, Con = Continuous Water Quality Monitoring

2. Aquatic Resource Profiles

2.1 Appomattox Court House National Historical Park

2.1.1 Park Overview

Appomattox Court House NHP (APCO) is located in an area of gently rolling hills within the Piedmont region of central Virginia, two miles northeast of the town of Appomattox (Figure A-1). The park was established in 1935 for the purpose of commemorating the end of the Civil War and includes the McLean home surrender site and the village of Appomattox Court House. Also located in the park is the burial place of Joel Sweeney, who popularized the modern five string banjo. APCO covers 718 ha (1,774 acres), within the headwater region of the Appomattox River, approximately 70% of which is forested while the other 30% is maintained as fields.

2.1.2 Landscape Setting

APCO is located along the southern edge of the Chesapeake Bay watershed and within the Piedmont physiographic province. Appomattox Court House NHP is characterized by gently rolling topography, deeply weathered bedrock, and outcrops alongside the Appomattox River floodplain (Thornberry-Ehrlich 2009). Soils within APCO tend to be deep, derived from crystalline parent materials, rich in weathering products (clay and iron oxides), very red in color, and consist primarily of clay, silt, and sandy loams.

2.1.3. Land Cover and Vegetation

Within the boundaries of APCO, the primary land cover class is forest (63.1%), followed by agriculture (28.3%), wetlands (4.1%) and developed (4.0%; Figure A-2). This is substantially more forested land than is found in the contributing watersheds of APCO (45.8%) and across the entire Chesapeake Bay Watershed (CBW; 54.7%). The watersheds that support APCO streams are similar in the amount of development (9.1%) to the CBW (11.0%) and much more land is devoted to agriculture (40.8%) than the CBW (24.6%; Homer et al. 2015). These characteristics are integral to understanding stream conditions at APCO. Forested watersheds and buffers around streams have the ability to improve stream conditions by removing nutrients, controlling sediments, ameliorating temperature increases, and protecting physical habitat (Lowrance and Altier 1997, Jacobson 2001, Kaushal and Likens 2010). In such an agriculturally dependent region, APCO's protected lands help to mitigate the effects on aquatic resources.

The vegetation within APCO was classified and mapped during 2001-2006 using extensive field reconnaissance and aerial photography (Patterson 2008b). The vast majority of vegetation present in the park has been influenced significantly by recent land use history and ongoing management to maintain the historical and cultural landscape of the United States Civil War era (Patterson 2008a). Areas of human maintained vegetation represent 40% of the park's acreage (699.9 acres), and include mowed or maintained fields (532.5 acres), grazed woodlots, loblolly pine plantations, Virginia pine plantations, and man-made structures (Patterson 2008b). Early successional or transitional vegetation caused by recent (20-80 years) abandonment of fields or tree canopy removal by pine bark beetle infestation, wind, beaver activity, or silvicultural practices, covers an additional 36% of the land in the park (620.9 acres).



Appomattox Courthouse National Historical Park - Overview

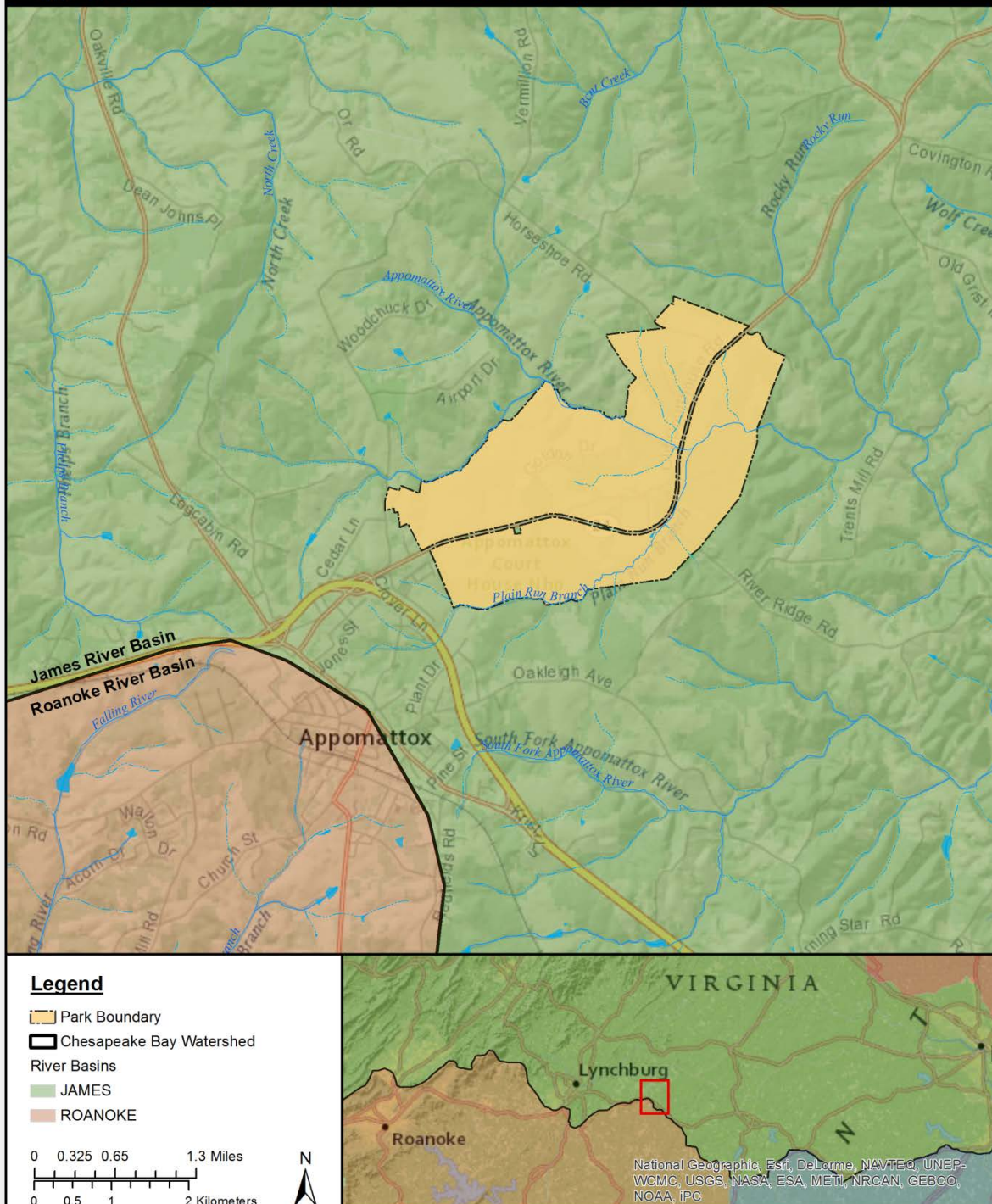


Figure A-1. Map displaying Appomattox Court House National Historical Park highlighting the aquatic resources.

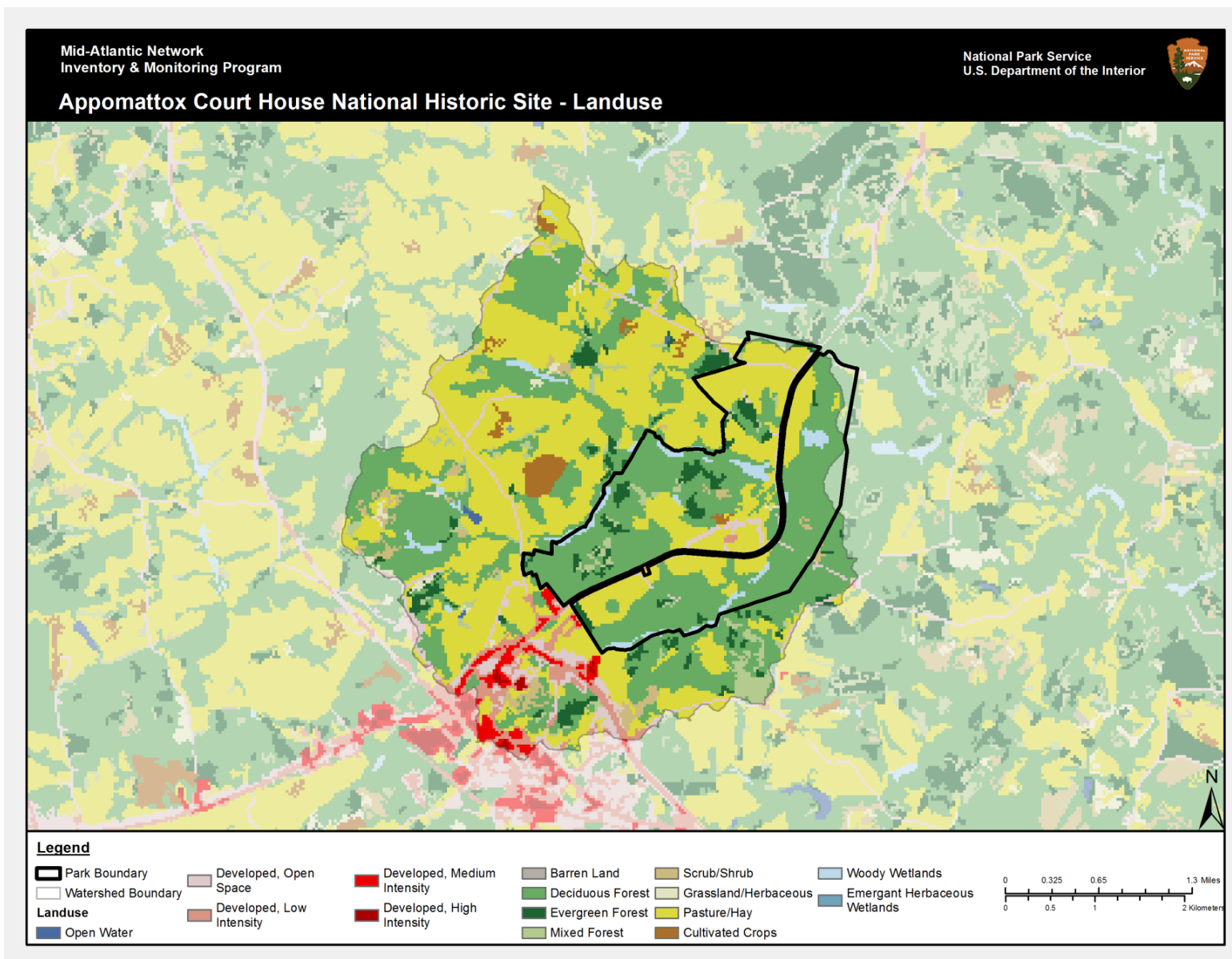


Figure A-2. Map displaying the National Land Cover Dataset classes (Homer et al. 2015) for the contributing watersheds to the streams of APCO.

Seventeen percent of the park (418.5 acres) is composed of native, late successional forests, the most common of which is oak-hickory forest which covers 13.5% (234.6 acres) of the park land and is found on undisturbed rolling uplands. Other forest types include small patches of Piedmont / Low Elevation Mixed Oak / Heath Forest, as well as the Inner Piedmont / Blue Ridge Basic Mesic Forest and Mesic Mixed Hardwood Forest found on the cool, moist, north to northwest facing slopes over the Appomattox River and Plain Run Branch (Patterson 2008b).

Approximately 100 acres of wetlands exist within the park, most being associated with the Appomattox River and its tributaries. The most common wetland association is the Piedmont / Mountain Alluvial Forest. APCO is also home to two rare wetland communities, Upland Depression Swamp, which is considered globally rare, and the Northern Piedmont / Lower New England Basic Seepage Swamp, a state rare wetland community (Patterson 2008b). These wetland resources are especially important as substantial wetlands losses have occurred (42% of wetlands from 1982 – 1992) throughout the greater Appomattox River watershed. The Environmental Protection Agency noted this “high level” of wetland loss and attributed urban development as a major threat to aquatic resources within the watershed.

2.1.4 Water Resources and Current Status of Water Quality

The National Park Service manages approximately 19.3 km of streams at APCO and the watersheds associated with these streams drain over 22 km² of the region (Figure A-3, Table A-2) (USGS 2014). APCO lies in the headwater region of the Appomattox River watershed (total drainage area 3,480 km² (1,344 mi²), the largest tributary to the James River. These watersheds are located within the greater CBW, home to the largest estuary in the United States which has been degraded over time primarily due to excess nutrient and sediment loads delivered from the upland watershed (Kemp and Boynton 2005). In aggregate, headwater streams play a primary role in the nutrient flux and flow in receiving waters and are important for nutrient cycling. This benefit can be diminished in streams where peak discharge and flashiness have been increased (i.e., urbanized streams) as a result of less contact with the hyporheic zone (e.g., less opportunity for denitrification to take place; Alexander and Boyer 2007). However, agricultural practices do pose a threat to the ecological integrity of the aquatic resources within the boundaries of APCO. Livestock grazing and crop production can increase sedimentation within the stream system and degrade habitat for fishes and benthic macroinvertebrates.

Perennial streams within APCO consist entirely of headwater reaches (Table A-3). Headwater streams (stream order 1-3) are typically dominated by allochthonous inputs, streams are shaded by riparian vegetation reducing primary production and much of the organic matter comes from terrestrial sources (Vannote et al. 1980). The streams within APCO are host to a rich faunal biodiversity given its size; over 25 species of fishes have been documented as well as 19 species of amphibians, including the mole salamander (*Ambystoma talpoideum*) which is listed by the Virginia Department of Game and Inland Fisheries as a species of special concern (Mitchell 2006, Atkinson 2008). Fishes include game and non-games species, notably a diversity of darters (Percidae, n=4) and nest builders (e.g., bluehead chub, central stoneroller). Many of these species require high quality habitat free from excess sedimentation. Benthic macroinvertebrate monitoring (2009-2012) indicates

good ecological condition. Although these streams are currently in good condition, care must be taken to maintain this state as there are significant concerns regarding sedimentation due to agricultural uses and development within the contributing watershed.

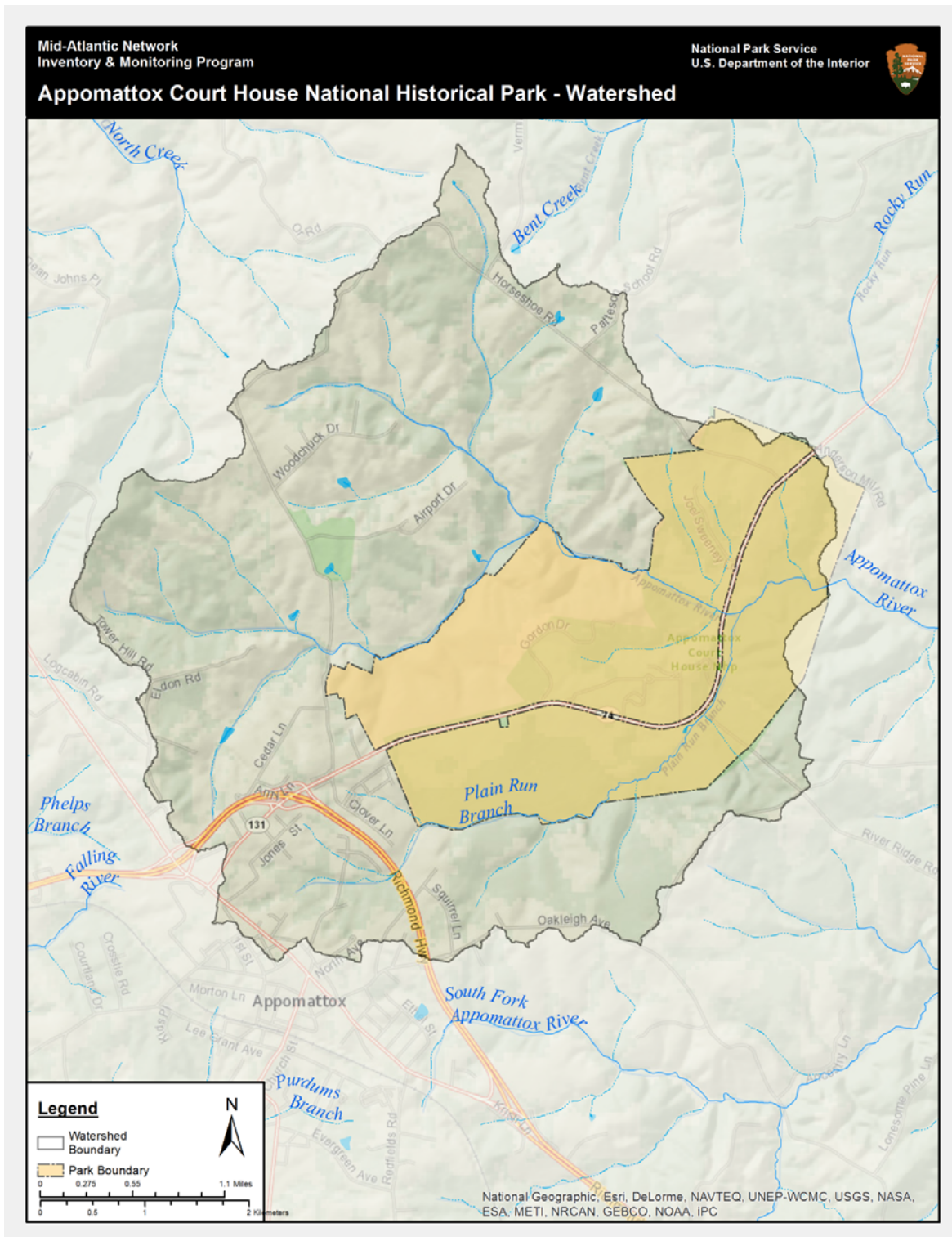


Figure A-3. Map displaying the streams and contributing watersheds of APCO.

Table A-2. Land cover classification (Homer et al. 2015) of watersheds and riparian areas (100 meter buffer) associated with APCO, within APCO, and the CBW.

Land Cover Type	Watershed		100 Meter Buffer		Park		Chesapeake Bay Watershed	
	%	Area (km ²)	%	Area (km ²)	%	Area (km ²)	%	Area (km ²)
Forest Total	45.8	10.16	58.4	1.12	63.1	4.35	54.7	91,329
Deciduous Forest	39.4	8.74	54.0	1.04	56.3	3.88	42.8	71,401
Evergreen Forest	3.8	0.85	4.1	0.08	5.2	0.36	5.8	9,716
Mixed Forest	2.6	0.57	0.3	0.01	1.6	0.11	6.1	10,212
Agriculture Total	40.8	9.05	24.6	0.47	28.3	1.95	24.6	40,996
Pasture/Hay	39.4	8.74	24.5	0.47	28.0	1.93	14.9	24,913
Cultivated Crops	1.4	0.31	0.1	<0.01	0.2	0.02	9.6	16,083
Developed Total	9.1	2.03	3.1	0.06	4.0	0.27	11.0	18,432
Developed, Open Space	4.7	1.04	2.8	0.05	3.6	0.25	6.6	10,992
Developed, Low Intensity	2.8	0.61	0.3	0.01	0.4	0.03	2.8	4,696
Developed, Medium Intensity	1.4	0.31	-	-	<0.1	<0.01	1.2	2,005
Developed, High Intensity	0.3	0.07	-	-	-	-	0.4	739
Grassland/Herbaceous	0.5	0.1	-	-	0.1	<0.01	0.8	1,335
Scrub/Shrub	1.6	0.35	0.2	<0.01	0.4	0.03	2.2	3,709
Open Water	0.1	0.03	-	-	-	-	1.8	2,950
Barren Land	-	-	-	-	-	-	0.3	489
Woody Wetlands	2.0	0.45	13.6	0.26	4.1	0.29	3.7	6,244
Emergent Herbaceous Wetlands	<0.1	<0.01	-	-	-	-	0.9	1,471
Total	100.0	22.18	100.0	1.92	100.0	6.89	100.0	166,957

Table A-3. Strahler stream order classification by length (km) within the contributing watershed of APCO streams.

Stream Order	Intermittent	Perennial	All Streams (Within Park)	% Perennial
1	19.5	0.7	20.2 (7.4)	3
2	3.8	6.7	10.5 (7.2)	64
3		4.8	4.8 (4.8)	100
Total	23.3	12.1	35.4 (19.3)	
% Headwater	100	100	100	

During the 2012 assessment cycle the Commonwealth of Virginia found that all stream lengths within the park boundaries met water quality standards for their designated uses (Figure A-4, Table A-4) (VADEQ 2014). Until recently, water quality data within APCO has been very limited. The first water quality sampling was completed in 2000, when the U.S. Geological Survey conducted a level 1 water quality inventory. The inventory found physical, chemical and biological water quality parameters to be within state regulations with the exception of 3 fecal coliform samples and low levels of mercury contamination at all the sites. This study identified potential threats to water-quality in the park including encroaching development and agricultural activities. From June 2002 through March 2004, Lynchburg College sampled physical, chemical and biological parameters along the Appomattox River, Plain Run Branch and several tributaries to inventory existing water quality and to assess the potential impact of agriculture on stream water quality. The results of the study demonstrated that the water quality of the Appomattox River was higher as it exited the park than when it entered the park. Cattle grazing and hay production within the park did not result in impairments on water quality but recommendations were made to keep stocking rates low and maintain adequate riparian buffers. However, some damage to wetlands and sedimentation from stream bank erosion due to grazing was identified by the wetland inventory (Environmental Concern 2002). In addition to these investigations, the Water Resources Division (WRD) of the NPS produced a baseline water quality report in which an analysis of patterns of stream discharge was conducted (NPS 1998b). Patterns in stream discharge can be informative in interpreting stream conditions. This analysis established three distinct hydrological seasons: rising limb (mid-Oct. – Feb.), falling limb (March – June), and base flow (July – mid-Oct.; Figure A-5). More recently, MIDN initiated a water quality pilot study to establish a long-term monitoring protocol, as well as, a benthic macroinvertebrate sampling program to assess stream conditions at APCO. Over the course of the pilot study no measured parameters indicated an impaired status with respect to state standards (Figure A-6). Although stream acidification has been identified as a significant risk for Mid-Atlantic streams (Sullivan et al. 2011), current data indicates that APCO streams are well buffered against this threat. Acid neutralizing capacity was analyzed in the Appomattox River and Plain Run Branch (n=27) and was well above (mean(sd): 673 (121) $\mu\text{eq/L}$) the NPS Air Resources Division's 100 $\mu\text{eq/L}$ threshold (Fenn et al. 2011) indicating a significant risk due to acid deposition. The primary concerns regarding water quality are related to development and agricultural impacts via sedimentation and alteration of watershed characteristics.

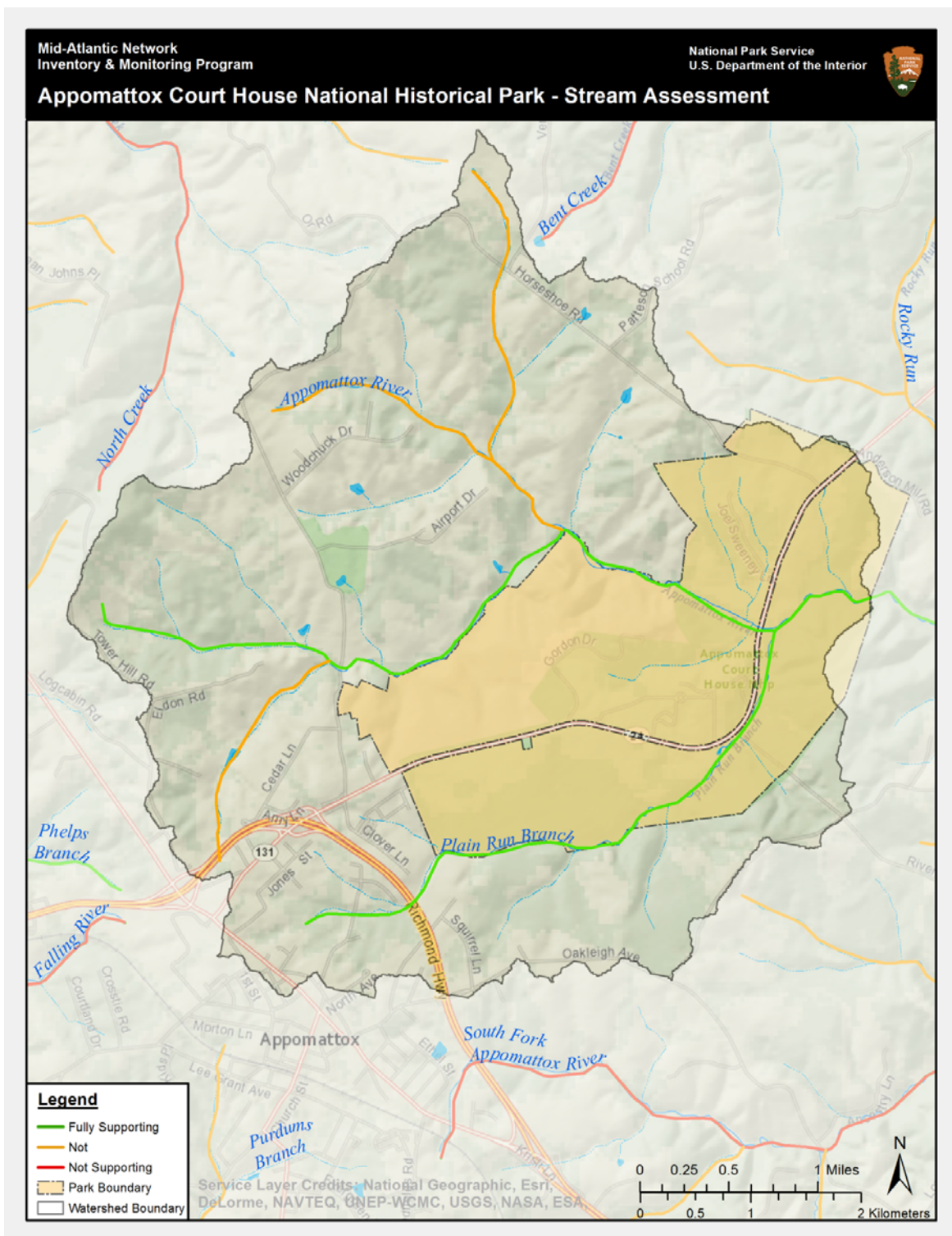


Figure A-4. Map displaying the attainment status of APCO streams from the VA DEQ 2012 305(b)/303(d) biannual water quality assessment.

Table A-4. Regulatory standards for baseline water quality parameters (temperature, pH, and dissolved oxygen) in the Commonwealth of Virginia and EPA recommended guidance.

Regulatory Parameter	Beneficial Use	EPA National Recommended Water Quality Criteria (2012)	State of Virginia Standard - 9VAC25-260-50 (2011)
Temperature (°C)	Warm-water fishes	Species specific criteria	32°C Max Temp Non-tidal Waters (Coastal and Piedmont Zones)
pH	Aquatic Life	6.5 - 9	6 - 9
Dissolved Oxygen (mg/l)	Aquatic Life	Warm water Min. Criteria - early life stages = 5.0, other life stages = 3.0, invertebrate min. criteria = 4.0	Min. = 4, Daily Avg = 5

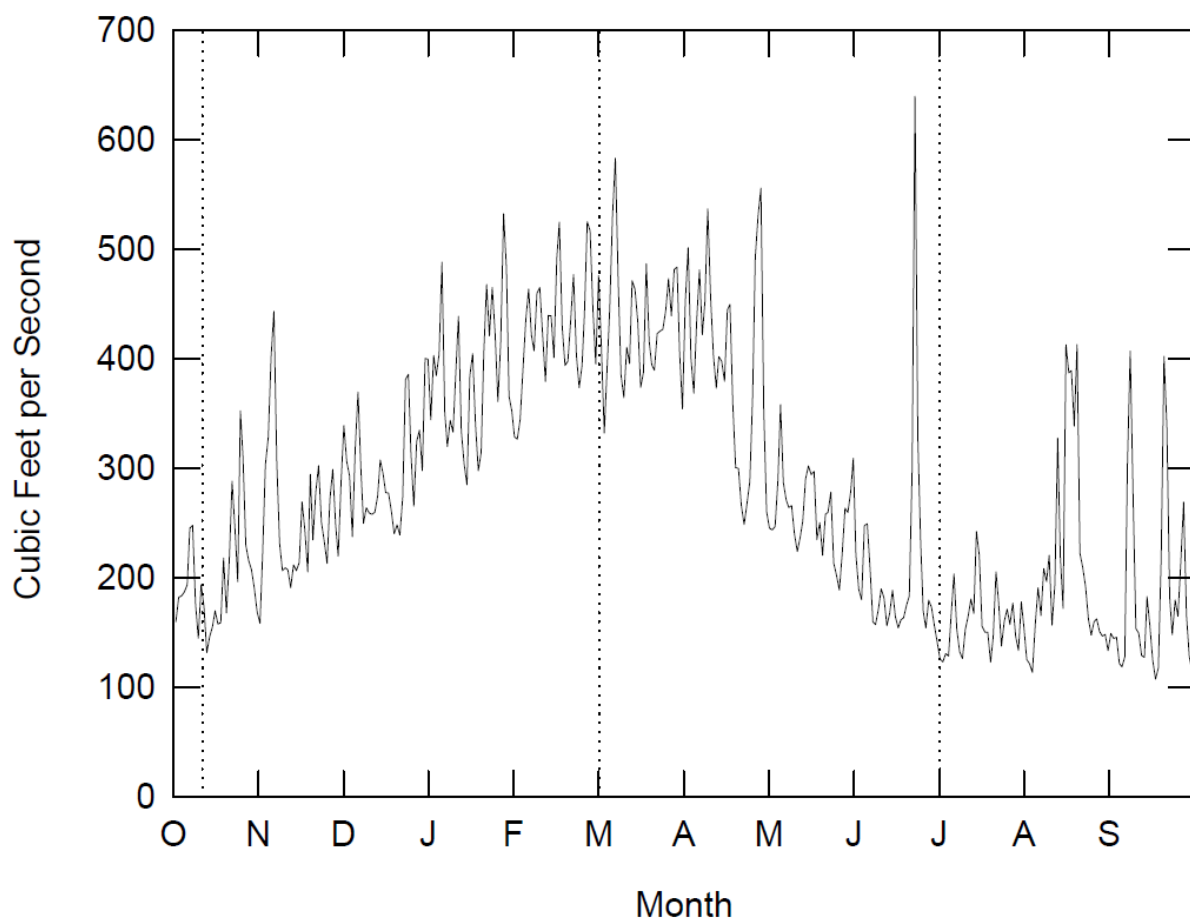


Figure A-5. Representative mean annual hydrograph (Appomattox River at Farmville, VA) used to conduct hydrologic seasonal analysis. Adapted from "Baseline water Quality Data: APCO" by NPS, 2000. P. 36. Reprinted with permission.

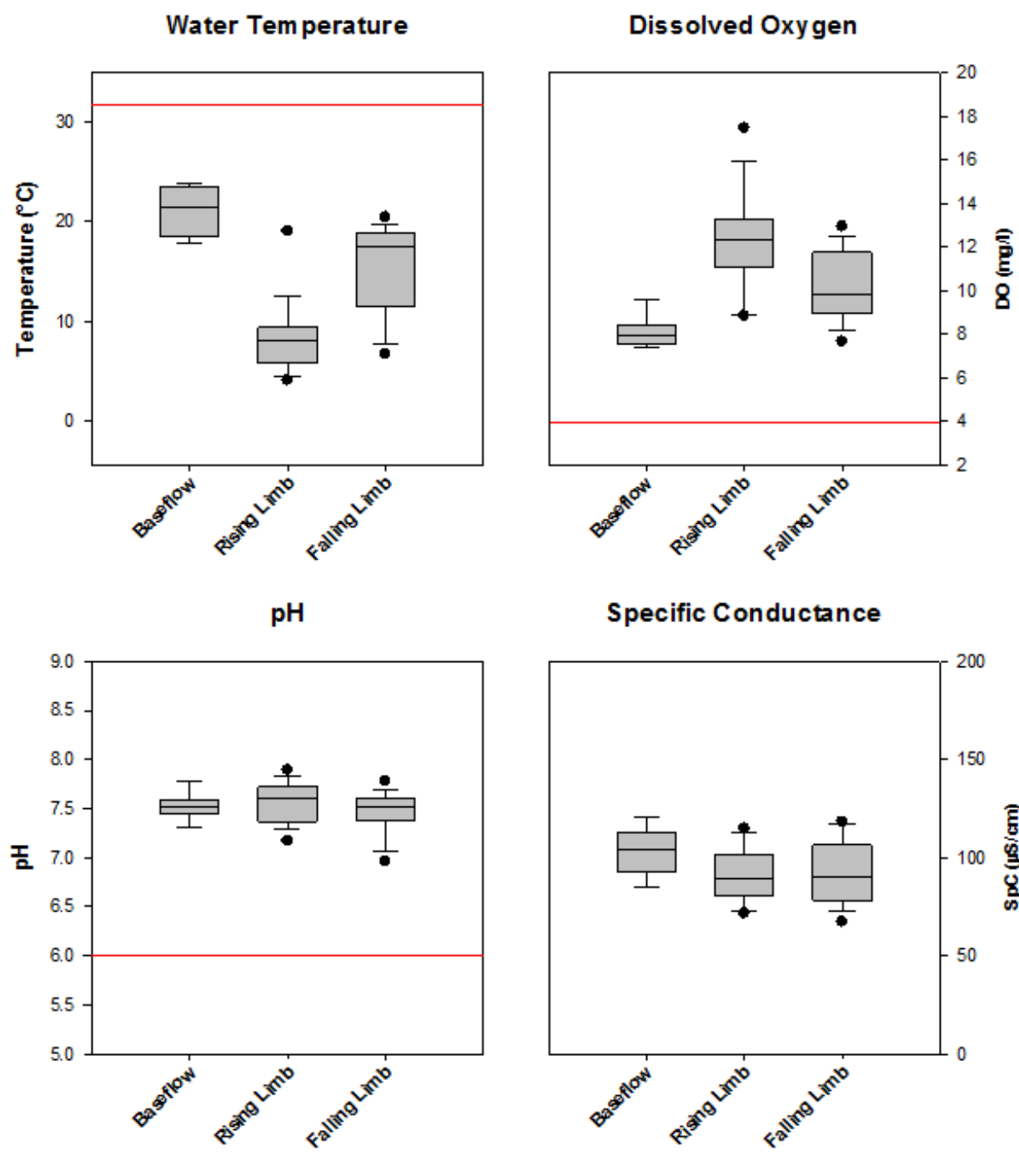


Figure A-6. Box plots (box: median, interquartile range; whiskers: 10th and 90th percentile; points: 5th and 95th percentile) for “core” water quality parameters measured during pilot study and grouped by hydrologic season at APCO (2010 – 2013). Red lines indicate water quality thresholds established by the Commonwealth of Virginia.

2.1.5 Long-term Monitoring Sites

In an effort to monitor the status and trends of wadeable streams at APCO several long-term monitoring sites have been selected. Sites were placed in streams of significant value to the park as determined by APCO and MIDN staff (Table A-5, Figure A-7). Stream reaches of particular importance to park management were identified from within these established sites for enhanced monitoring by integrating other MIDN protocols (BMI monitoring) and continuous monitoring of water quality parameters. Additionally, a summary of land cover classes is provided for the watershed at each long-term site (Table A-6).

APCO_01: Upper Appomattox River

APCO_01 is located near VA highway 24 which bisects the park. The site is located above a large tributary and the contributing watershed at this site is primarily located outside of park boundaries. Within this watershed there is a substantial amount of agriculture including row cropping and livestock grazing.

APCO_02: Plain Run Branch

APCO_02 is located on Plain Run above the confluence with the Appomattox River. The contributing watershed includes a substantial portion of developed land associated with the town of Appomattox at the top of the watershed. The watershed is primarily forested in and around the park with increasing development and agriculture at the further reaches of the watershed.

APCO_04: Appomattox River near lower boundary

APCO_03 is located along the downstream boundary of the park. This site captures watershed associated with APCO. Land cover within the watershed is primarily split between agricultural and forested. The primary threats to the park are associated with sedimentation due to historical and current agricultural practices and increased development around the town of Appomattox.

Table A-5. List of long-term monitoring sites at APCO.

Site ID	Stream Name	USGS HUC-14	Latitude	Longitude	Type of Site (D,BMI, Con)*
APCO_01	Appomattox River	02080207001211	37.38192	-78.78909	D
APCO_02	Plain Run	02080207001219	37.38191	-78.78817	D, BMI
APCO_03	Appomattox River	02080207001210	37.38347	-78.78149	D, BMI, Con

* D = Discrete Water Quality, BMI = Benthic Macroinvertebrate, Con = Continuous Water Quality Monitoring



Appomattox Court House NHP - Long-term Monitoring Sites

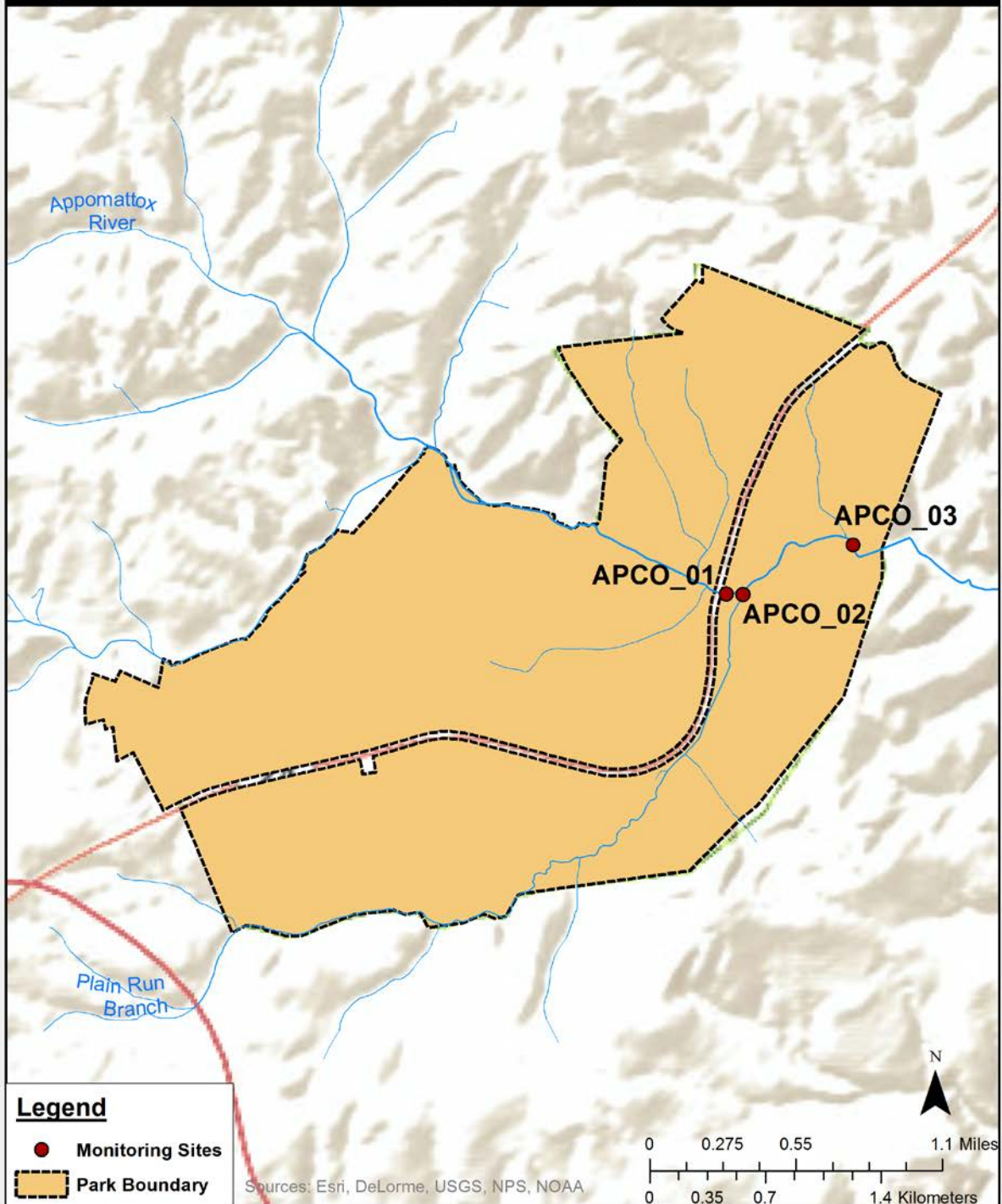


Figure A-7. Map of long-term monitoring sites at APCO.

Table A-6. Land cover (%) of the major land-use classifications from the NLCD (Homer et al. 2015) for the watershed and riparian areas (100 meter buffer) associated with each site selected for long-term monitoring, and within the park boundary of those watersheds.

Site ID	Watershed					100-meter Buffer				
	Forest	Wetlands	Agriculture	Developed*	Other	Forest	Wetlands	Agriculture	Developed*	Other
APCO_01	42.4	2.0	48.5	5.0 (0.6)	2.0	44.8	6.0	44.3	2.0 (0.1)	2.8
APCO_02	52.3	1.7	24.5	18.7 (4.4)	2.7	60.9	6.8	15.6	13.0 (1.8)	3.7
APCO_03**	45.8	2.1	40.8	9.1 (1.7)	2.2	49.2	6.5	36.4	5.0 (0.5)	2.9
Within Park	63.1	4.1	28.3	4.0 (<0.1)	0.5	58.4	13.6	24.6	3.1 (-)	0.2

* Values in parenthesis are the proportion of developed total that is medium to high intensity

** Drains all streams at APCO

2.2 Booker T. Washington National Monument

2.2.1 Park Overview

Booker T. Washington National Monument (BOWA) is located in Franklin County Virginia, in the rolling hills of the Virginia Piedmont, twenty-two miles south of Roanoke (Figure A-8). The park was established to commemorate the birthplace of Booker T. Washington and provide a direct link to the local community's agricultural past. The park's 97 hectares (239 acres) are primarily managed as an 1850 rural plantation consisting 65% as woodlands, 30% as pasture/hay/grassland (actively managed through an agricultural lease program) and the remaining 5% is sparsely developed (<40% impervious cover) consisting of the visitor center and historic buildings (Homer et al. 2015). The park, with its rolling pastures, tobacco fields, and woodlands, preserves a piece of the region's rural character in the midst of increasing modern development along the Route 122 corridor (NPS 2000).

2.2.2 Landscape Setting

BOWA lies on the western edge of the Piedmont region near the foothills of the Blue Ridge Mountains and is part of the Roanoke River basin that eventually drains into Albemarle Sound along the coast of North Carolina. The majority of the park is made up of Eliaoak Fine Sandy Loam Soils with a 7 to 15% slope. This soil type is primarily found in the historic area of the park as well as in high visitor use areas. Chester Loam, with a 15% to 45% slope, is located in the eastern and northeastern sections of the park, concentrated around Gills Creek and its tributaries. A very small percentage of the park located to the southeast, primarily in areas where streams are present, consists of Orenda Loam with a 7 to 15% slope and Springs Gravelly Loam with a 25 to 45% slope (NPS 2004b).

2.2.3 Land Cover and Vegetation

Land cover within the boundaries of BOWA and its contributing watershed are similar, however, significant differences are noteworthy. The primary land cover class is forested (65% Park, 62% watershed), followed by agricultural (29% Park, 32% watershed) and developed (5% park, 2% watershed) (Figure A-9, Table A-7). This is substantially more forested and agricultural land than is found throughout the Albemarle Sound watershed (43% forested; 22% agriculture). The Albemarle Sound watershed also has more development (7%). These characteristics are integral to understanding stream conditions at BOWA. Forested watersheds and buffers around streams have the ability to improve stream conditions by removing nutrients, controlling sediments, ameliorating temperature increases, and protecting physical habitat (Lowrance and Altier 1997, Jacobson 2001, Kaushal and Likens 2010). However, changes in patterns of land cover are occurring on all lands adjacent to and surrounding the park at an accelerated rate as a result of development on and around Smith Mountain Lake, a hydroelectric project with approximately 965 km (600 miles) of shoreline. This development is a significant threat to the ecological integrity of the aquatic resources at BOWA, especially small, headwater streams.

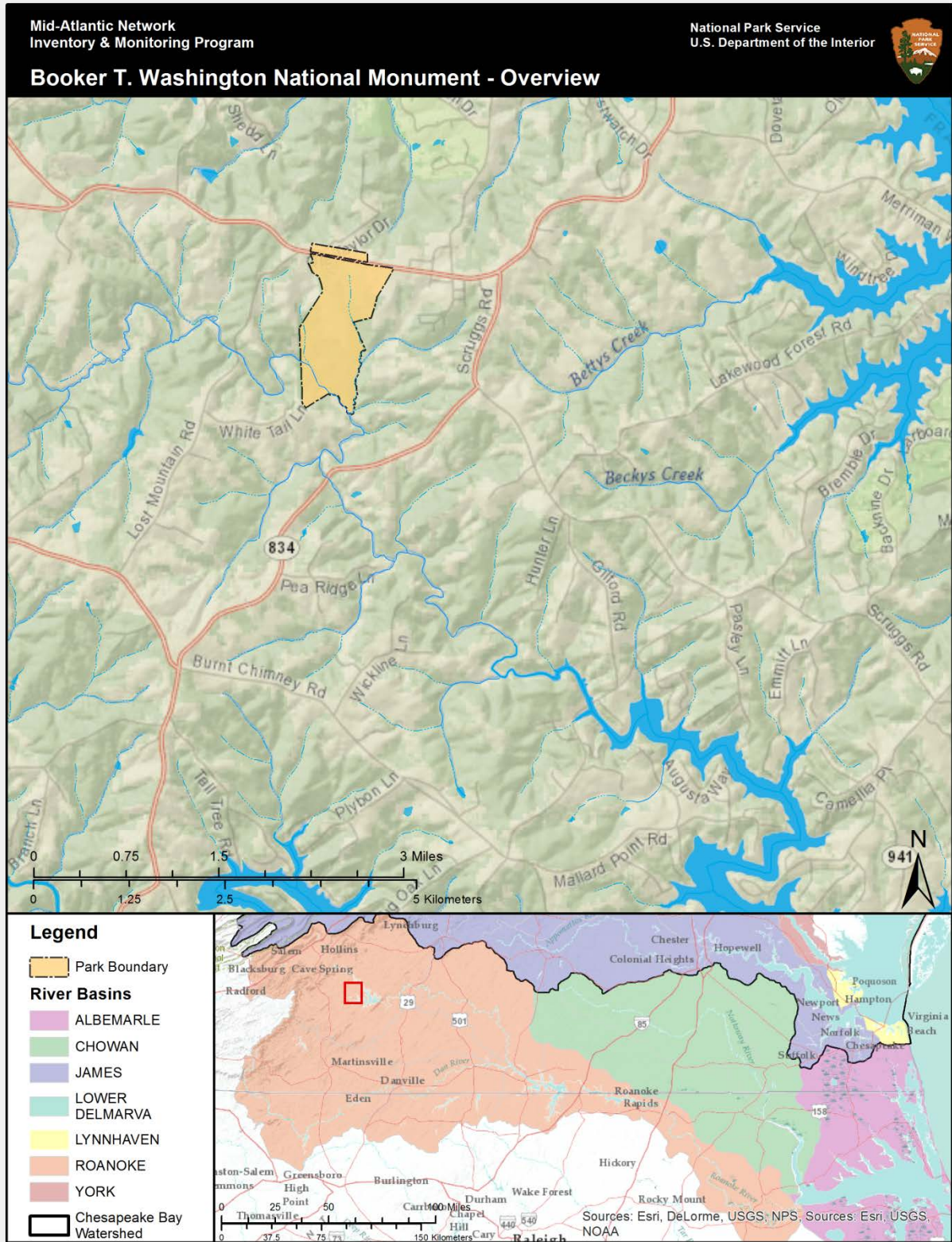


Figure A-8. Map displaying Booker T. Washington National Monument highlighting the aquatic resources.

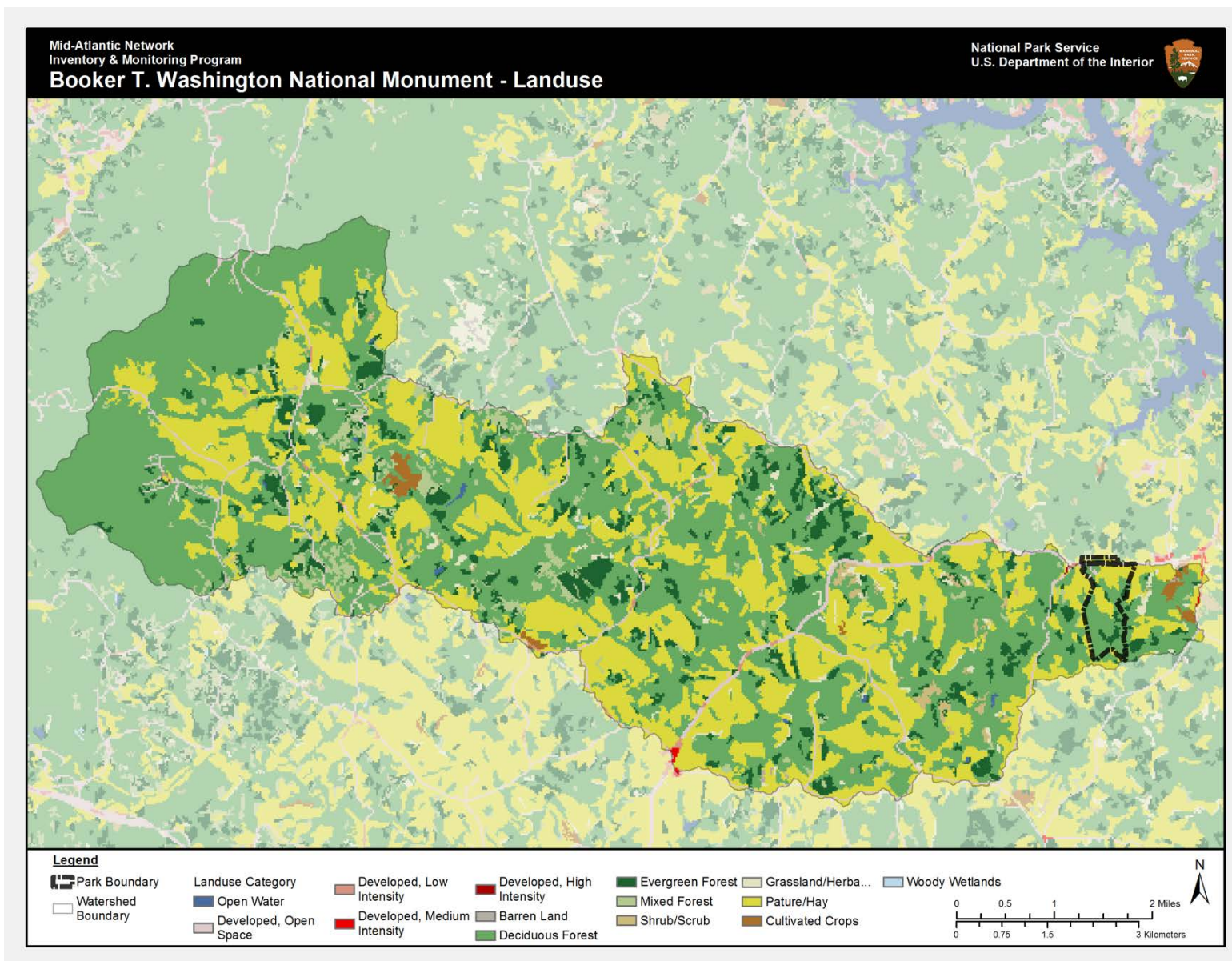


Figure A-9. Map displaying the National Land Cover Dataset classes for the contributing watershed to the streams of BOWA.

Table A-7. Land cover classification (Homer et al. 2015) of watersheds and riparian areas (100 meter buffer) associated with BOWA, within BOWA, and receiving waters associated with BOWA.

Land Cover Type	Watershed		100 Meter Buffer		Park		Albemarle Sound Watershed	
	%	Area (km ²)	%	Area (km ²)	%	Area (km ²)	%	Area (km ²)
Forest Total	61.5	48.50	66.0	19.17	65.0	0.65	42.5	19340
Deciduous Forest	51.4	40.58	57.6	16.74	55.8	0.55	27.2	12355
Evergreen Forest	6.6	5.20	5.7	1.65	9.2	0.09	12.6	5712
Mixed Forest	3.4	2.72	2.7	0.78	-	-	2.8	1273
Agriculture Total	32.2	25.40	29.4	8.55	29.6	0.29	22.1	10044
Pasture/Hay	31.8	25.06	29.3	8.50	29.6	0.29	12.3	5596
Cultivated Crops	0.4	0.34	0.2	0.05	-	-	9.8	4448
Developed Total	3.6	2.86	1.9	0.55	4.5	0.05	7.0	3189
Developed, Open Space	2.9	2.29	1.7	0.49	4.3	0.04	4.9	2223
Developed, Low Intensity	0.5	0.41	0.2	0.05	0.3	0.00	1.5	685
Developed, Medium Intensity	0.2	0.13	-	-	-	-	0.5	210
Developed, High Intensity	0.0	0.04	-	-	-	-	0.2	70
Grassland/Herbaceous	1.5	1.16	1.4	0.41	0.8	0.01	4.5	2062
Scrub/Shrub	1.1	0.85	0.8	0.24	-	-	6.7	3051
Open Water	0.1	0.09	0.3	0.09	-	-	2.5	1131
Barren Land	<0.1	0.03	<0.1	0.01	-	-	0.2	93
Woody Wetlands	<0.1	0.01	<0.1	0.01	-	-	13.3	6032
Emergent Herbaceous Wetlands	<0.1	0.03	0.1	0.03	-	-	1.2	532
Total	100.0	78.9	100.0	29.1	100.0	1.0	100.0	45473

Vegetation within BOWA was classified and mapped during 2001-2006 using extensive field reconnaissance and aerial photography (Patterson 2008). Vegetation maintained or altered by human activity cover 35% (32 ha [79 ac]) of the park and include areas of maintained turf, actively grazed pastureland, hayfields managed by agricultural lease, demonstration crop fields, garden areas, man-made structures, and a white pine plantation. Over 31% (69 acres) of the park is comprised of early successional or transitional vegetation classes including Successional Virginia Pine Forest, Successional Tulip tree Forest, and Dense Hardwood Regeneration (Patterson 2008a). These areas are dominated by early successional weedy tree species in the canopy and sub-canopy and have high cover of nonnative invasive plants in the shrub and herbaceous layers.

Undisturbed later successional forests cover the remaining 34% (77 acres) of the park and have been classified as “geographically unique” in that they host plant and tree species that are now considered to be somewhat out of their normal home ranges (Patterson 2008). These forests are most commonly found on rocky, eroded soils or steep slopes (Acidic Oak-Hickory Forest, 23%), as well as the protected, low slope locations above Gills Creek (Inner Piedmont/Lower Blue Ridge Basic Mesic Forest, 4%, vulnerable to nonnative plant invasion with high recruitment of tree of heaven). Piedmont/Mountain Alluvial Forest (corresponds to USGS palustrine forested wetlands) found along the narrow floodplains and terraces of Gills Creek and Jack-O-Lantern Branch (7%) also fall into this category.

2.2.4 Water Resources and Current Status of Water Quality

The National Park Service manages approximately 5.8 km of streams at BOWA and the watersheds associated with these streams drain over 78 km² of the region (Figure A-10) (USGS 2014). There are two major water features within the boundaries of BOWA: Gills Creek and Jack-O-Lantern Branch. Gills Creek is a larger stream which accounts for much of the watershed area while Jack-O-Lantern Branch is a headwater stream which originates in the park. The park is located within the Roanoke River Basin (approximately 25,000 km²/15,500 mi²) which starts on the eastern side of the Blue Ridge Mountains near the City of Roanoke in southern Virginia and drains southeast to the Albemarle Sound. As with many receiving waters (e.g., estuaries and bays), the Albemarle Sound is susceptible to excess nutrients and sediments inputs from agricultural and urban runoff (EPA 2006). Perennial streams within BOWA are predominately headwater reaches (~68% by length) and range from first to fourth order (Table A-8). Headwater streams (stream order 1-3) are typically dominated by allochthonous inputs, streams are shaded by riparian vegetation reducing primary production and much of the organic matter comes from terrestrial sources. As streams increase in size (stream order 3-5), there is a shift towards autochthonous resources, primary production increases and shifts in the composition of the biological community occur (Vannote et al. 1980).

There are five cold springs located in the park. The first three springs form the headwaters of the Jack-O-Lantern Branch and the fourth forms the headwaters of an unnamed stream. The fifth spring flows into Gills Creek. There are at least two streams that enter the park from outside sources and one joins Jack-O-Lantern on the park's south boundary. The other enters the park in a forested area along the north boundary and flows into Gill's Creek.



Booker T. Washington National Monument - Watershed

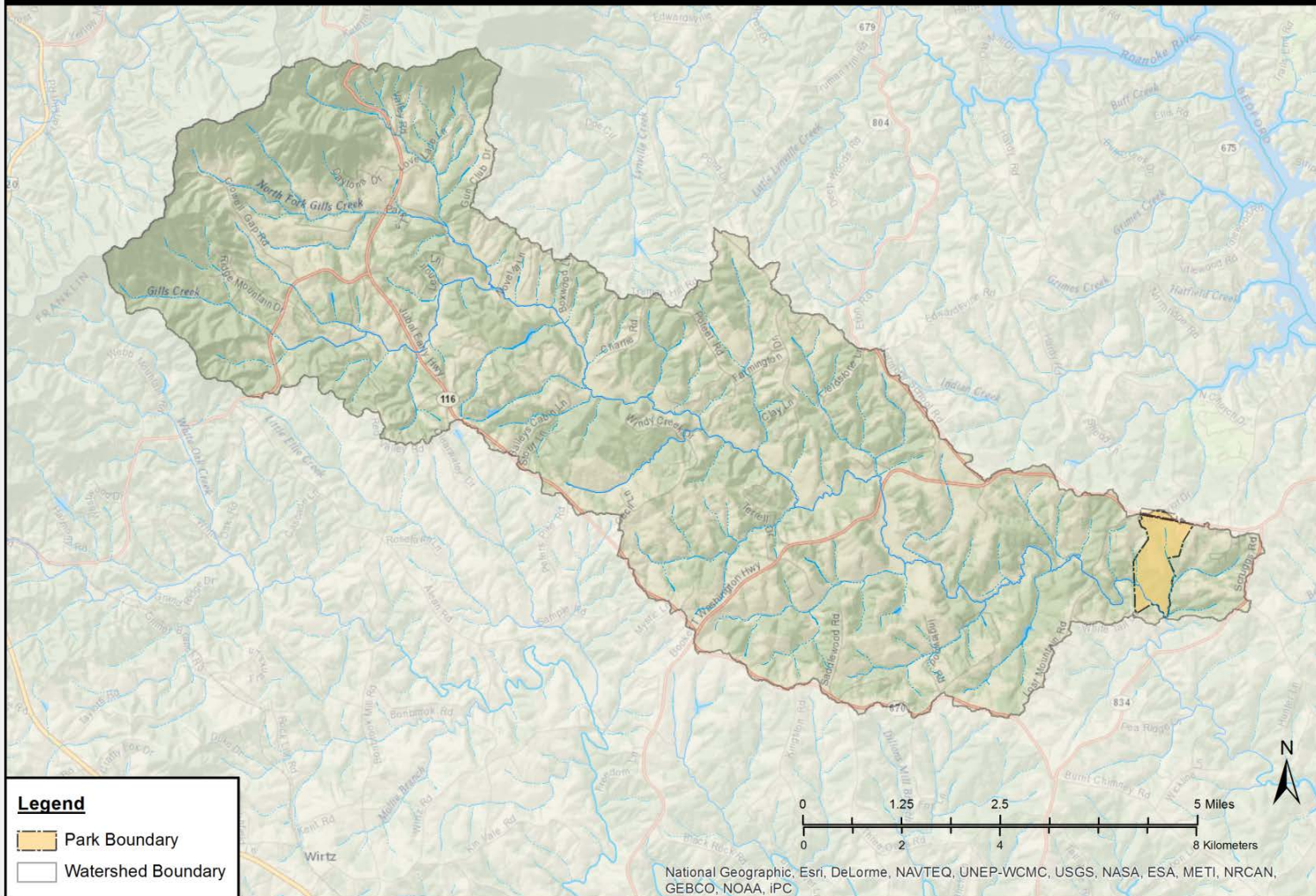


Figure A-10. Map displaying the streams and contributing watersheds of BOWA.

Table A-8. Strahler stream order classification by length (km) within the contributing watershed of BOWA streams.

Stream Order	Intermittent	Perennial	All Streams (Within Park)	% Perennial
1	86.9	9.5	96.4 (3.8)	10
2	21.9	4.3	26.2 (0.6)	16
3	5.2	5.0	10.3 (-)	49
4	-	20.0	20.0 (1.3)	100
Total	114.0	38.9	152.9 (5.8)	
% Headwater	100	48	87 (77)	

Over thirty species of fish have been documented in BOWA streams (Atkinson 2008). This diversity is attributed to several factors including its proximity to Smith Mountain Lake, with the associated spawning runs in its tributaries, as well as its location within the Roanoke drainage, one of the most diverse assemblages on the Atlantic slope (Jenkins and Burkhead 1994, Atkinson 2008). Of particular note, 10 species of catostomids (suckers) have been detected in Gills Creek, as well as, several species endemic to the Roanoke drainage. Additionally, included in this assemblage are nest building species such as the bluehead chub which provide spawning habitat for several other species found in Jack-O-Lantern Branch and Gills Creek. These species can be especially sensitive to sediment pollution from urban and agricultural run-off, one of the primary threats to the integrity of the aquatic ecosystem at BOWA.

The Commonwealth of Virginia has established water quality standards for various designated uses (e.g., aquatic use, public water supply, recreational, etc.) for surface waters (Table A-9). All streams within BOWA are designated for aquatic life use and are currently meeting the standards established for this designation (temp, DO, pH). Gills Creek is also designated for and attaining wildlife and public water supply uses, however, it's not supporting recreational use due to E.coli contamination from septic systems, livestock and other unspecified waste (Figure A-11) (VADEQ 2014). Fish consumption advisories due to PCB levels are in effect for Smith Mountain Lake and the Roanoke River which are located within 10 kilometers of Booker T. Washington.

Table A-9. Regulatory standards for baseline water quality parameters (temperature, pH, and dissolved oxygen) in the Commonwealth of Virginia and EPA recommended guidance.

Regulatory Parameter	Beneficial Use	EPA National Recommended Water Quality Criteria (2012)	State of Virginia Standard - 9VAC25-260-50 (2011)
Temperature (°C)	Warm-water fishes	Species specific criteria	31°C Max Temp - Mountainous Zones Waters
pH	Aquatic Life	6.5 - 9	6 - 9
Dissolved Oxygen (mg/l)	Aquatic Life	Warm water Min. Criteria - early life stages = 5.0, other life stages = 3.0, invertebrate min. criteria = 4.0	Min. = 4, Daily Avg = 5



Booker T. Washington National Monument - Stream Assessment

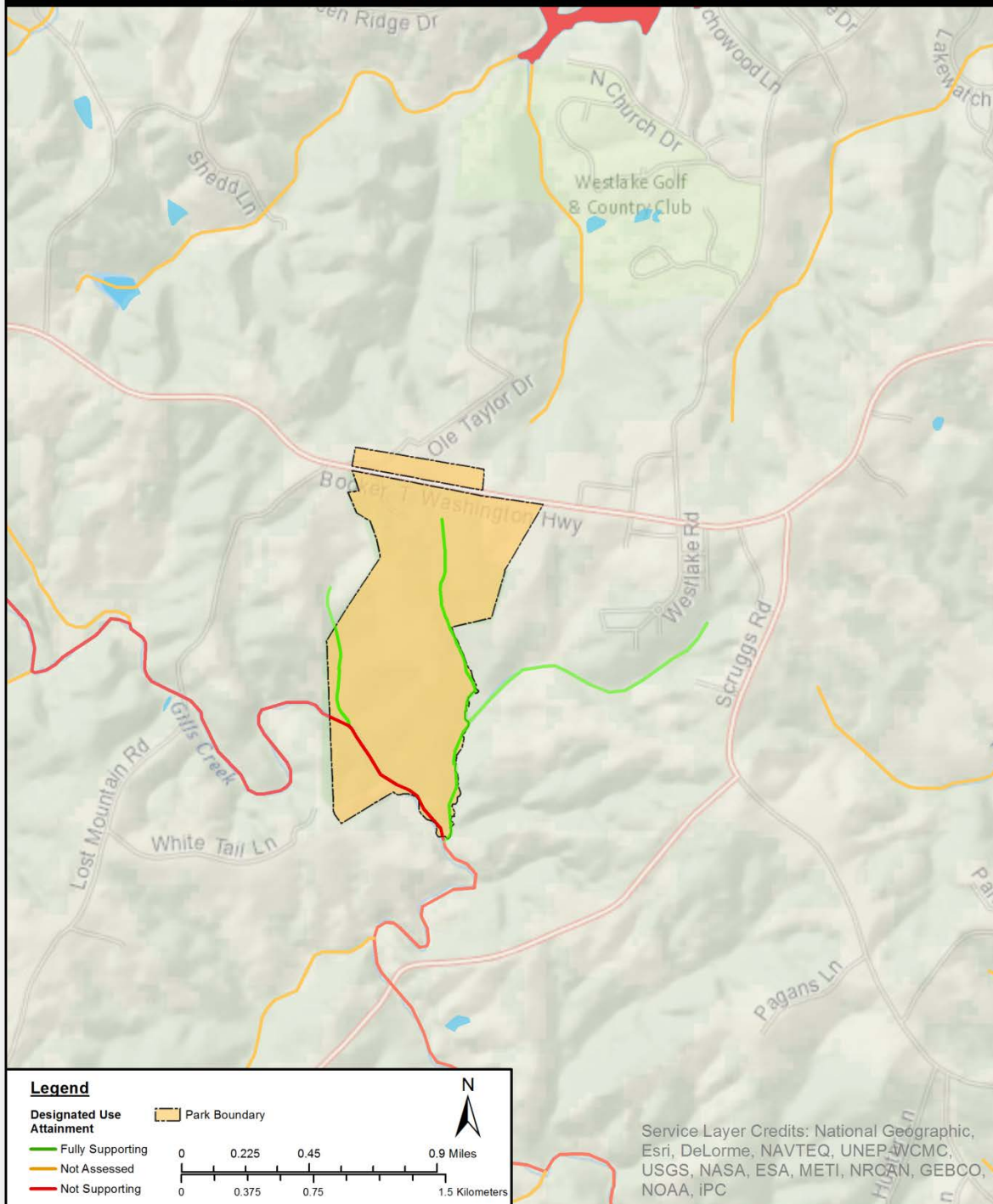


Figure A-11. Map displaying the attainment status of BOWA streams from the VA DEQ 2012 305(b)/303(d) biannual water quality assessment.

Until recently, water quality data within BOWA has been sparingly and inconsistently collected. A baseline water quality inquiry by the WRD of the NPS revealed little relevant historical data for the park; however, it did reveal seasonal patterns in discharge within the region. Based on these findings three distinct hydrological seasons: rising limb (mid-Oct. – Apr.), falling limb (Apr. – July), and base flow (July – mid-Oct.; Figure A-12) were established (NPS 1997b). More recently the BOWA and MIDN have partnered to initiate a water quality pilot study as well as a benthic macroinvertebrate sampling program to assess stream conditions at BOWA. Preliminary benthic macroinvertebrate data (2009–2012) suggests that these streams are in slightly impaired or healthy condition but that there is a significant risk that they could become impaired in the future. Mean (SD) Stream Condition Index for Virginia Non-Coastal Streams (VASCI) scores for this period were 54.2 (20.5) and 60.6 (4.9) for Jack-O-Lantern Branch and Gills Creek, respectively. VASCI scores greater than 60 indicate healthy conditions (Burton and Gerritsen 2003). Preliminary water quality data (2010-2013) indicate that the core water quality parameters, dissolved oxygen, pH, and water temperature, all fell within the designated range for healthy conditions by the state of Virginia (Figure A-13). These results suggests that the leading ecological concerns are likely not factors affecting core parameters but related to the in-stream or riparian habitat conditions, namely degradation due to sedimentation.

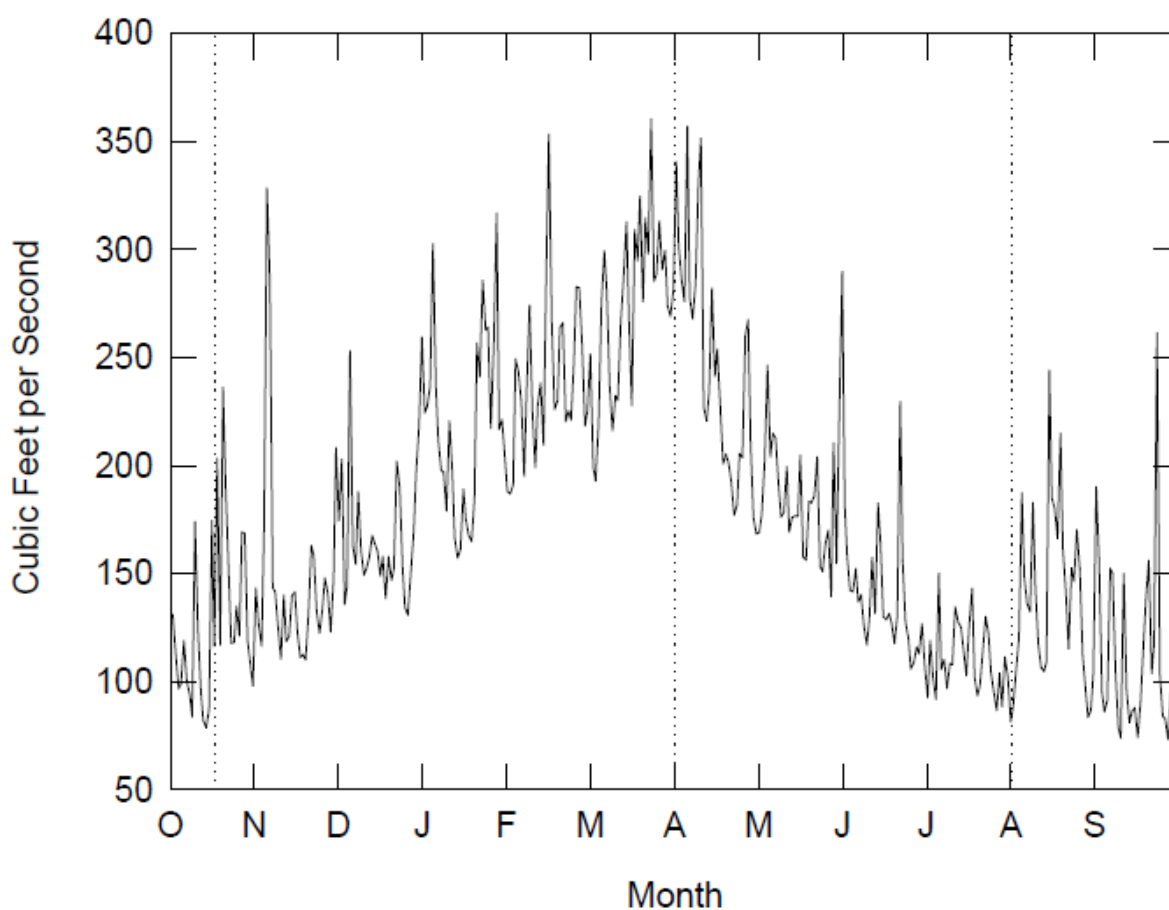


Figure A-12. Representative mean annual hydrograph for Goose Creek (37° 10' 23" N, 79° 31' 14" W) used to conduct hydrologic seasonal analysis. Adapted from "Baseline Water Quality Data: BOWA" by NPS, 2000. P. 36. Reprinted with permission.

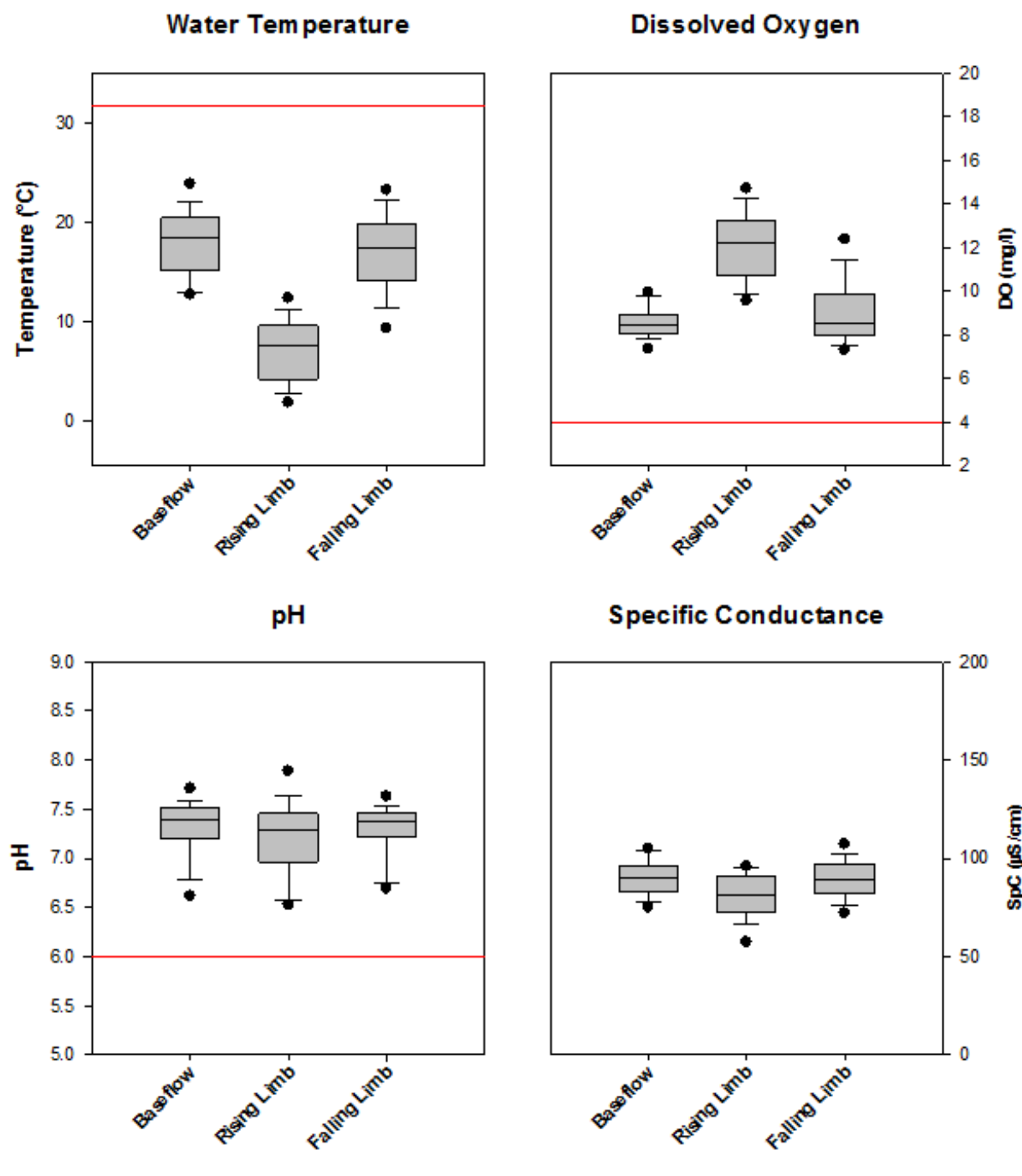


Figure A-13. Box plots (box: median, interquartile range; whiskers: 10th and 90th percentile; points: 5th and 95th percentile) for "core" water quality parameters measured during pilot study and grouped by hydrologic season at BOWA (2010–2013). Red lines indicate water quality thresholds established by the Commonwealth of Virginia.

2.2.5 Long-term Monitoring Sites

Sites were placed in streams of significant value to parks as determined by BOWA and MIDN staff (Figure A-14, Table A-10). Stream reaches of particular importance to park management were identified from within this group for enhanced monitoring by integrating other MIDN protocols (BMI monitoring) and continuous monitoring of water quality parameters. Additionally, a summary of land cover classes is provided for the watershed at each long-term site (Table A-11).

BOWA_01: Upper reach of Jack-O-Lantern Branch

BOWA_01 is located near the beginning of the perennial flows of Jack-O-Lantern Branch below the spring run. The watershed of Jack-O-Lantern Branch is predominately within the boundaries of BOWA. This site has the lowest influence of land management practices by adjacent landowners in Jack-O-Lantern Branch.

BOWA_02: Middle Jack-O-Lantern Branch

BOWA_02 is located below the first of two perennial tributaries to Jack-O-Lantern Branch. The first tributary (unnamed; HUC: 03010101001881) is under pressure from land use change (urban development). Although the watershed above BOWA_02 only represents approximately two percent of lands contributing to BOWA streams, over 90% of the high-intensity development and over 65% of the medium intensity development are found in this watershed. Development in this area east of the park is expected to continue.

BOWA_03: Lower Jack-O-Lantern Branch

BOWA_03 is located immediately above the confluence with Gills Creek and below its second tributary (HUC: 03010101006232). Land cover within the watershed for this tributary is primarily a mix of pastureland and forest.

BOWA_04: Gills Creek

BOWA_04 is located along the central-southern boundary of BOWA after the creek flows through the south-western quadrant of the park. This stream is much larger than Jack-O-Lantern Branch and the watershed is predominately outside of the boundaries of BOWA. Gills Creek serves a spring spawning run for catostomids residing in Smith Mountain Lake.

BOWA_05: tributary to Gills Creek

BOWA_05 is the other perennial stream found within BOWA boundaries. Approximately half of the contributing watershed is found within BOWA, the remaining area is found to the north and west of the park.



Booker T. Washington National Monument - Monitoring Sites

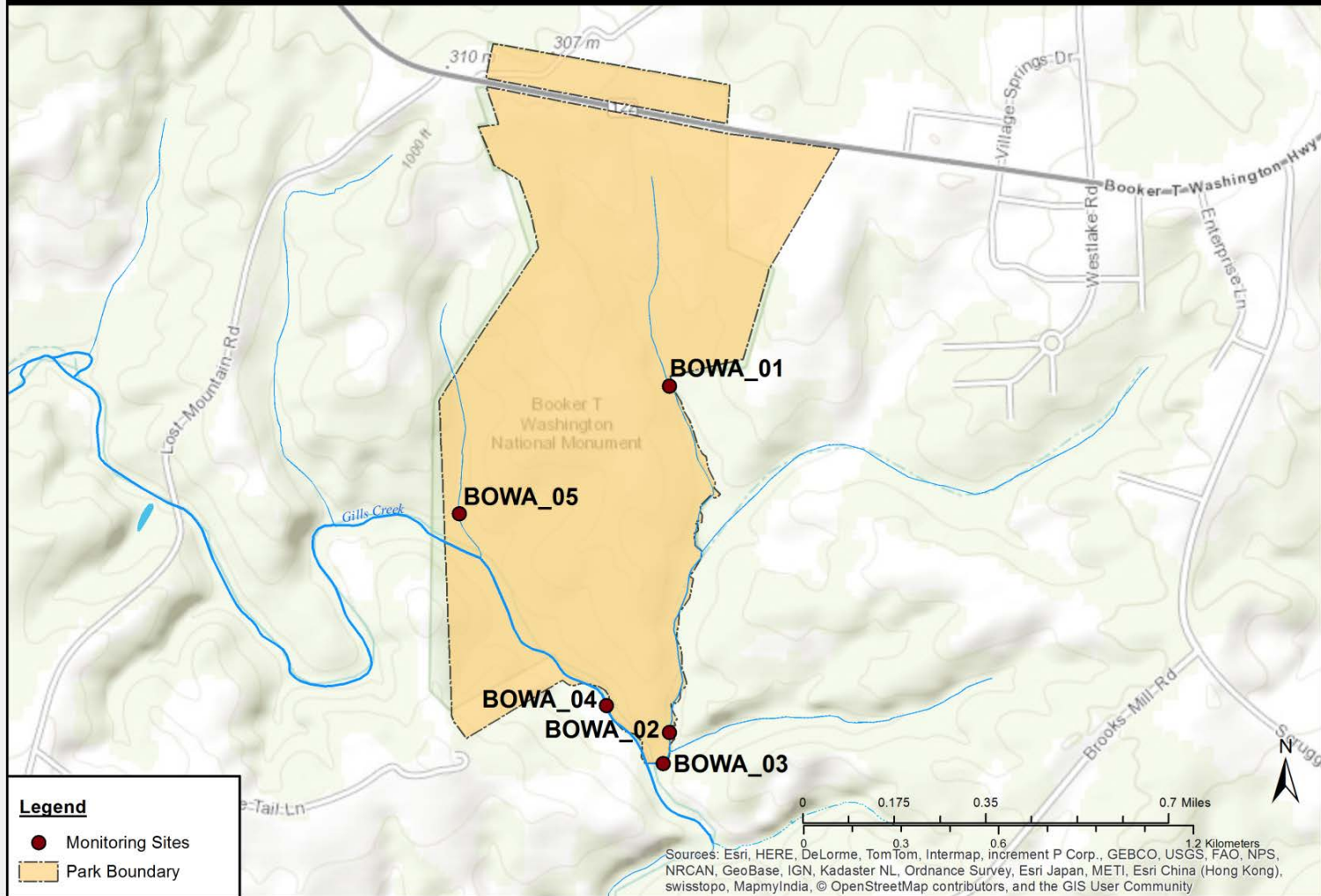


Figure A-14. Map of monitoring sites at BOWA.

Table A-10. List of long-term monitoring sites at BOWA.

Site ID	Stream Name	USGS HUC-14	Latitude	Longitude	Type of Site (D,BMI,Con)*
BOWA_01	Jack-O-Lantern Branch	03010101006176	37.11521	-79.72990	D
BOWA_02	Jack-O-Lantern Branch	03010101001881	37.10757	-79.72993	D, BMI, Con
BOWA_03	Jack-O-Lantern Branch	03010101001881	37.10692	-79.73014	D
BOWA_04	Gills Creek	03010101000446	37.10817	-79.73154	D, BMI
BOWA_05	tributary of Gills Creek	03010101006190	37.11239	-79.73579	D

* D = Discrete Water Quality, BMI = Benthic Macroinvertebrate, Con = Continuous Water Quality Monitoring

Table A-11. Land cover (%) of the major land-use classifications from the NLCD (Homer et al. 2015) for the watershed and riparian areas (100 meter buffer) associated with each site selected for long-term monitoring.

Site ID	Watershed			100-meter Buffer		
	Forest	Agriculture	Developed*	Forest	Agriculture	Developed*
BOWA_01	37.8	48.7	12.7 (0.0)	45.5	54.5	-
BOWA_02	45.8	31.4	15.8 (6.4)	75.9	14.8	0.8 (0.0)
BOWA_03	51.9	28.9	13.1 (5.1)	80.6	12.0	0.6 (0.0)
BOWA_04	61.8	32.3	3.3 (0.1)	65.6	29.9	1.9 (0.0)
BOWA_05	44.3	52.6	2.5 (0.0)	68.1	31.9	-

* Values in parenthesis are the proportion of developed total that is medium to high intensity

2.3 Fredericksburg & Spotsylvania National Military Park

2.3.1 Park Overview

Fredericksburg and Spotsylvania National Military Park (FRSP) is spread across parts of 376 km² (145 mi²) of the Virginia Piedmont and Coastal Plain, and consists of four major Civil War battlefields: Fredericksburg, Chancellorsville, Wilderness and Spotsylvania Courthouse (Figure A-15). Across this landscape, the NPS manages approximately 7,800 ac of forests, fields, wetlands and streams spanning portions of Orange, Spotsylvania, Caroline, and Stafford counties as well as the City of Fredericksburg. Within the park boundaries the landscape is predominately forested (> 65%) while some of the park is actively managed as open land to maintain the historic scene (> 20%; croplands, hayfields, prescribed fire and mowing). However, the region surrounding FRSP is one of the fastest developing localities in the United States, with the City of Fredericksburg experiencing a population growth rate of over 15 percent between 2010 and 2013 (US Census Bureau 2012, Gunter 2014). As FRSP becomes one of the few remaining undeveloped, protected spaces in a rapidly developing region, its streams and wetlands are becoming increasingly important ecologically, for historical context, and for recreational uses.

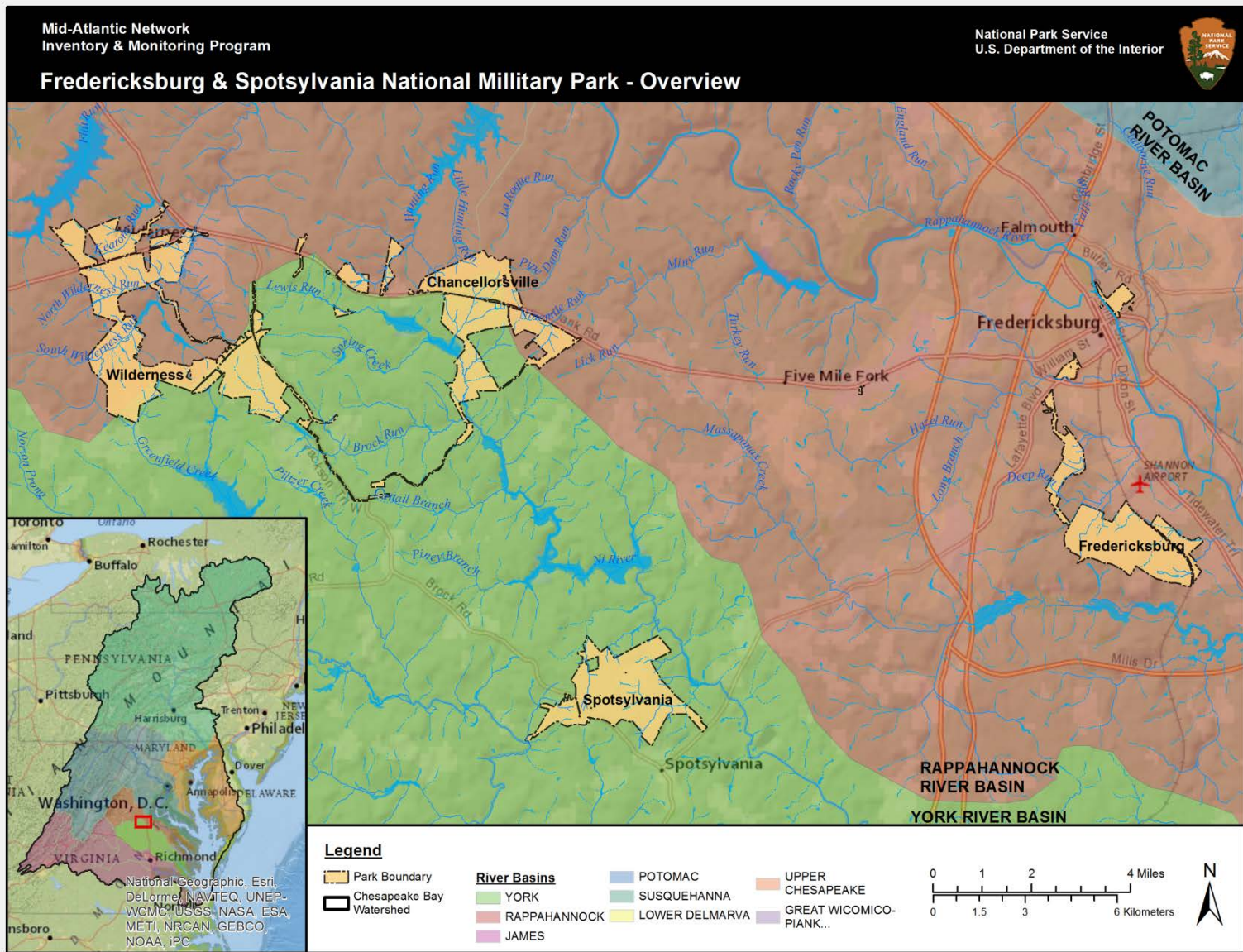


Figure A-15. Map displaying the four major units of Fredericksburg and Spotsylvania National Military Park highlighting the aquatic resources.

2.3.2 Landscape Setting

FRSP is located within the Chesapeake Bay watershed (CBW) and is underlain with two primary landform types; the Piedmont and the Coastal Plain (Thornberry-Ehrlich 2010). The Piedmont is composed of hard crystalline rocks producing narrow to moderately broad ridges and gentle to steep side slopes along streams. The Coastal Plain is composed of soft sedimentary rocks producing flat laying terraces and wetlands. Wilderness, Chancellorsville, and Spotsylvania Courthouse units are located well in the Piedmont zone while the Fredericksburg unit is located along the fall line, the transition zone between the Piedmont and Coastal Plain. Within the region, these landforms support a wide variety of land uses which include agriculture (croplands and pasture/hay), urban development, and mature, late successional forests.

2.3.3 Land use and Vegetation

Within the boundaries of FRSP the primary land cover class is forested (67.5%), followed by agricultural (14.2%) and developed (9.7%) (Figure A-16, Table A-12) (Homer et al. 2015). This is substantially more forested land than is found in the contributing watersheds of FRSP (50.8%) and across the entire CBW (54.7%). The watersheds that support FRSP streams are much more urbanized (28.6%) than the CBW (11.0%) and have less land devoted to agriculture (10.3%) than the CBW (24.6%). These characteristics are integral to understanding stream conditions at FRSP. Forested watersheds and buffers around streams have the ability to improve stream conditions by removing nutrients, controlling sediments, ameliorating temperature increases, and protecting physical habitat (Lowrance and Altier 1997, Jacobson 2001, Kaushal and Likens 2010). In such a highly developed region, FRSP's protected battlefields help to mitigate the effects of an urbanized landscape on aquatic resources.

The vegetation within Fredericksburg and Spotsylvania NMP was classified and mapped during 2001-2006 using extensive field reconnaissance and aerial photography (Taverna and Patterson 2008). Fifty-two percent of the forests in the park remain relatively undisturbed and consist of mature late successional forest. These late successional forests consist of Oak / Heath Forest (most common), Acidic Oak - Hickory Forest, Mesic Mixed Hardwood Forest, and Eastern White Pine - Hardwood Forest as well as six classes of forested wetlands (see below for more detail). Early successional or transitional vegetation (Successional Virginia Pine Forest, Successional Tuliptree Forest, Successional Red-cedar Forest, Successional Mixed Scrub, and Beaver Wetland Complex) cover make up 26% of park land and is the result of relatively recent (20–60 yrs) abandonment of fields or tree canopy removal by wind disturbance, beaver activity, or silvicultural practices (Taverna and Patterson 2008).

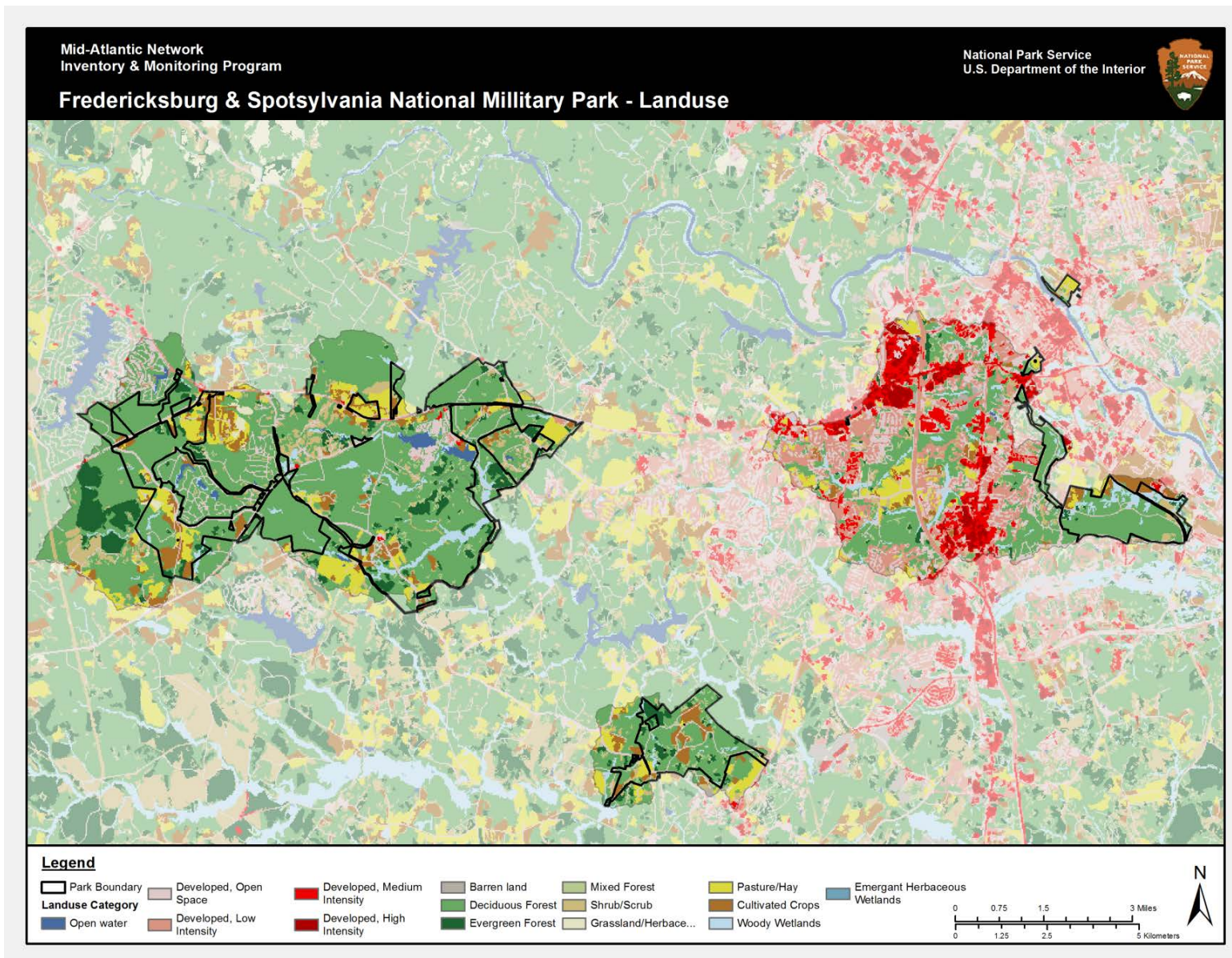


Figure A-16. Map displaying the National Land Cover Dataset classes for the contributing watersheds to the streams of FRSP.

Table A-12. Land cover classification (Homer et al. 2015) of watersheds and riparian areas (100 meter buffer) associated with FRSP, within FRSP, and the CBW.

Land Cover Type	Watershed		100 Meter Buffer		Park		Chesapeake Bay Watershed	
	%	Area (km2)	%	Area (km2)	%	Area (km2)	%	Area (km2)
Forest Total	50.8	60.97	55.3	18.60	67.5	19.94	54.7	91329
Deciduous Forest	44.8	53.82	51.1	17.22	59.0	17.44	42.8	71401
Evergreen Forest	4.5	5.45	3.0	1.00	5.9	1.73	5.8	9716
Mixed Forest	1.4	1.70	1.1	0.38	2.6	0.77	6.1	10212
Agriculture Total	10.3	12.34	9.8	3.30	14.2	4.19	24.6	40996
Pasture/Hay	5.6	6.78	5.4	1.81	6.7	1.99	14.9	24913
Cultivated Crops	4.6	5.56	4.4	1.49	7.4	2.20	9.6	16083
Developed Total	28.6	34.31	18.3	6.15	9.7	2.87	11.0	18432
Developed, Open Space	14.3	17.13	10.6	3.57	9.3	2.75	6.6	10992
Developed, Low Intensity	7.9	9.47	4.7	1.57	0.4	0.11	2.8	4696
Developed, Medium Intensity	4.3	5.16	2.2	0.73	<0.1	0.01	1.2	2005
Developed, High Intensity	2.1	2.56	0.8	0.28	<0.1	<0.01	0.4	739
Grassland/Herbaceous	0.5	0.58	0.6	0.20	0.1	0.02	0.8	1335
Scrub/Shrub	4.8	5.71	3.8	1.28	2.5	0.73	2.2	3709
Open Water	0.7	0.88	2.2	0.74	-	-	1.8	2950
Barren Land	0.2	0.27	0.3	0.09	-	-	0.3	489
Woody Wetlands	4.1	4.90	9.6	3.23	5.9	1.73	3.7	6244
Emergent Herbaceous Wetlands	0.1	0.11	0.2	0.06	0.2	0.05	0.9	1471
Total	100.0	120.07	100.0	33.67	100.0	29.54	100.0	166,957

There are an estimated 1062 acres) of wetland located within the park, the majority of which are palustrine forested wetland systems, but also includes palustrine emergent and scrub-shrub wetlands. The forested wetland systems can be divided into alluvial floodplain and non-alluvial forests. The alluvial floodplain forests (approximately 670 acres) consist of well-drained floodplains along streams (Coastal Plain/Piedmont Floodplain Forest) and rivers (Piedmont/Mountain Floodplain Forest) as well as poorly drained floodplain swamps (Coastal Plain/Piedmont Floodplain Swamp Forest, conservation rank G3/G4 due to its relatively restricted range and threats to intact stands). The non-alluvial wetland forests (395 acres) typically have standing water due to impermeable soils with poor drainage and high clay content found near seeps, poorly drained upland basins and areas with high water tables rather than by overland flooding (Taverna and Patterson 2008). Many of the non-alluvial forested wetlands in the park are uncommon or rare throughout the state of Virginia and/or Mid-Atlantic region (Coastal Plain / Piedmont Acidic Seepage Swamp (G3), Non-Riverine Saturated Forest (G2)). These isolated wetlands play an important role as amphibian breeding areas and provide habitat for many at-risk plant and animal species (Comer et al. 2005). They are vulnerable to alteration or destruction by direct and indirect hydrologic modifications from anthropogenic sources, beaver activity, vegetation change/removal and pollution.

2.3.4 Water resources and current status of water quality

The National Park Service manages approximately 120 km of streams at FRSP and the watersheds associated with these streams drain over 100 km² of the region (Figure A-17, Table A-13) (USGS 2014). These watersheds are located within the greater Chesapeake Bay watershed, home to the largest estuary in the United States which has been degraded over time primarily due to excess nutrient and sediment loads delivered from the upland watershed (Kemp and Boynton 2005). Perennial streams within FRSP are predominately smaller, headwater reaches (>90%) and range from first to fourth order (Table A-13). Streams in the north-western reaches of FRSP (Wilderness-Chancellorsville) straddle the divide between the two major river systems draining central Virginia, the Rappahannock and York Rivers (Fig. A-15). Waters flowing through much of the Wilderness unit drain to Wilderness Run and on to the Rapidan River, the largest tributary to the Rappahannock River. Streams in the eastern portion of Wilderness and the southern region of Chancellorsville (south of Route 3) serve as a headwater source for the Ni and Po Rivers (York River system). The Ni River begins its path to the bay at the confluence of Brock and Lewis Runs which are the dominant water features of Chancellorsville and eastern Wilderness. The Ni River serves as a public water supply for Spotsylvania County at the Ni River Reservoir. The reservoir is located downstream from Chancellorsville and upstream of Spotsylvania Courthouse and is the second largest contributor to the public water system for the county following the Rappahannock River. Water from Spotsylvania drains south-east into the York River system through two separate pathways. The majority of the water flows through second to third order streams into the Ni River while the water from the south-west section of Spotsylvania drains into the Po River. All of the waters within the Fredericksburg unit drain into the Rappahannock River. A vast majority of this water is conveyed through Hazel and Deep Runs.



Fredericksburg & Spotsylvania National Military Park - Watershed

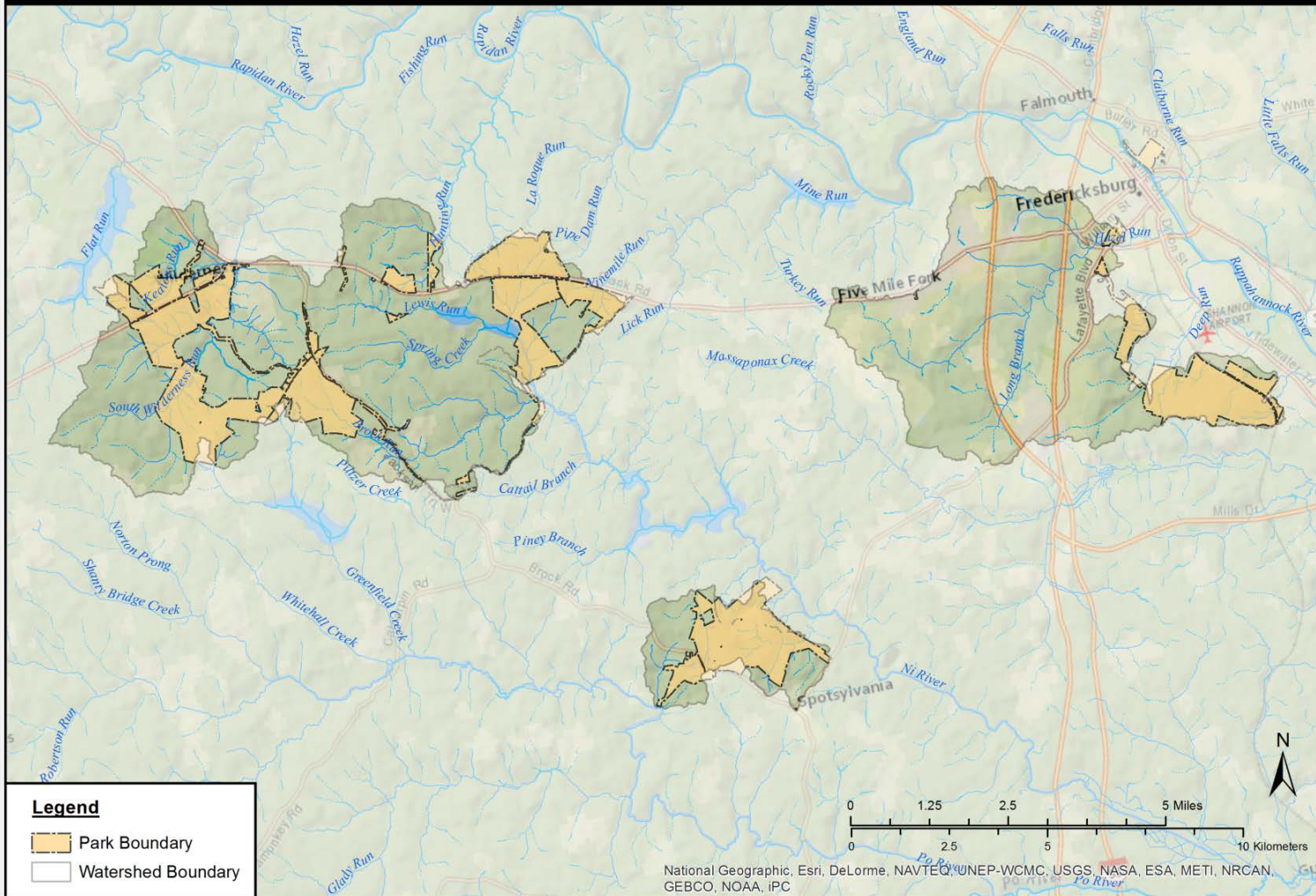


Figure A-17. Map displaying the streams and contributing watersheds of FRSP.

Table A-13. Strahler stream order classification by length (km) within the contributing watershed of FRSP streams.

Stream Order	Intermittent	Perennial	All Streams (Within Park)	% Perennial
1	93.6	55.6	149.2 (77.8)	37
2	11.9	54.5	66.4 (36.5)	82
3	1.1	24.5	25.6 (12.4)	96
4	0.0	5.8	5.8 (5.6)	100
Total	106.6	140.5	247.0 (132.3)	
% Headwater	100	96	98 (96)	

Over 40 species of fish have been documented in FRSP streams, one of the most diverse populations within the MIDN. This diversity is attributed to the availability of small to medium sized streams found across a larger area (Atkinson 2008). Seasonal sampling of these streams (spring/fall) found additional species revealing a shift in species composition with respect to seasonal conditions (e.g., water temperature, spawning, etc.). Thirty-eight species of aquatic macroinvertebrates have been found within a single stream (MIDN data) and 22 species of amphibians have been documented throughout FRSP (Mitchell 2007a). Additionally, state-listed rare or sensitive mollusks have been found within the region and might be present in NPS streams. In a rapidly urbanizing landscape, these streams and associated lands are significant regional resources as a result of the protection of the landscape provided by the National Park Service.

During the 2012 surface water assessment cycle the Commonwealth of Virginia found that 16% of stream lengths across the state did not meet water quality standards, 78% were not assessed, and 6% were not impaired (Table A-14) (VADEQ 2014). Although streams within FRSP had approximately the same proportion listed as impaired compared to statewide numbers (Figure A-18), the proportion of streams fully supporting designated uses was three times greater (33%) and the unassessed proportion was substantially less (40%; VADEQ 2014). E. coli contamination impairing recreational activities was found in Wilderness Run, Brock Run and Hazel Run. Aquatic life use impairments due to low dissolved oxygen or pH were found in Deep Run, Brock Run, as well as Lewis Run and one of its unnamed tributaries. As a result of benthic macroinvertebrate bioassessments, an aquatic life use impairment has been revealed in Hazel Run. Additionally, a fish consumption advisory has been issued for Hazel Run based on elevated levels of PCB's found in fish tissue samples.

Two leading water quality concerns have emerged from the available data collected in and around FRSP: stream acidification and hypoxia. Until recently, water quality data within FRSP has been sparingly and inconsistently collected. A richer historical data set is available by reaching outside of NPS boundaries, unfortunately much of this data concerns larger, distant rivers resulting in an inability to infer conditions in FRSP streams. However, the data can reveal some general water quality concerns at the regional scale. At little over nine percent (n = 119) of acid neutralizing capacity observations in FRSP streams fell below the NPS Air Resources Division's threshold of 100

µeq/L (Fenn et al. 2011) indicating a significant risk due to acid deposition. pH was outside of State water quality criteria in 11.3% (n = 595) of observations. In both cases the bulk of the pH and ANC exceedances were skewed towards smaller streams with all pH observations below 6 units and approximately 75% of poor ANC observations found in first or second order streams. During baseflow conditions (July – mid-Oct.; Figure A-19), 14.9% (n = 208) of dissolved oxygen observations were outside of State criteria distributed across stream size classes (Figure A-20). During this period of the hydrologic year stream temperature reaches its maximum and discharge reaches its minimum making the stream more susceptible to hypoxia. Stream water temperature was highest during baseflow periods (late summer) and reached the minimum values during the rising limb. Specific conductance was consistent across hydrologic seasons although several peak values were observed during the rising limb likely a result of winter application of road salts. Benthic macroinvertebrate data indicates impaired conditions across FRSP streams with all biotic index scores (Stream Condition Index; Burton and Gerritsen 2003) at or below the threshold for healthy conditions for streams in the Piedmont physiographic zone (n = 18).

Table A-14. Regulatory standards for baseline water quality parameters (temperature, pH, and dissolved oxygen) in the state of Virginia and EPA recommended guidance.

Regulatory Parameter	Beneficial Use	EPA National Recommended Water Quality Criteria (2012)	State of Virginia Standard - 9VAC25-260-50 (2011)
Temperature (°C)	Warm-water fishes	Species specific criteria	32°C Max Temp - Non-tidal Waters (Coastal and Piedmont Zones)
pH	Aquatic Life	6.5 - 9	6-9
Dissolved Oxygen (mg/l)	Aquatic Life	Warm water Min. Criteria - early life stages = 5.0, other life stages = 3.0, invertebrate min. criteria = 4.0	Min. = 4, Daily Avg = 5

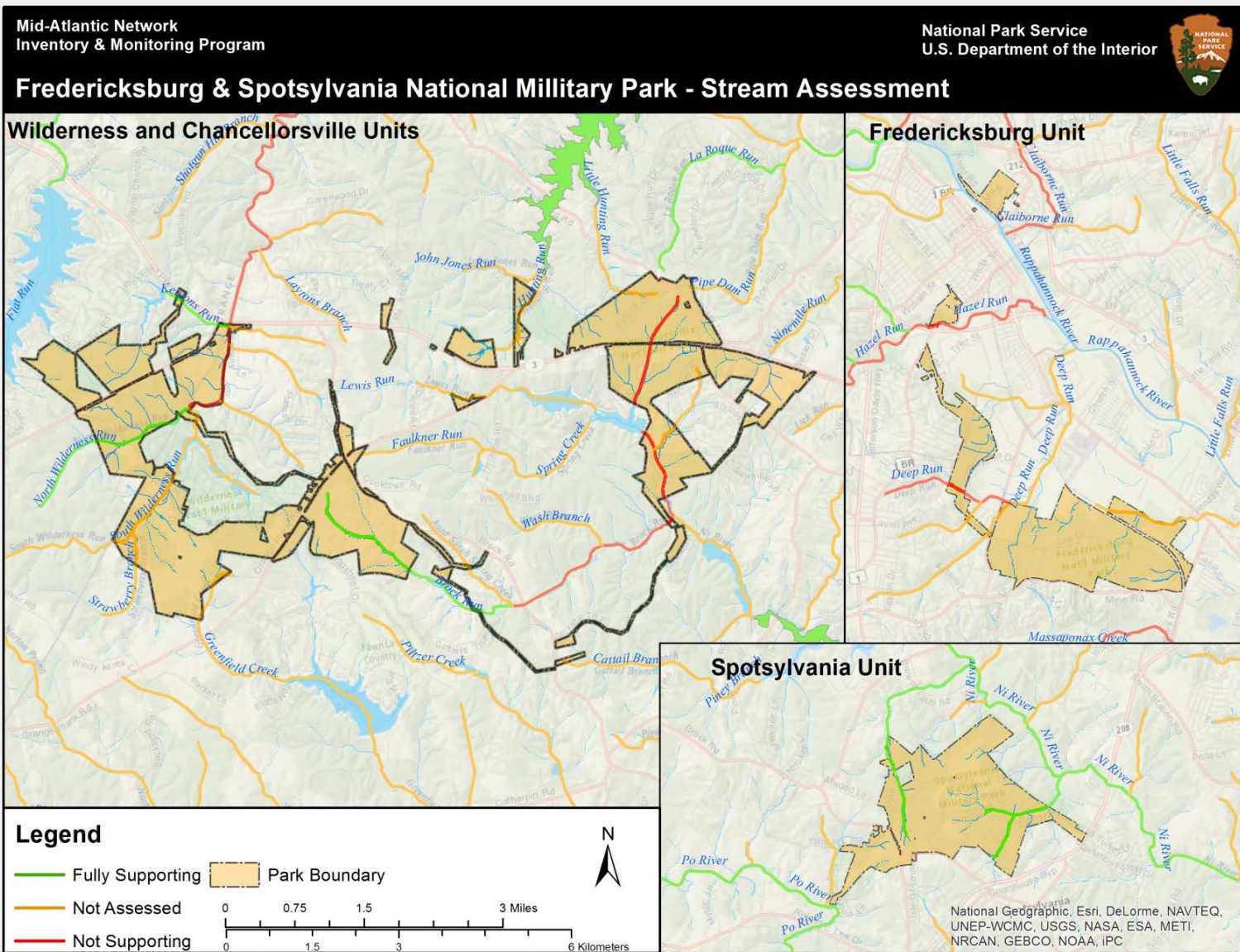


Figure A-18. Map displaying the attainment status of FRSP streams from the VA DEQ 2012 305(b)/303(d) biannual water quality assessment.

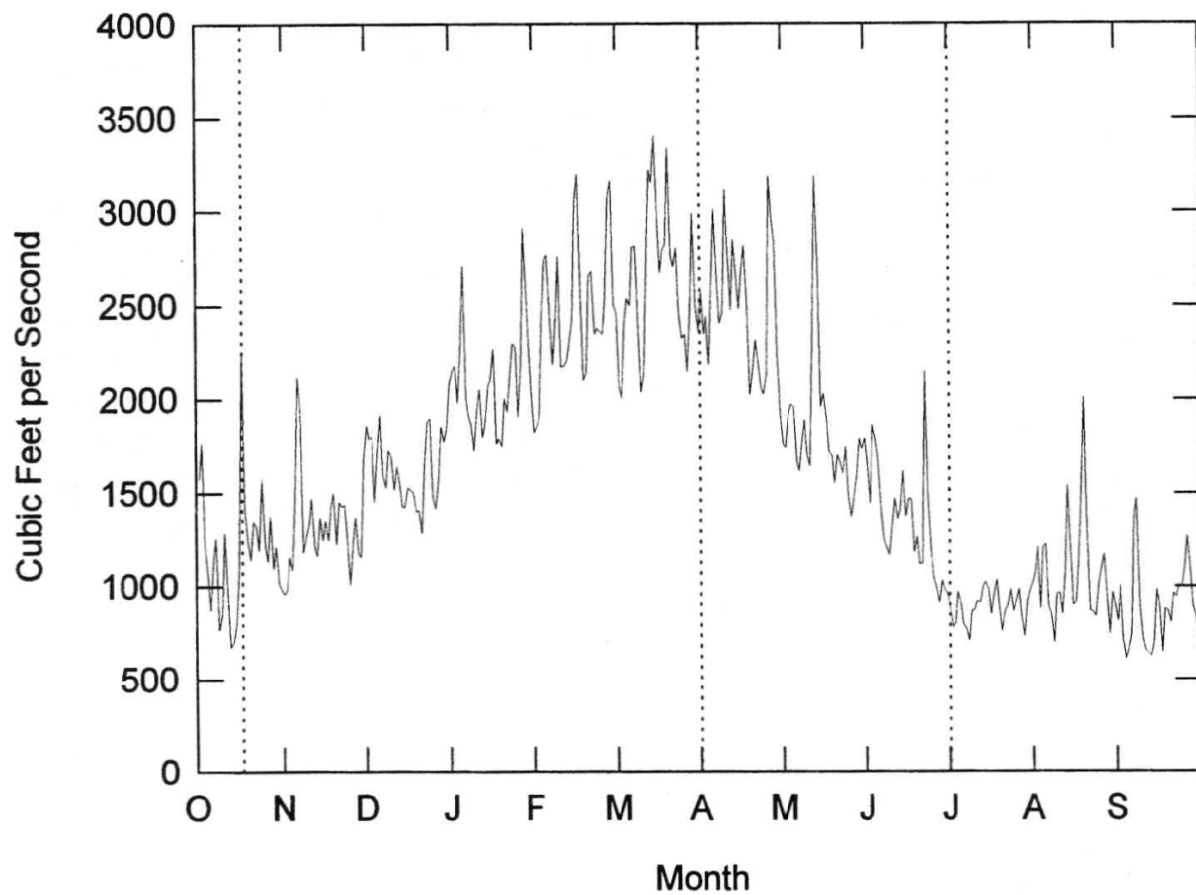


Figure A-19. Representative mean annual hydrograph used to conduct hydrologic seasonal analysis (Rappahannock River: 38° 18' 30" N, 77° 31' 46" W). Adapted from "Baseline water Quality Data: FRSP" by NPS, 2000. P. 47. Reprinted with permission.

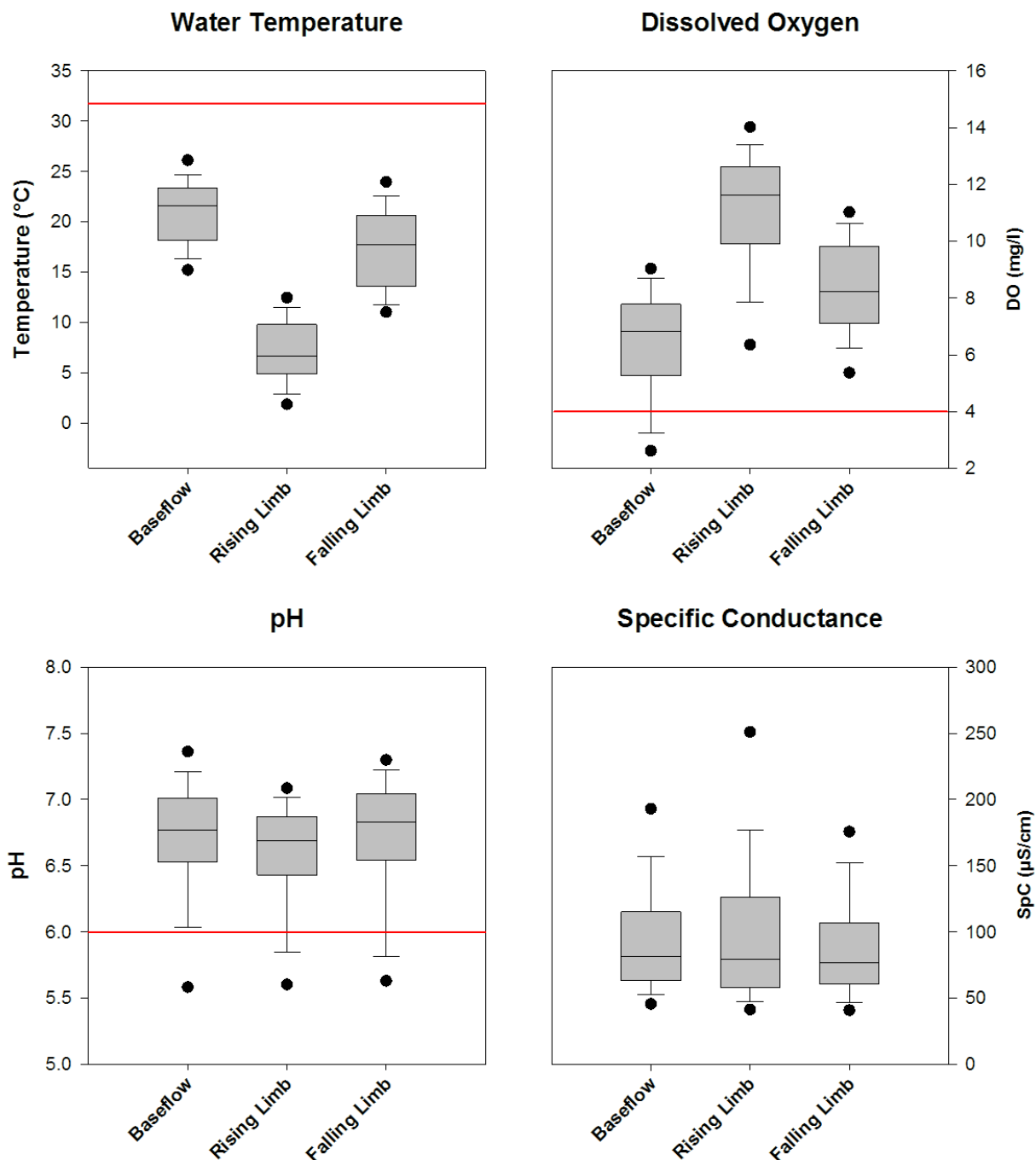


Figure A-20. Box plots (box: median, interquartile range; whiskers: 10th and 90th percentile; points: 5th and 95th percentile) for “core” water quality parameters measured during pilot study and grouped by hydrologic season at FRSP (2010–2013). Red lines indicate water quality thresholds established by the Commonwealth of Virginia.

2.3.5 Long-term Monitoring Sites

In an effort to monitor the status and trends of wadeable streams at FRSP several long-term monitoring sites have been selected. Sites were placed in streams of significant value to parks as determined by FRSP and MIDN staff (Table A-15, Figure A-21). Stream reaches of particular

importance to park management were identified from within these established sites for enhanced monitoring by integrating other MIDN protocols (BMI monitoring) and continuous monitoring of water quality parameters. Additionally, a summary of land cover classes is provided for the watershed at resources and highly susceptible to flash floods and biological degradation due to the large amount of impervious surface in the watershed.

FRSP_09: tributary to Ni River

FRSP_09 drains a large portion of the southwest section of the Spotsylvania unit of FRSP. The watershed is almost entirely within the park boundaries and is primarily forested with a small proportion of agriculture in the upland areas of the drainage.

FRSP_10: North Branch of each long-term site (Table A-16).

FRSP_01: Lewis Run

FRSP_01 is located immediately downstream from the impoundment that forms Cool Springs Lake (HUC: 02080105001454). Lewis Run is the dominant perennial water body in the Chancellorsville unit of FRSP. This stream segment is listed as impaired by the Virginia DEQ for E. coli contamination and a TMDL is under development for the watershed. Alterations to discharge and water quality from the impoundment are major concerns for this waterbody.

FRSP_02: Tributary to Lewis Run

FRSP_02 is a tributary to Lewis Run at Cool Springs Lake and primarily drains park owned lands in the northern section of the Chancellorsville unit of FRSP. This watershed is primarily forested, however, a portion of the watershed within the park is kept in agriculture to maintain an open viewshed for the cultural landscape. Additionally, the watershed is bisected by a primary highway which, along with several smaller roads, adds impervious cover to the watershed.

FRSP_03: Lewis Run

FRSP_03 is located near the downstream boundary of the Chancellorsville unit above a major tributary (Brock Run). This site is located in a woody wetland complex. The watershed has several impoundments and primarily a mix of forested and developed land cover classes.

FRSP_04: Lower Brock Run

FRSP_04 is located above the confluence of Brock Run with Lewis Run near the boundary of the Chancellorsville unit. This site is downstream of FRSP_17 and land cover within the watershed shifts from almost entirely forested at the upper site (FRSP_17) to mixed use (shifts towards urbanization and agriculture) at the downstream site (FRSP_04). A majority of the land in this watershed is located outside of park boundaries.

FRSP_06: Deep Run

FRSP_06 is located in the Fredericksburg unit of FRSP and is the only perennial stream in the main unit of Fredericksburg. This stream drains mostly outside of the park boundaries in a suburban area. There is no agriculture within the watershed as it is a mix between urban development and forested lands.

FRSP_08: Hazel Run

FRSP_08 is located adjacent to Fredericksburg National Cemetery and drains a highly urbanized watershed with over 65% of the area in the developed land cover class. This is one of the largest Wadeable streams found across FRSP.

FRSP_10 drains much of the center of the Spotsylvania unit of FRSP. The park maintains approximately 20% of the land as an open viewshed through a variety of land management practices such as mowing, leasing to agricultural interests, and prescribed fire. Several smaller park roads cross the watershed. Beaver activity has been advancing upstream from the downstream park boundary in this watershed creating open wetland meadows after dam abandonment.

FRSP_11: South Branch of Burnside Creek

FRSP_11 drains the southeast section of the Spotsylvania unit with approximately 70% of the watershed within park boundaries. Much of the watershed outside (upstream) of the park boundary has been converted from forested or agricultural uses to suburban development.

FRSP_14: North Wilderness Run

FRSP_14 is located in the Wilderness unit and primarily drains a forested landscape outside of the park boundaries. There is little development or agriculture currently in the watershed which is reflected in the condition of physical habitat in this stream reach. FRSP_15 is located downstream from this site on the mainstem of Wilderness Run and has a much higher proportion of urban development and agriculture within the watershed, which is also reflected in degraded physical habitat within the stream.

FRSP_15: Wilderness Run

FRSP_15 is located at the downstream boundary of the Wilderness unit at Virginia highway route three. There is substantial portion of the watershed which has been converted to agricultural and developed land uses. Much of the downstream reach is dominated by agricultural uses including livestock grazing.

FRSP_16: Keatons Run

FRSP_16 is located above the confluence with Wilderness Run and drains a large suburban development to the west-north-west of the park and forested park property in the southwest of the Wilderness unit. Both of these segments flow into an impoundment located in the development upstream from FRSP_16.

FRSP_17: Brock Run

FRSP_17 has the highest proportion of forested land cover of any of the watersheds monitored in FRSP and is predominately located within park boundaries. There is a large suburban development located on the southern edge of this watershed which has been developed as a residential area. This stream typically maintains flow year round, however in dry years surface flows can be interrupted.

FRSP_18: Burnside Creek

FRSP_18 is located in the northeast of the Spotsylvania unit near the downstream boundary of the park. This site is downstream of both FRSP_10 and FRSP_11 which drains much of the eastern portion of Spotsylvania. In addition this drainage captures a substantial area of both agricultural and urbanized areas to the south of NPS property.

FRSP_19: Lewis Run

FRSP_19 is located upstream of two major impoundments (HUCs: 02080105001453 and 02080105001454) on Lewis Run above the Chancellorsville unit of FRSP. This site allows for a comparison of the conditions found in the stream above and below the lentic waters and the associated development on Lewis Run.

Table A-15. List of long-term monitoring sites at FRSP.

Site ID	Stream Name	USGS HUC-14	Latitude	Longitude	Type of Site D,BMI, Con)*
FRSP_01	Lewis Run	02080105000217	38.29559	-77.64842	D, BMI
FRSP_02	tributary to Lewis Run	02080105000800	38.30171	-77.64934	D
FRSP_03	Lewis Run	02080105000216	38.28919	-77.64619	D
FRSP_04	Lower Brock Run	02080105000370	38.28189	-77.6469	D
FRSP_06	Deep Run	02080104000796	38.26545	-77.4744	D
FRSP_08	Hazel Run	02080104000321	38.29135	-77.4704	D, BMI
FRSP_09	tributary to Ni River	02080105000805	38.2234	-77.61086	D
FRSP_10	North Branch Burnside Creek	02080105000807	38.21676	-77.59143	D
FRSP_11	South Branch Burnside Creek	02080105001995	38.21504	-77.59084	D
FRSP_14	North Wilderness Run	02080103000736	38.31017	-77.75092	D, BMI, Con
FRSP_15	Wilderness Run	02080103008906	38.32463	-77.72655	D, BMI
FRSP_16	tributary to Wilderness Run	02080103000726	38.32522	-77.72694	D
FRSP_17	Brock Run	02080105007455	38.28349	-77.70177	D, BMI
FRSP_18	Burnside Creek	02080105000807	38.21617	-77.58217	D, BMI
FRSP_19	Lewis Run	02080105000799	38.30652	-77.68146	D, BMI

* D = Discrete Water Quality, BMI = Benthic Macroinvertebrate, Con = Continuous Water Quality Monitoring

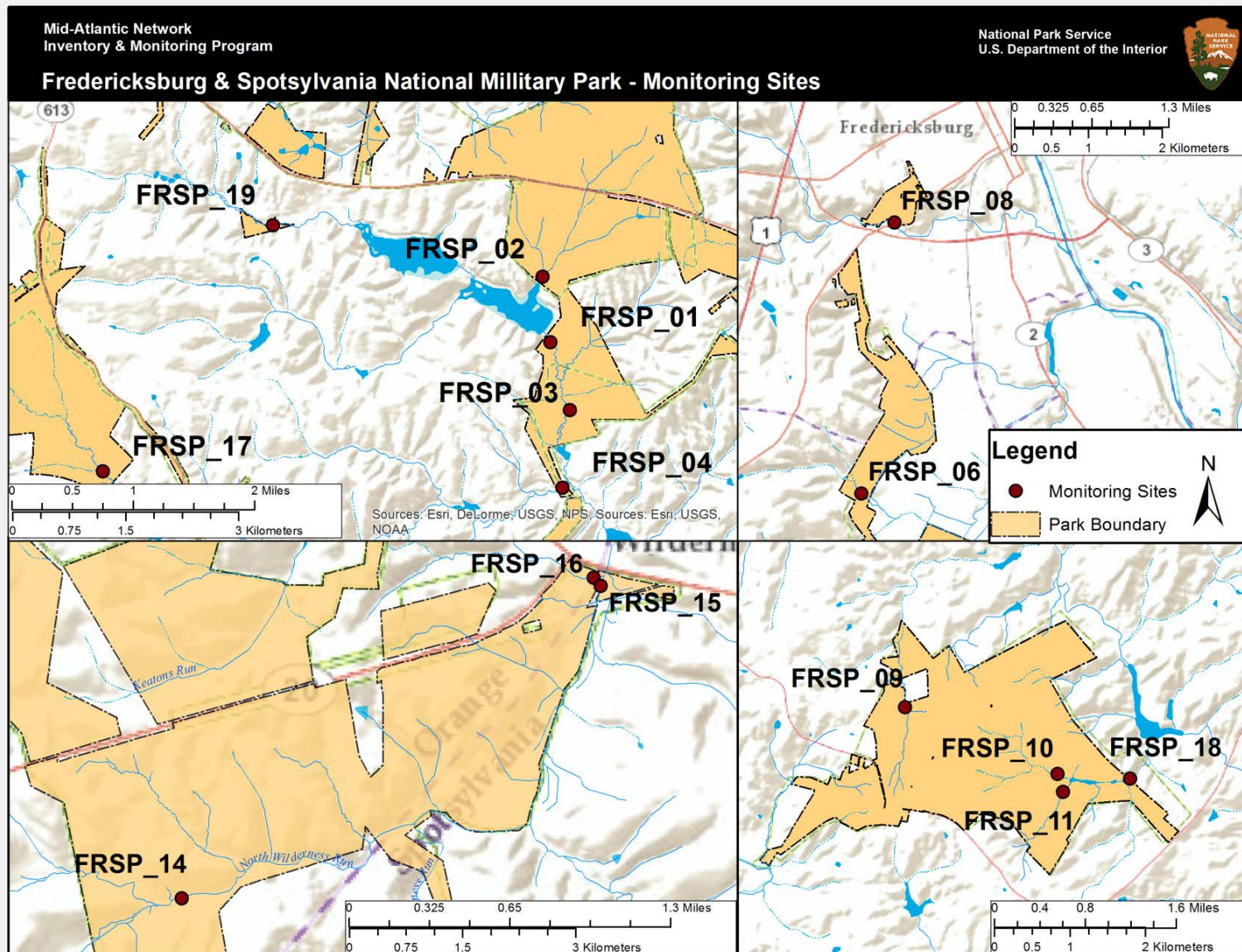


Figure A-21. Location of long-term monitoring sites at FRSP.

Table A-16. Land cover (%) of the major land-use classifications from the NLCD (Homer et al. 2015) for the watershed and riparian areas (100 meter buffer) associated with each site selected for long-term monitoring.

Site ID	Watershed			100-meter Buffer		
	Forest	Agriculture	Developed*	Forest	Agriculture	Developed*
FRSP_01	62.2	5.2	15.1 (0.3)	57.0	4.7	9.4 (0.1)
FRSP_02	72.4	7.9	15.7 (<0.1)	72.6	9.4	14.1 (<0.1)
FRSP_03	62.2	4.5	16.1 (0.3)	57.6	4	17.4 (<0.1)
FRSP_04	70.2	11	9.1 (0.1)	68.3	7.4	5.6 (-)
FRSP_06	32.3	-	60.7 (14.4)	52.6	-	40.7 (8.8)
FRSP_08	20.2	5.4	67.8 (21.7)	32.4	4.1	48.8 (12.2)
FRSP_09	80	7.3	4.6 (-)	63.7	9.2	3.5 (-)
FRSP_10	64.3	20.9	10.7 (-)	68	20.9	5.9 (-)
FRSP_11	77	2.1	20.5 (0.8)	70.6	3.9	25.6 (1.7)
FRSP_14	88.5	0.8	5.6 (0.2)	90.2	1.6	1.4 (-)
FRSP_15	59.4	18.1	10.9 (0.1)	59.5	20.6	7.9 (<0.1)
FRSP_16	66.5	2.2	24.2 (0.6)	72.1	1.5	15.7 (0.9)
FRSP_17	86.1	3	6.4 (-)	92.1	0.8	0.6 (-)
FRSP_18	77.2	11	9.4 (0.6)	67	15.2	11.5 (0.4)
FRSP_19	51.5	5.5	15.5 (0.2)	47.4	6.9	10.4 (0.2)

*Values in parenthesis are the proportion of developed total that is medium to high intensity

2.4 Gettysburg National Military Park and Eisenhower National Historic Site

2.4.1 Park Overview

Gettysburg National Military Park (GETT) and Eisenhower National Historic Site (EISE) are located in and around the small town of Gettysburg, Pennsylvania in Adams County, south central Pennsylvania (Figure A-22). GETT was the site of the largest and bloodiest Civil War battle in which over 51,000 soldiers were killed, wounded or captured. Approximately 1,400 monuments and memorials and 400 artillery pieces stand tribute along 64 km (40 miles) of avenues through the park. In contrast, EISE served as a weekend retreat and meeting place for world leaders during the administration of Dwight D. Eisenhower. Situated in the Piedmont province, these parks consist of gently rolling hills and valleys with elevations averaging between 152 to 177 m (500 to 580 feet) above sea level. The landscape is a mosaic of mature and maturing woodlands and woodlots, agricultural fields, pasturelands, open parkland, and streams.



Gettysburg NMP / Eisenhower NHS - Overview

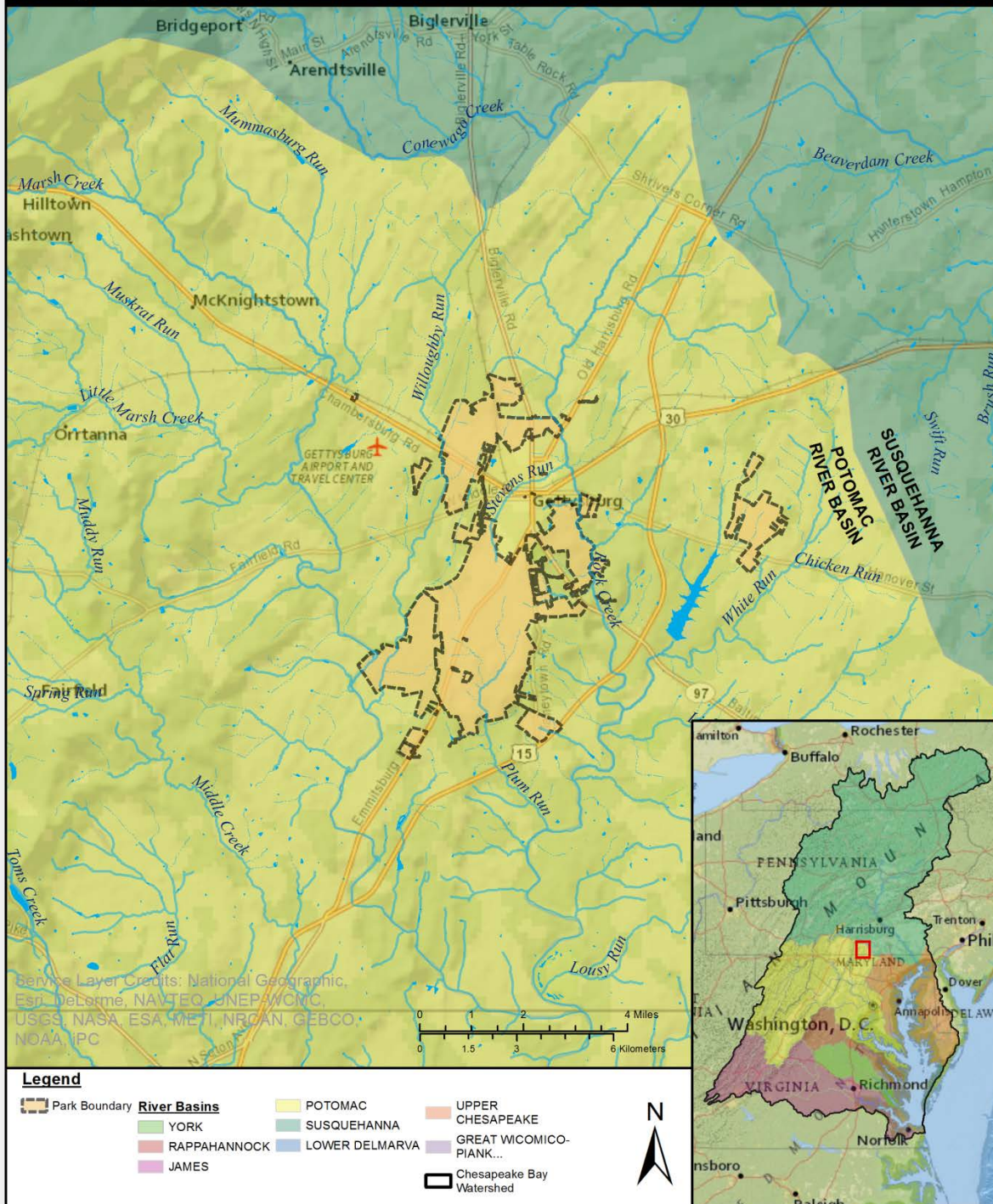


Figure A-22. Map displaying GETT/EISE highlighting the aquatic resources.

2.4.2 Landscape Setting

GETT/EISE is located at the north-eastern edge of the Potomac River basin within the Chesapeake Bay watershed (CBW). Approximately 180 million years ago during the late Triassic Period, the Gettysburg Formation (comprised of sandstones, siltstones, and shales) was deposited in a large carved out basin in the Gettysburg area. These lowlands were broken by hills and ridges that were formed as a result of a dense 600 m (2000 foot) thick slab of igneous rock (called the Gettysburg Sill) and two 15 m (50 foot) dikes being thrust into the Gettysburg Formation. One of these dikes underlies Seminary Ridge in a north to south orientation while the other parallels the ridge to the west. Sills are responsible for the topographically high areas of the Round Tops, Culps Hill, and Cemetery Ridge and Hill.

Soils were described and classified in 1967 by the Soil Conservation Service (now called the Natural Resource Conservation Service). There are four major soil associations found in GETT/EISE: 1) Penn-Reddington-Croton association, 2) Klinesville-Penn-Abbotstown- Croton association, 3) Lehigh-Brecknock association, and 4) Montalto-Mount Lucas-Watchung association (NPS 1999b). Within the region, these landforms support a wide variety of land cover which include agriculture (croplands and pasture/hay), urban development, and forests (Comiskey and Callahan 2008).

2.4.3 Land Cover and Vegetation

Within the boundaries of GETT/EISE the primary land cover class is agriculture (56.8%), followed by forest and developed land (17.6% each) (Figure A-23, Table A-17). This is more agricultural land than is found in the contributing watersheds of GETT/EISE (49.7%); and substantially more than across the entire CBW (24.6%). The watersheds that support GETT/EISE streams have less forested land (28.3%) than the CBW (54.7%) and are similar in the amount of development (14.5%) as the CBW (11.0%). A vast majority of the forested land within the watershed is associated with South Mountain to the west of GETT and is only associated with one of the streams which crosses GETT/EISE. The remainder of the streams associated with GETT/EISE are dominated by agriculture and urban development. These characteristics are integral to understanding stream conditions at GETT/EISE. Forested watersheds and buffers around streams have the ability to improve stream conditions by removing nutrients, controlling sediments, ameliorating temperature increases, and protecting physical habitat (Lowrance and Altier 1997, Jacobson 2001, Kaushal and Likens 2010) while agriculture and urban development are correlated with degradations in water quality.

Vegetation classification and mapping was conducted at GETT/EISE using 2003 aerial photography and 2004 field sampling (Perles et al. 2006). The report found that ongoing management to maintain the historic and cultural landscape has equal if not greater influence on the vegetation than the environmental setting with over 53% of the parks' area actively maintained as agricultural fields (most common), pasture or orchard (Perles et al. 2006). The rotational planting of grasses in the Agricultural Field areas in conjunction with the Successional Old Field, inactive Pasture, Wet Meadow (wetland), and Reed Canary Grass Riverine Grassland (wetland) areas create large expanses of grassland that are becoming increasingly rare in Pennsylvania due to land conversion for development and reforestation.



Gettysburg NMP / Eisenhower NHS - Landuse

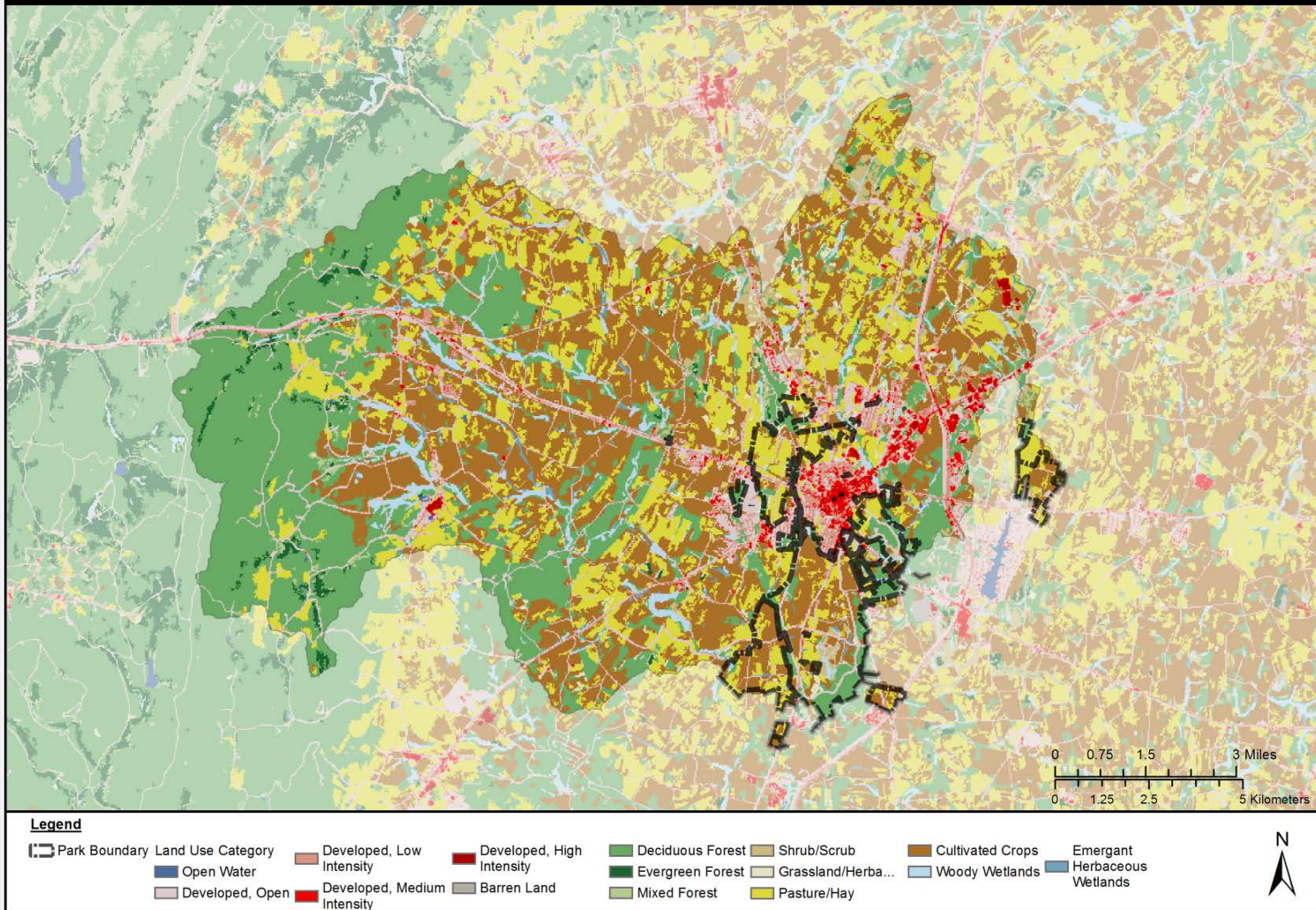


Figure A-2. Map displaying the National Land cover Dataset classes for the contributing watersheds to the streams of GETT/EISE.

Table A-17. Land cover classification (Homer et al. 2015) of watersheds and riparian areas (100 meter buffer) associated with GETT/EISE, within GETT/EISE, and the CBW.

Land Cover Type	Watershed		100 Meter Buffer		Park		Chesapeake Bay Watershed	
	%	Area (km ²)	%	Area (km ²)	%	Area (km ²)	%	Area (km ²)
Forest Total	28.3	66.97	25.2	18.62	17.6	3.59	54.7	91329
Deciduous Forest	26.9	63.59	23.1	17.07	17.1	3.48	42.8	71401
Evergreen Forest	0.9	2.11	1.4	1.03	0.2	0.03	5.8	9716
Mixed Forest	0.5	1.26	0.7	0.52	0.4	0.08	6.1	10212
Agriculture Total	49.7	117.62	45.6	33.74	56.8	11.56	24.6	40996
Pasture/Hay	19.0	44.91	14.2	10.50	23.0	4.68	14.9	24913
Cultivated Crops	30.7	72.72	31.4	23.24	33.8	6.88	9.6	16083
Developed Total	14.6	34.53	14.5	10.69	17.6	3.59	11.0	18432
Developed, Open Space	8.7	20.54	9.4	6.95	14.2	2.89	6.6	10992
Developed, Low Intensity	4.2	9.97	3.8	2.83	3.1	0.63	2.8	4696
Developed, Medium Intensity	1.3	3.20	1.0	0.74	0.3	0.05	1.2	2005
Developed, High Intensity	0.3	0.82	0.2	0.16	<0.1	0.01	0.4	739
Grassland/Herbaceous	1.3	3.18	1.6	1.15	2.3	0.47	0.8	1335
Scrub/Shrub	2.4	5.70	2.5	1.88	2.7	0.55	2.2	3709
Open Water	0.1	0.14	0.1	0.10	-	-	1.8	2950
Barren Land	0.1	0.20	0.1	0.09	0.2	0.05	0.3	489
Woody Wetlands	3.0	7.02	8.7	6.44	1.9	0.38	3.7	6244
Emergent Herbaceous Wetlands	0.6	1.45	1.7	1.26	0.8	0.16	0.9	1471
Total	100.0	236.80	100.0	73.96	100.0	20.34	100.0	166957

2.4.2 Landscape Setting

GETT/EISE is located at the north-eastern edge of the Potomac River basin within the Chesapeake Bay watershed (CBW). Approximately 180 million years ago during the late Triassic Period, the Gettysburg Formation (comprised of sandstones, siltstones, and shales) was deposited in a large carved out basin in the Gettysburg area. These lowlands were broken by hills and ridges that were formed as a result of a dense 600 m (2000 foot) thick slab of igneous rock (called the Gettysburg Sill) and two 15 m (50 foot) dikes being thrust into the Gettysburg Formation. One of these dikes underlies Seminary Ridge in a north to south orientation while the other parallels the ridge to the west. Sills are responsible for the topographically high areas of the Round Tops, Culps Hill, and Cemetery Ridge and Hill.

Soils were described and classified in 1967 by the Soil Conservation Service (now called the Natural Resource Conservation Service). There are four major soil associations found in GETT/EISE: 1) Penn-Reddington-Croton association, 2) Klinesville-Penn-Abbotstown- Croton association, 3) Lehigh-Brecknock association, and 4) Montalto-Mount Lucas-Watchung association (NPS 1999b). Within the region, these landforms support a wide variety of land cover which include agriculture (croplands and pasture/hay), urban development, and forests (Comiskey and Callahan 2008).

2.4.4 Water Resources and Current Status of Water Quality

The National Park Service manages approximately 55.1 km of streams at GETT/EISE and the watersheds associated with these streams drain over 230 km² of the region (Table A-18, Figure A-24) (USGS 2014). These watersheds are located within the greater Chesapeake Bay watershed, home to the largest estuary in the United States which has been degraded over time primarily due to excess nutrient and sediment loads delivered from the upland watershed (Kemp and Boynton 2005). Perennial streams within GETT/EISE are predominately smaller, headwater reaches of the Potomac River (>80%) and range from first to fifth order (Table A-18). There are four principal streams in the GETT/EISE: Marsh Creek, Rock Creek, Willoughby Run, and Plum Run. Rock Creek drains the eastern side of GETT. Willoughby Run drains the western portion of GETT and EISE. Willoughby Run is also a tributary to Marsh Creek that briefly crosses the southwestern corner of EISE. Plum Run drains the middle/central portion of GETT and drains into Rock Creek to the south. Rock Creek and Marsh Creek join at the Maryland border to form the Monocacy River. There are two springs within GETT, both with historical significance. Katalysine Spring to the northwest which was in the area the battle began (first day). Sprangler's spring, located in the eastern portion of the park and was the site of battle on days 2 and 3. The watersheds for both Marsh Creek and Rock Creek are primarily located well outside of park boundaries and are important for municipal water supplies. The watershed for Plum Run is entirely held within the boundaries of GETT. Thirty-one species of fish have been documented in GETT/EISE streams, one of the most diverse populations within the MIDN. Marsh Creek and Willoughby Run had the highest fish densities found throughout the MIDN (Atkinson 2008). Reptile and amphibian sampling during 1999-2000 found five salamander species, nine frog and toad species, five turtle species, and five snake species within the park (Yahner et al. 2001). The northern leopard frog (*Rana pipiens*) was one of the species detected and was a new species record for GETT/EISE and Adams County. In a landscape dominated by agriculture and

urban development, the streams of GETT/EISE are significant regional resources as a result of the protection of the landscape provided by the National Park Service.

Table A-18. Strahler stream order classification by length (km) within the contributing watershed of GETT/EISE streams.

Stream Order	Intermittent	Perennial	All Streams (Within Park)	% Perennial
1	193.0	46.1	239.1 (33.8)	19
2	19.2	64.5	83.7 (6.0)	77
3	1.4	54.5	56.0 (7.6)	97
4	-	22.0	22.0 (5.5)	100
5	-	9.2	9.2 (2.3)	100
Total	213.6	196.5	410.1 (55.1)	
% Headwater	100	84	84	



Gettysburg NMP / Eisenhower NHS - Watershed

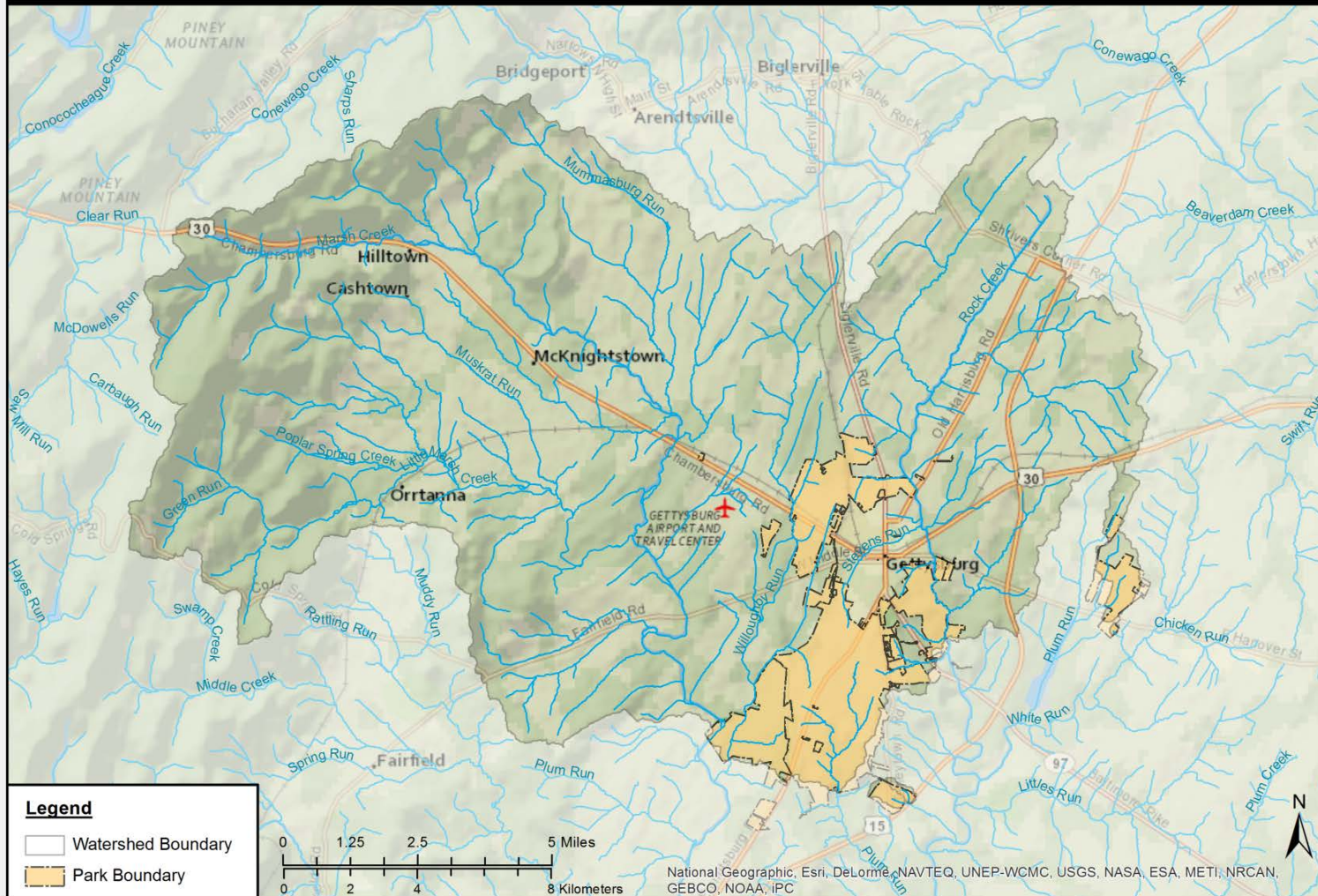


Figure A-24. Map displaying the steams and contributing watersheds of GETT/EISE.

During the 2012 surface water assessment cycle the Commonwealth of Pennsylvania found that approximately 20% of all stream lengths across the state did not meet water quality standards for the aquatic life use designation (Figure A-25, Table A-19) (PADEP 2014). Within the watersheds that drain to GETT/EISE streams and within GETT/EISE boundaries, approximately 17% and 27% of stream lengths were listed as impaired for aquatic life by the Commonwealth. Within GETT/EISE Willoughby Run along with Rock Creek and several of its tributaries are listed as impaired. These impairments are primarily related to nutrient enrichment due to agricultural activities as well as municipal inputs within Rock Creek. Willoughby Run is listed due to agricultural activities resulting in siltation, habitat alterations, and organic enrichment.

Until recently, water quality data within GETT/EISE has been inconsistently collected. A baseline water quality inquiry by the WRD of the NPS provided some historical data and established seasonal patterns in discharge within the region (NPS 1999a). This report defined three distinct hydrological seasons: rising limb (Nov. – mid Mar.), falling limb (mid Mar. – June), and base flow (July – Oct.; Figure A-26). More recently GETT/EISE and the MIDN have partnered to initiate a water quality pilot study as well as a benthic macroinvertebrate sampling program to assess stream conditions at GETT/EISE (Figure A-27). Preliminary benthic macroinvertebrate data (2009–2012) suggests that these streams are generally impaired with approximately 80% (n=16) falling below the aquatic life use standard established by the PADEP (PADEP 2012). Plum Run (mean: 49.1, S.D. 4.1) for this period was the only site where the stream was near what is considered to be healthy conditions regarding benthic macroinvertebrate biotic integrity scores (50; PADEP 2012). Water quality data collected during the pilot study confirmed findings suggested in the baseline water quality inquiry. The primary concerns for water quality are related to pH (alkaline) and dissolved oxygen (Willoughby Run and Rock Creek). Dissolved oxygen diel patterns likely swing to extreme values during the growing season as mid-day observations at Willoughby Run and Rock Creek are supersaturated. This suggests that dissolved oxygen levels drop precipitously by dawn as the plant community consumes oxygen through respiration during the nighttime hours. The nutrient impairment in these streams contributes to excess algal and plant communities. Additionally, pH observations at Willoughby Run and Rock Creek have had several observations above the aquatic life criteria for surface waters (Figure A-27). The pilot study data collected confirms that there are outstanding concerns regarding the streams associated with GETT/EISE.



Gettysburg NMP / Eisenhower NHS - Stream Assessment

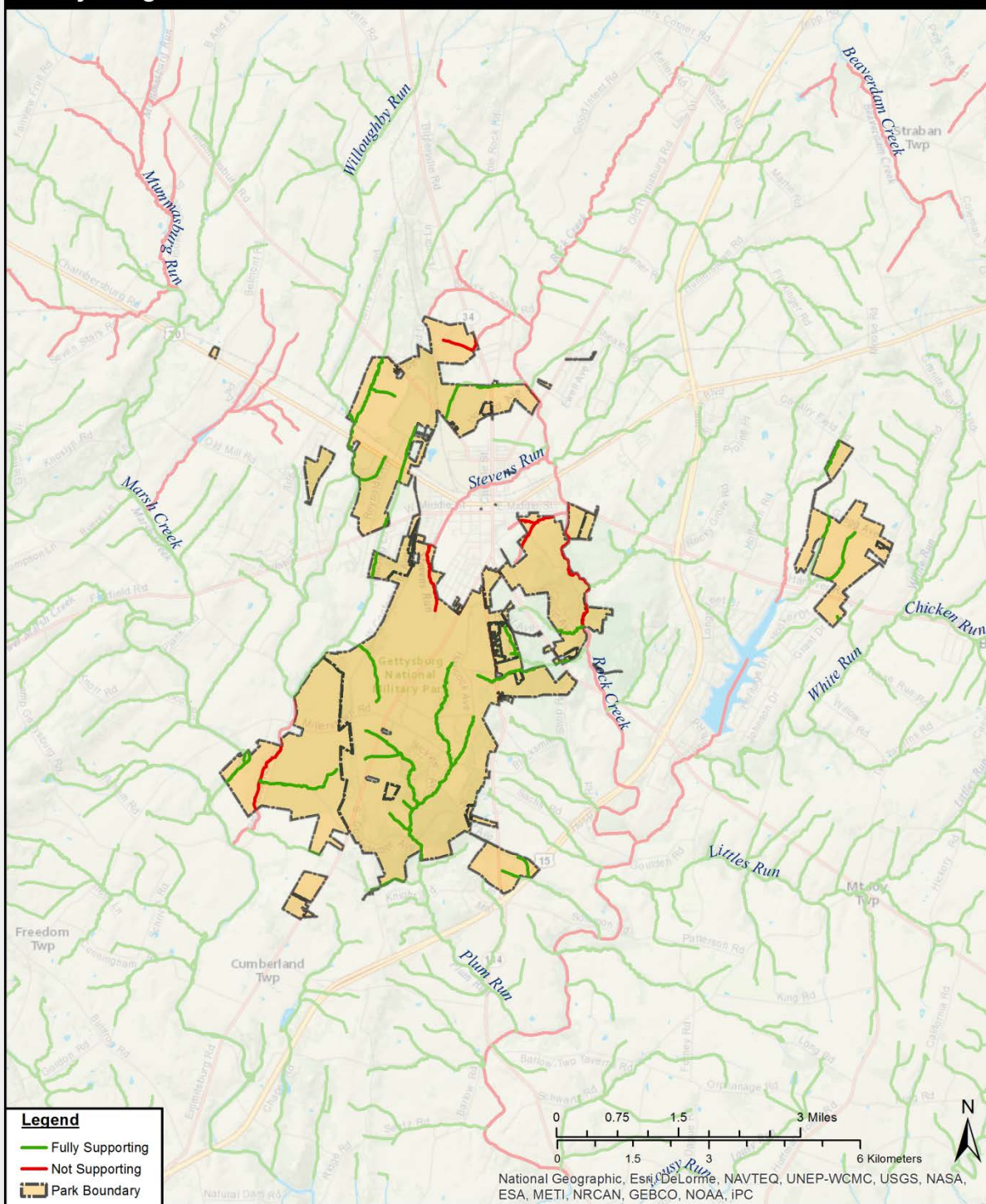


Figure A-25. Map displaying the attainment status of GETT/EISE streams from the PADEP 2012 305(b)/303(d) biannual water quality assessment.

Table A-19. Regulatory standards for baseline water quality parameters (temperature, pH, and dissolved oxygen) in the Commonwealth of Pennsylvania and EPA recommended guidance.

Regulatory Parameter	Beneficial Use	EPA National Recommended Water Quality Criteria (2012)	State of Pennsylvania Specific Water Quality Standards CH 93.7 (2009)
Temperature (°C)	Warm-water fishes	Species specific criteria	Varies by date, 87 °F max summer temp
	Cold Water Fishes	Species specific criteria	Varies by date, 66 °F max summer temp
pH	Drinking water	5 - 9	All uses = 6 - 9
	Aquatic Life	6.5 - 9	
Dissolved Oxygen (mg/l)	Warm Water fishes	Min. Criteria - early life stages = 5.0, other life stages = 3.0,	min. = 4.0, daily avg = 5.0
	Cold Water Fishes	Min. Criteria - early life stages = 5.0, other life stages = 4.0,	min. = 5.0, daily avg. = 6.0
	Invertebrate	Min. Criteria - 4.0	

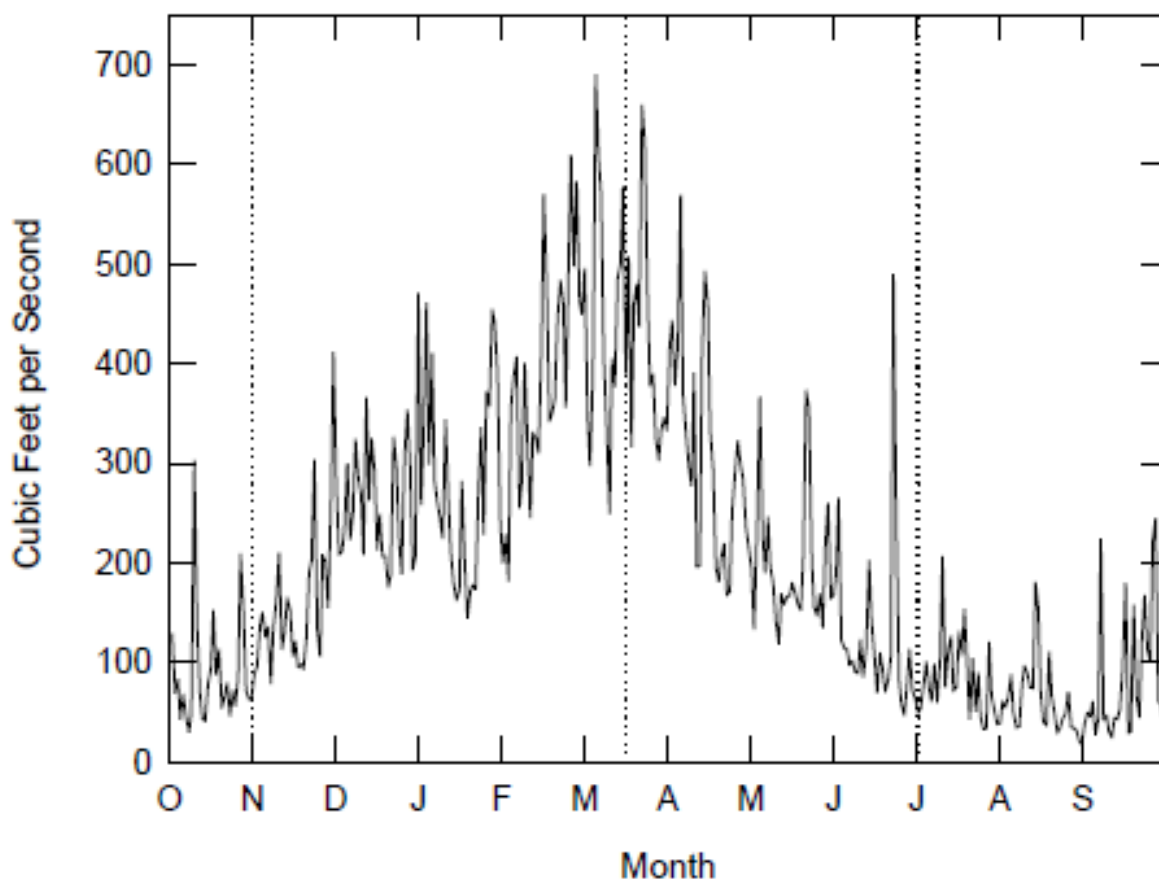


Figure A-26. Representative mean annual hydrograph used to conduct hydrologic seasonal analysis (Monocacy River: 39° 40' 43.8" N, 77° 14' 04.2" W). Adapted from "Baseline water Quality Data: GETT/EISE" by NPS, 1999. P. 42. Reprinted with permission.

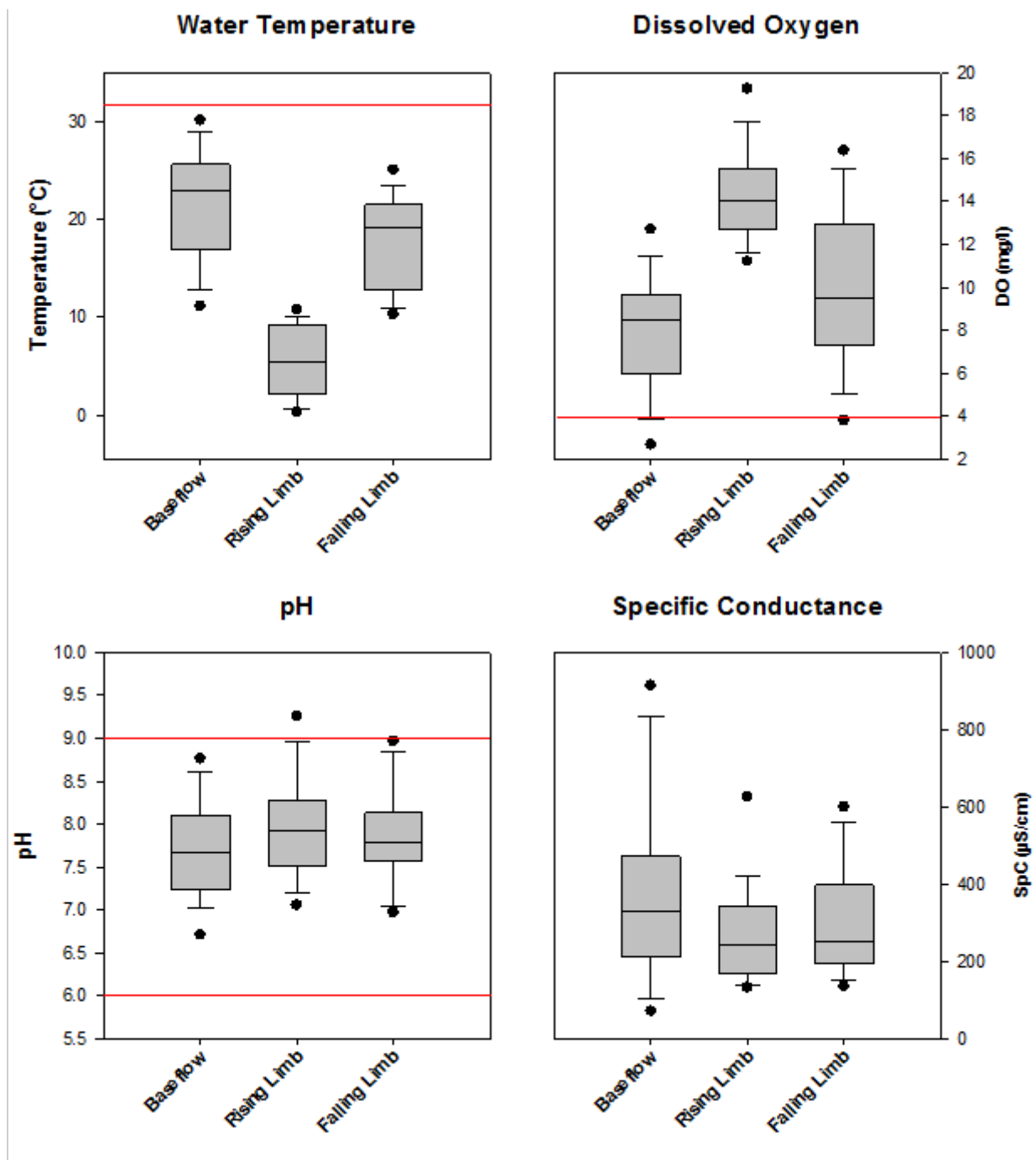


Figure A-27. Box plots (box: median, interquartile range; whiskers: 10th and 90th percentile; points: 5th and 95th percentile) for “core” water quality parameters measured during pilot study and grouped by hydrologic season at GETT/EISE (2010-2013). Red lines indicate water quality thresholds established by the Commonwealth of Pennsylvania.

2.4.5 Long-term Monitoring Sites

In an effort to monitor the status and trends of wadeable streams at GETT/EISE several long-term monitoring sites have been selected. Sites were placed in streams of significant value to the parks as determined by GETT/EISE and MIDN staff (Figure A-28, Table A-20). Stream reaches of particular importance to park management were identified from within these established sites for enhanced monitoring by integrating other MIDN protocols (BMI monitoring) and continuous monitoring of water quality parameters. Additionally, a summary of land cover classes is provided for the watershed at each long-term site (Table A-21).

GETT_01: Upper Willoughby Run:

GETT_01 is located in the northwest section of GETT where Willoughby Run enters GETT before the stream flows into EISE. At the sample site, the riparian zone is buffered by forest cover, however most of the watershed and riparian zone is influenced by agriculture and urban development. Substrate in this stream reach is primarily bedrock.

EISE_03: Marsh Creek

EISE_03 is located in the southwest corner of EISE where Marsh Creek exits the park. Marsh Creek has the largest watershed associated with GETT/EISE and drains lands up to the eastern slopes of South Mountain. The mountain slopes are primarily forested shifting to agriculture, which is the dominant land cover in the watershed, as the stream crosses the Piedmont. This stream is impounded prior to entering EISE near Pumping Station Road.

EISE_04: Lower Willoughby Run

EISE_04 is located at the downstream boundary of EISE in Willoughby Run. The stream in this reach is markedly different than the upper location. There is little to no forested cover along the riparian zone and the substrate shifts from exposed bedrock to fine grained sediments. This stream is listed by PADEP as impaired as a result of habitat alteration and nutrient enrichment.

GETT_06: Rock Creek

GETT_06 is located near the downstream boundary of GETT in the east section of the park. Rock Creek is the second largest water feature associated with GETT and serves as water discharge point for a municipal wastewater plant immediately upstream from the park. The watershed is primarily located up gradient from the park and is dominated by agricultural and urban land uses. This stream is listed as impaired by PADEP due to nutrient enrichment from urban and agricultural impacts.

GETT_07: Plum Run

GETT_07 is located near the downstream boundary of GETT in Plum Run. The watershed is entirely located within the boundaries of GETT and is in the best condition of all streams associated with GETT. The watershed is dominated by agricultural land use with a mix of row cropping and pasture. However, the riparian zone for 250 meters immediately upstream of this site is well buffered by

forest cover. Additionally, the watershed and the 100 meter buffer around the stream contain the largest proportion of wetlands of any of the streams associated with GETT/EISE.

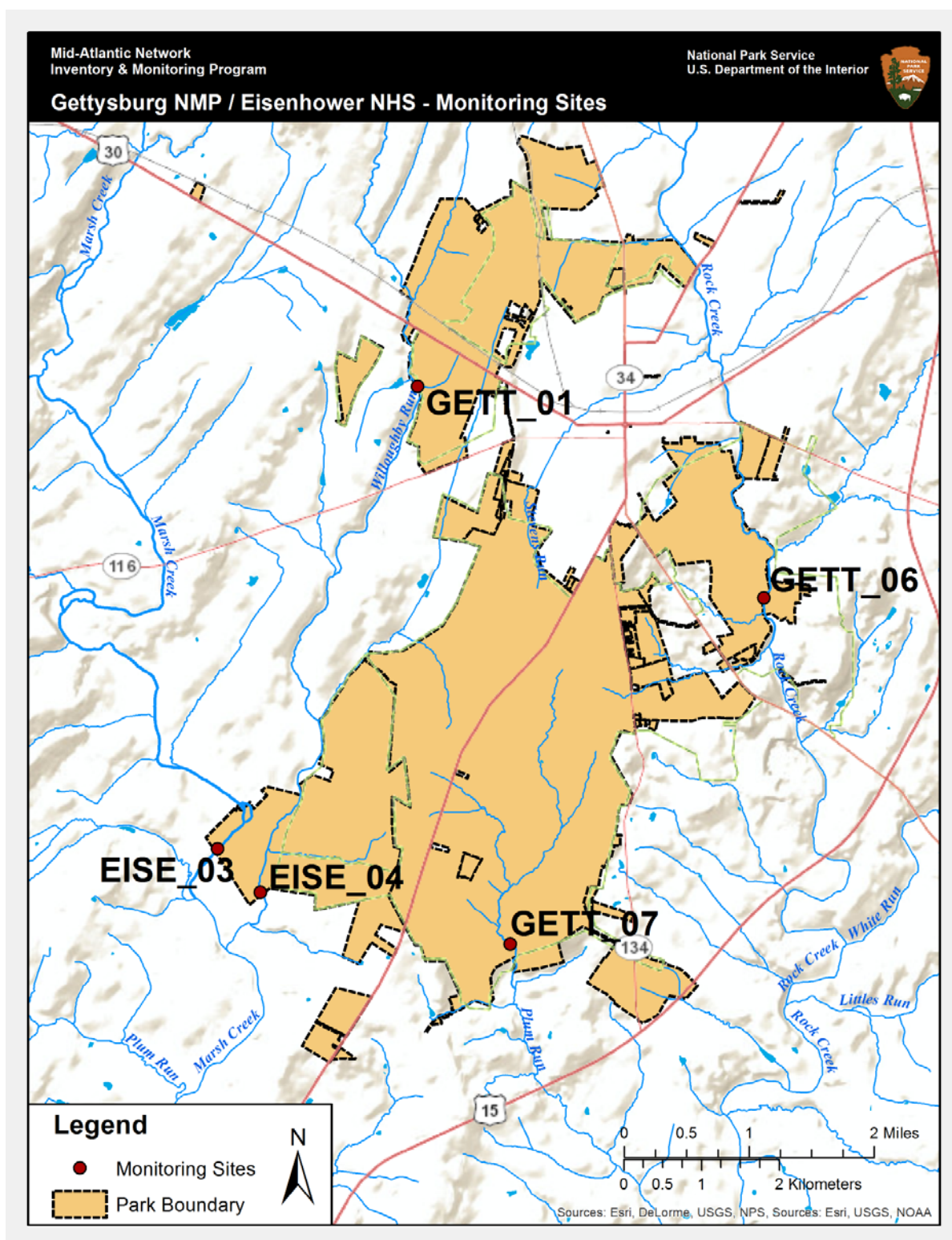


Figure A-28. Map of long-term monitoring sites at GETT/EISE.

Table A-20. List of long-term monitoring sites at GETT/EISE.

Site ID	Stream Name	USGS HUC-14	Latitude	Longitude	Type of Site (D,BMI, Con)*
GETT_01	Willoughby Run	02070009000819	39.83426	-77.25502	D, BMI
EISE_03	Marsh Creek	02070009000243	39.7929	-77.27814	D
EISE_04	Willoughby Run	02070009000816	39.7893	-77.27327	D, BMI
GETT_06	Rock Creek	02070009000232	39.81544	-77.21507	D, BMI
GETT_07	Plum Run	02070009000814	39.78465	-77.24446	D, BMI, Con

* D = Discrete Water Quality, BMI = Benthic Macroinvertebrate, Con = Continuous Water Quality Monitoring

Table A-21. Land cover (%) of the major land-use classifications from the NLCD (Homer et al. 2015) for the watershed and riparian areas (100 meter buffer) associated with each site selected for long-term monitoring.

Site ID	Watershed					100-meter Buffer				
	Forest	Wetlands	Agriculture	Developed*	Other	Forest	Wetlands	Agriculture	Developed*	Other
GETT_01	12.6	3.0	59.0	15.4 (0.5)	10.0	10.7	8.4	56.6	15.0 (0.3)	9.3
EISE_03	38.4	3.9	47.3	9.1 (0.3)	1.3	32.9	11.1	43.8	10.7 (0.3)	1.5
EISE_04	12.1	2.6	58.9	20.1 (1.2)	6.2	10.8	7.2	54.2	21.0 (0.6)	6.8
GETT_06	10.9	3.1	51.7	25.5 (5.6)	8.7	11.9	9.7	46.5	21.9 (4.0)	10.0
GETT_07	11.8	4.4	53.8	17.7 (0.1)	12.2	6.0	14.0	50.1	13.8 (0.1)	16.1
Within GETT/EISE	17.6	2.7	56.8	17.6 (0.3)	5.2	12.8	9.4	57.8	13.4 (<0.0)	6.7
All Watersheds	28.3	3.6	49.7	14.6 (1.7)	3.9	25.2	10.4	45.6	14.5 (1.2)	4.3

* Values in parenthesis are the proportion of developed total that is medium to high intensity

2.5 Hopewell Furnace National Historic Site

2.5.1 Park Overview

Hopewell Furnace National Historic Site (HOFU) is one of the finest examples of a rural American 19th century iron plantation, located in the Piedmont region of southeastern Pennsylvania (Figure A-29). HOFU was founded in 1771 by Ironmaster Mark Bird and operated until 1883. The site is significant primarily for its cultural resources, and consists of 14 restored structures in the core historic area and a total of 848 mostly wooded acres. Two-thirds of HOFU is bordered by French Creek State Park which preserves the lands the furnace utilized for its natural resources. HOFU, French Creek State Park, the Natural Lands Trust preserve, and State Game Lands #43 comprise a contiguous tract of over 9,000 acres that are part of the Hopewell Big Woods Project coordinated by the Natural Lands Trust.

2.5.2 Landscape Setting

Elevation within the park ranges from a high of over 280 m (920 feet) in the north to a low point of 140 m (460 feet) where French Creek exits the park. The low lying areas drained by French Creek and its tributary, Baptism Creek, are underlain by Cretaceous dolomite. To the south are crystalline, pre-Cambrian gabbro and gneiss, and a very resistant Cretaceous quartzite which provides the basis for the steep hills in the area. North of the park is underlain by Triassic conglomerate and shales (Bascom and Stose 1938). Soils within the park range from well-drained on the gabbro, to deep and poorly drained along the major creeks, to very stony on much of the northern conglomerate (Staff 1993). The watershed around HOFU remains relatively isolated due to its location next to French Creek State Park and within the Hopewell Big Woods conservation area. The Hopewell Big Woods partnership is a group of government agencies, private non-profits, and municipal entities seeking to conserve old growth and unbroken forest as well as the watersheds supported by the forest surrounding HOFU and French Creek State Park. French Creek, however, is impounded twice in its headwaters prior to entering HOFU within French Creek State Park. French Creek, the primary water feature at HOFU, has been designated as a stream of exceptional value by the Commonwealth of Pennsylvania. This designation provides additional protections for streams within the state due to the special value that they hold.

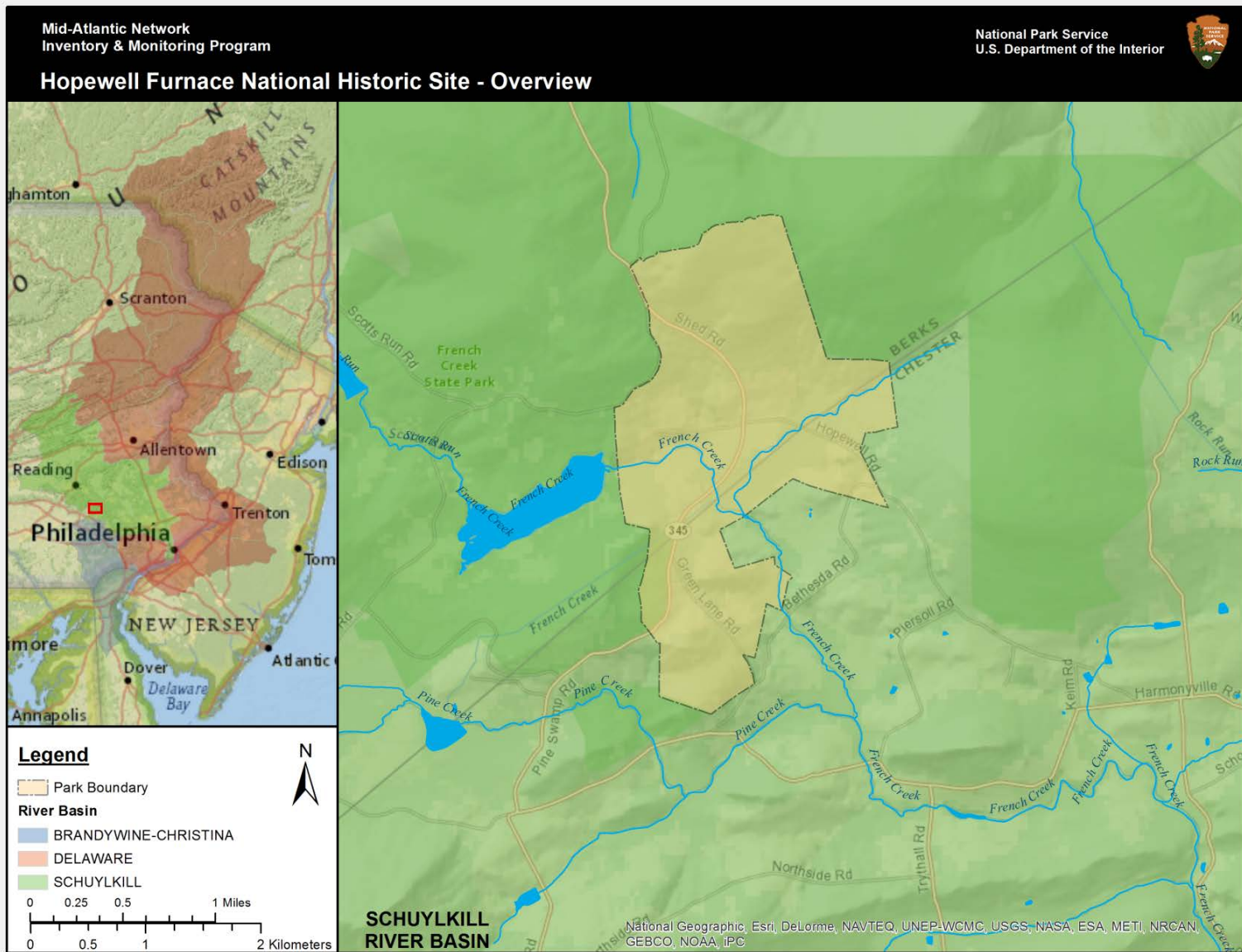


Figure A-29. Map displaying HOFU highlighting aquatic resources.

2.5.3 Land Cover and Vegetation

Within the boundaries of HOFU the primary land cover class is forest (69.9%), followed by agricultural (11.1%) and developed (11.0%; Table A-22; Figure A-30). The contributing watershed for HOFU is similar but has more land devoted to forest (78.3% forest; 5.8% agricultural, and 8.1% developed). The receiving waters for HOFU streams, Delaware Bay, has substantially less forest (45.6%) and nearly double the agriculture (19.7%) and development (20.4%) in the watershed as compared to the HOFU streams (Homer et al. 2015). Forested watersheds and buffers around streams have the ability to improve stream conditions by removing nutrients, controlling sediments, ameliorating temperature increases, and protecting physical habitat (Lowrance and Altier 1997, Jacobson 2001, Kaushal and Likens 2010).

The vegetation within HOFU was classified and mapped during 2002-2003 using extensive field reconnaissance and aerial photography. Twelve natural or semi-natural vegetation types were identified, which are closely linked to the underlying geology and human land use history (Podniesinski et al. 2005a). The park consists of 628 acres of mixed secondary deciduous forest, 135 acres of agricultural special use zones and 67 acres of developed or historic property. All the vegetation of the park was cleared during the time the iron furnace was active, though the area has been able to recover for most of the 20th century (Bowersox and Larrick 1999). The most common vegetation types were the Dry Oak–Heath and Dry Oak–Mixed Hardwood Forests which, combined, covered approximately 500 acres of the park (approximately 56% of park), followed by Tulip Poplar Forest, Modified Successional Forest, Eastern Red Cedar Woodland, Birch Rocky Slope Woodland and Modified Successional Woodland.

Podniesinski et al. (2005) found that wetlands comprise 10% of the park and consist of seasonally flooded forests and shrublands. The most common most common wetland type is the Red Maple–Mixed Hardwood Palustrine Forest (8.5%). The shrubland wetlands consist mainly of Highbush Blueberry–Meadowsweet Wetlands, as well as Mixed Shrub/Forest Wetlands and Buttonbush Wetlands.

Table A-22. Land cover classification (Homer et al. 2015) of watersheds and riparian areas (100 meter buffer) associated with HOFU, within HOFU, and the CBW.

Land Cover Type	Watershed		100 Meter Buffer		Park		Delaware Bay Watershed	
	%	Area (km ²)	%	Area (km ²)	%	Area (km ²)	%	Area (km ²)
Forest Total	78.3	10.61	53.7	0.77	69.9	2.39	45.6	15,267
Deciduous Forest	76.8	10.41	53.5	0.77	69.9	2.39	38.1	12,753
Evergreen Forest	1.0	0.14	0.3	<0.00	-	-	2.8	0,936
Mixed Forest	0.5	0.07	-	-	-	-	4.7	1,578
Agriculture Total	5.8	0.79	5.2	0.07	11.1	0.38	19.7	6,606
Pasture/Hay	4.5	0.60	3.8	0.05	10.2	0.35	9.3	3,115
Cultivated Crops	1.3	0.18	1.4	0.02	0.9	0.03	10.4	3,491
Developed Total	8.1	1.11	5.0	0.07	11.0	0.38	20.4	6,816
Developed, Open Space	7.8	1.06	4.9	0.07	10.9	0.37	10.9	3,637
Developed, Low Intensity	0.3	0.04	0.1	<0.01	0.2	0.01	5.4	1,811
Developed, Medium Intensity	<0.1	0.01	-	-	<0.1	<0.01	2.8	0,937
Developed, High Intensity	<0.1	<0.01	-	-	-	-	1.3	0,430
Grassland/Herbaceous	0.1	0.02	-	-	0.4	0.01	0.5	0,152
Scrub/Shrub	3.4	0.47	2.3	0.03	3.6	0.12	1.9	0,634
Open Water	2.4	0.33	18.1	0.26	-	-	2.6	0,874
Barren Land	-	-	-	-	-	-	0.4	0,127
Woody Wetlands	1.7	0.23	15.7	0.23	4.0	0.14	6.6	2,216
Emergent Herbaceous Wetlands	-	-	-	-	-	-	2.3	0,761
Total	100.0	13.55	100.0	1.43	100.0	3.43	100.0	33,453

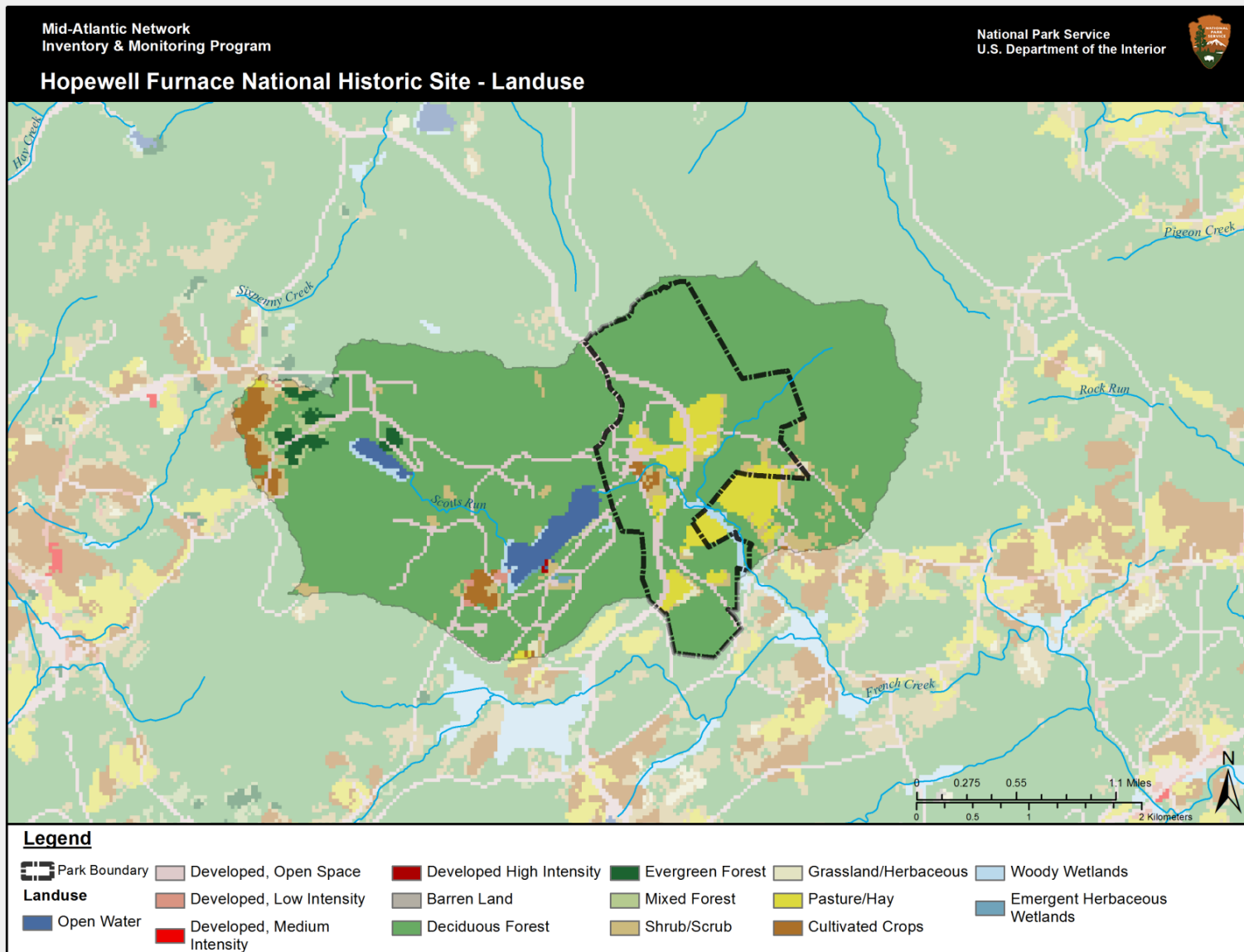


Figure A-30. Map displaying the National Land Cover Dataset classes for the contributing watersheds to the streams of HOFU.

2.5.4 Water Resources and Current Status of Water Quality

The National Park Service manages approximately 5.2 km of streams at HOFU which drain over 13 km² of the region (Table A-23, Figure A-31) (USGS 2014). HOFU's watersheds are located within the greater Delaware Bay watershed (the Delaware Bay Estuary is a Ramsar Wetland of international importance), home to the largest population of Horseshoe crabs in the world. The bay's watershed primarily drains southeast Pennsylvania, southwest New Jersey, and northeast Delaware. Although nutrient loading is a concern for the bay, pollution from the 300 year legacy of the industrial revolution poses a larger concern for the estuary (EPA 2007). Perennial, headwater streams are the primary aquatic resource at HOFU and range from first to second order (Table A-23). The entire park is drained by French Creek, a tributary of the Schuylkill River. French Creek, and its main tributary, Baptism Creek, are major components of the resource base of the park. French Creek enters the park from the west and flows through the heart of HOFU. Prior to the confluence with Baptism Creek, French Creek drains the eastern half of HOFU along with much of southwestern portion of French Creek State Park. Within the state park, French Creek is impounded twice. Baptism Creek, above the confluence, drains the northeastern portion of HOFU along with additional lands, primarily in the state park. French Creek, along with Baptism Creek, was designated as an Exceptional Value stream by the State of Pennsylvania in 1982 because of its outstanding natural and scenic values. French Creek supports a diverse assemblage of fishes, with 17 species present all of which are typical of a warm water fishery while Baptism Creek supports an assemblage more typical of a cold water fishery, most notably brook trout (*Salvelinus fontinalis*; Sharpe and Kenner 2003). There are 19 amphibian and 22 reptile species documented in the park (Yahner et al. 1999, Tiebout III 2003). Species of special concern included the four-toed salamander (*Hemidactylium scutatum*), spotted salamander (*Ambystoma maculatum*) which is an indicator species of the ecological health of vernal pools, wood turtle (*Clemmys insculpta*) and the threatened bog turtle (*Glyptemys muhlenbergii*).

Table A-23. Strahler stream order classification by length (km) within the contributing watershed of HOFU streams.

Stream Order	Intermittent	Perennial	Within Park	% Perennial
1	-	6.6	6.6 (3.5)	100
2	-	1.7	1.7 (1.7)	100
Total	-	8.3	8.3 (5.2)	
% Headwater	-	100	100 (100)	



Legend

- Park Boundary
- Watershed Boundary

0.5 1 2 Miles
0.75 1.5 3 Kilometers

N

Union Tp
Berks
Chester
Warwick Tp

French Creek State Park
French Creek
Scotts Run
Pine Creek
Rock Run
Pigeon Creek
South Branch French Creek
Warwick County Park

Warwick Rd
Ridge Rd
Sawyer Rd
Tryhill Rd
Northside Rd
Pine Swamp Rd
Laurel Ln
Warwick Rd
Redding Farm Rd
Hartman Rd
Enoch Rd
Ridge Rd
Sawyer Rd
Tryhill Rd
Northside Rd
Pine Swamp Rd
Laurel Ln
Warwick Rd
Redding Farm Rd
Hartman Rd
Enoch Rd

French Creek
Scotts Run
Pine Creek
Rock Run
Pigeon Creek
South Branch French Creek
Warwick County Park

National Geographic, Esri, DeLorme, NAVTEQ, UNEP-WCMC, USGS, NASA, ESA, METI, NRCAN, GEBCO, NOAA, IPC

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Currently French and Baptism Creeks are assessed by the state as meeting designated uses which include aquatic life and recreational (Figure A-32, Table A-24). Although the streams flowing through HOFU are not listed as impaired, both impoundments (Hopewell Lake: 0204023001996 and Scotts Run Lake: 02040203001990) upstream of the park on French Creek are listed as impaired for aquatic life due to pollution (PADEP 2014). Until recently, water quality data within HOFU has been inconsistently collected. A baseline water quality inquiry by the Water Resources Division of the NPS provided some historical data and established seasonal patterns in discharge within the region (NPS 1998a). This report defined three distinct hydrological seasons: rising limb (Nov. –March), falling limb (April – July), and base flow (August – October; Figure A-33). More recently HOFU and the MIDN have partnered to initiate a water quality pilot study as well as a benthic macroinvertebrate sampling program to assess stream conditions at HOFU (Figure A-34). Preliminary benthic macroinvertebrate data (2009–2012) suggests that French Creek has been impaired with all observations (n=4) below the aquatic life use standard established by the PADEP (PADEP 2012). Baptism Creek, however, has scored in the healthy range (n=2). Mean (SD) benthic macroinvertebrate scores for French and Baptism Creeks for this period were 43.5 (6.8) and 65.4 (8.1), respectively. Water quality data collected during the pilot study suggests that dissolved oxygen and pH are well within the Pennsylvania’s criteria, however there are elevated temperatures in French Creek due to the impoundments upstream of HOFU (Fig. 32).

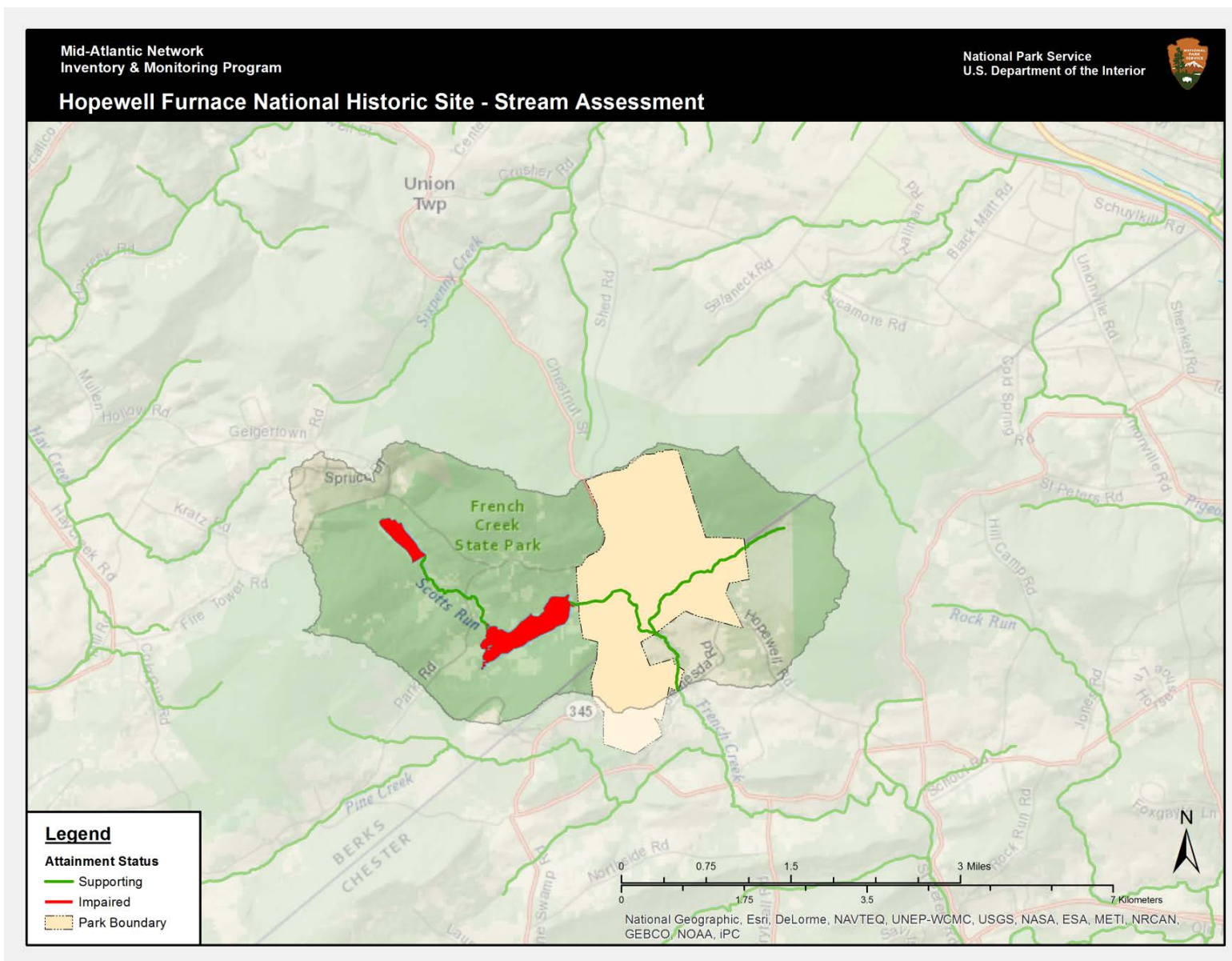


Figure A-32. Map displaying the attainment status of HOFU streams from the PA DEP 2012 305(b)/303(d) biannual water quality assessment.

Table A-24. Regulatory standards for baseline water quality parameters (temperature, pH, and dissolved oxygen) in the Commonwealth of Pennsylvania and EPA recommended guidance.

Regulatory Parameter	Beneficial Use	EPA National Recommended Water Quality Criteria (2012)	State of Pennsylvania Specific Water Quality Standards CH 93.7 (2009)
Temperature (°C)	Warm-water fishes	Species specific criteria	Varies by date, 87 °F max summer temp
	Cold Water Fishes	Species specific criteria	Varies by date, 66 °F max summer temp
pH	Drinking water	5 - 9	All uses = 6 - 9
	Aquatic Life	6.5 - 9	
Dissolved Oxygen (mg/l)	Warm Water fishes	Min. Criteria - early life stages = 5.0, other life stages = 3.0,	min. = 4.0, daily avg = 5.0
	Cold Water Fishes	Min. Criteria - early life stages = 5.0, other life stages = 4.0,	min. = 5.0, daily avg. = 6.0
	Invertebrate	Min. Criteria - 4.0	

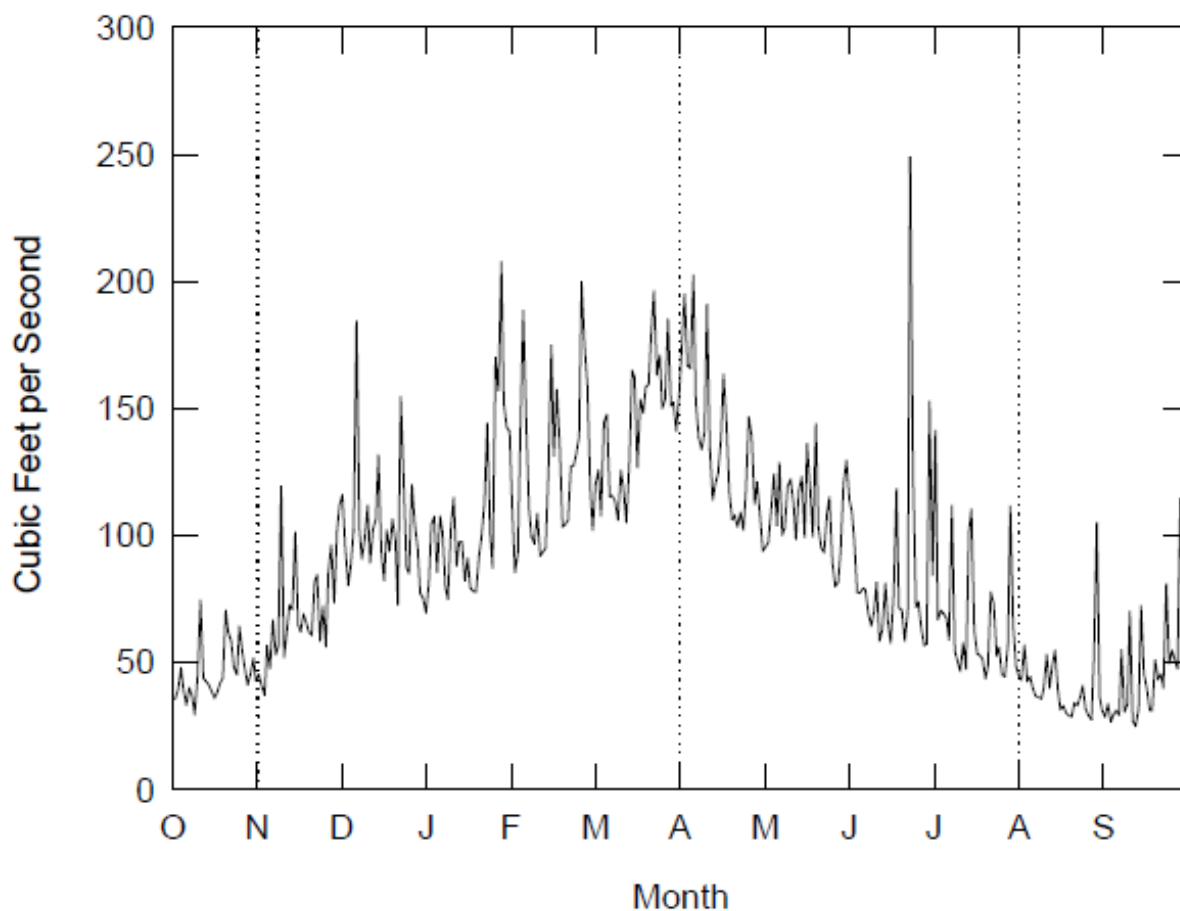


Figure A-33. Representative mean annual hydrograph used to conduct hydrologic seasonal analysis (French Creek: 40° 09' 05" N, 75° 36' 06"). Adapted from "Baseline water Quality Data: HOFU" by NPS, 1998. P. 42. Reprinted with permission.

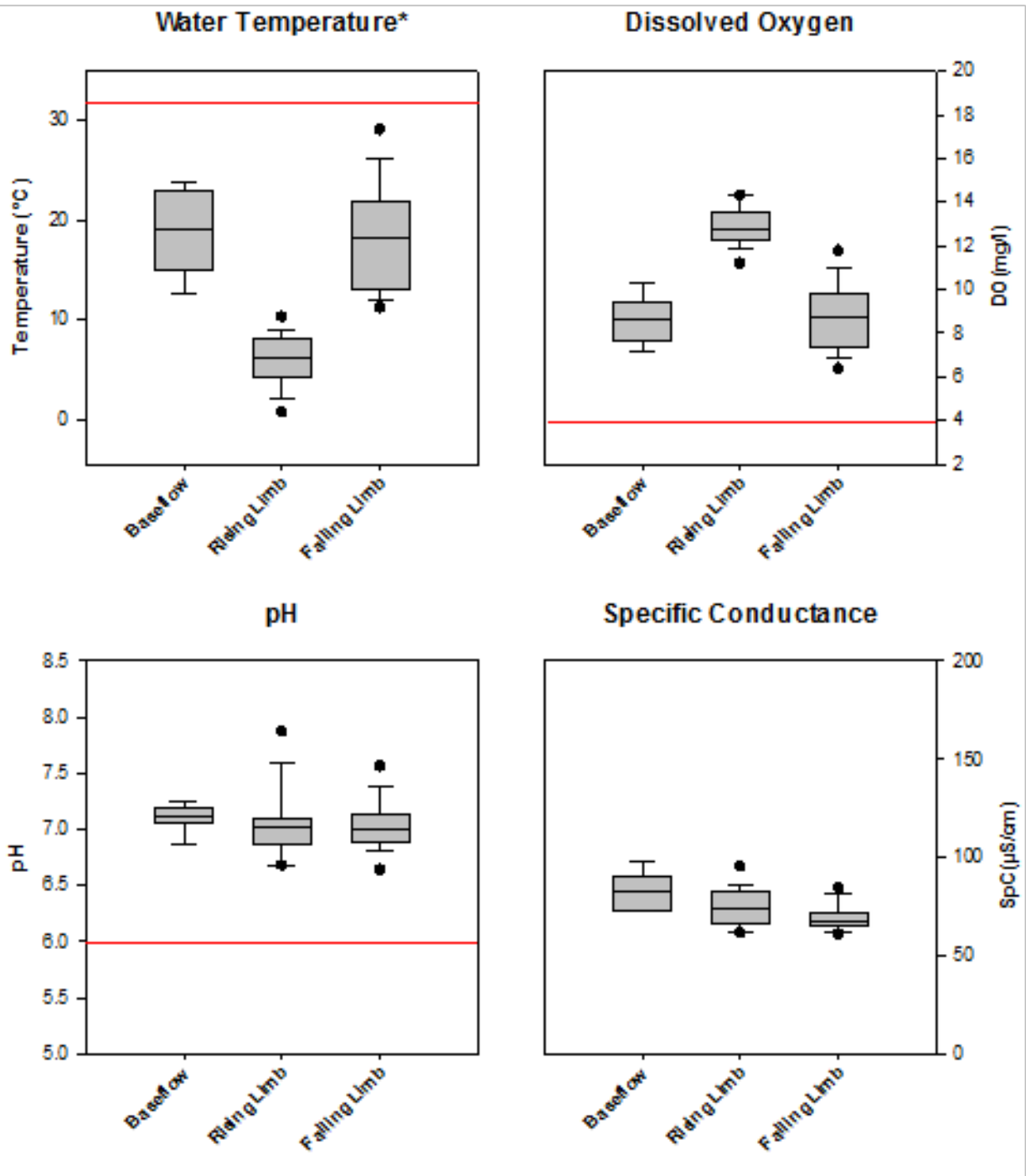


Figure A-34. Box plots (box: median, interquartile range; whiskers: 10th and 90th percentile; points: 5th and 95th percentile) for "core" water quality parameters measured during pilot study and grouped by hydrologic season at HOFU (2010-2013). Red lines indicate water quality thresholds established by the Commonwealth of Pennsylvania. *Threshold displayed is maximum summer temperature.

2.7.5 Long-term Monitoring Sites

In an effort to monitor the status and trends of wadeable streams at HOFU two long-term monitoring sites have been selected. Sites were placed in streams of significant value to the park as determined by HOFU and MIDN staff (Table A-25, Figure A-35). Stream reaches of particular importance to park management were identified from within these established sites for enhanced monitoring by integrating other MIDN protocols (BMI monitoring) and continuous monitoring of water quality parameters. Additionally, a summary of land cover classes is provided for the watershed at each long-term site (Table A-26).

HOFU_01: French Creek

HOFU_01 is located on French Creek above the confluence with Baptism Creek which is immediately downstream of the park boundary. This site is approximately 2 km downstream from the lower impoundment which creates Hopewell Lake in French Creek State Park. The stream drains the cultural center of the park which consists of several historic structures and active livestock grazing in open fields.

HOFU_02: Baptism Creek

HOFU_02 is located on Baptism Creek above the confluence with French Creek. Baptism Creek drains the northeast section of HOFU along with state park land and private holdings. This stream supports Brook Trout and is in a less impacted condition than French Creek which drains the remainder of HOFU.

Table A-25. List of long-term monitoring sites at HOFU.

Site ID	Stream Name	USGS HUC-14	Latitude	Longitude	Type of Site (D,BMI, Con)*
HOFU_01	French Creek	02040203000268	40.2017	-75.76757	D, BMI, Con
HOFU_02	Baptism Creek	02040203000679	40.20205	-75.76715	D, BMI

* D = Discrete Water Quality, BMI = Benthic Macroinvertebrate, Con = Continuous Water Quality Monitoring

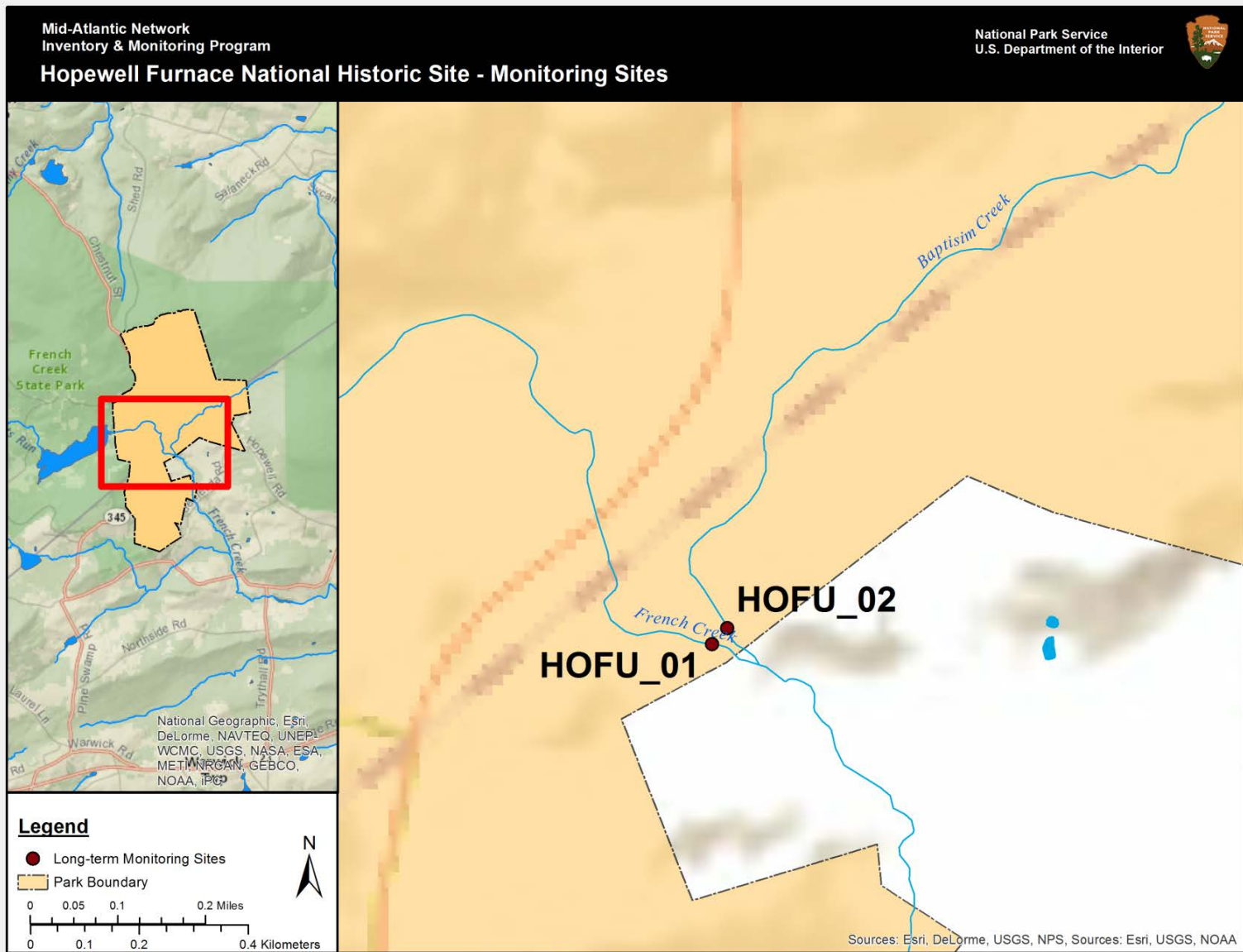


Figure A-35. Map of long-term monitoring sites at HOFU.

Table A-26. Land cover (%) of the major land-use classifications from the NLCD (Homer et al. 2015) for the watershed and riparian areas (100 meter buffer) associated with each site selected for long-term monitoring.

Site ID	Watershed					100-meter Buffer				
	Forest	Wetlands	Agriculture	Developed*	Other	Forest	Wetlands	Agriculture	Developed*	Other
HOFU_01	77.8	1.0	3.8	10.7 (0.1)	6.6	46.3	8.7	5.1	6.9 (-)	33.1
HOFU_02	89.5	1.8	5.2	1.6 (-)	1.9	78.7	13.8	3.1	2.0 (-)	2.4
Within Park	69.9	4.0	11.1	11.1 (<0.0)	4.0	54.0	24.1	9.6	7.6 (-)	4.7
All Watersheds	78.3	1.7	5.8	8.2 (0.1)	6.0	53.7	15.7	5.2	5.0 (-)	20.4

* Values in parenthesis are the proportion of developed total that is medium to high intensity

2.6 Petersburg National Battlefield

2.6.1 Park Overview

Petersburg National Battlefield (PETE) is located in the Coastal Plain physiographic region of south central Virginia, approximately 32 km (20 miles) south of Richmond. The park consists of 2,740 acres in ten separate units scattered over two counties and the cities of Petersburg and Hopewell commemorating the 9 1/2 months of battles for the control of Petersburg during the Civil War. Two units, the Eastern Front and Five Forks units, account for the vast majority of the land holdings (Figure A-36). Of these 2,740 acres, approximately 80% is forested. The remaining park acreage consists of open developed areas (4.9%), open fields (4.7%), cropland (3.5%), and wetlands (2.8%; Homer et al. 2015). Many of the open field areas are managed under agricultural permits for harvesting hay.

2.6.2 Landscape Setting

The two dominant holdings of PETE straddle the divide between the Chesapeake Bay Watershed (Eastern Front) and the Albemarle Sound Watershed (Five Forks) near the transition zone between the Coastal Plain and Piedmont. The Eastern Front is situated on the upper Coastal Plain very close to the Fall Zone, a geologic zone that divides the Coastal Plain and Piedmont. All of the lotic aquatic resources within PETE are classified as coastal plain streams. This region is underlain by mainly sedimentary rocks and unconsolidated sands, clays, and gravels. Igneous, sedimentary, and metamorphic rocks underlie the Piedmont. The park ranges in elevation from a low point of 12 m (40 feet) at the northeastern boundary adjacent to the Appomattox floodplain, and a high of 51 m (168 feet) in the southeastern section of the Eastern Front and 92 m (302 feet) at the Five Forks Unit. The predominant soil type in the Eastern Front is Emporia and Norfolk sandy loam. Soils in the Five Forks Unit are well-drained sandy loam with a clay loam subsurface (Comiskey and Callahan 2008). Within the region, these landforms support a wide variety of land cover which include agriculture (croplands and pasture/hay), urban development, and mature, late successional forests.

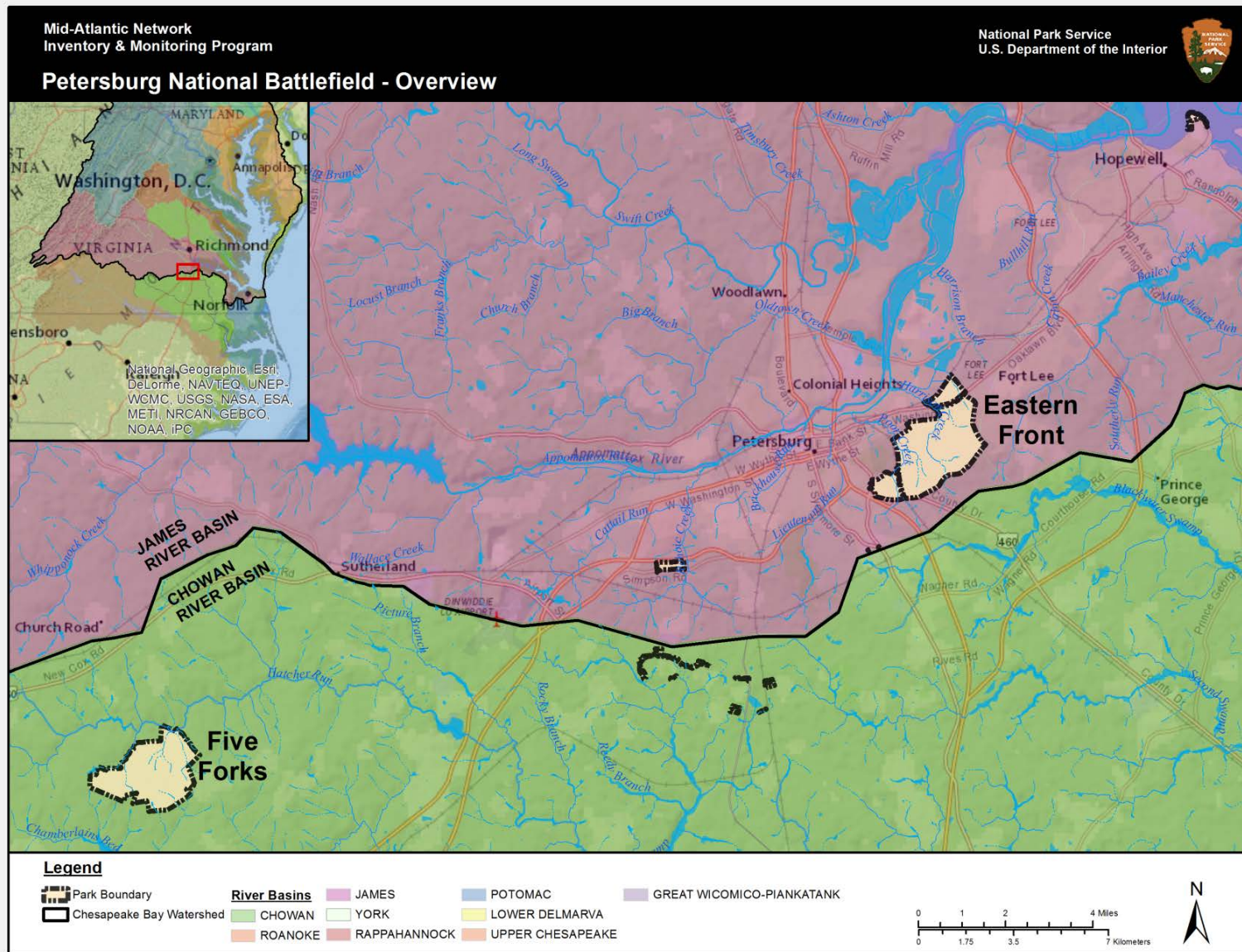


Figure A-36. Map displaying PETE highlighting aquatic resources.

2.6.3 Land Cover and Vegetation

Within the boundaries of PETE the primary land cover class is forested (81.7%), followed by agriculture (8.2%), and developed land (5.9%; Figure A-37, Table A-27) (Homer et al. 2015). This is substantially more forested land than is found in the contributing watersheds of PETE (62.8%) and across the entire CBW (55.3%) or ASW (46.5%). The watersheds that support PETE streams are more developed (11.9%) than lands within the park and in the ASW (7.0%) but is consistent with the level of development found in the (CBW 10.6%). It is important to note that a vast majority of the development is adjacent to the Eastern Front in the CBW. Agricultural development is primarily found in the watersheds of the Five Forks unit and is concentrated within a single watershed largely outside of the park boundaries. These characteristics are integral to understanding stream conditions at PETE. Forested watersheds and buffers around streams have the ability to improve stream conditions by removing nutrients, controlling sediments, ameliorating temperature increases, and protecting physical habitat (Lowrance and Altier 1997, Jacobson 2001, Kaushal and Likens 2010).

The two primary units at PETE, Five Forks and Eastern Front, face different land use pressures that are common to the greater watersheds. Urbanization is the primary threat to aquatic resources in the Eastern Front unit. Although the watershed associated with Eastern Front accounts for less than half of the total watershed area for PETE it has almost all of the land in the developed land cover classifications. While much of the watershed is protected NPS land, a significant portion is outside of the boundary to the southeast (Fig. A-37). Land use in the park vicinity, particularly in northeastern Dinwiddie County is changing from a more rural area within an agricultural setting to an increasingly suburban and industrial area. The 2010 US Census showed that Prince George County doubled the 2000 population growth estimate from the Virginia Employment Commission, growing by eight percent to a total of 35,725 (NPS 2004a). At the Five Forks unit the primary water quality concern is agricultural. Where Eastern Front accounts for a vast majority of the developed land cover classes in PETE watersheds, Five Forks accounts for the vast majority of the agricultural classes. Both of these land cover categories can have a profound impact on ecological integrity of aquatic systems.

The vegetation within PETE was classified and mapped during 2002-2006 using extensive field reconnaissance and aerial photography (Patterson 2008c). The majority (59.8%) of the park consists of early successional or transitional forest and shrub land with a history of disturbance. This includes disturbed areas along the bluffs of the Appomattox and James Rivers (Disturbed Calcareous Forest), and areas that have gone through relatively recent (20–60 years) disturbance or transition such as field abandonment, wind disturbance, beaver activity, or silvicultural practices (Successional Mixed Scrub, Successional Sweetgum and Tuliptree Forests, Loblolly Pine Plantations, Loblolly Pine - Hardwood Forest, Beaver Wetland Complex). Later successional vegetation covers 24.6% of the land in the park and consists of upland forests (18.1%, Acidic Oak-Hickory Forest, Mesic Mixed Hardwood Forests, and Coastal Plain Mixed Oak/Heath Forest), as well as forested wetland (6.5%) found on floodplains and near seeps (see wetlands section). Human manipulated areas of the park, such as fields under agricultural leases for hay and row crops as well as earthworks, cover 10.4% of the park with an additional 5.2% being developed. Most of the Five Forks area was logged and is now composed of fairly young pine forest.

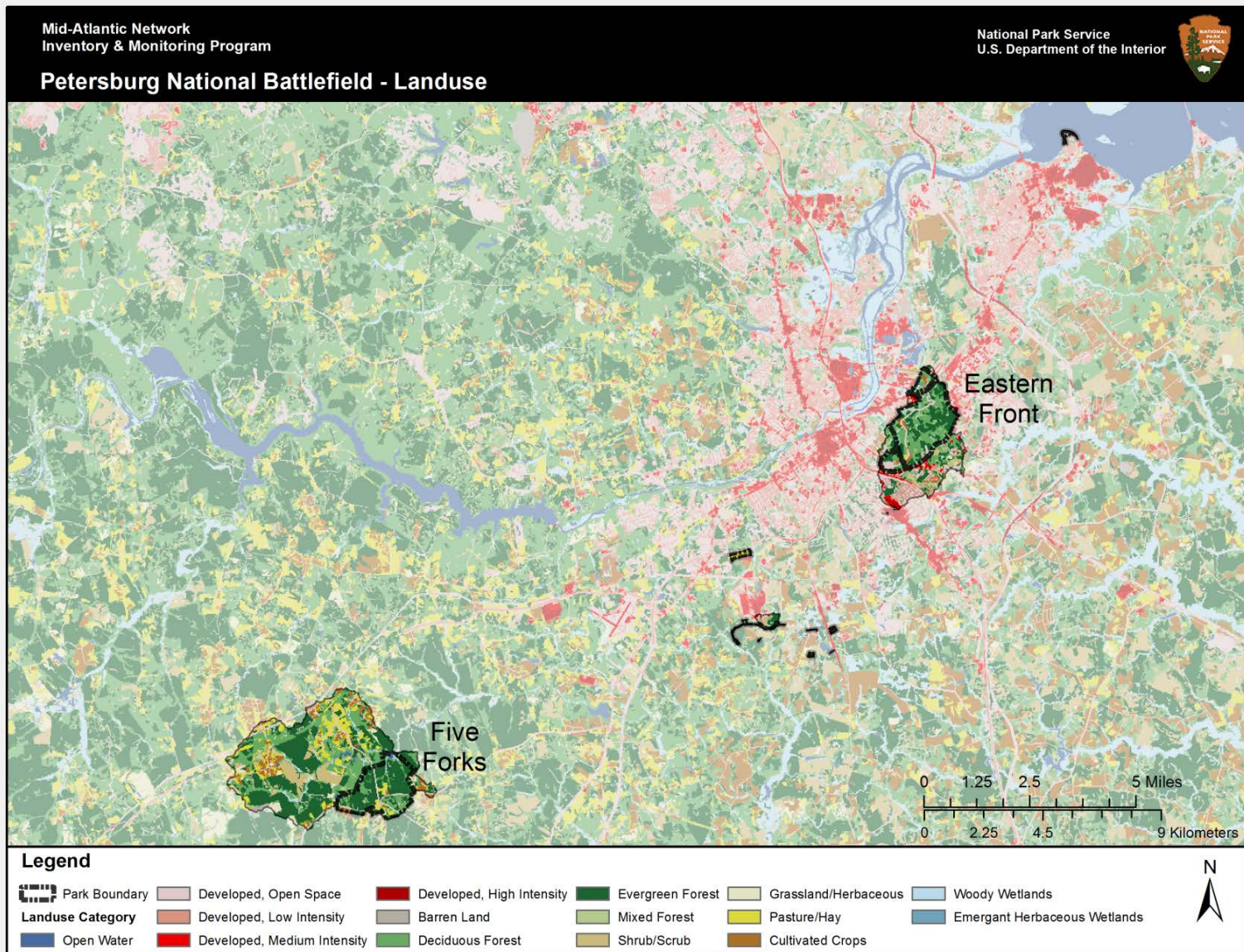


Figure A-37. Map displaying the National Land Cover Dataset classes for the contributing watersheds to the streams of PETE.

Table A-27. Land cover classification (Homer et al. 2015) of watersheds and riparian areas (100 meter buffer) associated with PETE, within PETE, and the CBW.

Land Cover Type	Watershed		100 Meter Buffer		Park		Chesapeake Bay Watershed		Albemarle Sound Watershed	
	%	Area (km2)	%	Area (km2)	%	Area (km2)	%	Area (km2)	%	Area (km2)
Forest Total	61.7	21.79	71.3	6.52	81.7	8.90	54.7	91,329	42.5	19,340
Deciduous Forest	25.3	8.93	40.0	3.66	29.7	3.24	42.8	71,401	27.2	12,355
Evergreen Forest	33.6	11.86	27.8	2.54	47.3	5.15	5.8	9,716	12.6	5,712
Mixed Forest	2.8	1.00	3.5	0.32	4.6	0.51	6.1	10,212	2.8	1,273
Agriculture Total	13.6	4.79	7.2	0.66	8.2	0.90	24.6	40,996	22.1	10,044
Pasture/Hay	8.6	3.05	4.4	0.40	4.7	0.51	14.9	24,913	12.3	5,596
Cultivated Crops	4.9	1.73	2.8	0.25	3.5	0.38	9.6	16,083	9.8	4,448
Developed Total	11.9	4.21	5.5	0.51	5.9	0.64	11.0	18,432	7.0	3,189
Developed, Open Space	6.7	2.37	2.9	0.27	4.9	0.53	6.6	10,992	4.9	2,223
Developed, Low Intensity	3.3	1.16	1.7	0.15	0.7	0.07	2.8	4,696	1.5	685
Developed, Medium Intensity	1.3	0.47	0.7	0.06	0.2	0.02	1.2	2,005	0.5	210
Developed, High Intensity	0.6	0.21	0.2	0.02	-	-	0.4	739	0.2	70
Grassland/Herbaceous	3.7	1.31	3.1	0.28	0.2	0.02	0.8	1,335	4.5	2,062
Scrub/Shrub	6.1	2.14	5.3	0.48	1.0	0.11	2.2	3,709	6.7	3,051
open water	0.5	0.17	1.6	0.14	0.3	0.03	1.8	2,950	2.5	1,131
Barren Land	0.4	0.14	-	-	0.1	0.01	0.3	489	0.2	93
Woody Wetlands	2.1	0.75	6.0	0.55	2.8	0.30	3.7	6,244	13.3	6,032
Emergent Herbaceous Wetlands	0.0	0.00	0.0	0.00	<0.1	0.01	0.9	1,471	1.2	532
Total	100.0	35.31	100.0	9.15	100.0	10.90	100.0	166,957	100.0	45,473

Petersburg National Battlefield contains 175 acres of wetlands, many of which can be found in floodplains, near seeps and in areas of beaver activity. Coastal Plain / Piedmont Small-Stream Floodplain Forest is a relatively common association (G4), but high quality, undisturbed examples, such as that within the park, are rare. Coastal Plain / Piedmont Floodplain Swamp Forest (Mixed Oak - Red Maple Type) is a somewhat uncommon community (G3G4) in the Mid-Atlantic Coastal Plain. The numerous perennial streams and small wetland areas in the Five Forks unit support a forested wetland mapped as Coastal Plain / Piedmont Acidic Seepage Swamp, which also is an uncommon (G3) wetland habitat (Patterson 2008c). Five Forks is an important ecological area that contains marshy wetland habitat created through beaver activity. Although no wetland species of special concern have been documented, this area contains excellent habitat for wetland plants (Rosenzweig and Porter 1991).

2.6.4 Water resources and current status of water quality

The National Park Service manages approximately 27 km of streams at PETE and the watersheds associated with these streams drain over 35 km² of the region (Table A-28, Figure A-38) (USGS 2014). PETE is located within two drainage basins: the Appomattox River (Eastern Front unit) and the Nottaway River (Five Forks unit) which ultimately joins the Chowan River. These watersheds are located within either the Chesapeake Bay Watershed or the Albemarle Sound Watershed, home to the largest and second largest estuary in the United States, respectively, which have been degraded over time primarily due to excess nutrient and sediment loads delivered from the upland watershed (Kemp and Boynton 2005, EPA 2006).

Table A-28. Strahler stream order classification by length (km) within the contributing watershed of PETE streams.

Stream Order	Intermittent	Perennial	All Streams (Within Park)	% Perennial
1	28.1	3.9	32.0 (14.6)	12
2	5.3	11.3	16.6 (9.8)	68
3	-	6.0	6.0 (2.6)	100
Total	33.4	21.2	54.6 (27.0)	
% Headwater	100	100	100 (100)	

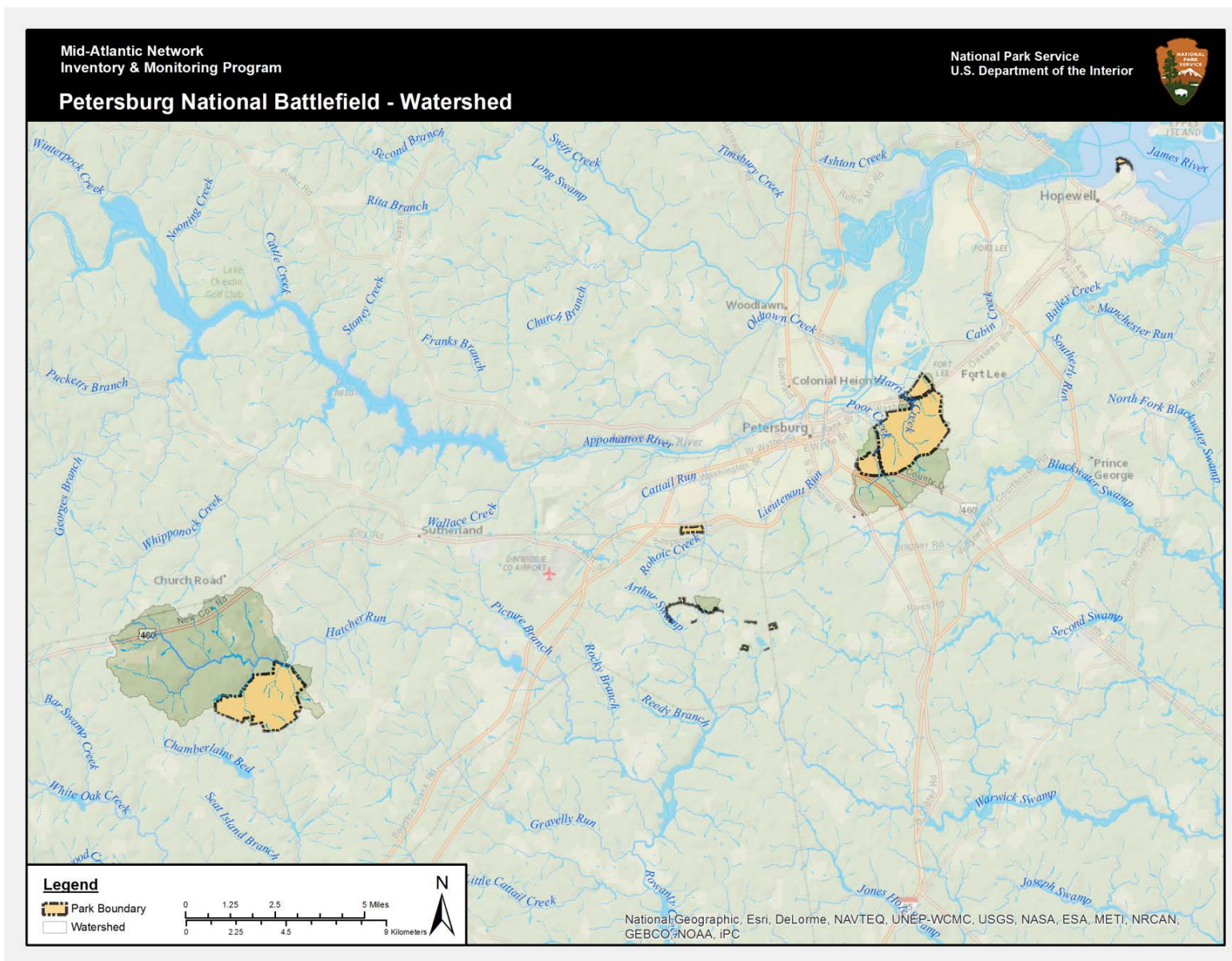


Figure A-38. Watersheds associated with PETE streams.

Perennial streams within PETE are composed completely of smaller, headwater reaches (Table A-28) and range from first to third order. Headwater streams (stream order 1-3) are typically dominated by allochthonous inputs and are shaded by riparian vegetation reducing primary production. Much of the organic matter comes from terrestrial sources. As streams increase in size (stream order 3-5), there is a shift towards autochthonous resources, primary production increases and shifts in the composition of the biological community occur (Vannote et al. 1980). Typical of headwater streams, the smaller streams support a less diverse fish population, however there are some notable records. These species include the least brook lamprey (*Lanpetra aepyptera*) and sea lamprey (*Petromyzon marinus*), bowfin (*Amia calva*), and chain pickerel (*Esox niger*), all of which are associated with low-gradient coastal systems (Atkinson 2008). Streams within PETE represent a unique resource and provide habitat in the ecoregion which has less land in conservation than either more coastal or mountainous areas of Virginia.

A vast majority of the stream resources in PETE are found in either the Five Forks or Eastern Front units (Fig. A-38). Within the Eastern Front there are two major streams, Poor and Harrison Creeks, along with their associated tributaries. Poor Creek originates outside of the park along the southwestern boundary and flows northwest across the park unit and on to the Appomattox River. Harrison Creek follows a similar pattern and drains to the Appomattox River but is the next drainage basin situated to the northeast of Poor Creek. The Five Forks unit is within the watershed of the Nottoway River which drains to the Chowan River. All of the stream resources within this unit originate within the boundaries of PETE and display at least some intermittent characteristics except for a section of Hatcher Run which enters the park where it forms the northwestern boundary and is a larger, perennial stream. White Oak Road runs along the watershed divide through the Five Forks unit with all of the land north of the road draining to Hatcher Run and lands south of the road draining to Gravelly Brook and Chamberlains Bed and then on to Stoney Creek and, ultimately, the Nottoway River.

In addition to stream resources, PETE also has several ponds within and adjacent to its boundaries. Soldier's Pond, approximately 0.7 acres in size, is located behind the Resource Management office within the Eastern Front unit of the park. The earthen dam forming the pond was naturally breached in 2001 reducing it to its current size. The Five Forks unit contains 4 ponds. The largest pond is located on Hatcher Run along the northern boundary of the Five Forks unit. This creek is naturally dammed, typically forming a one to four acre pond along the boundary. Three other small ponds are located at the headwaters of unnamed tributaries to Gravelly Brook (1.4 acres), Hatcher Run (0.2 acres), and Beaverdam Creek (0.1 acres).

During the 2012 assessment cycle the Commonwealth of Virginia found that approximately 36% of stream lengths within PETE did not meet water quality standards (Figure A-39, Table A-29) (VADEQ 2014). In the Eastern Front unit, the two major streams, Harrison Creek and Poor Creek, have impaired regulatory status due to bacteria contamination impairing recreational uses but are currently meeting all other designated uses. In the Five Forks unit, Hatcher Run and Gravelly Run are not meeting aquatic life uses due to low dissolved oxygen levels and exceeding pH standards in Gravelly Run. Hatcher Run also has fish consumption advisories due to elevated mercury

contamination found in fish tissue samples. Some of these streams may not meet water quality standards due to natural conditions. In order for these streams to be reclassified (i.e. - from tidal water to swamp water) or have changes to their designated uses, a water quality standards use attainability analysis would need to be performed to ensure streams are classified properly and can meet current standards under natural conditions.

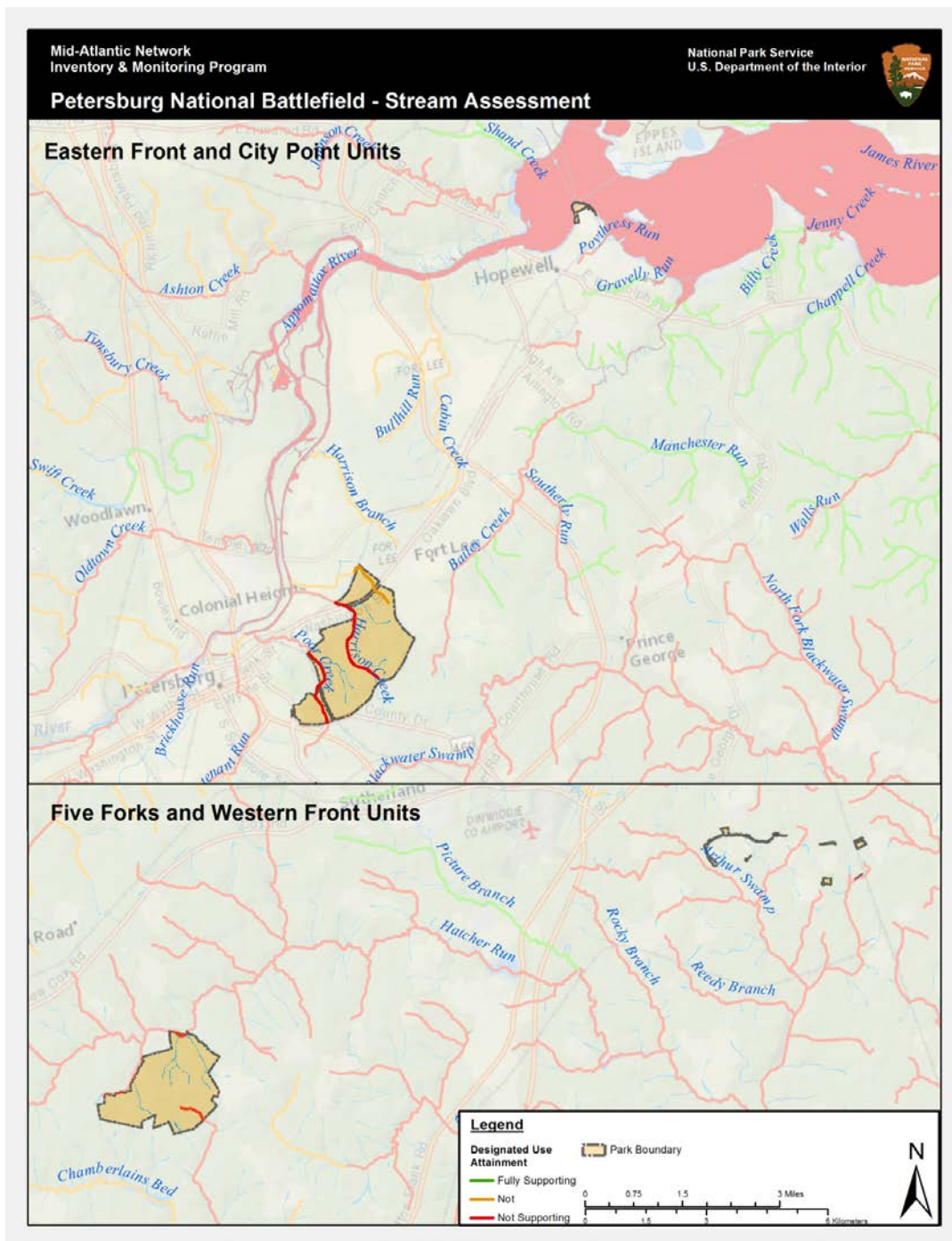


Figure A-39. Map displaying the attainment status of PETE streams from the VA DEQ 2012 305(b)/303(d) biannual water quality assessment.

Table A-29. Regulatory standards for baseline water quality parameters (temperature, pH and dissolved oxygen) in the Commonwealth of Virginia and EPA recommended guidance.

Regulatory Parameter	Beneficial Use	EPA National Recommended Water Quality Criteria (2012)	State of Virginia Standard - 9VAC25-260-50 (2011)
Temperature (°C)	Warm-water fishes	Species specific criteria	32°C Max Temp - Non-tidal Waters (Coastal and Piedmont Zones)
pH	Aquatic Life	6.5 - 9	6-9
Dissolved Oxygen (mg/l)	Aquatic Life	Warm water Min. Criteria - early life stages = 5.0, other life stages = 3.0, invertebrate min. criteria = 4.0	Min. = 4, Daily Avg = 5

Until recently, water quality data within PETE has been sparingly and inconsistently collected. A richer historical data set is available by reaching outside of NPS boundaries, however much of this data concerns larger, distant rivers resulting in an inability to directly infer conditions in PETE streams. In addition, the data has been inconsistently collected over time. The legacy data can reveal some general water quality concerns at a regional scale. A data mining project completed by the Water Resources Division (WRD) of the NPS found that some significant areas of concern throughout the region were related to stream pH, dissolved oxygen and total bacterial concentrations (NPS 1997a). Approximately 10 percent of pH observations (n = 3879) fell below the EPA recommended water quality criteria of 6.5 units. Six percent of dissolved oxygen observations (n = 4384) fell below Virginia's minimum criteria of 4 mg/l. The WRD's baseline water quality report also identified seasonal patterns in stream discharge which can be informative in interpreting stream conditions. Based on these findings three distinct hydrological seasons: rising limb (mid-Oct. – early-March), falling limb (early-March – June), and base flow (July – mid-Oct.; Figure A-40) were established. More recently, MIDN and PETE initiated a water quality pilot study to establish a long-term monitoring protocol as well as a benthic macroinvertebrate sampling program to assess stream conditions at PETE.

Two leading concerns have emerged from this pilot study: stream acidification and hypoxia. Data discussed in the following text refers to observations made during the pilot study starting in the summer of 2010 (Falling Limb) through the 2013 calendar year (Rising Limb). Approximately 258 site visits occurred during this time period across streams in each of the four major units of PETE. pH was outside of State water quality criteria in 20% (n = 257) of observations (Fig. A-41). All but 3 of the observations (n= 52) below the state criteria for pH were collected within the Five Forks unit of PETE. During baseflow conditions, 17.5% (n = 251) of dissolved oxygen observations were outside of Virginia's criteria, again with a vast majority of these observation made in the Five Forks unit. Stream water temperature was highest during baseflow periods and reached the minimum values during the rising limb. Specific conductance was consistent across hydrologic seasons (Figure A-41). Benthic macroinvertebrate data indicates slightly impaired conditions across PETE streams with biotic index scores (Coastal Plain Macroinvertebrate Index; Maxted et al. 2000) near the

threshold for impaired conditions for streams in the Coastal Plain physiographic zone ($n = 8$). The pilot data collected confirms that there are outstanding concerns in terms of stream conditions at PETE. The natural range of variability of these parameters must be carefully considered prior to drawing firm conclusions about the impairment status of these streams.

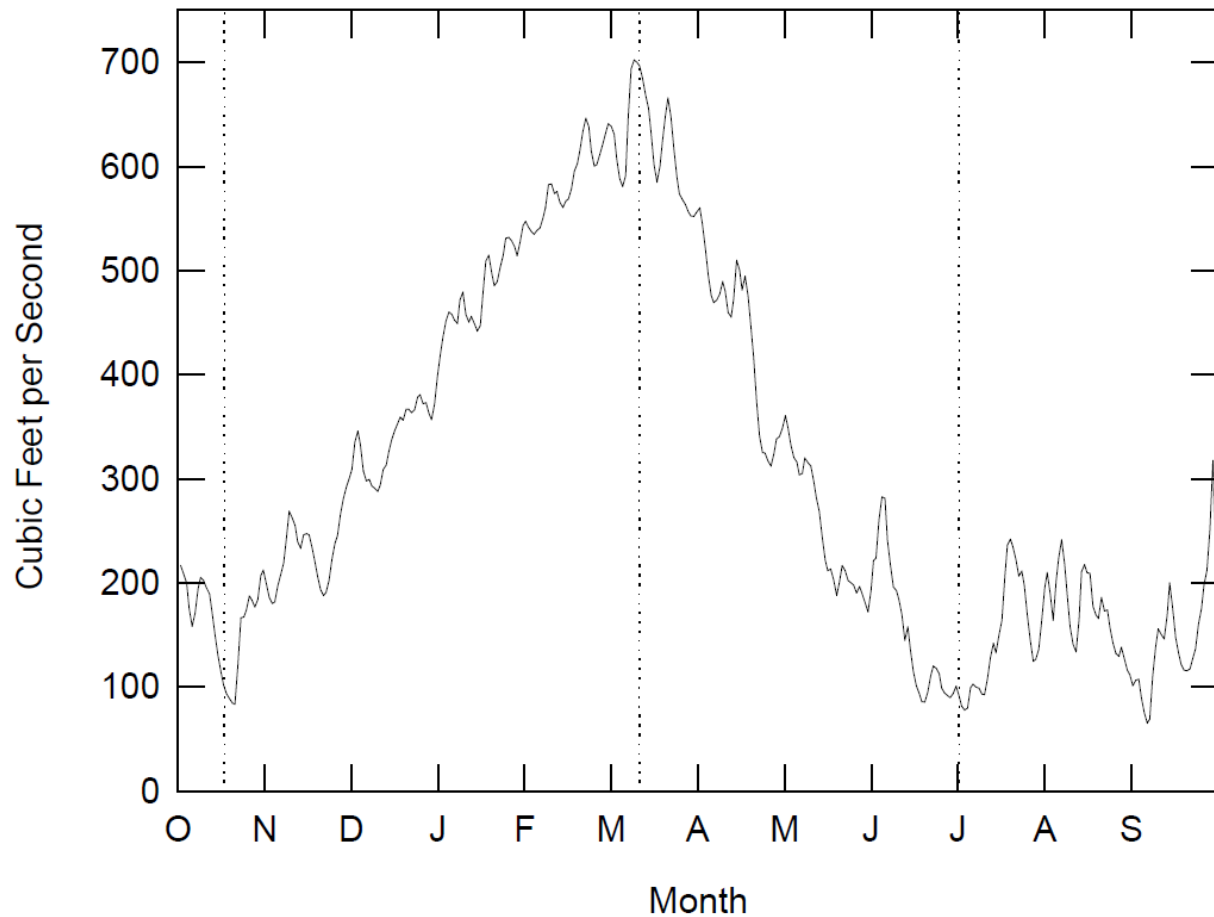


Figure A-40. Representative mean annual hydrograph from the James River used to conduct hydrologic seasonal analysis (Blackwater River: $37^{\circ} 01' 30''$ N, $76^{\circ} 52' 30''$ W). Adapted from "Baseline Water Quality Data: PETE" by NPS, 2000. P. 43. Reprinted with permission.

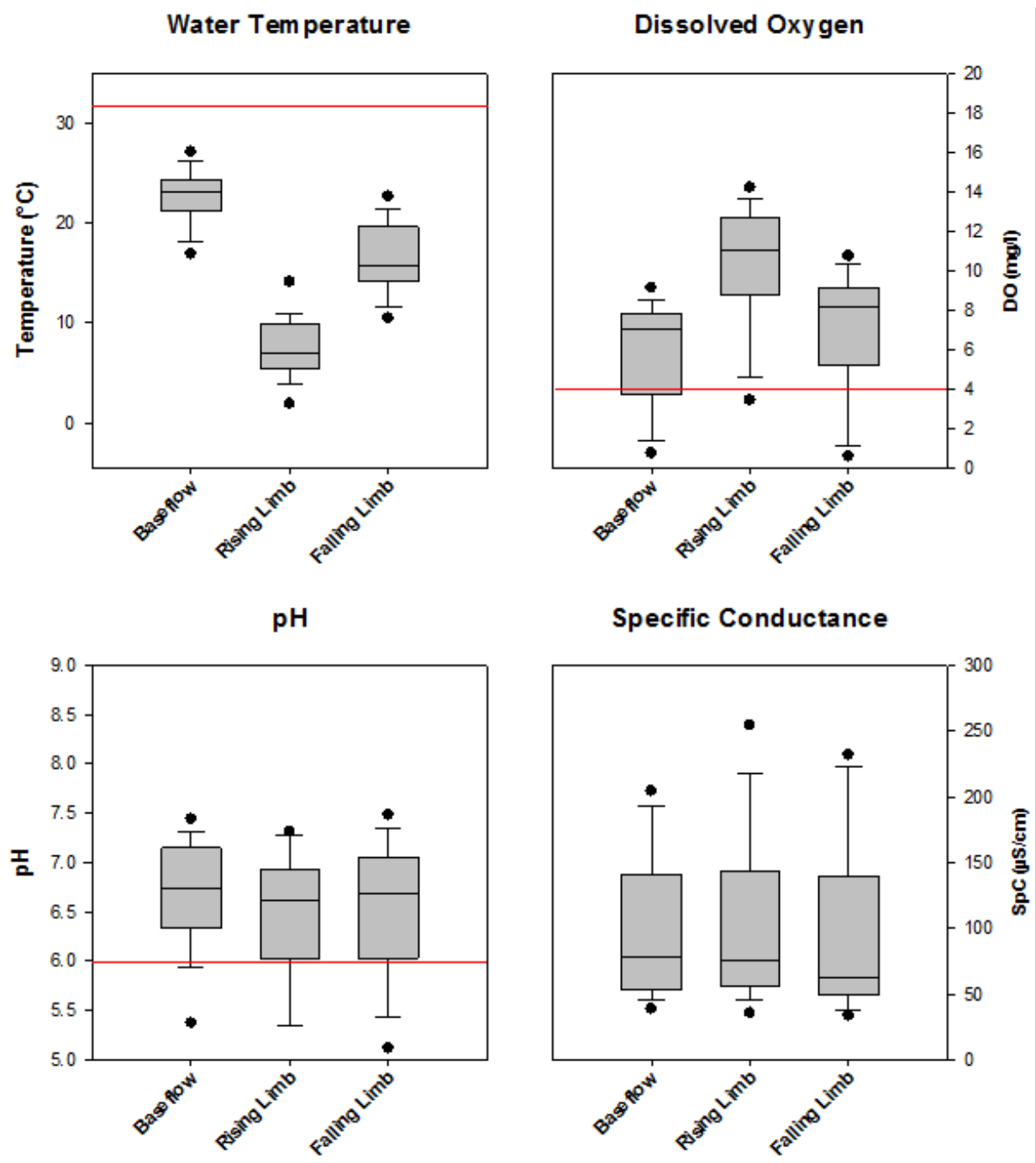


Figure A-41. Box plots (box: median, interquartile range; whiskers: 10th and 90th percentile; points: 5th and 95th percentile) for "core" water quality parameters measured during pilot study and grouped by hydrologic season at PETE (2010-2013). Red lines indicate water quality thresholds established by the Commonwealth of Virginia.

2.6.5 Long-term Monitoring Sites

In an effort to monitor the status and trends of wadeable streams at PETE several long-term monitoring sites have been selected. Sites were placed in streams of significant value to the park as determined by PETE and MIDN staff (Figure A-42, Table A-30). Stream reaches of particular importance to park management were identified from within these established sites for enhanced monitoring by integrating other MIDN protocols (BMI monitoring) and continuous monitoring of water quality parameters. Additionally, a summary of land cover classes is provided for the watershed at each long-term site (Table A-31).

PETE_01: tributary to Appomattox River

PETE_01 is located in the northern most section of the Eastern Front unit of PETE. The watershed is primarily forested, however heavy development is approaching the park boundary to the northeast within the watershed. Additionally a major state route (VA 36) crosses the center of watershed.

PETE_02: Branch Creek

PETE_02 is located near its confluence with Harrison Creek. The watershed is primarily located within the boundaries of PETE and is predominantly forested. The upper reaches of the watershed drain a portion of a highly developed section of Fort Lee, a major Army facility.

PETE_03: Harrison Creek

PETE_03 is located above the confluence of Branch Creek with Harrison Creek and is the largest watershed at the Eastern Front unit. Approximately half of the watershed is located outside of the boundaries of PETE. Within the park the landscape is dominated by deciduous and mixed forests. The watershed outside of PETE is undergoing a period of development associated with the expansion of Fort Lee. Harrison Creek is considered to be the primary aquatic feature of the Eastern Front unit.

PETE_04: Taylor Creek

PETE_04 is located within the boundaries of PETE above Taylor Creek's confluence with Poor Creek. Taylor Creek has a smaller watershed which is dominated by forests but has both agricultural land classes and some development outside of the park boundaries.

PETE_05: Poor Creek

PETE_05 is located above the confluence of Poor Creek with Taylor Creek. This watershed is primarily located outside of the park boundaries. The watershed is predominately developed with some agriculture. This watershed is expected to develop more around Fort Lee and creates a concern for stream velocity creating erosion problems within PETE.

PETE_06: tributary to Hatcher Run

PETE_06 is located in southwest section of the Five Forks unit of PETE. This is a first order stream which originates and is predominately with PETE. This watershed is dominated by forests and displays some intermittent characteristics.

PETE_07: Hatcher Run

PETE_07 is located outside of the boundaries of PETE where access to the stream is logistically feasible. The watershed is predominately outside of PETE, however it serves as the border for a section of the northern boundary and streams draining to the north in the Five Forks unit drain to Hatcher Run. There is harvesting of forest resources within this region and there is a mosaic of land cover classes within this watershed.

PETE_08: Beaverdam Creek

PETE_08 is located in the central section of the Five Forks unit and is entirely with PETE. This is a first order stream and displays some intermittent characteristics. The watershed is mostly forested along with some agricultural lands.

PETE_09: Boulder Creek

PETE_09 is located eastern section of Five Forks. The watershed is split between PETE and private lands. Within the park the watershed is completely forested while lands outside of PETE are primarily agricultural. This is a first order stream and displays some intermittent characteristics.

PETE_10: Gravelly Brook

PETE_10 is located in the southern section of Five Forks and is the only stream within the unit which does not drain to Hatcher Run. The watershed is entirely within PETE and is predominately forested. During baseflow conditions this stream can display some intermittent characteristics.

PETE_11: Harrison Creek

PETE_11 is located in the center of the Eastern Front unit. This site is located upstream of PETE_03 and therefore has similar land use pressures. However this site is located in the center of PETE and is more distant from development located along the boundary of the Eastern Front unit.



Petersburg National Battlefield - Stream Assessment

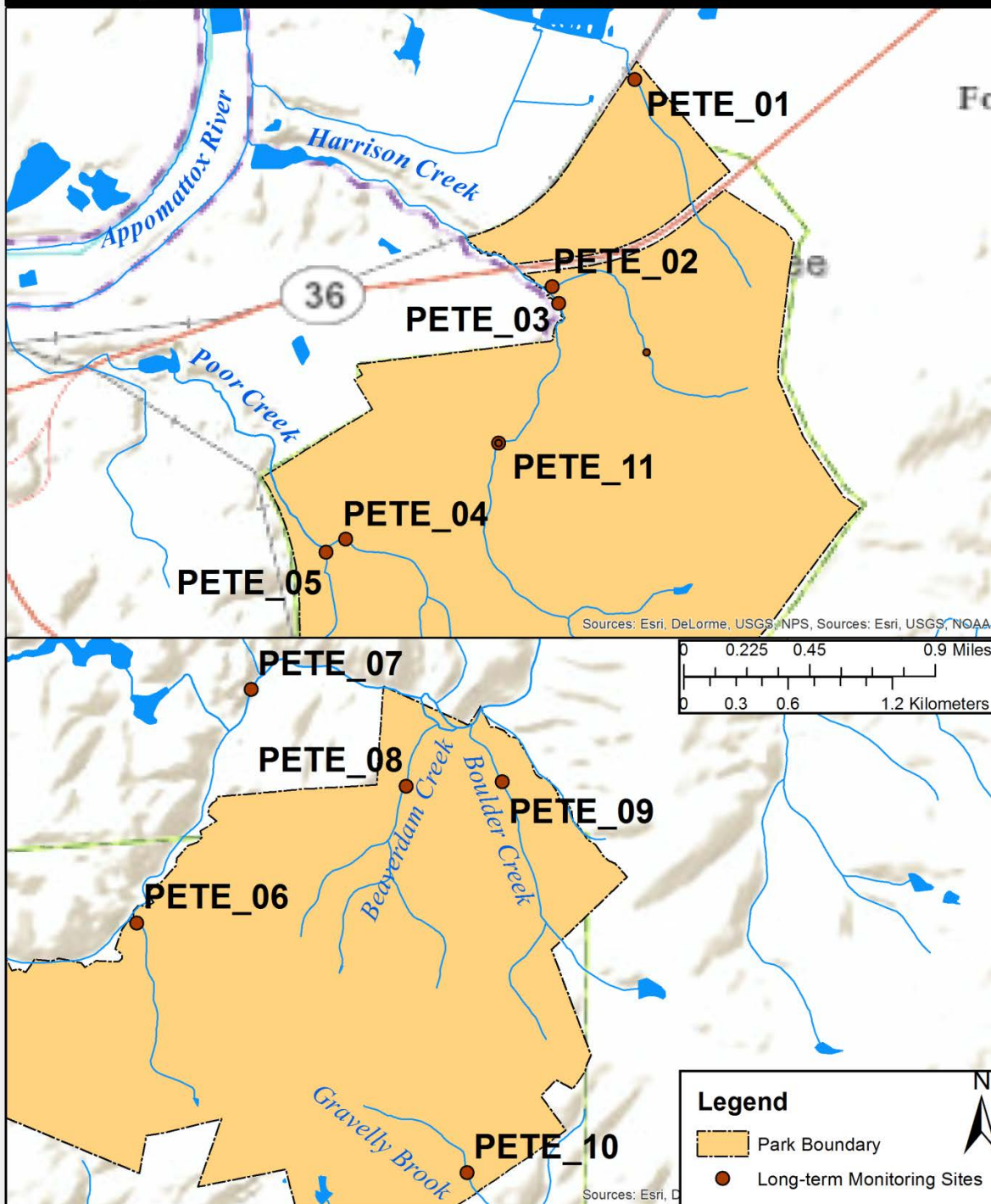


Figure A-42. Long-term water quality monitoring sites at PETE.

Table A-30. List of long-term monitoring site at PETE.

Site ID	Stream Name	USGS HUC-14	Latitude	Longitude	Type of Site (D,BMI, Con)*
PETE_01	tributary to Appomattox River	02080207004856	37.24769	-77.35696	D
PETE_02	Branch Creek	02080207004917	37.23926	-77.36127	D
PETE_03	Harrison Creek	02080207000863	37.23846	-77.36091	D, BMI, Con
PETE_04	Taylor Creek	02080207005047	37.22871	-77.37199	D
PETE_05	Poor Creek	02080207000855	37.22841	-77.37243	D
PETE_06	tributary to Hatcher Run	03010201010641	37.14602	-77.63109	D
PETE_07	Hatcher Run	03010201000158	37.15575	-77.62536	D
PETE_08	Beaverdam Creek	03010201013641	37.15169	-77.61715	D
PETE_09	Boulder Creek	03010201013648	37.15189	-77.612	D
PETE_10	Gravelly Brook	03010201001171	37.13572	-77.61411	D, BMI
PETE_11	Harrison Creek	02080207000863	37.25271	-77.36402	D, BMI

* D = Discrete Water Quality, BMI = Benthic Macroinvertebrate, Con = Continuous Water Quality Monitoring

Table A-31. Land cover (%) of the major land-use classifications from the NLCD (Homer et al. 2015) for the watershed and riparian areas (100 meter buffer) associated with each site selected for long-term monitoring.

Site ID	Watershed					100-meter Buffer				
	Forest	Wetlands	Agriculture	Developed*	Other	Forest	Wetlands	Agriculture	Developed*	Other
PETE_01	76.0	-	1.9	20.7 (2.3)	1.4	91.7	-	1.6	6.0 (-)	0.4
PETE_02	88.1	1.0	-	10.4 (0.4)	0.5	93.8	0.3	-	5.6 (-)	0.3
PETE_03	70.3	1.9	2.7	17.8 (4.1)	7.3	78.0	6.7	0.6	6.5 (1.8)	8.2
PETE_04	82.6	0.6	9.2	4.9 (1.7)	2.6	92.7	0.2	4.3	- (-)	2.8
PETE_05	38.2	1.0	11.1	43.2 (9.7)	6.5	62.2	3.1	1.5	27.3 (3.9)	5.9
PETE_06	86.5	-	7.4	5.5 (-)	0.7	100.0	-	-	- (-)	-
PETE_07	61.6	2.0	15.6	6 (<0.0)	14.8	66.6	6.5	11.2	2.1 (-)	13.6
PETE_08	82.0	1.6	11.9	4.5 (-)	-	88.9	3.2	5.1	2.8 (-)	-
PETE_09	70.9	0.2	15.2	3.6 (-)	10.1	80.8	0.4	6.8	- (-)	12.0
PETE_10	80.6	-	6.8	12.6 (-)	-	100.0	-	-	- (-)	-
PETE_11	64.0	1.4	3.5	22.0 (4.9)	9.1	76.7	5.3	0.8	7.0 (1.5)	10.1
Within Park	81.7	2.8	8.2	5.7 (0.2)	1.6	90.9	5.1	1.7	1.0 (-)	1.3
All Watersheds	61.7	2.1	13.6	11.9 (1.9)	10.6	71.3	6.1	7.2	5.5 (0.9)	9.9

* Values in parenthesis are the proportion of developed total that is medium to high intensity

2.7 Richmond National Battlefield Park

2.7.1 Park Overview

Richmond National Battlefield Park (RICH) is located in and around the city of Richmond, Virginia (Figure A-43). This battlefield park commemorates the Siege of Richmond, the Confederate capital during the Civil War. The park and city lie along the transition (fall line) between the Coastal Plain and the Piedmont physiographic regions and between the James and York River basins. The park consists of approximately 2,900 acres (11.8 km²) contained in many disjunct units spread out over approximately 350 km² (135 mile²), ranging in size from less than ten acres to over 1,424 acres.

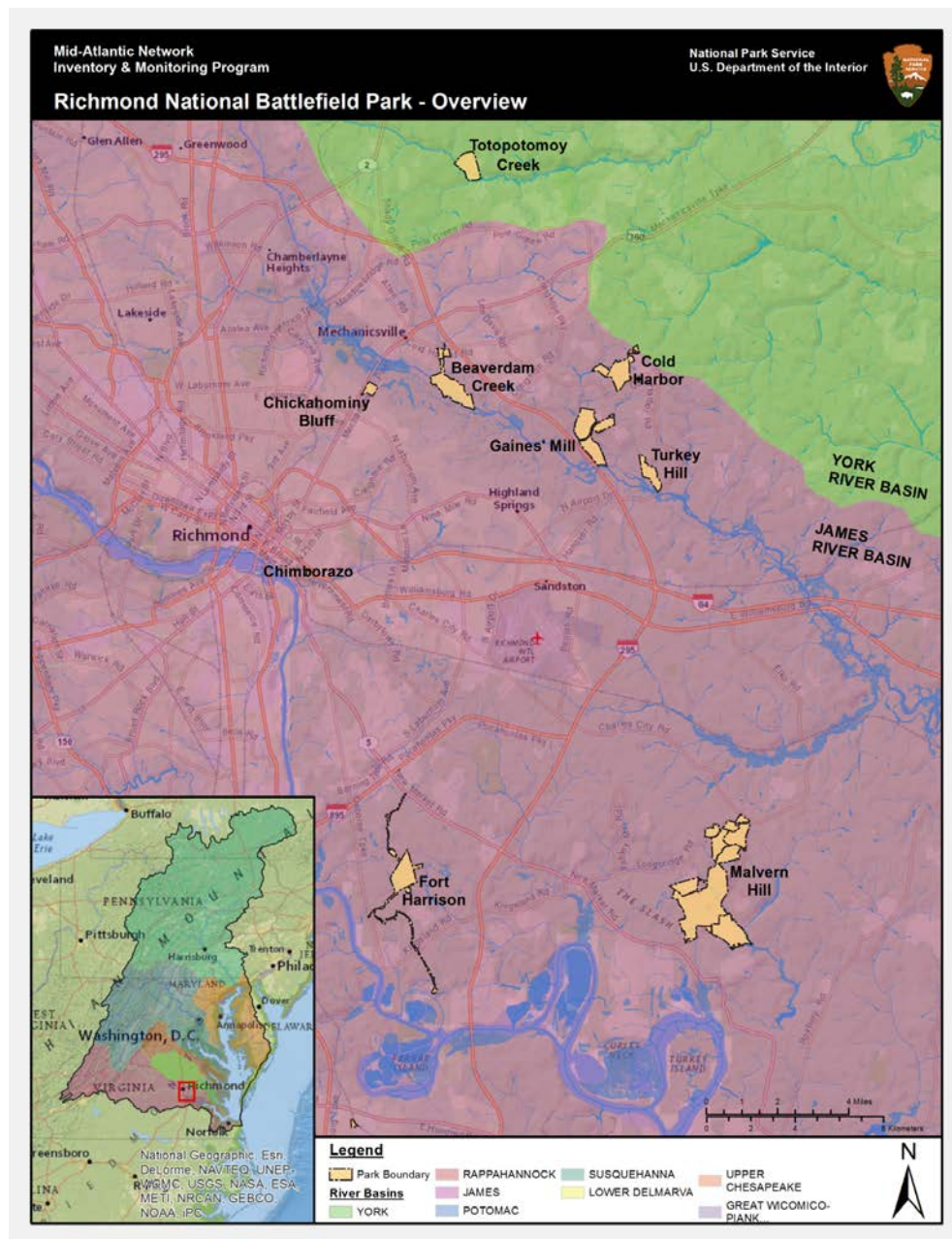


Figure A-43. Map displaying RICH highlighting aquatic resources.

2.7.2 Landscape setting

RICH is located in an area with level to gently rolling topography through which the James, Chickahominy, and Pamunky Rivers (Chesapeake Bay Watershed) have cut wide floodplains with terraces and steep valley sides (Brown 1939). The park is located at the western edge of the Coastal Plain physiographic province, along the fall line, which is the physiographic transition between the Coastal Plain and the Piedmont Plateau. The bedrock consists of partially consolidated sedimentary rocks of Cretaceous, Eocene, and Miocene marine sands; gravels, clays, shell marls, and diatomaceous sediment (Dietrich 1970). All of the park units are located on the Coastal Plain with the exception of the Chimborazo Visitor Center, where the crystalline Petersburg granite bedrock of the Piedmont province is visible.

The soils of the Coastal Plain are composed primarily of loosely consolidated sediments formed during the Cretaceous Period, less than 130 million years ago. It is characterized nearly throughout by terraces laid down by streams bringing sediments from the interior of the continent. The Coastal Plain is level or rolling, and covered with sand, silt, gravel, and other materials laid down over the millennia by the action of incoming streams. The soils are primarily sandy and silt loams (Brown 1939). Within the region, these landforms support a wide variety of land cover which includes agriculture (croplands and pasture/hay), urban development, wetlands and late successional forests.

2.7.3 Land Cover and Vegetation

Within the boundaries of RICH the primary land cover class is forested (45%), followed by wetlands (27.9%), agriculture (20.5%) and developed (Figure A-44, Table A-32) (5.6%; Homer et al. 2015). This is substantially more forested land than is found in the contributing watersheds of RICH (37.0%) and less than across the Chesapeake Bay Watershed (CBW; 54.7%). The watersheds that support RICH streams are much more developed (37.2%) than the CBW (11.0%) and have less land devoted to agriculture (20.5%) than the CBW (24.6%). RICH has substantially more wetland habitat (27.9%) than is found in either the contributing watersheds (8.8%) or the greater CBW (4.6%). These characteristics are integral to understanding stream conditions at RICH. Forested watersheds and buffers around streams have the ability to improve stream conditions by removing nutrients, controlling sediments, ameliorating temperature increases, and protecting physical habitat (Lowrance and Altier 1997, Jacobson 2001, Kaushal and Likens 2010). Acidic wetland habitats can naturally lower stream pH to levels that would normally be considered to be impaired unless this is taken into consideration.

The majority of vegetation within RICH is actively managed or has been modified by human activities within the recent past. Early successional or transitional vegetation covers 32% of the land in the park (444 acres) and actively managed areas, including mowed or maintained fields, agricultural lease lands, and man-made structures, cover an additional 25% (355 acres) of the park. The remaining land (43%) is dominated by late successional vegetation cover (600 ac; Patterson and VADCR 2008). In general, forest types transition from mixed hardwood to pine to mixed oak communities depending primarily on past land cover and the stage of succession. Dominant vegetation groups include oak/heath forest, mesic acidic forests, oak hickory forests, seepage wetlands, alluvial forests, and non-riverine forests (Patterson and VADCR 2008).

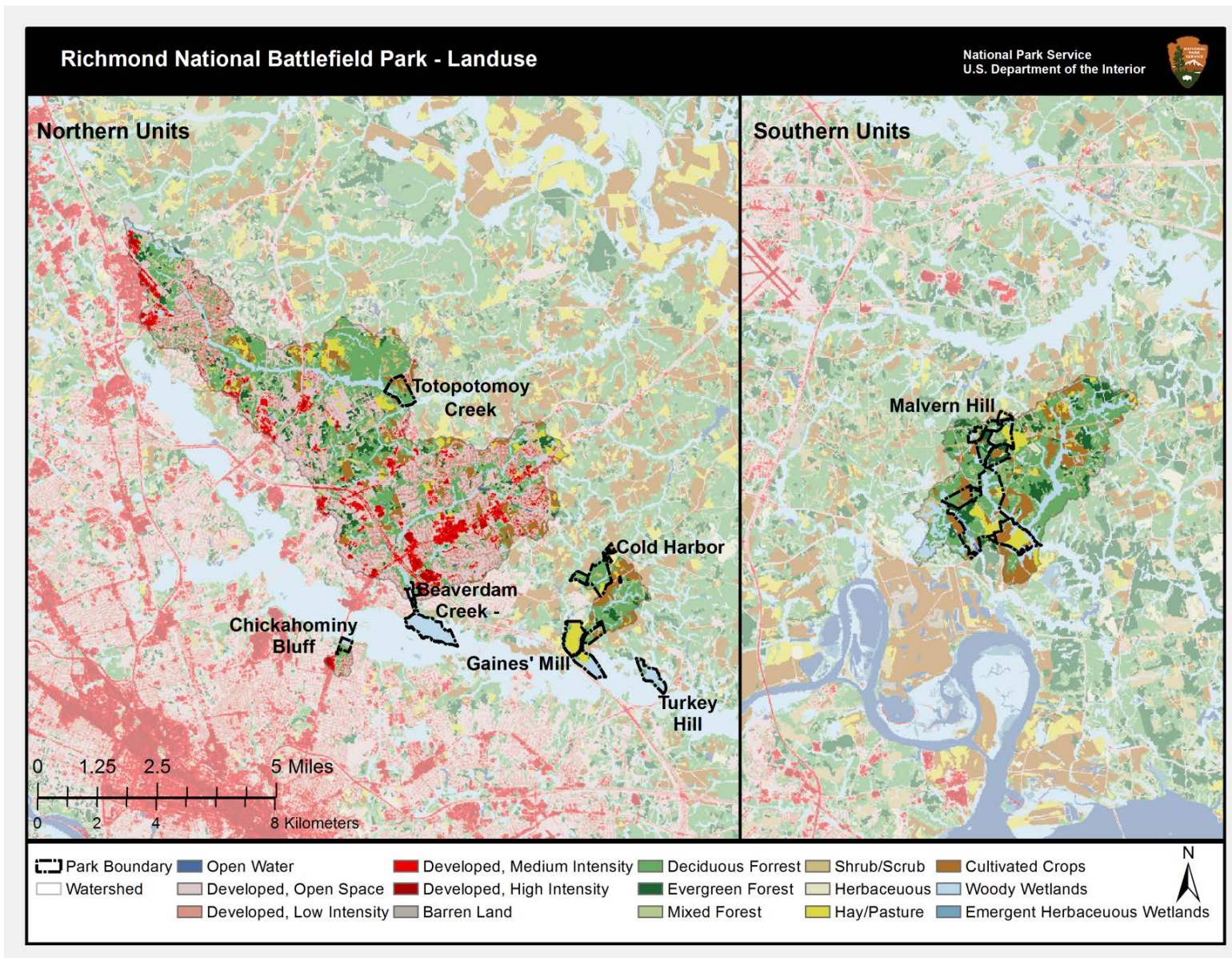


Figure A-44. Map displaying the National Land Cover Dataset classes for the contributing watersheds to the streams of RICH.

Table A-32. Land cover classification (Homer et al. 2015) of watersheds and riparian areas (100 meter buffer) associated with RICH, within RICH, and the CBW.

Land Cover Type	Watershed		100 Meter Buffer		Park		Chesapeake Bay Watershed	
	%	Area (km ²)	%	Area (km ²)	%	Area (km ²)	%	Area (km ²)
Forest Total	37.0	36.22	44.5	11.06	42.1	4.97	54.7	91,329
Deciduous Forest	26.1	25.53	34.0	8.45	29.8	3.53	42.8	71,401
Evergreen Forest	5.6	5.43	4.7	1.17	6.8	0.80	5.8	9,716
Mixed Forest	5.4	5.26	5.8	1.45	5.5	0.65	6.1	10,212
Agriculture Total	12.7	12.46	3.0	0.75	20.5	2.43	24.6	40,996
Pasture/Hay	3.8	3.72	1.1	0.26	12.8	1.51	14.9	24,913
Cultivated Crops	8.9	8.75	1.9	0.48	7.7	0.91	9.6	16,083
Developed Total	37.2	36.41	22.0	5.47	5.6	0.66	11.0	18,432
Developed, Open Space	20.3	19.81	12.6	3.12	5.4	0.64	6.6	10,992
Developed, Low Intensity	11.6	11.39	7.7	1.91	0.2	0.02	2.8	4,696
Developed, Medium Intensity	4.2	4.14	1.6	0.39	<0.1	<0.01	1.2	2,005
Developed, High Intensity	1.1	1.07	0.2	0.05	-	-	0.4	739
Grassland/Herbaceous	0.3	0.32	0.2	0.05	0.5	0.06	0.8	1,335
Scrub/Shrub	3.5	3.45	3.5	0.87	3.1	0.37	2.2	3,709
Open Water	0.2	0.19	0.8	0.19	0.2	0.03	1.8	2,950
Barren Land	0.1	0.12	0.1	0.02	-	-	0.3	489
Woody Wetlands	8.7	8.47	25.4	6.31	27.0	3.19	3.7	6,244
Emergent Herbaceous Wetlands	0.1	0.14	0.5	0.13	0.9	0.11	0.9	1,471
Total	100.0	97.78	100.0	24.84	100.0	11.81	100.0	166,957

There are approximately 110 acres of forested wetlands occurring in the park. In general, the wetlands are found along the banks of several small tributaries of the James and Chickahominy Rivers, or within the floodplain of the Chickahominy River. The majority of the forested wetlands in the park (80 acres) are mapped as Non-Riverine Saturated Forest or Non-Riverine Saturated Forest - pine subtype at Chickahominy Bluff, Fort Harrison, and Malvern Hill. Several isolated headwater wetlands totaling 22 acres in Cold Harbor, Malvern Hill, and Fort Harrison support Coastal Plain / Piedmont Acidic Seepage Swamps. The portion in Cold Harbor is considered globally rare. Several uncommon odonates (dragonflies and damselflies) depend on such forested seeps for breeding habitat. Small areas totaling 10 acres at Beaverdam Creek, Chickahominy Bluff, Malvern Hill, and Watt House are mapped as Coastal Plain / Piedmont Small-Stream Floodplain Forest. Much of the area that formerly supported this community has been altered by beaver activity and is now mapped as Beaver Wetland Complex (Patterson and VADCR 2008).

RICH is composed of many disjunct units distributed across the Coastal Plain, primarily to the east of the City of Richmond. The Beaver Dam Creek unit (30 acres) consists of a wide wetland area bordering the creek and the surrounding forested floodplain. Much of the site is dominated by wetland plants; however, the forest portion is made up of relatively young mixed hardwoods. The Cold Harbor unit (186 acres) is made up primarily of drier upland areas with sandy soil that support upland secondary growth forest types (oak-hickory). The park maintains an open savannah-like pine forest with the use of prescribed fire to enhance habitat conditions for wildlife. Bloody Run Creek bisects the unit from east to west and supports a rare sedge species. Additionally, a portion of the area mapped as Coastal Plain / Piedmont Acidic Seepage Swamp in Cold Harbor is considered a Natural Heritage exemplary natural community occurrence. The vegetation at the Malvern Hill unit (1,024 acres) ranges from flat uplands, to rich coves, drier side slopes, moist bottomlands, and wetlands. One notable community is a small section of streamside bottomland that is home to a bald cypress grove along with a canopy of sweetgum, red maple, and tulip poplar. The forest is secondary growth with transitional species of loblolly pines, oaks and beeches bordering parts of the fields. The western portion drops to wetland swamp containing diverse flora. Cherrybark oaks (*Quercus pagoda*) noted at Malvern Hill measured over 80 cm (31.5 in) in diameter. The Gaines' Mill unit (59.7 acres) contains a plateau covered by grassland and early successional mixed hardwood-pine forest, wooded slopes dominated by an old-growth oak forest community, and a wide bottomland community along Boatswain Creek. Older woodlands are dominated by white oak, tulip, and American holly while younger successional areas are dominated by loblolly pine and exotics. The Chickahominy Bluff unit (37 acres) contains an 18 acre wooded slope dropping to the Chickahominy River floodplain and a tributary stream. There is a one acre vista clearing maintained in native meadow species. Willow oaks (*Quercus phellos*) greater than 1.0 m (3.3 ft) in diameter were recorded from this area. The Drewry's Bluff unit (39.5 acres) is primarily forested, containing a mix of oak and oak-hardwood forests. Non-forested areas include a closed and reclaimed county landfill capped with soil and maintained in native warm season grasses. The unit is bisected by a small unnamed stream within a steeply sloped ravine. The Parker's Battery unit (10 acres) is flat and covered with secondary growth eastern deciduous mesic forest.

2.7.4 Water resources and current status of water quality

The National Park Service manages 28.6 km of streams at RICH and the watersheds associated with these streams drain approximately 100 km² of the region (Figure A-45, Table A-33) (USGS 2014). These watersheds are located within the greater Chesapeake Bay watershed, home to the largest estuary in the United States which has been degraded over time primarily due to excess nutrient and sediment loads delivered from the upland watershed (Kemp and Boynton 2005). The James River is the dominant water feature in the region. Feeding into the Chesapeake Bay and originating in the mountains of western Virginia, the James River spans almost the entire state. The park units overlooking the James (Chimborazo, Fort Harrison, and Drewry's Bluff) provide unique perspectives on an important change in the river's composition. Chimborazo is located in downtown Richmond and the river to the west is generally shallow and faster moving which marks the transition zone from the Piedmont and the Coastal Plain. At Drewry's Bluff and Fort Harrison to the east of the city, the river is much deeper and slower moving in the Coastal Plain. The park's other units contain smaller streams that ultimately serve as tributaries to the James River. Beaverdam Creek, Boatswain Creek and Bloody Run, all located in the park's northern most units, empty into the Chickahominy River, which in turn, empties into the James. Crewes Channel and Western Run, both located at the park's Malvern Hill unit, empty directly into the James River. The Totopotomoy unit has the only stream which is outside of the James River Basin, Totopotomoy Creek, located north of the watershed divide in the York River Basin.

Perennial streams within RICH are predominately smaller, headwater tributaries to the James River (~93%; Table A-33) and range from first to fourth order. Headwater streams (stream order 1-3) are typically dominated by allochthonous inputs, streams are shaded by riparian vegetation reducing primary production and much of the organic matter comes from terrestrial sources. As streams increase in size (stream order 3-5), there is a shift towards autochthonous resources, primary production increases and shifts in the composition of the biological community occur (Vannote et al. 1980). Thirty species of fish have been documented in RICH streams during 2002-2003 sampling efforts (Atkinson 2008), including 3 species from Beaverdam Creek that are not found elsewhere within the MIDN including gizzard shad (*Dorosoma cepedianum*), ironcolor shiner (*Notropis chalybaeus*), and swamp darters (*Etheostoma fusiforme*). Twenty-seven species of aquatic macroinvertebrates have been found within a single stream (MIDN data) and 15 species of frogs, 12 species of salamanders, and eight species of turtles have been documented throughout RICH (Mitchell 2007b). In a rapidly urbanizing landscape, these streams and associated lands are significant regional resources as a result of the protection of the landscape provided by the National Park Service.

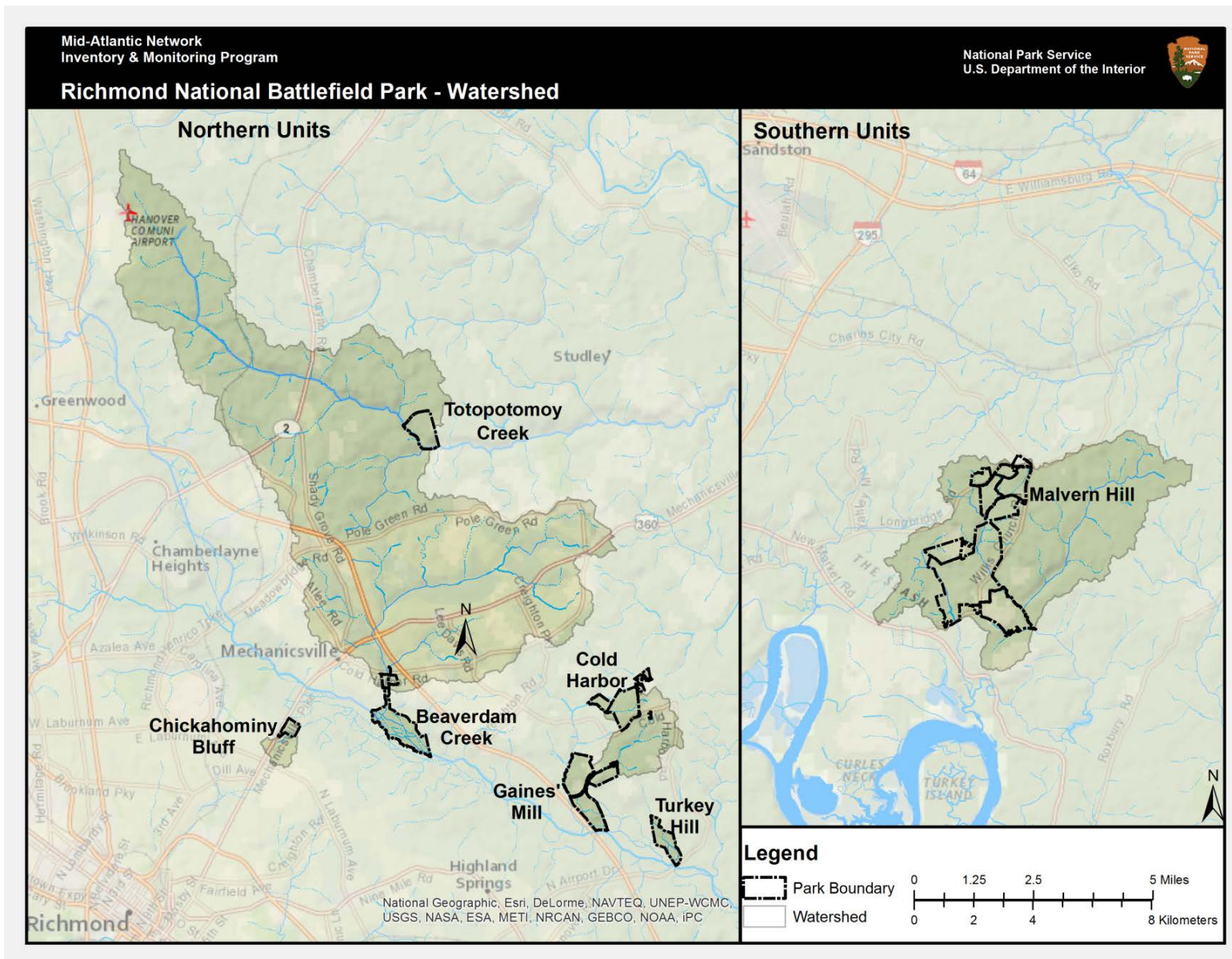


Figure A-45. Watersheds associated with RICH streams.

Table A-33. Strahler stream order classification by length (km) within the contributing watershed of RICH streams.

Stream Order	Intermittent	Perennial	All Streams (Within Park)	% Perennial
1	61.8	12.9	74.7 (10.7)	17
2	10.2	17.8	28.0 (6.2)	64
3	-	22.8	22.8 (7.4)	100
4	-	6.0	6.0 (4.3)	100
Total	72.0	59.5	131.5 (28.6)	
% Headwater (1st – 3rd)	100	90	95 (85)	

During the 2012 assessment cycle the Commonwealth of Virginia found that approximately 16% of all stream lengths did not meet water quality standards, 6% were not impaired, and 78% were not assessed (Figure A-46, Table A-34) (VADEQ 2014). Although streams within RICH had a higher proportion listed as impaired compared to statewide numbers (Fig. A-46), the proportion of streams fully supporting designated uses was three times greater (51%) and the unassessed proportion was substantially less (3%; VADEQ 2011). The majority (70%) of the park units within RICH contain at least one stream that doesn't fully support one or more of its designated uses due to water quality impairments. Where aquatic life use standards were not met, 80% of the impairments were due to dissolved oxygen and pH levels. Many of these streams may not meet water quality standards due to natural conditions. In order for these streams to be reclassified (i.e. - from tidal water to swamp water) or have changes to their designated uses, a water quality standards use attainability analysis would need to be performed to ensure streams are classified properly and can meet current standards under natural conditions. Eighty-six percent of streams assessed for recreational use were found to have E. coli bacteria contamination. Bacteria contamination usually results from improper treatment of waste from leaky septic and sewer systems as well as agricultural practices. Chickahominy River in the Beaverdam Creek unit also has a fish consumption advisory in effect due to high mercury levels found in fish tissue samples. Mercury contamination is caused by atmospheric deposition and due to the developed and industrial nature of the area it is not surprising. All streams assessed for wildlife uses were found to be fully supporting those uses.

The Drewry's Bluff unit has several areas of concern. These include: (1) the erosion of the bluff which poses a threat to Fort Darling; (2) the Central Oil Asphalt Terminal on the northern boundary of the unit, which discharges stormwater to an unnamed tributary flowing through the unit; and (3) a landfill within the southern portion of the unit, which discharges leachate to the unnamed tributary that flows through the unit and discharges into the James River (Rice et al. 2003). The park is presently working, through an NPS Attorney Advisor, and in cooperation with Chesterfield County, to complete an Engineering Evaluation/Cost Analysis for remediation action at the landfill site. An assessment of the landfill located in the Fort Darling unit from 1989 to 1992 was conducted and concluded that CERCLA hazardous substances were present in the leachate. More recent investigations of the macroinvertebrate community upstream and downstream from the landfill indicate that there is some impact (Nimmo et al. 1994).

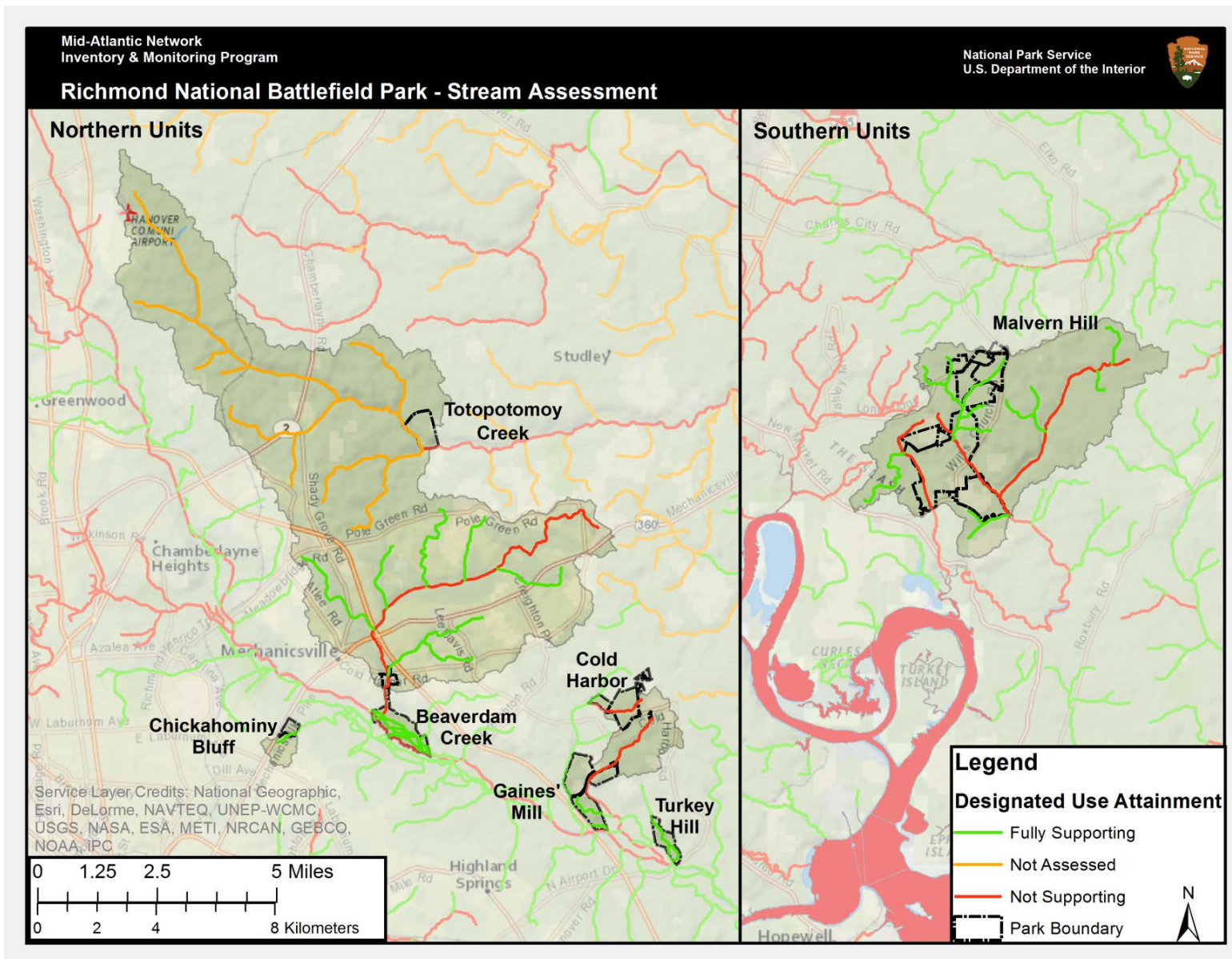


Figure A-46. Map displaying the attainment status of RICH streams from the VA DEQ 2012 305(b)/303(d) biannual water quality assessment.

Table A-34. Regulatory standards for baseline water quality parameters (temperature, pH and dissolved oxygen) in the Commonwealth of Virginia and EPA recommended guidance.

Regulatory Parameter	Beneficial Use	EPA National Recommended Water Quality Criteria (2012)	State of Virginia Standard - 9VAC25-260-50 (2011)
Temperature (°C)	Warm-water fishes	Species specific criteria	32°C Max Temp Non-tidal Waters (Coastal and Piedmont Zones)
pH	Aquatic Life	6.5 - 9	6 - 9
Dissolved Oxygen (mg/l)	Aquatic Life	Warm water Min. Criteria - early life stages = 5.0, other life stages = 3.0, invertebrate min. criteria = 4.0	Min. = 4, Daily Avg = 5

Until recently, water quality data within RICH has been sparingly and inconsistently collected. A richer historical data set is available by reaching outside of NPS boundaries, however much of this data concerns larger, distant rivers resulting in an inability to directly infer conditions in RICH streams. This data can, however, reveal some general water quality concerns at a regional scale. A data mining project completed by the Water Resources Division (WRD) of the NPS found that two of the biggest concerns throughout the region were stream pH and total coliform concentrations (NPS 1999c). pH observations were below the EPA chronic criteria for aquatic life (6.5 – 9) in 21% of observations (n = 7535). The acidification risk has also been highlighted in an NPS Air Resources Division study where the MIDN was ranked as having the highest overall risk of acidification to surface waters of any of the NPS' 32 Inventory and Monitoring Networks (Sullivan et al. 2011). The WRD's baseline water quality report also conducted an analysis to determine seasonal patterns in stream discharge, which can be informative in interpreting stream conditions, that established three distinct hydrological seasons: rising limb (mid-Oct. – mid-March), falling limb (mid-March – June), and base flow (July – mid-Oct.; Figure A-47). More recently the MIDN initiated a water quality pilot study to establish a long-term monitoring protocol as well as a benthic macroinvertebrate sampling program to assess stream conditions at RICH. Approximately 15% of pH observations (n = 249) collected as part of this pilot study were below the water quality criteria established by the Commonwealth of Virginia. Additionally, 5% of dissolved oxygen concentration observations were below the criterion (Figure A-48, Table A-34). Some of these waters, however, will likely be reclassified from tidal waters for assessment to swamp waters after review by state regulators. This reclassification would relax the pH and dissolved oxygen standards for these waters due to natural conditions. The primary water issues facing RICH streams are related to anthropogenic alterations to the contributing watershed. RICH is located in close proximity to one of the largest cities in Virginia and urban development has altered the ecology of many of the streams. Streams in currently rural watershed may also become impacted if these watersheds are developed in the future.

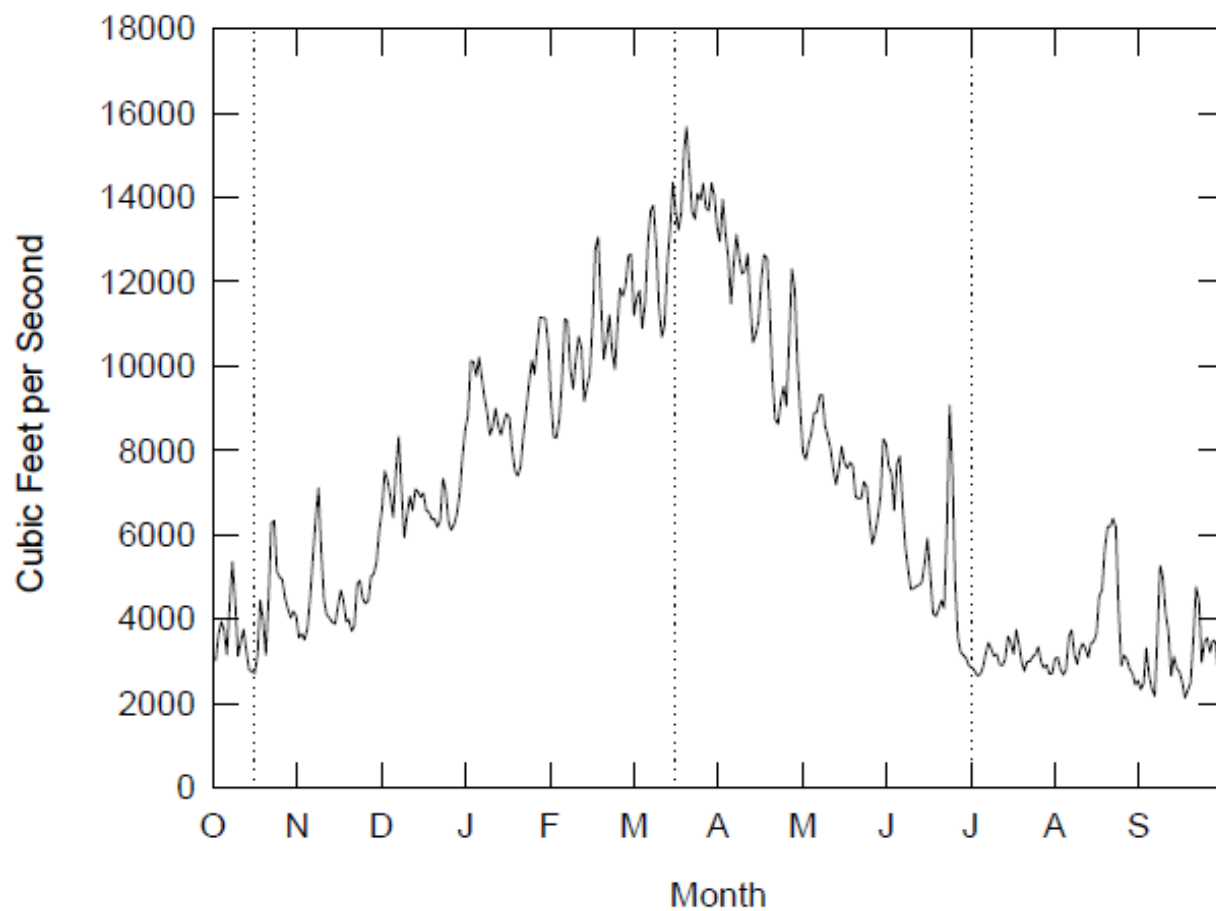


Figure A-47. Representative mean annual hydrograph used to conduct hydrologic seasonal analysis (James River: 37° 33' 47" N, 77° 32' 50" W). Adapted from "Baseline Water Quality Data: RICH" by NPS, 2000. P. 46. Reprinted with permission.

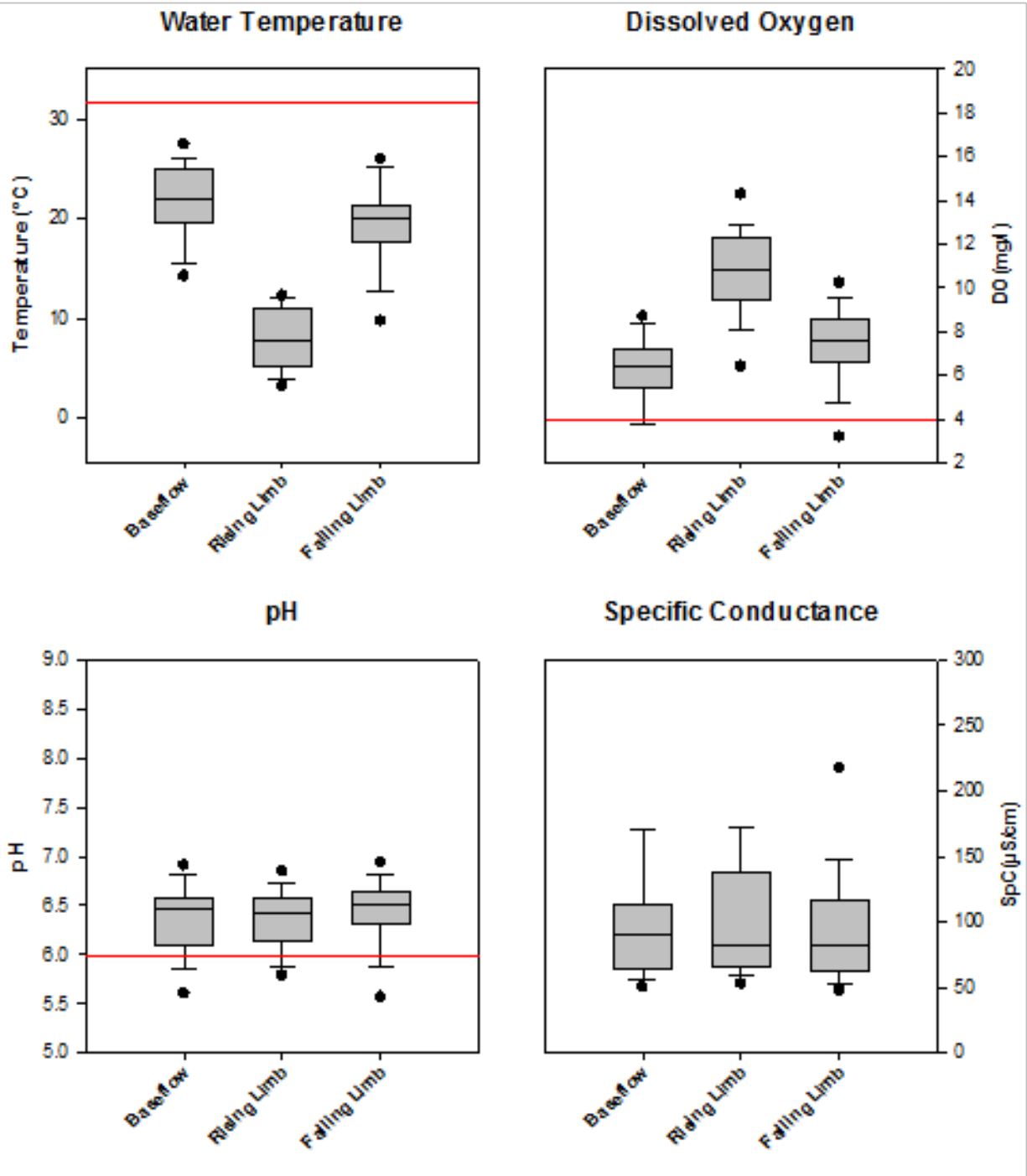


Figure A-48. Box plots (box: median, interquartile range; whiskers: 10th and 90th percentile; points: 5th and 95th percentile) for "core" water quality parameters measured during pilot study and grouped by hydrologic season at RICH (2010-2013). Red lines indicate water quality thresholds established by the Commonwealth of Virginia.

2.7.5 Long-term Monitoring Sites

In an effort to monitor the status and trends of wadeable streams at RICH several long-term monitoring sites have been selected. Sites were placed in streams of significant value to the park as determined by RICH and MIDN staff (Figure A-49, Table A-35). Stream reaches of particular importance to park management were identified from within these established sites for enhanced monitoring by integrating other MIDN protocols (BMI monitoring) and continuous monitoring of water quality parameters. Additionally, a summary of land cover classes is provided for the watershed at each long-term site (Table A-36). The Chickahominy River was excluded from monitoring and all land cover metrics as it is a larger stream which is classified as non-wadeable.

RICH_01: Beaver Dam Creek

RICH_01 is located upstream of the confluence of Beaver Dam Creek with the Chickahominy River. The contributing watershed is highly urbanized; however, Beaver Dam Creek supports the greatest diversity of fish within RICH. The stream is a wide, deep slough that crosses a broad marsh and forested lands within park boundaries.

RICH_02: Tributary to Chickahominy River

RICH_02 is located within one of the smaller units of RICH (Chickahominy Bluff) to the south of the Chickahominy River. The watershed is small and dominated by urban development with the park lands contributing forested cover. The stream channel cuts through a sandy valley and commonly shifts location during high discharge events.

RICH_03: Boatswain Creek

RICH_03 is located in the Gaines Mill unit of RICH. Gaines Mill is in a rural area where the majority of the landscape is forested. Development pressures in this watershed include urban development and agricultural land uses. There is substantial wetland area within this watershed as well as beaver activity which alters the stream channel.

RICH_04: Bloody Run

RICH_04 is located in the Cold Harbor unit of RICH and drains an acidic seepage swamp. This unit is located in a rural area and is dominated by agricultural and forested land cover classes. Bloody Run is a first order perennial stream.

RICH_05: Totopotomoy Creek

RICH_05 is the northernmost sampling location in RICH and is the only park stream located in the York River Basin. Totopotomoy Creek is located in a highly suburbanized watershed. Within the park unit, Totopotomoy is a wide, deep slough.

RICH_06: Crewes Channel

RICH_06 is located at the discharge point of a seasonally inundated wetland system. Due to beaver activity and culvert blockages at VA Route 156, a large, shallow pond forms. The culvert is cleared periodically by VDOT to protect the infrastructure associated with the state road. This watershed has the highest proportion of wetland habitat of any of the RICH streams.

RICH_07: Western Run

RICH_07 is located in the Malvern Hill unit of RICH. This stream is located in one of the largest contiguous units of RICH and the park owns a substantial portion of the contributing watershed. The watershed is primarily forested with a substantial portion of wetland habitat associated with the riparian corridor.

RICH_08: Tributary to James River

RICH_08 is located in a small unit (Drewry's Bluff) adjacent to the James River. This site is monitored due to concerns of leachate from a decommissioned landfill. This monitoring is meant to capture data concerning water quality while other efforts are made to address issues associated with the landfill (K. Allen pers. com.).



Richmond National Battlefield Park - Monitoring Sites

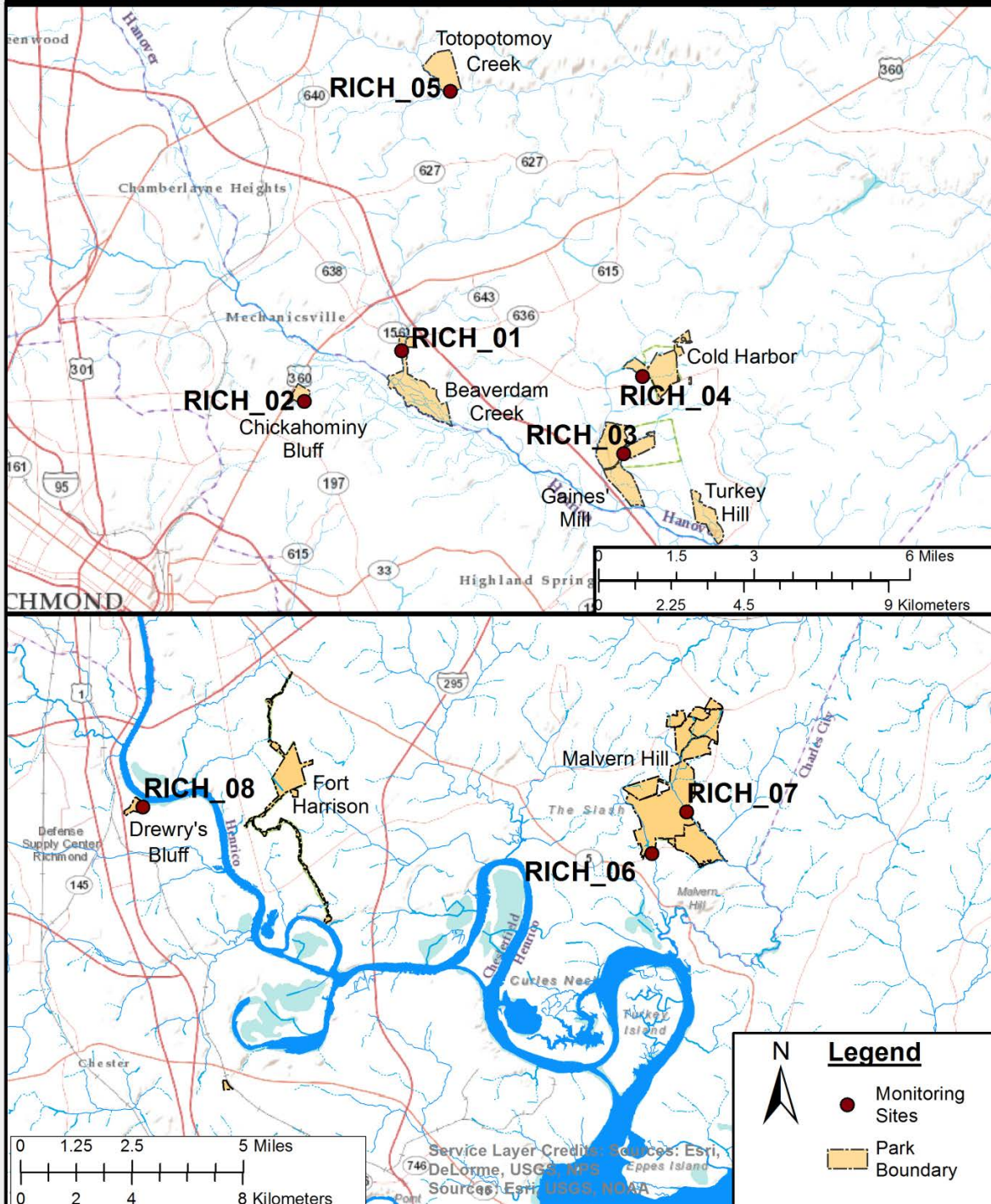


Figure A-49. Long-term water quality monitoring sites at RICH.

Table A-35. List of long-term monitoring site at RICH.

Site ID	Stream Name	USGS HUC-14	Latitude	Longitude	Type of Site (D,BMI, Con)*
RICH_01	Beaverdam Creek	02080206001170	37.59513	-77.35908	D
RICH_02	tributary to Chickahominy River	02080206001332	37.58375	-77.3862	D, BMI
RICH_03	Boatswain Creek	02080206001163	37.57236	-77.29733	D
RICH_04	Bloody Run	02080206001167	37.5892	-77.29192	D, BMI
RICH_05	Totopotomoy Creek	02080106000447	37.65249	-77.34549	D
RICH_06	Crews Channel	02080206016368	37.4087	-77.25588	D
RICH_07	Western Run	02080206013920	37.41948	-77.24512	D, BMI, Con
RICH_08	tributary to James River	02080206-----	37.42057	-77.42125	D

* D = Discrete Water Quality, BMI = Benthic Macroinvertebrate, Con = Continuous Water Quality Monitoring

Table A-36. Land cover (%) of the major land-use classifications from the NLCD (Homer et al. 2015) for the watershed and riparian areas (100 meter buffer) associated with each site selected for long-term monitoring.

Site ID	Watershed					100-meter Buffer				
	Forest	Wetlands	Agriculture	Developed*	Other	Forest	Wetlands	Agriculture	Developed*	Other
RICH_01	19.7	4.0	8.7	65.1 (10.9)	2.6	37.7	15.4	1.6	40.6 (3.8)	4.7
RICH_02	31.0	-	-	69.0 (18.8)	-	79.3	-	-	20.7 (2.1)	-
RICH_03	59.1	8.4	25.5	4.1 (-)	2.9	67.8	24.0	3.6	2.4 (-)	2.1
RICH_04	40.7	8.4	41.6	3.4 (-)	6.0	63.3	27.6	6.7	- (-)	2.4
RICH_05	39.1	6.4	9.1	41.2 (5.0)	4.2	47.8	19.6	2.6	25.1 (1.8)	4.9
RICH_06	49.5	24.4	16.2	1.9 (-)	8.0	39.6	48.5	5.1	- (-)	6.8
RICH_07	57.6	14.7	15.7	6.4 (-)	5.6	45.6	36.8	7.1	5.2 (-)	5.4
RICH_08	53.7	-	5.4	35.7 (9.4)	5.1	**	**	**	**	**
Within Park	42.1	27.9	20.5	5.6 (<0.0)	3.9	38.9	48.7	4.8	2.3 (-)	5.3
All Watersheds	37.0	8.8	12.7	37.2 (5.3)	4.2	44.5	25.9	3.0	22.0 (1.8)	4.5

* Values in parenthesis are the proportion of developed total that is medium to high intensity

** Stream is not included in the NHD so no values for the buffer area were derived

2.8 Valley Forge National Historical Park

2.8.1 Park Overview

Valley Forge National Historical Park (VAFO) is located in Valley Forge, Pennsylvania 20 km (12 miles) northwest of Philadelphia, PA (Figure A-50). The park preserves approximately 3500 acres of cultural and natural resources associated with the winter encampment of General George Washington and the Continental Army. The park is surrounded by extensive urban and suburban development associated with the western suburbs of Philadelphia. VAFO is primarily composed of open land (pasture: 33.3% and open developed land: 12.6%) and forests (39.2%) while the contributing watershed for Valley Creek, the primary water feature of the park, is dominated by developed lands (56.7%) (Homer et al. 2015).

2.8.2 Landscape Setting

VAFO is located within the Delaware Bay Watershed (DBW) and is a part of the Piedmont physiographic province. The rocks in this area range from metamorphosed and deformed Precambrian gneisses and Paleozoic metamorphosed sedimentary rocks to the gently tilted, much younger sedimentary strata of the Mesozoic rift basins. Soils are predominantly, moderately well drained silt loams derived from weathered limestone, schist, gneiss, and quartzite. Soils types found within VAFO and the surrounding area are considered a moderate to severe erosion hazard (Comiskey and Callahan 2008).

2.8.3 Land Cover and Vegetation

Within the boundaries of VAFO the primary land cover class is forested (39.2%), followed by agricultural (36.6%) and developed (16.6; Homer et al. 2015) (Figure A-51, Table A-37). The vast majority of the lands classified as agriculture and developed within VAFO are managed meadows intended to support a variety of native grassland associated flora and fauna. The acreage of managed meadows exceeds forested area at VAFO. These grasslands represent one of the largest uncultivated, permanently maintained meadow complexes in the mid-Atlantic piedmont (Latham 2012). The watersheds that support Valley Creek are significantly more urbanized (56.7%) than the DBW (20.4%) and have less forested land (28.7%) than the DBW (45.6%). The trend towards urbanization has been occurring over a long period of time and the watershed has undergone numerous and varied development pressures since European settlement when the region was predominantly forested. Aerial photos from 1937 indicate that approximately 50% of the watershed had been converted for use as agricultural land, 24% was forested, and only 4% of the lands were considered developed (urban/suburban/commercial; CCWRA 2010). However, by 1997, land cover shifted away from agriculture (7%) towards development (48%) and forested land cover (32%; Reif 2002). These characteristics are integral to understanding stream conditions at VAFO. Forested watersheds and buffers around streams have the ability to improve stream conditions by removing nutrients, controlling sediments, ameliorating temperature increases, and protecting physical habitat (Lowrance and Altier 1997, Jacobson 2001, Kaushal and Likens 2010).

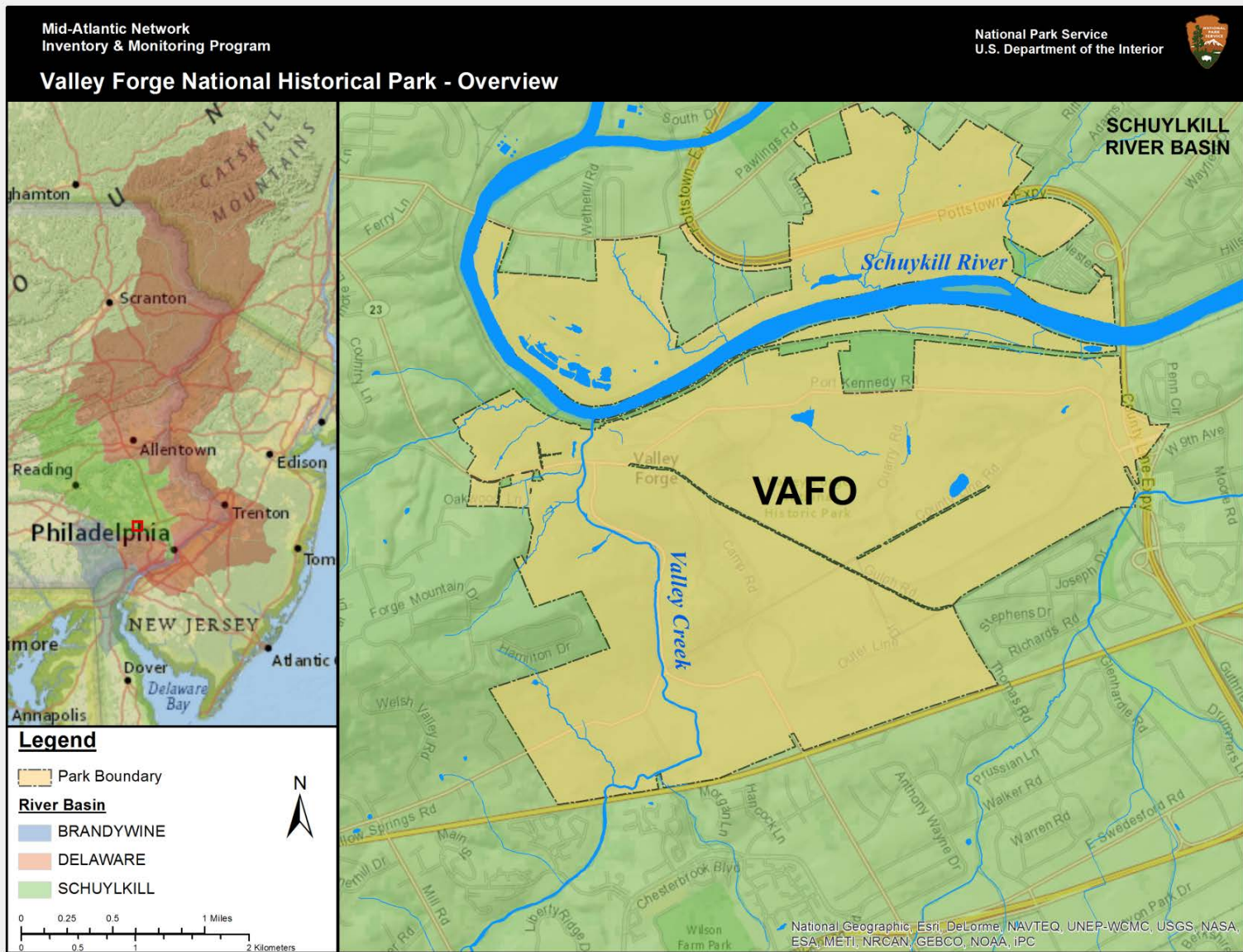


Figure A-50. Map displaying VAFO highlighting the aquatic resources.

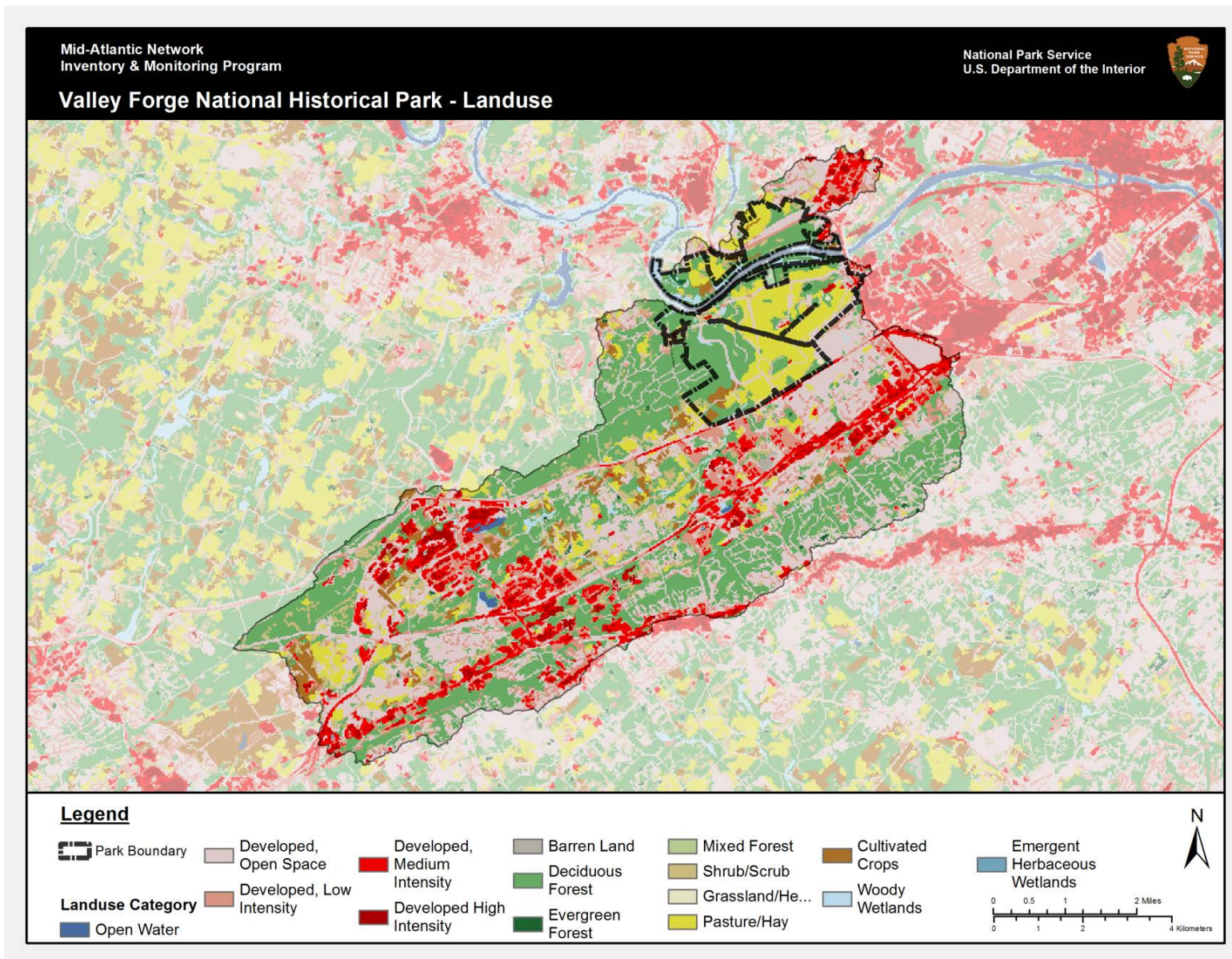


Figure A-51. Map displaying the NLCD classes for the watersheds associated with VAFO (excluding the Schuylkill River).

Table A-37. Land cover classification (Homer et al. 2015) of watersheds and riparian areas (100 meter buffer) associated with RICH, within RICH, and the CBW.

Land Cover Type	Watershed		100 Meter Buffer		Park		Delaware Bay Watershed	
	%	Area (km ²)	%	Area (km ²)	%	Area (km ²)	%	Area (km ²)
Forest Total	28.7	15.42	39.7	4.07	39.2	4.86	45.6	15,267
Deciduous Forest	27.7	14.88	38.1	3.90	38.1	4.73	38.1	12,753
Evergreen Forest	0.1	0.08	0.3	0.03	0.7	0.08	2.8	0,936
Mixed Forest	0.9	0.46	1.3	0.14	0.4	0.05	4.7	1,578
Agriculture Total	7.3	3.94	6.2	0.64	36.6	4.54	19.7	6,606
Pasture/Hay	4.2	2.25	3.7	0.38	33.3	4.13	9.3	3,115
Cultivated Crops	3.2	1.69	2.5	0.26	3.3	0.41	10.4	3,491
Developed Total	56.7	30.41	43.7	4.48	16.6	2.05	20.4	6,816
Developed, Open Space	28.9	15.49	25.4	2.60	12.6	1.56	10.9	3,637
Developed, Low Intensity	12.3	6.59	8.2	0.84	3.0	0.38	5.4	1,811
Developed, Medium Intensity	11.7	6.28	7.8	0.80	0.9	0.11	2.8	0,937
Developed, High Intensity	3.8	2.05	2.2	0.23	0.1	0.01	1.3	0,430
Grassland/Herbaceous	0.1	0.04	<0.1	<0.01	0.1	0.02	0.5	0,152
Scrub/Shrub	5.7	3.06	4.9	0.50	3.5	0.44	1.9	0,634
open water	0.3	0.19	0.6	0.06	0.1	0.02	2.6	0,874
Barren Land	0.1	0.06	0.1	0.01	-	-	0.4	0,127
Woody Wetlands	1.0	0.55	4.9	0.50	3.6	0.45	6.6	2,216
Emergent Herbaceous Wetlands	-	-	-	-	0.2	0.03	2.3	0,761
Total	100.00	53.66	100.0	10.25	100.0	12.40	100.0	33,453

The vegetation of VAFO was mapped during 2000 and 2001 using a combination of aerial imagery and vegetation plots. Before European settlers arrived, VAFO was mostly forested but the original forest was progressively cleared for agriculture, shelter and firewood (Rhoads 1989). The Northeastern Modified Successional Forest is the most common forest type found throughout the park in areas with a history of disturbance, such as abandoned farmland and forest gaps (400 acres; Podniesinski et al. 2005b). The western portion of the park and south of the Schuylkill River consists primarily of the Tuliptree - Oak Forest (316 acres). Moderate to steep slopes (including Mount Misery and Mount Joy) generally consist of Dry Oak Forest. Grasslands comprise a significant percentage of park property. Prior to implementation of the Field Management Plan in 1992, approximately 1050 acres of mowed lawn were maintained south of the Schuylkill River but by 2000 over 885 acres had been converted to tall grass meadow. The establishment of tall grass meadows met several management objectives including a return to a landscape more suggestive of the small grain agriculture prior to the arrival of the Continental Army. The desired future condition of these meadow complexes, and management actions to achieve these goals, were updated by VAFO to further enhance the value and quality of these native grasslands (Latham 2012).

VAFO also has a significant number of wetlands with a total of 51 palustrine wetlands encompassing 64 acres. Forested wetlands, consisting of Sycamore – Green Ash Forests and Silver Maple Temporarily Flooded Forests, can be found along the floodplains of the Schuylkill River and smaller streams as well as poorly drained depressions. Emergent herbaceous wetlands can be found in poorly drained fields (Wet Meadows) and in springheads or moist draws of upland forest (Skunk Cabbage Seepage Meadows). Of those 51 wetland ecosystems, 17 wetlands met the PA Title 25, Chapter 105 Exceptional Value (EV) wetland designation due to their location in or along the floodplain of a wild-reproducing trout stream that runs through the park (Sharpe et al. 2012).

Riparian areas throughout the park are ecologically significant in terms of providing critical habitat for a variety of plant and animal species. Many of the plant and animal species of concern found within the park rely on riparian habitats for their continued survival including such species as the Great Egret (state threatened bird) and the Bridle Shiner (*Notropis bifrenatu*) (state endangered fish). Many of the frogs and reptiles of high conservation value utilize stream banks, rivers and ponds, and wetlands. Possum haw (*Viburnum nudum*), a state endangered plant, is associated with wetland and riparian areas specifically in the Valley Creek watershed (Comiskey and Callahan 2008).

2.8.4 Water Resources and Current Status of Water Quality

VAFO's watershed is located within the greater Delaware Bay watershed (the Delaware Bay Estuary is a Ramsar Wetland of international importance), home to the largest population of Horseshoe crabs in the world. The bay's watershed primarily drains southeast Pennsylvania, southwest New Jersey, and northeast Delaware. Although nutrient loading is a concern for the bay, pollution from the 300 year legacy of the industrial revolution poses a larger concern for the estuary (EPA 2007). Wadeable streams within VAFO are composed of smaller, headwater reaches and range from first to third order (Table A-38). Valley Creek, a perennial tributary to Schuylkill River, is a third order stream and the dominant wadable aquatic resource within the park. Valley Creek has been recognized widely as a valuable natural resource within the region and is classified as a Class A Trout Stream as well as an

Exceptional Value (EV) waterway, Pennsylvania Department of Environmental Protection's (PADEP) most protective stream designation. Designated in 1993, it is the most urbanized watershed in Pennsylvania to have achieved EV classification (Cahill 1997). The NPS manages approximately 10 km of Valley Creek and its tributaries within the boundaries of VAFO and the watersheds associated with these streams drain approximately 60 km² of the region (Table A-38, Figure A-52) (USGS 2014). Stream reaches within VAFO act as a refuge for fishes, namely brown trout, and benthic macroinvertebrates. Brown trout have been largely excluded from the upstream reaches of the watershed due to the effects of urbanization and the largest individuals are found within the boundaries of VAFO (Kemp and Sporila 1997).

The watershed outside of VAFO is highly developed (>50%) and has a legacy of industrial pollution affecting the Valley Creek. As a result, Valley Creek is included in the PADEP 303(d) list of impaired waters and a fish consumption advisory has been issued based on elevated accumulation of polychlorinated biphenyls (PCBs; PADEP 2014). The PCB contamination is attributed to the Paoli Rail Yard, which is on the EPA's National Priority List (i.e., Superfund sites), in the upper watershed of Valley Creek. For decades PCBs were released into Valley Creek and by 1980 PCB levels had reached 15 parts per million (ppm) in Little Valley Creek. In 1984, the PA Fish and Boat Commission put Valley Creek under a catch and release restriction to protect the public from high PCBs found in the flesh of trout. PCB-carrying runoff was found in three tributaries of Little Valley Creek, the lower half of Little Valley Creek, and the lower part of Valley Creek. Although water quality in Valley Creek is good, bottom sediments are contaminated with PCBs. As a result of a suit filed by the U.S. Environmental Protection Agency, a settlement of \$850,000 was paid to the Valley Creek Watershed Trustee Council. The council is a joint effort by the Pennsylvania Fish and Boat Commission and VAFO to ensure that future uses of Valley Creek will make up for the lost uses of the PCB-contaminated resource. The Council is currently developing a Restoration Plan for this purpose.

Table A-38. Strahler stream order classification by length (km) within the contributing watershed of RICH streams.

Stream Order	Intermittent	Perennial	All Streams (Within Park)	% Perennial
1	2.2	34.2	36.3 (2.2)	94
2	<0.1	18.3	18.3 (1.6)	100
3	-	8.2	8.2 (4.3)	100
Total	2.2	60.6	62.8 (8.1)	
% Headwater (1st-3rd)	100	100	100 (100)	

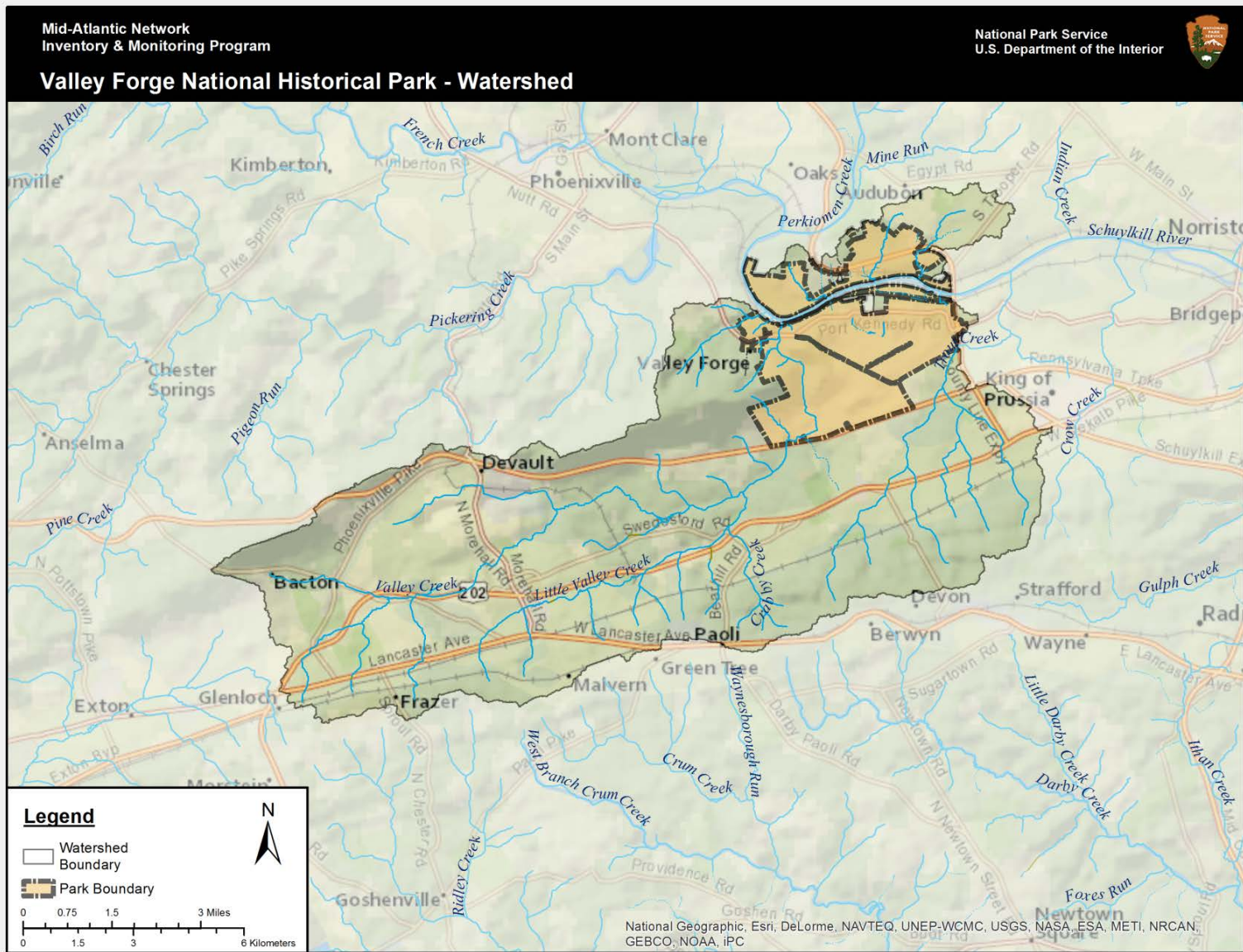


Figure A-52. Map displaying the streams and contributing watersheds of VAFO.

Additionally, segments of Valley Creek are listed as impaired by the PADEP due to siltation, turbidity, and bank modification (Figure A-53, Table A-39) (PADEP 2014). These issues can be tied to historic development as well. As with many first to third order streams in the region, mill dams were built by European settlers which resulted in aggradation behind the dams. The increased erosion of uplands that took place during the early settlement period due to land clearing and agricultural practices was transported to the valley bottom and trapped behind the mill dams. As these dams were abandoned and breeched, degradation of the sediments occurs and the channel becomes incised leading to increased bank erosion. The region surrounding VAFO had some of the highest densities of mill dam construction in the country during the settlement era (Walter and Merritts 2008).

Despite the significant issues facing Valley Creek and its tributaries, these resources are highly prized in the region. Valley Creek supports a diverse population of 18 fish species, including a reproducing population of brown trout, popular with anglers. Fishes within Valley Creek, however, had a much higher incidence of lesions and deformities as compared to other MIDN streams, likely associated with the legacy of industrial pollution in the stream (Atkinson 2008). Since 2007 the USGS has collected benthic macroinvertebrate samples from Valley Creek adjacent to the upstream boundary of VAFO. According to the indices which the USGS calculate with these data, Valley Creek at this location has consistently ranked in the slightly impaired category (2007-2014; USGS 2015).

A substantial body of knowledge has been developed around Valley Creek due to its high profile, proximity to an urban center, and known impairments. This includes multiple reports and publications concerning physical habitat, biological resources, and management actions (Strekal 1978, Sloto 1988, Kemp and Sporila 1997, NPS 2004c, Reif 2012). Chester County has a long established cooperative program with the USGS to conduct stream gaging, assess stream conditions, and conduct special studies in Valley Creek and adjacent watersheds.

2.8.5 Long-term Monitoring Sites

In an effort to monitor the status and trends of wadeable streams at VAFO a long-term monitoring site has been selected to monitor water quality. This site was placed in Valley Creek due to its significant value to VAFO as determined by VAFO and MIDN staff (Figure A-54, Table A-40). Additionally, a summary of land cover classes is provided for the watershed at this long-term site (Table A-41).

VAFO_01: Valley Creek at upstream boundary

VAFO_01 is located on Valley Creek at the upstream boundary of VAFO collocated with a long-term monitoring site established by USGS (USGS site: 01473169). Valley Creek is the dominant wadable stream resource in the park and is therefore the focus of monitoring.

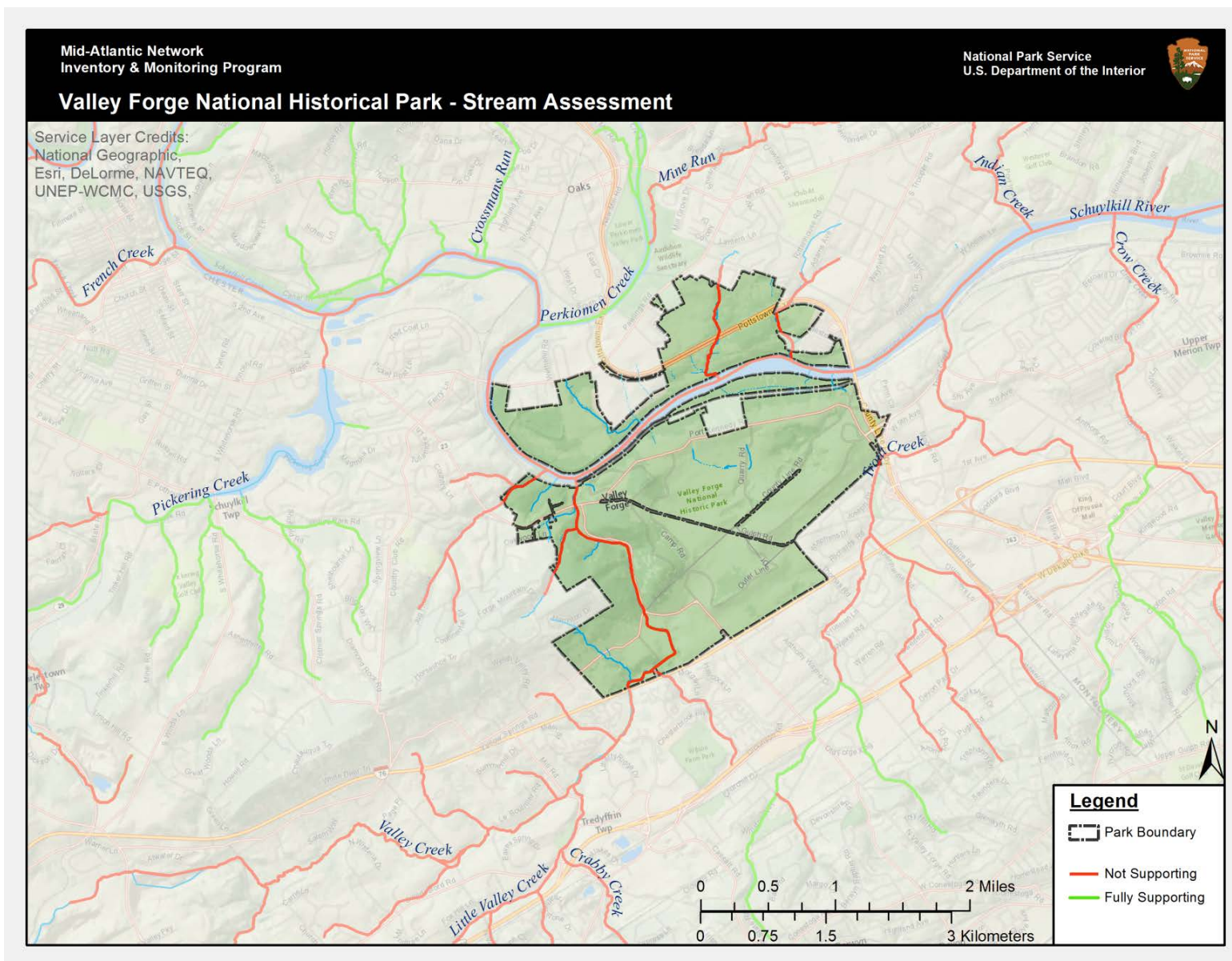


Figure A-53. Map displaying the attainment status of VAFO streams from the PA DEP 2012 305(b)/303(d) biannual water quality assessment.

Table A-39. Regulatory standards for baseline water quality parameters (temperature, pH, and dissolved oxygen) in the Commonwealth of Pennsylvania and EPA recommended guidance.

Regulatory Parameter	Beneficial Use	EPA National Recommended Water Quality Criteria (2012)	State of Pennsylvania Specific Water Quality Standards CH 93.7 (2009)
Temperature (°C)	Warm-water fishes	Species specific criteria	Varies by date, 87 °F max summer temp
	Cold Water Fishes	Species specific criteria	Varies by date, 66 °F max summer temp
pH	Drinking water	5 - 9	All uses = 6 - 9
	Aquatic Life	6.5 - 9	
Dissolved Oxygen (mg/l)	Warm Water fishes	Min. Criteria - early life stages = 5.0, other life stages = 3.0,	min. = 4.0, daily avg = 5.0
	Cold Water Fishes	Min. Criteria - early life stages = 5.0, other life stages = 4.0,	min. = 5.0, daily avg. = 6.0
	Invertebrate	Min. Criteria - 4.0	

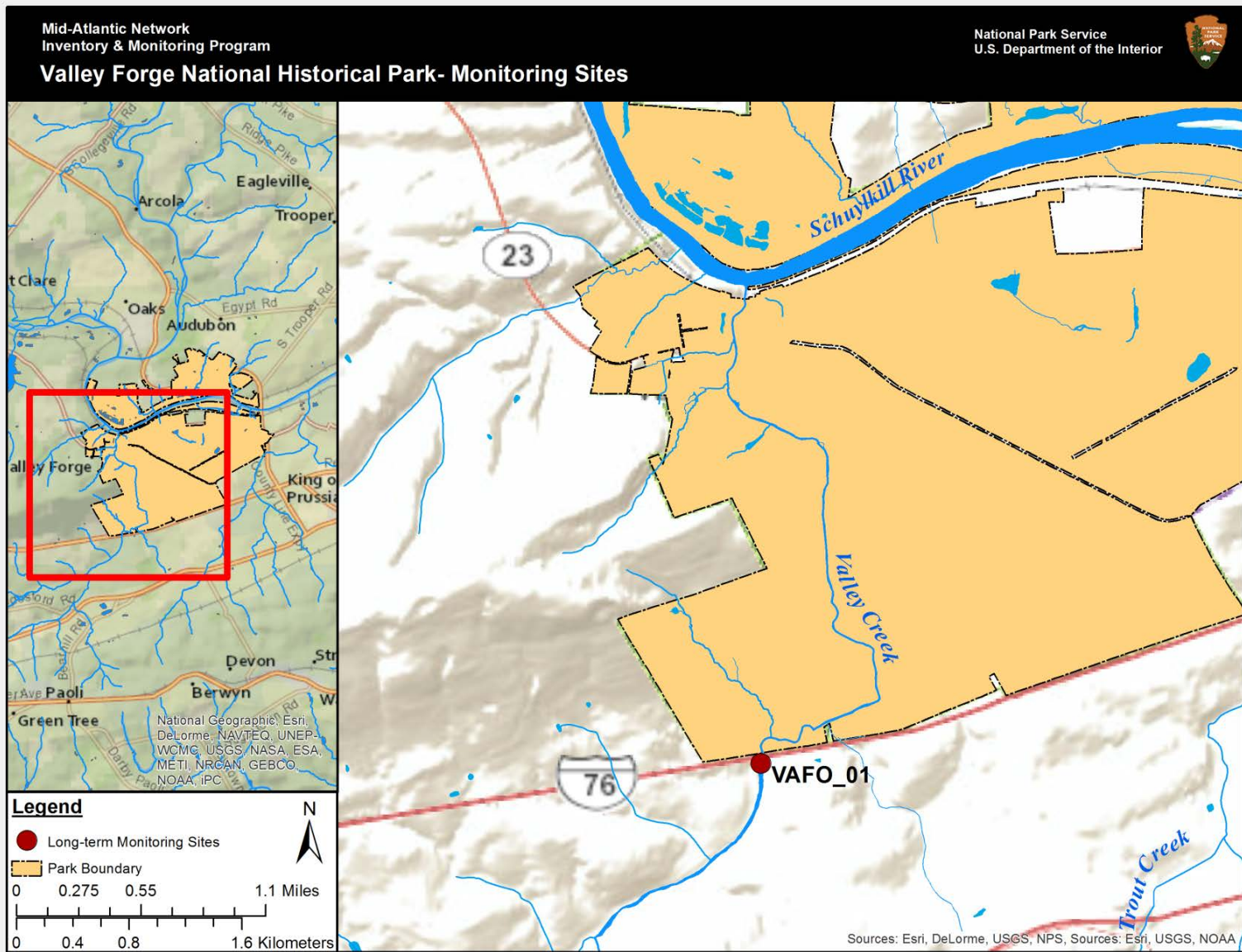


Figure A-54. Map monitoring site at VAFO.

Table A-40. List of long-term monitoring sites at VAFO.

Site ID	Stream Name	USGS HUC-14	Latitude	Longitude	Type of Site (D,BMI, Con)*
VAFO_01	Valley Creek	02040203000511	40.07925	-75.4609	D, Con

* D = Discrete Water Quality, BMI = Benthic Macroinvertebrate, Con = Continuous Water Quality Monitoring

Table A-41. Land cover (%) of the major land-use classifications from the NLCD (Homer et al. 2015) for the watershed and riparian areas (100 meter buffer) associated with each site selected for long-term monitoring.

Site ID	Watershed					100-meter Buffer				
	Forest	Wetlands	Agriculture	Developed*	Other	Forest	Wetlands	Agriculture	Developed*	Other
VAFO_01	28.7	1.0	7.3	56.7 (15.5)	6.2	39.7	4.9	6.2	43.7 (10.1)	5.6
Within Park	39.2	3.9	36.6	16.6 (1.0)	3.8	61.7	2.6	11.9	21.0 (0.4)	2.8

* Values in parenthesis are the proportion of developed total that is medium to high intensity

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Appendix B. Power Analysis to assist in developing the Mid-Atlantic Network sampling strategy

Background and Justification

The primary objective of water quality monitoring in the MIDN is to evaluate the trend in the monthly and extreme values of core parameters within each stream of interest over time. Sampling locations were not randomly selected but specifically selected in streams of management interest. The primary interest of the collected data, and of this power analysis, is evaluating temporal changes in these metrics at the stream-level. Power to detect changes in monthly core parameters will allow MIDN to evaluate whether certain parameters are changing more or less during particular months and extreme values were selected for analysis due to their physiological importance to the biota of MIDN streams. This power analysis does not evaluate our ability to make comparisons of core parameters among streams but some MIDN-level data summaries are presented for illustrative purposes.

General approach

We evaluated our sampling methods by calculating the power to detect a change in the temporal slope (trend) of core water quality parameters (temperature, dissolved oxygen, specific conductance, and pH) collected during discrete, monthly samples (*in situ*) from park streams (2010-2014). We used the following general linear model as a framework for estimating power in our current sampling design.

$$Y = \beta_0 + \beta_1 \cdot \text{time} + \varepsilon,$$

where Y is the monthly or annual core parameter value, *time* refers to the specified period of interest (typically annual), and ε is the measurement error. Detectable changes in the mean of a core parameter over time will be indicated by a regression slope estimate that is significantly different from zero ($\alpha = 0.05$).

Our overall objectives were to:

1. Assess the power to detect changes in monthly core parameters, and
2. Assess the power to detect changes in extreme annual values (one maximum and minimum per site per year).

Site sample means and variance estimates of all monthly and annual parameters were used as inputs for the power analysis. Power analyses of monthly parameters were restricted to sites with at least 5 years of monthly observations. Power calculations on the annual extreme values were based on sample estimates from all sites. Power of our sampling design was calculated using the ‘power.t.test’ function in the ‘pwr’ package in R (Champerley et al. 2015) following methods from Cohen (1988) to determine the ability to detect changes in annual extreme and monthly parameter values for four sampling periods (4, 8, and 12 years) at a significance level of $\alpha = 0.05$. For each of the sampling periods, we ran separate power analyses to detect a 10%, 20%, and 50% change in the monthly and annual extreme values of each core parameter at a significance level of $\alpha = 0.05$. For monthly data,

independent power analyses were conducted for each month in all streams. For extreme data, power was estimated separately in each stream for the annual maximum and minimum values of each core parameter.

Power to detect a change in the monthly core parameters over time

The power to detect a linear trend in core parameters was generally high in all months for all parameters at most sampling time frames (> 0.90), however, power at sites and in some months was low depending on the mean detectable change and sampling period (Tables B-1, B-3 through B-6).

Although there was modest variation in power across the monthly core parameters by site and month, the power to detect the smallest increase (10%) over the shortest time frame (4 years) averaged over 0.90 among sites for all core parameters (B-3 through B-6). Despite low power to detect a change in January and December temperatures the power quickly increases to over 0.80 after 8 years of sampling (Table B-1).

In sum, the current sampling design has very strong power to detect a 50% increase over a 4-yr sampling period in monthly parameter; power to detect a 10% linear increase improves substantially over an 8-year time period (Table B-1).

Table B-4. Mean power to detect a 10%, 20%, and 50% increase in monthly core parameter values across all MIDN streams. Asterisks denotes months where power calculation is based on less than 5 monthly observations. See Tables A1-A4 for power calculations for each month per site.

Core Parameter	Month	4 years			8 years		
		10%	20%	50%	10%	20%	50%
Temperature (°C)	January*	0.54	0.58	0.67	0.82	0.84	0.90
	February	0.82	0.87	0.96	1.00	1.00	1.00
	March*	0.79	0.82	0.90	0.98	0.99	1.00
	April	0.98	0.99	1.00	1.00	1.00	1.00
	May	1.00	1.00	1.00	1.00	1.00	1.00
	June	1.00	1.00	1.00	1.00	1.00	1.00
	July	1.00	1.00	1.00	1.00	1.00	1.00
	August	1.00	1.00	1.00	1.00	1.00	1.00
	September	1.00	1.00	1.00	1.00	1.00	1.00
	October*	0.98	0.98	0.99	1.00	1.00	1.00
	November	0.93	0.95	0.98	1.00	1.00	1.00
	December	0.53	0.59	0.73	0.94	0.96	0.99
DO (mg/L)	January*	0.98	0.98	0.98	0.99	0.99	1.00
	February*	0.97	0.98	0.99	1.00	1.00	1.00
	March*	0.99	0.99	1.00	1.00	1.00	1.00
	April	1.00	1.00	1.00	1.00	1.00	1.00
	May	1.00	1.00	1.00	1.00	1.00	1.00

Core Parameter	Month	4 years			8 years		
		10%	20%	50%	10%	20%	50%
pH	June	0.94	0.95	0.97	0.99	1.00	1.00
	July	0.93	0.94	0.97	0.99	1.00	1.00
	August	0.84	0.87	0.92	0.99	1.00	1.00
	September	0.92	0.94	0.97	1.00	1.00	1.00
	October*	0.88	0.89	0.92	0.98	0.98	0.99
	November	0.92	0.94	0.97	1.00	1.00	1.00
	December	1.00	1.00	1.00	1.00	1.00	1.00
	January*	1.00	1.00	1.00	1.00	1.00	1.00
	February*	1.00	1.00	1.00	1.00	1.00	1.00
	March*	1.00	1.00	1.00	1.00	1.00	1.00
	April	1.00	1.00	1.00	1.00	1.00	1.00
	May	1.00	1.00	1.00	1.00	1.00	1.00
	June	1.00	1.00	1.00	1.00	1.00	1.00
	July	1.00	1.00	1.00	1.00	1.00	1.00
	August	1.00	1.00	1.00	1.00	1.00	1.00
	September	1.00	1.00	1.00	1.00	1.00	1.00
	October*	1.00	1.00	1.00	1.00	1.00	1.00
	November	1.00	1.00	1.00	1.00	1.00	1.00
	December	1.00	1.00	1.00	1.00	1.00	1.00
SpC (mS/cm)	January*	0.88	0.90	0.93	0.98	0.99	1.00
	February	0.95	0.97	0.99	1.00	1.00	1.00
	March*	0.87	0.89	0.93	0.98	0.99	1.00
	April	1.00	1.00	1.00	1.00	1.00	1.00
	May	1.00	1.00	1.00	1.00	1.00	1.00
	June	0.97	0.98	0.99	1.00	1.00	1.00
	July	0.97	0.98	0.99	1.00	1.00	1.00
	August	0.85	0.87	0.92	0.99	0.99	1.00
	September	0.97	0.98	0.99	1.00	1.00	1.00
	October*	0.89	0.90	0.94	0.99	1.00	1.00
	November	0.99	1.00	1.00	1.00	1.00	1.00
	December	0.95	0.96	0.98	1.00	1.00	1.00

Power to detect a change in the annual extreme values over time

Overall, the power to detect a linear trend in the extreme annual values of all core parameters differed slightly by site and metric (maximum vs. minimum). Estimates of power were generally higher for maximum than minimum values of temperature (Fig. B-1) and DO (Fig. B-2). For example, the average power to detect a 10 and 20% increase in the annual minimum temperature was about half that compared to maximum temperature (Table B-2 and Fig. B-1).

Table B-2. Mean power to detect a 10%, 20%, and 50% increase in minimum and maximum temperatures across all MIDN streams. See Tables A1-A4 for estimates of power per site for temperatures in January and July, which are the months recording minimum and maximum values, respectively.

Temperature	4 years			8 years			12 years		
	10%	20%	50%	10%	20%	50%	10%	20%	50%
Minimum	0.54	0.58	0.67	0.82	0.84	0.90	0.86	0.89	0.93
Maximum	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

The power of our sampling design to detect changes in minimum and maximum pH is high for all sampling periods (Fig. B-3) because pH is the most stable parameter in MIDN streams (Fig. B-3). Overall, the sampling design also has high power to detect small to larger changes in specific conductance; for some streams power to detect changes in SpC will increase notably after 8 years (Fig. B-4).

In sum, the current sampling design has a very strong power to detect a 10% increase in the annual maximum extreme values of all parameters even for a 4-year sampling period. Power to detect a linear increase in the minimum values is generally lower than the maximum, but this will improve substantially after 8 years.

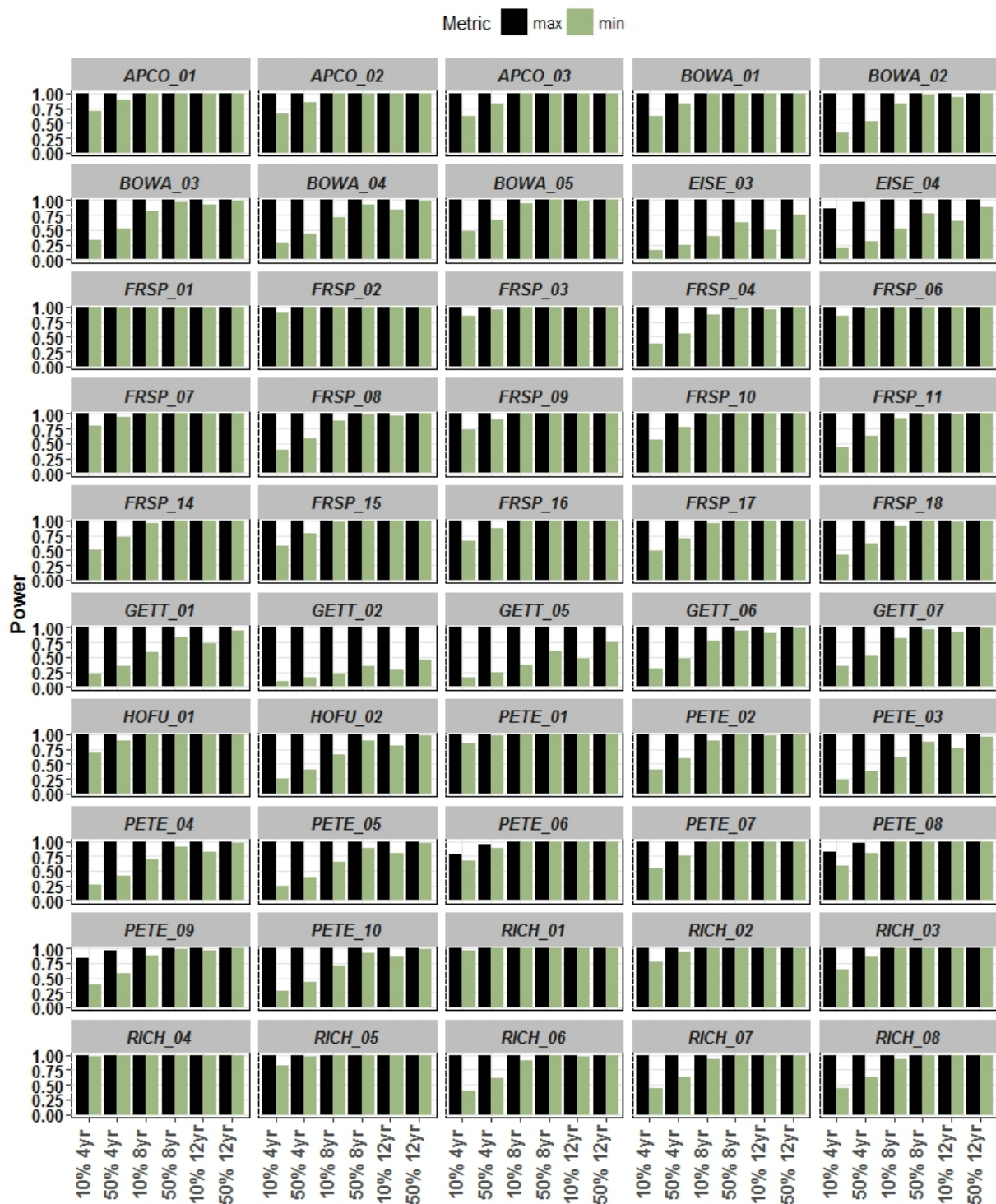


Figure B-3. Power to detect a 10% and 50% increase in minimum (green) and maximum (black) annual temperature (°C) for three sampling periods (4, 8, and 12 years) among MIDN streams.

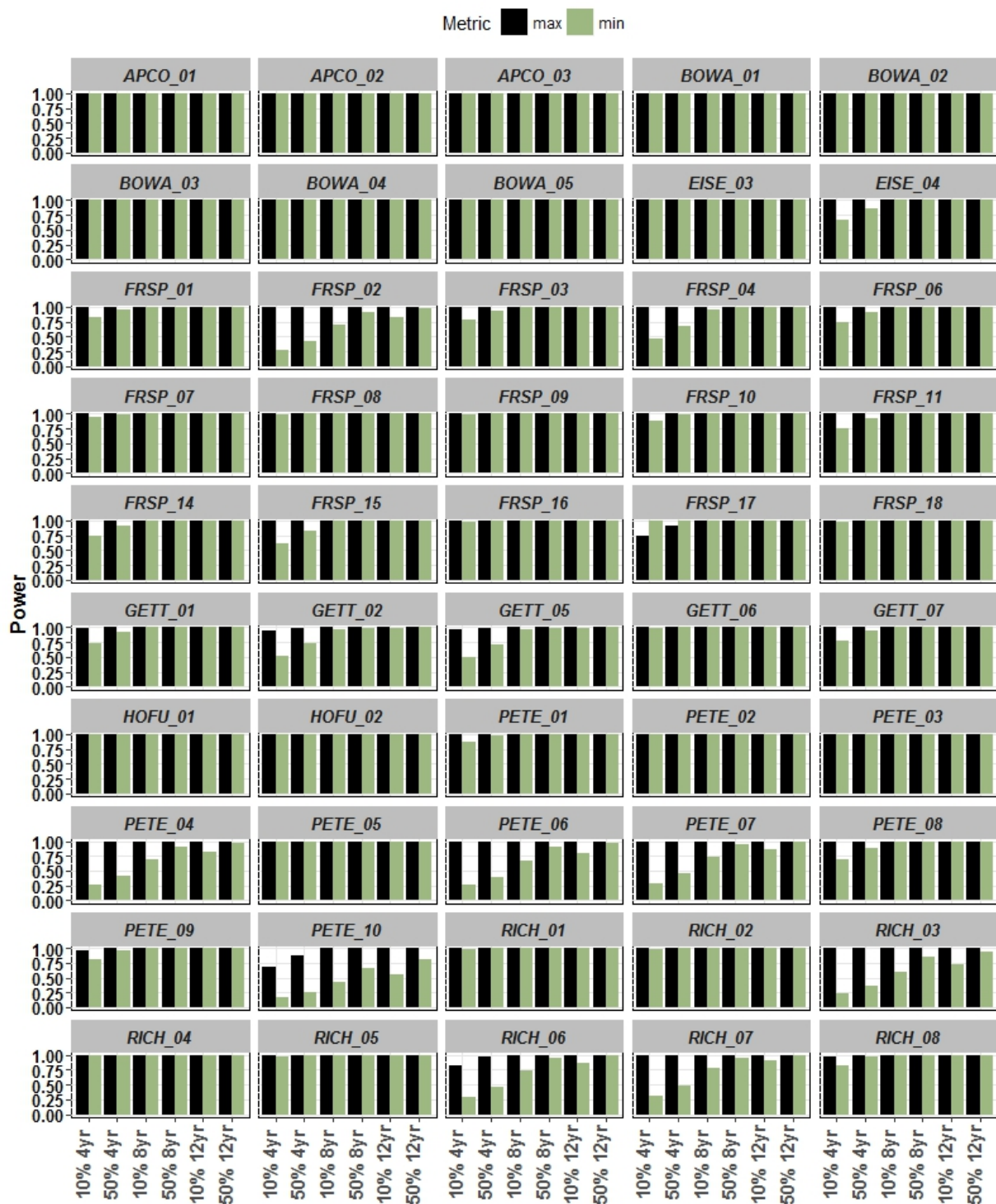


Figure B-4. Power to detect a 10% and 50% increase in minimum (green) and maximum (black) dissolved oxygen (mg/L) for three sampling periods (4, 8, and 12 years) in MIDN streams.

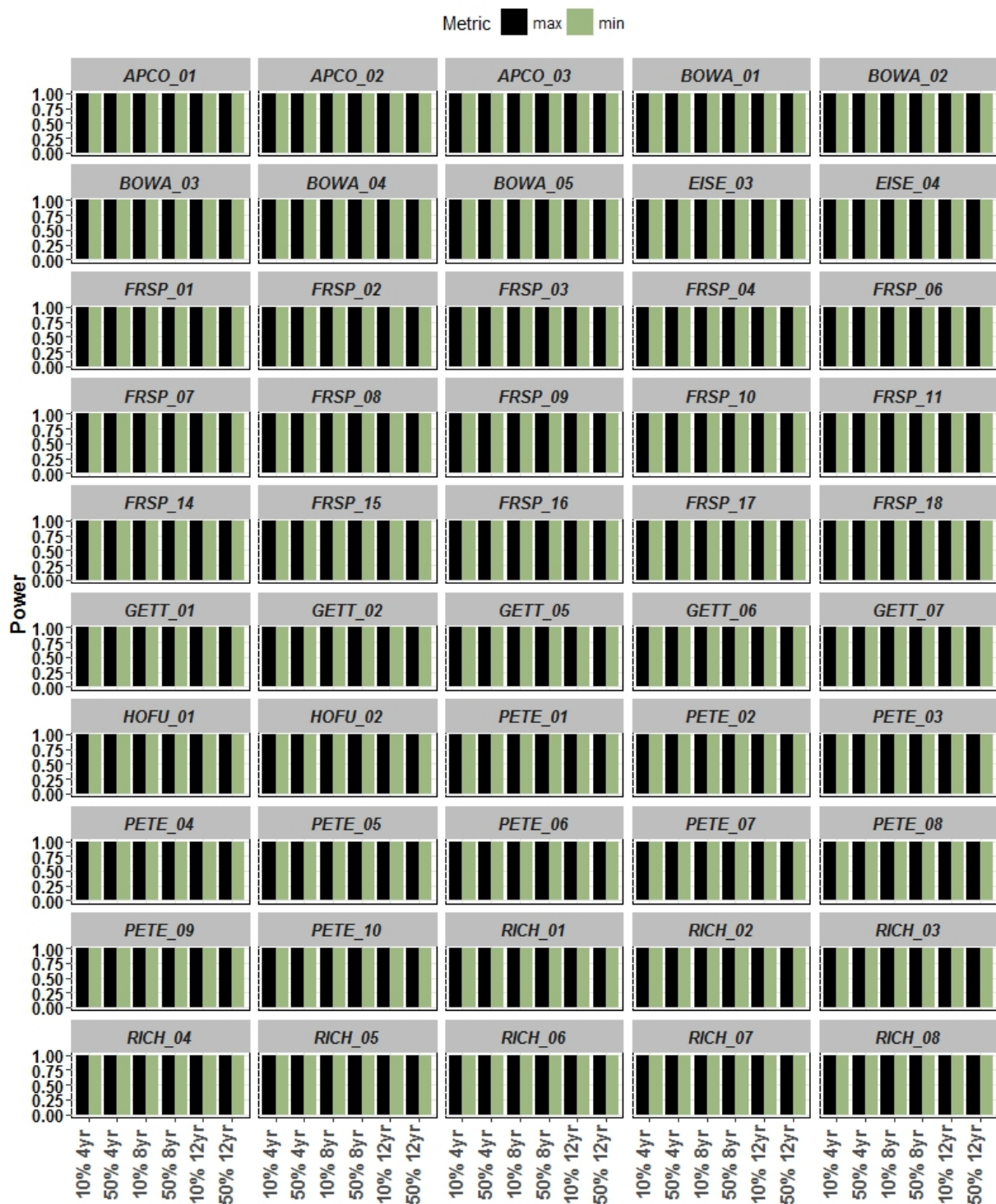


Figure B-3. Power to detect a 10% and 50% increase in minimum (green) and maximum (black) pH for three sampling periods (4, 8, and 12 years) in MIDN streams.

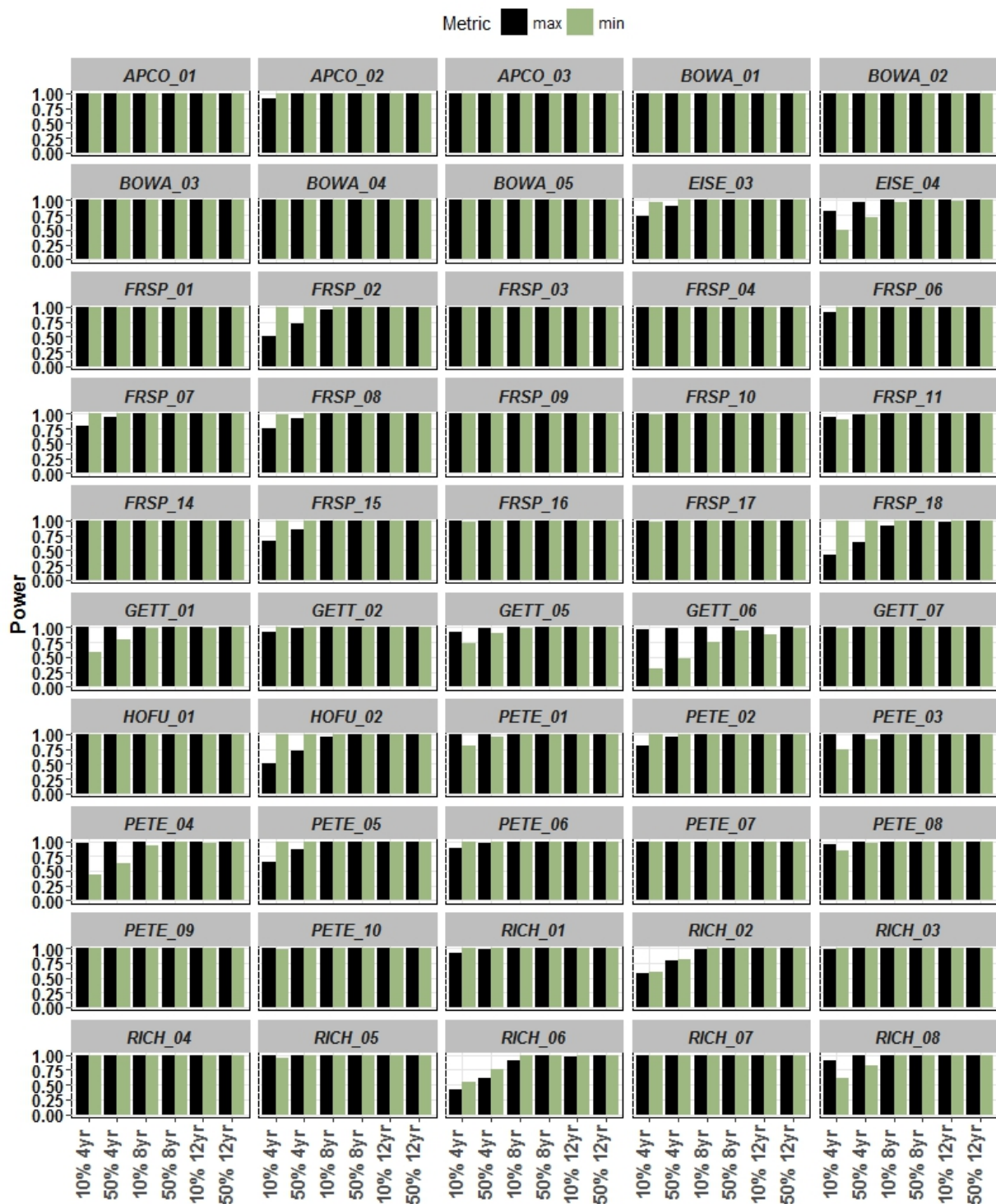


Figure B-4. Power to detect a 10% and 50% increase in minimum (green) and maximum (black) Specific conductance ($\mu\text{S}/\text{cm}$) for three sampling periods (4, 8, and 12 years) in MIDN streams.

Table B-3. Power to detect a 10%, 20%, and 50% increase in monthly temperature (°C) for three sampling periods (4, 8, and 12 years) in MIDN streams sampled for 5 years.

Stream ID	Month	Mean temp. (°C) ± SE	4 years			8 years			12 years		
			10%	20%	50%	10%	20%	50%	10%	20%	50%
APCO_01	November	8.4 ± 1.4	0.72	0.78	0.90	1.00	1.00	1.00	1.00	1.00	1.00
APCO_02	November	8.5 ± 1.4	0.74	0.80	0.91	1.00	1.00	1.00	1.00	1.00	1.00
APCO_03	November	8.1 ± 1.5	0.67	0.73	0.87	1.00	1.00	1.00	1.00	1.00	1.00
BOWA_01	June	16.6 ± 0.5	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
BOWA_01	July	18.8 ± 0.6	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
BOWA_01	August	18.9 ± 0.7	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
BOWA_01	September	17.4 ± 0.4	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
BOWA_01	November	9.1 ± 0.3	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
BOWA_01	December	9.4 ± 1.3	0.83	0.88	0.96	1.00	1.00	1.00	1.00	1.00	1.00
BOWA_02	February	6.4 ± 0.9	0.82	0.87	0.96	1.00	1.00	1.00	1.00	1.00	1.00
BOWA_02	May	15.2 ± 1	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
BOWA_02	June	17.7 ± 0.7	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
BOWA_02	July	20.4 ± 0.8	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
BOWA_02	August	20.2 ± 0.9	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
BOWA_02	September	18.2 ± 0.5	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
BOWA_02	November	7.9 ± 0.4	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
BOWA_02	December	8.6 ± 1.8	0.57	0.63	0.78	0.99	1.00	1.00	1.00	1.00	1.00
BOWA_03	June	18 ± 0.8	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
BOWA_03	July	20.5 ± 0.8	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
BOWA_03	August	20.3 ± 0.9	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
BOWA_03	September	18.3 ± 0.5	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
BOWA_03	November	8.1 ± 0.3	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
BOWA_03	December	8.5 ± 1.8	0.56	0.62	0.77	0.99	0.99	1.00	1.00	1.00	1.00
BOWA_04	February	5.6 ± 0.8	0.82	0.87	0.96	1.00	1.00	1.00	1.00	1.00	1.00
BOWA_04	May	16.8 ± 1.2	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
BOWA_04	June	20 ± 1	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
BOWA_04	July	23.3 ± 1.1	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
BOWA_04	August	22.5 ± 1.1	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
BOWA_04	September	19.8 ± 0.7	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
BOWA_04	November	8.1 ± 0.4	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
BOWA_04	December	8 ± 1.9	0.47	0.53	0.68	0.95	0.98	1.00	0.99	1.00	1.00
BOWA_05	June	18 ± 0.8	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
BOWA_05	August	20.3 ± 0.9	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
BOWA_05	September	18.6 ± 0.5	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
BOWA_05	November	9.6 ± 0.2	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

Stream ID	Month	Mean temp. (°C) ± SE	4 years			8 years			12 years		
			10%	20%	50%	10%	20%	50%	10%	20%	50%
BOWA_05	December	8.9 ± 1.5	0.72	0.77	0.90	1.00	1.00	1.00	1.00	1.00	1.00
EISE_03	August	24.6 ± 1.1	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
FRSP_01	April	16.5 ± 1.7	0.96	0.98	1.00	1.00	1.00	1.00	1.00	1.00	1.00
FRSP_01	June	22.8 ± 1.3	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
FRSP_01	July	21.2 ± 1.3	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
FRSP_01	September	22.8 ± 0.6	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
FRSP_01	November	11.8 ± 0.9	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
FRSP_01	December	6.8 ± 1.1	0.77	0.82	0.93	1.00	1.00	1.00	1.00	1.00	1.00
FRSP_02	June	19.1 ± 0.7	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
FRSP_02	July	22.3 ± 0.8	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
FRSP_02	August	22.6 ± 0.9	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
FRSP_02	September	18.5 ± 0.4	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
FRSP_02	November	9.2 ± 0.9	0.96	0.98	1.00	1.00	1.00	1.00	1.00	1.00	1.00
FRSP_02	December	7.1 ± 1.5	0.54	0.60	0.75	0.98	0.99	1.00	1.00	1.00	1.00
FRSP_03	June	21.5 ± 0.7	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
FRSP_03	July	22.8 ± 0.6	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
FRSP_03	August	23.6 ± 0.7	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
FRSP_03	September	18 ± 0.6	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
FRSP_03	November	9 ± 1.2	0.84	0.89	0.97	1.00	1.00	1.00	1.00	1.00	1.00
FRSP_03	December	6.7 ± 1.4	0.56	0.62	0.77	0.98	0.99	1.00	1.00	1.00	1.00
FRSP_04	June	20.7 ± 0.9	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
FRSP_04	July	22.1 ± 0.3	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
FRSP_04	August	22.4 ± 0.5	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
FRSP_04	September	17.7 ± 0.4	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
FRSP_04	November	8.5 ± 0.9	0.95	0.97	1.00	1.00	1.00	1.00	1.00	1.00	1.00
FRSP_04	December	5.8 ± 1.9	0.31	0.35	0.48	0.77	0.84	0.96	0.89	0.94	0.99
FRSP_06	April	12.6 ± 1.1	0.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
FRSP_06	June	19.2 ± 0.5	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
FRSP_06	September	18.4 ± 0.3	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
FRSP_06	November	10 ± 1	0.97	0.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00
FRSP_06	December	7.1 ± 1.7	0.48	0.54	0.69	0.95	0.98	1.00	0.99	1.00	1.00
FRSP_07	July	21.4 ± 0.5	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
FRSP_07	September	18.5 ± 0.2	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
FRSP_07	November	10.4 ± 1	0.98	0.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00
FRSP_07	December	7.4 ± 1.7	0.51	0.57	0.72	0.97	0.99	1.00	1.00	1.00	1.00
FRSP_08	April	13.9 ± 1.4	0.97	0.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00
FRSP_08	June	22.3 ± 1	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

Stream ID	Month	Mean temp. (°C) ± SE	4 years			8 years			12 years		
			10%	20%	50%	10%	20%	50%	10%	20%	50%
FRSP_08	July	24.2 ± 0.9	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
FRSP_08	August	24 ± 0.7	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
FRSP_08	September	19.5 ± 0.2	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
FRSP_08	November	9.8 ± 1.1	0.95	0.97	1.00	1.00	1.00	1.00	1.00	1.00	1.00
FRSP_08	December	6.1 ± 1.9	0.32	0.36	0.49	0.79	0.85	0.96	0.90	0.94	0.99
FRSP_09	June	18.9 ± 0.8	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
FRSP_09	July	21.5 ± 0.6	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
FRSP_09	August	21.6 ± 0.8	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
FRSP_09	September	18.6 ± 0.7	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
FRSP_09	November	10.2 ± 1.2	0.92	0.95	0.99	1.00	1.00	1.00	1.00	1.00	1.00
FRSP_09	December	8.7 ± 2.1	0.46	0.51	0.67	0.94	0.97	1.00	0.99	1.00	1.00
FRSP_10	June	21.7 ± 1.5	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
FRSP_10	July	24.8 ± 0.8	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
FRSP_10	August	23.4 ± 0.7	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
FRSP_10	September	19.7 ± 0.7	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
FRSP_10	November	8.7 ± 1	0.92	0.95	0.99	1.00	1.00	1.00	1.00	1.00	1.00
FRSP_10	December	6.6 ± 1.9	0.36	0.41	0.54	0.85	0.90	0.98	0.94	0.97	1.00
FRSP_11	June	20.3 ± 1.1	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
FRSP_11	July	22.1 ± 0.9	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
FRSP_11	August	22.9 ± 0.8	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
FRSP_11	September	20.3 ± 1.2	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
FRSP_11	November	9.8 ± 1.3	0.87	0.91	0.98	1.00	1.00	1.00	1.00	1.00	1.00
FRSP_11	December	7.8 ± 2.3	0.35	0.40	0.53	0.83	0.89	0.98	0.93	0.96	1.00
FRSP_14	June	20.7 ± 0.8	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
FRSP_14	July	22.6 ± 0.4	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
FRSP_14	August	22.2 ± 0.4	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
FRSP_14	November	9.4 ± 1	0.95	0.97	1.00	1.00	1.00	1.00	1.00	1.00	1.00
FRSP_14	December	5.8 ± 1.7	0.37	0.42	0.56	0.86	0.92	0.99	0.95	0.98	1.00
FRSP_15	June	21.5 ± 0.8	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
FRSP_15	July	23.7 ± 0.5	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
FRSP_15	August	24 ± 0.9	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
FRSP_15	September	19.8 ± 0.4	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
FRSP_15	November	9.7 ± 1	0.95	0.97	1.00	1.00	1.00	1.00	1.00	1.00	1.00
FRSP_15	December	6.2 ± 1.8	0.37	0.42	0.56	0.86	0.91	0.98	0.95	0.98	1.00
FRSP_16	June	20.8 ± 0.8	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
FRSP_16	July	23.7 ± 0.4	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
FRSP_16	August	24.4 ± 1.1	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

Stream ID	Month	Mean temp. (°C) ± SE	4 years			8 years			12 years		
			10%	20%	50%	10%	20%	50%	10%	20%	50%
FRSP_16	September	19.5 ± 0.4	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
FRSP_16	November	9.4 ± 0.9	0.98	0.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00
FRSP_16	December	6.6 ± 1.6	0.46	0.51	0.66	0.94	0.97	1.00	0.99	1.00	1.00
FRSP_17	November	9.6 ± 0.8	0.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
FRSP_18	June	23.3 ± 1.4	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
FRSP_18	July	26 ± 1.1	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
FRSP_18	August	24.1 ± 0.9	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
FRSP_18	September	19.8 ± 0.9	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
FRSP_18	November	8.5 ± 1.3	0.79	0.84	0.94	1.00	1.00	1.00	1.00	1.00	1.00
FRSP_18	December	6.7 ± 2.1	0.33	0.37	0.51	0.80	0.86	0.97	0.91	0.95	1.00
GETT_07	August	22.2 ± 0.8	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
PETE_02	June	20.1 ± 0.7	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
PETE_02	December	7.8 ± 1.3	0.72	0.77	0.90	1.00	1.00	1.00	1.00	1.00	1.00
PETE_03	December	6.9 ± 1.5	0.52	0.58	0.73	0.97	0.99	1.00	1.00	1.00	1.00
PETE_04	June	21.5 ± 1.1	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
PETE_04	December	6.9 ± 1.4	0.58	0.64	0.79	0.99	1.00	1.00	1.00	1.00	1.00
PETE_05	June	21.3 ± 0.8	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
PETE_05	December	6.9 ± 1.6	0.51	0.57	0.72	0.97	0.99	1.00	1.00	1.00	1.00
PETE_07	June	21.3 ± 1.7	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
PETE_07	December	5.6 ± 1.1	0.60	0.66	0.81	0.99	1.00	1.00	1.00	1.00	1.00
RICH_01	June	22.5 ± 0.5	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
RICH_01	July	24.4 ± 0.6	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
RICH_01	August	24.4 ± 0.8	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
RICH_01	September	21.5 ± 0.8	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
RICH_01	November	11.4 ± 1	0.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
RICH_01	December	8.8 ± 1.3	0.80	0.85	0.95	1.00	1.00	1.00	1.00	1.00	1.00
RICH_02	June	19.9 ± 0.2	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
RICH_02	July	24.1 ± 0.6	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
RICH_02	August	23.2 ± 0.8	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
RICH_02	September	21 ± 0.5	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
RICH_02	November	11.6 ± 0.9	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
RICH_02	December	9.5 ± 1.9	0.61	0.67	0.81	0.99	1.00	1.00	1.00	1.00	1.00
RICH_03	June	22.4 ± 1.4	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
RICH_03	August	23.9 ± 0.8	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
RICH_03	September	20.3 ± 0.9	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
RICH_03	November	11.3 ± 1.4	0.88	0.92	0.98	1.00	1.00	1.00	1.00	1.00	1.00
RICH_03	December	7.8 ± 1.6	0.59	0.65	0.80	0.99	1.00	1.00	1.00	1.00	1.00

Stream ID	Month	Mean temp. (°C) ± SE	4 years			8 years			12 years		
			10%	20%	50%	10%	20%	50%	10%	20%	50%
RICH_04	June	18.6 ± 0.5	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
RICH_04	July	21.2 ± 0.4	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
RICH_04	August	21.1 ± 0.7	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
RICH_04	September	19.2 ± 0.5	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
RICH_04	November	11.2 ± 1	0.99	0.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00
RICH_04	December	9.2 ± 1.5	0.75	0.81	0.92	1.00	1.00	1.00	1.00	1.00	1.00
RICH_05	August	25 ± 1	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
RICH_05	November	11.2 ± 1.3	0.94	0.96	0.99	1.00	1.00	1.00	1.00	1.00	1.00
RICH_06	June	26.1 ± 0.6	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
RICH_06	August	26 ± 0.6	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
RICH_07	June	21.7 ± 1	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
RICH_07	July	23.5 ± 0.4	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
RICH_07	August	23.6 ± 1	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
RICH_07	September	20.9 ± 0.5	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
RICH_07	November	10.8 ± 1.2	0.94	0.96	0.99	1.00	1.00	1.00	1.00	1.00	1.00
RICH_07	December	7.3 ± 1.8	0.47	0.53	0.68	0.95	0.98	1.00	0.99	1.00	1.00
RICH_08	August	20.5 ± 0.7	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

Table B-4. Power to detect a 10%, 20%, and 50% increase in monthly dissolved oxygen (mg/L) for three sampling periods (4, 8, and 12 years) in MIDN streams sampled for 5 years.

Stream ID	Month	Mean DO (mg/L) $\pm$ SE	4 years			8 years			12 years		
			10%	20%	50%	10%	20%	50%	10%	20%	50%
BOWA_01	June	8.5 $\pm$ 0.2	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
BOWA_01	July	8 $\pm$ 0.2	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
BOWA_01	September	8.2 $\pm$ 0.1	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
BOWA_01	November	9.7 $\pm$ 1.2	0.90	0.94	0.99	1.00	1.00	1.00	1.00	1.00	1.00
BOWA_01	December	10.4 $\pm$ 0.4	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
BOWA_02	May	9.5 $\pm$ 0.3	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
BOWA_02	June	8.8 $\pm$ 0.3	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
BOWA_02	July	8.1 $\pm$ 0.3	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
BOWA_02	September	8.6 $\pm$ 0.1	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
BOWA_02	November	11.8 $\pm$ 0.2	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
BOWA_02	December	11.5 $\pm$ 0.6	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
BOWA_03	June	8.5 $\pm$ 0.3	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
BOWA_03	July	7.9 $\pm$ 0.4	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
BOWA_03	September	8.5 $\pm$ 0.1	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
BOWA_03	November	11.4 $\pm$ 0.1	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
BOWA_03	December	11.2 $\pm$ 0.6	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
BOWA_04	May	9.3 $\pm$ 0.3	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
BOWA_04	June	8.3 $\pm$ 0.3	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
BOWA_04	July	8.1 $\pm$ 0.3	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
BOWA_04	September	8.5 $\pm$ 0.1	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
BOWA_04	November	13.1 $\pm$ 0.4	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
BOWA_04	December	11.6 $\pm$ 0.7	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
BOWA_05	June	8.2 $\pm$ 0.3	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
BOWA_05	September	8.3 $\pm$ 0.1	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
BOWA_05	November	10.3 $\pm$ 0.2	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
BOWA_05	December	10.7 $\pm$ 0.6	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
EISE_03	August	8.5 $\pm$ 0.4	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
FRSP_01	April	9.3 $\pm$ 0.5	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
FRSP_01	June	5.7 $\pm$ 0.2	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
FRSP_01	July	4.2 $\pm$ 0.5	0.91	0.94	0.99	1.00	1.00	1.00	1.00	1.00	1.00
FRSP_01	September	5.4 $\pm$ 0.7	0.90	0.93	0.99	1.00	1.00	1.00	1.00	1.00	1.00
FRSP_01	November	8.8 $\pm$ 0.6	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
FRSP_01	December	12 $\pm$ 0.5	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
FRSP_02	June	6.2 $\pm$ 0.9	0.83	0.88	0.96	1.00	1.00	1.00	1.00	1.00	1.00
FRSP_02	July	3.7 $\pm$ 1.1	0.37	0.42	0.56	0.86	0.91	0.98	0.95	0.98	1.00

Stream ID	Month	Mean DO (mg/L) ± SE	4 years			8 years			12 years		
			10%	20%	50%	10%	20%	50%	10%	20%	50%
FRSP_02	August	5.4 ± 1	0.65	0.71	0.85	1.00	1.00	1.00	1.00	1.00	1.00
FRSP_02	September	4.6 ± 0.8	0.71	0.76	0.89	1.00	1.00	1.00	1.00	1.00	1.00
FRSP_02	November	5.7 ± 1.4	0.44	0.50	0.65	0.93	0.96	1.00	0.98	0.99	1.00
FRSP_02	December	9.3 ± 0.7	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
FRSP_03	June	6.2 ± 0.3	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
FRSP_03	July	5.5 ± 0.3	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
FRSP_03	August	5.4 ± 0.6	0.96	0.98	1.00	1.00	1.00	1.00	1.00	1.00	1.00
FRSP_03	September	6.6 ± 0.3	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
FRSP_03	November	7.3 ± 1.3	0.66	0.72	0.86	1.00	1.00	1.00	1.00	1.00	1.00
FRSP_03	December	10.6 ± 0.9	0.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
FRSP_04	June	6.8 ± 0.2	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
FRSP_04	July	4.5 ± 0.8	0.71	0.77	0.89	1.00	1.00	1.00	1.00	1.00	1.00
FRSP_04	August	5.2 ± 1.2	0.53	0.59	0.74	0.98	0.99	1.00	1.00	1.00	1.00
FRSP_04	September	5.7 ± 1	0.70	0.76	0.89	1.00	1.00	1.00	1.00	1.00	1.00
FRSP_04	November	8.5 ± 1	0.91	0.94	0.99	1.00	1.00	1.00	1.00	1.00	1.00
FRSP_04	December	11.9 ± 0.7	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
FRSP_06	April	10.1 ± 0.4	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
FRSP_06	June	7.8 ± 0.2	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
FRSP_06	September	6 ± 0.9	0.79	0.85	0.94	1.00	1.00	1.00	1.00	1.00	1.00
FRSP_06	November	10 ± 0.5	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
FRSP_06	December	11.5 ± 0.7	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
FRSP_07	July	5.1 ± 0.6	0.91	0.94	0.99	1.00	1.00	1.00	1.00	1.00	1.00
FRSP_07	September	5.3 ± 0.8	0.83	0.88	0.96	1.00	1.00	1.00	1.00	1.00	1.00
FRSP_07	November	7.9 ± 1	0.89	0.92	0.98	1.00	1.00	1.00	1.00	1.00	1.00
FRSP_07	December	9.5 ± 1	0.97	0.98	1.00	1.00	1.00	1.00	1.00	1.00	1.00
FRSP_08	April	11.1 ± 0.5	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
FRSP_08	June	8.1 ± 0.2	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
FRSP_08	July	7.7 ± 0.3	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
FRSP_08	August	7.4 ± 0.6	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
FRSP_08	September	8.9 ± 0.3	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
FRSP_08	November	11.7 ± 0.4	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
FRSP_08	December	13 ± 0.7	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
FRSP_09	June	8 ± 0.3	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
FRSP_09	July	7.3 ± 0.2	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
FRSP_09	August	7.1 ± 0.3	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
FRSP_09	September	7.6 ± 0.4	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
FRSP_09	November	7.5 ± 1	0.87	0.91	0.98	1.00	1.00	1.00	1.00	1.00	1.00

Stream ID	Month	Mean DO (mg/L) ± SE	4 years			8 years			12 years		
			10%	20%	50%	10%	20%	50%	10%	20%	50%
FRSP_09	December	9.6 ± 0.7	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
FRSP_10	June	5.8 ± 0.6	0.96	0.98	1.00	1.00	1.00	1.00	1.00	1.00	1.00
FRSP_10	July	5.4 ± 0.5	0.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
FRSP_10	August	5.3 ± 0.7	0.86	0.91	0.97	1.00	1.00	1.00	1.00	1.00	1.00
FRSP_10	September	6.6 ± 1	0.76	0.82	0.93	1.00	1.00	1.00	1.00	1.00	1.00
FRSP_10	November	8.4 ± 1.1	0.86	0.90	0.97	1.00	1.00	1.00	1.00	1.00	1.00
FRSP_10	December	10.6 ± 0.9	0.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
FRSP_11	June	7.4 ± 0.3	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
FRSP_11	July	7.1 ± 0.5	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
FRSP_11	August	6.1 ± 1	0.71	0.77	0.90	1.00	1.00	1.00	1.00	1.00	1.00
FRSP_11	September	7.8 ± 0.3	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
FRSP_11	November	9.1 ± 1	0.95	0.97	1.00	1.00	1.00	1.00	1.00	1.00	1.00
FRSP_11	December	11 ± 0.7	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
FRSP_14	June	7.5 ± 0.2	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
FRSP_14	July	6.6 ± 0.5	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
FRSP_14	August	6.1 ± 1	0.77	0.82	0.93	1.00	1.00	1.00	1.00	1.00	1.00
FRSP_14	November	9.2 ± 0.9	0.97	0.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00
FRSP_14	December	12.1 ± 0.5	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
FRSP_15	June	7.1 ± 0.3	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
FRSP_15	July	6.8 ± 0.3	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
FRSP_15	August	5.6 ± 1.1	0.61	0.67	0.82	0.99	1.00	1.00	1.00	1.00	1.00
FRSP_15	September	7.9 ± 0.4	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
FRSP_15	November	9.9 ± 0.8	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
FRSP_15	December	12.6 ± 0.9	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
FRSP_16	June	7.5 ± 0.2	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
FRSP_16	July	6.9 ± 0.6	0.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
FRSP_16	August	6.3 ± 0.5	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
FRSP_16	September	8.1 ± 0.4	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
FRSP_16	November	8.6 ± 0.9	0.96	0.98	1.00	1.00	1.00	1.00	1.00	1.00	1.00
FRSP_16	December	11.5 ± 0.6	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
FRSP_17	November	7 ± 1.1	0.74	0.79	0.91	1.00	1.00	1.00	1.00	1.00	1.00
FRSP_18	June	7.3 ± 0.5	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
FRSP_18	July	6.7 ± 0.5	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
FRSP_18	August	6.6 ± 0.5	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
FRSP_18	September	8.3 ± 0.2	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
FRSP_18	November	10.7 ± 0.6	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
FRSP_18	December	12.1 ± 0.8	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

Stream ID	Month	Mean DO (mg/L) ± SE	4 years			8 years			12 years		
			10%	20%	50%	10%	20%	50%	10%	20%	50%
GETT_07	August	6.2 ± 0.5	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
PETE_02	June	8 ± 0.6	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
PETE_02	December	11.7 ± 0.4	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
PETE_03	December	12 ± 0.4	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
PETE_04	June	5.7 ± 1.4	0.47	0.52	0.68	0.95	0.97	1.00	0.99	1.00	1.00
PETE_04	December	11.1 ± 0.6	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
PETE_05	June	8 ± 0.4	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
PETE_05	December	12.3 ± 0.6	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
PETE_07	June	1.6 ± 0.3	0.68	0.74	0.88	1.00	1.00	1.00	1.00	1.00	1.00
PETE_07	December	6.4 ± 0.8	0.92	0.95	0.99	1.00	1.00	1.00	1.00	1.00	1.00
RICH_01	June	6.9 ± 0.5	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
RICH_01	July	6.5 ± 0.2	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
RICH_01	August	5.9 ± 0.7	0.90	0.93	0.99	1.00	1.00	1.00	1.00	1.00	1.00
RICH_01	September	6.8 ± 0.5	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
RICH_01	November	10.2 ± 0.6	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
RICH_01	December	11.3 ± 0.4	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
RICH_02	June	7.7 ± 0.1	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
RICH_02	July	7 ± 0.2	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
RICH_02	August	6.2 ± 0.6	0.96	0.98	1.00	1.00	1.00	1.00	1.00	1.00	1.00
RICH_02	September	6.8 ± 0.3	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
RICH_02	November	9.7 ± 0.3	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
RICH_02	December	10.6 ± 0.7	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
RICH_03	June	5.8 ± 0.7	0.89	0.93	0.98	1.00	1.00	1.00	1.00	1.00	1.00
RICH_03	August	4.7 ± 1.1	0.47	0.52	0.67	0.95	0.97	1.00	0.99	1.00	1.00
RICH_03	September	4.8 ± 1	0.57	0.63	0.79	0.99	1.00	1.00	1.00	1.00	1.00
RICH_03	November	8.5 ± 1.3	0.76	0.82	0.93	1.00	1.00	1.00	1.00	1.00	1.00
RICH_03	December	10.4 ± 0.7	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
RICH_04	June	7.3 ± 0.2	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
RICH_04	July	6.9 ± 0.3	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
RICH_04	August	6.7 ± 0.4	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
RICH_04	September	7 ± 0.2	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
RICH_04	November	9.8 ± 0.8	0.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
RICH_04	December	10.1 ± 0.5	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
RICH_05	August	5.2 ± 0.5	0.96	0.98	1.00	1.00	1.00	1.00	1.00	1.00	1.00
RICH_05	November	9.4 ± 0.6	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
RICH_06	June	3.5 ± 0.9	0.41	0.46	0.61	0.91	0.95	0.99	0.97	0.99	1.00
RICH_07	June	6.5 ± 0.3	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

Stream ID	Month	Mean DO (mg/L) ± SE	4 years			8 years			12 years		
			10%	20%	50%	10%	20%	50%	10%	20%	50%
RICH_07	July	5.6 ± 1	0.65	0.71	0.85	1.00	1.00	1.00	1.00	1.00	1.00
RICH_07	August	5.1 ± 1.3	0.43	0.48	0.63	0.92	0.96	1.00	0.98	0.99	1.00
RICH_07	September	5.8 ± 0.6	0.95	0.97	1.00	1.00	1.00	1.00	1.00	1.00	1.00
RICH_07	November	8 ± 0.8	0.96	0.98	1.00	1.00	1.00	1.00	1.00	1.00	1.00
RICH_07	December	10.6 ± 0.6	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
RICH_08	August	5.7 ± 0.6	0.95	0.97	1.00	1.00	1.00	1.00	1.00	1.00	1.00

Table B-5. Power to detect a 10%, 20%, and 50% increase in monthly pH for three sampling periods (4, 8, and 12 years) in MIDN streams sampled for 5 years.

Stream ID	Month	Mean pH ± SE	4 years			8 years			12 years		
			10%	20%	50%	10%	20%	50%	10%	20%	50%
APCO_01	November	7.5 ± 0.1	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
APCO_02	November	7.5 ± 0.1	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
APCO_03	November	7.5 ± 0.1	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
BOWA_01	June	6.8 ± 0.1	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
BOWA_01	July	6.9 ± 0	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
BOWA_01	August	6.9 ± 0	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
BOWA_01	September	6.7 ± 0.1	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
BOWA_01	November	6.6 ± 0	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
BOWA_01	December	6.4 ± 0.2	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
BOWA_02	May	7.4 ± 0	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
BOWA_02	June	7.4 ± 0.1	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
BOWA_02	July	7.5 ± 0	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
BOWA_02	August	7.5 ± 0.1	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
BOWA_02	September	7.4 ± 0.1	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
BOWA_02	November	7.2 ± 0	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
BOWA_02	December	7 ± 0.1	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
BOWA_03	June	7.4 ± 0.1	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
BOWA_03	July	7.5 ± 0	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
BOWA_03	August	7.5 ± 0	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
BOWA_03	September	7.5 ± 0	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
BOWA_03	November	7.3 ± 0.1	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
BOWA_03	December	7.2 ± 0.1	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
BOWA_04	May	7.4 ± 0	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
BOWA_04	June	7.3 ± 0.1	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
BOWA_04	July	7.5 ± 0.1	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
BOWA_04	August	7.5 ± 0	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
BOWA_04	September	7.4 ± 0.1	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
BOWA_04	November	7.4 ± 0.1	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
BOWA_04	December	7.2 ± 0.2	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
BOWA_05	June	7.2 ± 0.1	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
BOWA_05	August	7.5 ± 0.1	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
BOWA_05	September	7.3 ± 0.1	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
BOWA_05	November	7.3 ± 0.1	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
BOWA_05	December	7.1 ± 0.1	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
EISE_03	August	7.9 ± 0.2	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

Stream ID	Month	Mean pH ± SE	4 years			8 years			12 years		
			10%	20%	50%	10%	20%	50%	10%	20%	50%
FRSP_01	April	6.8 ± 0.1	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
FRSP_01	June	6.6 ± 0.1	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
FRSP_01	July	6.6 ± 0	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
FRSP_01	September	6.6 ± 0.1	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
FRSP_01	November	6.6 ± 0.1	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
FRSP_01	December	6.8 ± 0.1	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
FRSP_02	June	6.2 ± 0.1	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
FRSP_02	July	6.4 ± 0.1	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
FRSP_02	August	6.2 ± 0.1	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
FRSP_02	September	6.3 ± 0.2	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
FRSP_02	November	6 ± 0.1	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
FRSP_02	December	6.3 ± 0.1	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
FRSP_03	June	6.7 ± 0.1	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
FRSP_03	July	6.8 ± 0	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
FRSP_03	August	6.7 ± 0.1	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
FRSP_03	September	6.7 ± 0.2	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
FRSP_03	November	6.5 ± 0	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
FRSP_03	December	6.7 ± 0.1	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
FRSP_04	June	6.7 ± 0.1	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
FRSP_04	July	6.6 ± 0	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
FRSP_04	August	6.6 ± 0.1	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
FRSP_04	September	6.5 ± 0.2	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
FRSP_04	November	6.6 ± 0	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
FRSP_04	December	6.8 ± 0	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
FRSP_06	April	5.6 ± 0.1	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
FRSP_06	June	6.1 ± 0.1	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
FRSP_06	September	6 ± 0.2	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
FRSP_06	November	6 ± 0.1	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
FRSP_06	December	6 ± 0.1	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
FRSP_07	July	5.5 ± 0.1	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
FRSP_07	September	5.4 ± 0.2	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
FRSP_07	November	5.7 ± 0.1	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
FRSP_07	December	5.6 ± 0.1	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
FRSP_08	April	7.1 ± 0.1	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
FRSP_08	June	7.1 ± 0.1	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
FRSP_08	July	7 ± 0.1	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
FRSP_08	August	7 ± 0.1	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

Stream ID	Month	Mean pH ± SE	4 years			8 years			12 years		
			10%	20%	50%	10%	20%	50%	10%	20%	50%
FRSP_08	September	6.9 ± 0.1	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
FRSP_08	November	6.9 ± 0.2	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
FRSP_08	December	6.7 ± 0.1	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
FRSP_09	June	6.5 ± 0.2	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
FRSP_09	July	6.8 ± 0	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
FRSP_09	August	6.7 ± 0.1	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
FRSP_09	September	6.7 ± 0.1	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
FRSP_09	November	6.3 ± 0.1	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
FRSP_09	December	6.6 ± 0	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
FRSP_10	June	6.6 ± 0.1	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
FRSP_10	July	6.8 ± 0.1	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
FRSP_10	August	6.7 ± 0.1	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
FRSP_10	September	6.7 ± 0.1	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
FRSP_10	November	6.5 ± 0.1	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
FRSP_10	December	6.7 ± 0.1	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
FRSP_11	June	6.9 ± 0.1	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
FRSP_11	July	7 ± 0.1	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
FRSP_11	August	6.9 ± 0.1	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
FRSP_11	September	6.9 ± 0.1	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
FRSP_11	November	6.7 ± 0.1	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
FRSP_11	December	6.8 ± 0	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
FRSP_14	June	7 ± 0.2	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
FRSP_14	July	7.3 ± 0.1	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
FRSP_14	August	6.9 ± 0.1	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
FRSP_14	November	7 ± 0.1	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
FRSP_14	December	7.1 ± 0.1	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
FRSP_15	June	7 ± 0.2	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
FRSP_15	July	7.2 ± 0.1	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
FRSP_15	August	7.1 ± 0.1	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
FRSP_15	September	7.1 ± 0	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
FRSP_15	November	6.9 ± 0.1	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
FRSP_15	December	7.1 ± 0.1	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
FRSP_16	June	6.9 ± 0.2	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
FRSP_16	August	7.2 ± 0.1	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
FRSP_16	September	7.2 ± 0	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
FRSP_16	November	6.8 ± 0.1	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
FRSP_16	December	6.9 ± 0.1	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

Stream ID	Month	Mean pH ± SE	4 years			8 years			12 years		
			10%	20%	50%	10%	20%	50%	10%	20%	50%
FRSP_17	November	6.3 ± 0.1	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
FRSP_18	June	7 ± 0	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
FRSP_18	July	7.1 ± 0.1	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
FRSP_18	August	7 ± 0.2	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
FRSP_18	September	7 ± 0.1	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
FRSP_18	November	6.8 ± 0.1	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
FRSP_18	December	7.1 ± 0.1	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
GETT_07	August	7.5 ± 0.1	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
PETE_02	June	6.9 ± 0.1	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
PETE_02	December	6.7 ± 0.2	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
PETE_03	December	6.7 ± 0.2	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
PETE_04	June	6.8 ± 0.1	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
PETE_04	December	6.9 ± 0.2	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
PETE_05	June	7.4 ± 0.1	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
PETE_05	December	7.3 ± 0.1	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
PETE_07	June	6.1 ± 0.1	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
PETE_07	December	6.2 ± 0.1	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
RICH_01	June	6.6 ± 0.1	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
RICH_01	July	6.5 ± 0.1	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
RICH_01	August	6.6 ± 0.1	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
RICH_01	September	6.7 ± 0.1	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
RICH_01	November	6.5 ± 0.1	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
RICH_01	December	6.6 ± 0	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
RICH_02	June	6.6 ± 0.1	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
RICH_02	July	6.4 ± 0.2	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
RICH_02	August	6.6 ± 0.1	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
RICH_02	September	6.5 ± 0.1	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
RICH_02	November	6.5 ± 0.1	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
RICH_02	December	6.6 ± 0.1	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
RICH_03	June	6.3 ± 0.2	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
RICH_03	August	6.3 ± 0.1	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
RICH_03	September	6.1 ± 0.1	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
RICH_03	November	6.1 ± 0.1	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
RICH_03	December	6.2 ± 0.1	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
RICH_04	June	5.7 ± 0.1	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
RICH_04	July	5.6 ± 0.2	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
RICH_04	August	6 ± 0	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

Stream ID	Month	Mean pH ± SE	4 years			8 years			12 years		
			10%	20%	50%	10%	20%	50%	10%	20%	50%
RICH_04	September	5.7 ± 0.2	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
RICH_04	November	5.9 ± 0.1	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
RICH_04	December	5.9 ± 0.1	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
RICH_05	August	6.5 ± 0	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
RICH_06	June	6.5 ± 0	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
RICH_06	August	6.8 ± 0.1	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
RICH_07	June	6.5 ± 0.1	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
RICH_07	July	6.3 ± 0.1	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
RICH_07	August	6.7 ± 0.2	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
RICH_07	September	6.3 ± 0.2	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
RICH_07	November	6.4 ± 0	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
RICH_07	December	6.5 ± 0.1	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
RICH_08	August	6.5 ± 0	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

Table B-6. Power to detect a 10%, 20%, and 50% increase in monthly Specific Conductance (μS) for three sampling periods (4, 8, and 12 years) in MIDN streams sampled for 5 years.

Stream ID	Month	Mean ($\mu\text{S}/\text{cm}$) $\pm$ SE	4 years			8 years			12 years		
			10%	20%	50%	10%	20%	50%	10%	20%	50%
APCO_01	November	82.4 $\pm$ 0.9	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
APCO_02	November	112.6 $\pm$ 1.4	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
APCO_03	November	91.5 $\pm$ 0.9	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
BOWA_01	June	85.8 $\pm$ 1.5	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
BOWA_01	July	88.9 $\pm$ 1.8	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
BOWA_01	August	89 $\pm$ 1.5	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
BOWA_01	September	89.5 $\pm$ 0.9	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
BOWA_01	November	83.9 $\pm$ 0.8	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
BOWA_01	December	81.7 $\pm$ 3.4	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
BOWA_02	February	87.3 $\pm$ 5	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
BOWA_02	May	96.2 $\pm$ 3.5	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
BOWA_02	June	95 $\pm$ 3.7	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
BOWA_02	July	100.2 $\pm$ 3.5	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
BOWA_02	August	101.4 $\pm$ 2.7	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
BOWA_02	September	96.2 $\pm$ 3.3	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
BOWA_02	November	96.8 $\pm$ 2.2	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
BOWA_02	December	83.9 $\pm$ 7.8	0.98	0.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00
BOWA_03	June	94.4 $\pm$ 3.6	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
BOWA_03	July	99.5 $\pm$ 2.8	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
BOWA_03	August	101.4 $\pm$ 2.2	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
BOWA_03	September	96.2 $\pm$ 2.9	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
BOWA_03	November	96.7 $\pm$ 1.9	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
BOWA_03	December	82.8 $\pm$ 7.9	0.98	0.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00
BOWA_04	February	69.2 $\pm$ 8.5	0.90	0.94	0.99	1.00	1.00	1.00	1.00	1.00	1.00
BOWA_04	May	76.5 $\pm$ 2.6	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
BOWA_04	June	79.3 $\pm$ 1.6	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
BOWA_04	July	82.7 $\pm$ 1.7	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
BOWA_04	August	81 $\pm$ 2.1	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
BOWA_04	September	78.6 $\pm$ 3.5	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
BOWA_04	November	85.6 $\pm$ 6.1	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
BOWA_04	December	67.3 $\pm$ 3.9	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
BOWA_05	June	98.4 $\pm$ 3.4	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
BOWA_05	August	93.1 $\pm$ 1.3	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
BOWA_05	September	90.6 $\pm$ 2.7	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

Stream ID	Month	Mean ($\mu\text{S}/\text{cm}$) $\pm$ SE	4 years			8 years			12 years		
			10%	20%	50%	10%	20%	50%	10%	20%	50%
BOWA_05	November	85.4 $\pm$ 1.9	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
BOWA_05	December	76.3 $\pm$ 3.2	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
EISE_03	August	327.2 $\pm$ 75.8	0.50	0.56	0.71	0.96	0.98	1.00	0.99	1.00	1.00
FRSP_01	April	73.5 $\pm$ 4.6	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
FRSP_01	June	79 $\pm$ 5.7	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
FRSP_01	July	110.6 $\pm$ 12.2	0.94	0.97	1.00	1.00	1.00	1.00	1.00	1.00	1.00
FRSP_01	September	76.5 $\pm$ 4.6	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
FRSP_01	November	62.4 $\pm$ 2.6	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
FRSP_01	December	75.4 $\pm$ 12.4	0.73	0.79	0.91	1.00	1.00	1.00	1.00	1.00	1.00
FRSP_02	June	45.5 $\pm$ 2.5	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
FRSP_02	July	45.1 $\pm$ 3.7	0.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
FRSP_02	August	60.3 $\pm$ 6.7	0.94	0.96	0.99	1.00	1.00	1.00	1.00	1.00	1.00
FRSP_02	September	51.6 $\pm$ 6.5	0.89	0.93	0.98	1.00	1.00	1.00	1.00	1.00	1.00
FRSP_02	November	53.1 $\pm$ 5.8	0.95	0.97	1.00	1.00	1.00	1.00	1.00	1.00	1.00
FRSP_02	December	55.3 $\pm$ 5.4	0.98	0.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00
FRSP_03	June	78.9 $\pm$ 4.6	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
FRSP_03	July	89.1 $\pm$ 6.8	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
FRSP_03	August	80.9 $\pm$ 7.9	0.98	0.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00
FRSP_03	September	74.3 $\pm$ 4.9	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
FRSP_03	November	68.3 $\pm$ 5.3	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
FRSP_03	December	65.5 $\pm$ 3.2	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
FRSP_04	June	43.9 $\pm$ 1.8	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
FRSP_04	July	46.5 $\pm$ 2.4	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
FRSP_04	August	52.8 $\pm$ 4.6	0.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
FRSP_04	September	54.3 $\pm$ 5.3	0.97	0.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00
FRSP_04	November	57.1 $\pm$ 3.1	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
FRSP_04	December	55.8 $\pm$ 1.4	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
FRSP_06	April	106.2 $\pm$ 3.6	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
FRSP_06	June	97 $\pm$ 4.4	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
FRSP_06	September	93.5 $\pm$ 6.8	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
FRSP_06	November	97.5 $\pm$ 2.7	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
FRSP_06	December	101.3 $\pm$ 2.6	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
FRSP_07	July	115.2 $\pm$ 7.9	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
FRSP_07	September	130.4 $\pm$ 5.4	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
FRSP_07	November	121.7 $\pm$ 6.6	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
FRSP_07	December	116.1 $\pm$ 6.7	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
FRSP_08	April	184.4 $\pm$ 8.5	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

Stream ID	Month	Mean ($\mu\text{S}/\text{cm}$) $\pm$ SE	4 years			8 years			12 years		
			10%	20%	50%	10%	20%	50%	10%	20%	50%
FRSP_08	June	170 $\pm$ 7.6	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
FRSP_08	July	168.3 $\pm$ 20	0.92	0.95	0.99	1.00	1.00	1.00	1.00	1.00	1.00
FRSP_08	August	146.1 $\pm$ 15.4	0.96	0.98	1.00	1.00	1.00	1.00	1.00	1.00	1.00
FRSP_08	September	165.6 $\pm$ 14.9	0.99	0.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00
FRSP_08	November	167.2 $\pm$ 4.7	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
FRSP_08	December	168 $\pm$ 6.2	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
FRSP_09	June	63.8 $\pm$ 3.5	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
FRSP_09	July	74.7 $\pm$ 2	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
FRSP_09	August	70.4 $\pm$ 5.1	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
FRSP_09	September	80.9 $\pm$ 2.5	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
FRSP_09	November	75.5 $\pm$ 5	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
FRSP_09	December	62.8 $\pm$ 4.6	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
FRSP_10	June	53.7 $\pm$ 2.5	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
FRSP_10	July	59.3 $\pm$ 1.7	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
FRSP_10	August	56.3 $\pm$ 1.9	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
FRSP_10	September	57.9 $\pm$ 2.1	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
FRSP_10	November	54.2 $\pm$ 1.7	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
FRSP_10	December	50.7 $\pm$ 0.9	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
FRSP_11	June	111.8 $\pm$ 11.1	0.97	0.98	1.00	1.00	1.00	1.00	1.00	1.00	1.00
FRSP_11	July	101.2 $\pm$ 6.8	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
FRSP_11	August	98.9 $\pm$ 20.6	0.57	0.63	0.78	0.99	1.00	1.00	1.00	1.00	1.00
FRSP_11	September	143.4 $\pm$ 19.3	0.86	0.90	0.97	1.00	1.00	1.00	1.00	1.00	1.00
FRSP_11	November	128 $\pm$ 14.5	0.94	0.96	0.99	1.00	1.00	1.00	1.00	1.00	1.00
FRSP_11	December	133.6 $\pm$ 13.9	0.96	0.98	1.00	1.00	1.00	1.00	1.00	1.00	1.00
FRSP_14	June	97.7 $\pm$ 3.5	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
FRSP_14	July	113.2 $\pm$ 8	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
FRSP_14	August	78.6 $\pm$ 14.9	0.63	0.69	0.84	1.00	1.00	1.00	1.00	1.00	1.00
FRSP_14	November	95.7 $\pm$ 5.1	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
FRSP_14	December	89.9 $\pm$ 5	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
FRSP_15	June	69 $\pm$ 1.2	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
FRSP_15	July	77.3 $\pm$ 1.9	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
FRSP_15	August	114 $\pm$ 28.2	0.46	0.51	0.66	0.94	0.97	1.00	0.99	1.00	1.00
FRSP_15	September	76.6 $\pm$ 1.4	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
FRSP_15	November	77.5 $\pm$ 1.6	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
FRSP_15	December	72.8 $\pm$ 1.1	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
FRSP_16	June	156.5 $\pm$ 11.4	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
FRSP_16	July	177.6 $\pm$ 20.7	0.92	0.95	0.99	1.00	1.00	1.00	1.00	1.00	1.00

Stream ID	Month	Mean ($\mu\text{S}/\text{cm}$) $\pm$ SE	4 years			8 years			12 years		
			10%	20%	50%	10%	20%	50%	10%	20%	50%
FRSP_16	August	141.4 $\pm$ 24.9	0.69	0.75	0.88	1.00	1.00	1.00	1.00	1.00	1.00
FRSP_16	September	186.6 $\pm$ 17.9	0.98	0.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00
FRSP_16	November	170.9 $\pm$ 11.2	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
FRSP_16	December	162.4 $\pm$ 12.6	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
FRSP_17	November	39.4 $\pm$ 2.3	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
FRSP_18	June	97 $\pm$ 9.8	0.97	0.98	1.00	1.00	1.00	1.00	1.00	1.00	1.00
FRSP_18	July	82.6 $\pm$ 3.8	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
FRSP_18	August	92.8 $\pm$ 10.7	0.93	0.96	0.99	1.00	1.00	1.00	1.00	1.00	1.00
FRSP_18	September	117.1 $\pm$ 21.4	0.66	0.72	0.86	1.00	1.00	1.00	1.00	1.00	1.00
FRSP_18	November	104.4 $\pm$ 9.8	0.98	0.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00
FRSP_18	December	99.4 $\pm$ 8.3	0.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
GETT_07	August	286.5 $\pm$ 16.9	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
PETE_02	June	51.3 $\pm$ 1.5	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
PETE_02	December	71.4 $\pm$ 11.6	0.74	0.80	0.92	1.00	1.00	1.00	1.00	1.00	1.00
PETE_03	December	130.8 $\pm$ 21.5	0.73	0.79	0.91	1.00	1.00	1.00	1.00	1.00	1.00
PETE_04	June	125.3 $\pm$ 22.3	0.68	0.74	0.87	1.00	1.00	1.00	1.00	1.00	1.00
PETE_04	December	147.8 $\pm$ 35.4	0.48	0.53	0.69	0.95	0.98	1.00	0.99	1.00	1.00
PETE_05	June	212.5 $\pm$ 11.1	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
PETE_05	December	197.6 $\pm$ 25.4	0.88	0.92	0.98	1.00	1.00	1.00	1.00	1.00	1.00
PETE_07	June	55.1 $\pm$ 1.5	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
PETE_07	December	59 $\pm$ 4.4	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
RICH_01	June	108.8 $\pm$ 2.9	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
RICH_01	July	100.6 $\pm$ 5.6	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
RICH_01	August	96.1 $\pm$ 6.6	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
RICH_01	September	113 $\pm$ 6.4	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
RICH_01	November	103 $\pm$ 7.3	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
RICH_01	December	112 $\pm$ 2.7	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
RICH_02	June	135.7 $\pm$ 5.3	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
RICH_02	July	107.7 $\pm$ 22.6	0.56	0.62	0.78	0.99	0.99	1.00	1.00	1.00	1.00
RICH_02	August	123.8 $\pm$ 7.7	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
RICH_02	September	143.3 $\pm$ 6.9	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
RICH_02	November	151.3 $\pm$ 3.7	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
RICH_02	December	150.6 $\pm$ 5.7	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
RICH_03	June	68.9 $\pm$ 3.1	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
RICH_03	August	78.3 $\pm$ 7.9	0.97	0.98	1.00	1.00	1.00	1.00	1.00	1.00	1.00
RICH_03	September	82.2 $\pm$ 4.5	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
RICH_03	November	89 $\pm$ 5.9	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

Stream ID	Month	Mean ($\mu\text{S/cm}$) $\pm$ SE	4 years			8 years			12 years		
			10%	20%	50%	10%	20%	50%	10%	20%	50%
RICH_03	December	76.7 $\pm$ 4.4	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
RICH_04	June	57.1 $\pm$ 2.1	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
RICH_04	July	59.3 $\pm$ 3	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
RICH_04	August	61.3 $\pm$ 4.4	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
RICH_04	September	62.9 $\pm$ 2.6	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
RICH_04	November	61.6 $\pm$ 2.1	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
RICH_04	December	58.5 $\pm$ 2.6	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
RICH_05	August	89.7 $\pm$ 7	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
RICH_05	November	97.1 $\pm$ 9.8	0.97	0.98	1.00	1.00	1.00	1.00	1.00	1.00	1.00
RICH_06	June	110 $\pm$ 23.2	0.56	0.62	0.77	0.98	0.99	1.00	1.00	1.00	1.00
RICH_06	August	201.7 $\pm$ 66.5	0.31	0.35	0.47	0.76	0.83	0.95	0.88	0.93	0.99
RICH_07	June	67.4 $\pm$ 4.2	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
RICH_07	July	60.3 $\pm$ 1.7	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
RICH_07	August	65.9 $\pm$ 11.2	0.71	0.77	0.89	1.00	1.00	1.00	1.00	1.00	1.00
RICH_07	September	62.6 $\pm$ 1	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
RICH_07	November	79.5 $\pm$ 1.6	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
RICH_07	December	70 $\pm$ 1.4	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
RICH_08	August	293.1 $\pm$ 59.5	0.59	0.65	0.80	0.99	1.00	1.00	1.00	1.00	1.00

Appendix C. List of Standard Operating Procedures for the MIDN Water Quality Monitoring Protocol

A series of standard operating procedures (SOPs) have been developed to ensure that the protocol is implemented in a consistent manner and high quality data is captured. Unlike the protocol these SOPs are intended to change more frequently over time as specific methods are refined and equipment is replaced. Therefore, the SOPs are published in the NPS Natural Resource Report series separately from the protocol to facilitate timely updates to procedures. The most updated versions of the SOPs will be maintained by the MIDN office and distributed to park staff and volunteers as needed. Updated SOPs will be published through the NPS Data Store and made available on the NPS Integrated Resource Management Application portal (<http://irma.nps.gov>). The MIDN has adopted a similar numbering system for SOPs from the Southeast Coastal Barrier Network (SECN). To aid in understand the versioning of the SOPs, a three part numbering system separated by periods is used (e.g., 1.2.3). The first number indicates the major subject area (e.g., 1.x.x Field and Laboratory Methods), the second number indicates the number associated with the specific topic area (e.g., 1.9.x Field Site Visit Procedures: Discrete WQ Monitoring), and the third number indicates the version number. As SOPs are revised the version number will be changed to indicate a change in methods.

Table C-1. Standard operating procedures to implement the Mid-Atlantic Water Quality Monitoring Protocol.

Subject Area	SOP #	Citation	IRMA Record Number
Field and Laboratory	1.0.1	Mid-Atlantic Network. 2016. Aquatic Safety Procedures. Mid-Atlantic Network Standard Operating Procedure NPS/MIDN/SOP 1.0.1. National Park Service, Fredericksburg, VA.	
	1.1.1	Dammeyer, N.T. 2016. Site Establishment and Documentation. Mid-Atlantic Network Standard Operating Procedure NPS/MIDN/SOP 1.1.1. National Park Service, Fredericksburg, VA.	
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