



Long-Term Discrete Water Quality Monitoring at Big South Fork National River and Recreation Area, Blue Ridge Parkway, and Obed Wild and Scenic River

Protocol Narrative

Natural Resource Report NPS/APHN/NRR—2018/1840



ON THE COVER

Morning mist rising from the Big South Fork near Pine Creek.
Photograph by Evan Raskin.

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Natural Resource Report NPS/APHN/NRR—2018/1840

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Standard Operating Procedures

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Revision Log

Revision Date	Author	Changes Made	Reason for Change	New Version #
2/28/2016	UGA	Formatting and scientific editing.	Format to NPS standards	Not published
6/10/2016	APHN	Addressing UGA comments.	Address UGA comments	Not published
11/20/2016	APHN	Addressing Regional comments	Addressing regional comments	Not published
7/12/2018	APHN	Addressing Peer review comments	Addressing Peer review comments	Not published
10/25/2018	APHN	Addressing Regional comments	Addressing Regional comments	1.0

Executive Summary

Under the mandate of the National Parks Omnibus Management Act (1998), the National Park Service (NPS) developed a natural resources Inventory and Monitoring (I&M) program as part of a comprehensive effort to identify key natural resources within the National Park system and to provide long term monitoring of the integrity of those resources. The NPS has grouped parks into 32 I&M networks based on ecological similarity and geographic proximity. The Appalachian Highlands Inventory and Monitoring Network (APHN) includes four NPS units: Big South Fork National River and Recreation Area (BISO), Obed Wild and Scenic River (OBRI), Blue Ridge Parkway (BLRI), and Great Smoky Mountains National Park (GRSM). Natural resource inventories of APHN parks that have been completed to date indicate that these parks are among the most ecologically and biologically diverse within the National Park system.

This protocol describes the background, rationale, and sampling design for monitoring water quality using discrete sampling of water at fixed and rotating sampling stations for three APHN parks: Big South Fork NRRRA, Obed WSR and Blue Ridge Parkway. The main goals of this document are: (1) to describe the overall strategy for discrete water-quality monitoring that is credible and scientifically rigorous, (2) to identify the sampling design and sampling stations within each park, (3) to identify and justify key water-quality and -quantity indicators that will be monitored, and (4) to provide a specific set of instructions in the form of standard operating procedures (SOPs) that are sufficiently detailed to ensure consistent and comparable data collection for current and future practitioners.

The structure of this document follows the recommended framework and suggestions of Oakley *et al.* (2003). This document also describes important aquatic resources within the affected parks, and briefly summarizes characteristics of geology, soils, climate and hydrology that must be considered when monitoring water quality at Big South Fork NRRRA, Obed WSR, and Blue Ridge Parkway. A case is made for the relevance of this effort by highlighting known water-quality issues in the parks, as well as describing some of the important linkages between water quality and park resources that may help provide early warning of changing conditions or issues of concern in the future.

The objective of this long-term monitoring project is to determine annual status and long-term trends for key indicators of water resource condition. Field analyses include pH, specific conductance, temperature, dissolved oxygen, acid neutralization capacity (ANC), and turbidity. Laboratory analyses are broadly grouped into the following analytical schedules: (1) pH/buffering capacity, (2) (dissolved) solids, (3) routine anions/cations, (4) nutrients, (5) metals/metalloids, and (6) bacteriology. To complement these field and laboratory analyses, the network will make concurrent stream discharge measurements in accordance with USGS methodologies at each sampling station.

The APHN Long-Term Water Quality Monitoring Protocol for Discrete Sampling provides a tiered approach to optimize assessment of water resource integrity in network parks within the constraints of available resources. Level I monitoring includes fixed stations on and adjacent to the Blue Ridge Parkway corridor and at main stem rivers and key tributaries within the Obed Wild and Scenic River and the Big South Fork National River and Recreation Area. These stations will be sampled on either a monthly (if co-located with a USGS Gage) or quarterly frequency. Level II monitoring includes a

bank of sampling stations from which sites will be chosen and sampled on an annually rotating basis at a quarterly frequency. Level II monitoring is intended to supplement the long term fixed stations described above to provide more complete evaluation of water resource integrity throughout designated park lands.

Data collected using this protocol are stored in NPStoret and analyzed using a variety of analytical programs. A primary emphasis of the National Park Service (NPS) Inventory and Monitoring Program is to ensure that results and knowledge obtained from monitoring are communicated in a timely manner and to maximize information exchange in order to best meet park needs. Where appropriate to support the NPS mission, monitoring results will be shared as broadly as possible with park partners, NPS staff, and the public. Water quality status will be summarized in annual reports and resource briefs at the end of each calendar year. Longer term trends and/or synthesis reports will be written every three to seven years, depending on the needs of the parks. The synthesis reports will include information from a regional perspective in order to look at landscape-scale changes. Water quality data collected using this protocol will provide a scientific foundation for evaluating water-quality in the parks' major tributaries. The APHN discrete water-quality monitoring protocol (this document) is intended to complement additional protocols that will be developed by the Appalachian Highlands Network to monitor aquatic, riparian, and terrestrial resources of APHN park units.

Background and Objectives

In 1999, the National Park Service's Inventory and Monitoring (I&M) Program initiated a long-term ecological monitoring program known as Vital Signs Monitoring. It was designed to provide the infrastructure to allow more than 270 national park system units to identify and monitor conditions of their highest priority natural resources (Fancy *et al.* 2009). Established programmatically under the Natural Resource Challenge, the Appalachian Highlands Network (APHN) is one of thirty-two networks formed to implement this integrated monitoring program which is tailored to the specific needs of parks located in similar environmental settings. The overarching purpose of natural resource monitoring conducted under this program is to collect data and produce scientifically sound information on the current status of—and long-term trends in—the composition, structure, and function of park resources and ecosystems, as well as to determine how current management practices are sustaining those systems. Efforts implemented under the Vital Signs Monitoring Program seek to address the following five major goals for all parks with significant natural resources:

- Determine the status and trends in selected indicators of the condition of park ecosystems to allow managers to make better-informed decisions and to work more effectively with other agencies and individuals for the benefit of park resources.
- Provide early warning of abnormal conditions of selected resources to help develop effective mitigation measures and reduce costs of management.
- Provide data to better understand the dynamic nature and condition of park ecosystems and provide reference points for comparisons with other, altered environments.
- Provide data to meet certain legal and Congressional mandates related to natural resource protection and visitor enjoyment.
- Provide a means of measuring progress towards performance goals.

Development of the APHN Discrete Water Quality Monitoring Protocol

This protocol narrative describes the background, rationale, and sampling design for monitoring water quality using discrete sampling at three APHN parks: Big South Fork National River and Recreation Area (BISO), Blue Ridge Parkway (BLRI) and Obed Wild and Scenic River (OBRI). Due to its national importance to numerous park resources, as well as to visitor experience, water quality was selected as one of the twelve core NPS natural resource inventories for which baseline data were collected system-wide in the earliest phases of the newly-established I&M Program. This baseline water resource inventory information for parks in the Southern Appalachian Mountains and Cumberland Plateau was incorporated into the APHN planning process when the network began designing its long-term Vital Signs Monitoring Program in 2001. Water-quality monitoring was identified as a high-priority vital sign for all the network parks during the initial planning process.

In order to identify and prioritize issues of concern related to water quality, we began the sorting process by soliciting information from APHN parks' management (through questionnaires and meetings), asking them to rank the importance of the different water resources in the individual parks and to identify potential concerns that a monitoring program might address.

Each park developed a list of the issues and monitoring questions that were of greatest concern to park managers. In summary form, these questions included the following:

- How are upstream or adjacent disturbances, particularly coal mining, oil and gas extraction, logging (all related to Big South Fork NRRRA, Obed WSR), acid deposition (Blue Ridge Parkway) and agriculture and development (all parks) affecting water quality in the parks?
- What is the state of water quality in the parks in relation to EPA and state standards (all parks)?
- What are the long-term trends in water quality in the parks, including trends which may relate to climate change (all parks)?
- Is water pollution having an affect on significant aquatic biological resources in the parks (all parks)?
- What is the influence of park operations on water quality in the parks (all parks)?
- How is water quality being affected by forest insects and diseases (all parks)?

From 2002 to 2005, network, park and USGS Water Resources Division staff conducted a series of meetings and discussions to establish monitoring objectives and develop a sampling design for long-term water quality monitoring at Big South Fork NRRRA, Blue Ridge Parkway and Obed WSR (USGS had been contracted by Appalachian Highlands Network to do a retrospective water-quality analysis and develop a preliminary water-quality monitoring plan). We compiled information on past and ongoing monitoring in the parks, conducted literature reviews, and identified monitoring programs ongoing in areas adjacent to the parks that could be applied to or combined with NPS monitoring efforts. When we reviewed past studies of water quality in the network parks, we examined these closely with respect to the resources we anticipated being able to devote to long-term monitoring.

Under this protocol, water-quality data are collected in the field at discrete intervals (monthly where co-located with a USGS Gage, or quarterly otherwise), and samples are collected and sent to a water-quality lab for further analysis. This water resource monitoring protocol builds upon previous NPS efforts from 1982 to 1988, when water-quality monitoring at Big South Fork NRRRA and Obed WSR was conducted by park staff (Rikard et al. 1986). Due to funding and operational constraints, monitoring was discontinued, but these "legacy" data provide a valuable benchmark for comparison with more recent and future monitoring efforts.

Goals of this document are to: (1) outline a credible and scientifically rigorous water-quality monitoring program for Appalachian Highlands Network, and (2) provide a specific set of instructions in the form of standard operating procedures (SOPs) that are sufficiently detailed to ensure consistent and comparable data collection. The structure of this protocol follows the recommended framework and suggestions of Oakley et al. (2003). Furthermore, the protocol narrative describes: (1) important aquatic resources within the affected parks; (2) characteristics of geology, soils, climate and hydrology that must be taken into account when monitoring water quality in this area; (3) relevancy of APHN water-quality monitoring by highlighting known water-quality issues in the parks; and (4) important linkages between water quality and park resources.

The network's water-quality monitoring program also includes continuous sampling at fixed stations. The rationale and design for continuous monitoring is covered in *Long-Term Continuous Water-Quality Monitoring at Big South Fork National River and Recreation Area and Obed Wild and Scenic River: Protocol Narrative* (Hughes et al. 2018a).

Environmental Setting and Overview of Water Resources

Although linked by creation during a series of cyclic mountain building orogenies and subsequent periods of erosion, the Blue Ridge Mountains (containing Blue Ridge Parkway) and the Cumberland Plateau (containing Big South Fork NRRA and Obed WSR) are ecologically distinct. These physiographic provinces include varied geology, landforms, and climate and they support a highly diverse assemblage of terrestrial and aquatic flora and fauna. Moderate temperatures and a wide range of precipitation (50–90 inches/year [130–230 cm/year]) and elevation (1,000–6,684 feet [300 to 2,000 meters (m)] mean sea level) sustain diverse forest types and create an abundance of perennial and intermittent streams and wetlands that support one of the world's greatest assemblages of biological diversity and endemism (NPS 2018). The higher elevations of the Southern Appalachian Blue Ridge are second in the U.S. only to the Pacific Northwest in the average amount of rainfall annually (Catlin 1984).

The Blue Ridge physiographic province consists of the eastern ranges of the Appalachian Mountains. This province is characterized by roughly parallel mountain ridges oriented from northeast to southwest. The Blue Ridge province parallels the Ridge and Valley province of the Appalachians to the west and separates the Ridge and Valley from the Piedmont province to the east. The province was largely formed during the Paleozoic Era by tectonic shifting and faulting when the Blue Ridge was thrust to the northwest over the Ridge and Valley province (McNab and Avers 1994; Hatcher 2005). Many areas along the Blue Ridge Parkway allow observers to see evidence of regional plate tectonic activity, including folds, joints, and faults in the Linville Falls region and multiple rock types in the Grandfather Mountain area, where the Iapetus Ocean existed 300 million years ago. In several places such as the Grandfather Mountain Window, older rocks formed 1.1 billion years ago were overthrust atop younger rocks, and then subsequently eroded away in areas, exposing a “window” to these younger rocks.

The Cumberland Plateau, extending 450 miles from southern West Virginia to northeastern Alabama, is an extensive tableland of sandstone and shale, carved by water into a labyrinth of rocky ridges flanking deep gorges. According to The Nature Conservancy (2018), it is the world's longest expanse

of hardwood-forested plateau. Near its eastern boundary, the Cumberland Plateau exhibits mountainous topography that exceeds 3,500 feet (1,067) in elevation and is locally referred to as the Cumberland Mountains. Further west, the landscape is a classic dissected tableland, distinguished by flat to rolling upland areas, deeply incised river gorges, and long cliff lines. Some gorge sections are quite narrow, only 800 feet (244 m) from rim to rim, with nearly vertical walls up to 400 feet high. Average elevations on the Plateau are typically 1,200 to 2,000 feet (366–610 m) above sea level, equaling or exceeding those of the highest ridges of the adjacent Ridge and Valley province, but substantially lower than the high peaks of the Blue Ridge province to the east (NPS 1994; NPS 1999a).

The climate of the Appalachian Highlands Region is generally temperate, but varies locally with latitude and elevation. In the central and southern Appalachians, average annual temperatures may range from 50 to 64 °F (10 to 18 °C) from north to south. Elevation also plays a key role in temperature extremes. On the Cumberland Plateau, a weather station in Oneida, Tennessee (elevation 1440 feet [439 m]) reports daily maximum temperature exceeding 90 °F during the months of May through October for an average of 14 days per year. In contrast, a weather station atop Grandfather Mountain (elevation 5300 feet) reports only a single day (91 °F on August 27, 1968) of maximum temperature exceeding 90 °F between 1955 through 2012 (WRCC 2015). The Cumberland Plateau receives an average of 54 inches of precipitation annually (NPS 1997; NPS 1998), while the precipitation in the Blue Ridge may exceed 100 inches annually at the highest elevations (Catlin 1984).

Geology and Soils

The geologic history that shaped the Cumberland Plateau contributes to the wide range of naturally-occurring water-quality conditions observed in the vicinity of APHN parks located there (Big South Fork NRR and Obed WSR). Rocks underlying these parks are formed from sediments that were transported westward from the ancestral Appalachian Blue Ridge into an inland sea that covered much of the North American continent during the Mississippian and Pennsylvanian geologic periods. This depositional environment initially was dominated by marine shelf and shoreline conditions (beaches, barrier islands, lagoons, and tidal marsh) similar to the southeastern coast of the United States today. As sediment accumulated over time and displaced the inland sea, freshwater deltaic swamps and terrestrial environments became more prevalent. Coal was formed where organic matter accumulated in freshwater and marine swamps.

Much of the northern Cumberland Plateau in Tennessee, including the Obed and Big South Fork watersheds, is capped by erosion-resistant sandstones such as the Rockcastle Conglomerate, which is immediately underlain by siltstone, shale, coal, and fine-grained sandstone (Figure 1). The presence of marine trace fossils reflects saline conditions, as typical of a tidal flat (Miller et al. 2006). These variations in deposition exert significant influence on water quality, especially where the land surface is disturbed by activities such as mining. Coal seams and associated overburden that formed in a marine depositional setting are prone to acid mine drainage, while those seams that formed in a freshwater environment are not.



Figure 1. Rockcastle conglomerate sandstone outcrop flanking dissected stream valley on the Cumberland Plateau near the Big South Fork National River and Recreation Area.

Soils of the Cumberland Plateau are derived from sandstone, shale, and siltstone, which have a low capacity to buffer acidic input. Parent rock lithology influences the pH or acid/base value of the soil that is formed and, in turn, the plants the soil will support. As plants decompose, organic matter is added to eroded rock, concentrating nutrients in the top layer of soil, or topsoil. Topsoil helps soil retain water and nutrients instead of allowing them to wash away with rainwater, and plants keep topsoil in place. An abundance of rich soil produces greater plant life, so coves and valley bottoms with rich, humic topsoil, support a more diverse vegetative community than do the exposed ridge tops that flank the larger, incised stream reaches at Big South Fork NRR and Obed WSR. These thin-soiled ridge tops do not retain water or nutrients effectively during precipitation events. As a consequence they are sparsely vegetated and support only the hardiest of plants.

In the Southern Appalachians, geological stability over millennia, coupled with a large variety of soils, landforms and climates and the lack of glaciation, has fostered enormous biodiversity. Blue Ridge Parkway traverses five major mountain ranges—the Blue Ridge, Black, Great Craggy, Great Balsam and Plot Balsam Mountains—encompassing diverse high elevation habitat corridors along an ecological transect spanning 4.5 degrees of longitude and 2.5 degrees of latitude (the third-largest geographic range of any unit in the national park system (Teague 2000)). The height of the mountains, compared with the surrounding landscape, has influenced local weather patterns. For every 1,000 feet of elevation gained, the temperature drops approximately 3 °F (Catlin 1984), making the highest mountains of Blue Ridge Parkway an average of 18–20 °F cooler than its lowest areas. These high-elevation sites are also wetter, because the high ridges intercept warm, rain-bearing winds from the southwest. Some areas in the Southern Appalachians receive 100 inches (254 cm) of rainfall per year,

making the Blue Ridge highlands the second wettest place on the North American continent (only the Pacific Northwest coast has higher levels of precipitation; Catlin 1984).

Because of the complex geology found within the Blue Ridge province, and the extended time period over which geologic strata have been exposed to erosion, a large variety of soil types (100 different series [Smathers and Pittillo 1978]) have weathered from different parent materials, dramatically affecting distribution of plants and some animal species. Changes in soil chemistry related to acid rain are a source of concern at Blue Ridge Parkway. Specifically, acid deposition (including cloud and fog deposition at the higher elevations) may cause heavy nitrification of soils. This may decrease the availability of nutrients to forest plants, trigger the release of toxic aluminum ions in soils, and cause harm to terrestrial and aquatic plants and animals (NPS 2010).

Water Resources of APHN Parks

Blue Ridge Parkway

Designed as a scenic highway, the 469 mile- (739 km-) long Blue Ridge Parkway (Figure 2) encompasses 83,343 acres (130 square miles [sq mi]) and ranges in elevation from 649 feet to 6,411 feet (198–1,954 m) as it winds along the crest of the Southern Appalachian Mountains. The long corridor of designated park lands within Blue Ridge Parkway protects a wealth of aquatic resources, including seeps and springs, wetlands, and upland coldwater trout streams (natural and stocked). The park crosses 15 sub-watersheds, and intersects approximately 1,200 stream segments. Major river intersections include the French Broad and Swannanoa rivers near Asheville, North Carolina, the Linville River near Linville Falls, North Carolina, the Roanoke River near Roanoke, Virginia, and the James River near Lynchburg, Virginia (Emmott et al. 2005).

Because the Blue Ridge Parkway primarily follows the ridgeline of the Southern Appalachians, a substantial number of its streams originate within the park and flow outward. As a result, precipitation is the primary input sustaining flow in headwater streams along much of the length of the Blue Ridge parkway (Hopkins 1984). Precipitation is also the source of recharge to groundwater resources of the Blue Ridge Parkway. Much of this groundwater is stored within the surface layer of weathered regolith overlying bedrock units (Winner 1977), but groundwater resources also include deeper resources. Heavily fractured and tilted bedrock of the Blue Ridge promotes connectivity between the surface and groundwater regime. Springs and seeps that discharge from bedrock and regolith may exhibit dramatic differences in water chemistry depending upon source rock lithologies, which may be spatially variable over short vertical and lateral distances as a consequence of faulting. These seeps and springs sustain streamflow in upland drainages and are an important influence to a number of unique high elevation wetlands and to the thermal regime of coldwater fisheries.

Where the Blue Ridge Parkway descends into lowland valleys, stream corridors enter the park unit from outside sources. In these cases, sources of runoff may include adjacent agricultural lands and developed areas.

The Blue Ridge Parkway protects a significant proportion of the remaining Southern Appalachian bog/fen habitat. It also protects several rare aquatic species, including the federally-listed (threatened) bog turtle (*Glyptemys muhlenbergii*) and swamp pink (*Helonias bullata*).

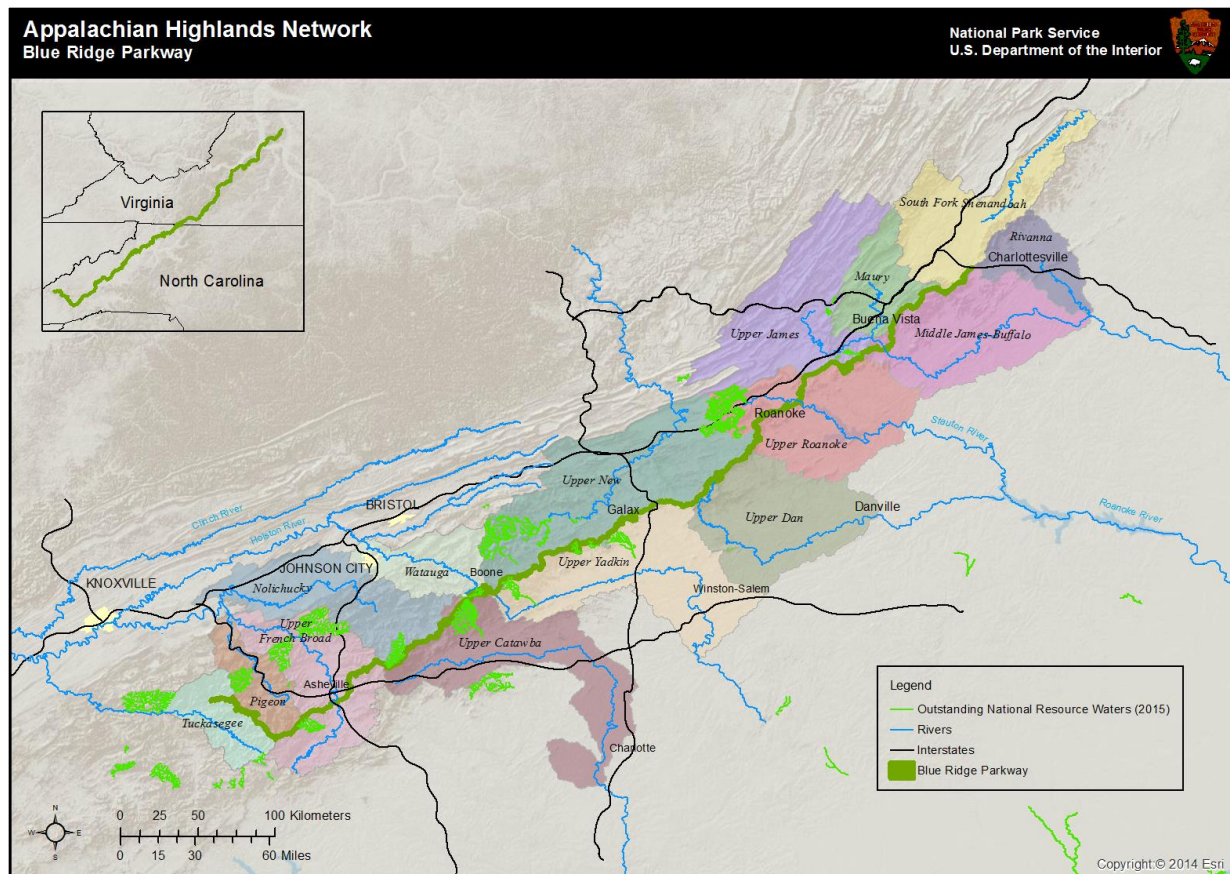


Figure 2. Blue Ridge Parkway sub-watersheds and surrounding municipal areas.

Big South Fork National River and Recreation Area

The Big South Fork of the Cumberland River (Figure 3), is the largest free-flowing river that lies entirely within the Cumberland Plateau of Kentucky, Tennessee, Alabama and Georgia. The Big South Fork watershed drains approximately 1,120 square miles (2,901 square kilometer [sq km]) in seven counties of Tennessee and Kentucky. Approximately 14% of that area lies within the boundaries of the Big South Fork National River and Recreation Area (NRRA). Water resources within Big South Fork NRRA include approximately 80 miles (129 km) of the Big South Fork of the Cumberland River along with its two major tributaries, Clear Fork and New River (Worsham et al. 2013). In addition, there are hundreds of miles of small to medium sized tributaries and low order headwater streams within the park's 125,000 acres (50,585 hectares [ha]). Although waters in most of the park are unaffected by impoundment, approximately 15 miles (24 km) of the Big South Fork of the Cumberland River in the northernmost (downstream) portion of the park include backwaters of Lake Cumberland, a U.S. Army Corps of Engineers impoundment on the Cumberland River.

Appalachian Highlands Network Big South Fork NRR Watershed

National Park Service
US Department of the Interior

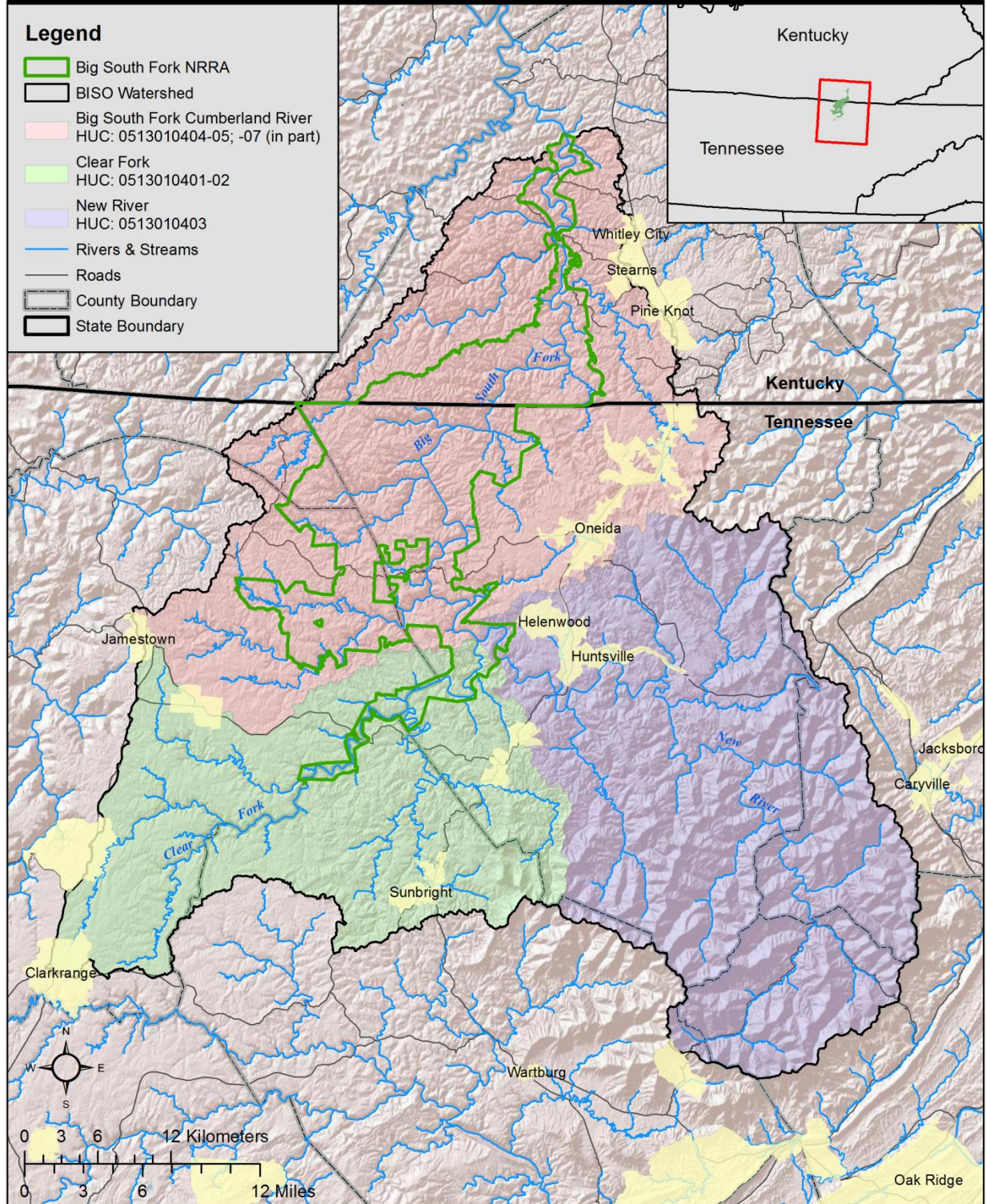


Figure 3. The Big South Fork National River and Recreation Area watershed, major sub-watersheds, and surrounding municipal areas.

Obed Wild and Scenic River

The Obed Wild and Scenic River (OBRI; Figure 4) is a major free-flowing tributary in the upper Tennessee River system. The Obed River is the only Wild and Scenic River in Tennessee and is one of 203 Wild and Scenic Rivers nationally, only 20 of which occur in the Southeast. Obed WSR encompasses 5,057 acres (2,046 ha) in Morgan and Cumberland Counties (the Obed drainage area also includes portions of Fentress County) that are largely restricted to 45.2 linear miles (72.7 km) of stream corridors of the Obed and Emory Rivers and of the Daddys Creek and Clear Creek tributaries of the Obed. The Park watershed drainage area is approximately 612 square miles (158,507 ha). Lands within and adjacent to the Obed Wild and Scenic River corridor are shared with the State of Tennessee's Catoosa Wildlife Management Area (WMA), and managed lands within the Catoosa WMA surround and buffer a significant portion of the Wild and Scenic River corridor.

Streamflow

Streamflow is controlled by rainfall and runoff patterns, groundwater recharge and discharge, and anthropogenic withdrawal and alterations to natural flow patterns that occur in the watershed. Peak flows and highest seasonal baseflow in APHN parks are typically greatest during winter and spring, with low flow periods normally occurring in summer and early autumn when tributaries and headwater reaches of main stem rivers sometimes approach zero flow conditions. Thin soils atop low-permeability sandstones and shales of the Plateau inhibit infiltration of rainfall and promote direct overland runoff. As a consequence, stream systems on the Cumberland Plateau are characterized by rapid surface runoff and relatively low groundwater storage, creating a range of flows from violent, high-volume flash floods to extreme low streamflow conditions during drier seasons and during drought (NPS 1997; NPS 1998).

In the Southern Appalachians, flow regimes vary depending on slope position. The thin soils that generally prevail on higher, steep slopes and southerly aspects have little water storage capacity and promote rapid runoff; however, high rainfall and moderate year-round temperatures have combined to produce deep, stable soils in many midslope and valley bottom positions. Although these soils are often porous and well drained, their depth and the density of vegetative cover promote slope stability, and soils may have significant water holding capacity (Daniels et al. 1987). Peak flows resulting from storms may be less flashy than those on the Plateau, but are sustained and remain elevated for longer periods of time due to greater input from the groundwater system. Aquatic ecosystems within all of the parks are adapted to and dependent upon these natural, widely varying flow regimes.

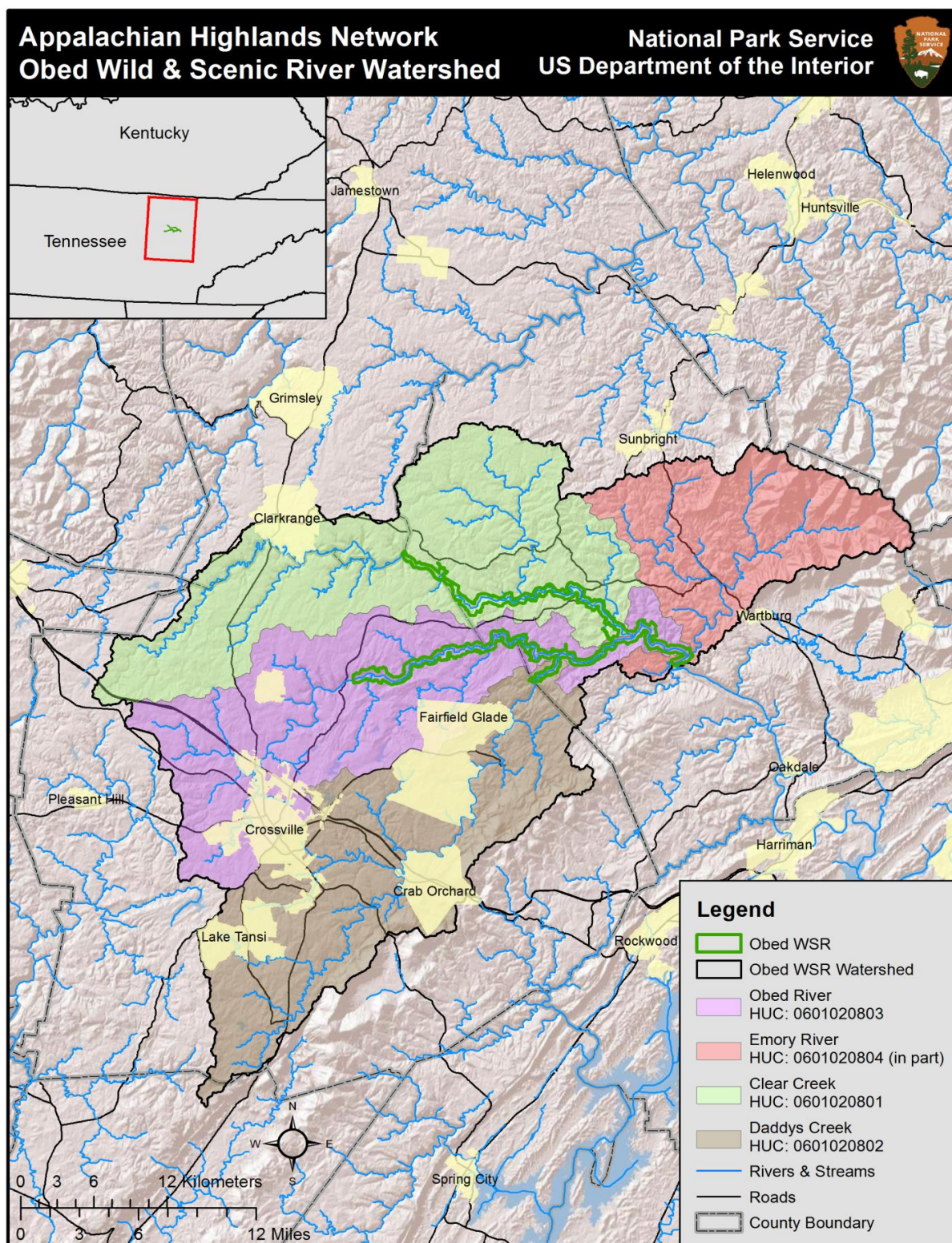


Figure 4. The Obed Wild and Scenic River watershed, major sub-watersheds, and surrounding municipal areas.

Water Chemistry

Under undisturbed conditions, water chemistry in network parks ranges from extremely dilute, soft water in the headwater drainages to moderately soft water in the larger streams. In general, streams in the western portion of the Big South Fork NRR watershed are less disturbed than streams in the eastern and southern portions of the watershed, which have been subjected to more frequent and severe impacts related to coal mining, logging, and stormwater runoff (Rikard et al. 1986). At Obed WSR, the main stem of the Obed River and Rock Creek are two of the most impacted reaches, primarily as a consequence of municipal development and wastewater discharges, agricultural and commercial forestry operations, and coal mining (NPS 1998). There is significant variation in water chemistry, depending on the parent geologic material underlying the land surface. Most streams are sandstone-influenced and are susceptible to acid contamination because of their very low alkalinity (O'Bara et al. 1982). This lack of buffering capacity renders park waters highly susceptible to degradation by acidic input, such as the acid mine drainage that has adversely affected many streams on the Plateau, including Big South Fork NRR and Obed WSR (NPS 1997).

Soils within many Southern Appalachian watersheds are inherently low in base cations such as calcium, magnesium, and potassium (Holzmueller et al. 2007). Base cations are essential for vegetation and animal growth, and for regulating water chemistry by buffering acidic inputs. Acid deposition is a particular problem in the Appalachians because it overwhelms the generally low acid-neutralizing capacity of soil and bedrock, and causes soil water pH to permanently drop over time, mobilizing nutrients and metals from the soil into streams. Leaching of toxic metals, such as aluminum, may cause acute mortality in freshwater organisms and chronic reproductive and health stress on sensitive native fish, such as brook trout (*Salvelinus fontinalis*; Neff et al. 2008). These effects may be exacerbated during storm runoff and spring snow melt runoff, which can cause significant loading of acid materials into streams, especially after long dry periods when accumulated dry particles wash from leaves and soil (Deyton et al. 2009).

Park Water Quality Issues and Rationale for Monitoring

Blue Ridge Parkway

Blue Ridge Parkway is a water-rich park, owing to its complex topography and the heavy precipitation common to the Southern Appalachian Mountains (approaching 100 inches (254 cm) per year in some high elevation areas (Davey et al. 2007; Billings and Anderson 1966). Maintaining water quality in an unimpaired state represents a challenge for the parkway because of its narrow, linear configuration, and because most threats to park water quality originate outside its approximately 1,000-mile (1,609 km) long perimeter. Water quality concerns at Blue Ridge Parkway can be broadly classified as either regional or local in nature. Local concerns may include the need to protect a particular resource such as a high elevation wetland of listed species or to mitigate a site-specific disturbance such as a campground or wastewater treatment system. Regional concerns include issues such as atmospheric deposition or forest insect and disease infestations.

Site-specific Issues

The parkway's aquatic habitats and species may be impacted by a variety of localized disturbances such as development of facilities within the park and residential and urban development adjacent to

the park. Parkway waters affect or are affected by 149 industrial/municipal discharges, 40 drinking water intakes, and 78 impoundments. Facilities within the park also discharge into streams, including those at Otter Creek, Rocky Knob and Pisgah Campgrounds. Blue Ridge Parkway manages over 500 agricultural leases within the park boundary and some of these are associated with Southern Appalachian bog/fen habitat. While light to moderate grazing has been found to be beneficial to some of the rare species that occupy these habitats, particularly the federally-listed bog turtle (Herman 2003), grazing at higher intensities can detrimentally affect wetlands by increasing the amount of nutrients in these naturally nutrient-poor systems, and by causing soil compaction which reduces water infiltration and can alter hydrology (Cole et al. 1996; Sutter et al. 1996). Infestations of non-native insects and forest diseases have also caused long-term changes to local drainages. For example defoliation of hemlocks by the hemlock wooly adelgid (*Adelges tsugae*) may increase water temperatures and alter the community structure of aquatic plants and animals.

Atmospheric Deposition

Atmospheric deposition is probably the most widespread water-quality issue in the Blue Ridge Physiographic Province, including Blue Ridge Parkway, where some of the highest total nitrate and sulfate levels in the United States have been documented. The average pH of rainfall in nearby Great Smoky Mountains National Park in recent years has been 4.3 (on a logarithmic scale from 1 to 14, with 7 being neutral) (NPS 2018a). A single large storm at higher elevations can lower stream pH 1.0-1.8 units for 6-12 hours after the event (Deyton et al. 2009). Sustained pH levels below 5.0 can result in declines in benthic invertebrates and fish, and reproductive failure of acid-sensitive amphibians (Schwartz et al. 2014). Chronic and episodic acidification of streams can lead to elevated levels of toxic monomeric aluminum, which can further reduce survival and diversity of aquatic invertebrate and fish populations (SAMAB 1996).

Based upon work conducted in the Great Smoky Mountains and on the adjacent Pisgah and Nantahala National Forests, the streams and wetlands most affected by acidic deposition are first order headwater streams at higher elevations (Southern Appalachian Mountains Initiative 2002). These high-elevation watersheds on the parkway are predominately overlain by non-calcareous soils and bedrock lithologies characterized by low alkalinity that is insufficient to buffer acidic deposition through rain and snow fall or cloud vapor. With current nitrate and sulfate deposition levels, streams at high elevations in the southern Appalachians are particularly susceptible to acidification (Fakhraei et al. 2016). Problems with nitrate acidification can also be exacerbated in watersheds where gypsy moths have defoliated the trees, as is occurring on the northern sections of Blue Ridge Parkway

Big South Fork National River and Recreation Area

Big South Fork NRRRA occupies a small, downstream portion of its large (1,120 square mile [2,901 sq km]) watershed, and therefore, the health of its aquatic systems is dependent to a large degree on external factors. Some streams within Big South Fork NRRRA are severely polluted, yet the park also contains some of the most biologically diverse and pristine waters on the Cumberland Plateau. The primary threats to water quality at Big South Fork NRRRA are related to acid mine drainage from active and abandoned coal mines, sedimentation associated with mining, roads and trails, forestry, agriculture, and oil and gas activities (NPS 1997). Big South Fork NRRRA is also potentially

threatened by negative impacts associated with impoundments and water withdrawal by municipalities and agricultural operations.

Coal Mining

The majority of past coal mining in Tennessee occurred within the Big South Fork drainage (Figure 5). Big South Fork NRRA has more abandoned mines and associated acid mine drainage within its boundaries than any other National Park Service unit nationwide (NPS 1997). Big South Fork NRRA is also at risk from water quality impacts associated with mines outside its boundaries. The New River, the largest tributary to the Big South Fork, drains a basin which supplied more than half of Tennessee's coal during the 1970s. More than forty years later, the effects of this mining activity are still evidenced by acid and ferruginous runoff from mined lands and by bedload and streambank deposits of coal and mine spoils. Most of the New River watershed was mined prior to the enactment of the Surface Mining Control and Reclamation Act of 1977 (SMCRA), which requires reclamation of mined lands and development of hydrologic reclamation plans to protect water resources. There are approximately 25,100 acres of abandoned or poorly reclaimed coal mines in Tennessee counties adjacent to the park, and 10 abandoned surface coal mines adjacent to the park in Kentucky (NPS 1997). As a result, many tributaries of the Big South Fork are acidic and have high concentrations of heavy metals such as iron, manganese, aluminum, and zinc (Rikerd 1985; U.S. Forest Service 1982). There are approximately 100 abandoned deep coal mine openings and associated spoil tailings inside the BISO boundaries, and future mining within the park is possible on the 18,900 acres where mineral rights have been retained by private owners (NPS 1997; NPS 2012). Even without additional future mining activity, the Big South Fork already contains twice the amount of dissolved and suspended solids and 2.5 times the sulfate yield of a similar river basin where mining has not occurred (NPS 2005).

Oil and Gas Extraction

There are over 300 active or abandoned oil or gas wells inside the BISO park boundary. In an attempt to address environmental and health/safety issues, park resource management staff are working with state and federal partners to plug as many abandoned wells as possible (NPS 2012). Oil and gas operations are allowed to continue within the park on the 18,900 acres where mineral rights have been retained by private owners. The 2012 Oil and Gas Management Plan and EIS for Big South Fork NRRA and Obed WSR (NPS 2012) identified a "reasonably foreseeable development scenario" of up to 25 wells that could be drilled in Big South Fork NRRA and Obed WSR in the next 15 to 20 years, and up to 125 wells that could be amended or serviced to restore or improve production (Zurawski 1995; NPS 1997).

Brine discharge from oil and gas extraction negatively affects water quality in at least three major tributaries to Big South Fork. Additional impacts associated with oil and gas extraction include increased runoff and sedimentation as a consequence of soil compaction and vegetation damage; discharge of oil, gas or production chemicals (in addition to brine) from separation or holding ponds; contamination of groundwater by improperly cased or unplugged wells; and runoff and sedimentation from poorly maintained access roads (NPS 1997; NPS 2012).

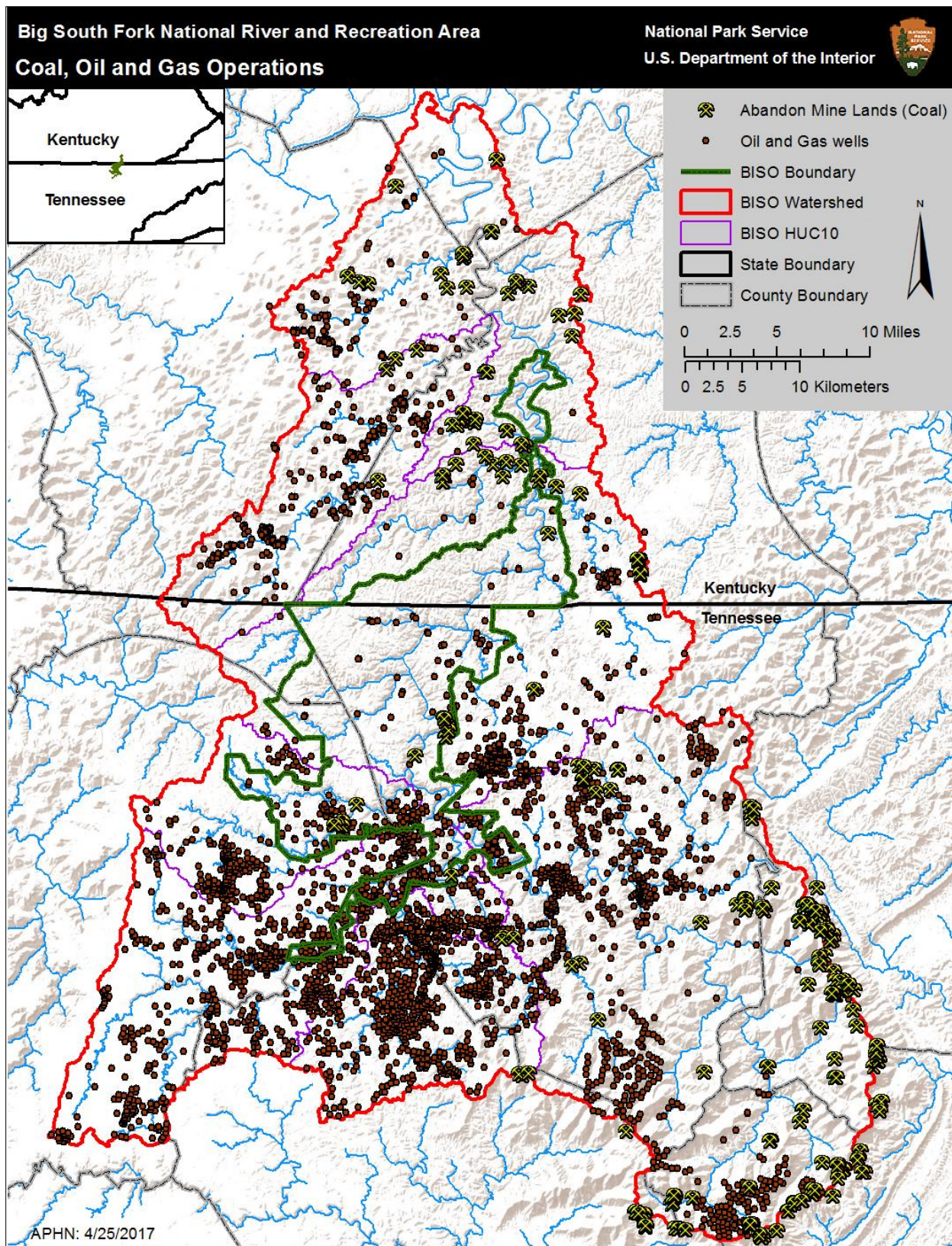


Figure 5. Permitted coal mines (black X) and oil & gas operations (black dots) in Big South Fork watershed (re-processed Google Earth KML coverage using ArcGIS).

Timber Harvest

Timber production is a major land use in the BISO watershed. Large tracts of land, particularly in the New River watershed, are owned by commercial timber companies (NPS 1997). Large timber stands in the New River basin are located on or near previously-mined land or mine spoils, where future harvest could destabilize the already modified topography, resulting in excessive erosion (NPS 1997). Potential impacts associated with forestry operations include increased runoff and sedimentation as a result of loss of vegetation and soil erosion.

Water Development

The demand for domestic and industrial water use is outgrowing existing water supply systems on the Cumberland Plateau and adjacent areas, due in large part to the fact that groundwater resources are insufficient to meet public water supply needs (NPS 1997). In recent decades there have been several proposals to establish drinking water supply intakes within the BISO watershed, one of which was located inside the park boundary (NPS 1997). Water withdrawal and the concomitant increase in industrial and municipal wastewater discharge can potentially alter natural streamflow, water quality, aquatic habitat, and recreational use.

Obed Wild and Scenic River

The park's land base is relatively small compared to the size of its watershed; therefore, the quality and quantity of its waters largely reflect conditions upstream of the park boundary. Municipal development, water-supply impoundments, agricultural and forestry operations, and coal mining and oil and gas operations represent the most significant threats to the park's aquatic systems. As is true for Big South Fork NRR, there are both severely polluted waters as well as relatively pristine waters within Obed WSR.

Key natural resource issues facing the park are related to efforts to preserve the "outstandingly remarkable" character of park waters—the reason it was designated a Wild and Scenic River. Resource management challenges involve not only protecting park waters, but defining baseline conditions, so the park can more effectively manage potential resource threats.

Principal potential impacts to water quality in the park include siltation and suspended solids loading associated with mining and timbering operations, acid coal mine drainage and elevated dissolved solids associated with mining and oil and gas operations, pathogenic bacterial contamination (*Escherichia coli*), and nutrient enrichment and dissolved oxygen reduction associated with municipal runoff, wastewater discharges, and agricultural practices. Elevated specific conductance and high levels of silt from construction sites and agricultural operations have been documented on the main stem of the Obed and several of its major tributaries (Rikard et al. 1986).

Development

Upstream urban and suburban growth and associated increases in water demand, wastewater discharge, and a proliferation of recreational and water supply impoundments are significant management concerns at the Obed. As population increases in the watershed, increased pressure on natural resources may occur in the absence of sound development and management practices. The City of Crossville is also a key partner in protection of the water resources of the Obed Wild and

Scenic River. Dramatic improvements to wastewater treatment at the city's sewage treatment plant have resulted in concomitant improvement to water quality within the city and in downstream reaches of the Obed River. The City of Crossville has also developed an MS4 stormwater management program (mandated by EPA) to promote best management practices for new and existing developed areas within the city. These efforts, in combination with development practices implemented through the Cumberland Habitat Conservation Plan (HCP) and protection of wildlife habitat on Tennessee Wildlife Resource Agency (TWRA) managed properties through the Forest Resources HCP, are intended to promote the long-term viability of land and water resources of the Cumberland Plateau and the Obed Wild and Scenic River.

Water Withdrawal and Impoundment

Water withdrawal or impoundment can alter water quality, as well as the quantity, frequency and duration of flows downstream, and threaten associated biological systems. Between 1943 and 1994, 2,903 impoundments were constructed in the watershed upstream of the park boundary, from farm ponds to large reservoirs (TVA 1998). As of 1997, there were 3,871 impoundments in the Obed watershed (Keller 2004; NPS 2012). As development pressures around the town of Crossville increase, demand for water in this section of the Plateau has become a high-profile issue. Requests for permits to construct large impoundments, for water supply or recreation upstream of the park, have been made several times in the last few years. There is concern that upstream impoundments may individually and cumulatively impair natural variability of streamflows and water-related resource attributes, but there is uncertainty regarding the extent and nature of these impacts (NPS 2012).

Agricultural Runoff

Approximately 72% of the Obed/Emory River watershed is forested, 25% comprises pasture, and the remaining 3% is in agricultural production for livestock and row crops (TVA 1998). Runoff from agriculture and livestock operations results in high levels of bacteria and elevated conductivity that threaten water-quality conditions at certain places within Obed WSR (TVA 1998).

Coal Mining

There is no active coal mining currently being conducted in the Obed River watershed (there is one inactive permitted mine); however, runoff from abandoned mines continues to affect water quality in portions of the park. There are concentrations of abandoned strip mines in the headwaters of Daddys Creek, the Emory River, and various tributaries of Clear Creek. Within the Obed WSR boundary there are portions of two abandoned strip mines and one abandoned deep mine, all of which have naturally re-vegetated (TVA 1998).

Oil and Gas Extraction

Oil and gas extraction occurs within and outside the park. Within Obed WSR, new oil and gas exploration is limited, by deed restrictions, to directional drilling from outside the boundary. However, seven oil and gas wells are located within the legislated boundary; five of these are on federal land, and two are situated on private inholdings. Two wells have been abandoned and plugged (O'Dell 2005). As noted above in the BISO description, there is the potential for multiple new wells to be established and/or old ones refitted for future production.

Significant Aquatic Resources

The complexity of the Blue Ridge Parkway's geology and topography, including its 5,700-foot elevation range, provides habitat for an extraordinary diversity of plant and animal life. The park's high-elevation wetlands represent a significant proportion of North Carolina's remaining habitat of this type. Two federally-listed species inhabit these wetlands. Blue Ridge Parkway's waters support 93 species of fish, including native brook trout (*Salvelinus fontinalis*) (Shull and Walker 1995). Park lands harbor 43 amphibian species, more amphibians than any other NPS unit. Recent aquatic macroinvertebrate collections from high-elevation streams, seeps and other wetlands on Blue Ridge Parkway have produced some significant finds, including more than eight species new to science, three new genera, and other species known from fewer than half a dozen sites worldwide (Lenat 2007), emphasizing the importance of monitoring these unique and highly threatened habitats.

Big South Fork NRRRA and Obed WSR contain significant aquatic resources, including Outstanding National Resource Waters and numerous imperiled species. Big South Fork NRRRA protects a nationally important freshwater fauna, including 11 federally-listed mussel species and the only population in existence of the federally-endangered tuxedo darter (*Etheostoma lemniscatum*). Big South Fork NRRRA is considered one of the most species-rich sites for freshwater mussels in the Cumberland River watershed, which stretches 700 miles from the Ohio River to the foothills of the Appalachian Mountains (Ahlstedt *et al.* 2003). Among its aquatic resources, Obed WSR protects one of only two existing populations of the federally-endangered Alabama lampshell mussel (*Lampsilis virescens*), and a significant population of the federally-threatened spotfin chub (*Erimonax monachus*).

In addition, these two parks support the largest concentration and most pristine examples remaining of the Globally Imperiled Cumberlandian cobble bar or riverside scour prairie, a unique vegetation association endemic to the Cumberland Plateau of Tennessee and Kentucky. No other habitat type within these parks supports such a large assemblage of globally rare plants (27 species). Among these are two federally-listed threatened species – Cumberland rosemary (*Conradina verticillata*) and Virginia spirea (*Spiraea virginiana*); Big South Fork NRRRA and Obed WSR contain 89% of all the remaining Cumberland rosemary populations. These cobble bar prairies and the rare species that inhabit them thrive in the presence of frequent catastrophic floods, and are dependent upon natural flood regimes and unpolluted water.

Status of Blue Ridge Parkway, Big South Fork NRRRA and Obed WSR Waterbodies (Stream Classifications under the Clean Water Act)

To meet the requirements of the Clean Water Act of 1972, Kentucky, North Carolina, Tennessee and Virginia classify waters into “use” categories, with distinct water-quality criteria for each category. Streams may be classified for multiple uses. Waters not meeting the criteria for a designated use are classified as impaired and placed on the states' 303(d) lists to ensure that the sources of impairment are addressed. These states also maintain lists relating to waters of exceptional quality or those with average conditions well above the standards for aquatic life (North Carolina Division of Water Resources 2012, Kentucky Division of Water 2012, Tennessee Department of Environment and Conservation 2012, Virginia Department of Environmental Quality 2012). Fourteen streams

intersecting Blue Ridge Parkway in North Carolina are classified as state Outstanding Resource Waters. All streams in Big South Fork NRR and Obed WSR are listed as “Exceptional Waters” in Tennessee, which conveys a degree of protection against degradation of their classified uses. Classification as an Outstanding National Resource Water (ONRW) is the most protective designation that can be conveyed by the states under the Clean Water Act. The free flowing portions of the Big South Fork in Tennessee and Kentucky and the Obed River within Obed WSR are listed as ONRWs.

303(d) Classification

Under Section 303(d) of the Clean Water Act, states are required to evaluate all available water quality-related data and information to develop a list of waters that do not meet established water-quality standards (impaired) and those that currently meet water-quality standards, but may exceed standards in the next reporting cycle (threatened). Section 303(d) lists of impaired waters within and adjacent to parks of the Appalachian Highlands Network have been developed by each state. In cases where the impairment is due to a specific and identifiable pollutant, a recovery plan is developed that includes specification of a Total Maximum Daily Load (TMDL) for pollutants found to be the cause of impaired water quality. Assignment of waters to the list helps each state prioritize water quality improvement efforts. According to the final 2012 303(d) lists for each state, portions of 14 303(d)-listed streams fall within or immediately upstream of Blue Ridge Parkway, Big South Fork NRR and Obed WSR (Table 1, Figures 6, 7, and 8; NPS-WRD 2018).

Table 1. 303d-listed streams within and near Blue Ridge Parkway, Big South Fork National River & Recreation Area, and Obed Wild and Scenic River as of 2012. These streams are 303d-listed for causes originating outside park boundaries. <https://www.nature.nps.gov/water/HIS/>

Park	Stream/Impaired Sections	Cause	Pollutant Source	Use Comments
BLRI	Middle Fork South Fork New River (Chetola Lake), from source to Sumpter Cabin Branch; 0.77 mi w/in the park	biological integrity; benthos	Non-point sedimentation, nutrients, habitat degradation	Aquatic Life
BLRI	East Fork South Fork New River, from source to Watauga County SR 1524; 0.36 mi w/in the park	ecological integrity; benthos	Non-point sedimentation, nutrients, habitat degradation; wastewater plant	Aquatic Life
BLRI	Richland Creek (Lake Junaluska), from source to US Route 23; 0.17 mi w/in the park	Fecal coliform	Non-point livestock runoff and septic system failure.	Aquatic Life
BLRI	West Fork Dodd Creek mainstem from the confluence of an unnamed tributary upstream to its headwaters. 0.6 mi w/in the park.	Fecal coliform	Livestock runoff	Recreation

Table 1 (continued). 303d-listed streams within and near Blue Ridge Parkway, Big South Fork National River & Recreation Area, and Obed Wild and Scenic River as of 2012. These streams are 303d-listed for causes originating outside park boundaries. <https://www.nature.nps.gov/water/HIS/>

Park	Stream/Impaired Sections	Cause	Pollutant Source	Use Comments
BLRI	Glade Creek mainstem from the mouth of Coyner Spring Branch upstream to its headwaters. 0.16 mi w/in the park.	E. coli	Municipal (Urbanized High Density Area), Wastes from Pets, Livestock (Grazing or Feeding Operations), Domestic Waste	Recreation
BLRI	James River mainstem from the Balcony Falls Dam downstream to the mouth of Hunting Creek. Approx 0.5 mi w/in the park.	Hg fish concentrations	Source unknown	Fish Consumption
BLRI	Toms Branch from the headwaters downstream to a point 1.1 miles upstream of Back Creek. 0.6 mi w/in the park	Macroinvertebrate assessments	Impairment from drought impacts	Aquatic Life
BLRI	Roanoke River mainstem waters from Niagara Dam downstream to the mouth of Back Creek. 0.7 mi w/in the park.	Macroinvertebrate Impairment, E. coli, PCB fish and water concentrations	Discharges from Municipal Separate Storm Sewer Systems (MS4), Industrial Point Source Discharge	Recreation, Wildlife, Aquatic Life, Fish Consumption, Public Water System
BISO	Bear Creek/ca 7 mi immediately upstream of the park	low pH, iron, siltation	acid mine drainage	TMDLs are approved
BISO	Pine Creek/ca 2.75 mi within the park and ca 21 mi of headwaters immediately upstream of the park	nutrients, low DO, E. coli, habitat alteration	municipal point source, septic tanks, contaminated sediments, channelization	water contact advisory
BISO	Roaring Paunch Creek/7.8 mi upstream of the park	low pH	acid mine drainage	–
BISO	Rock Creek/22.4 mi of headwater streams, and ca 6.4 mi w/in the park; 4.3 mi downstream section, and 0.4 mi w/in the park at the stream mouth	upper section –low pH, methyl mercury; lower section – low pH	upper section - source unknown; lower section – acid mine drainage	–
OBRI	Clear Creek/the 1.4 mi section immediately downstream of Barnett Bridge	oil	petroleum activities	spill from an upstream oil well
OBRI	Obed River/the 14.5 mi section immediately upstream of the park. At time of printing, TDEC proposes to extend 303d listing to Obed River at mile 9.1 to include 15.6 miles of park waters	nitrate, nitrite, total phosphorus	municipal point source discharges	Additional 303d reach based upon failing IBI scores

Outstanding National Resource Waters

The Clean Water Act of 1972 requires states to incorporate anti-degradation standards into regulatory decisions. Part of the responsibility this policy places on the states is identification of Outstanding National Resource Waters (ONRWs). Within ONRWs, no new discharges, expansions of existing discharges, or mixing zones are permitted unless a determination is made that such activities will not result in measurable degradation of water quality. Waters eligible for ONRW designation include waters that are part of a national or state park, wildlife refuge or wilderness area, special trout waters, waters with exceptional recreational or ecological significance, and high quality waters that have not been significantly modified by human activities. The Big South Fork is recognized as an ONRW by the states of Tennessee and Kentucky, from its origin downstream to Blue Heron. The Obed River is a designated ONRW from the upstream boundary of the Wild and Scenic River downstream to its confluence with the Emory River (Table 2; Figures 6, 7, and 8).

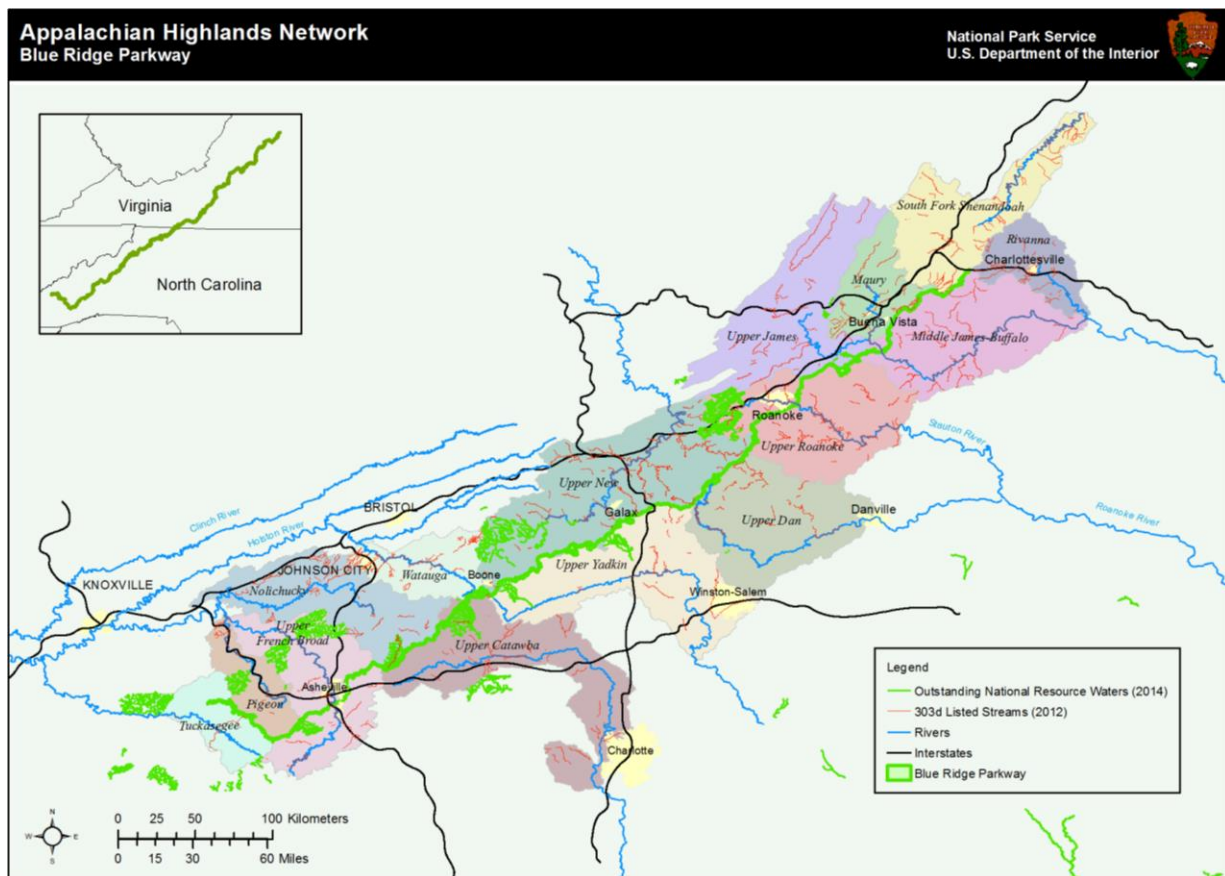


Figure 6. Outstanding National Resource Waters (ONRW) and 303d listed waters within and near Blue Ridge Parkway.

**Big South Fork NRA
Tennessee and Kentucky
APHN Water Quality Sites for Continuous Sampling**

**National Park Service
U.S. Department of the Interior**

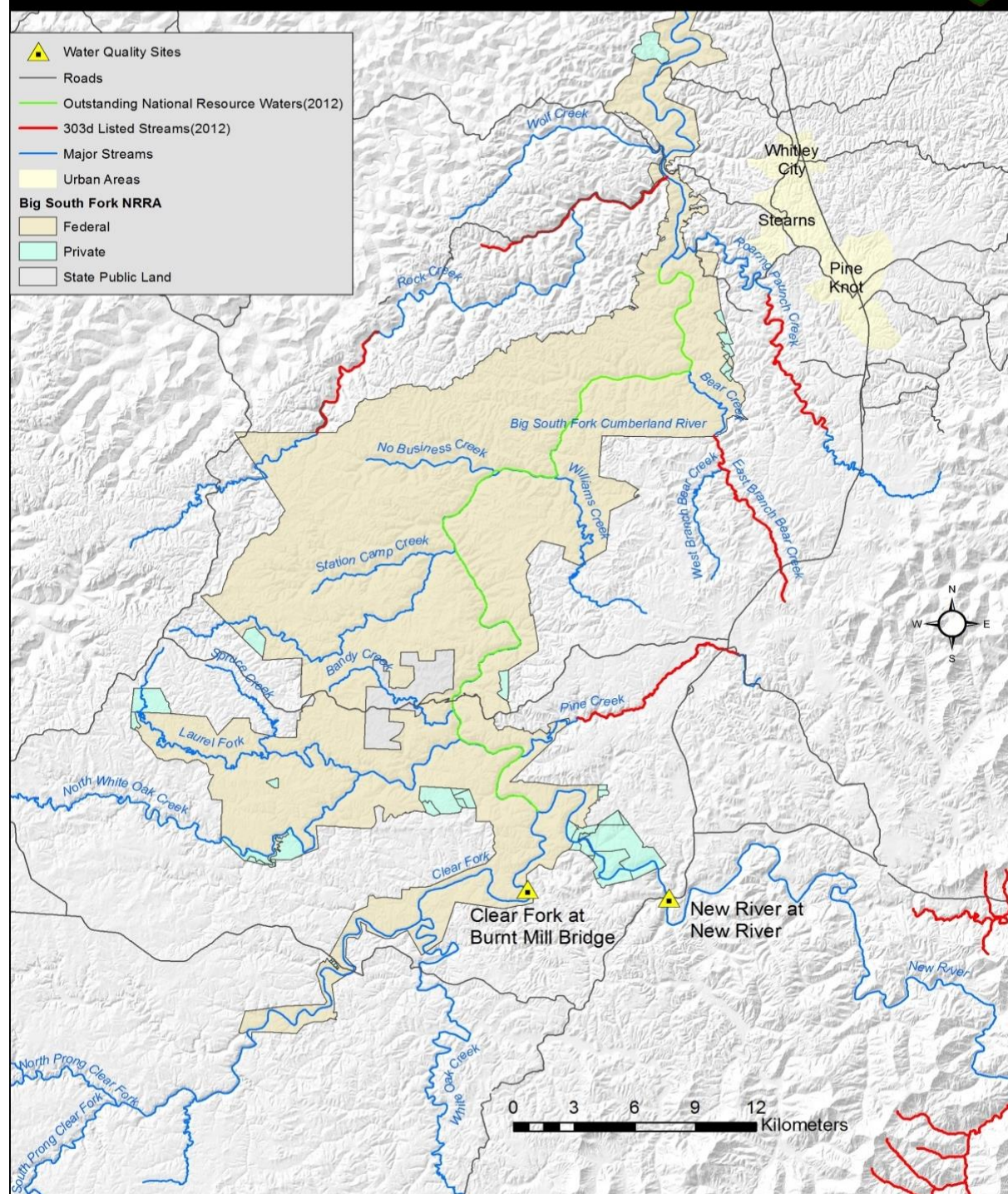


Figure 7. Outstanding National Resource Waters and 303(d) streams within and near the Big South Fork NRA. Water quality monitoring sites under companion APHN Long-Term Water-Quality Monitoring Protocol for Continuous Sampling are also shown.

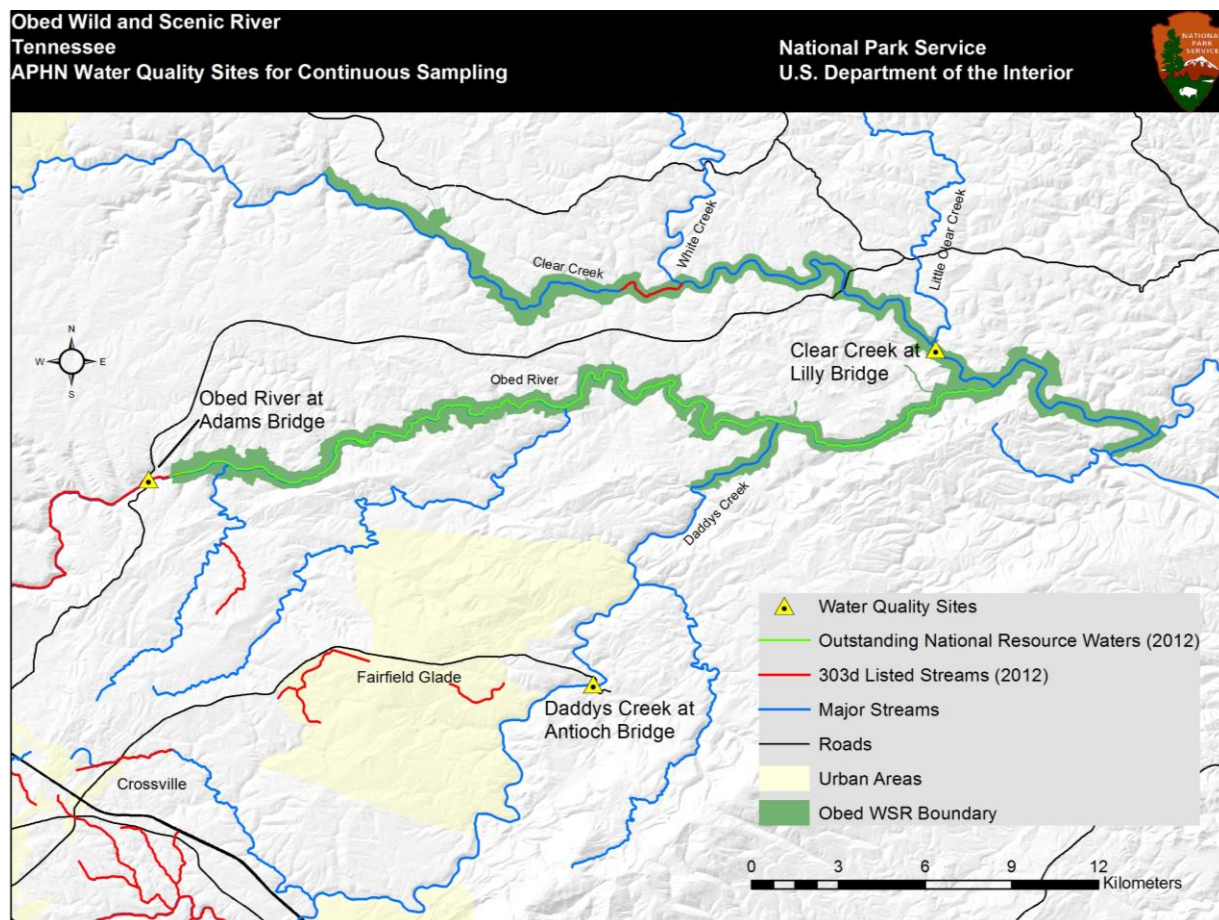


Figure 8. Outstanding National Resource Waters and 303(d) streams within and near the Obed Wild and Scenic River. Water-quality monitoring sites under companion APHN Long-Term Water-Quality Monitoring Protocol for Continuous Sampling are also shown.

Table 2. Outstanding National Resource Waters (ONRW) designated streams within Big South Fork NRA and Obed WSR as of 2016.

Park	Designated Stream Section	Comments
BISO	Big South Fork of the Cumberland River – 33 river miles, from Blue Heron upstream to the New River, Clear Fork confluence	ONRW in both Tennessee and Kentucky
OBRI	Obed River – from river mile 0 upstream to river mile 24.7, at the park boundary	ONRW designation makes an exception for possible use of Obed waters for a regional water supply

Applicability to Management

As described above, because of legislative and other mandates, Big South Fork NRRA and Obed WSR place special emphasis on management of their riverine resources, and accordingly, a Water Resource Management Plan has been developed for these parks (NPS 1997; NPS 1998).

Water resources at Blue Ridge Parkway are managed according to NPS policy, which states that the National Park Service will work with appropriate governmental bodies to obtain the highest possible standards available under the Clean Water Act for protection of park waters; and that they will take all necessary actions to maintain or restore the quality of surface waters and ground waters within the parks, consistent with the Clean Water Act and other applicable Federal, state and local laws and regulations (NPS 2006). Blue Ridge Parkway staff have identified a number of management questions related to long-term monitoring of water resources in the park, including the need to understand how water quality is changing in high elevation streams as a result of acid deposition, how disturbances are affecting water quality and hydrology in high elevation wetlands, and how development, both within and outside the park, may be affecting water quality.

The Final General Management Plan and Environmental Impact Statement for Big South Fork NRRA (NPS 2005) identified several intended management goals for the park, related to water quality, including:

- Preservation of natural free-flowing character of the Big South Fork and its tributaries within the NRRA.
- Continued existence of natural aquatic, riparian, and wetland environments in which natural physical, chemical, and biological processes function healthfully.
- Maintenance of aquatic systems to support sensitive native indicator species.
- Ensure natural hydrological processes continue to shape the landscape of the NRRA, periodically flooding the bottomlands in a dynamic process of erosion and deposition.
- Ensure surface waters provide high quality fishing and swimming and are consistent with the Clean Water Act and other applicable laws and regulations.

The Obed Water Resource Management Plan (WRMP; NPS 1998) acknowledged that water resources of the designated Wild and Scenic River corridor are a critical component of a larger ecosystem that extends beyond the park's boundaries, and identified a need to develop cooperative partnerships with local, state, and federal regulators, land-use planners, adjacent landowners, the research community, and the general public to realize the goals of the WRMP. Water resource management objectives from the WRMP and the OBRI General Management Plan (NPS 1994) include:

- Maintaining the highest water quality possible and the free-flowing condition of all streams within the Obed WSR.

- Protecting the natural systems, cultural resources, landscape character and biodiversity of the WSR area.
- Providing the opportunity and means to learn about, experience, and enjoy the special values of the Obed WSR while assuring protection of those values.

Long-term sampling at key locations along tributary streams and rivers will provide park managers with much-needed information to evaluate status and trends of water quality in these systems. Park managers will use the data to work with appropriate partners and governmental bodies to attain the highest possible standards available under the Clean Water Act (CWA) for protection of park waters, as called for in NPS Management Policies (NPS 2006).

Monitoring data will also help inform and refine the reference condition for water-quality parameters within the parks, particularly in cases where state water-quality criteria are not applicable, or where no state standard exists (for example, in Tennessee, the criteria for minimum pH is set at 6.5 for protection of fish and wildlife, while naturally occurring pH levels are often below 6.5 in the unbuffered sandstone-influenced headwater streams typical of conditions in the parks).

Integration with Other Monitoring Protocols

Because of the diversity of resources selected for APHN Vital Signs monitoring, a single overarching sampling design for the network is not practical. Nevertheless, network vital signs are interrelated in many ways, and in some cases there are opportunities for developing multiple lines of evidence for detecting trends.

For Big South Fork NRRA and Obed WSR, trends in water quality and flow in park streams that are monitored under both the discrete and continuous water-quality monitoring efforts are directly relevant to the trends that Appalachian Highlands Network is monitoring in other park aquatic and riparian resources, including cobble bar communities and Cumberland rosemary (Murdock et al. 2013), and freshwater mussels (in preparation). In many cases, monitoring stations for discrete water-quality sampling are co-located with cobble bar and mussel monitoring stations. Additionally, co-location of continuous water-quality monitoring stations with USGS stage/discharge streamflow gages provides additional insight regarding the interrelationship between daily, seasonal, and annual streamflow trends with both continuous and discrete water quality, as well as associated aquatic and riparian resources (e.g., riparian cobblebar communities) that are directly influenced by the natural cycle of baseflow and flood events characteristic of Cumberland Plateau streams.

Co-location of continuous water-quality monitoring stations with monitoring stations for other resources is intended to complement those efforts and provide a more holistic assessment of water and associated aquatic and riparian resource condition. For example, the stations that are monitored under the *Long-Term Continuous Water-Quality Monitoring at Big South Fork National River and Recreation Area and Obed Wild and Scenic River: Protocol Narrative* (Hughes et al. 2018a) are a subset of stations monitored using this protocol.

At some stations, Appalachian Highlands Network will monitor a site for freshwater mussels, riparian cobble bar communities, and both discrete and continuous water-quality sampling. While

discrete monitoring stations are not co-located with cobble bar and mussel monitoring stations in all cases, discrete (and continuous) water-quality monitoring will be conducted at strategic integrator stations utilized to identify water resource integrity for those stream reaches that will be sampled under companion protocols. Additionally, field water-quality measurements will be made at freshwater mussel monitoring locations to support management of the mussel resources at Big South Fork NRR and Obed WSR.

The health of aquatic and riparian resources is directly linked to water quality and quantity. The combined approach of discrete and continuous water resource monitoring provides a more comprehensive evaluation of water resource integrity than either approach as a stand-alone effort. Continuous monitoring as described in *Long-Term Continuous Water-Quality Monitoring at Big South Fork National River and Recreation Area and Obed Wild and Scenic River: Protocol Narrative* (Hughes et al. 2018a) identifies seasonal and diurnal trends that may otherwise be undetected by discrete sampling alone. However, continuous monitoring of five core parameters under that protocol will not identify underlying water-quality perturbations that influence those five core parameters. For example, OBRI continuous-monitoring stations exhibit distinct fingerprints of diurnal pH and dissolved oxygen fluctuation at each of the three continuous monitoring stations, in essence identifying the effect of subtle differences in water quality on those core parameters. By supplementing the continuous effort with a more comprehensive analytical schedule under the discrete monitoring protocol, the network will identify those factors (e.g., nutrient loading) that influence the seasonal and diurnal variability in pH and dissolved oxygen between monitoring stations.

Similarly, discrete and continuous water resource monitoring complements other monitoring efforts. Monitoring of cobble bar communities (including Cumberland rosemary) quantifies the trends at those monitoring stations, while streamflow information provided in partnership with USGS at the continuous monitoring stations quantifies the occurrence of (1) drought conditions that negatively affect cobble bar health and (2) the number of scouring floods that sustain the cobble bars. Monitoring of the five core water-quality indicators on a continuous basis, supplemented by more comprehensive analytical schedule under discrete sampling, provides insight into variability of freshwater mussel communities.

Monitoring Objectives

All of the issues and monitoring questions identified during Appalachian Highlands Network scoping meetings were expressions of the need for better information to assist managers in protecting water quality. Therefore, the goal of the APHN water-quality monitoring program is to obtain information that will aid the parks in making informed management decisions that will protect and improve water quality within the network parks. With that goal in mind, and cognizant of our limitations in staffing and funding, we have established the following objectives for water-quality monitoring using discrete sampling (see Table 3 for a more detailed explanation of the significance of the parameters to be sampled):

- Determine seasonal and annual water quality trends for four core parameters (pH, temperature, dissolved oxygen, conductivity) using discrete sampling during seasonal

baseflow conditions at fixed stations in Big South Fork NRRA, Blue Ridge Parkway and Obed WSR.

- Determine seasonal and annual trends in concentrations of ANC, nutrients, major anions and cations, trace metals, turbidity, and *E. coli* bacteria using discrete sampling during seasonal baseflow conditions at fixed stations in Big South Fork NRRA, Blue Ridge Parkway and Obed WSR.
- Determine seasonal and annual trends in water quantity (streamflow) during seasonal baseflow conditions using discrete sampling at fixed stations in Big South Fork NRRA, Blue Ridge Parkway, and Obed WSR.

In addition to detecting trends in water quality and quantity, monitoring data will be compared to relevant state and federal thresholds to document and report exceedances. Monitoring data are obtained from field measurements of streamflow and field and laboratory measurements of water quality samples collected at monthly (where co-located with a USGS gage) and quarterly intervals at permanent stations along streams and rivers within the parks. These stations are strategically positioned to capture the effects of known stressors on sensitive aquatic resources, which will allow us to determine compliance with state and regional water-quality standards and ensure NPS has the data needed to detect long-term changes in these systems. Dissolved oxygen, conductivity, temperature, pH, streamflow and turbidity are measured in the field; ANC and *E.coli* are determined by field crews in the lab on the same day that sampling occurs. Water samples are sent to a contracted water-quality lab for analyses of the remaining parameters. The combined field and laboratory analytical suite will also identify water-quality stressors influencing water-quality trends indicated by time-series monitoring as described in *Long-Term Continuous Water-Quality Monitoring at Big South Fork National River and Recreation Area and Obed Wild and Scenic River: Protocol Narrative* (Hughes et al. 2018a).

Table 3. Metrics and objectives for water-quality monitoring using discrete sampling for Blue Ridge Parkway (BLRI), Big South Fork National River & Recreation Area (BISO), and Obed Wild and Scenic River (OBRI).

Category	Metric	Significance	Monitoring Objective
NPS WRD Core Water-quality Parameters	pH	Most living organisms can tolerate only small changes in pH without life-threatening physiological reactions. Surface waters of all APHN parks exhibit moderately acidic to circumneutral pH, and have little buffering capacity, which renders them highly susceptible to degradation by acidic input. Park waters have been adversely affected by acid deposition in the Blue Ridge highlands and by acid mine drainage on the Cumberland Plateau.	Determine seasonal and annual water-quality trends for pH using discrete sampling during seasonal baseflow conditions at fixed stations in BISO, BLRI and OBRI.
	Temperature	Temperature directly affects aquatic life, especially since oxygen becomes less soluble in water as water temperature increases. Increased temperatures accelerate the biodegradation of organic material, increasing demands on the oxygen resources of the system. These demands can lead to total oxygen depletion and septic conditions. Aquatic species have different temperature tolerances, with trout, for example, tolerating water temperatures only up to about 66° F.	Determine seasonal and annual water-quality trends temperature using discrete sampling during seasonal baseflow conditions at fixed stations in BISO
	Dissolved oxygen (DO)	Although DO is not a natural limiting factor in these parks, human-related runoff and discharges (such as sewage and agricultural runoff) and other sources of nutrient enrichment can affect oxygen levels, primarily during warm seasons in low streamflow conditions. Most aquatic life requires greater than 5.0 mg/L of dissolved oxygen for survival.	Determine seasonal and annual water-quality trends for dissolved oxygen using discrete sampling during seasonal baseflow conditions at fixed stations in BISO
	Conductivity	Specific conductance is directly proportional to the amount of total dissolved solids in the water and can be an indicator of pollution. In addition, specific conductance is an indicator of habitat suitability for certain threatened and endangered fish and mussel species.	Determine seasonal and annual water-quality trends for conductivity using discrete sampling during seasonal baseflow conditions at fixed stations in BISO

Table 3 (continued). Metrics and objectives for water-quality monitoring using discrete sampling for Blue Ridge Parkway (BLRI), Big South Fork National River & Recreation Area (BISO), and Obed Wild and Scenic River (OBRI).

Category	Metric	Significance	Monitoring Objective
Water Chemistry	ANC (acid-neutralizing capacity) ¹	ANC is a measure of a water body's capacity to buffer, or resist, the effects of acids, an important measure where acid mine drainage (BISO, OBRI) or acid deposition (BLRI) are an issue. All APHN parks, especially BLRI and GRSM, have very low ANC values, in the range of 1-20mg/L as CaCO ₃	Determine seasonal and annual trends in concentrations of ANC using discrete sampling during seasonal baseflow conditions at fixed stations in BISO, BLRI and OBRI.
	Nutrients ² (Table 10, schedule IV)	Nutrients include nitrogen and phosphorus compounds essential for plant growth, and can result from runoff as well as biological activity in streams. Elevated nutrient enrichment can contribute to eutrophication which can result in death of animal life from lack of oxygen. Elevated ammonia can have serious negative effects on sensitive aquatic communities.	Determine seasonal and annual trends in concentrations of nutrients using discrete sampling during seasonal baseflow conditions at fixed stations in BISO, BLRI and OBRI.
	Major Anions and Cations ² (Table 10, schedule III)	Major anions and cations (Ca ²⁺ , Mg ²⁺ , Na ⁺ , K ⁺ , SO ₄ ²⁻ , HCO ₃ ⁻ , Cl ⁻) identify gross water chemistry of surface waters and the effect of natural (watershed geology) and anthropogenic (mining, wastewater effluents, atmospheric deposition) influences on park waters. Whole water analyses that include major anions and cations can be used to identify reference conditions, spatial departure from reference conditions, and the relative effect of land use activities within individual watersheds on water resources.	Determine seasonal and annual trends in concentrations of major anions and cations using discrete sampling during seasonal baseflow conditions at fixed stations in BISO, BLRI and OBRI.
	Metals and metalloids ³ (Table 10, schedule V)	Trace elements, such as metals, are mobilized in low pH environments associated with acid coal mine drainage on the Cumberland Plateau and with acid precipitation in the Blue Ridge highlands, sometimes at concentrations that adversely affect aquatic biota. Elevated concentrations of aluminum, iron, manganese, copper, lead, and zinc have been documented in surface waters of the Cumberland Plateau and Blue Ridge Provinces.	Determine seasonal and annual trends in concentrations of trace metals using discrete sampling during seasonal baseflow conditions at fixed stations in BISO, BLRI and OBRI.

¹ Unfiltered sample

² Filtered sample

³ Filtered and acidified sample

Table 3 (continued). Metrics and objectives for water-quality monitoring using discrete sampling for Blue Ridge Parkway (BLRI), Big South Fork National River & Recreation Area (BISO), and Obed Wild and Scenic River (OBRI).

Category	Metric	Significance	Monitoring Objective
Water Chemistry (continued)	Turbidity / suspended sediment concentration ¹	Excessive sediment in streams has serious adverse impacts on aquatic life, causing reproductive failure and impairing survival of fish, freshwater mussels and other aquatic invertebrates. BISO and OBRI are especially vulnerable to increased sediment loads resulting from land use activities in headwaters upstream of park boundaries, including municipal and suburban development, agriculture, timber harvest, oil and gas development and coal mining.	Determine seasonal and annual trends in concentrations of turbidity using discrete sampling during seasonal baseflow conditions at fixed stations in BISO, BLRI and OBRI.
	<i>Escherichia coli</i> (<i>E. coli</i>) bacteria ¹	<i>E. coli</i> is a species of bacteria specific to fecal waste originating from humans and other warm-blooded mammals. The Environmental Protection Agency recommends monitoring <i>E. coli</i> as the best indicator of health risk from human contact in recreational waters.	Determine seasonal and annual trends in concentrations of bacteria using discrete sampling during seasonal baseflow conditions at fixed stations in BISO, BLRI and OBRI.
Streamflow	Discharge measurements	Water quantity measurements, paired with water chemistry metrics, permit calculation of pollutant loads and evaluation of seasonal and event-related changes in water quality. Adequate flows, as well as scouring floods, are necessary for the survival of globally-imperiled cobble bar communities, as well as federally-listed fish, mussels, and plants at BISO and OBRI	Determine seasonal and annual trends in water quantity (streamflow) during seasonal baseflow conditions using discrete sampling at fixed stations in BISO, BLRI, and OBRI.

¹ Unfiltered sample

Sampling Design

To effectively monitor the diverse water resources of APHN parks, a two-tiered, targeted sampling approach is employed. The exception is the headwaters monitoring at Blue Ridge Parkway, where a probabilistic sampling design is used. Monitoring strategies are conceptually described below, and detailed descriptions of key water resources and monitoring schemes at individual parks are provided later in this section. Summarized, the APHN tiered approach will utilize annual monitoring of fixed long-term monitoring stations and a bank of annually rotating monitoring stations as the base level of monitoring at each park.

Level I: Core Sampling Stations

Level I “core” monitoring stations represent the foundation of APHN water resource monitoring. Under the core monitoring effort, Appalachian Highlands Network will monitor a fixed network of monitoring stations that will be sampled annually over the long-term. The core sampling network includes key stations within and adjacent to the individual APHN parks and consists largely of sampling stations identified in the initial draft of the APHN Water Quality Protocol (National Park Service, unpublished).

Core monitoring stations are sampled on a fixed monthly (where co-located with a USGS gage) or quarterly frequency, with sampling timed to characterize seasonal variability in water quality during baseflow conditions. These core stations will be the primary monitoring locations for evaluation of long-term trends in APHN park waters and will be utilized to detect climatic or anthropogenic influence to park waters. By sampling seasonal baseflow conditions and avoiding runoff events, it is anticipated that short term temporal variability associated with changing streamflow conditions will be avoided, with a concomitant increase in precision and statistical power to detect trends.

Figure 9 illustrates the annual streamflow hydrograph for Daddys Creek near Hebbertsburg (USGS # 03539600) in the Obed system. The annual hydrograph is characterized by alternating peaks associated with precipitation events with a rising limb at the onset of each event and a falling limb as the precipitation event ceases. To sample seasonal baseflow, Appalachian Highlands Network will target sampling between the period at or near the bottom of a falling limb of a runoff event and prior to the rising limb of the next event. A judgement call must be made and discretion must be taken to assure that baseflow events are sampled. It is preferable to extend the sampling schedule (as opposed to forcing the sampling effort into one week) when a runoff event occurs mid-week at an individual park to ensure that baseflow conditions are sampled.

Level II: Rotating Sampling Stations

To complement long-term monitoring of Level I stations, Level II water-resource monitoring stations in APHN parks include a rotating bank of tributaries to main stem drainages at Big South Fork NRRA and Obed WSR and high elevation watersheds at Blue Ridge Parkway. Level II monitoring sites are intended to enhance spatial distribution of water-resource monitoring in each park within the limitations of budget and manpower. These manpower and budget limitations, in conjunction with geographic constraints such as the length of the Blue Ridge Parkway corridor, the relatively large land base at Big South Fork NRRA, and the influence of upstream land use on park waters of Big

South Fork NRRA and Obed WSR, prevent complete geographic coverage of water resource monitoring at the intensity of level I monitoring. Resource managers nevertheless need data to assess the general condition of water resources throughout individual parks to assist management decisions.

Level II monitoring stations at Obed WSR and Big South Fork NRRA are intended to provide more comprehensive coverage of both NPS managed waters and of waters upstream of park boundaries that influence waters within the Obed River corridor and the Big South Fork NRRA. Toward that end, a bank of important tributaries to main stem drainages has been developed, from which a subset of Level II monitoring stations will be sampled on a two year rotating cycle (using a six-year panel design) to supplement Level I stations. Sites in each panel are monitored for two consecutive years, and six years are needed to sample all three panels. In this manner, over time, a broader geographic coverage or water-quality assessment will be provided.

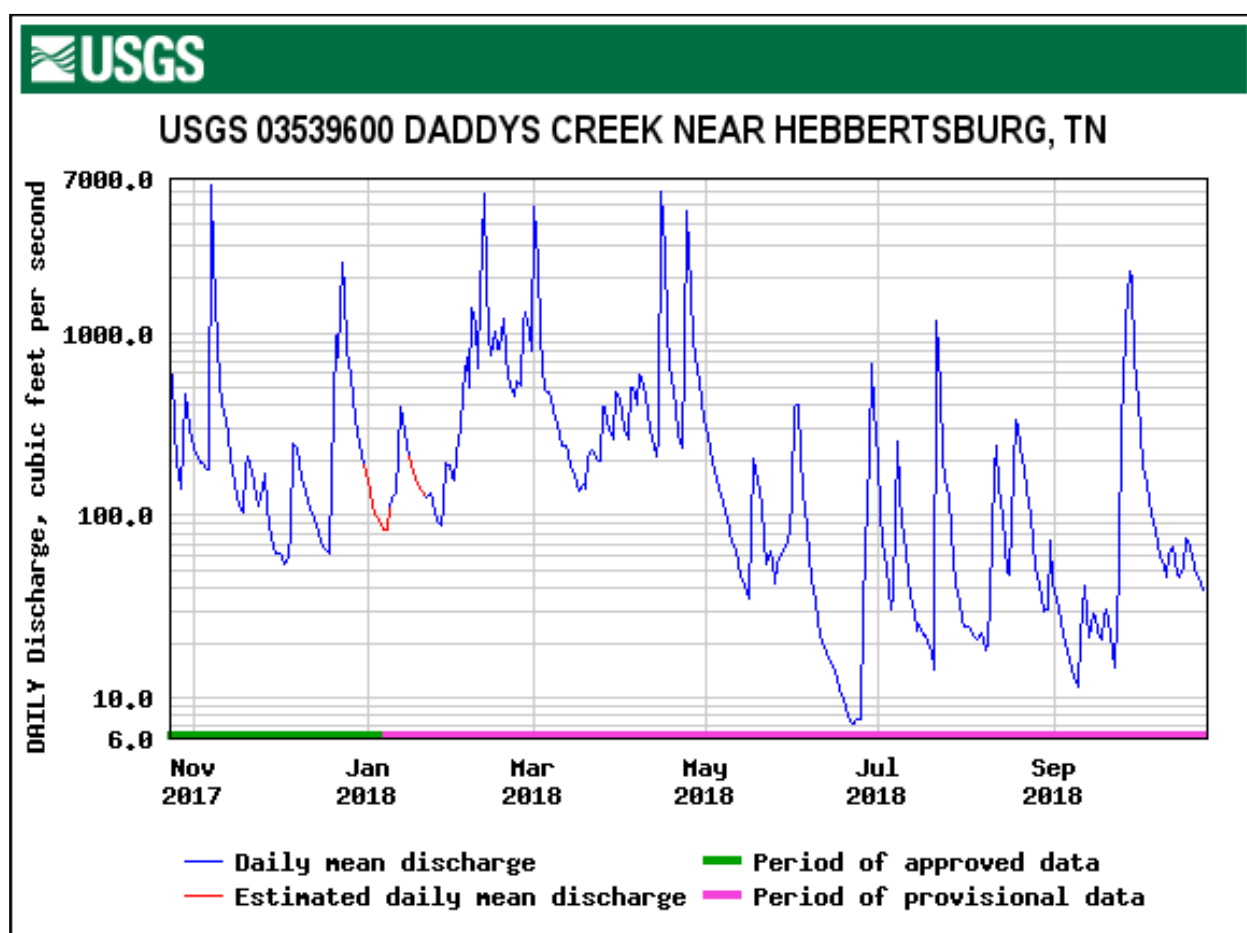


Figure 9. Daily mean discharge during 2014 water year (USGS 03539600: Daddys Creek near Hebbertsburg, Tennessee).

At Blue Ridge Parkway, Level II rotations will involve sampling of headwater streams that are affected by atmospheric deposition. The average pH of rainfall in nearby Great Smoky Mountains National Park in recent years has been 4.3 (NPS 2018a). Because headwater streams of the Blue

Ridge highlands (including Blue Ridge Parkway) are negligibly buffered to acid input, these headwater streams respond dramatically to precipitation events. As a consequence, pH of headwater resources at high elevation can be lowered two units or more for 6–12 hours after an event (Deyton et al. 2008). Sustained pH levels below 5.0 can result in declines in benthic invertebrates and fish, and reproductive failure of acid-sensitive amphibians (Schwartz et al. 2014). Chronic and episodic acidification of streams can lead to elevated levels of toxic monomeric aluminum, which can further reduce survival and diversity of aquatic invertebrate and fish populations (SAMAB 1996c).

Temporal reduction of pH and associated leaching of metals and nitrogen species in response to episodic precipitation events affecting BLRI headwater resources is not effectively evaluated by base flow sampling of these headwater resources. At Blue Ridge Parkway, the Appalachian Highlands Network will utilize a variety of methods to identify critical impacts to these headwater resources. These methods will include remote deployment of water-quality sondes to evaluate response of pH and water depth during runoff events. To identify the timing of these runoff events, remote data loggers will be deployed at those headwater stations selected for enhanced monitoring to measure depth of the water column. Standard operating procedures for continuous sampling of Level II headwater streams is described in detail in SOP DWQ18 *Continuous Measurements* (APHN 2018a). Because Level II stations will be sampled less frequently, initial results may be less precise than results from Level I monitoring; but Level II efforts will provide useful synoptic characterization of a larger spatial distribution of waters at Blue Ridge Parkway.

Site Selection

Blue Ridge Parkway

A number of short term water resource investigations have been conducted on the Blue Ridge Parkway over the years (Mass 1992), but there is an absence of long-term, comprehensive water-quality trend analyses. As part of the initial screening of potential water-quality monitoring stations, Appalachian Highlands Network, in concert with USGS and park resource management staff assessed water-quality sampling records from the vicinity of Blue Ridge Parkway for the period 1945 to 2002, and found no monitoring data within the study area (park properties plus a one-to-three mile buffer outside the boundary) with a sufficiently long enough period of record to effectively analyze trends. An initial list of potential long-term monitoring stations for the Parkway was developed by APHN and BLRI staff, along with USGS hydrologists. Utilizing that initial screening and a detailed database of Parkway waters compiled by BLRI personnel, a list of candidate stations that included seven categories of key water resource types was developed. This list was developed in part because of perceived importance of key water resources and because of known threats to these waters as identified by Parkway resource managers (Maas 1992; Walker 1996). The seven identified categories of waters were:

- Impaired waters (303d),
- Pristine waters (ONRW, ORW, WSR),
- Waters affected by acid deposition,

- Waters draining agricultural leases,
- Waters affected by vegetation change (insect/disease infestation, e.g. hemlock adelgid),
- Developed areas (e.g. campgrounds and visitor use centers),
- Significant or high quality resources (e.g. managed trout waters, T&E species habitat).

Level I: Core Sampling Stations

Using professional judgment, the initial list of 40 candidate stations was narrowed to a final list of 14 stations that are intended to focus on water resources or water resource threats of highest significance while also providing a geographic distribution of monitoring stations along the entire length of the Parkway to the extent possible. Level I stations were selected utilizing input from park resource managers and are intended to address specific resource management concerns. Individual Level I stations are not intended to represent park waters as a whole.

Core monitoring stations include those stations which will be sampled annually on a long-term basis on a quarterly schedule. These stations have been established at strategic locations along the length of the Parkway corridor and within the larger land holdings such as Doughton Park, Rocky Knob, and Peaks of Otter. These stations are intended to evaluate water resource integrity as influenced by environmental stressors (e.g., acid deposition, invasive species) and by NPS managed activities (e.g., campgrounds, wastewater drain fields) at the larger land holdings. Sampling stations include high elevation seeps and springs, low order headwater streams, larger streams draining NPS developed landholdings, and wetlands. These sampling stations were selected to:

1. Evaluate current conditions and to provide long-term monitoring of water resource integrity in selected headwater drainages and seeps
2. Evaluate water resource integrity in waters potentially impacted by development or agriculture
3. Evaluate waters which have specific Federal or state designations as pristine (ONRW, ORW, WSR) or impaired (303d) waters
4. Quantify and monitor water resource integrity in waters supporting aquatic resources of management concern, including federally or state listed aquatic and riparian species

It should be noted that these sites were selected using targeted sampling and cannot be aggregated to provide a general description of BLRI water quality. The 14 sampling stations chosen for long-term Level I sampling are shown in Figure 10 and Table 4.

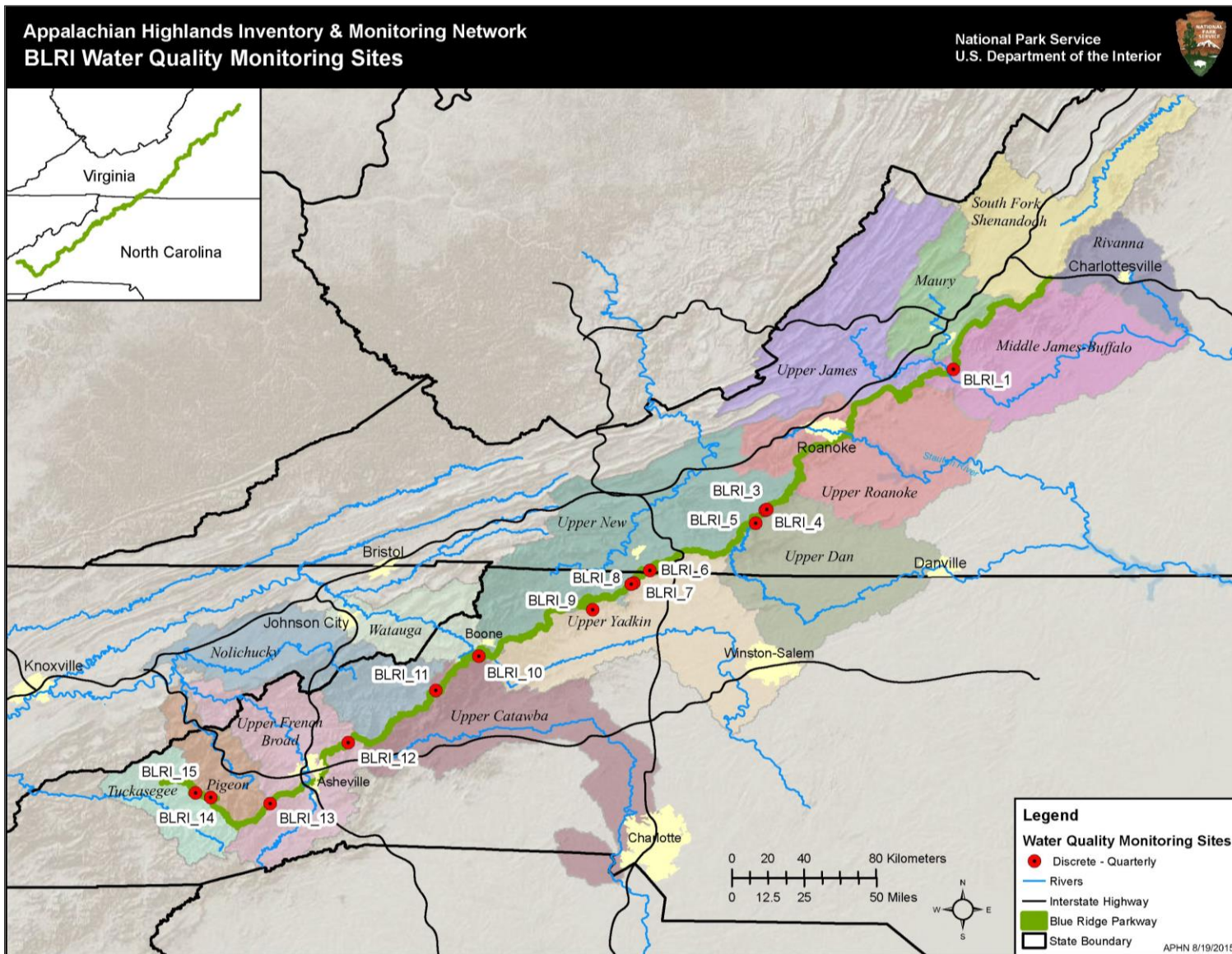


Figure 10. Level I water-quality sampling stations at Blue Ridge Parkway.

Table 4. Blue Ridge Parkway (BLRI) Level I Sampling Stations. Fourteen sites sampled quarterly = 56 total samples per year.

Site No.	Site Name	Milepost	Latitude	Longitude	Sampling Frequency	Comments
BLRI-1	Otter Creek	60	37.574800	79.342200	Quarterly	BLRI campground, other in-park development impacts; leach field issues; 8 miles on BLRI (one of the park's longest stream reaches)
BLRI-3	Dodd Creek	162	36.938400	80.340600	Quarterly	Dodd Creek: 303d-listed; creek and tribs parallel BLRI for approx. 2 miles; West Fork drains Rocky Knob Campground; string of wetlands.
BLRI-4	Simon Thomas	162	36.90000	80.280000	Quarterly	Rare wetland type; trib to Dodd Cr. (303(d)); Ag impacts from NPS leases & off-park agriculture.
BLRI-5	Rock Castle Creek	169	36.785167	80.372833	Quarterly	Relatively pristine watershed; almost all within BLRI boundary; imminent threats to watershed from gypsy moth and HWA; wetland at the bottom; VADGIF may be doing some sampling here.
BLRI-6	Chestnut Creek	215	36.570300	80.859300	Quarterly	Ag. impacts; VADGIF fish sampling site; runs through Fishers Peak wetlands
BLRI-7	Saddle Mountain Church NHA	222	36.503833	80.947917	Quarterly	State-designated Natural Heritage Area; Grazing impacts mitigated by fencing.
BLRI-8	Big Pine Creek	222	36.510000	80.900000	Quarterly	Rare wetland type; trib to Dodd Cr. (303d); Agricultural impacts from NPS leases & off-park agriculture.
BLRI-9	Basin Creek	243	36.375361	81.145389	Quarterly	Relatively pristine watershed; almost entirely within BLRI boundary; imminent threats to watershed from gypsy moth and HWA; wetland in lower watershed; possible VADGIF sampling site.
BLRI-10	Simms Creek	296	36.391000	81.157667	Quarterly	Ag. impacts; VADGIF fish sampling site; runs through Fishers Peak wetlands
BLRI-11	Linville River	317	35.966083	81.646667	Quarterly	Impacts from NPS campground; off-park development, nurseries (pesticides); heavy visitor use; acid dep. (USFS found extremely low pH and high aluminum in this watershed); under consideration as Wild and Scenic River.

Table 4 (continued). Blue Ridge Parkway (BLRI) Level I Sampling Stations. Fourteen sites sampled quarterly = 56 total samples per year.

Site No.	Site Name	Milepost	Latitude	Longitude	Sampling Frequency	Comments
BLRI-12	Graybeard Mountain Overlook	363	35.711317	82.366867	Quarterly	4 high-elevation (5,450') seeps; pH measured in 1974-75 at 5.0-5.1; water source for Craggy Visitors Center.
BLRI-13	Flat Laurel Gap Bog	407	35.400000	82.760000	Quarterly	High elevation wetland type; state-designated RHA; surrounded by Mt. Pisgah campground and crossed by NPS wastewater line; acid deposition.
BLRI-14	Redbank Branch	442	35.497983	83.154767	Quarterly	High-elevation (4,600'); BLRI owns this small watershed; State-designated Natural Heritage Site (Redbank Cove); northern hardwoods
BLRI-15	Yellowface Overlook	450	35.467000	83.142133	Quarterly	High elevation; low ANC watershed.

Level II: Rotating Stations to Monitor Headwater Resources

Because of its location along the crest of the Blue Ridge Mountains, headwater streams are the predominant water resource on the Parkway. These headwater streams provide essential water, food, and wildlife habitat and are important sites of biodiversity and productivity. Sampling of these resources by Lenat (2007) identified 15 previously undescribed taxa of macroinvertebrates as well as two genera new to science. Headwater resources are also important sentinels of atmospheric deposition and climate change, as evidenced by macroinvertebrate anatomical deformities in high elevation seeps, possibly as a consequence of acidification at high elevations (Lenat 2007).

The primary influence to water quality of BLRI headwater resources is atmospheric deposition (SAMAB 1996). To evaluate spatial variability of water resource integrity of these resources, Appalachian Highlands Network has conducted pilot sampling of a subset of those streams to provide a preliminary evaluation of water-quality trends as influenced by geology, watershed size, and elevation. Results conformed with trends identified in similar watersheds at Great Smoky Mountains NP (Robinson et al. 2008), which indicate that elevation gradients are a primary influence on water quality in these headwater resources. Monitoring of baseflow water-quality conditions at Level II headwater resources of Blue Ridge Parkway will be supplemented with deployment of continuous monitors (datasondes, dataloggers, and/or automated samplers) to evaluate the effect of runoff events on these resources.

Sampling Design for Selecting Headwater Monitoring Stations at Blue Ridge Parkway

A subset of 18 water-quality stations will be chosen for monitoring long-term changes in headwater (first order) streams at Blue Ridge Parkway, particularly for trends related to atmospheric deposition and climate change. To select stations, the high resolution National Hydrologic Dataset (NHD) stream layer (USGS 2007–2014, 2015) was acquired for the length of Blue Ridge Parkway to use as a basis for the sampling frame. A method for generating spatially-balanced, random samples called Generalized Random Tessellation Sampling (GRTS; Stevens and Olsen 2004) was used, so that sampling results can be inferred to BLRI headwater streams that meet the prescribed sampling conditions. GRTS has the particularly favorable feature of allowing stations which are later found not to meet sampling criteria to be dynamically replaced with stations that do, while maintaining a randomized, spatially-balanced sample. The GRTS sample was stratified by elevation, and within each stratum all sites had an equal probability of selection. Elevation classes and the number of points selected in each are shown in Table 5. Final site selection is pending site evaluations of the selected sites.

Table 5. Elevation classes and sampling schedule for headwater monitoring stations.

Elevation stratum (Elevation range in meters)	Selected # stations	Year 1 # of stations (Panel #)	Year 2 # of stations (Panel #)	Year 3 # of stations (Panel #)	Year 4 # of stations (Panel #)	Year 5 # of stations (Panel #)	Year 6 # of stations (Panel #)
HIGH (1,067+)	6	2 (1)	2 (1)	2 (2)	2 (2)	2 (3)	2 (3)
MID (762-1,067)	6	2 (1)	2 (1)	2 (2)	2 (2)	2 (3)	2 (3)
LOW (182-762)	6	2 (1)	2 (1)	2 (2)	2 (2)	2 (3)	2 (3)
TOTAL	18	6	6	6	6	6	6

Potential sampling stations were established at the downstream end of stream segments, either upstream of their confluence with streams of like or higher order or where streams exit the park corridor. Streams not originating within Blue Ridge Parkway, or on adjacent public lands, were not considered for sampling, to avoid the confounding effects of upstream disturbances due to changing land use. Only perennial streams (based on USGS hydrology data) were considered for monitoring stations, so that samples can be obtained year round, on a quarterly basis. For safety and accessibility, stations on very steep slopes (greater than 50 percent slope), or more than 200 meters from a drivable road, were excluded from the sampling frame. In total, 139 streams were included in the sampling frame out of a possible 495 headwater streams on the Parkway. A total of six headwater stations will be sampled each year on a two year rotating schedule, with all eighteen stations sampled within six years.

Big South Fork National River and Recreation Area

The water resource monitoring plan for Big South Fork NRRRA described below builds upon previous NPS efforts during the 1980s (Rikard et al. 1986). Water resource monitoring at the Big South Fork and Obed Rivers was conducted by staff of these parks during the mid to late 1980's. Due to funding and operational constraints, water resource monitoring was discontinued, but these "legacy" data provide a valuable benchmark for comparison with more recent and future monitoring efforts. The legacy water-quality sampling efforts generally targeted waters inside the legislative boundaries of the parks.

To more effectively evaluate the existing water-quality data set, Appalachian Highlands Network contracted with the U.S. Geological Survey (USGS) to summarize available water-quality data for the Big South Fork watershed (USGS 2002). USGS utilized available historic water-quality data, from the following sources to evaluate water-quality trends. The period of record ranged from the early 1960's to 2000. These data sets will be utilized where possible as a benchmark for comparison with ongoing water resource monitoring efforts.

- Environmental Protection Agency (EPA) STORET database which includes data sets from multiple agencies including EPA, NPS, Tennessee Valley Authority (TVA), U.S. Office of Surface Mining Reclamation and Enforcement (OSM), TN and KY state agencies.

- USGS NWIS database
- NPS local Access database
- Tennessee Department of Environment and Conservation (TDEC) Excel spreadsheet
- OSM Access database

The APHN Water Quality Monitoring Protocol for the Big South Fork NRRRA uses a two-tiered approach to optimize the effectiveness of water resource monitoring within the constraints of manpower and budget. Water resource monitoring efforts will consist of fixed long-term sampling stations and an annually rotating sampling of a bank of tributary streams.

Level I: Core Sampling Stations

As a foundation for the water resource monitoring plan for the Big South Fork NRRRA, “core” long-term monitoring will be conducted at strategic locations on the Big South Fork proper and its larger tributaries. These locations were selected using professional judgment and will be sampled annually for the long-term on either a monthly, if co-located with a USGS gage, or quarterly frequency. Level I stations were selected utilizing input from park resource managers and are intended to address specific resource management concerns. Level I monitoring stations include many legacy monitoring stations. Individual Level I stations are not intended to represent park waters as a whole. These sampling locations have been selected and the frequency has been identified for each location:

1. To evaluate current conditions and to provide long-term monitoring of water resource integrity near the point that main stem rivers and tributaries enter designated park lands, thereby reflecting the condition of recreational waters as influenced by land use activities upstream of NPS managed lands,
2. To evaluate water resource integrity in the more heavily utilized recreational waters (fishing, boating, swimming) within the NRRRA,
3. To evaluate incremental change in water quality as Big South Fork proper and its tributaries flow through the park, and
4. To quantify and monitor water resource integrity in support of GPRA goals at those stream reaches supporting aquatic resources of management concern, including federally or state listed aquatic and riparian species.

Note that these sites were selected using targeted sampling and cannot be aggregated to provide a general description of Big South Fork NRRRA water quality. A total of eleven sampling stations have been chosen for long-term sampling (Table 6 and Figure 11).

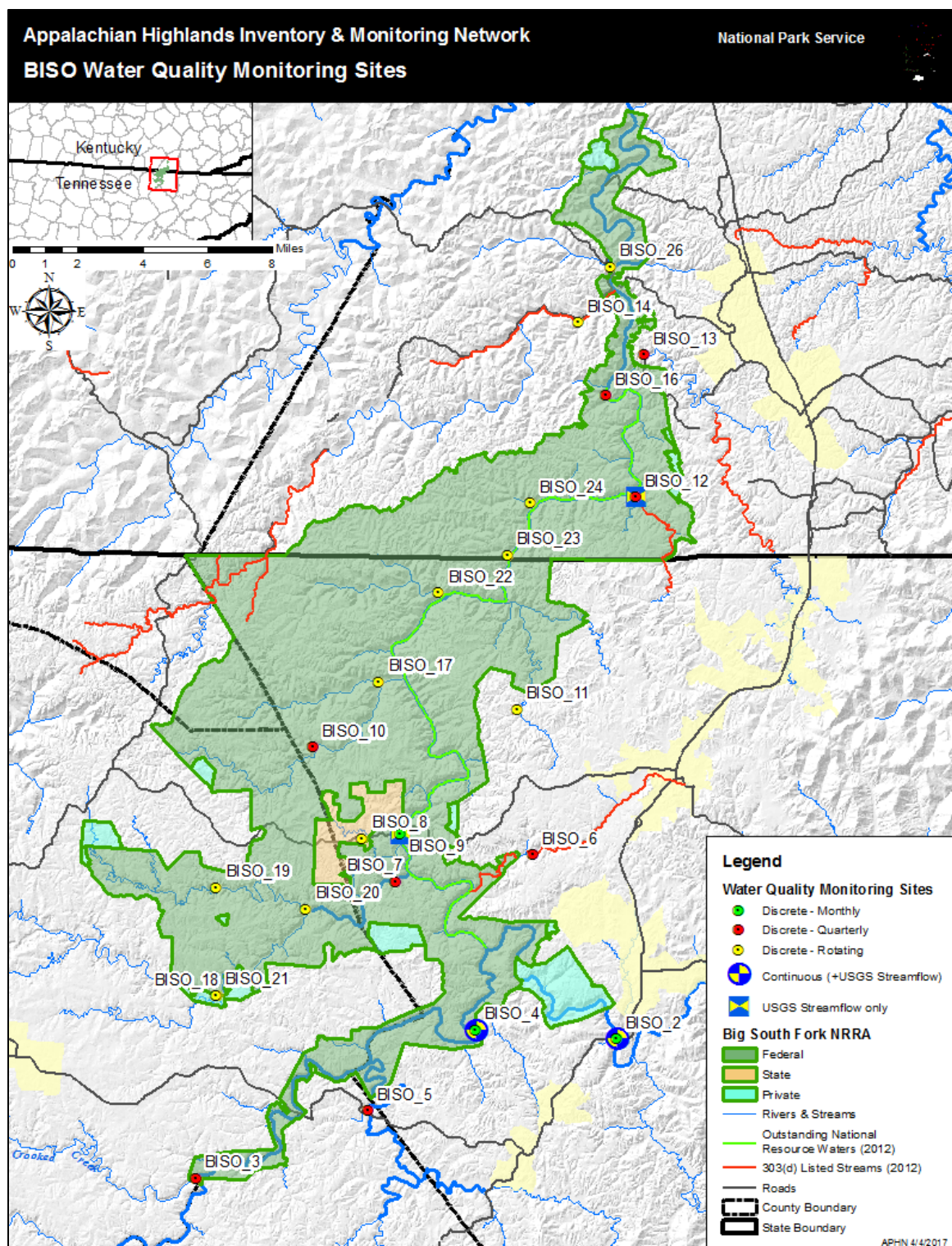


Figure 11. Level I and Level II water-quality monitoring stations at Big South Fork NRRA

Table 6. Big South Fork National River & Recreation Area (BISO) Level I Sampling Stations. Three monthly stations = 36 samples per year, eight quarterly stations = 32 samples per year for a total of 68 annual fixed station samples [CR—Continuous recording; SP—Staff plate; QW—Continuous water quality].

Site no.	Site name	Latitude	Longitude	Sampling Frequency	Gauge type	Period of record	Comments
BISO-2	New River at New River, Tennessee	36.38262	84.55239	Monthly	CR, QW	1934–2015	Represents major water quality contribution concerns in BISO from surface mining, oil and gas exploration and timbering operations. Co-located with USGS gage # 03408500. NPS continuous QW station. Event sampling from bridge.
BISO-3	Clear Fork at Peters Bridge	36.32499	84.78655	Quarterly	SP	—	Upstream reach of cleanest major tributary at BISO upstream boundary. Event sampling from bridge.
BISO-4	Clear Fork at Burnt Mill Bridge near Robbins, Tennessee	36.38225	84.55239	Monthly	CR, QW	1930–1971, 1975–2015	Eight mussel species (one federally listed). Co-located with USGS gage # 03409500. Removed from TN 303d list in 1998, was listed for siltation due to silviculture. Event sampling from bridge.
BISO-5	White Oak Creek at Rugby, Tennessee	36.35324	84.69080	Quarterly	SP	—	Removed from TN 303(d) list in 1998 (siltation). First STP constructed five years ago. Six mussel species (one endangered). Oil and gas development in tributaries and main stem. Event sampling from bridge.
BISO-6	Pine Creek at Toomey	36.46596	84.59602	Quarterly	SP	—	Eastern tributary draining city of Oneida, TN: Eight sections of Pine Creek are on the TN 303d list. Industrial and domestic wastewater discharges.
BISO-7	North White Oak Creek near mouth	36.45533	84.67209	Quarterly	SP	—	Development; municipal water supply impoundment; Oil and gas; Two mussel species (one federally listed). Removed from TN 303(d) list in 1998 (acid mine effluent). Bacterial contamination indicated by initial sampling.

Table 6 (continued). Big South Fork National River & Recreation Area (BISO) Level I Sampling Stations. Three monthly stations = 36 samples per year, eight quarterly stations = 32 samples per year for a total of 68 annual fixed station samples [CR—Continuous recording; SP—Staff plate; QW—Continuous water quality].

Site no.	Site name	Latitude	Longitude	Sampling Frequency	Gauge type	Period of record	Comments
BISO-9	Big South Fork at Leatherwood Ford	36.47648	84.66900	Monthly	CR	1983–2012	Main stem integrator site for upper portion of the drainage basin. Co-located with USGS gage # 03410500. Historic water-quality data available. Event sampling from bridge.
BISO-10	Laurel Fork of Station Camp Creek at Trail Crossing	36.51637	84.71593	Quarterly	SP	–	TDEC ecoregion reference site for Cumberland Plateau; Bacterial contamination identified by initial sampling.
BISO-12	Bear Creek at mouth	36.62457	84.53412	Quarterly	SP	–	KY303d listed for iron, pH and siltation from mining. Mussel population poor just downstream of mouth. Possibly BISO's most severely degraded stream.
BISO-13	Roaring Paunch Creek at Barthell	36.68788	84.52747	Quarterly	SP	–	Poor biological health but supports rare crayfish. Oil and gas exploration and extraction and coal mining. Recently removed from KY 303-d list for siltation and low pH from acid mine drainage.
BISO-16	Big South Fork at Blue Heron	36.66770	84.54577	Quarterly	SP	–	Integrator site near upper limit of impoundment influence from Wolf Creek Dam (Lake Cumberland). Event sampling from pedestrian bridge.

Level II: Rotating Sampling Stations

Sampling efforts also include a bank of tributary streams from which stations were chosen subjectively to be sampled on a two year rotating basis at a quarterly frequency. Sites in each panel are monitored for two consecutive years, and six years are needed to sample all three panels. The rotating tributary bank includes key stations on streams draining populated and developed lands in the eastern portion of the Big South Fork watershed as well as streams draining generally undeveloped lands, mostly in the western section of the park. Sampling stations included in the tributary bank include watersheds both wholly owned and managed by NPS as well as watersheds affected by land use activities outside of park boundaries. Level I stations were selected utilizing input from park resource managers and are intended to address specific resource management concerns. Individual Level I stations are not intended to represent park waters as a whole. Quarterly sampling of the rotating tributary bank is intended to supplement the long-term fixed stations described above:

1. To provide more complete evaluation of water resource integrity throughout designated park lands,
2. To evaluate water resource integrity as influenced by NPS managed activities within the park,
3. To identify stressors to Big South Fork NRRRA water resources from land use activities outside of the park boundary in a manner that will support development of municipal, state, federal, and private partnerships, and
4. To evaluate water resource integrity of key western tributaries, which have been identified as critical water resources that sustain the overall health of the Big South Fork proper.

Note that these sites were selected using targeted sampling and cannot be aggregated to provide a general description of BISO water quality. The bank of tributary streams was derived in part from previous sampling conducted by NPS, but also targets sampling stations that have not previously been sampled by NPS. Stations to be sampled on a rotating basis are identified in Table 7.

Table 7. Big South Fork National River & Recreation Area (BISO) Level II Rotating Sampling Stations. Four rotating quarterly stations per year = 16 samples/year. Total fixed stations = 68 samples per year for a total of 84. Total fixed plus rotating stations samples per year [SP—Staff plate].

Site no.	Site name	Latitude	Longitude	Sampling Frequency	Gauge type	Period of record ¹	Comments
BISO-8	Bandy Creek at TN Route 297	36.47495	84.68993	Quarterly	SP	2	NPS waste water treatment plant for Bandy Creek campground.
BISO-11	Williams Creek at Williams Creek Road	36.57814	84.60772	Quarterly	SP	1	Drains portions of City of Oneida
BISO-14	Rock Creek at Devil's Ck. Road	36.71365	84.54816	Quarterly	SP	1	KY Wild River. 303d listed in KY (2 sections) - low pH and mercury [acid mine drainage (AMD)].
BISO-17	Station Camp u/s Laurel Fork	36.54585	84.67027	Quarterly	–	2	Western trib., draining only NPS lands. Intensive horse use. Enters BSF at a shoals area containing very sensitive aq. resources.
BISO-18	Mill Creek near Stockton (NWO)	36.40627	84.77247	Quarterly	SP	2	Major tributary to North White Oak Creek; drains Stockton and vicinity.
BISO-19	Spruce Branch of NWO	36.46147	84.76628	Quarterly	–	2	Western tributary draining equestrian community.
BISO-20	Laurel Fork of NWO at mouth	36.37640	84.72145	Quarterly	SP	1	High quality tributary to important drainage. Darrow Ridge.
BISO-21	North White Oak Creek at Zenith	36.42746	84.73687	Quarterly	SP	3	Upstream reach of watershed exhibiting high bacterial counts.

¹ Individual rotation panels will be sampled for two consecutive years, then replaced with next panel. After panel 3 is sampled for two years, panel 1 will be returned to rotation.

Table 7 (continued). Big South Fork National River & Recreation Area (BISO) Level II Rotating Sampling Stations. Four rotating quarterly stations per year = 16 samples/year. Total fixed stations = 68 samples per year for a total of 84. Total fixed plus rotating stations samples per year [SP—Staff plate].

Site no.	Site name	Latitude	Longitude	Sampling Frequency	Gauge type	Period of record ¹	Comments
BISO-22	No Business Creek near mouth	36.58379	84.64433	Quarterly	SP	1	Western tributary draining only NPS lands; partial year of monthly sampling complete; discharges to critical mussel/fish habitat.
BISO-23	Difficulty Creek	36.60010	84.60583	Quarterly	–	3	Western tributary draining only NPS lands; limited influence on main stem Big South Fork.
BISO-24	Troublesome Creek	36.62302	84.59250	Quarterly	–	3	Western tributary draining only NPS lands; limited influence on main stem Big South Fork.
BISO-26	Wolf Creek near Yamacraw	36.72633	84.54420	Quarterly	SP	3	Western tributary draining DBNF; T&E fish species (blackside dace). Short stream segment in NRRRA.

¹ Individual rotation panels will be sampled for two consecutive years, then replaced with next panel. After panel 3 is sampled for two years, panel 1 will be returned to rotation.

Obed Wild and Scenic River

Selection of monitoring sites at Obed WSR was accomplished by a team of network and park staff, working with USGS hydrologists. Primary resources used during the site selection process included a report of prior NPS monitoring efforts in Obed WSR (Rikard, 1985), and a compilation and analysis of historic water-quality data from the watersheds contributing flow to the park (NPS, 1999). Additionally, Appalachian Highlands Network contracted with USGS to compile a synopsis of all water-quality data collected within the Obed watershed (USGS, 2004). For the latter project, data from multiple agencies from 62 sites was compiled for the period from 1965 to 2002. Results confirmed that the most significant water-quality impacts to Obed WSR have been from resource extraction activities (coal mining, and oil and gas extraction) and urban influences. Based on this information, a list of candidate sites was developed, and informally ranked. The list was narrowed to a final list of nine sites, by stationing sites in the locations best situated to capture water-quality influences from major pollution events.

Level I: Core Monitoring Stations

As a foundation for the water resource monitoring plan for the Obed, “core” long-term monitoring will be conducted at subjectively selected strategic stations on the Obed River proper and its two largest tributaries, Daddys Creek and Clear Creek. These stations will be sampled annually for the long-term on either a monthly, if co-located with a USGS gage, or quarterly frequency. Level I stations were selected utilizing input from park resource managers and are intended to address specific resource management concerns. Individual Level I stations are not intended to represent park waters as a whole. These sampling stations have been selected and the frequency has been identified for each location:

1. To evaluate the current condition and to provide long-term monitoring of water resource integrity near the point that main stem rivers and tributaries enter designated park lands, thereby reflecting the condition of recreational waters as influenced by land use activities upstream of NPS managed lands,
2. To evaluate water resource integrity in the more heavily utilized recreational waters (fishing, boating, and swimming) within the Wild and Scenic River corridor.
3. To evaluate incremental change in water quality as the Obed River and its tributaries flow through the park, and
4. To quantify and monitor water resource integrity in support of GPRA goals at those stream reaches supporting aquatic resources of management concern, including federally or state-listed aquatic and riparian species.

Note that these sites were selected using targeted sampling and cannot be aggregated to provide a general description of Obed WSR water quality. A total of nine sampling locations have been chosen for long-term sampling (Figure 12 and Table 8).

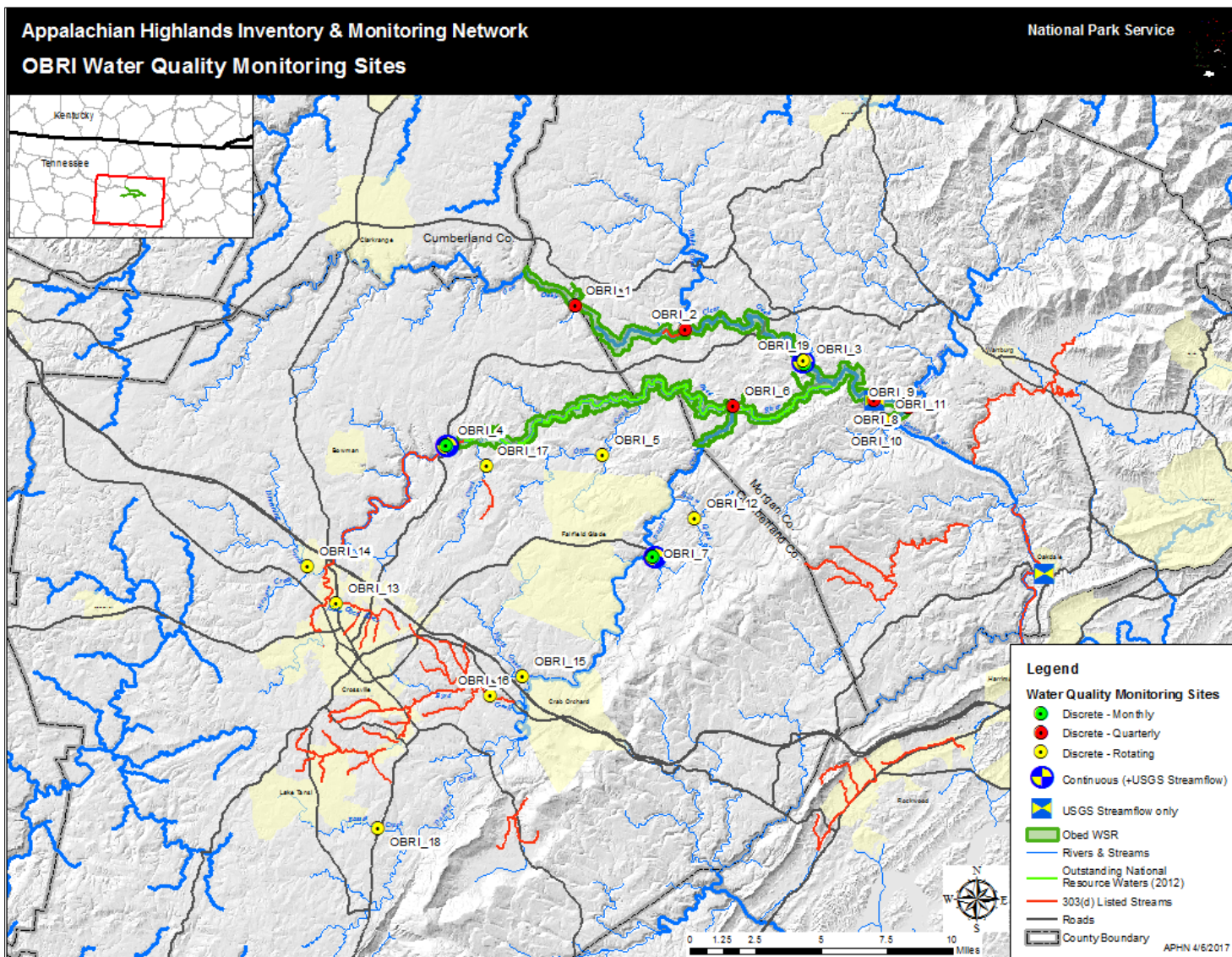


Figure 12. Level I and Level II water-quality monitoring stations at Obed Wild and Scenic River.

Table 8. Obed Wild and Scenic River (OBRI) Core Water-quality Monitoring Stations. Three monthly stations = 36 samples per year plus six quarterly stations = 24 samples per year = 60 total annual samples [CR—Continuous recording; SP—Staff plate; QW—Continuous water quality].

Site no.	Site name	Latitude	Longitude	Sampling Frequency	Gauge type	Period of record	Comments
OBRI-1	Clear Creek at Norris Ford	36.137229	84.872312	Quarterly	SP	—	High quality tributary near upstream boundary of Clear Creek arm of OBRI WSR corridor.
OBRI-2	White Creek at mouth near Barnett Bridge	36.122778	84.797500	Quarterly	SP	—	Large tributary to Clear Creek. Oil and gas exploration and extraction; site of major oil spill and fire in 2002. Residential development.
OBRI-3	Clear Creek at Lily Bridge	36.101944	84.716944	Monthly	CR, QW	1997–2015	Co-located with USGS gage# 03539778. NPS continuous QW station.
OBRI-4	Obed River at Adams Bridge	36.061667	84.961667	Monthly	CR, QW	2010–2015	Short distance upstream of Obed WSR corridor waters co-located with USGS gage # 03538830. Influenced by urban development (Crossville, TN). NPS continuous QW station. Monitors urban influences on the Obed River. Event sampling from bridge.
OBRI-6	Obed River at Obed Junction u/s Daddys Creek	36.076806	84.767500	Quarterly	SP	—	Site to be sampled for comparative purposes. Nearly identical drainage size as Daddys Creek and Clear Creek.
OBRI-7	Daddys Creek near Hebbertsburg at Antioch Bridge	35.997594	84.822547	Monthly	CR, QW	1957–1968 1999–2015	Influenced by urban development (Fairfield Glade). Upstream of park waters co-located with USGS gage # 03539600. NPS continuous QW station.
OBRI-8	Obed River at Alley Ford	36.081389	84.670833	Quarterly	CR	1956–1968 1973–1987 1999–2012	Access by hiking or ATV. Condemned cableway cannot be used for high stage measurements or sampling. Good biological diversity at this site. Most downstream site before confluence with Emory River.
OBRI-9	Emory River upstream of Obed confluence	36.076160	84.648380	Quarterly	SP	—	Very diverse biological community including federally listed fish.
OBRI-10	Emory River at Nemo Bridge	36.069167	84.662778	Quarterly	SP	—	Downstream integrator site. Lowest point in Obed WSR corridor.

Level II: Rotating Sampling Stations

Sampling efforts will also include a bank of tributary streams from which sites were subjectively chosen and sampled on a two year rotating basis at a quarterly frequency. Sites in each panel are monitored for two consecutive years, and six years are needed to sample all three panels. The rotating tributary bank includes key stations on streams draining populated and developed lands upstream of park waters in the Daddys Creek and upper Obed River watersheds. Sampling stations included in the tributary bank include watersheds affected by land use activities outside of park boundaries. Quarterly sampling of the rotating tributary bank is intended to supplement the long-term fixed stations described above:

1. To provide more complete evaluation of water resource integrity throughout designated park waters,
2. To evaluate water resource integrity as influenced by NPS managed activities within the park,
3. To identify stressors to Obed Wild and Scenic River water resources from land use activities outside of the park boundary in a manner that will support development of municipal, state, federal, and private partnerships.

Note that these sites were selected using targeted sampling and cannot be aggregated to provide a general description of Obed WSR water quality. The bank of tributary streams was derived in part from previous sampling conducted by NPS, (Rikard et al. 1986) but also targets sampling stations that have not been sampled by NPS. Stations to be sampled on a rotating basis are identified in Figure 12 and Table 9.

Table 9. Obed Wild and Scenic River (OBRI) Level II Rotating Water Quality Monitoring Stations (three stations per year). Three–four rotating stations (12–16 samples per year) plus 60 total fixed stations samples = 72–76 total fixed + rotating samples per year [SP—staff plate].

Site no.	Site name	Latitude	Longitude	Sampling Frequency	Gauge type	Period of record ¹	Comments
OBRI-5	Otter Creek at Firetower Road	36.054111	84.855444	Quarterly	SP	1	Urbanization, including water supply and recreational reservoirs may influence streamflow and water quality. Land application of municipal waste.
OBRI-11	Rock Creek at mouth near Nemo Bridge	36.068889	84.663611	Quarterly	SP	2	Impacted of by acid mine drainage (AMD). Watershed potentially targeted for mitigation. Rock Creek is at lower end of park.
OBRI-12	Yellow Creek at Hebbertsburg	36.018583	84.793978	Quarterly	SP	2	Receiving stream for coal mine and proposed ash disposal landfill.
OBRI-13	Little Obed River at Crossville	35.983056	85.03500	Quarterly	SP	1	Upstream tributary of Obed River. Urbanization, including urban runoff. Pilot sampling indicates poor water quality.
OBRI-14	Black Drowning Creek near Crossville	35.996481	85.0575	Quarterly	SP	1	History of high nutrient loading from dairy feedlot. Conditions have improved.
OBRI-15	North Creek near Fairfield Glade	35.933722	84.912975	Quarterly	SP	2	Receives runoff from Fairfield Glade.
OBRI-16	Byrd Creek at Homestead	35.923544	84.935456	Quarterly	SP	1	Drains city of Crossville and Homestead community.
OBRI-17	Fox Creek near Crossville	36.048911	84.939575	Quarterly	SP	3	Potential site to be sampled as part of comparative investigations.
OBRI-18	Basses Creek	35.851294	85.013211	Quarterly	SP	3	Tributary potentially impacted by upstream impoundment of Lake Tansi.
OBRI-19	Little Clear Creek at Lily Bridge	36.10405	84.718072	Quarterly	SP	3	Large Clear Ck. tributary. Drains mostly forest and pastureland.

¹Individual rotation panels will be sampled for two consecutive years, then replaced with next panel. After panel 3 is sampled for two years, panel 1 will be returned to rotation.

Detectable Level of Change

Power analysis methods: The ability to detect statistically-significant change in parametric (normally-distributed) data are determined using statistical power analysis. Statistical power analysis requires an understanding of five key parameter values: mean, variance, alpha, beta, and sample size. Mean and variance are calculated from the observed data, while alpha and beta are selected as the acceptable levels of uncertainty (Type I and Type II errors), 5% and 20%, respectively. When conducting power analysis on a single site, the number of independent data points is the sample size (n). Statistical power is especially dependent upon variability in the data. However, as sample size increases, the variance of the data tends to decrease. As the monitoring record grows, an assessment of between-year variability of the annual means will be possible. Once this information is developed, the change that is detectable from the data set above this degree of variability can be determined. The minimum detectable change represents the smallest difference or change that would be statistically significant.

For Level I sampling sites the desired detectable level of change for individual sites over a six year-period is:

- Change of 50% for most parameters.
- Change of 30 ANC units.
- pH change of 0.5.

For Level II sampling sites the desired detectable level of change for individual sites over a twelve-year period is:

- Change of 70% for most parameters.
- Change of 30 ANC units.
- pH change of 1.0.

The actual time period required to detect this level of change will differ for monthly vs. quarterly sites. Once there are sufficient data available, a power analysis will be conducted to determine whether the protocol meets the target detectable level of change.

A power analysis provided by Cheng (2018) estimated the statistical power of trend data that may be expected under various sampling scenarios for Blue Ridge Parkway Level II sites under the APHN Long-Term Water-Quality Monitoring Protocol for Discrete Sampling, focusing on headwater streams. Those sampling scenarios are described below:

- Six or twelve monitoring stations per elevation class
- Two or four annual surveys following a three-year panel design (one year on, two off for each site)

- 12 or 24 years of data collection

The analysis used historical water-quality data collected at Great Smoky Mountains National Park, and analyzed the data using robust regression methods. Summarized, the statistical power analyses indicated that the following levels of change detection may be expected with a design of quarterly sampling of six stations using a three-year panel design. These results should be comparable to the current six-year panel design but the current design was not explicitly tested. The analysis used an alpha of 0.1 and a power of 0.8.

- Change of 50% for most parameters is detectable over a 12 year period.
- Change of 30 ANC units is detectable over a 12 year period; in some scenarios (e.g., high elevation sites), change as low as 10 ANC units is detectable.
- pH change at 8 levels (-1, -0.75, -0.5, -0.25, +0.25, +0.5, +0.75, +1 standard units) could be detected over a 12 year period.

Field Methods and Analytical Schedules

Fixed Station Discrete Water Resource Monitoring

Field methods and laboratory criteria utilized under the APHN Discrete Water Quality Monitoring Protocol are consistent with methodologies described in the USGS National Field Manual for the Collection of Water-Quality Data (USGS, variously dated) and Standard Methods for the Examination of Water and Wastewater (APHA et al. 2005). The adoption of USGS and American Public Health Association (APHA) methodologies for acquisition of water resource data will meet APHN objectives to provide scientifically defensible water resource information to managers of each APHN park unit as well as to provide data that is nationally and regionally compatible.

Methods used to collect surface-water samples depend not only on streamflow conditions but also on the following considerations:

- Safety of field personnel
- Temporal and spatial heterogeneity
- Physical setting, ecological characteristics
- Antecedent weather conditions
- Fluvial sediment transport
- Target analytes and analyte-specific sample collection requirements
- Point and nonpoint sources of contamination
- Investigation-specific monitoring objectives, including data quality requirements.

Each sampling site must be examined and sampled in a manner that minimizes bias caused by the collection process and that most accurately represents the environmental conditions at the time of sampling.

Equal Width Increment Sampling

Typically, the network will utilize equal-width-increment sampling (EWI) methodologies to collect isokinetic, depth-integrated samples in accordance with procedures described in detail in Standard Operating Procedure (SOP) DWQ11 *Sample Collection Methods: Inorganic Chemistry and Bacteriology* (APHN 2018b). EWI methodologies produce a discharge weighted sample that is representative of the entire water body and eliminates sampling bias that could occur due to incomplete mixing of a water body as a consequence of inflow from upstream tributaries or other factors. EWI samples are obtained by stretching an incrementally marked tagline or measuring tape across the stream cross section, then collecting subsamples at equally spaced intervals along the tagline. All equally spaced subsamples are collected by lowering and raising an isokinetic water sampler at a consistent rate through the water column at the center of each increment (each subsample location is referred to as a vertical). The combination of a constant transit rate used to

sample at each vertical and the isokinetic property of the sampler results in a discharge-weighted total sample that proportionally subsamples each vertical based upon depth and streamflow velocity.

Collection of an isokinetic, depth integrated, discharge weighted sample is standard APHN procedure; however, site characteristics, sampling equipment limitations, or study objectives may constrain how a sample is collected and could necessitate use of other methods. EWI sampling during base flow conditions will typically utilize USGS approved wading samplers, while EWI samples collected during storm flows will utilize USGS approved samplers suspended from bridge cranes or bridge boards.

Single vertical at centroid-of-flow (VCF) method

The overwhelming majority of water samples collected by Appalachian Highlands Network will utilize EWI (or EDI) methods. However alternate isokinetic sampling methods may be utilized at small headwater streams at the Blue Ridge Parkway or during periods of low flow at smaller streams at the Big South Fork and Obed River. Isokinetic samples may be collected at a single vertical at the centroid of streamflow if the station is known to be well mixed laterally and vertically with respect to concentrations of target analytes. Verify mixing by making field measurements of specific conductance, pH, and turbidity across the width and depth of the stream.

The VCF method (described in SOP DWQ11) for collecting water samples is identical to the EDI method except that there is one centroid of flow for the stream cross section (only one vertical is sampled).

Timing of Sampling

Frequency and timing of the sampling effort are significant factors affecting representative sampling throughout the range of the annual hydrograph. Seasonal variability is reflected by variable physical and chemical water quality throughout the course of a water year, with higher dissolved solids typically occurring during low flow months of late summer and early fall during the drier portions of the water year. Additionally, samples collected during storm flow runoff conditions typically reflect significantly different physical and chemical water-quality conditions compared to those samples collected during seasonal base flow conditions. For example, a significant portion of the annual mass transport of sediments for a basin may occur during one or more runoff events. A rigidly fixed frequency sampling design will generally reflect the range of flow conditions over time; however, there may be a concomitant reduction in statistical power as a consequence of sampling the full range of flow conditions.

To increase the statistical power of APHN water resource evaluations, core sampling initiatives will target water-quality conditions during seasonal base flow conditions that are largely unaffected by runoff events. In this manner, more precise determination of current conditions will be possible and statistical power of water-quality analyses will be increased, providing a benchmark for comparison with future conditions. Because stressors to water and associated aquatic resources are also linked to runoff events, core water resource investigations targeting seasonal base flow conditions will be supplemented with transient or targeted monitoring initiatives that will be employed to evaluate physical and chemical water-quality conditions during storm flow events. Data derived from seasonal

base flow sampling and targeted runoff event sampling will be analyzed as separate data sets. A detailed description of sampling methodologies that will be employed by Appalachian Highlands Network at all network parks is included in SOP DWQ11.

Stream Discharge and Stage

Surface water quality is heavily influenced by the annual runoff cycle as manifested by seasonal and event-related variations in streamflow. To complement EWI water-quality evaluations that will be conducted on a routine basis, Appalachian Highlands Network will conduct stream discharge measurements as a standard operating procedure (SOP DWQ07 *Stream Discharge Measurements* [APHN 2018c]). At those water-quality monitoring stations that coincide with established USGS stream gages, Appalachian Highlands Network will rely upon stream discharge indicated by the streamflow gage. At water-quality monitoring stations where continuous stream gaging stations are not available, Appalachian Highlands Network will make stream discharge measurements in accordance with USGS standards at the time of water sample collection. Appalachian Highlands Network will also install outside gages (staff plates) to measure stream stage in concert with discharge measurements. As detailed in SOP DWQ07, staff plates will be leveled in accordance with USGS practices, which specify that new installations are leveled on an annual basis for the first three years and every three years thereafter. With time, as an adequate number of measurements are made at different stages, rating curves will be developed to correlate stream stage with discharge. If the outside gage staff plates are not rated, or are not present, a discharge measurement must be made to correspond with each sample unless a wading or bridge measurement cannot be safely made.

SOP DWQ07 describes methods that will be utilized by Appalachian Highlands Network to measure stream discharge in accordance with methodologies described in USGS Water Supply Paper 2175 (Rantz, et al. 1982), and Stednick and Gilbert (1998). Additional details of stream discharge measurement methodologies can be obtained from the USGS Techniques for Water Resources Investigations (TWRI) Book 3, Section A (USGS, variously dated).

Analytical Schedules

Schedule 1: Field Analyses

Appalachian Highlands Network staff will conduct routine field analyses in accordance with procedures detailed under SOP DWQ08 *Equipment and Calibration* (APHN 2018d), to include the following parameters:

- Field pH
- Specific Conductance
- Field Temperature
- Acid Neutralizing Capacity (ANC)
- Dissolved Oxygen
- Turbidity

Field measurements should represent, as closely as possible, the natural condition of the surface-water or ground-water system at the time of sampling. Field teams must determine if the instruments and method to be used will produce data of the type and quality required to fulfill study needs and to meet mandated NPS requirements (Hughes et al. 2018). Experience and knowledge of field conditions are indispensable for determining the most accurate field measurement. To ensure the quality of the data collected:

- Calibration is required at the field site for most instruments (SOP DWQ08). Field measurements will only be conducted with calibrated instruments.
- Each field instrument must have a permanent log book for recording calibrations and repairs. The log book is reviewed by staff before leaving for the field.
- Each instrument (meters and sensors) is tested before leaving for the field (SOP DWQ08). Any staff unfamiliar with the equipment or measurement technique will be trained and must practice and become proficient prior to using the equipment in the field.
- The network maintains readily available backup instruments in good working condition.

The following discussion of field parameters and the significance of their measurement is paraphrased from the InSitu Troll 9500 WQP-100 Operator's Manual (InSitu Inc. 2006).

Temperature

Water temperature plays an important role in water chemistry, which in turn influences the biological activity and growth of aquatic organisms. Generally, higher water temperature contributes to higher biological activity and a higher rate of chemical reactions. An important example of the effects of temperature on water chemistry is its impact on oxygen. Warm water holds less oxygen than cool water; the maximum amount of oxygen that can be dissolved in the water decreases as water temperature increases. Artificially high temperatures are often referred to as “thermal pollution,” which may result from discharge of municipal or industrial effluents. Thermal pollution can have a significant ecological impact. In running waters, particularly small urban streams, elevated temperatures from road and parking lot runoff can be a serious problem for populations of cool- or cold-water fish.

Field pH

A pH value indicates the concentration of hydrogen ion that is present in an aqueous environment. The hydrogen ion concentration gives an indication of the acidity of a substance. The pH of natural waters is an important measurement because most chemical and biochemical processes are pH dependent. The physiological chemistry of most living organisms can tolerate only small changes in pH to avoid disruption of the chemical reactions that sustain life. The solubility of many chemicals is pH dependent. Thus, pH determines their availability to living organisms.

Natural waters usually have pH values in the range of 4 to 9. Most natural waters are slightly basic (~ pH 8) because of the presence of carbonates (CO_3^{2-}) and bicarbonates (HCO_3^-). Low ionic strength fresh water within APHN parks can even be slightly acidic (~ pH 6), depending on the concentration

of dissolved carbon dioxide (CO_2). The carbon dioxide combines with water to form a small amount of carbonic acid (H_2CO_3) thereby lowering pH. Nitrogen oxides (NO_x) and sulfur dioxides (SO_2) from automobile exhaust, agricultural practices and the burning of fossil fuels combine with water in the atmosphere to form nitric (HNO_3) and sulfuric acid (H_2SO_4), both of which are transported to the ground as acid rain to subsequently accumulate in soils and surface water. Runoff from mining spoils and the decomposition of plant materials can also acidify surface water.

Freshwater fish prefer a pH range of 6 to 9. Surface water pH also affects the ammonia/ammonium ($\text{NH}_3/\text{NH}_4^+$) equilibrium in water. Even a small amount of ammonia is detrimental to fish, while a moderate amount of ammonium is tolerated. At a pH of 6.5, almost all ammonia is in the form of ammonium. However, as the pH becomes slightly basic, ammonium is changed into harmful ammonia. The lethal dose of ammonia for trout is only 0.2 mg/L (Lang et al. 1987).

Alkalinity or Acid Neutralizing Capacity (ANC)

ANC is a measure of the ability of water to neutralize acidic (low pH) input. In general, carbonate geologic settings have high ANC and sandstone and metamorphic geologic settings typical of APHN parks have lower values. ANC is performed on an unfiltered sample to include the buffering capacity of the suspended solids fraction. ANC is reported as milligrams/liter as CaCO_3 or in milliequivalents/liter.

Specific Conductance

Specific conductance (SC) is a measure of water's capacity to conduct an electrical current. Specific conductance is the reciprocal of resistance (in ohms) as measured by sensors equipped with two opposing electrodes. The unit 1/ohm or mho was given the name Siemens (S) for specific conductance measurements. Specific conductance measurements will be reported in micromhos/cm or microsiemens/cm.

Specific conductance is a valuable field water-quality measurement that provides a reasonable approximation of the concentration of total dissolved solids in the water. Specific conductance is directly proportional to the amount of total dissolved solids in the water. Pure water, such as distilled water, will have a very low specific conductance, while sea water will have a high specific conductance. Rainwater often dissolves airborne gasses and airborne dust before reaching the land surface and typically exhibits higher specific conductance than distilled water.

Changes in the conductance of a body of water are often utilized as an indicator of an environmental event. For example, a drastic increase in conductance at a remotely deployed datasonde might indicate a chemical spill. Similarly, a dramatic increase in conductance along the longitudinal reach of a stream provides a good indicator of inflow of tributaries with higher dissolved solids. Thus, conductance measurements are valuable to track a pollutant plume, or to verify the zone of complete mixing for waters.

Many factors can influence specific conductance, from geology to anthropogenic contamination in a water body. The geologic character of the Obed Wild and Scenic River is dominated by outcropping of the orthoquartzitic Rockcastle conglomerate sandstone that is resistant to physical and chemical

weathering. As a consequence, waters of the Obed are primarily chemically dilute (soft) and exhibit low specific conductance, except where influenced by runoff from urban development in the headwaters. Waters of the Big South Fork are also influenced to a great extent by large areas of Rockcastle conglomerate outcropping. The Big South Fork is also influenced by calcareous shale units that outcrop in the upper (younger) sequence of Pennsylvanian lithology in the New River watershed, and also by breach of underlying calcitic Mississippian limestone in the Big South Fork gorge. As a consequence, conductance values in some portions of the Big South Fork drainage are somewhat higher than those in the Obed watershed. Geology of the Blue Ridge Parkway is dominated by resistant sedimentary sandstones and metamorphic granites as reflected by very low specific conductance values of headwater streams of the Parkway that often approach that of distilled water.

Dissolved Oxygen

The concentration of dissolved oxygen (DO) in natural waters and wastewater is a function of several factors. Dissolved oxygen is highly dependent on both temperature and atmospheric pressure. Dissolved oxygen solubility in natural waters is inversely related to water temperature. Higher temperature reduces the dissolved oxygen solubility of water, while lower temperature increases the solubility of dissolved oxygen. Conversely, higher atmospheric pressures result in increased dissolved oxygen solubility.

Chemical and biochemical processes affect dissolved oxygen concentrations. Most of the dissolved oxygen in water originates from the atmosphere, but oxygen produced as a byproduct of photosynthetic activity of aquatic macrophytes and algae is also a significant source. Dissolved oxygen concentrations in surface water will typically follow a cyclic or diurnal pattern over the course of a day, rising and falling as light intensity changes from dawn to dusk, promoting photosynthetic activity during the day (oxygen generating) that is replaced by decay at night (oxygen consuming).

Most aquatic life requires an average DO value greater than 5.0 milligrams dissolved oxygen per liter of water (mg/L) in order to survive. Although the amount of dissolved oxygen in a body of water fluctuates due to natural processes, large deviations may occur as a result of anthropogenic activities such as sewage discharge, runoff from agricultural lands and concentrated feed lots, or from industrial discharge. Organic wastes often contain nitrates and phosphates, which are nutrient sources for aquatic plants and algae that promote nuisance algal blooms, macrophyte growth, and eutrophication; these plants and algae reduce the available oxygen through biological respiration.

Turbidity

Turbidity renders water cloudy or opaque. During periods of low flow (base flow), streams are typically clear and turbidities are low (0 to 5 NTU). Conversely, during significant precipitation events, particulates are transported from upland areas into streams, rendering the water “muddy” or brown, indicative of higher turbidity values. Material that contributes to turbidity in natural waters includes:

- Silt

- Clay
- Finely divided organic and inorganic matter
- Soluble colored organic compounds
- Plankton
- Microscopic organisms

Turbidity sensors measure the scattering of light caused by suspended solids in a water body. Turbidity, reported in nephelometric turbidity units (NTUs), is measured by instrumentation that shines a beam of light through the water and quantifies the scattering of that beam by suspended particulates in the water column. The higher the intensity of scattered light, the higher the turbidity. Real time water-quality monitors that have been established at the USGS stream gages have documented significant variation in the sediment load carried by waters of the Big South Fork and Obed River system. Typically, turbidity peaks associated with runoff from significant precipitation events range from 40 to 60 NTU at monitors on Daddys Creek (OBRI), Clear Creek (OBRI), and Clear Fork (BISO), but spike at 50 to 80 at the Obed at Adams Bridge (OBRI) and 300 to 800 NTU at the New River gage (BISO), which drains heavily mined and logged lands in that watershed.

Sample Handling and Preservation of Samples submitted for Laboratory Analytical Schedule

NPS staff will collect, filter, and preserve water samples in the field in accordance with APHA methodology (APHA 2005). Appalachian Highlands Network will purchase field filtering equipment and will provide acid vials for preservation of samples for trace metals analyses. Detailed descriptions of equipment cleaning and sample handling and preservation methodologies that will be employed by Appalachian Highlands Network at all network parks are included in SOP DWQ03 *Laboratory and Sampling Equipment Cleaning* (APHN 2018e) and SOP DWQ06 *Field Sampling Sequence and Sample Handling* (APHN 2018f).

Sample blanks and concurrent sample replicates will be collected as a standard practice under the quality assurance/quality control provisions described in SOP DWQ13 *Quality Assurance/Quality Control* (APHN 2018g) of the APHN Long-Term Water Quality Monitoring Protocol for Discrete Sampling. These sample blanks and replicates will be handled and preserved in the identical manner as the routine discrete samples, and analyzed in the same way. The quality control (QC) effort consists of collection and laboratory analyses of sample blanks prior to each quarterly sampling event and concurrent sample replicates of every tenth sample to ensure that error and bias of samples are quantified. Four annual sample blanks will be collected (one for each of the quarterly sampling efforts), and 24 concurrent sample replicates will be collected annually (one for every tenth sample). Refer to Standard Operating Procedures SOP DWQ03 (Laboratory and Sampling Equipment Cleaning), SOP DWQ06 (Field Sampling Sequence and Sample Handling), and SOP DWQ13 (Quality Assurance /Quality Control) for additional detail.

Laboratory Analytical Schedules (Inorganic Chemistry)

Appalachian Highlands Network will utilize NELAP or equivalent certified laboratories to conduct chemical analyses of water samples. The laboratory support described herein is primarily in the area of chemical analysis of water samples, with additional support in laboratory prep of bottles and other field sampling equipment. The laboratory is configured to analyze lake and stream water and passive ozone filter samples. The laboratory is staffed by experienced technicians and is equipped with high-quality computer automated analytical systems. Analyses performed and data generated are carefully reviewed in accordance with QA/QC procedures established by the U.S. Environmental Protection Agency and the American Society for Testing and Materials. Reliability of data, strict adherence to QA/QC protocols, and prompt service are the primary goals of the laboratory personnel.

The full suite of constituents in Table 10 will be analyzed as part of core monitoring efforts at Big South Fork NRRA, Blue Ridge Parkway, and Obed WSR because they are relevant to the monitoring objectives of all three parks. These analytes have been selected as indicators of potential effects of anthropogenic activities on water resources of the parks, and also to provide a basis for characterizing pristine waters. The APHN field analyses and contract laboratory analyses will provide water-quality data in accordance with the five general schedules indicated in Table 10.

Schedule II: Solids

Schedule II analytes (Table 10) will be utilized to define gross water chemistry, to develop a specific conductance/TDS curve, and as a measure of QA/QC through comparison of field and laboratory analyses for specific conductance.

Schedule III: Routine Anions/Cations

Schedule III analytes include the predominant anions and cations that are typically found in relatively high concentrations (> 1 mg/L) in all surface and groundwater. These are listed in Table 10.

Table 10. Appalachian Highlands Network discrete water-quality analytical schedules [ICPE—Inductively Coupled Plasma Emission Spectroscopy; MDL—method detection limit].

Schedule	Metric	Equipment	MDL
Schedule I: APHN In Situ Measurements and Buffering Capacity	Field pH	YSI 556 Multi-parameter Meter (SOP DWQ08)	–
	Field Temperature	YSI 556 Multi-parameter Meter (SOP DWQ08)	–
	Specific Conductance	YSI 556 Multi-parameter Meter (SOP DWQ08)	–
	Dissolved oxygen	YSI 556 Multi-parameter Meter (SOP DWQ08)	–
	Acid Neutralizing Capacity	Gran titration (SOP DWQ10)	–
	Turbidity	Hach Model 2100Q (SOP DWQ06)	–
Schedule II: Solids (unfiltered aliquot)	Specific Conductance	PC-Titrate Model 4310 Conductivity Meter	–
	Hardness	APHA Method 2340B (calculated)	–
	Total Dissolved Solids	Calculated	–
Schedule III: Major Anions/Cations (filtered aliquot)	Calcium (Ca)	Ion Chromatograph	0.01
	Magnesium (Mg)	Ion Chromatograph	0.04
	Potassium (K)	Ion Chromatograph	0.01
	Sodium (Na)	Ion Chromatograph	0.01
	Chloride (Cl)	Ion Chromatograph	0.07
	Sulfate (SO ₄)	Ion Chromatograph	0.04
	Anion-Cation balance	Calculated	NA
Schedule IV: Nutrients (filtered aliquot)	Nitrogen species:	–	–
	Nitrogen total dissolved (TDN)	Total Nitrogen Analyzer	–
	Nitrate (NO ₃)	Ion Chromatograph	0.03
	Nitrite (NO ₂)	Ion Chromatograph	0.02
	Ammonia (NH ₄)	Ion Chromatograph	0.04
	Phosphorus species:	–	–
	Phosphorus (P), total dissolved	ICPE ¹	0.05

Table 10 (continued). Appalachian Highlands Network discrete water-quality analytical schedules [ICPE—Inductively Coupled Plasma Emission Spectroscopy; MDL—method detection limit].

Schedule	Metric	Equipment	MDL
Schedule V: Metals/metalloids (filtered and acidified aliquot)	Aluminum, total (Al)	ICPE	0.030
	Copper (Cu)	ICPE	0.036
	Iron (Fe)	ICPE	0.041
	Manganese (Mn)	ICPE	0.009
	Zinc (Zn)	ICPE	0.012
	Silica (SiO ₂)	ICPE	0.017
Schedule VI: Bacteriological Analyses (unfiltered aliquot)	<i>Escherichia coli</i> (<i>E. coli</i>)	Idexx Colilert Defined Substrate (SOP DWQ12)	–

Schedule IV: Nutrients

Nutrients include nitrogen and phosphorus compounds that are essential for plant growth and occur in natural waters at varying concentrations as a result of runoff and biological activity in streams. At elevated concentrations, nutrient enrichment of water bodies can contribute to eutrophication and can promote dense blooms of algal species and other nuisance aquatic plants. Subsequent decay of algal blooms can load water bodies with debris and result in foul odors, bad taste, and reduced dissolved oxygen levels, which are harmful to other aquatic life.

Elevated nutrient concentrations often originate from many of the same point and nonpoint sources that are attributed to elevated bacteriological level. Point source discharges typically include piped effluent from wastewater treatment facilities and from large urban and industrial waste treatment systems. Nonpoint sources include overland stormwater runoff from urban and agricultural lands and from dairy and feed lot operations. Applications of manures and synthetic fertilizers on agricultural lands may contribute to nuisance nutrient enrichment of waters. Potential sources of nutrient enrichment at APHN parks also include turf management practices at golf courses and at ornamental and pulpwood nurseries and tree farms.

Monitoring of nutrient levels can assist in determining whether activities in a drainage basin are negatively influencing aquatic resources. Often, nutrient issues can be addressed by implementing best management practices or by physical improvement in waste handling systems. Elevated ammonia can have serious negative effects on sensitive aquatic communities.

Schedule V: Metals/Metalloids

Trace elements include those inorganic chemicals that typically occur in small amounts in nature. Trace elements are mobilized in low pH environments associated with acid coal mine drainage on the Cumberland Plateau or with acid precipitation in the Blue Ridge Highlands, sometimes at

concentrations that adversely affect aquatic biota. Elevated concentrations of aluminum, iron, manganese, copper, lead, and zinc have been documented in surface waters of the Cumberland Plateau and the Blue Ridge Provinces.

Bacteriological Analyses

Escherichia coli (E. coli)

E. coli is a species of coliform bacteria that is specific to fecal waste originating from humans and other warm-blooded animals. Studies conducted by the EPA to determine the correlation between various bacterial indicators and the occurrence of digestive system illness at swimming beaches and other areas of recreational contact with surface waters suggest that the best indicators of health risk from recreational water contact in fresh water are *E. coli* and *E. enterococci*. Towards that end, the EPA recommends *E. coli* as the best indicator of health risk from human contact in recreational waters; and most states have amended their water-quality standards and are monitoring *E. coli* accordingly.

Appalachian Highlands Network will conduct in-house bacteriological examination of unfiltered samples of water at all monitoring stations utilizing the IDEXX Colilert system. Colilert-18 and Colilert-24 utilize Defined Substrate Technology® (DST®) nutrient indicators ortho-Nitrophenyl- β -galactoside (ONPG) and 4-methylumbelliferyl- β -D-glucuronide (MUG) to detect coliforms and *E. coli* (APHA, 2005 Method 9223A – Enzyme Substrate Coliform Test). Coliforms use their β -galactosidase enzyme to metabolize ONPG and change it from colorless to yellow. *E. coli* use β -glucuronidase to metabolize MUG and create fluorescence. All IDEXX DST reagents can be used in a presence/absence (P/A) vessel, [Quanti-Tray®](#) or [Quanti-Tray®/2000](#). The IDEXX Colilert methodologies are EPA approved analytical technologies for analyses of total coliform bacteria and for presence of *E. coli* bacteria, which are indicator bacteria for detecting the presence of waste from the intestines of warm-blooded animals. This information is of use in determining the magnitude of both human influences (municipal and non-municipal wastewater treatment facilities, individual household septic systems, untreated discharges) and from domestic and wild warm-blooded animals (concentrated livestock feed lots and stables, dairy operations, feral hogs and boars) – all potential sources of pollutants at Big South Fork NRR, Blue Ridge Parkway, and Obed WSR.

A detailed description of IDEXX Colilert® methodologies that will be utilized by Appalachian Highlands Network for the detection of total coliform, *E. coli*, and fecal coliform is provided in SOP DWQ12 *Bacteriological Sampling and Analyses* (APHN 2018h).

Equipment Cleaning

Correct cleaning procedures are critical for collecting uncontaminated water-quality samples. Detailed procedures and the required supplies for cleaning sampling equipment are listed in SOP DWQ03. In general, equipment must be washed between each sample, or adequate equipment must be available to have clean equipment for each site. The equipment must be soaked in a laboratory-grade soap solution such as Liquinox, rinsed two times with tap water, then rinsed two times with distilled water. Equipment used for trace element sampling must be soaked in an HCl solution before

the distilled water rinse. Distilled water will be prepared in-house at the BISO Resource Management water lab.

Field sampling equipment will be disinfected in accordance with SOP *DWQ04 Disinfection Procedures for Aquatic Resource Sampling* (APHN 2018i). This SOP provides standardized methods for cleaning and disinfecting all equipment used to collect samples from APHN waters in a manner that will prevent the spread and/or introduction of disease-causing pathogens and invasive algae, plant, and animal species. These methods are consistent with the decontamination procedures of other entities conducting water resource sampling activities in Virginia, North Carolina, Tennessee, and Kentucky.

Field Folders

SOP *DWQ05 Field Folders* (APHN 2018j) describes maintenance of field folders for each water-quality monitoring site. Information that is needed for reference while at a surface-water site is kept in a field folder. The field folder contains information and directions to monitoring sites needed by trained personnel to locate and safely collect and process water samples. The field folder is taken along on each sampling trip. General contents of the field folder are listed on the field-folder checklist, but the folder should be customized according to specific conditions of individual sampling stations (USGS NFM A1, Wilde et al. 2005). At a minimum, field folders should contain directions to sampling stations, including maps and field parameter results from last sampling visit (compare to see if current results are outliers).

Data Management, Analysis and Reporting

Data collected as part of the APHN discrete water resource monitoring effort include synoptic water quality and stream discharge data from a network of core water-quality monitoring stations that will be sampled on a fixed rotation. Fixed network water-quality monitoring stations will be sampled and analyzed for a robust schedule of physical and chemical water quality and water quantity indicators (see Table 10). Analytical techniques that will be employed are described in Standard Operating Procedure (SOP) DWQ16 *Data Analyses and Reporting* (APHN 2018k). Additional analytical techniques will be evaluated as data sets are more fully developed.

Overview of Data Flow and Database Design

Physical and chemical water-quality data will be generated via field measurements and laboratory analyses as follows:

- Field water-quality analyses.
- In-house laboratory and field wet bench chemistry.
- In-house bacteriological analyses utilizing IDEXX Colilert-18 or Colilert-24.
- Inorganic chemistry analyses by contract laboratories.
- QW datasondes deployed in tandem with USGS streamflow gages at New River (USGS # 03408500) and Clear Fork near Robbins (USGS # 03409500) in the Big South Fork NRRA system and at Clear Creek at Lilly Bridge near Lancing (USGS # 03539778), Obed River at Adams Bridge near Crossville (USGS # 03538830), and Daddys Creek near Hebbertsburg (USGS # 03539600) stations in the Obed River system.

Figure 13 depicts the process flow for collection, management, analyses, and reporting of discrete water resource monitoring data.

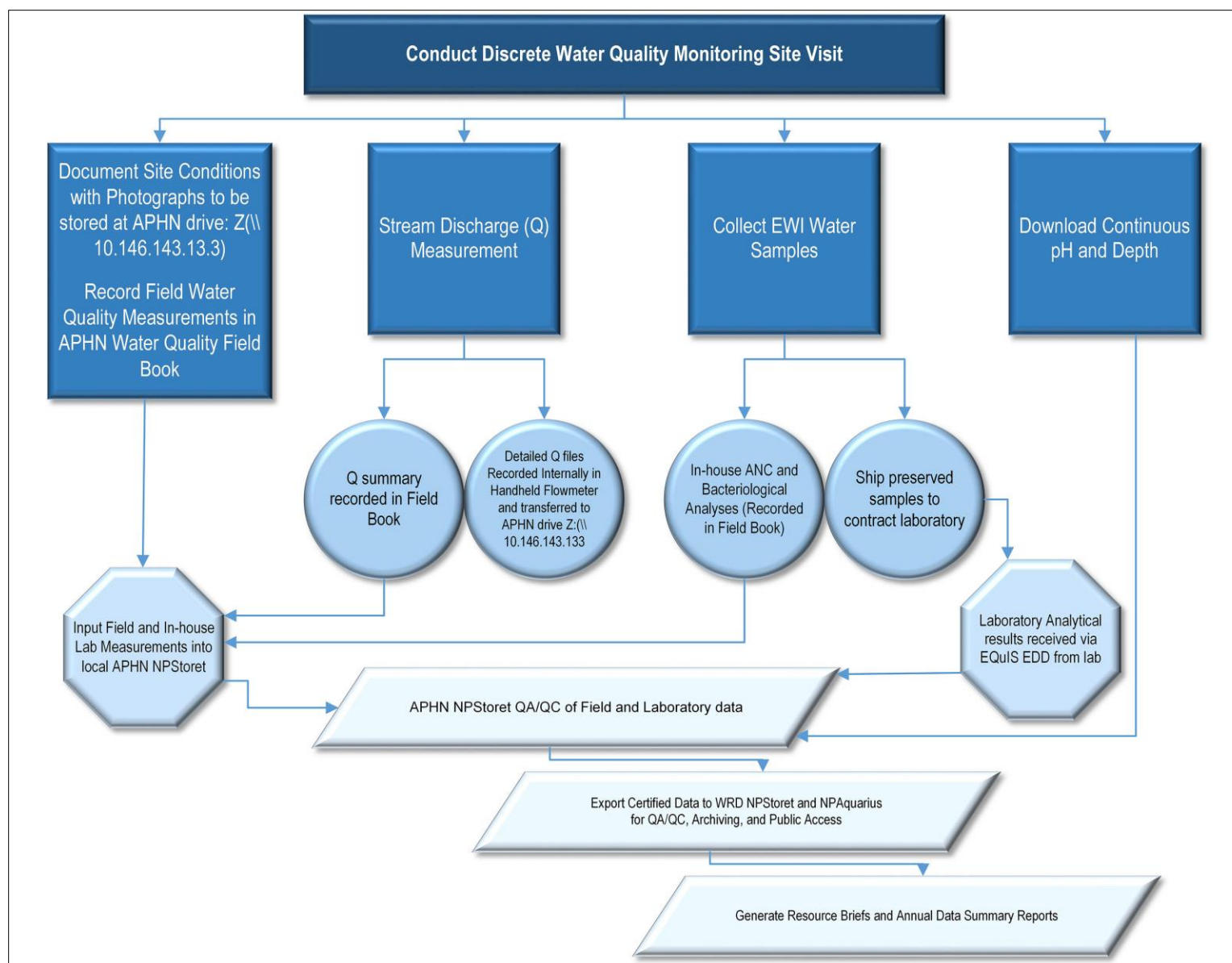


Figure 13. Process flow chart for management of discrete water-quality monitoring data.

Data Import and Data Entry

Data generated from the above sources will be electronically assembled and managed as follows:

- Electronic discharge summary files will be saved to the OBRI/BISO share all drive and to the BLRI share all drive. Refer to SOP DWQ07 *Stream Discharge Measurements* for additional detail.
- Field water-quality analyses will be hand recorded in the pre-printed APHN Water-quality field books during site visits and subsequently entered into APHN NPStoret by the APHN protocol lead or support personnel. Handheld water-quality meters may be used to internally log field data if equipped to do so; however, paper backup copies will be maintained as duplicates. Photographs of field data sheets will be taken prior to leaving a sampling location. Refer to SOP DWQ08 *Field Parameters and Equipment Calibration* for additional details.
- In-house laboratory data will be hand recorded in the pre-printed APHN Water-quality Field Book and subsequently entered into APHN NPStoret as described above. Refer to SOP DWQ10 *ANC Titrations for Low Alkalinity Waters* (APHN 2018l) for additional details.
- In-house bacteriological analytical results will be recorded in the pre-printed APHN Water-quality Field Book and subsequently entered into APHN NPStoret as described above. Refer to SOP DWQ12 for additional details.
- Inorganic chemistry analytical results conducted by the contract laboratory will be recorded via automated entry into NPStoret EDD (electronic data deliverable) and forwarded via email to the lab manager, who will then forward the EDD via email to the APHN Hydrologist. The APHN Hydrologist will conduct validation.
- Field data sheets will be scanned in an expeditious manner at the end of a multi-day sampling effort and saved electronically in pdf format on the APHN drive Z:(\\10.146.143.133).
- Data from the above sources will be merged into an EDD by the APHN hydrologist and subsequently forward via email to the APHN data manager for entry into the NPS instance of NPStoret. The EDD will be directly backed up on the OBRI/BISO share drive and the BLRI share all drive.

Data Verification

Field and in-house laboratory water-quality data, streamflow data, and associated field notes are recorded in the pre-printed APHN Water Quality Monitoring Program field notebook. These data and field notes are manually entered into NPStoret. Data are verified during data entry in a process which involves checking the accuracy of computerized records against the original source, mainly paper field data sheets and laboratory EDD files. Data entry staff check 100% of the records against the original data sheets. A subsequent 10% check of the data is done by the protocol lead. Its purpose is to identify generic errors in the data record, for example, missing, mismatched, duplicate records, or values outside of sensor limits. See SOP DWQ13 for additional detail.

In addition to field and in-house laboratory data, Appalachian Highlands Network will receive laboratory data from contract labs via NPStoret EDD. Upon receipt of these data, the protocol lead will review, verify, and validate the data to ensure that analytical results are reasonable. Once this step is complete, the protocol lead will import the data into NPStoret maintained by the NPS Water Resources Division.

Data Validation

The hydrologist will validate the data during data entry and after verification is complete. Look-up tables contain project specific data, and prohibit entry of data into a field if a corresponding value is not included in the look-up table. For these fields, only valid names or measures may be entered and spelling mistakes are eliminated. For the remaining data fields, validation controls prevent impossible values from being entered (e.g., a negative pH value), and data entry alert messages are provided any time a number is entered that is not realistic. The user is offered a chance to re-enter the data or keep abnormal data.

A second step of the validation process is the graphing of data for comparison to previous results and seasonal norms. For this step values for a single event are graphed on a 12-month graph against a long term trend representing all previous values from a single site. This allows the hydrologist to quickly visually identify any outlier values. This step is completed within NPStoret. Any outliers noted are subject to further comparison to flow levels and values from adjacent locations to try and determine the validity of reported values. This step applies to both data collected by Appalachian Highlands Network and data provided by the lab. For parameters that are measured both in the field and in the lab (i.e., pH and specific conductance) values will be compared to check for discrepancies.

Data Certification

After the data are verified and validated, the protocol lead will certify that all data pass QA/QC checks. Paper data sheets are archived and the approved (certified) electronic data are used for subsequent data analysis and reporting. If a review of the data sheets indicates clear errors or document validation issues that necessitate editing at a later date, the updated data sheets will be scanned and archived along with the original.

Metadata

Complete metadata facilitates data longevity, helps publicize the existence of all data sets produced, and enables effective access and use of data by future users. Monitoring data will be accompanied by metadata documentation that includes: dataset identification information, data quality information, entity and attribute information, spatial reference information, distribution information, and contact information. A record containing this information will be created in the [NPS Data Store](#) and will be reviewed and updated annually.

Sensitive Information

Water resource information to be collected under the discrete water-quality monitoring protocol includes physical, chemical, bacteriological, and stream discharge data. These data are intended to complement additional APHN protocols to monitor freshwater mussel communities and riparian cobble bar communities. Monitoring efforts under these companion protocols may produce sensitive

information; however, water-quality data will generally be considered “operationally sensitive” data which may be released after consultation with resource managers at each park. Detailed discussion of the quality assurance procedures for data review, data standards, and data sensitivity is under development (Hughes et al. 2018)

Data Archiving

As described above, raw field data and approved, certified data are stored in NPStoret. The APHN digitally archives field data sheets and instrument calibration data sheets as well as electronic photographs taken during site visits. Digital files are stored on APHN drive Z: (\\10.146.143.133), which has daily and weekly routine backup procedures. Paper copies of field data sheets are stored in the office of the protocol lead (in Oneida Tennessee) following data entry, verification, and validation.

Data Analysis & Reporting

A primary goal of the National Park Service Inventory and Monitoring Program is to ensure that the data obtained from water resource monitoring are provided to park superintendents and resource management staff in a timely manner and are presented in formats that best meet park needs. Monitoring results will be shared as broadly as possible with NPS staff and with park partners and the public, where appropriate.

A detailed description of water resource data management and analyses is provided in SOP DWQ15: *Data Management* (APHN 2018m) and SOP 16 *Data Analyses and Reporting*. These SOPs provide instructions for the development, maintenance and distribution of monitoring data and reports associated with the *Long-term Discrete Water-quality Monitoring at Big South Fork National River and Recreation Area, Blue Ridge Parkway, and Obed Wild and Scenic River: Protocol Narrative* (Hughes 2018, this document).

Annual Reports

The network will provide annual data summary reports and resource briefs to Big South Fork NRR, Blue Ridge Parkway, and Obed WSR that can be shared with the park staff, partners, and the public. Data summary reports will conform to the format of the [Natural Resource Publication Series](#) guidelines. These reports will describe and summarize the results of monitoring efforts conducted during the previous water year (October 1 through September 30) and will be completed by April of the following year. Assessment of water resource integrity in each park will be supported by summary statistics and graphics, will identify pervasive water resource conditions of concern, and will identify factors affecting park resources. Annual water resource reports will interpret data and describe the condition of water resources in each park relative to those general schedules of analytes described above (Field Methods and Analytical Schedules).

- Schedule I: In Situ Analyses and Buffering Capacity
- Schedule II: Solids
- Schedule III: Routine Anions/Cations

- Schedule IV: Nutrients
- Schedule V: Metals/Metalloids
- Schedule VI: Bacteriological Analyses (*E. coli*)
- Streamflow

Appalachian Highlands Network parks lie within four different states, each of which has promulgated specific water-quality standards for some of the analytes that are monitored as part of the discrete water-quality monitoring protocol and the companion *Long-Term Continuous Water-Quality Monitoring at Big South Fork National River and Recreation Area and Obed Wild and Scenic River: Protocol Narrative* (Hughes et al. 2018). State water-quality standards and reference values for undisturbed watersheds in Big South Fork NRRRA and OBRI headwater streams are provided in Table 11. State water-quality standards for North Carolina and Virginia and reference values for BLRI streams are provided in Table 12.

Appalachian Highlands Network water resource monitoring will also gather data for analytes that do not have specific numeric regulatory water-quality criteria. Often, state regulatory standards provide narrative rather than numeric criteria that reference a desired condition. For example, Tennessee Department of Environment and Conservation (TDEC) narrative criteria for turbidity state:

“there shall be no turbidity, total suspended solids, or color in such amounts or of such character that will materially affect fish and aquatic life. In wadeable streams, suspended solid levels over time should not be substantially different than conditions found in reference streams.”

Table 11. Tennessee (TN) and Kentucky (KY) water quality (WQ) criteria for fish and aquatic life, and reference water-quality values in headwater streams at Big South Fork National River & Recreation Area (BISO) and Obed Wild and Scenic River (OBRI) (from Rikard et al. 1986).

Parameter	Tennessee WQ Criteria (2013)	Kentucky Surface Water Standards (2013)	Reference Values ¹
Conductivity (µS/cm)	n/a	Shall not adversely affect the indigenous aquatic community	≤ 50 (sandstone); ≤ 100 (limestone)
pH	6.5–9.0; shall not change more than 1 unit over a 24 hr. period	6.0–9.0; shall not change more than 1 unit over a 24 hr. period	5.5–7.0 (sandstone); 6.0–7.5 (limestone)
Turbidity (NTUs)	shall not materially affect fish and aquatic life; should not differ appreciably from reference streams	shall not adversely affect the indigenous aquatic community	< 10
Temperature (°C)	≤ 30.5; shall not change more than 2 °C/hr.	≤ 31.7; the normal fluctuation of temp shall be maintained	0–25.0
Dissolved Oxygen (mg/L)	≥ 5.0	≥ 5.0 as a 24 hour average; ≥4.0 at any time	≥ 5.0
Nutrients (°C)	shall not reduce aquatic habitat or cause biological integrity to fail to meet regional goals.	shall not result in eutrophication problem; Unionized ammonia ≤ 0.05	–
E. coli and fecal coliforms ²	E. coli: ≤ 126 colony forming units per 100 mL, as a geometric mean based on a minimum of 5 samples	May 1 through October 31: ≤ 130 E. coli colony forming units per 100 mL; Remainder of year: fecal coliforms ≤ 1000 colonies/100 mL. (both as a geometric mean; based on a minimum of 5 samples)	

¹ Reference values are in undisturbed BISO and OBRI Streams (Rikard, et al. 1986).

² NPS Reference Manual 83(d1) provides E. coli standards of ≤100 colony forming units per 100 mL, as a geometric mean based on a minimum of 5 samples, or ≤ 320 colony forming units per 100 mL, based on a single sample (NPS 2018b)

Table 12. North Carolina (NC) and Virginia (VA) water quality (WQ) criteria for fish and aquatic life, and reference water-quality values in headwater streams at Blue Ridge Parkway (BLRI).

Parameter	NC WQ Criteria (2013)	VA Water Quality Standards (2013)	Reference Values ¹
Conductivity (µS/cm)	n/a	shall not adversely affect the indigenous aquatic community	≤ 30
pH	6.0–9.0	6.0–9.0	5.0–7.0
Turbidity (NTUs)	shall not materially affect fish and aquatic life	shall not adversely affect the indigenous aquatic community	< 10
Temperature (°C)	≤ 29°C; shall not exceed natural water temperatures by more than 2.8°C	≤ 31; shall not change more than 2°C/hr.; 0.5°C in Class VI waters (natural trout waters)	0–20
Dissolved Oxygen (mg/L)	≥ 5.0	Statewide: ≥ 5.0 as a 24 hour average; ≥ 4.0 at any time. Trout waters: ≥ 6.0 as a 24 hour average; ≥ 5.0 at any time	≥ 6.0
Nutrients (°C)	Shall not reduce aquatic habitat or cause biological integrity to fail to meet regional goals.	shall not result in eutrophication problem; Unionized ammonia ≤ 0.05	–
<i>E. coli</i> and fecal coliforms ²	Fecal coliform: shall not exceed a geometric mean of 200 per 100 mL.	<i>E. coli</i> : ≤ 126 colony forming units per 100 mL, as a geometric mean based on a minimum of 5 samples.	–

¹ Reference values are in BLRI Headwater Streams (Webb et al. 2001).

² NPS Reference Manual 83A (NPS 2018b) provides standards for recreational waters in the absence of state standards. The *E. coli* standard is ≤ 100 colony forming units per 100 mL, as a geometric mean based on a minimum of 5 weekly samples, or no more than 10% of samples exceeding 320 colony forming units per 100 mL.

In those cases where states have not promulgated specific water-quality standards for parameters that are important indicators of water resource condition, provisional standards will be utilized that are based upon recommended criteria available in scientific literature, historic data that document water quality at the time of legislative designation of individual parks, and data that are reliable indicators of reference (undisturbed) conditions (see Table 13). These provisional indicators are particularly useful in those cases where park waters are afforded Outstanding National Resource Water (ONRW) status, where waters are protected by anti-degradation regulatory provisions within the regulatory code of each respective state.

Appalachian Highlands Network established provisional conductivity criteria based on scientific literature. Black et al. (2013) found that the strongest performing habitat models incorporated categorized conductivity as an indicator variable for blackside dace, a sentinel threatened and endangered species of the Cumberland Plateau. After validation with independent data, it was apparent that blackside dace have an affinity for waters with conductivities less than 240 µS/cm,

above which this species and probably other sensitive species were eliminated. Bernhardt et al. (2012) reported mean conductivities of 64 μS in reference streams, 118 μS in unmined streams, and 626 μS in mined streams. These authors found biological impairment was likely to occur when surface coal mines exceeded 5.4% of their contributing watershed area, or when conductivity exceeded 308 μS , a value very close to the 300- μS benchmark value recently developed for Central Appalachian ecoregion streams by USEPA (2011).

Table 13. Target criteria for select water-quality indicators. Blue Ridge Parkway (BLRI), Big South Fork National River & Recreation Area (BISO), and Obed Wild and Scenic River (OBRI).

Parameter	Provisional Criteria BISO	Provisional Criteria OBRI	Provisional Criteria BLRI
Conductivity ($\mu\text{S}/\text{cm}$) ¹	200 in main stem Big South Fork (recommended sensitive species upper limit in literature): 100 in western tributaries	100 (reference conditions)	50 (reference conditions)
Turbidity (NTUs)	Narrative standard: "shall not be present in concentrations that harm aquatic life."	Narrative standard: "shall not be present in concentrations that harm aquatic life."	10 ²
Nutrients ³	NO ₃ + NO ₂ ≤ 0.27 mg/L Total P ≤ 0.02 mg/L (draft TDEC numerical standards for ecoregion 69d)	NO ₃ + NO ₂ ≤ 0.23 mg/L Total P ≤ 0.02 mg/L (draft TDEC numerical standards for ecoregion 68a)	Total N ≤ 0.31 mg/L Total P ≤ 0.01 mg/L (EPA guidance for VA ecoregion 11)

¹ Provisional conductance standard based upon values in undisturbed reference streams.

² North Carolina Department of Natural Resources (NCDNR) criteria for designated trout waters (North Carolina 15A NCAC 02B Surface Water-quality Standards. Updated June 30, 2016.).

³ Numerical standards for nutrients are under development in all states. Provisional values based upon draft numeric standards and EPA guidance (EPA 2016). Nutrient limits are subject to change.

An example report table with summary statistics is shown in Table 14. The primary audiences for annual data summary reports include park superintendents and resource managers, park staff, partners, and the general public, as appropriate. Reports will be produced during the first quarter of each year and will include the following.

Resource Briefs and Resource Report Cards

Aimed at park superintendents and other non-resource management staff, the resource briefs will be concise synopses of preliminary monitoring findings and management considerations. The briefs will be non-technical and will be illustrated with photos, graphs, and maps. An example water-quality resource report card is provided below in Table 15a. A minimum of one water-quality resource brief per park will be generated at the end of each calendar year during the months of November and December. Water quality resource briefs may combine findings indicated by both continuous and discrete water-quality monitoring efforts.

Water Resource Alerts

On occasion, field monitoring efforts through the discrete or continuous water-quality monitoring protocols may identify conditions of concern that merit additional action. On these occasions, park superintendents and resource management staff will be notified via email or other appropriate method of communication and will be briefed on the conditions of concern.

Trend/Synthesis Reports

Analyses and interpretation of water resource data will include a description of the status of park waters and will identify trends in water resource conditions over time. Status refers to a static description of water resource conditions at a given moment in time while trend reflects change over a period of time. Status description will be utilized to characterize water quality in relation to regulatory established numeric criteria for formally designated water use(s) at individual monitoring locations. Trend/Synthesis reports will be produced every six years.

Additionally, regional, park, or site-specific water-quality trends will be described and related to potential stressors to park water resources as indicated by physical and chemical water quality at individual discrete water-quality monitoring stations. Synoptic water-quality monitoring as described in this protocol is not intended to evaluate individual point source impacts to park water resources, but should be adequate to identify water resource stressors sufficient to support targeted investigations of individual land use or point source stressors that are outside of the scope of this monitoring protocol. Trend analyses will compare legacy data available from historical water resource monitoring with current conditions and will also describe ongoing trends in water resource integrity as monitoring continues in the future. Common analytical and statistical methods for assessing status and for evaluating trends in water resource conditions are described in SOP DWQ16.

Table 14. Example report table showing summary statistics for Water Years 2016 and 2017 (partial) for Level I monthly discrete water-quality sampling stations within the Obed Wild and Scenic River.

Season	Site	SpC ($\mu\text{S/cm}$)	ANC mg/L as CaCO_3	$\text{NO}_3 + \text{NO}_2$ mg/L	Total P mg/L	<i>E.coli</i> MPN/ 100 mL
Fall 2015	Obed at Adams	188–195	58.8–63.3	0.0160–3.190	0.127–0.143	25–66
	Daddys Creek	85–92	27.0–27.5	0.220–0.377	0.098–0.170	3–29
	Clear Creek at Lilly	59–62	13.0–15.9	< 0.001–0.028	0.152–0.171	3–4
Winter 2016	Obed at Adams	81–132	18.0–23.1	2.029–2.755	0.001–0.037	33–613
	Daddys Creek	64–67	15.4–24.2	0.908–1.321	< 0.001–0.008	17–48
	Clear Creek at Lilly	19–36	4.1–6.2	0.779–1.290	0.002–0.024	17–23
Spring 2016	Obed at Adams	82–133	23.0–29.0	0.566–2.020	0.001–0.002	9–18
	Daddys Creek	59–76	17.3–26.5	0.521–0.699	0.002–0.011	4–9
	Clear Creek at Lilly	31–60	6.3–9.5	< 0.001–1.832	< 0.001–0.005	2–5
Summer 2016	Obed at Adams	196–313	61.8–89.6	3.962–11.14	0.010–0.390	27–99
	Daddys Creek	137–262	37.2–43.0	0.521–1.321	0.001–0.002	17–35
	Clear Creek at Lilly	56–87	14.1–21.5	<0.001 – 0.170	<0.001–0.005	2–50

Table 15a. Example water-quality report card for use in annual reports and resource briefs.

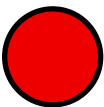
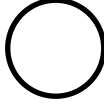
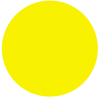
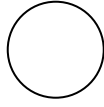
Location	Specific Measures	Condition	Explanation
Obed River at Adams Bridge (USGS # 03538830)	pH, temperature, dissolved oxygen, specific conductance, turbidity		Tennessee Department of Environment and Conservation 303(d)-listed for nutrient loading. Routinely exceeds recommended specific conductance associated with healthy aquatic systems. Diurnal pH fluctuation exceeds 1.0 unit per day frequently during low flow seasons.
Daddys Creek near Hebbertsburg (USGS # 03539600)	pH, temperature, dissolved oxygen, specific conductance, turbidity		Water-quality monitoring indicates generally good water quality. Data do indicate that Daddys Creek is affected to some extent by urban and suburban development in the Fairfield Glades community and surrounding areas.
Clear Creek at Lilly Bridge (USGS # 03539778)	pH, temperature, dissolved oxygen, specific conductance, turbidity		Water-quality monitoring at the Clear Creek at Lilly Bridge (03539778) Although not pristine, Clear Creek water quality approaches reference conditions for undisturbed watersheds on the Cumberland Plateau. An isolated week long sag in overnight dissolved oxygen concentrations was observed during late summer of 2013.

Table 15b. Legend for natural resource condition symbols.

Condition Status		Trend in Condition		Confidence in Assessment	
Condition Icon	Condition Icon Definition	Trend Icon	Trend Icon Definition	Confidence Icon	Confidence Icon Definition
	Resource is in Good Condition		Condition is Improving		High
	Resource warrants Moderate Concern		Condition is Unchanging		Medium
	Resource warrants Significant Concern		Condition is Deteriorating		Low

Conference Presentations

When possible, the protocol lead will present monitoring results at regional and national scientific conferences. Such presentations will allow the network to reach the broader scientific community, as well as land managers and conservation practitioners.

Other Articles and Presentations

We may also take advantage of additional opportunities to present our findings as they arise. For example, we may publish articles about our work in park newspapers, which are aimed at a public audience. Field season summaries will appear in the network's newsletter each fall, reaching a mixed audience of both park staff and the general public. Oral presentations at parks may include those to the public, at seasonal orientations, or at staff brown bag lunches.

Personnel and Training Requirements

This protocol relies primarily on network staff to conduct all aspects of discrete water-quality monitoring including field measurements, sample collection, data management, data analysis, and reporting. Although network staff will be primarily responsible for all work elements related to discrete water-quality monitoring, we will take advantage of opportunities to work with park staff or watershed partners should they have an interest in assisting with protocol tasks. See Operational Cost, below, for estimated annual operating costs for this protocol (based on FY 2015 costs). Staff personnel that will implement this protocol currently comprise the network hydrologist (the protocol lead), data manager, and a hydrologic intern. The protocol lead has responsibility for all aspects of the discrete water-quality monitoring protocol. The data manager provides quality control, ensures data are properly archived, and assists with developing queries and providing data summaries. The hydrologic intern's main responsibilities include assisting with field data collection, data management, and operation and maintenance of equipment. Roles and responsibilities for program personnel are summarized below.

Personnel and Qualifications

Protocol Lead

The protocol lead coordinates all aspects of the discrete water-quality monitoring protocol, including protocol design, implementation, data analysis, and reporting. The protocol lead applies principles of aquatic ecology and hydrology to the design of the project and to the interpretation of results. The person in this position is responsible for ensuring the collection of high-quality data and interpretation of findings in relation to established assessment criteria, regulatory requirements, and management targets. The protocol lead will routinely be required to perform statistical tests and analyses, and to communicate and interact effectively with a wide variety of audiences, in both technical and non-technical language. The position may require preparation of complex memoranda, reports, briefings, and peer-reviewed scientific papers. The protocol lead may provide supervision for interns and/or partners working on the project, and ensures that Network equipment is maintained in good working order.

Data Manager

The data manager has a central role in ensuring that project data management conforms to I&M program standards, that data are of high quality, and that project data can be retrieved and disseminated in useful formats. The data manager collaborates with the protocol lead to develop data entry forms, QA/QC procedures, and automated reports. The data manager maintains spatial data themes associated with discrete water-quality monitoring and is responsible for incorporating and disseminating water resource and GIS data to network parks and partners. The data manager is responsible for documenting the network's data management procedures, including roles and responsibilities, work flows, and guidance in the use of databases and data management tools. The data manager also provides coordination and oversight for the population and maintenance of all APHN data that is input into national information management systems (e.g., NPStoret).

Hydrologic Intern

The hydrologic intern assists with field operations as well as a variety of data management tasks, including data entry and quality control, data formatting, and data retrieval. The position also assists in the preparation of graphs, charts and maps for use in monitoring reports. The hydrologic intern is also responsible for providing technical support to NPS staff and external agency partners who are collaborating on protocol implementation. On these occasions, the position may be responsible for planning, overseeing, and safely carrying out logistics involving a field team. The hydrologic intern position requires a basic background in water-quality monitoring and in the use and maintenance of water-quality monitoring equipment, particularly water-quality field meters, and acoustic doppler (Sontek Flowtracker) and vertical pivot (Pygmy/Price AA) flow meters.

A summary of the staff requirements is provided in Table 16.

Table 16. Primary duties of network staff for discrete water-quality monitoring.

Position	Primary Duties
Protocol Lead	Provides guidance, oversight, and management of discrete water-quality monitoring. Conducts data analyses, summaries and reports, data validation and verification. Works with program professionals to provide information to parks and partners in useful formats. Provides supervision of interns and partners working on the project.
Data Manager	Provides direction and oversight for data management activities. Conducts data archiving and dissemination, development of queries and summaries, and overall QA/QC for continuous water-quality monitoring. Works with the Protocol Lead to ensure data are provided to parks and partners in useful formats. Implements data management partnerships.
Hydrologic Intern	Works with protocol lead to collect field data, conduct basic maintenance, and document methods, procedures and anomalies. Conducts data entry and verification. Assists in the preparation of maps, charts and graphs.

Training

Training in safety, field techniques, and data handling procedures required to implement this protocol will be the responsibility of the protocol lead and will be conducted by the protocol lead, the hydrologic intern, or an appropriately trained alternate. Training will include briefings on safe practices while conducting field operations and principles of Operational Leadership; an overview of the network's water-quality monitoring program; and a thorough orientation to field procedures, Network monitoring equipment, and principles of data collection and data handling. Training will be required for each person before participating in field sampling or, alternately, untrained personnel may assist in the presence of trained personnel. Adequate staff will be required to provide a safe

working environment, and provide consistency in sample quality. Field crews should be encouraged to take as much time as necessary to provide quality results, and be flexible when issues arise in the field that require additional time to resolve. Details on safe practices and required training are provided in SOP DWQ01 *Safety* (APHN 2018n), SOP DWQ02 *Job Hazard Analysis* (APHN 2018o) and SOP DWQ14 *Training Field Personnel* (APHN 2018p).

The protocol lead will seek out opportunities for technical training that may be beneficial for network personnel, including training in data collection techniques, equipment operation and maintenance, data handling, and data analysis. Courses covering these topics may be offered by equipment manufacturers, private consultants, or government agencies, including the NPS and USGS Water Resources Divisions. When formal training sessions are organized, these sessions will be open for park resource staff and cooperating partners, if possible.

Required Formal Training

To provide a sound foundation in sampling techniques, the following USGS field training courses (or their equivalent) are required for the protocol lead:

- USGS QW 1028: Field Water-Quality Methods for Groundwater and Surface Water
- USGS SW 1286: Introduction to Surface Water Records Computation
- USGS SW 2298: Standard Procedures for Continuous Water-Quality Monitors

Operational Requirements

Annual Workload

The implementation schedule for this protocol is provided in Table 17.

Water quality field data and water samples are collected year-round on a monthly (where co-located with a USGS gage) or quarterly basis. The approximate sampling schedule for field personnel is summarized in Table 18. After field data are collected, samples are processed in-house for ANC and bacteria, and delivered to a contract lab for further analysis. Field and lab data are validated, entered into the APHN NPStoret database, and verified. These data are then batch-uploaded to NPStoret on a quarterly basis. Data summaries and annual reports are prepared each winter by the protocol lead and distributed to APHN parks, upon approval by the network program manager. An internal review of protocol procedures is conducted each winter and needed changes are implemented.

The data manager assists the protocol lead with data verification, preparation of metadata files, and updating metadata in the NPS Data Store. The data manager also assists with batch-uploading data to NPStoret, developing automated reports and data summaries, and preparing GIS layers for use in annual monitoring reports.

Table 17. Schedule of tasks associated with water-quality monitoring using discrete sampling.

Project Stage	Task Description	Responsibility	Status/Schedule
Data Collection	Data collected for field parameters (temp, dissolved oxygen (DO), pH, conductivity, turbidity, flow)	Protocol Lead/APHN staff	Monthly/Quarterly
	Samples analyzed in the APHN lab for E. coli, fecal coliform and ANC	Protocol Lead/APHN staff	Same day as field data collection
	Samples collected for lab analysis are labeled w/sample ID number, refrigerated and shipped	Protocol Lead/APHN staff	Coincident with field data collection
Data Management	Datasheets scanned	Protocol Lead/APHN staff	Same day as field data collection
	Field data validated and entered into APHN NPStoret, along w/ ID numbers for lab samples	Protocol Lead/APHN staff	Within one week of sample collection
	Conduct quality review and 100% data verification	Protocol Lead/APHN staff	Within one week of sample collection
	Upon receipt, lab data are uploaded to APHN NPStoret. Validate and verify within APHN NPStoret.	Protocol Lead/APHN staff	Within three months of sample collection
	Upload QA/QC'd data to APHN NPStoret QA/QC'd field and laboratory data uploaded to WRD NPStoret.	Data Manager	Quarterly

Table 17 (continued). Schedule of tasks associated with water-quality monitoring using discrete sampling.

Project Stage	Task Description	Responsibility	Status/Schedule
Data Analysis and Reporting	Prepare graphics and data summaries	Protocol Lead/Data Manager	Nov–Dec
	Submit draft briefings and reports to Program Manager for review	Protocol Lead	Jan–Feb
	Submit reports to Parks	Program Manager	March
Posting and Distribution	Upload APHN data to WASO NPStoret	Data Manager	Quarterly
	Upload completed reports to IRMA Data Store and Network website	Data Manager	March
	Archive completed reports on APHN shared drive	Data Manager	March
Project Review	Meet to discuss the recent field season; document needed changes to the protocol	Program Mgr/Protocol Lead/Data Manager	Jan–Feb

Table 18. Approximate annual water quality sampling schedule (values are number of sites sampled). Blue Ridge Parkway (BLRI), Big South Fork National River & Recreation Area (BISO), and Obed Wild and Scenic River (OBRI).

Month	BISO Monthly	BISO Quarterly	BLRI Quarterly	OBRI Monthly	OBRI Quarterly	TOTAL
January	3	8 fixed, 4 rotating	–	3	–	18
February	3	–	–	3	6 fixed, 3-4 rotating	15-16
March	3	–	14 fixed, 6 rotating	3	–	26
April	3	8 fixed, 4 rotating	–	3	–	18
May	3	–	–	3	6 fixed, 3-4 rotating	15-16
June	3	–	14 fixed, 6 rotating	3	–	26
July	3	8 fixed, 4 rotating	–	3	–	18
August	3	–	–	3	6 fixed, 3-4 rotating	15-16
September	3	–	14 fixed, 6 rotating	3	–	26
October	3	8 fixed, 4 rotating	–	3	–	18

¹Laboratory conducts QA/QC analyses at no cost in accordance with bulk contract.

Table 18 (continued). Approximate annual water quality sampling schedule (values are number of sites sampled). Blue Ridge Parkway (BLRI), Big South Fork National River & Recreation Area (BISO), and Obed Wild and Scenic River (OBRI).

Month	BISO Monthly	BISO Quarterly	BLRI Quarterly	OBRI Monthly	OBRI Quarterly	TOTAL
November	3	–	–	3	6 fixed, 3-4 rotating	15-16
December	3	–	14 fixed, 6 rotating	3	–	26
ANNUAL TOTAL	–	–	–	–	–	236-240
1QA/QC	(4 blanks, 24 replicates)	–	–	–	–	28

¹Laboratory conducts QA/QC analyses at no cost in accordance with bulk contract.

Permitting Requirements

No installation of infrastructure is required for this protocol. No NPS or other federal or state permits are required for implementation of discrete water-quality monitoring by the Network.

Facilities and Equipment

One vehicle, stored at Big South Fork NRRRA, is assigned to the protocol lead, and is used for field sampling and travel necessary to implement the protocol. A second vehicle, kept at Blue Ridge Parkway, is used for field sampling on the parkway. Principal equipment employed for this protocol includes three YSI 556 multi-parameter water-quality meters, four Oakton pH meters used for ANC titrations, two portable flow meters used for discharge measurements, a USGS Type A bridge crane and a D-95 water sampler for equal-width increment sampling at large river sites, and (two each) sealers and incubators used for in-house bacteriological analysis. Detailed equipment lists can be found in SOPs DWQ03, DWQ07, DWQ08, DWQ11, and DWQ012. A wet lab is available for network purposes at Big South Fork NRRRA, which is used for storage, calibration and maintenance of water-quality sampling equipment. Field samples are processed in the wet lab (ANC and bacteria measurements) and refrigerated while awaiting shipment to a contracted lab for further analysis. Startup costs are listed in Table 19.

Table 19. Startup costs for protocol implementation.

Category	Equipment	Quantity	Costs	Unit	Extended
Field Meters and accessories	YSI 556 MultiMeter w/ barometer, PC cable, and soft-sided case	2	\$1,776	ea.	\$3,552
	4 meter cable W/ Oxygen/conductivity/temperature standard	2	\$846	ea.	\$1,692
	ph/ORP sensor	2	\$276	ea.	\$552
	Rechargeable battery pack kit	2	\$290	ea.	\$580
	spare sensor oxygen	2	\$138	ea.	\$276
	spare sensor pH	2	\$276	ea.	\$552
	SubTotal	—	—	—	\$7,204
ANC Titrations	Dedicated Oakton pH meter for ANC	2	\$458	ea.	\$916
	Spare pH sensors	2	\$96	ea.	\$192
	Micro Burette Titrator battery operated	2	\$820	ea.	\$1,640
	Sulfuric Acid (0.02 N) 2 liters	2	\$25	ea.	\$50
	Bottle-Safety PVC coated amber Type 3 glass (500 mL	4	\$25	ea.	\$100
	SubTotal	—	—	—	\$2,898
Idexx Colilert Bacteriological	Colilert vessels, reagents, and quantitrays (6 month supply)	2	\$1,500	ea.	\$3,000
	Quantitray sealers	2	\$1,600	ea.	\$3,200
	Incubators	2	\$700	ea.	\$1,400
	Viewing cabinets and UV lamps	2	\$450	ea.	\$900
	SubTotal	—	—	—	\$8,500
Stream Discharge Measurement	Sontek Flowtracker, wading rod, and accessories	1	\$10,250	ea.	\$10,250
Water Sampling Equipment	USGS DH-84 sample bottles	32	\$65	ea.	\$2,080
	DH-81A samplers and adaptors	4	\$100	ea.	\$400
	Millipore filters and syringes	—	—	—	\$1,300
	Subtotal	—	—	—	\$3,780
Total	Total Startup Costs	—	—	—	\$32,632

Operational Costs

Operational costs include 40% (0.4 FTE) of the protocol lead's time dedicated to protocol-related activities. Table 20 summarizes annual operational costs for personnel, lab analysis, equipment and supplies.

Table 20. Approximate annual operating costs (based on FY 2015 dollars) for implementation of the APHN Discrete Water Quality Monitoring Protocol.

Category	Sub-category	FY15 low	FY15 high	Notes
Personnel	Protocol Lead	17,250	34,500	0.2/0.4 FTE, GS-11
	Data Manager	9,700	9,700	0.1 FTE, GS-11
	Hydrologic Intern	8,900	–	0.2 FTE
	SubTotal	35,850	44,200	–
Equipment/ Supplies	Reagents/Calibration Standards	2,000	3,000	–
	Meter/Sensor Repairs	1,500	2,000	–
	Meter Replacements Due to Age/Loss ¹	2,000	2,000	–
	SubTotal	5,500	7,000	–
Laboratory Analysis	236–240 samples @ bulk contract rate ²	20,000	20,000	–
	SubTotal	20,000	20,000	–
Totals	–	61,350	71,200	–

¹ Based on an assumption that one field meter would be replaced every two years

² Laboratory conducts QA/QC analyses at no cost in accordance with bulk contract.

Safety

Procedures to mitigate risks associated with specific activities related to protocol implementation are presented in SOP DWQ01 (Laboratory and Field Safety). Additionally, SOP DWQ02 (Job Hazard Analyses [JHA]), provides hazard analyses for individual tasks associated with the APHN long-term water-quality monitoring protocol for discrete sampling, which describes these risks and mitigation strategies in detail. The most significant concerns associated with this activity include:

- Injury while in transit to field sites. Crew members will spend many hours driving to, between, and back from sampling stations.
- Injury while out of communication range. Crew members will be regularly working in park areas outside of communications range (either by park radio or by cell phone).

Mitigation measures to deal with both of these situations, as well as a number of other protocol-related risks, are found in the JHA. Based on the JHA and associated risk mitigation measures, it was determined that this protocol can be safely carried out provided that staff implement it in accordance

with the referenced SOPs. In addition to standard operating procedures that have been developed to safely implement this protocol, specific training needs for all staff have been identified and are described in SOP DWQ14.

Safety procedures will be reviewed with network staff, volunteers, and partners before each field season, and weekly tailgate sessions will be held to reinforce these procedures during the field season. Safety SOPs are reviewed at least annually and updated as necessary to ensure that they adequately mitigate risks to personnel, property, and the public. Any park staff or volunteers working with the project will be required to review the safety procedures (or a summary of them) and sign off that they have read them. They will also be provided an opportunity to ask questions about safety risks and procedures prior to field work.

In addition to protocol-specific safety procedures and guidelines, APHN staff will follow the general guidelines set forth in the NPS Occupational Safety and Health Program (Director's Order 50B, September 2008). These procedures are outlined below.

- Adhere to established occupational safety and health procedures, including those contained within Director's Order 50B.
- Work collaboratively with supervisors to develop and use JHAs or equivalent for all routine tasks, and help develop and use site-specific safety plans for non-routine, complex, multi-phase jobs.
- Properly use and maintain required clothing and/or personal protective equipment.
- Maintain a level of personal wellness and fitness as needed for assigned work tasks.
- Identify and, where appropriate, correct unsafe conditions and work practices.
- Report unsafe/unhealthful conditions and/or operations to the immediate supervisor or the appropriate chain of command.
- Report mishaps, including minor accidents and "near-misses," to a supervisor as soon as possible.
- Participate in establishing a safe working culture, and practice safe work procedures, especially when working alone.

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