



# Long-Term Continuous Water-Quality Monitoring at Big South Fork National River and Recreation Area and Obed Wild and Scenic River

## *Protocol Narrative*

Natural Resource Report NPS/APHN/NRR—2018/1722



**ON THE COVER**

Historic USGS stilling tower and gage infrastructure on right bank of Clear Fork near Robbins, Tennessee, in the Big South Fork NRRRA. The National Park Service has established a continuous water quality monitoring station that is co-located with USGS streamflow gage number 03409500 at this location.

NPS photo / James Hughes, Appalachian Highlands Network

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## Executive Summary

This protocol describes the background, rationale, and sampling design for monitoring water quality using continuous sampling at two Appalachian Highlands Inventory and Monitoring Network (APHN) parks: Big South Fork National River and Recreation Area (BISO), and Obed Wild and Scenic River (OBRI). The main goals of this document are: (1) to outline an overall strategy for time series water-quality monitoring that is credible and scientifically rigorous, and (2) 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 protocol 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 NRR and Obed WSR. A case is made for the relevancy 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 five core water-quality parameters (dissolved oxygen, conductivity, temperature, pH and turbidity) at selected index sites using fixed station continuous data loggers at Big South Fork NRR and Obed WSR. Continuous water-quality monitors (YSI 6920 datasondes) are deployed year-round at five U.S. Geological Survey (USGS) streamflow gauges located in the parks' major streams, upstream of their most sensitive aquatic resources. Water-quality parameters are measured at 30-minute intervals, allowing for eventual determination of trends at daily, monthly, seasonal and annual time scales. Water-quality data is broadcast to the USGS National Water Information System (NWIS) available on the Internet in near real-time, providing park managers, partners and the public with early warning of upstream disturbances, which enables APHN staff to conduct repairs efficiently, to avoid long disruptions in the data record.

Data collected using this protocol will be stored in NWIS and analyzed using Aquarius software. Two primary emphases of the National Park Service (NPS) Inventory and Monitoring Program are to ensure that results and knowledge obtained from monitoring are communicated in a timely manner and to maximize understanding in order to best meet park needs. Where appropriate, monitoring results are shared as broadly as possible with park partners, NPS staff, and the public. Water-quality status is summarized in annual reports and resource briefs at the end of each calendar year. Longer-term trends and synthesis reports are 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.



## Background and Objectives

In 1999, the National Park Service (NPS) Inventory and Monitoring (I&M) Program initiated a long-term ecological monitoring program known as Vital Signs Monitoring. Its design provided 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 Inventory and Monitoring Network (APHN) is one of 32 networks formed to implement this integrated monitoring program, 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 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 Protocol for Monitoring Water Quality Using Time Series Data (Continuous Sampling) in the Appalachian Highlands Network**

Water quality is important to numerous park resources, as well as to visitor experience. Therefore, water quality was selected as one of the 12 core NPS natural resource inventories for which baseline data were collected system-wide in the earliest phases of the newly established inventory and monitoring program. Information from this baseline water resource inventory 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 APHN parks during these scoping meetings.

To identify and prioritize issues of concern related to water quality, we began the vital signs planning process by soliciting information from APHN parks' management (through questionnaires and

meetings), asking managers to rank the importance of the different water resources in their parks and to identify potential concerns a monitoring program might address.

Managers at each park developed a list of the issues and monitoring questions of greatest concern. In summary form, these questions included the following (those questions that relate directly to continuous or time-series monitoring are marked by an asterisk; relational (cause and effect) monitoring is beyond the scope of this protocol):

- How are upstream or adjacent disturbances, particularly coal mining, oil and gas extraction, logging, municipal development (all related to Big South Fork National River and Recreation Area and Obed Wild and Scenic River), 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 U. S. Environmental Protection Agency (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 affecting significant aquatic biological resources in the parks (all parks)?\*
- What is the affect 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, staff from the network, the park, and U. S. Geological Survey (USGS) Water Resources Division, conducted a series of meetings and discussions to establish monitoring objectives. They also developed a sampling design for long-term water-quality monitoring at Big South Fork National River and Recreation Area (BISO), Blue Ridge Parkway (BLRI), and Obed Wild and Scenic River (OBRI). The USGS was retained by the 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 ongoing monitoring programs 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 APHN parks, we examined these closely with respect to the resources we anticipated being able to devote to long-term monitoring. These initial discussions focused on discrete water-quality sampling, but during the protocol-testing phase we incorporated continuous sampling techniques in our sampling design.

This protocol describes the background, rationale, and sampling design for monitoring water quality using continuous data at two APHN parks: Big South Fork National River and Recreation Area, and Obed Wild and Scenic River. This water resource monitoring protocol builds on previous NPS efforts from 1982 to 1988, when water-quality monitoring at Big South Fork NRR and Obed WSR was conducted by park staff (Rikard et al. 1986). Monitoring was discontinued due to funding and operational constraints at that time, but the “legacy” data provide a valuable benchmark for comparison with more recent and future monitoring efforts.

Under this protocol, monitoring data are collected using datasondes that are deployed year-round. Measurements of dissolved oxygen, pH, temperature, conductivity, and turbidity are taken at 30-minute intervals. These time series data are broadcast to a USGS-hosted webpage, enabling remote monitoring of daily, seasonal, and event-driven fluctuations in real time. This configuration of instruments allows short-term pollution events to be communicated to park management in a timely manner, reduces safety risks to personnel because storm events can be monitored remotely, and allows APHN staff to detect instrument fouling or sensor failure in near real time, reducing the number and cost of maintenance trips and decreasing interruptions in the data record.

The main goals of this document are: (1) to outline an overall strategy for continuous water-quality monitoring that is credible and scientifically rigorous, and (2) 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 in the future. The structure of this protocol follows the recommended framework and suggestions of Oakley et al. (2003). This document also describes important aquatic resources within the affected parks, as well as briefly summarizing characteristics of geology, soils, climate and hydrology that must be taken into account when monitoring water quality in this area. A case is made for the relevancy 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 warnings of changing conditions or issues of concern in the future.

The network's overall water-quality monitoring strategy also includes discrete sampling at fixed stations in APHN parks. The rationale and design for this monitoring is covered in a separate protocol.

### **Environmental Setting and Overview of Water Resources**

The Cumberland Plateau, extending 450 miles (724 kilometers [km]) from southern West Virginia to northeastern Alabama, is an extensive tableland of sandstone and shale, carved by water into a labyrinth of rocky ridges and deep gorges. According to The Nature Conservancy (TNC 2003), 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 in elevation and is referred to locally 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 lines of cliffs. Some gorge sections are quite narrow—only 800 feet (244 meters [m]) across, with nearly vertical walls up to 400 feet (122 m) high. Average elevations on the Cumberland Plateau are typically 1,200 to 2,000 feet (366 to 610 m) above sea level, equaling or exceeding those of the highest ridges of the adjacent Valley and Ridge province, but substantially lower than the high peaks of the Blue Ridge Mountains to the east (NPS 1994; NPS 1999).

The region's climate is warm and humid, with temperatures reaching or exceeding 90°F (32°C) about 75 days per year. Winter temperatures seldom drop below -5°F (-21°C). The frost-free season lasts about 180 days, from late April to late October. The Cumberland Plateau receives about 52 inches (132 centimeters) of precipitation annually (NPS 1997; NPS 1998).

### ***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 formed from sediments that were transported westward from the ancestral Appalachian Mountains into the inland sea that covered much of the North American continent during the Mississippian (360–320 million years ago) and Pennsylvanian (320–296 million years ago) 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.

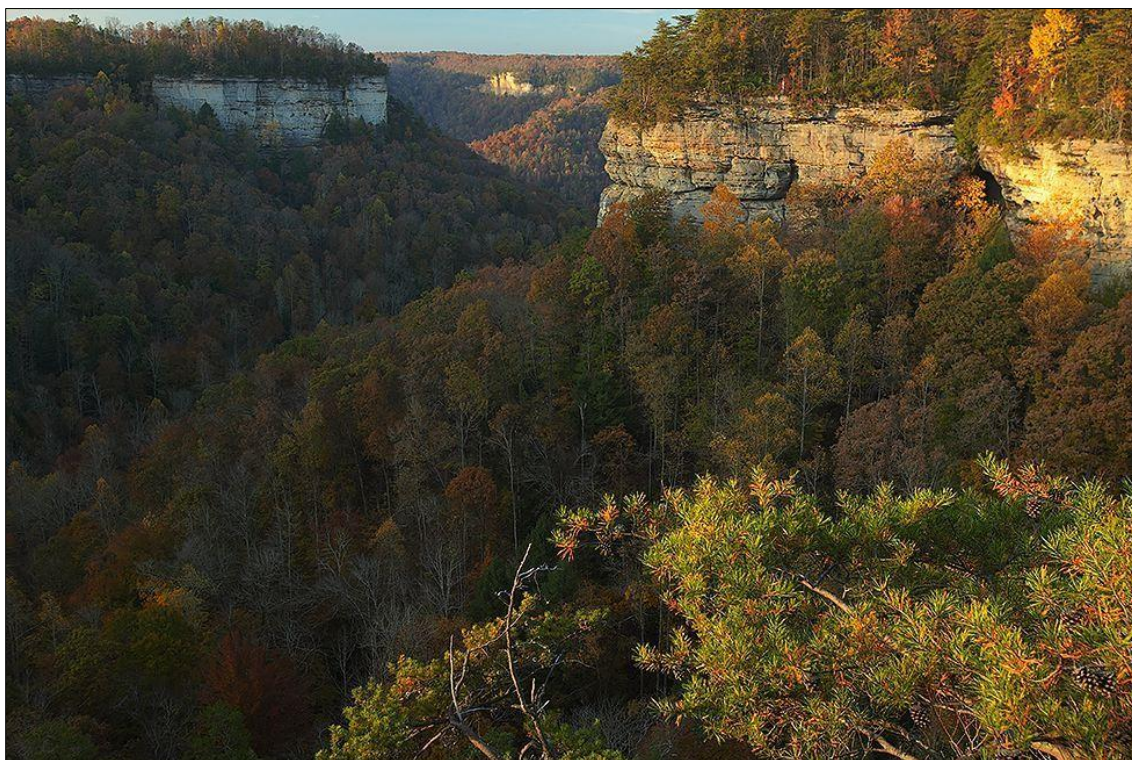


**Figure 1.** Rockcastle conglomerate sandstone outcrop flanking dissected stream valley on the Cumberland Plateau near the Big South Fork National River and Recreation Area.

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 and 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 supports greater plant life, so areas with rich, black topsoil—like coves—support a more diverse vegetative community than the exposed ridge tops that flank much of the main river reaches at Big South Fork NRR and Obed WSR. These thin-soiled ridge tops support only the hardiest of plants, and such sparsely vegetated communities do not retain water or nutrients effectively during storms.

### **Water Resources**

The Big South Fork of the Cumberland River (Figure 2), a tributary to the Cumberland River, is the largest free-flowing river that lies entirely within the Cumberland Plateau. The Big South Fork watershed drains approximately 716,800 acres (290,079 hectares [ha]) in seven counties of Tennessee and Kentucky. Approximately 14 percent of that drainage area lies within the boundaries of the Big South Fork NRR. Water resources within the park include approximately 72 miles (116 km) of small- to medium-sized streams, including the Big South Fork proper and its two major tributaries, Clear Fork and New River. In addition, there are hundreds of miles of smaller tributary and low-order headwater streams within the park's 125,000 acres (50,586 ha). Although waters in most of the park are unaffected by impoundment, approximately 15 miles (24 km) of the Big South Fork and its tributaries 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.

The Obed Wild and Scenic River park unit contains the Obed River (Figure 3), a major drainage in the upper Tennessee River system. The Obed river proper and its Daddys Creek and Clear Creek tributaries are free-flowing within the OBRI park boundaries, but are affected to some extent by small ponds and water supply and recreational impoundments in the headwaters upstream of the park. The Obed River is the only Wild and Scenic River in Tennessee and is one of 203 Wild and Scenic Rivers nationally, only two of which are located in the Southeast. Obed WSR encompasses 5,057 acres (2,046 ha) in Morgan and Cumberland Counties primarily surrounding 45.2 miles (72.7 km) of stream corridors of the Obed and Emory Rivers and of the Daddys Creek and Clear Creek tributaries to the Obed River. The park watershed area is approximately 393,599 acres (159,284 ha). A significant portion (82,000 acres [33,184 ha]) of lands within and adjacent to the Obed Wild and Scenic River include state-owned lands of the Tennessee Wildlife Resources Agency (TWRA) and Catoosa Wildlife Management Area (WMA). The Catoosa WMA is sustainably managed by TWRA, providing an important natural resource buffer for the Obed WSR corridor.

Protection of water quality in these parks is a considerable challenge, since the parks' land bases are relatively small compared to their watersheds, and many effects occur outside park boundaries. Major water-quality and quantity issues for both parks revolve around contaminated drainage from abandoned mines; contaminants and siltation, including coal fines (particulate material weathered from coal), associated with current mining operations (including oil and gas extraction); water

withdrawals for municipal and industrial use; and erosion-related sedimentation associated with development within and outside the parks. Nevertheless, some of the most pristine streams remaining on the Cumberland Plateau are in Big South Fork NRA and Obed WSR, reflected by Outstanding National Resource Water designations in both parks (Figures 5 and 6).

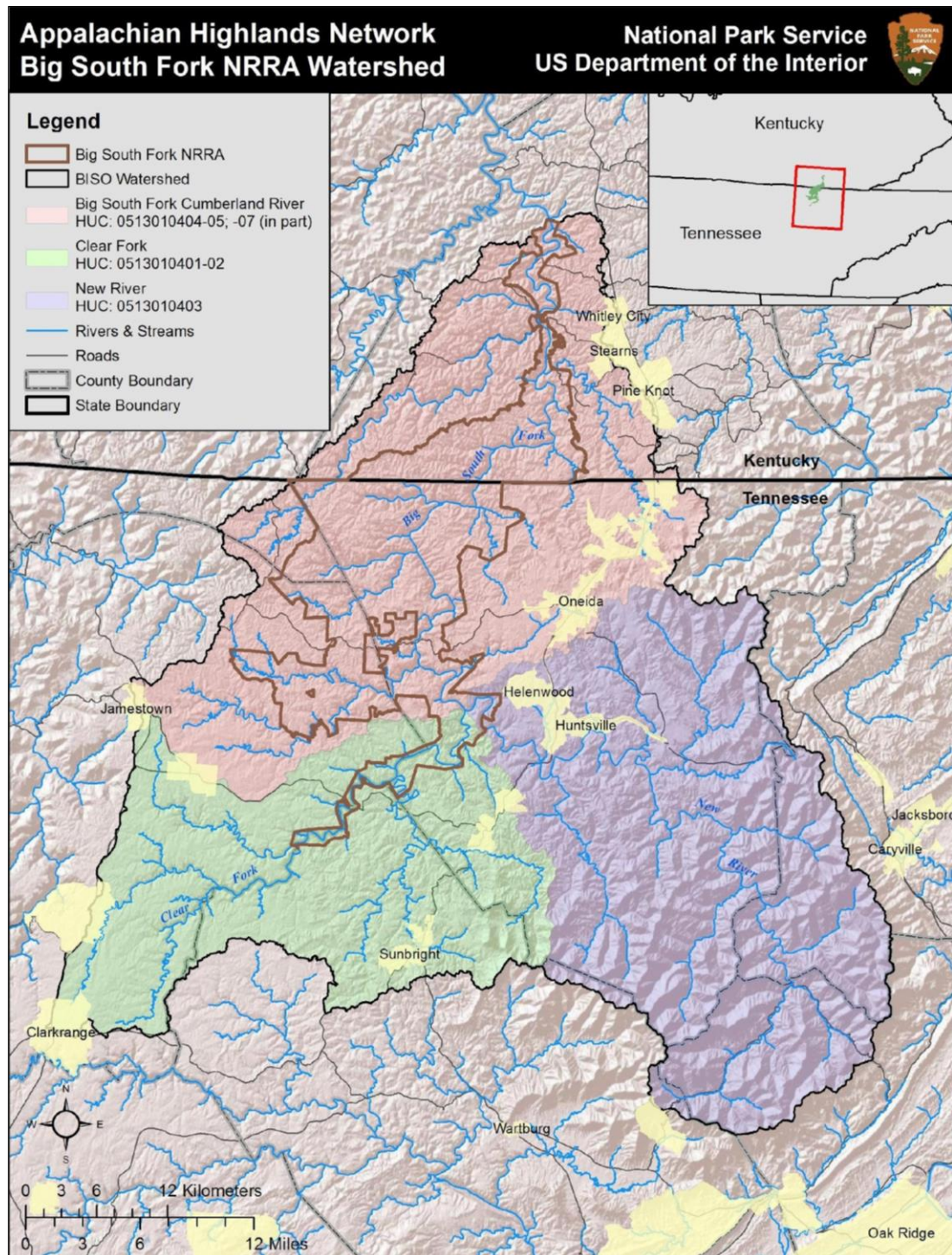


**Figure 2.** The Big South Fork National River and Recreation Area watershed, major sub-watersheds, and surrounding municipal areas.

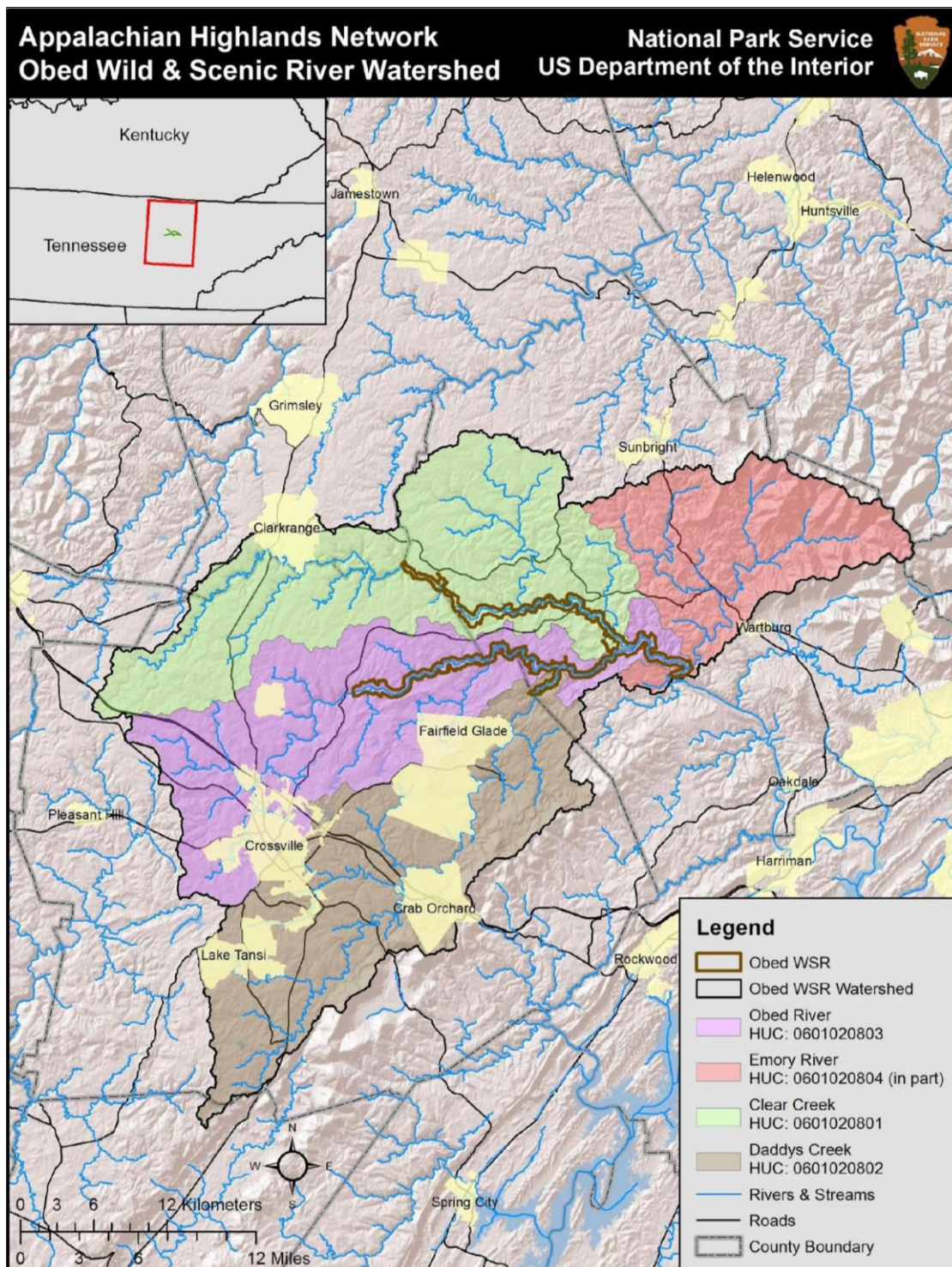


**Figure 3.** The Obed Wild and Scenic River watershed, major sub-watersheds, and surrounding municipal areas.

### Streamflow

Streamflow patterns are determined by rainfall and runoff patterns, groundwater recharge, and flow alterations occurring in the watershed. Cumberland Plateau streams have their highest flows during the winter and spring, with low-flow periods normally occurring in summer and early autumn, when tributaries and upper river reaches can resemble intermittent streams. Thin soils atop low-permeability sandstones and shales of the plateau inhibit infiltration of rainfall and promote direct overland runoff. Appreciable groundwater resources are generally limited to isolated fracture zones associated with minor faulting and with stress relief at the flanks of mountains and near canyon walls. As a consequence, stream systems on the Cumberland Plateau are characterized by rapid surface runoff and little groundwater storage, creating a wide range of flows, from violent, high-volume flash floods to extreme low-water conditions (NPS 1997; NPS 1998). For example, streamflows at the Obed River near Lancing, Tennessee gauge (USGS #035539800), at Alley Ford inside park waters, have been measured from nearly 0 cubic feet per second (cfs) (0 liters per second [L/s]) to more than 100,000 cubic feet per second (2.83 million L/s) since the gauge was established in 1957. At the Big South Fork at Leatherwood Ford gauge (USGS #03410210), streamflows have been measured as low as 2.7 cfs (76) L/s to 67,000 cfs (1.90 million L/s) and have likely exceeded peak flows at the Obed near Lancing gauge prior to establishment of the Leatherwood Ford gauge in 1985. Aquatic ecosystems within the parks are adapted to and dependent on this natural, widely fluctuating flow regime.

### Water Chemistry

Under undisturbed conditions, water chemistry in the Cumberland Plateau parks ranges from extremely dilute, soft water (Total Dissolved Solids [TDS] < 50 milligrams/liter [mg/l]) in the headwater drainages to moderately soft water (TDS 60 – 120 mg/l) in the larger streams. In general, streams in the western portion of the BISO watershed are less disturbed than streams in the eastern and southern portions of the watershed, which have been subjected to more frequent and severe effects related to coal mining, forestry, 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 affected reaches, primarily due to municipal discharges, agricultural and commercial forestry operations, and coal mining (NPS 1998). Water chemistry of streams in both parks fluctuates seasonally, particularly in measures including pH, dissolved oxygen, iron, aluminum, sulfate, suspended solids, turbidity and conductivity (O'Bara et al. 1982).

Aquatic chemistry varies significantly depending on the geologic parent material underlying the watersheds. Sandstone-influenced streams are more susceptible to acid contamination because of their very low alkalinity and low buffering capacity. Limestone-influenced streams are more resilient to acidification. Surface waters exhibit moderately acidic to circumneutral pH (6.0 to 7.5) and are typically poorly buffered where draining Pennsylvanian aged sandstones and shales. Larger, incised streams, which have breached geologic contacts to expose older Mississippian aged limestone formations may exhibit somewhat higher pH and buffering, as will streams that are influenced by land use activities and municipal development that have altered background conditions. This lack of buffering capacity renders park waters highly susceptible to degradation by acidic input, such as the

acid mine drainage that has already adversely affected many streams on the Cumberland Plateau, especially at Big South Fork (NPS 1997).

## **Park Water Quality Issues and Rationale for Monitoring**

### ***Big South Fork National River and Recreation Area***

Big South Fork NRRA waters are located in the downstream portion of a large (1,120 square mile [290,079 ha]) watershed so the health of its aquatic systems depends to a large degree on external factors. Some of the streams within Big South Fork NRRA are severely polluted, yet the park also contains some of the most biologically diverse and pristine waters on the Cumberland Plateau.

The main threats to the quality of BISO park waters relate 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), as well as potential negative effects from impoundments and water withdrawal by municipalities and agricultural operations.

### **Coal Mining**

Most historical coal mining in Tennessee occurred within the Big South Fork drainage (Figure 4). Big South Fork NRRA has more abandoned coal mines and associated acid mine drainage within its boundaries than any other National Park System unit nationwide (NPS 1997). Big South Fork NRRA is also at risk from water-quality effects associated with coal mines outside its boundaries. The New River, the largest tributary to the Big South Fork, drains a basin that supplied more than half of Tennessee's coal during the 1970s. Forty years later, the effects of this mining activity are still evident in large deposits of coal fines on the riverbed and banks, and acid mine drainage seeping out of once clear-flowing streams. Most of this area was mined prior to 1977, when the Surface Mining Control and Reclamation Act (SMCRA) required reclamation of mine sites. There are approximately 25,100 acres (10,158 ha) of un-reclaimed abandoned 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 zinc, aluminum, iron, and manganese. There are approximately 100 abandoned deep coal mine openings and associated spoil piles inside BISO boundaries, and future coal mining within the park is possible on the 18,900 acres (7,649 ha) where mineral rights have been retained by private owners (NPS 1997; NPS 2012). Even without future mining activity, water quality of the Big South Fork proper is characterized by twice the amount of dissolved and suspended solids and two and a half times the sulfate yield of a similar river basin without mining (NPS 2005).

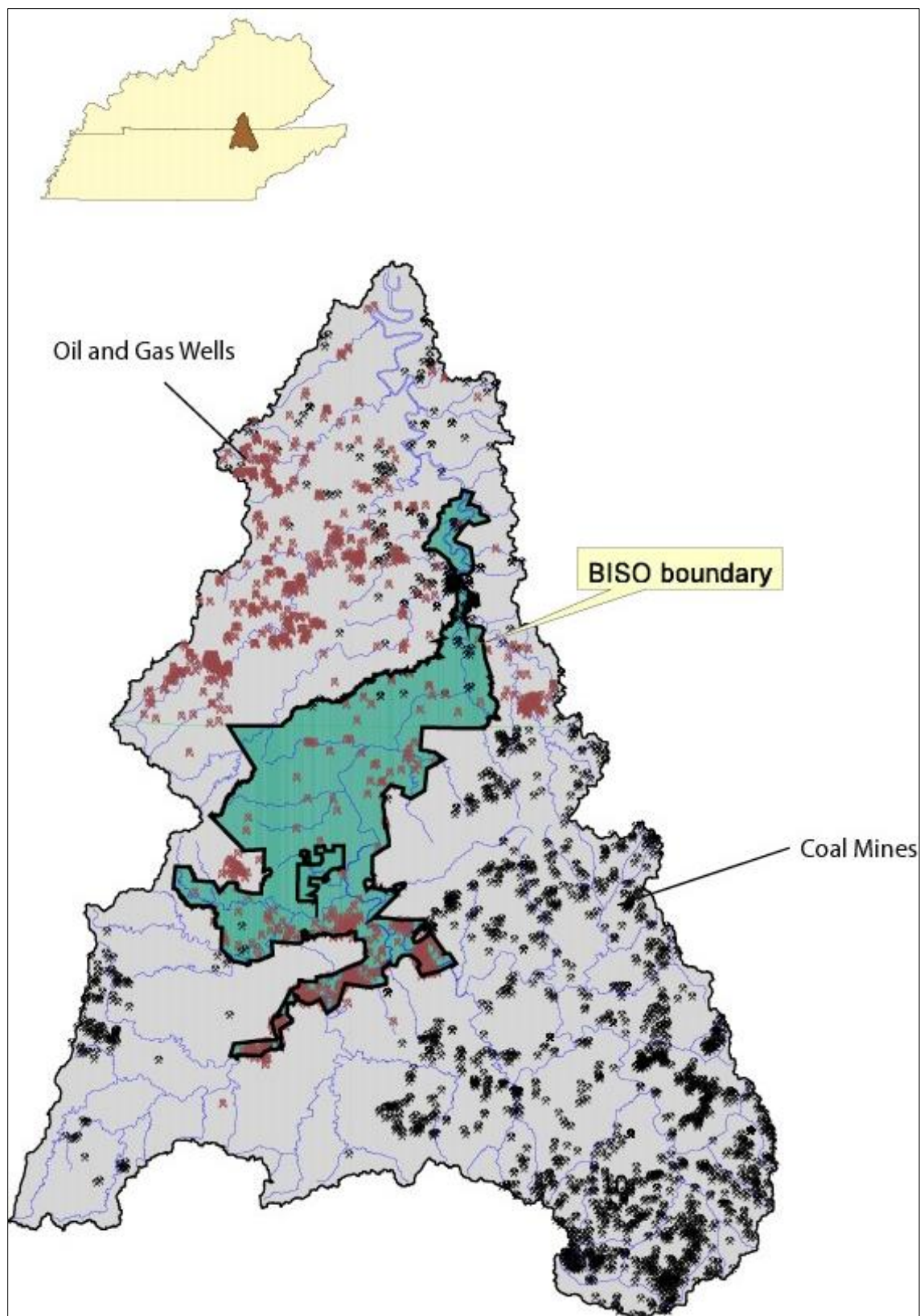


**Figure 4.** Coal mines (black symbols), and oil and gas wells (red symbols) in the BISO watershed (Johnson 2003).

### Oil and Gas Extraction

There are more than 300 active or abandoned oil or gas wells inside the Big South Fork NRRRA boundaries. In an attempt to address environmental, health and safety issues, park staff are working with state partners to plug as many abandoned wells as possible (NPS 2012). Oil and gas operations continue within the park on the 18,900 acres (7,649 ha) where mineral rights have been retained by private owners. The Oil and Gas Management Plan and EIS for Big South Fork NRRRA and Obed WSR (NPS 2012) identified a “reasonably foreseeable development scenario” of up to 25 new wells that could be completed in Big South Fork NRRRA in the next 15 to 20 years. Additionally, up to 125 wells could be recompleted or serviced to restore or improve production (Zurawski 1995; NPS 1997).

Brine discharge from oil and gas extraction affects water quality in some tributaries to the Big South Fork River, including the New River and Roaring Paunch Creek. Additional effects associated with oil and gas extraction include increased runoff due to soil compaction and vegetation damage; increased sedimentation associated with access roads; and brine, oil, gas, or production chemical contamination of surface water and groundwater associated with formation damage, well casing failure, or discharge from separation or holding ponds. Groundwater contamination may also occur due to improperly cased or unplugged wells (NPS 1997; NPS 2012).

### Timber Harvest

Timber production is a major land use in the BISO watershed. Commercial timber companies own large tracts of land, particularly in the New River watershed (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 effects associated with forestry operations include increased runoff and sedimentation, a result of soil compaction or loss of vegetation.

### Water Development

Water use from present and predicted population growth is stressing current water supplies and, since groundwater resources are insufficient, surface water sources are likely to be sought in the future (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 park boundaries (NPS 1997). Construction of impoundments, in combination with water withdrawal, can potentially alter natural streamflow, water quality, aquatic habitat, and recreational use.

### ***Obed Wild and Scenic River***

The Obed WSR 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, where development, water-supply impoundments, agricultural and forestry operations, coal mining, and oil and gas operations are the most significant threats to the park’s aquatic systems. As in Big South Fork NRRRA, there are severely polluted waters and relatively pristine waters within Obed WSR.

The main 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 effectively manage potential resource threats. The Outstanding National Resource Waters designation implies an understanding of baseline aquatic conditions exists, so anti-degradation provisions can be applied.

Principal potential effects to water quality in the park are from high levels of siltation and suspended solids, bacterial contamination, low dissolved oxygen content, high nutrient levels, oil and gas spills, and disturbance of acidic strata. High bacterial counts from sewage effluent, raised sulfate levels and severely reduced biodiversity from coal mining, elevated conductivity from agricultural operations, and high levels of silt from construction sites, have been documented from the main stem of the Obed River and several of its major tributaries (Rikard et al. 1986).

#### Development

Increasing residential and commercial development in the watershed presents an external threat to the water quality and quantity in Obed. In the counties surrounding the park, there are no regulations on storm water management for developments so associated water-quality effects from septic tanks and drain fields are expected to increase in future years (TVA 1998).

#### 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, ranging in size 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 (Tennessee) increase, demand for water in this section of the Cumberland Plateau has become a high-profile issue. There have been several requests in the last few years for permits to construct large impoundments for water supply or recreation upstream of the park. These upstream impoundments could impair, either individually or cumulatively, the natural variability of streamflows and water-related resource attributes (NPS 2012).

#### Agricultural Runoff

The Obed/Emory River watershed is approximately 72% forest, 25% pasture, and 3% 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 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 OBRI boundary, there are portions of two abandoned strip mines and one abandoned deep mine, which have naturally revegetated (TVA 1998).

### Oil and Gas Extraction

Oil and gas extraction occurs both 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 are on federal land and two are on private inholdings. Two wells were abandoned and plugged (O’Dell 2005). Like Big South Fork NRR, there is potential for new wells to be established or old ones refitted for future production.

### **Significant Aquatic Resources**

Big South Fork NRR and Obed WSR contain significant aquatic resources, including stream reaches designated as Outstanding National Resource Waters (ONRWs) that sustain numerous imperiled species. Big South Fork NRR waters support nationally important freshwater fauna, including 11 U.S. Fish and Wildlife Service (USFWS) federally-listed mussel species and the only population in existence of the federally endangered tuxedo darter (*Etheostoma lemniscatum*). The Big South Fork River proper is considered one of the most species-rich streams with respect to freshwater mussel assemblages in the Cumberland River system (Ahlstedt et al. 2003). Obed WSR waters include designated critical habitat for the federally endangered purple bean mussel (*Villosa perpurpurea*), one of only two existing populations of the federally endangered Alabama lampshell (*Lampsilis virescens*), and for a significant population of the federally threatened spotfin chub (*Erimonax monachus*).

In addition, Big South Fork NRR and Obed WSR 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 NRR and Obed WSR contain 89% of existing Cumberland rosemary populations. These cobble bar prairies and the rare species that inhabit them thrive with frequent catastrophic floods, and depend on natural flood regimes and unpolluted water.

### **Status of Big South Fork NRR and Obed WSR Waterbodies (Stream Classifications Under the Clean Water Act)**

To meet the requirements of the Clean Water Act of 1972, Kentucky and Tennessee both classify waters into “use” categories, with separate water-quality criteria for each category. Streams may be classified for multiple uses. Waters not meeting a designated use are classified as impaired and placed on the states’ 303(d) lists, to ensure that the sources of impairment are addressed. Both states also maintain lists relating to waters of exceptional quality or waters with average conditions well above the standards for aquatic life (TDEC 2012; KDW 2012). Classification as an ONRW is the most protective designation states can convey under the Clean Water Act. The free flowing portion of both the Big South Fork River in Tennessee and Kentucky, and the Obed River within the Obed WSR park unit, are listed as ONRWs. 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.

### **303(d) Classification**

Under the Clean Water Act (1972), states are required to provide a list of impaired waters to the EPA every other year, referred to as the 303(d) list. Impaired waters violate water-quality regulatory standards for designated water use classifications of the water body. If 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 (TDEC 2014). Assignment of waters to the list helps each state prioritize water-quality improvement efforts. Currently, portions of four 303(d)-listed streams fall within Big South Fork NRRA and Obed WSR waters. Within Big South Fork NRRA, Pine Creek is 303(d) listed for nutrients and bacteriological contamination while Rock Creek is 303(d) listed for acid coal mine drainage. In Obed WSR, a 1.4 mile (2.3 km) reach of Clear Creek, below the mouth of White Creek, is listed for oil well contamination. While the Obed River proper, from the headwaters to Obed junction at the mouth of Daddys Creek, is listed as impaired by nutrient enrichment, a total length of 30.1 miles (48.4 km) that includes a 15.6 mile (25.1 km) reach within the park. In addition, portions of five listed streams lie immediately upstream of the parks (Table 1; Figures 5 and 6).

**Table 1.** 303(d)-listed streams within and near Big South Fork and Obed as of 2016. These streams are 303(d)-listed for causes originating outside park boundaries. [TMDL—total maximum daily load].

| <b>Park</b> | <b>Stream/Impaired Sections</b>                                                                                                                                                                 | <b>Cause</b>                                               | <b>Pollutant Source</b>                                                      | <b>Comments</b>                 |
|-------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------|------------------------------------------------------------------------------|---------------------------------|
| BISO        | Bear Creek / 7 miles (11.3 km) immediately upstream of the park                                                                                                                                 | low pH, iron, siltation                                    | acid mine drainage                                                           | TMDLs are approved              |
| BISO        | Pine Creek / 2.75 miles (4.4 km) within the park and 21 miles (33.8 km) 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 miles (12.6 km) upstream of the park                                                                                                                                 | low pH                                                     | acid mine drainage                                                           | –                               |
| BISO        | Rock Creek / 22.4 miles (36 km) of headwater streams, and 6.4 miles (10.3 km) within the park; 4.3-mile (6.9-km) downstream section, and 0.4 miles (0.6 km) within 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-mile (2.3-km) section immediately downstream of Barnett Bridge                                                                                                            | oil                                                        | petroleum activities                                                         | spill from an upstream oil well |

**Table 1 (continued).** 303(d)-listed streams within and near Big South Fork and Obed as of 2016. These streams are 303(d)-listed for causes originating outside park boundaries. [TMDL—total maximum daily load].

| Park | Stream/Impaired Sections                                                      | Cause                              | Pollutant Source                  | Comments                                                                        |
|------|-------------------------------------------------------------------------------|------------------------------------|-----------------------------------|---------------------------------------------------------------------------------|
| OBRI | Obed River / the 14.5-mile (23.3-km) section immediately upstream of the park | nitrate, nitrite, total phosphorus | municipal point source discharges | –                                                                               |
| OBRI | Obed River/ the 15.6 mile reach from the park boundary to Obed Junction       | nitrate, nitrite, total phosphorus | municipal point source discharges | recent (2016) designation extending above 303 (d) listing into OBRI park waters |

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

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

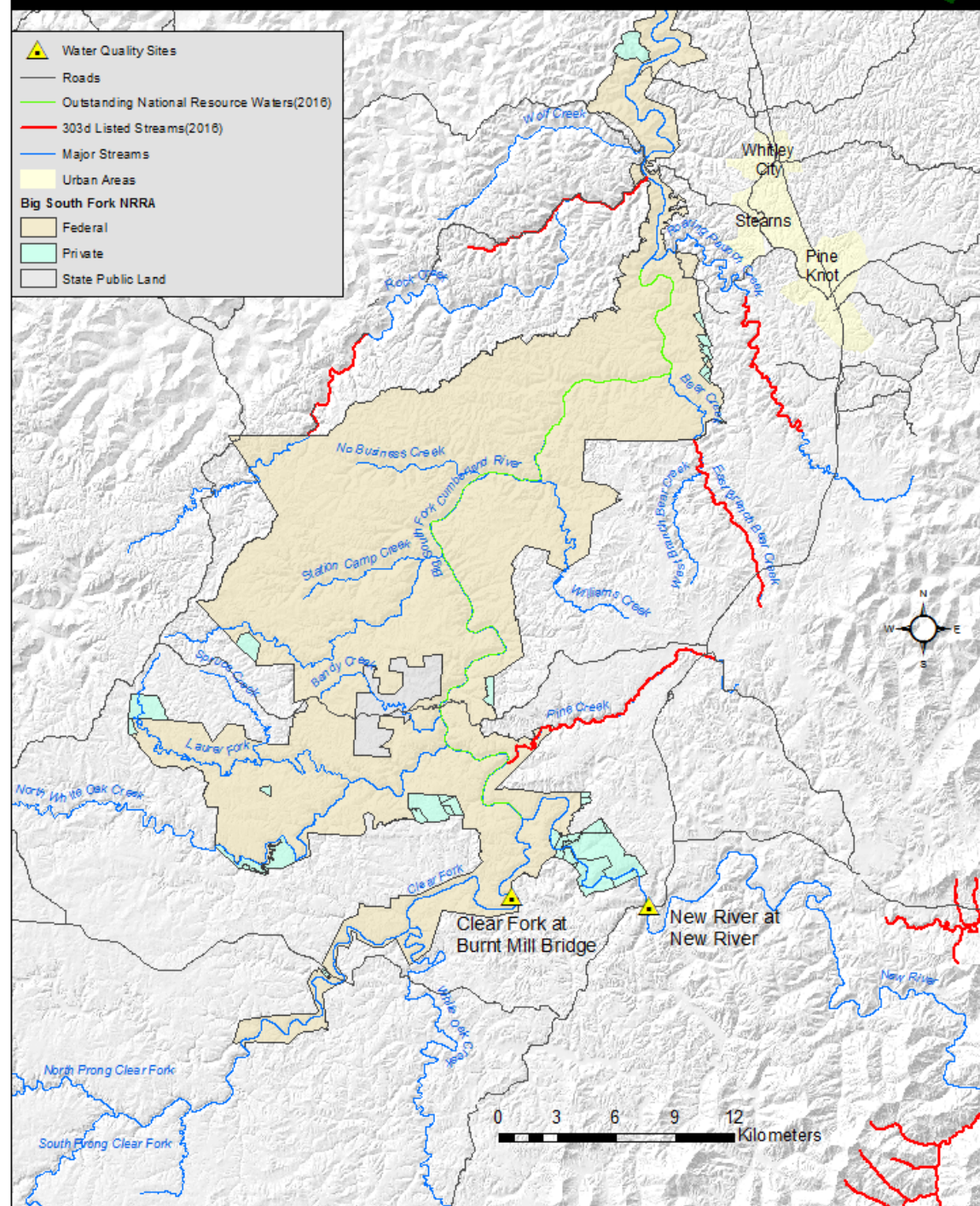


**Figure 5.** Continuous water-quality monitoring sites at Big South Fork NRR. Outstanding National Resource Waters and 303(d) streams within and near the park are also shown.

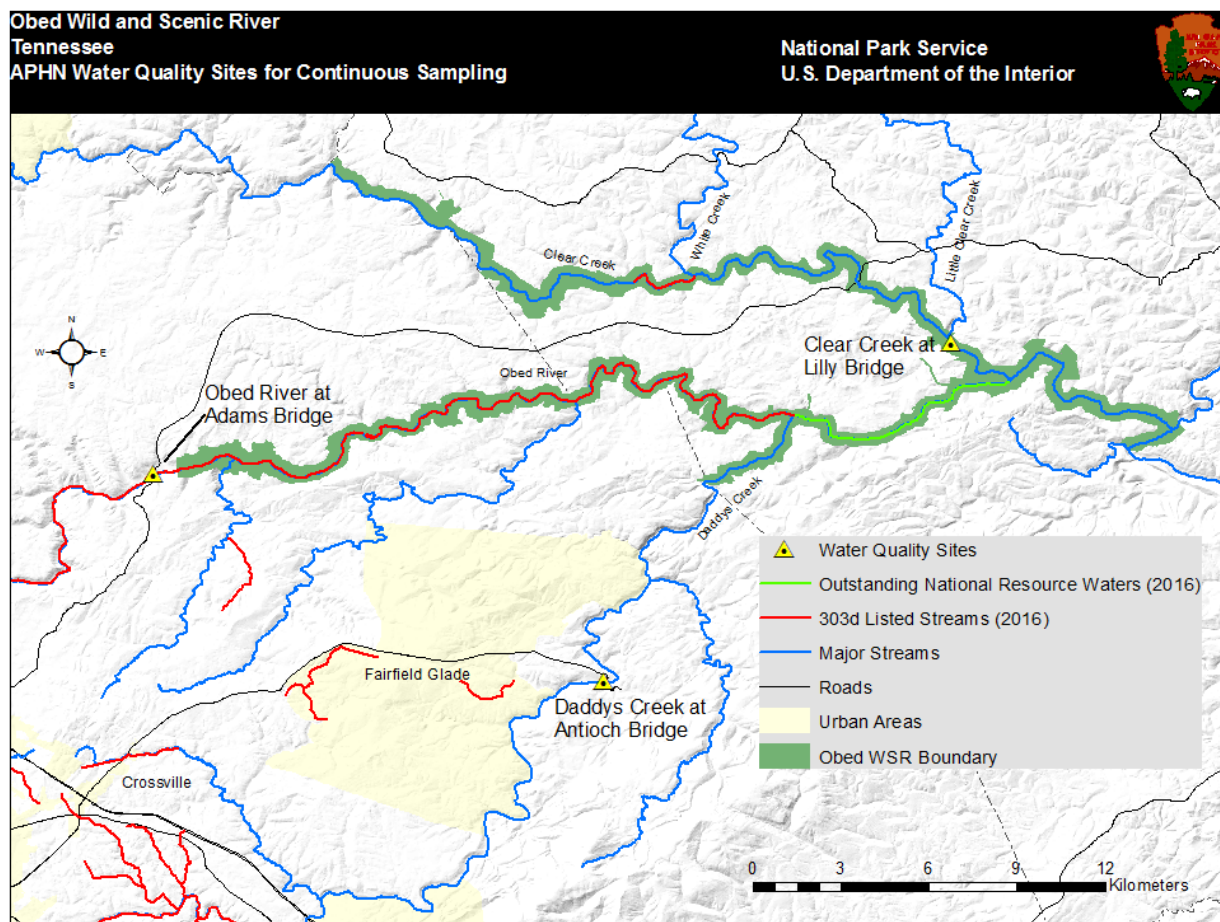


**Figure 6.** Continuous water quality monitoring sites at Obed WSR. Outstanding National Resource Waters and 303(d) streams within and near the park are also shown.

### ***Outstanding National Resource Waters (ONRW)***

The Clean Water Act (1972) requires states to incorporate antidegradation standards into regulatory decisions. Part of the responsibility this policy places on the states is identification of waters as ONRW. Within an ONRW 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 River 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 and Figures 5 and 6).

**Table 2.** Streams designated as Outstanding National Resource Waters (ONRW) within Big South Fork and Obed as of 2012.

| Park | Designated Stream Section                                                                                                         | Comments                                                                                        |
|------|-----------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------|
| BISO | Big South Fork of the Cumberland River—33 river miles (53.1 km), from Blue Heron upstream to the New River, Clear Fork confluence | ONRW in both Tennessee and Kentucky                                                             |
| OBRl | Obed River—from river mile 0 upstream to river mile 24.7 (39.8 km), at the park boundary                                          | ONRW designation makes an exception for possible use of Obed waters for a regional water supply |

### Applicability to Management

Because of legislative and other mandates, Big South Fork NRRRA and Obed WSR place special emphasis on management of their riverine resources, which resulted in a Water Resource Management Plan (WRMP) being developed for each park (NPS 1997; NPS 1998). More recently, the two parks developed draft foundation documents describing in detail significant park resources and measures to protect those resources.

The Draft Foundation Document for the Big South Fork NRRRA (NPS 2016) identifies significant water and aquatic resources that include:

- The Big South Fork of the Cumberland River, designated as Outstanding National Resource Water (ONRW) in both Tennessee and Kentucky, is one of the largest remaining free-flowing rivers in the southeastern United States. The Big South Fork and its tributaries pass through 90 miles (145 km) of scenic gorges and valleys. Tennessee and Kentucky have designated their portions of the Big South Fork River as an Outstanding National Resource Water. Kentucky has also recognized the section of the Big South Fork from the state line to Blue Heron mine as a Kentucky Wild River.
- Big South Fork NRRRA protects diverse aquatic and terrestrial habitats that represent the original components of the Cumberland Plateau ecosystem and support regionally and globally rare flora and fauna. These resources include more than 60 species of fish including channel catfish, sunfish, muskellunge, and smallmouth bass. In addition, walleye, striped bass, and white bass do migrate upstream from Lake Cumberland. The river is also home to several important freshwater mussels.

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

- Preservation of the natural free-flowing character of the Big South Fork River and its tributaries within the Big South Fork National River and Recreation Area.

- 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.
- Continuation of natural hydrological processes that shape the landscape of the Big South Fork National River and Recreation Area, by periodically flooding the bottomlands in a dynamic process of erosion and deposition.
- Existence of surface waters that provide high-quality fishing and swimming and are consistent with the Clean Water Act and other applicable laws and regulations.

The Obed Foundation Document (NPS 2015) identifies significant water and aquatic resources within Obed WSR that include:

- **Free-Flowing Riverine Habitat:** The dynamic free-flowing nature, narrow gorges, and high water quality of the Obed Wild and Scenic River system create an extraordinary biologically diverse riverine system and provide habitat for rare and unique species. Water flows freely through the 45 miles (72 km) of the Obed Wild and Scenic River system allowing for conditions that reflect natural variability including low flows of late summer and raging torrents during the periodic storms. During storms, the river's volume and force can rapidly increase within a few hours resulting in the movement of large boulders and scouring away vegetation in and along the channel. These extreme flow conditions give rise to an ecosystem whose habitats, species diversity, and human history reflect the river's tumultuous nature.
- **Water Quality:** Water quality in the Obed watershed is driven by geology influenced by the unique chemical characteristics of the Cumberland Plateau bedrock, and ranges from extremely dilute, low ionic water in headwaters to moderately soft waters in the larger streams. The low ionic water supports the thriving aquatic communities and contributes to excellent habitat. The exceptional water quality also supports many types of water-based recreation.
- **Biodiversity and Cobble Bar communities:** The park protects an intact riverine ecosystem that contains terrestrial and aquatic habitats and species associated with the Cumberland Plateau river system. The area remains one of the most biologically diverse riverine systems and is unique within the Cumberland Plateau ecoregion. The Obed River System also contains the vast majority of the globally imperiled cobble bar ecological community, of which there are fewer than 500 acres (202 ha) remaining (according to NatureServe's "An Online Encyclopedia of Life").

The Obed WSR Water Resource Management Plan (NPS 1998) acknowledged that water resources of the designated Obed Wild and Scenic River corridor are a critical component of a larger ecosystem that spreads beyond the boundaries of the park. It identified a need to develop cooperative partnerships with local, state, and federal regulators, land-use planners, adjacent landowners, the

research community, and the public to realize the goals of the plan. Objectives from the plan and the Obed WSR General Management Plan (NPS 1994) include:

- Maintaining the highest water quality possible and the free-flowing condition for all streams within the Obed Wild and Scenic River.
- Protecting the natural systems, cultural resources, landscape character, and biodiversity of the OBRI area.
- Providing the opportunity and means to learn about, experience, and enjoy the special values of the Obed Wild and Scenic River while assuring protection of those values.

Continuous (time series) sampling of water quality at key locations along major tributaries will provide park managers with much-needed data to evaluate the status and trends of water quality in those stream 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 for protection of park waters, as called for by the NPS Management Policies (NPS 2006).

Monitoring data will also help inform and refine the reference condition for water-quality parameters within Big South Fork NRRA and Obed WSR. This is especially true 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 units for protection of fish and wildlife, while naturally occurring pH levels are often below 6.5 in 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, APHN vital signs are interrelated in many ways, and there are opportunities for developing multiple lines of evidence for detecting trends.

Trends in water quality and flow in park streams monitored under both the continuous and discrete water-quality monitoring efforts are directly relevant to the trends we are monitoring in other park aquatic and riparian resources. This includes cobble bar communities and Cumberland rosemary (Murdock et al. 2013), freshwater mussels (in preparation), benthic macroinvertebrates (in preparation) and rare fish (in preparation). In many cases, monitoring stations for discrete water-quality sampling are co-located with cobble bar, fish, and mussel monitoring locations. Additionally, co-location of continuous water quality monitoring stations with USGS stage/discharge streamflow gages provides insight into the relationship 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 cobble bar communities) 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 complements those efforts and provides a more holistic assessment of water and associated

aquatic and riparian resource condition. For example, the stations monitored under the *Long-Term Water Quality Monitoring Protocol for Continuous Sampling* described herein are a subset of stations monitored under the companion *Long-Term Discrete Water-Quality Monitoring: Protocol Narrative* (Hughes, et al in prep). Similarly, annual benthic macroinvertebrate monitoring efforts will include monitoring of a rotating subset of stations that will be co-located with discrete water quality sampling stations.

At some locations, the Appalachians Highland Network will monitor a site for freshwater mussels, benthic macroinvertebrates, rare fish, riparian cobble bar communities, and both discrete and continuous water-quality sampling. While discrete monitoring stations are not co-located with cobble bar, mussel, and fish monitoring locations in all cases, continuous (and discrete) water-quality monitoring will be conducted at strategic integrator locations utilized to identify water resource integrity for those stream reaches sampled under companion protocols.

The health of aquatic and riparian resources is linked to the water quality and quantity at all APHN parks. The combined approach of continuous and discrete water-resource monitoring provides a more comprehensive evaluation of water-resource integrity than either approach as a stand-alone effort. This protocol identifies seasonal and diurnal trends that may otherwise be undetected by discrete sampling alone. However, continuous monitoring of five core parameters under this protocol will not identify underlying water-quality perturbations that influence those five core parameters. For example, Obed WSR 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 Appalachians Highlands Network will identify factors (e.g. nutrient loading) that influence the seasonal and diurnal variability in pH and dissolved oxygen fluctuation between monitoring stations.

### **Measurable Objectives**

All of the issues and monitoring questions identified during APHN scoping meetings revealed the need for better information to assist managers in protecting water quality. Therefore, the overarching goal of the APHN water-quality monitoring program is to obtain information that will aid the parks in making informed management decisions to protect and improve water quality. Considering that goal, while cognizant of our limitations in staffing and funding, we established the following objectives for continuous sampling (see Table 3 for a more detailed explanation of the significance of the core parameters, sampling objectives, and metrics):

- Determine diurnal, monthly, seasonal and annual water quality trends for five parameters (dissolved oxygen, conductivity, temperature, pH and turbidity) at selected index sites using fixed-station continuous-data loggers at Big South Fork NRR and Obed WSR.  
*Justification: Monitoring stations are strategically positioned upstream of the most sensitive sections of the Big South Fork and Obed River systems, which will allow us to determine compliance with state and regional water quality standards and ensure the National Park Service has the data needed to detect long-term changes in these systems. Four of these*

*measures (all except turbidity) have been identified by the NPS Water Resources Division as “core parameters” that all I&M networks should monitor.*

- Utilize USGS streamflow data to relate water-quality data (and monitoring data collected as part of other monitoring protocols) to daily, seasonal, and annual trends in streamflow and to the frequency, magnitude, and duration of extreme runoff events. *Justification: By utilizing complementary USGS streamflow data at the continuous monitoring stations, APHN can evaluate the inherent interrelation of streamflow on water quality as a consequence of short-term events and seasonal conditions, providing insight not only to continuous water quality monitoring trends but also to trends identified by discrete water quality monitoring and monitoring of other aquatic and riparian resources. Specifically, the Big South Fork and the Obed are affected by water withdrawal for municipal water supplies and wastewater discharges. By co-locating continuous monitoring stations with USGS streamflow gages the relationship between runoff events, seasonal conditions, and water quality can be determined.*

**Table 3.** Metrics and objectives for continuous-sampling water quality monitoring. Metrics include the NPS Water Resources Division core water quality parameters. [mg/L—milligrams per liter].

| Metrics         | Significance                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |
|-----------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| pH <sup>1</sup> | Most living organisms can tolerate only small changes in pH without life-threatening physiological reactions. In an unaltered state, surface waters of all APHN parks exhibit moderately acidic to circumneutral pH, and have little buffering capacity. Low buffering capacity renders park waters highly susceptible to degradation by acidic input and to diurnal pH fluctuation associated with fluctuating dissolved oxygen concentrations associated with nutrient loading. Park waters have been adversely affected by acid mine drainage on the Cumberland Plateau. |

<sup>1</sup> The monitoring objectives for pH, temperature, dissolved oxygen, conductivity, and turbidity are to determine diurnal, monthly, seasonal and annual water quality trends for five parameters (pH, temperature, dissolved oxygen, conductivity, and turbidity) at selected index sites using fixed station continuous data loggers at Big South Fork and Obed. These data will also be utilized to detect variability in water quality conditions between continuous monitoring stations and can be utilized to identify variations in the amplitude of diurnal fluctuations in key water quality parameters (pH, dissolved oxygen) to identify compliance with regulatory standards. The sampling objectives for these same parameters are to Detect a 20% change over 10 years in the daily medians of conductivity, dissolved oxygen, and turbidity in selected streams with 80% power and 10% acceptable false change error ( $\alpha$  or type I error) (preliminary estimates indicate this should be achievable for all parameters except turbidity). For temperature, detect the number of days per month that maximum daily temperature exceeds 20 degrees Celsius. For pH, identify variability in daily maximum and minimum pH between sampling stations and identify trends in regulatory exceedance of maximum 1.0 pH unit diurnal pH fluctuation.

<sup>2</sup> The monitoring objective for streamflow is to utilize USGS streamflow data to determine trends in the annual water budget at continuous monitoring stations and to determine variations in long term annual and seasonal trends in streamflow. Continuous data sets can also be utilized to detect frequency, magnitude, and duration of extremes in streamflow (scouring floods, drought) that are directly relevant to other vital signs monitoring efforts. The USGS is responsible for developing and meeting sampling objectives for streamflow gages

**Table 3 (continued).** Metrics and objectives for continuous-sampling water quality monitoring. Metrics include the NPS Water Resources Division core water quality parameters. [mg/L—milligrams per liter].

| Metrics                            | Significance                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |
|------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Temperature <sup>1</sup>           | 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; trout, for example, tolerate water temperatures only up to about 66°F (18.9°C).                              |
| Dissolved Oxygen (DO) <sup>1</sup> | Although DO is not a natural limiting factor in APHN 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 of low streamflow. Most aquatic life requires greater than 5.0 mg/L of dissolved oxygen for survival. Continuous monitoring on a 24 hour cycle can be utilized to identify excursions from regulatory standards of minimum dissolved oxygen for designated water uses. |
| Conductivity <sup>1</sup>          | 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.                                                                                                                                                                                                                                 |
| Turbidity <sup>1</sup>             | 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. Big South Fork and Obed are especially vulnerable to increased sediment loads resulting from land use activities in headwaters above park boundaries, including municipal and suburban development, agriculture, timber harvest, oil and gas development, coal mining, and stone quarrying.                          |

<sup>1</sup> The monitoring objectives for pH, temperature, dissolved oxygen, conductivity, and turbidity are to determine diurnal, monthly, seasonal and annual water quality trends for five parameters (pH, temperature, dissolved oxygen, conductivity, and turbidity) at selected index sites using fixed station continuous data loggers at Big South Fork and Obed. These data will also be utilized to detect variability in water quality conditions between continuous monitoring stations and can be utilized to identify variations in the amplitude of diurnal fluctuations in key water quality parameters (pH, dissolved oxygen) to identify compliance with regulatory standards. The sampling objectives for these same parameters are to Detect a 20% change over 10 years in the daily medians of conductivity, dissolved oxygen, and turbidity in selected streams with 80% power and 10% acceptable false change error ( $\alpha$  or type I error) (preliminary estimates indicate this should be achievable for all parameters except turbidity). For temperature, detect the number of days per month that maximum daily temperature exceeds 20 degrees Celsius. For pH, identify variability in daily maximum and minimum pH between sampling stations and identify trends in regulatory exceedance of maximum 1.0 pH unit diurnal pH fluctuation.

<sup>2</sup> The monitoring objective for streamflow is to utilize USGS streamflow data to determine trends in the annual water budget at continuous monitoring stations and to determine variations in long term annual and seasonal trends in streamflow. Continuous data sets can also be utilized to detect frequency, magnitude, and duration of extremes in streamflow (scouring floods, drought) that are directly relevant to other vital signs monitoring efforts. The USGS is responsible for developing and meeting sampling objectives for streamflow gages

**Table 3 (continued).** Metrics and objectives for continuous-sampling water quality monitoring. Metrics include the NPS Water Resources Division core water quality parameters. [mg/L—milligrams per liter].

| Metrics                 | Significance                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |
|-------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Streamflow <sup>2</sup> | Aquatic and riparian resources are directly influenced by streamflow. Globally imperiled riparian cobble bar communities are sustained by scouring floods during seasons of high runoff during winter and spring. Conversely, aquatic resources such as fish, freshwater mussels, and benthic macroinvertebrates are dependent upon adequate streamflow during seasons of low flow typical of summer and fall seasons. Monitoring streamflow provides critical information to detect changes in the historical flow regime due to upstream water resources development and/or climate change and to determine a stream's assimilative capacity for wastewater. Streamflow data also provide the ability to detect long term changes in annual and seasonal streamflow rates |

<sup>1</sup> The monitoring objectives for pH, temperature, dissolved oxygen, conductivity, and turbidity are to determine diurnal, monthly, seasonal and annual water quality trends for five parameters (pH, temperature, dissolved oxygen, conductivity, and turbidity) at selected index sites using fixed station continuous data loggers at Big South Fork and Obed. These data will also be utilized to detect variability in water quality conditions between continuous monitoring stations and can be utilized to identify variations in the amplitude of diurnal fluctuations in key water quality parameters (pH, dissolved oxygen) to identify compliance with regulatory standards. The sampling objectives for these same parameters are to Detect a 20% change over 10 years in the daily medians of conductivity, dissolved oxygen, and turbidity in selected streams with 80% power and 10% acceptable false change error ( $\alpha$  or type I error) (preliminary estimates indicate this should be achievable for all parameters except turbidity). For temperature, detect the number of days per month that maximum daily temperature exceeds 20 degrees Celsius. For pH, identify variability in daily maximum and minimum pH between sampling stations and identify trends in regulatory exceedance of maximum 1.0 pH unit diurnal pH fluctuation.

<sup>2</sup> The monitoring objective for streamflow is to utilize USGS streamflow data to determine trends in the annual water budget at continuous monitoring stations and to determine variations in long term annual and seasonal trends in streamflow. Continuous data sets can also be utilized to detect frequency, magnitude, and duration of extremes in streamflow (scouring floods, drought) that are directly relevant to other vital signs monitoring efforts. The USGS is responsible for developing and meeting sampling objectives for streamflow gages

Monitoring data are collected for these objectives from continuous monitoring of water-quality parameters using permanently deployed datasondes at key locations on major tributaries within the parks. Dissolved oxygen, conductivity, temperature, pH and turbidity are monitored at frequent (30 minute) set intervals. Status information is obtained quickly since time series data are broadcast to a USGS-hosted webpage, allowing us to recognize short-term pollution events in real-time, and making it possible for the parks to take timely management actions when necessary.

In Table 3, the monitoring objectives for pH, temperature, dissolved oxygen, conductivity, and turbidity are to Determine diurnal, monthly, seasonal and annual water quality trends for five parameters (pH, temperature, dissolved oxygen, conductivity, and turbidity) at selected index sites using fixed station continuous data loggers at Big South Fork and Obed. These data will also be utilized to detect variability in water quality conditions between continuous monitoring stations and can be utilized to identify variations in the amplitude of diurnal fluctuations in key water quality parameters (pH, dissolved oxygen) to identify compliance with regulatory standards. The sampling objectives for these same parameters are to Detect a 20% change over 10 years in the daily medians of conductivity, dissolved oxygen, and turbidity in selected streams with 80% power and 10%

acceptable false change error ( $\alpha$  or type I error) (preliminary estimates indicate this should be achievable for all parameters except turbidity). For temperature, detect the number of days per month that maximum daily temperature exceeds 20 degrees Celsius. For pH, identify variability in daily maximum and minimum pH between sampling stations and identify trends in regulatory exceedance of maximum 1.0 pH unit diurnal pH fluctuation.



## Sampling Design

Continuous water-quality monitors (YSI 6920 datasondes) are deployed year-round at five USGS streamflow gauges within or adjacent to Big South Fork NRR and Obed WSR (Figures 5 and 6). The deployment sites are located along major rivers and creeks near the parks' upstream boundaries, or in river reaches that have a major influence on the water quality affecting the parks' most sensitive aquatic resources. We chose to co-locate the datasondes with USGS streamflow gauges to take advantage of facilities that allow near real-time broadcast of continuous water-quality data to the Internet. Core water-quality measurements are complemented by continuous streamflow data collected by USGS at these sites. Data handling procedures are carried out in partnership with USGS, which archives APHN water-quality data in its National Water Information System (NWIS), and posts these data to the Internet as they are collected. A memorandum of understanding (MOU) with the USGS Tennessee Water Science Center (TNWSC) allows internal access to NWIS for specified APHN staff.

Datasondes are used to record data for five core water-quality parameters so status and trends can be determined. Water-quality parameters are measured continuously at frequent fixed intervals and broadcast to the Internet, allowing APHN staff to evaluate current conditions at a site, spatial variability among sites, and trends in core parameter values over a period of years. This continuous sampling protocol is part of an integrated approach to water-quality monitoring in these parks, which will include discrete sampling at selected sites. The rationale and design for water-quality monitoring using discrete sampling will be covered in a separate protocol.

### Representativeness and Target Populations

The Appalachian Highlands Network's continuous water-quality monitoring effort samples surface waters in the major tributary rivers that flow through the parks. Monitoring stations are generally positioned in the upstream sections of the larger rivers and tributaries designated for protection by park legislation. Monitoring locations were chosen as integrator sites that detect the physical and chemical water-quality conditions "delivered" to park waters from upstream areas of their respective watersheds.

Frequency and timing of sampling are important factors in obtaining representative samples across the hydrograph. Samples taken during high flow conditions may have significantly different properties than samples taken during base flow conditions. Much of the annual mass transport for a basin may occur in just a few storm events during the year. Care must be taken to avoid sampling bias toward favorable weather conditions at base flow stages, a concern circumvented by the use of datasondes. The fixed frequency sampling design in this protocol generally reflects a comprehensive range of flow conditions over time. We will sample at 30-minute intervals, which is considered appropriate to monitor temporal variability in water-quality conditions in individual watersheds (Wagner et al. 2006). Spatial differences in water resource conditions will be discernable by locating continuous monitoring stations in each of the major protected tributaries flowing through each park. Land use and development in the watersheds upstream of these stations differs substantially, and

preliminary continuous monitoring results reflect the distinct differences in water resource integrity associated with land use patterns in monitored watersheds.

### **Site Selection for Fixed Continuous Monitoring Stations**

The sampling design for water-quality monitoring in APHN parks was developed with input from park and APHN staff, USGS hydrologists, and non-NPS scientists. The design is based on an evaluation of historic water-quality data from numerous agencies, known threats to the parks' water resources, locations of both high-quality and impaired water resources (Figures 5 and 6), and known locations of significant aquatic resources. The general sampling design is based on the USGS National Water Quality Assessment (NAWQA) program and the NPS Water Quality Inventory Protocol for Riverine Environments (Stednick and Gilbert 1998), and builds on previous monitoring efforts at Big South Fork and Obed (Rikard 1985; Rikard et al. 1986).

The most useful and cost-effective approach for continuous water-quality monitoring at Big South Fork NRR and Obed WSR was to establish index sites at critical stream locations instead of randomly locating sample sites in order to make quantitative spatial inferences throughout park waters. This is based on historical data, pilot sampling by APHN staff, and knowledge of water-quality issues in sub-watersheds in the parks.

Numerous criteria used to choose sampling sites included:

- In the initial development of the network of continuous monitoring stations, the presence of an existing USGS streamflow gage was a prime consideration because of the real-time broadcast of data to USGS web pages. Continuous discharge gaging stations at or near the monitoring locations increase the usefulness of the water-quality data in detecting diurnal and seasonal trends of key water-quality indicators, the effect of runoff events on water quality, and discharge can be utilized as a surrogate to enable calculations of sediment loads (turbidity) and total dissolved solids (specific conductance). This information is useful to water resource managers and regulatory agencies.
- The site's utility as an "integrator site"—located downstream of river or tributary segments which are of interest either because they are significant sources of pollution, or because of their pristine water quality. Note that NPS obtained funding for the USGS Obed River at Adams Bridge (USGS # 03538830) at a location where a key integrator station was not previously equipped with a USGS gage.
- The presence of significant aquatic resources in a stream segment, where water-quality trend information is needed to corroborate trends in the resource of interest, or to provide managers with early warning of possible problems.
- The management importance attached to a site, either because protection of the water body is mandated in park legislation or required in a park resource management plan, or because the water body is designated by the state as pristine or polluted (303(d); Figures 5 and 6).

- The presence of existing water-quality information at the site. A long-term record of water-quality monitoring data increases the functional utility of trend monitoring at a site, and makes it possible to detect changes in the resource without having to establish baseline water-quality conditions.
- The existence of other long-term resource monitoring near a site, where water-quality information would be useful for corroborating other observed trends in biological communities.
- The safety of access to sampling sites. The presence of bridges for flood flow measurement of streamflow by USGS is advantageous to ensure the stage/discharge curve is accurate throughout the range of anticipated streamflow. Bridges are also advantageous for cross-section water-quality measurements to assure monitor placement is an accurate representation of the water body and for collection of complementary laboratory data under the companion *Long Term Discrete Water Quality Monitoring: Protocol Narrative* (Hughes, et al, in prep). Some bridges and roads create concerns due to poor line of sight, inadequate shoulders, minimal road width, or high traffic. Identification of good wading sections and documentation of safe wading stages is critical both for USGS wading discharge measurements and for cross-section water-quality determinations to verify monitor deployments are representative of the water body at the monitoring station.

Continuous monitoring stations (Table 4) are monitored on a monthly frequency as part of the companion APHN *Long Term Discrete Water Quality Monitoring: Protocol Narrative*. The continuous stations were established either at existing USGS streamflow stations or, in one instance, at a new USGS gauge established as part of the continuous monitoring effort (Obed River at Adams Bridge).

The parks' significant aquatic and riparian resources are concentrated in these stream reaches, as are many of the monitoring sites for the network's other vital signs. Determining status and trends at these integrator sites will provide information concerning upstream water resource integrity, and will allow us to target areas where more intensive discrete sampling may be warranted. Partnering with USGS allows data to be broadcast to the Internet, making current water-quality and streamflow data available to NPS resource managers and other state, federal, and municipal partners, as well as to the public.

**Table 4.** Monitoring sites and selection criteria for continuous water-quality sampling at Big South Fork NRRRA and Obed WSR (station names in parentheses are alternate site names used by the Appalachian Highlands Network). [TDEC—Tennessee Department of Environment and Conservation].

| <b>Park</b> | <b>Water Body Name</b> | <b>Station Name</b>                               | <b>USGS Station No. (NPS ID)</b> | <b>NPS and USGS Period of Record</b>                                     | <b>Site Justification</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |
|-------------|------------------------|---------------------------------------------------|----------------------------------|--------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| BISO        | New River              | New River at New River, Tenn.                     | USGS 03408500 (BISO-2)           | NPS QW: Sept. 2012 – present (USGS: Sept. 1934 – present)                | One of the two largest tributaries to the Big South Fork, the New River drains a region that has been heavily impacted by coal mining, logging, development for oil and gas production, and commercial development for off-road recreation. The New River has long been recognized as the primary source of high sediment loading that is the greatest stressor of aquatic resources of the Big South Fork. BISO enabling legislation mandates that the National Park Service develop strategies to evaluate and address water resource issues originating in this watershed. |
| BISO        | Clear Fork             | Clear Fork near Robbins, Tenn.                    | USGS 03409500 (BISO-4)           | NPS QW: Oct. 2012 – present (USGS period of record: March, 1929–present) | Clear Fork is designated critical habitat for endangered species. In the absence of the inflow of Clear Fork's high quality waters and other western tributaries to the Big South Fork that dilute degraded inflow from the New River, habitat for key aquatic resources in the Big South Fork proper would likely be imperiled.                                                                                                                                                                                                                                              |
| OBRI        | Obed River             | Obed River at Adams Bridge near Crossville, Tenn. | USGS 03539778 (OBRI-4)           | NPS QW: Jan. 2010 – present (USGS: Jan. 2010 – present)                  | This integrator site will provide water quality monitoring of the most extensively altered land area of the entire Obed watershed. Upstream reaches of the Obed River system above this station are on the state's 303(d) list because of elevated nutrient concentrations. More recently, TDEC has extended that 303(d) designation downstream to Obed Junction within the park.                                                                                                                                                                                             |
| OBRI        | Daddys Creek           | Daddys Creek near Hebbertsberg, Tenn.             | USGS 03539600 (OBRI-7)           | NPS QW: Oct. 2012 – present (USGS: May 1957 – present)                   | Daddys Creek is one of three major branches of the Obed system legislatively protected under the Wild and Scenic Rivers Act. The watershed is largely rural and agrarian, but also drains concentrated urban development in Cumberland County, Tenn.; this location is also a TDEC ambient monitoring station.                                                                                                                                                                                                                                                                |

**Table 4 (continued).** Monitoring sites and selection criteria for continuous water-quality sampling at Big South Fork NRR and Obed WSR (station names in parentheses are alternate site names used by the Appalachian Highlands Network). [TDEC—Tennessee Department of Environment and Conservation].

| Park | Water Body Name | Station Name                                    | USGS Station No. (NPS ID) | NPS and USGS Period of Record                                               | Site Justification                                                                                                                                                                                                                                                                                                                                                                                              |
|------|-----------------|-------------------------------------------------|---------------------------|-----------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| OBRI | Clear Creek     | Clear Creek at Lilly Bridge near Lancing, Tenn. | USGS 03538830 (OBRI-3)    | NPS QW: October 2012–present (USGS period of record: April 1, 1997–present) | Clear Creek is one of the three major branches of the Obed system legislatively protected under the Wild and Scenic Rivers Act. TDEC monitors Clear Creek at this location as a reference site (indicative of optimal water quality). Clear Creek exhibits the highest water quality of the three major drainages in the Obed system because of the largely undisturbed condition of the Clear Creek watershed. |

### Strengths and Limitations of the Sampling Design

This continuous water-quality monitoring approach provides several benefits to the Appalachian Highlands Network, park resource managers, and regional conservation partners (Table 5). The design will provide long-term data on status and trends in core water-quality parameters in key locations along the parks' major tributaries. Status and trends will be determined at multiple time scales (daily, weekly, seasonal, annual, and decadal), and will be available in near real-time. The data will provide a picture of status and trends in water quality in selected streams and rivers within Big South Fork NRR and Obed WSR.

While continuous monitoring datasondes collect only a limited set of core analytes, these data are particularly important as indicators of upstream disturbance (pH, specific conductance, turbidity), nutrient loading (dissolved oxygen), and long-term changes in climate (temperature, dissolved oxygen). Continuous flow data collected by USGS at these sites strengthens our assessment of long-term trends related to climate, improves the accuracy of trend calculations for water-quality measures that are flow dependent (specific conductance, turbidity; Helsel and Hirsch 2002), and quantifies relationships among water-quality constituents being measured indirectly (sediment concentration, as measured by turbidity). Time series water-quality data will also be used to complement long-term monitoring of water chemistry in streams using discrete sampling, as well as to fine-tune targeted investigations of specific water resource management issues related to seasonal or event-driven conditions.

Detection of concerning trends will provide the impetus and justification for the Appalachians Highlands Network and the parks to pursue additional funding and resources to address emerging problems through separate, targeted research. Overall, this monitoring protocol will provide a well-documented baseline of background conditions which can be implemented within the time and budget constraints of the network.

**Table 5.** Advantages and disadvantages of continuous water-quality monitoring, with data broadcast to the internet.

| <b>Advantages</b>                                                                                                                                                                                                                                                       | <b>Disadvantages</b>                                                                                                                                                                                                                                       |
|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Makes knowledge of current water quality conditions available in near-real time, improving the effectiveness of management responses.                                                                                                                                   | Sensors are susceptible to vandalism                                                                                                                                                                                                                       |
| Allows a large amount of data to be collected for a small investment in time.                                                                                                                                                                                           | Servicing sensors during flooding and freezing can be difficult.                                                                                                                                                                                           |
| Makes it possible to optimize the timing of sample collection for other studies.                                                                                                                                                                                        | Properly locating intakes or sensors in the cross section can be difficult.                                                                                                                                                                                |
| System can be monitored remotely for problems and needed service.                                                                                                                                                                                                       | Sensors are susceptible to debris and ice, especially during high flows and winter conditions.                                                                                                                                                             |
| Storm event monitoring can be accomplished remotely, greatly reducing safety risks.                                                                                                                                                                                     | Shifting channels may require adjustments to sensor placement.                                                                                                                                                                                             |
| Selected sites integrate upstream conditions for main stem rivers and major tributaries. Continuous monitors are effective for identification of reference water quality conditions and for monitoring upstream threats to water quality within designated park waters. | Limited coverage of smaller tributaries that may be important habitat for key aquatic resources. The companion APHN Long-Term Water-Quality Monitoring Protocol for Discrete Sampling Protocol includes monitoring locations of these smaller tributaries. |

## Field Methods and Standards

Water-quality parameters will be measured at 30-minute intervals in each of five major tributaries, allowing for determination of status, spatial variability, and inference of trends in core parameter values at diurnal, monthly, seasonal, annual, and eventually longer-term time scales. The core parameters to be measured using continuous monitoring are as follows, accompanied by measurement units (\*indicates ancillary data collected by USGS):

- Field pH (standard pH units)
- Specific Conductance (microsiemens per centimeter [ $\mu\text{S}/\text{cm}$ ] at 25°C)
- Field Temperature (Celsius)
- Dissolved Oxygen (milligrams/liter [ $\text{mg}/\text{L}$ ])
- Turbidity (nephelometric turbidity units [NTU])
- Stage\* (feet above datum)
- Stream Discharge\* (cubic feet per second [cfs], from stage/discharge rating curve)

### Site Considerations

Deployment, operation, and maintenance of APHN datasondes follows guidance recommended in Wagner et al. (2006). Sensor configuration is shown in Table 6. In general, the physical characteristics of a location that make it good for continuous water quality monitoring are the same conditions for measuring surface water discharge—both require a site that approaches uniform conditions across the entire width of the stream. The history of successful gauge operation at these sites (4 to 80 years) in stable, secure locations integrative of upstream conditions of the water bodies to be monitored was an important factor in our decision to deploy the instruments at these locations.

**Table 6.** Time series data sensor configuration and data collection frequency.

| Parameter                                        | Sensor                                     | Reporting Frequency |
|--------------------------------------------------|--------------------------------------------|---------------------|
| Field pH (standard units)                        | YSI 6589 Fast Response Amplified pH Sensor | 30 minutes          |
| Field Water temperature (°C)                     | YSI 6560 Temp/Conductivity Sensor          | 30 minutes          |
| Dissolved oxygen (mg/L)                          | YSI 6150 ROX Optical DO Sensor             | 30 minutes          |
| Specific conductance ( $\mu\text{S}/\text{cm}$ ) | YSI 6560 Temp/Conductivity Sensor          | 30 minutes          |
| Turbidity (NTU)                                  | YSI 6136 Optical Turbidity Sensor          | 30 minutes          |
| Stage (ft above datum) <sup>1</sup>              | Sutron constant flow bubbler               | 15 minutes          |
| Streamflow (cfs) <sup>1</sup>                    | Stage/discharge curve (calculated)         | 15 minutes          |

<sup>1</sup>Collected by USGS

### **Cross-Section Survey**

Prior to selection of a final deployment location at each monitoring site, cross-section surveys of field parameters were conducted to assure that locations were representative of the entire (well-mixed) water body rather than of an anomalous condition. Generally, the most critical parameters to be evaluated during cross-section surveys are specific conductance and turbidity, because they are most susceptible to large variations in unmixed waters (Wagner et al. 2006). Sufficient measurements were made at each cross-section to determine the degree of mixing and to quantify variability at each site. Cross-section surveys of the parameters to be monitored were conducted both at base flow and during a wadeable runoff event, and the results were compared with those at the deployment location. Cross-section analyses will be repeated annually to verify deployment locations continue to be representative of site conditions.

### **Monitoring Station Configuration**

At each location, the network's continuous monitoring equipment is secured by PVC conduit braced and bolted to bedrock outcrops or constructed concrete piers. This minimizes the potential loss of equipment due to vandalism and stormflow damage. Direct current (DC) 12-volt batteries and solar panels power the monitoring stations, which are sufficient to meet the power requirements of the sensors, data loggers, and USGS stage measurement hardware.

Water-quality data are logged to USGS data collection platform (DCP) hardware located at the stream gauges. The data are also transmitted via satellite into the USGS National Water Information System (NWIS), for display on the Internet. In addition to providing real-time access to data for the parks and the public, broadcast of water-quality data to the Internet enables remote review of data by APHN staff. This provides a logistical advantage compared with internal logging by datasondes and manual retrieval of data on fixed schedules (typically monthly) by field personnel. Remote access to real-time data alerts field personnel to sensor failure or fouling, triggering a site visit to service the monitoring station, and preventing extended logging of inaccurate data that could contribute to gaps in the data record.

In Aquarius, subroutines are used to edit water-quality data where appropriate. Both raw and edited data logs can be exported from Aquarius into other analytical software for subsequent analyses. Aquarius can also be configured to import data directly from NWIS. USGS has recently (spring of 2017) adopted Aquarius as their primary data management system (replacing ADAPS), making data processing and analysis more seamless for our purposes.

### **Operation and Maintenance**

A detailed description of methods required to operate and maintain continuous monitors in accordance with USGS criteria is provided in SOP CWQ05, *Equipment and Calibration—Version 1.4* (APHN 2018a); SOP CWQ06, *Linking YSI 6920 Datasondes to USGS Gages—Version 1.4* (APHN 2018b); SOP CWQ07, *Operation and Maintenance Site Visit—Version 1.4* (APHN 2018c). These methods are adapted from Wagner et al. (2006) and follow the instrument manufacturer's latest technical recommendations (YSI 2011). Eight datasondes (YSI 6920-V2 multi-parameter water quality datasondes with two YSI 650 MDS data display/loggers) are currently available for use at the five USGS gages where continuous sampling will occur. This allows instruments to be rotated out of

the field for maintenance, so there is always a unit available to replace one of the field datasondes. Field visits by APHN staff occur on an approximately monthly interval in order to clean and calibrate the sensors, although the frequency of visits varies depending on the season and the amount of fouling that occurs as a result of high flows.

Equipment function is monitored daily on the Internet so maintenance issues can be resolved as quickly as possible in order to preserve data integrity. Field visits are recorded on a calibration and maintenance field form (see SOP CWQ07) and data corrections are applied based on the calibration drift that has occurred since the most recent calibration. Both the corrected and the uncorrected data are stored in NWIS and in Aquarius, so the original data files are always available, if needed.



## Data Handling, Reporting and Analysis

As part of developing a long-term monitoring program, the Appalachian Highlands Network manages data, graphics, summaries, reports, and a number of other information products to report on and interpret monitoring results within the context of APHN long-term monitoring objectives. Proper management and quality control of data sets, and the products derived from them, is critical for effective analysis. Interpretation of water-quality monitoring data will provide managers, policy makers, and researchers with information necessary for making decisions regarding the use and conservation of the parks' water resources.

The types of data produced by continuous water-quality monitoring include field data collected at frequent intervals as part of routine continuous water-quality station operation and maintenance site visits (cross-section, fouling drift, sensor drift), corrected data, and metadata. Metadata include documentation of systematic corrections made during routine instrument calibration, as well as corrections made to eliminate transient errors in the data record due to fouling or instrument malfunction. Field data collected during operation and maintenance (O&M) site visits will be recorded on USGS continuous water-quality field forms initially. It's then entered into electronic format using USGS Continuous Hydrologic Instrumentation Monitoring Program (CHIMP) software, and converted into Aquarius ready e-format utilizing the USGS SiteVisitAq (SVAQ) software. The SVAQ files can be drag and dropped into Aquarius for automated shift correction of data to remedy fouling and/or calibration drift. Corrected data and metadata are archived for later evaluation and analysis by APHN staff, managers and researchers.

Data handling procedures are carried out in partnership with the USGS, which archives APHN water-quality data in the National Water Information System (NWIS) and posts these data to the Internet as they are collected. A memorandum of understanding with the USGS Tennessee Water Science Center allows internal access to NWIS for specified APHN staff. Aquarius software, which is supported by the NPS Water Resources Division and has recently been adopted by USGS, will be the principal software used by the Appalachian Highlands Network to analyze and display continuous water-quality data and produce summary statistics and graphics. Annual summary reports will provide detailed information on the status of water quality at each monitoring site. Water-quality trend reports will be produced every five years, depending on the needs of park staff. Detailed procedures for data management, data processing, and analysis and reporting are provided in SOP CWQ09, *Data Management—Version 1.3* (APHN 2018d); SOP CWQ10, *Continuous Water Quality Record Processing—Version 1.4* (APHN 2018e); and SOP CWQ11, *Data Analysis and Reporting—Version 1.4* (APHN 2018f) respectively.

### Data Acquisition

The flow for continuous water-quality monitoring data is shown in Figure 7. For this protocol, data are collected every 30 minutes for five water-quality parameters at each station (Table 6). Data are automatically transmitted to NWIS, displayed on the Internet, and archived in near real-time (one-hour delay). During monthly visits to calibrate each sonde, backup data logs are collected and stored

on a shared APHN storage drive. After each calibration, data files are corrected in NWIS, and copies of uncorrected and corrected data files are archived in NPS Aquarius for eventual analysis.

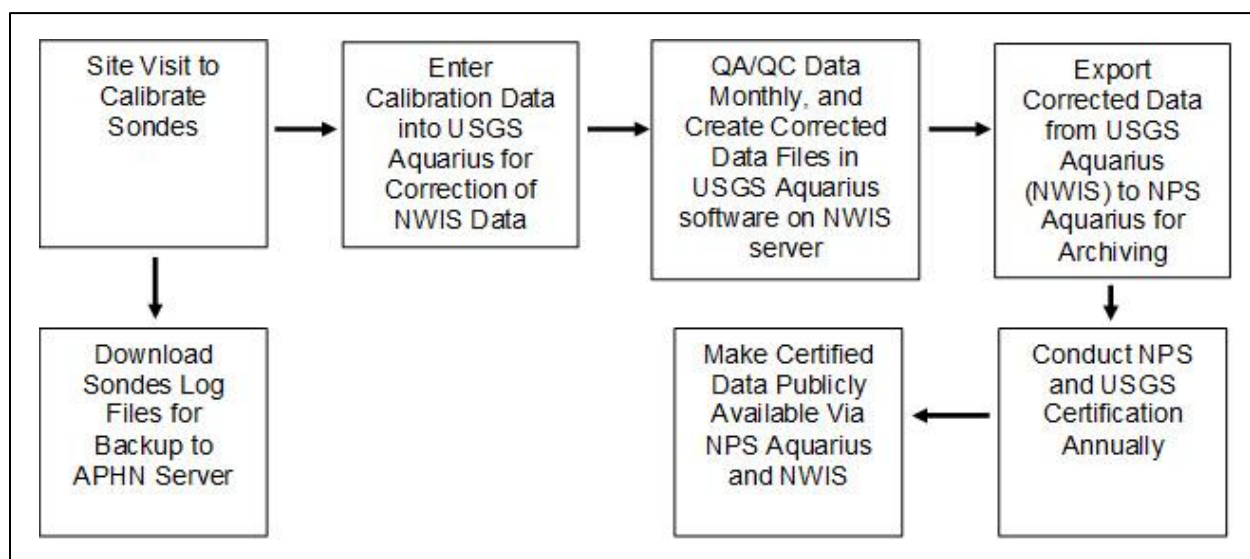


**Figure 7.** Process flow chart for management of continuous water quality monitoring data.

## Data Entry

Manual editing of data is routinely required to remove spikes or fill gaps in the data record caused by fouling or instrument malfunction. This editing is implemented online at a USGS workstation—on the USGS version of Aquarius resident on the USGS NWIS server. During monthly instrument calibration, automated shifts are also applied to the data based upon the amplitude of fouling and calibration drift that has occurred, as indicated by operation and maintenance site visit drift checks for individual sensors. In some cases, uncorrectable fouling data must be removed from the record (although raw data will remain in Aquarius). Corrections are entered by the protocol lead or other designated personnel into the Aquarius software, which is password-protected. Smart card two-factor authentication is also required. After fouling and calibration corrections have been entered, data verification and validation are completed by the protocol lead. Calibration data sheets (see SOP CWQ07) are scanned into PDF format, then archived by the protocol lead after drift corrections are made. Annual cross-section evaluations of continuous monitoring stations are recorded on the USGS Continuous Water-Quality Monitoring Field Form and scanned into PDF format and archived by the protocol lead. Cross-section evaluation data are entered into USGS SiteVisitAq software for drag and drop entry into Aquarius.

## Verification and Validation

Data are verified during data entry in a process which involves checking the accuracy of computerized records against the original source—mainly paper field calibration data sheets. Data entry personnel check 100% of the calibration records against the original data sheets. Validation is performed by the protocol lead subsequent to verification. The purpose of validation is to identify and correct generic errors in the data record (i.e., missing, mismatched, or duplicate records).

## **Data Certification**

After the data are verified and validated, paper data sheets are archived and the approved (corrected) electronic data are used for subsequent data analysis and reporting. Should data sheets require editing at a later date, the altered data sheets will be scanned and archived along with the original versions. Copies of the corrected and uncorrected data are archived monthly in Aquarius. Annually, the National Park Service and USGS will conduct a formal data quality review to ensure appropriate data correction, verification and validation steps have been completed. This process is documented in the Quality Assurance Plan for Long-Term Water-Quality Monitoring Plan for Continuous Sampling (Hughes et al. 2017). The resulting approved data will be marked as “certified” by the National Park Service, a data certification form will be completed and the certified data will be made publicly available through NPS Aquarius. The certified data will be available as “provided” data, through the USGS NWIS, and the five USGS gage web pages where the datasonde data are normally displayed.

## **Metadata**

Complete metadata facilitates data longevity, helps publicize the existence of all data sets produced, and enables effective access to data by future users. Raw and corrected versions of the monitoring data will be accompanied by metadata documentation that includes: data set 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 Integrated Resource Management Applications (IRMA) Data Store at <https://irma.nps.gov/DataStore/>, and will be reviewed and updated annually.

## **Data Archiving**

Raw field data, corrected data, and certified data are stored in NWIS with copies maintained in NPS Aquarius. The Appalachian Highlands Network digitally archives data sheets from the calibration process and photographs from site visits. Digital files are stored on the APHN server located in the Asheville, North Carolina network office, which has daily and weekly routine backup procedures. Paper copies of field data sheets are stored in permanent files in the office of the protocol lead in Oneida, Tennessee following data entry, verification and validation.

## ***Aquarius Time-Series Software***

The NPS Water Resources Division provides access to and technical support for Aquatic Informatics’ Aquarius time-series software for inventory and monitoring networks. Aquarius is specifically designed for archiving and analyzing continuous water-quality monitoring data. This remotely located, national instance of Aquarius includes data processing tools for importing and merging data streams, flagging and editing data spikes (Figure 8), application of sensor drift and fouling corrections, built-in routines for calculating summary statistics, as well as more sophisticated statistical analyses. Graphics tools can display continuous data in various forms that allow for ready interpretation. Aquarius provides additional flexibility by allowing custom reports to be designed and implemented by the national office and at the network level. Basic data processing steps in Aquarius are described in more detail in SOP CWQ10.

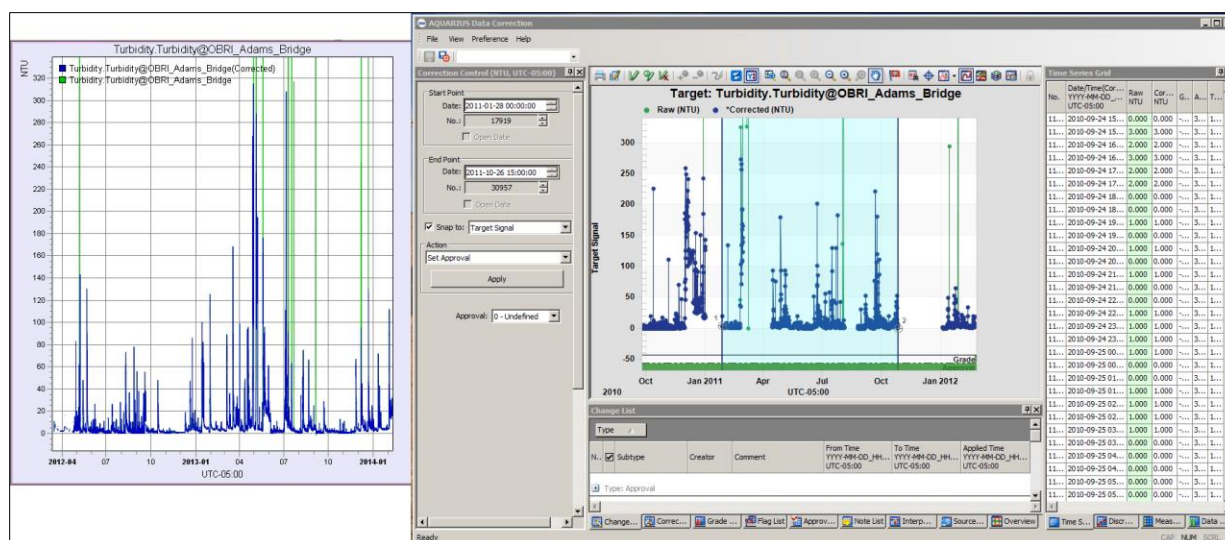


**Figure 8.** Examples of Aquarius raw data and data-editing displays.

## Reporting and Data Analysis

A primary goal of the NPS Inventory and Monitoring program is to ensure the results and knowledge obtained from monitoring are timely and presented in forms which best meet park needs. Where appropriate, monitoring results will be shared as broadly as possible with park partners, NPS staff, and the public.

### Annual Reports

The Appalachian Highlands Network will provide annual data summary reports and resource briefs to Big South Fork NRRRA and Obed WSR that can be shared with park staff, partners, and the public. A number of data summary report templates (e.g., annual data shift reports, data gap summaries, annual site visit and cross-section summaries) are resident in Aquarius and will be utilized by the network. Data summary reports will conform to the format of the Natural Resource Publication Series guidelines. Templates are available at <https://www.nps.gov/im/publication-series.htm>. These reports will describe and summarize the results of monitoring efforts conducted during the previous water year (1 October through 30 September). The reports will interpret results, supported by summary statistics and graphics; identify areas of concern; and provide a brief discussion of management recommendations when possible. One challenge we face is to find a way to characterize water quality in the parks without clear state standards for some water-quality constituents. In these cases, provisional standards will be used, based on historic data, and refined over time. State water-quality standards and typical historic values for Big South Fork NRRRA and Obed WSR headwater streams are provided in Table 7. Annual reports will also track frequency and duration of violation of state water- quality standards at each continuous monitoring station. An example report table with summary statistics is shown in Table 8. The primary audiences for annual data summary reports include park superintendents and resource managers, along with park staff, partners and the public, as appropriate. Reports will be produced during the first quarter of each year.

**Table 7.** Tennessee and Kentucky water quality (WQ) criteria for fish and aquatic life, (TDEC 2018; Kentucky Legislature 2018) and typical water quality values in headwater streams at Big South Fork (BISO) and Obed (OBRI) (from Rikard et al. 1986). [ $\mu\text{S}/\text{cm}$ —microsiemens per centimeter; NTU—nephelometric turbidity units; C—Celsius; mg/L—milligrams per liter].

| Parameter                                | Tenn. WQ Criteria (2013)                                              | Ky. Surface Water Standards (2013)                                      | Typical WQ Values in BISO, OBRI Headwater Streams |
|------------------------------------------|-----------------------------------------------------------------------|-------------------------------------------------------------------------|---------------------------------------------------|
| Conductivity ( $\mu\text{S}/\text{cm}$ ) | n/a                                                                   | shall not adversely affect the indigenous aquatic community             | $\leq 30$ (sandstone); $\leq 60$ (limestone)      |
| pH                                       | 6.5 – 9.0; shall not change more than 1 unit over a 24-hour period    | 6.0 – 9.0; shall not change more than 1 unit over a 24-hour period      | 5.5 – 7.0 (sandstone); 6.0 – 7.5 (limestone)      |
| Turbidity (NTUs)                         | shall not materially affect fish and aquatic life                     | shall not adversely affect the indigenous aquatic community             | $< 10$                                            |
| Temperature ( $^{\circ}\text{C}$ )       | $\leq 30.5$ ; shall not change more than $2^{\circ}\text{C}$ per hour | $\leq 31.7$ ; the normal fluctuation of temperature shall be maintained | 0 – 25.0                                          |
| Dissolved Oxygen (mg/L)                  | $\geq 5.0$                                                            | $\geq 5.0$ as a 24-hour average; $\geq 4.0$ at any time                 | $\geq 5.0$                                        |

**Table 8.** Example report table showing summary statistics for January–June, 2012 for Obed River, at Adams Bridge (“n” is the number of data points that have been checked and approved). [ $\mu\text{S}/\text{cm}$ —microsiemens per centimeter; Temp—temperature; C—Celsius; DO—Dissolved Oxygen; mg/L—milligrams per liter; NTU—nephelometric turbidity units; StDev—standard deviation].

| Month                 | Statistic | Specific Conductance ( $\mu\text{S}/\text{cm}$ ) | Temp ( $^{\circ}\text{C}$ ) | DO (mg/L) | pH    | Turbidity (NTU) |
|-----------------------|-----------|--------------------------------------------------|-----------------------------|-----------|-------|-----------------|
| January<br>(n=1,488)  | Mean      | 82.509                                           | 6.085                       | 11.967    | 7.44  | 7.065           |
|                       | StDev     | 11.637                                           | 1.975                       | 0.679     | 0.092 | 10.74           |
|                       | Maximum   | 125                                              | 10.1                        | 13.6      | 7.8   | 65              |
|                       | Minimum   | 64                                               | 1.8                         | 10.6      | 7.3   | 0               |
|                       | % valid n | 89.99                                            | 90.12                       | 90.12     | 90.18 | 90.12           |
| February<br>(n=1,392) | Mean      | 84.392                                           | 8.137                       | 11.753    | 7.545 | 4.095           |
|                       | StDev     | 10.556                                           | 2.03                        | 0.743     | 0.163 | 4.206           |
|                       | Maximum   | 136                                              | 10.9                        | 13.8      | 8.2   | 34              |
|                       | Minimum   | 70                                               | 1.4                         | 10.2      | 7.3   | 1               |
|                       | % valid n | 100                                              | 100                         | 100       | 100   | 85.56           |

**Table 8 (continued).** Example report table showing summary statistics for January–June, 2012 for Obed River, at Adams Bridge (“n” is the number of data points that have been checked and approved). [μS/cm—microsiemens per centimeter; Temp—temperature; C—Celsius; DO—Dissolved Oxygen; mg/L—milligrams per liter; NTU—nephelometric turbidity units; StDev—standard deviation].

| Month              | Statistic | Specific Conductance<br>(μS/cm) | Temp (°C) | DO (mg/L) | pH    | Turbidity<br>(NTU) |
|--------------------|-----------|---------------------------------|-----------|-----------|-------|--------------------|
| March<br>(n=1,488) | Mean      | 83.079                          | 12.646    | 10.163    | 7.602 | 3.219              |
|                    | StDev     | 8.396                           | 2.869     | 0.962     | 0.203 | 3.387              |
|                    | Maximum   | 127                             | 16.6      | 13.0      | 8.4   | 31                 |
|                    | Minimum   | 67                              | 6.3       | 8.0       | 7.2   | 1                  |
|                    | % valid n | 100                             | 100       | 100       | 100   | 44.79              |
| April<br>(n=1,440) | Mean      | 104.563                         | 14.786    | 9.156     | 7.555 | 3.453              |
|                    | StDev     | 25.542                          | 2.026     | 0.784     | 0.163 | 4.841              |
|                    | Maximum   | 172                             | 19.7      | 11.2      | 8.1   | 83                 |
|                    | Minimum   | 65                              | 10.2      | 7.3       | 7.2   | 1                  |
|                    | % valid n | 99.86                           | 99.86     | 99.86     | 99.86 | 56.72              |
| May<br>(n=1,488)   | Mean      | 152.193                         | 17.837    | 8.147     | 7.552 | 6.581              |
|                    | StDev     | 34.057                          | 1.912     | 0.904     | 0.178 | 14.04              |
|                    | Maximum   | 254                             | 22.3      | 9.8       | 8.0   | 143                |
|                    | Minimum   | 90                              | 14.6      | 5.9       | 7.1   | 0                  |
|                    | % valid n | 99.87                           | 100       | 100       | 100   | 99.4               |
| June<br>(n=1,440)  | Mean      | 273.812                         | 19.84     | 8.083     | 7.752 | 1.686              |
|                    | StDev     | 55.235                          | 1.729     | 0.803     | 0.178 | 1.547              |
|                    | Maximum   | 347                             | 25.2      | 10.6      | 8.4   | 26                 |
|                    | Minimum   | 153                             | 15.8      | 6.2       | 7.3   | 0                  |
|                    | % valid n | 99.86                           | 99.86     | 99.86     | 99.86 | 90.0               |

### Resource Briefs

Resource briefs are short (two to four pages), annual summaries written for park managers, staff and park partners, in brochure or newsletter form, which briefly describe water quality during the past year and highlight findings. These briefs will be completed by the end of January, so that findings will be current. Resource briefs will be illustrated using graphs, maps and photos. The briefs will summarize spatial variability of water-quality conditions and site-specific water-quality trends in the parks. Color coding will be used to characterize water-quality status and trends. Resource

management staff and the park superintendent will review and approve the colors used. The protocol lead will be the primary person responsible for gathering data and for assigning the resource rating. Graphic examples for resource briefs are found in Table 9 and Figure 9.

**Table 9.** Example summary table showing water-quality status and trends at two continuous monitoring sites in 2013. [ $\mu\text{s}/\text{cm}$ —microsiemens per centimeter].

| Priority Resource or Site              | Specific Measures                                          | Condition Status/Trend                                                            | Reference Condition/Resource Condition Comments                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            |
|----------------------------------------|------------------------------------------------------------|-----------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Water quality—New River, New River     | pH, temperature, dissolved oxygen, conductivity, turbidity |  | Continued high conductivity at the New River datasonde during 2013—above $150 \mu\text{s}/\text{cm}$ for 7 months during 2013, and above $300 \mu\text{s}/\text{cm}$ for most of November, a level thought to be detrimental to mussels. High turbidity in response to runoff events is indicative of land use disturbance in the watershed associated with mining and logging.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            |
| Water quality—Obed River, Adams Bridge | pH, temperature, dissolved oxygen, conductivity, turbidity |  | Data consistently indicate elevated conductivity at the Adams Bridge datasonde during seasonally low flow conditions during late summer and early fall, with conductivity regularly exceeding $300 \mu\text{s}/\text{cm}$ in the summer and early fall months. During September and October, 2016, conductivity exceeded $400 \mu\text{s}/\text{cm}$ for nearly 2 months, peaking at over $600 \mu\text{s}/\text{cm}$ as wastewater effluents became a proportionally higher percentage of total streamflow. Conductivity above $200 \mu\text{s}/\text{cm}$ is thought to be detrimental for mussels and other sensitive aquatic species. Data also indicate that dissolved oxygen concentration routinely falls below TDEC regulatory standards ( $\geq 5.0 \text{ mg}/\text{l}$ ) as a consequence of nutrient enrichment. Although water quality recovers with distance downstream of wastewater sources, the effect of wastewater effluents are detectable at the downstream extent (Emory river at Nemo) of the park. |

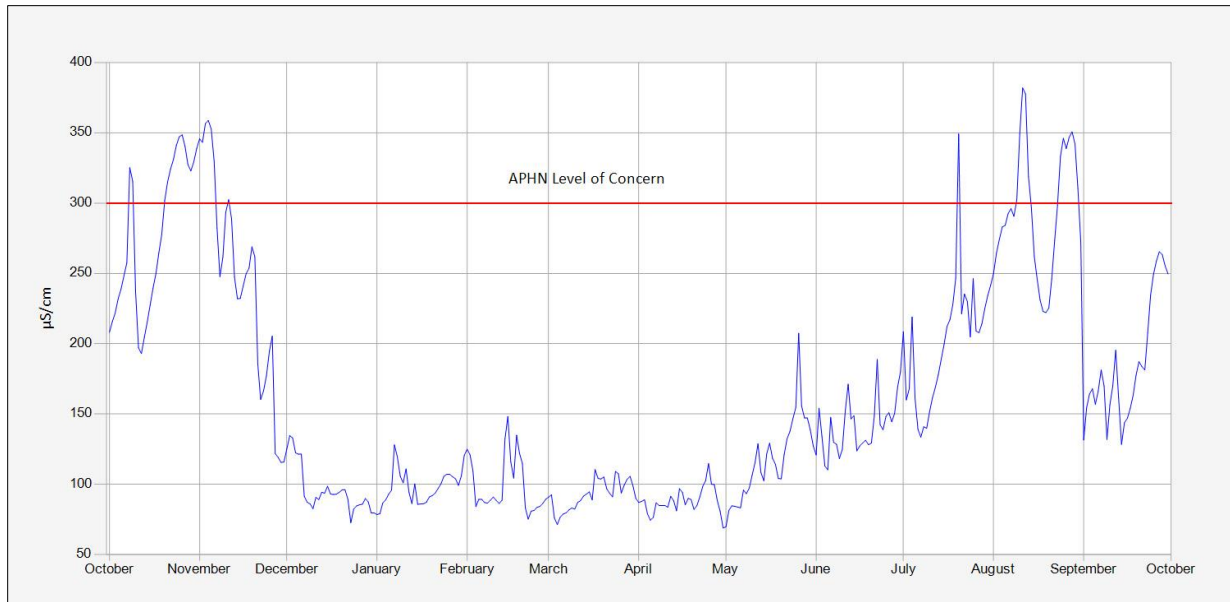


**Figure 9.** Example graph showing specific conductance for water year 2013 at Obed River at Adams Bridge. The graph highlights the 300 microsiemens per centimeter threshold, a level which may be detrimental for freshwater mussels (McGregor, Monte. Malacologist, Kentucky Center for Mollusk Conservation, personal communication 2014).

### **Resource Alerts**

Continuous water-quality data are available on the Internet in real time and will be reviewed on a daily basis. If these data indicate water-quality conditions that are either a concern or are of scientific interest, the park's resource management will receive alerts via email or personal interaction. These alerts may include short reports identifying the specific parameters of concern to water resource integrity, regulatory standards (if applicable), and recommended management activities that may be conducted in response to the event or trend indicated by the data.

### **Synthesis/Trend Reports**

Synthesis/trend reports will be prepared every five years, unless the network and park staff agree that report preparation at more frequent intervals is beneficial. These reports often have multiple objectives and attempt to place monitoring results in a broader regional and historical context. Analyses may include data sets from related projects, including other APHN monitoring, academic research, and studies of federal and state agencies working within the region. These reports will provide management recommendations. The potential for significant in-depth analyses within parks, and across the region, will continue to improve with the accumulation of long-term data.

The seasonal Kendall test runs a separate Mann Kendall trend test on each of  $m$  seasons separately, where  $m$  is the number of seasons. Data is only compared to the same season. For example, spring would only be compared with spring and summer would only be compared with summer. The overall  $S_k$  statistic is calculated from summing each season's Kendall  $S$  statistic. A modified seasonal Kendall test called the regional Kendall test can be run if you are more interested in spatial differences than seasonal. For example, you might want to evaluate whether a particular condition is

homogeneously present throughout an entire region or instead heterogeneously influenced by variations in geology or other factors throughout a region or watershed. The regional Kendall can evaluate trends based upon location, watershed geology or land use and land cover, or other factors. A seasonal Kendall Power test evaluates the strength of these trends (i.e., our ability to detect trends when they actually exist) and will be provided in the five-year synthesis/trend reports. An example power analysis was done for this protocol, again using the Obed River at Adams Bridge data. The R code for running the test was developed by Irvine et al. (2012), and adjusted to run with our data (see SOP CWQ11). The routine uses the variability in the existing data to simulate data for different time periods (5, 10, 15 and 20 years) and to run power analyses on these data sets. For this example, we tested for power to detect 1% and 2.5% annual rates of change, respectively, in specific conductance and dissolved oxygen. The results are shown in Figure 10. Power to detect a 2.5% per year change reaches nearly 100% after 10 years. To detect a 1% per year change at 80% power takes less than 8 and 16 years for dissolved oxygen and conductance, respectively. For future trend and power analyses, additional thought will be given to rates of change that are biologically meaningful and that might reasonably be expected to occur over coming decades.

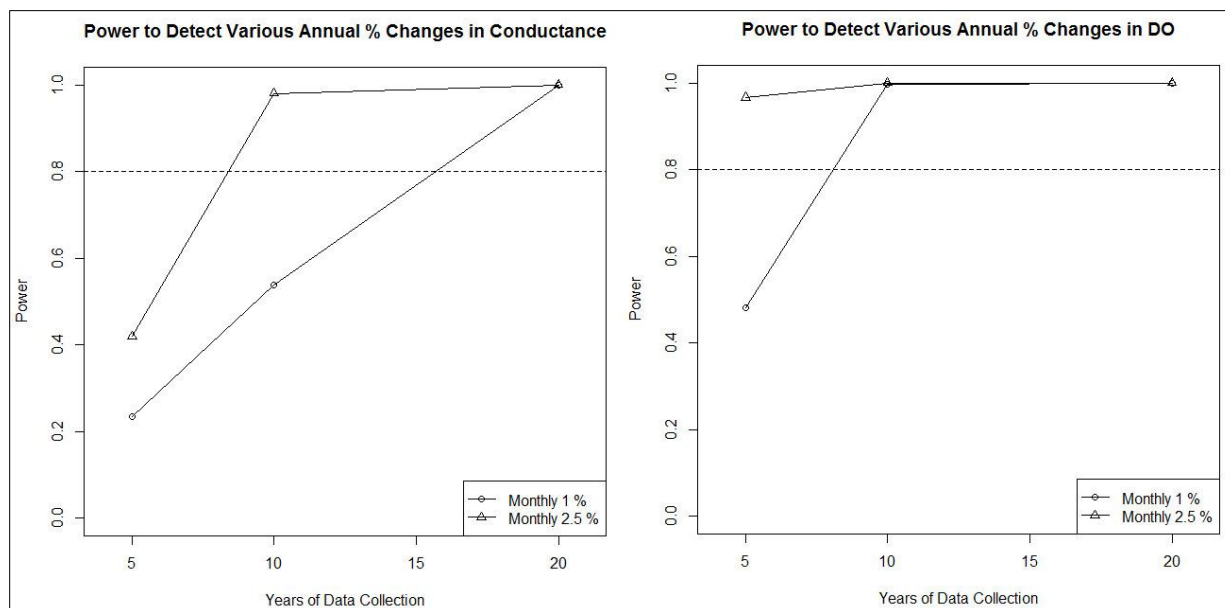


**Figure 10.** Estimated power of the seasonal Kendall test to detect 1% and 2.5% per year changes in specific conductance and dissolved oxygen, at Obed River, Adams Bridge, for 5, 10 and 20 years of sampling, using monthly medians.



## Budget, Personnel and Training Requirements

This protocol relies primarily on APHN staff to conduct all aspects of continuous water-quality monitoring, including datasonde calibration and maintenance, and data management, analysis, and reporting. Data handling procedures are carried out in partnership with the USGS, which archives APHN water-quality data in NWIS and posts these data to the Internet as they are collected. The United States Geological Survey also assists with station maintenance when telemetry equipment needs repairs. While APHN staff will be fully responsible for all work elements related to continuous water-quality monitoring, we will take advantage of opportunities to work with park staff, or watershed partners, should they have an interest in becoming involved with aspects of datasonde calibration, station maintenance, or data management. Table 10 shows initial startup costs while Table 11 shows the estimated annual operating costs for this protocol (based on FY2014 costs). The staff who will implement this protocol includes the network hydrologist (the protocol lead) and a data manager, with possible assistance from a term hydrologic technician. The protocol lead has responsibility for all aspects of the continuous 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 technician's main responsibilities would include assisting with the operation and maintenance of the datasondes, and with data management tasks. Datasonde maintenance is performed every month and—because of the proximity of the stations—does not require official travel. Roles and responsibilities for program personnel are described later in this section and in Table 12.

**Table 10.** Approximate startup costs (based on FY 2014 dollars) for implementation of the APHN Continuous Water Quality Monitoring Protocol.

| Category           | Detail                         | Cost (\$) |
|--------------------|--------------------------------|-----------|
| Equipment/Supplies | Reagents/Calibration Standards | 4,000     |
|                    | Datasonde/Sensor Repairs       | 2,500     |
|                    | Station Infrastructure         | 3,500     |
|                    | Datasonde (5)                  | 30,000    |
| Total              | —                              | 40,000    |

**Table 11.** Approximate annual operating costs (based on FY 2014 dollars) for the APHN Continuous Water Quality Monitoring Protocol.

| Category           | Detail                                              | Cost (\$) | Notes           |
|--------------------|-----------------------------------------------------|-----------|-----------------|
| Personnel          | Protocol Lead                                       | 34,500    | 0.4 FTE, GS-11  |
|                    | Data Manager                                        | 9,700     | 0.1 FTE, GS-11  |
|                    | Hydrologic Technician                               | 8,000     | 0.4 FTE, Intern |
|                    | Subtotal                                            | 52,200    | –               |
| Equipment/Supplies | Reagents/Calibration Standards                      | 4,000     | –               |
|                    | Datasonde/Sensor Repairs                            | 2,500     | –               |
|                    | Station Repairs                                     | 500       | –               |
|                    | <sup>1</sup> Datasonde Replacements Due to Age/Loss | 6,000     | –               |
|                    | Subtotal                                            | 9,400     | –               |
| Total              | –                                                   | 61,600    | –               |

<sup>1</sup> Based on a life of five years—probably a conservative estimate—and an assumption that one datasonde per year would be replaced.

**Table 12.** Primary duties of APHN staff for continuous water-quality monitoring.

| Position              | Primary Duties                                                                                                                                                                                                                                                                                                                                                                                                        |
|-----------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Protocol Lead         | <p>Provides guidance, oversight and management of continuous water quality monitoring</p> <p>Conducts project-specific data analyses, data validation, and data verification; produces data summaries and reports</p> <p>Works with program professionals to provide information to parks and partners in useful formats</p> <p>May supervise technicians and partners working on the project</p>                     |
| Data Manager          | <p>Provides direction and oversight for data management activities</p> <p>Conducts data archiving and dissemination, develops queries and summaries, and performs overall quality assurance/quality control (QA/QC) for continuous water quality monitoring</p> <p>Works with the protocol lead to ensure data is provided to parks and partners in useful formats</p> <p>Implements data management partnerships</p> |
| Hydrologic Technician | <p>Assists protocol lead with calibration and maintenance of datasondes</p> <p>Assists protocol lead with operation and maintenance (O&amp;M) site visits</p> <p>Assists with data entry</p>                                                                                                                                                                                                                          |

## **Personnel and Qualifications**

### ***Protocol Lead***

The protocol lead coordinates all aspects of the continuous water-quality monitoring protocol, including protocol design, protocol implementation, data correction (fouling and calibration drift), data analysis, and data reporting. The protocol lead applies principles of aquatic ecology and hydrology to the design of the project and to the interpretation of results. This position ensures 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. This may include preparation of complex memoranda, reports, briefings, and peer-reviewed scientific papers. The protocol lead may supervise technicians, interns or partners working on the project. The protocol lead also ensures APHN equipment is in good working order.

### ***Data Manager***

The data manager has a central role in ensuring that project data management conforms with Inventory and Monitoring program standards, data is of high quality, and data can be retrieved and disseminated in useful formats. The data manager collaborates with the protocol lead to develop data entry forms, quality assurance/quality control (QA/QC) procedures, and automated reports. The APHN data manager maintains spatial data themes associated with continuous water quality monitoring and disseminates this information to APHN parks and partners. The data manager documents APHN data management procedures, including roles and responsibilities, work flows, and guidance in the use of databases and data management tools. The data manager also coordinates and oversees the population and maintenance of national information management systems (e.g., Aquarius and NPSTORET).

### ***Training***

Training in safety, field techniques and data handling procedures required to implement this protocol is the responsibility of the protocol lead and will be conducted by the protocol lead or an appropriately trained surrogate. Training will include briefings on safe practices while conducting field operations; principles of Operational Leadership; an overview of the APHN continuous water-quality monitoring program; and a thorough orientation to field procedures, APHN monitoring equipment, and principles of data collection and data handling. Training will be required for each person before participation in field sampling, or 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 will 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 CWQ01, *Safety—Version 1.4* (APHN 2018g); SOP CWQ02, *Job Hazard Analysis—Version 1.4* (APHN 2018h); and SOP CWQ03, *Training Field Personnel—Version 1.4* (APHN 2018i).

At a minimum, the protocol lead will receive basic or refresher training as recommended by the NPS Washington Support Office (WASO) Inventory and Monitoring Division. The protocol lead will seek

out opportunities for technical training that may be beneficial for APHN personnel, including training in data collection techniques, equipment operation and maintenance, data handling, and data analysis. Equipment manufacturers, private consultants or government agencies, including the NPS and USGS Water Resources Divisions, may offer courses covering these topics. When formal training sessions are organized, these sessions will be opened—if possible—for park resource staff and cooperating partners.

## **Partnerships**

### ***U. S. Geological Survey (USGS)***

The Appalachian Highlands Network works in partnership with the United States Geological Survey, Big South Fork NRRRA, and Obed WSR to operate seven streamflow gages within and near the parks, including five gages equipped with APHN datasondes. This cost-sharing arrangement allows the network and the parks to use the USGS infrastructure and satellite telemetry system to view water quality and hydrologic conditions in real-time on USGS-hosted web pages. Data are stored on-site in USGS data loggers and sent to USGS NWIS web via telemetry and the National Oceanic and Atmospheric Administration's (NOAA) Geostationary Satellite Server (GOES) satellite. All site visits, data corrections, and data management are conducted within NWIS by APHN staff. The staff then provides annual data summaries in accordance with USGS procedures. The summaries are reviewed by USGS staff. This NPS-APHN/USGS partnership provides a cost-effective way for the network to operate continuous water-quality monitoring instruments, reducing the number of maintenance trips and decreasing the number of interruptions in the data record. This arrangement also allows the parks, the network, and watershed partners to monitor and respond to short-term pollution events as they happen, and to gain a better understanding of short-term variability and long-term trends in water quality.

# Operational Requirements

## Annual Workload

The five datasondes operate year-round. The protocol lead conducts regular maintenance and calibration for each datasonde approximately once every 30 days. Additional maintenance trips are made when equipment malfunctions. Data corrections, to correct for anomalies in the data record (transient spikes, gaps, or data shifts) are made by APHN staff at a USGS workstation via the USGS Aquarius software that is resident within NWIS and in accordance with USGS standards. Additional corrections are applied by the protocol lead after each monthly calibration visit, to adjust for fouling and calibration drift. The protocol lead conducts data verification and validation after each calibration visit and archives raw and corrected data files to Aquarius. Table 13 shows the implementation schedule for this protocol.

**Table 13.** Schedule of tasks associated with collection and analysis of time series data.

| Project Stage                   | Task Description                                                                                                    | Responsibility                    | Status/Schedule                                          |
|---------------------------------|---------------------------------------------------------------------------------------------------------------------|-----------------------------------|----------------------------------------------------------|
| Preparation                     | Install datasonde deployment infrastructure                                                                         | APHN staff (with USGS assistance) | Completed (2009–2013)                                    |
|                                 | Develop field calibration procedures                                                                                | Protocol Lead                     | Completed                                                |
|                                 | Attend USGS Continuous Monitoring Training                                                                          | Protocol Lead                     | Completed (2010)                                         |
|                                 | Complete Aquarius training                                                                                          | Protocol Lead/Data Manager        | In progress. Regular annual updates completed in Jan–Feb |
| Deployment and Data Acquisition | Deploy datasondes                                                                                                   | Protocol Lead                     | Completed (2009–2013)                                    |
|                                 | Service datasondes/acquire data logs (5 stations)                                                                   | Protocol Lead                     | Monthly                                                  |
| Data Handling                   | Complete routine data editing                                                                                       | Protocol Lead                     | As needed                                                |
|                                 | Complete data corrections associated with calibration drift                                                         | Protocol Lead                     | Monthly                                                  |
|                                 | Upload corrected and uncorrected data files to NPS Aquarius                                                         | Protocol Lead/Data Manager        | Monthly                                                  |
|                                 | Conduct NPS/USGS data quality review; upload certified data to NPS Aquarius; make certified data publicly available | Protocol Lead/Data Manager        | Annually                                                 |
| Data Analysis and Reporting     | Prepare graphics and data summaries using NWIS and Aquarius                                                         | Protocol Lead/Data Manager        | Nov–Dec                                                  |
|                                 | Submit draft briefings and reports to network program manager for review                                            | Protocol Lead                     | Jan–Feb                                                  |

**Table 13 (continued).** Schedule of tasks associated with collection and analysis of time series data.

| <b>Project Stage</b>                    | <b>Task Description</b>                                                          | <b>Responsibility</b>                              | <b>Status/Schedule</b> |
|-----------------------------------------|----------------------------------------------------------------------------------|----------------------------------------------------|------------------------|
| Data Analysis and Reporting (continued) | Submit reports to Parks                                                          | Network Program Manager                            | March                  |
| Posting and Distribution                | 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 | Network Program Manager/Protocol Lead/Data Manager | Jan–Feb                |

Annually, the protocol lead works with USGS to conduct a formal data quality review. Data are initially flagged as “provided” data within NWIS that are “provisionally” approved. After correction and review of data by the Appalachian Highlands Network, an annual data summary consistent with USGS procedures for continuous water-quality stations will be produced by the network at each monitoring station. Annually, the network and USGS will conduct a joint review of the data summaries. After approval by USGS, data will be flagged as approved within NWIS. The approved data are marked as “certified” by the National Park Service and made available through NPS Aquarius, NWIS and the five USGS gauge web pages where the continuous water-quality data are displayed.

The data manager periodically assists the protocol lead with data verification, preparation of metadata files and updates to metadata in the NPS Data Store. The data manager also assists with developing reports and data summaries from Aquarius, and with preparing GIS layers for use in annual monitoring reports.

### **Permitting Requirements**

Installation of infrastructure needed to operate the five datasondes required approval of a Categorical Exclusion by the parks pursuant to the National Environmental Protection Act (NEPA) (42 United States Code (USC) 4321 et seq). No other state or federal permits are required.

### **Facilities and Equipment**

The duty station for the hydrologist is located at Big South Fork NRRA, where office and storage space is provided by the park. One vehicle, stored at the park, is assigned to the protocol lead and used for field visits to maintain the datasondes. Datasondes are co-located with USGS streamflow gauges at each monitoring site and are situated in bolted and braced PVC housing, to minimize the potential for loss of equipment to vandalism and stormflow damage. A wet lab is at Big South Fork NRRA is available for the network to use for storage, calibration and maintenance of water sampling equipment. The space allows for instruments to be rotated out of the field for maintenance, cleaning and calibration so there is always a unit available to replace one of the field datasondes, if needed.

## **Operational Costs**

Operational costs include 40% (.4 FTE) of the protocol lead's time dedicated to protocol-related activities (Table 11). Tables 10 and 11 summarize annual operational costs for personnel, equipment and supplies.

## **Safety**

Procedures to mitigate risks of specific activities related to protocol implementation are presented in SOP CWQ01 and SOP CWQ02. Standard Operating Procedure CWQ02 is a Job Hazard Analysis (JHA) which describes these risks and mitigation strategies in detail. The most significant concerns with this protocol include:

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

Mitigation measures for both of these situations, as well as a number of other protocol-related risks, are found in the JHA. This protocol can be safely carried out provided staff implement it in accordance with the referenced SOPs. In addition to SOPs developed to safely implement this protocol, specific training needs for all staff have been identified, including Operational Leadership training and certification in basic first aid.

Safety procedures will be reviewed with APHN staff and partners before each field season, and periodic "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 they mitigate risks to personnel, property, and the public.

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 (NPS 2008). These procedures are generally outlined below:

- Adhere to established occupational safety and health procedures, including those contained within Reference Manual 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.
- Establish and follow a routine of communication and coordination with park staff and management when conducting field activities.
- Properly use and maintain required clothing and 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 and unhealthful conditions 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.
- Adhere to park-specific SOPs.

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